

# **Report on the Seismic Microzonation Assessment of the North-west New Territories**

**GEO Report No. 338**

**Arup**

**Geotechnical Engineering Office  
Civil Engineering and Development Department  
The Government of the Hong Kong  
Special Administrative Region**

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**This report was originally produced in January 2012  
as Agreement No. CE 49/2008(GE)**

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First published, November 2018

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## **Preface**

In keeping with our policy of releasing information which may be of general interest to the geotechnical profession and the public, we make available selected internal reports in a series of publications termed the GEO Report series. The GEO Reports can be downloaded from the website of the Civil Engineering and Development Department (<http://www.cedd.gov.hk>) on the Internet.



W.K. Pun  
Head, Geotechnical Engineering Office  
November 2018

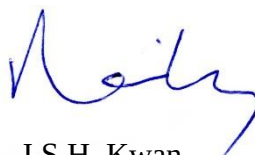


## Foreword

This GEO Report presents an area-specific seismic microzonation assessment of a Study Area in the North-west New Territories of Hong Kong by Arup, in collaboration with the GEO and the Guangdong Engineering Earthquake Resistance Research Institute (GEERRI) of the Earthquake Administration of Guangdong Province (EAGP).

As part of the study, some site-specific ground investigation (GI) works including vertical boreholes, geophysics field tests, microtremor tests, and laboratory cyclic and static triaxial tests were carried out. The results of the GI works have been used to evaluate the site response to earthquake ground motions and develop site classification for the Study Area. Microzonation maps have been produced with consideration given to liquefaction potential and topographic amplification effects. The results and the maps serve to provide a general picture of the seismic behaviour of the Study Area. Although they are not sufficiently precise for project-specific engineering design, practitioners can make reference with these materials for preliminary planning and other preliminary studies as appropriate.

This Report was prepared by a team led by Dr J.W. Pappin of Arup, in collaboration with the GEO and the GEERRI. The team members are Dr H. Jiang, Mr R.C.H. Koo, Mr Y.B. Yu, Dr P.L. Chen and Ms M.M.L. So. This work was overseen by Mr Y.K. Shiu and Mr K.K.S. Ho. Draft versions of the Report were circulated to relevant Government departments and local academics for comment. All contributions are gratefully acknowledged.



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## Executive Summary

On 1st April 2009, the Geotechnical Engineering Office (GEO) commissioned Arup to undertake the Investigation Assignment of “Pilot Seismic Microzonation Study in North-west New Territories for the Study of Potential Effect of Earthquake on Natural Terrain” under Agreement No. CE 49/2008 (GE). The Guangdong Engineering Earthquake Resistance Research Institute (GEERRI) is a sub-consultant to Arup on this Assignment. The Assignment involves, among others, an area-specific seismic microzonation assessment of the North-west New Territories.

To facilitate the area-specific seismic microzonation assessment, ground investigation (GI) works including 27 vertical boreholes, 59 geophysics field tests (19 downhole seismic tests, 17 suspension P-S velocity logging (PS Logging) tests, 22 multi-analysis of surface waves (MASW) tests and one crosshole seismic shear wave velocity test) and six laboratory cyclic and static triaxial tests have been carried out in a Study Area in the North-west New Territories. In addition, microtremor tests have been carried out at 60 locations. The results of GI works have been used to evaluate the site response to earthquake ground motions and classify the site in this seismic microzonation assessment. In order to better understand the trends of earthquake induced soil amplification in the Study Area, a series of one-dimensional site response analyses have been undertaken for all 27 boreholes with in-situ shear wave velocity measurements. A non-linear program *Oasys* SIREN has been used to perform time-domain site response analyses. The results of the analyses have been used to determine ground motion amplitude and period-dependent parameters for different site classes in the seismic microzonation assessment. GEERRI has also carried out an independent microzonation using a frequency-domain program for site response analyses. Spectral ratios for the 10% in the next 50 years ground motion calculated by Arup and GEERRI are found comparable.

The borehole data have been analysed in four different ways based on their spectral shape defined by (1) the ratios of their maximum spectral acceleration and the one-second spectral acceleration ( $S_{\max}/S_1$ ), (2) the average shear wave velocity down to a depth of 30 m ( $V_{s,30}$ ), (3) the average shear wave velocity down to a depth of 20 m ( $V_{s,20}$ ), and (4) the site periods calculated on the basis of the shear wave velocities down to the depth where the SPT-N values reached 100 ( $T_{N100}$ ). By comparing these four different groups, it is considered that the most consistent grouping was that using the  $S_{\max}/S_1$  ratios. Incorporating a larger dataset from the AGS borehole database, site response microzonation maps have been produced for  $V_{s,30}$ ,  $V_{s,20}$  and  $T_{N100}$ . Using correlations between natural slope angles and  $V_{s,30}$  values, another microzonation map has also been produced. All microzonation maps are broadly consistent with each other. In particular, they are very dependent on the underlying data distribution. Site response microzonation maps are not used directly in engineering design practice as overseas codes of practice generally demand site-specific site classification to be done using borehole data. However, they could be used for planning purpose as they provide useful information about the seismic effects on different types of buildings situated at different geological and topographical settings.

The GI and site response analysis results have also been used to assess the liquefaction potential in the Study Area. Microzonation maps have been produced for liquefaction potential. Arup adopted the Seed's empirical method developed in 2001 to assess the

probability of liquefaction potential, while GEERRI carried out an independent liquefaction assessment based on the Chinese Code GB50011-2010. In general, the Seed and Chinese Code methods give rise to similar findings on the level of liquefaction potential. Furthermore, GEERRI, using the Chinese Code method, produced a liquefaction index zoning map for Earthquake Intensities 7 and 8, which are approximately equivalent to the ground motions having a 10% and 2% probabilities of being exceeded in the next 50 years respectively. All in all, the Chinese Code method generally predicts a higher chance of liquefaction for the 10% in the next 50 years ground motion but is similar to the Seed method for the 2% in the next 50 years ground motion.

Finally, the recommendations in Eurocode 8 have been used to estimate the topographic amplification factors for the Study Area, where a microzonation map has also been produced. Topographic amplification with a factor on peak ground acceleration of up to 1.5 has been found at the crest regions in the Study Area. When the topographic amplification factor is less than 1.1, the topographic amplification effect would be insignificant. This study indicates that the amplification factors for ridge effects would be the largest at the natural period of the ridge and would reduce to unity at longer structural periods. The topographic amplification factors are restricted to ridge lines. Therefore, it is not envisaged to incur any significant impacts on the major building areas in the Study Area, which are mainly situated in low-lying areas along the coast and in inland valleys. However, topographic amplification may affect the risk of earthquake-induced landslides at ridge areas. The earthquake-induced natural terrain landslide hazard assessment has been carried out in a separate study.

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## **1 Introduction**

### **1.1 Background**

The Geotechnical Engineering Office (GEO) of the Civil Engineering and Development Department (CEDD) has previously assessed the potential effects of earthquakes on the stability of man-made slopes and retaining walls in Hong Kong, but not on natural terrain. As the management of natural terrain landslide risk is a focus of the post-2010 Landslip Prevention and Mitigation Programme, there is a need to examine the responses and stability of Hong Kong's natural terrain under earthquake conditions.

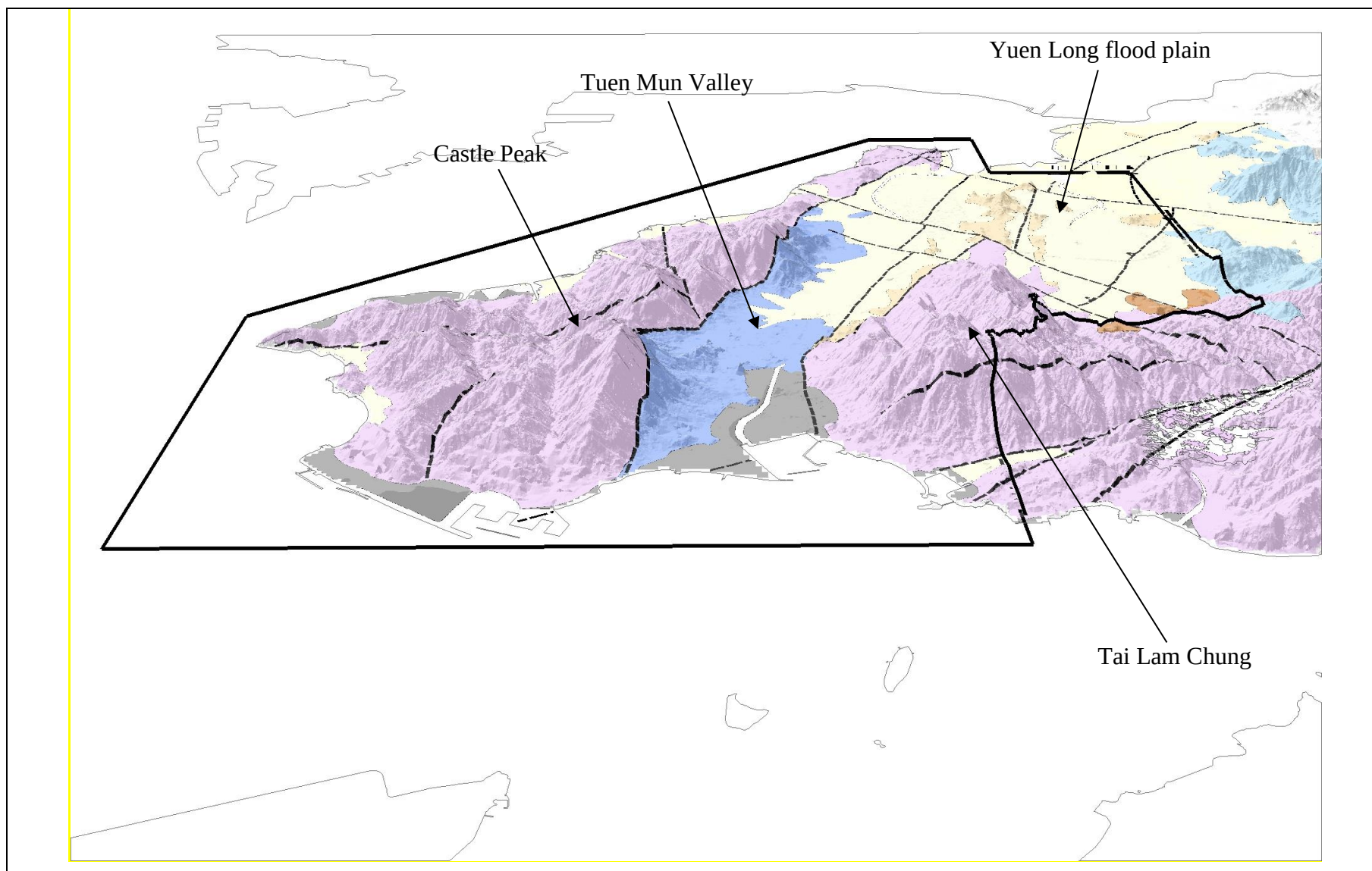
On 1st April 2009, GEO commissioned Ove Arup & Partners Hong Kong Limited (Arup) to undertake the Investigation Assignment of "Pilot Seismic Microzonation Study in North-west New Territories for the Study of Potential Effect of Earthquake on Natural Terrain" under the Agreement No. CE 49/2008 (GE). The Guangdong Engineering Earthquake Resistance Research Institute (GEERRI) is a sub-consultant to Arup on this Assignment.

The above study involves (a) an overall seismic hazard assessment of Hong Kong; (b) an area-specific seismic microzonation assessment for a Study Area in the North-west New Territories; and (c) an evaluation of the potential effects of earthquakes on the natural terrain, with an account taken of local geology, topography and envisaged ground responses. The study evaluates the overall seismic hazard assessment of Hong Kong and produces maps delineating zones with similar predicted seismic intensity and motion at the ground surface in the Study Area. The potential natural terrain landslide hazards associated with the seismic ground motions are also evaluated. Findings of part (a) of the study have been documented in Arup (2015).

This report documents part (b) of the study i.e. an area-specific seismic microzonation assessment of the North-west New Territories. To facilitate the study, ground investigation (GI) works including 27 vertical boreholes, 59 geophysics field tests (19 downhole seismic tests, 17 suspension P-S velocity logging (PS Logging) tests, 22 multi-analysis of surface waves (MASW) tests and one crosshole seismic shear wave velocity test) and six laboratory cyclic and static triaxial tests have been carried out under this project. In addition, microtremor tests have been carried out to measure the site dominant periods at 60 locations. The field and laboratory tests have been completed by the end of December 2010 and June 2011 respectively. The results of GI works have been used to evaluate the site responses under seismic ground motions and to develop the site classification.

### **1.2 Scope of this Report**

A seismic microzonation assessment for a Study Area in the North-west New Territories of Hong Kong is carried out in this study. Figure 1.1 shows the location of the Study Area. GEERRI, a sub-consultant to Arup on this Assignment, has been involved in this assessment. Key items of the work completed under the seismic microzonation assessment are listed below:



**Figure 1.1** Topographic Map Overlain with Geological Map in the Study Area

- **Development of Soil Profiles**

Soil profiles in the Study Area have been investigated with standard penetration tests (SPT) and in-situ shear-wave velocity measurements (Downhole seismic, PS logging, Crosshole seismic and MASW tests). The design profiles, defined in terms of soil types, shear wave velocity and small-strain shear modulus versus depth, have been determined.

- **Field and Laboratory Testing**

A series of laboratory and field tests to collect data for site response analyses have been carried out. Several soil properties, required in the site response analyses, have been derived. They include the soil and rock bulk density, shear wave velocity, small strain shear modulus and the degradation of shear modulus with increasing amplitude of cyclic shear strain.

- **Development of Rock Time Histories for Site Response Analysis**

The propagation of the ground motion through the soil profile requires input ground motions for bedrock in form of acceleration time histories. The ground motion records used for site response analyses have been derived to be compatible with the uniform hazard response spectra (UHRS) for bedrock as derived in the probabilistic seismic hazard assessment study (Arup, 2015). Arup adopted the latest time-domain method to modify suitable recorded earthquake time histories to match the target response spectrum. This method better preserves the original features of the recorded time histories. In a parallel study, GEERRI developed input time histories for bedrock using artificial Green's function simulations in a frequency-domain. A shortcoming of this method is that the original features of recorded earthquake time histories are not represented.

- **Site Response Analyses**

Although earthquake site response analyses have been carried out previously for a number of sites in Hong Kong, there are no existing recommendations for design site response spectra that can be applied throughout Hong Kong for regional site classification purpose. In order to understand the potential regional earthquake-induced soil amplification trends in the Study Area, a series of one-dimensional site response analyses have been undertaken for all boreholes with in-situ shear wave velocity measurements in this study. A non-linear program, *Oasys SIREN*, has been used by Arup to perform time-domain site response analyses. The results have been used to determine ground motion amplitude and period-dependent factors for each site class. GEERRI have also carried out independent microzonation using their frequency-domain program.

- **Seismic Ground Motion Microzonation**

The ground surface response spectra produced by site response analyses have been studied and classified such that a systematic seismic ground motion microzonation methodology is recommended for application to the entire Study Area. The



recommendations have also been compared with those of GEERRI considering the conventional practice in Mainland China.

- **Liquefaction**

Liquefaction generally refers to the cyclic generation of large pore water pressure in saturated granular soils and the resulted reduction of effective stress leading to a rapid strength loss of the soils. Among others, sandy soils are the most susceptible to liquefaction under earthquakes. The common engineering practice in assessing of liquefaction potential is based on empirical correlations derived based on field observations of liquefaction, or absence of liquefaction in past earthquakes. The cyclic liquefaction resistance is correlated with different in-situ soil properties measured from standard penetration tests (SPT), cone penetration tests (CPT), or in-situ shear-wave velocity ( $V_s$ ) tests. Arup assessed the probability of liquefaction potential based on the Seed's empirical method (Seed et al, 2001). GEERRI carried out an independent liquefaction assessment based on the current Chinese Code GB50011-2010 (Chinese Seismic Code, 2010). The soil properties have been derived from field and laboratory tests. Microzonation maps have also been produced.

- **Topographic effect**

Noticeable topographic features could affect seismic ground motions. Irregular surface features such as ridges, canyons or slopes can affect the amplitude of the surface ground motions. At ridgelines or cliff tops (convex features), the effect is an amplification of the ground motion, whereas in canyons, de-amplification occurs. In most seismic codes, topographic amplification is ignored considering that site amplification due to local soil conditions is more significant in many locations. Eurocode 8 (BSI, 2004b) makes recommendations for sites located near ridges or slopes and these recommendations have been used to estimate the topographic amplification factors for the Study Area in this study. A microzonation map has been produced.

GEERRI carried out an independent study of the above tasks, mainly based on the Chinese Code GB50011-2010 (Chinese Seismic Code, 2010) and local practice in Mainland China. The self-contained report, including discussions of the study methodologies and the results, is presented in Appendix E.

## **2 Ground Conditions**

### **2.1 General Ground Conditions**

#### **2.1.1 Topography**

The Study Area can generally be divided into two types of topographies i.e. mountainous terrain and low-lying area. The mountainous terrain bounds the Study Area at the southeast in Tai Lam Chung and the west in Castle Peak (Tsing Shan), with the highest elevation of about +560 mPD. The low-lying area covers the Yuen Long flood plain and Tuen Mun Valley in the middle of the Study Area bounded by two mountains, and is overlain by a thick layer of alluvial deposit. Figure 1.1 shows the topographic map overlain with 1:100,000 Hong Kong geological map.

## 2.1.2 General Geology

The geology of the Study Area is interpreted based on the available geological publications and maps published by GEO. A 1:100,000 Hong Kong geological map is presented in Figure 2.1. The solid geology is dominated by Mesozoic volcanic and intrusive igneous rocks overlying the hilly terrain of the Study Area. Extensive Quaternary superficial deposits underlain by Palaeozoic meta-sedimentary rocks cover the surface of the low-lying regions. The majority of the geological contacts are fault-bounded within the Study Area.

### 2.1.2.1 Solid Geology

The rock in the Study Area can be broadly classified into three types:

- (1) Metasedimentary rock of the Yuen Long Formation and the Lok Ma Chau Formation

The metasedimentary rock within the Study Area, Yuen Long Formation and Lok Ma Chau Formation, belongs to San Tin Group and is Carboniferous in age. The strata are metamorphosed, and occupy a northeast trending belt with width of 1 - 5 km, bounded by the Tuen Mun faults on the west and San Tin Thrust Fault on the east.

#### *Yuen Long Formation*

The Yuen Long Formation is dominantly calcareous, consisting of white, light to dark grey, often interbedded with impure marble and metasiltstone near the top. The marble can be intercalated with thin layers of phyllite. According to the 1:100,000 Hong Kong geological map, a subcrop of the Yuen Long Formation is noted in the Yuen Long area. This formation is inferred by borehole information and no surface outcrop can be found. The formation is widely distributed in Yuen Long and Tin Shui Wai.

#### *Lok Ma Chau Formation*

The Lok Ma Chau Formation is overlying the Yuen Long Formation. The formation dominantly consists of metamorphosed siltstone, sandstone conglomerate and carbonaceous siltstone. The formation is exposed at the surface in some locations. The formation is distributed in Yuen Long and Tin Shui Wai.



(2) Volcanic rocks of the Tuen Mun Formation and the Tai Mo Shan Formation

*Tuen Mun Formation*

The Tuen Mun Formation is fault bounded and commonly strongly foliated. The lower part comprises a large epiclastic and volcanoclastic sequence. The upper part of the formation is mainly composed of a sequence of andesitic lavas with some interbedded lapilli-bearing ash crystal tuffs. Within the lava in the formation, marble and other Palaeozoic clasts are also found. The formation occupies the lower foothills of Tsing Shan and along the west of Tuen Mun area.

*Tai Mo Shan Formation*

The Tai Mo Shan Formation can be found at the most eastern side of the Study Area. The formation is commonly a massive largely featureless, pale grey to dark grey lapill-ash or coarse ash crystal tuff.

(3) Tai Lam Granite and Tsing Shan Granite

*Tai Lam Granite*

The Tai Lam Granite can be found along the eastern part of the Study Area and is fault-bounded with the Palaeozoic metasedimentary rocks on its west. The granite is exposed at Tai Tam Chung and forms the mountainous terrain in the east of study area. It consists of a porphyritic medium-grained to equigranular fine grained granite.

*Tsing Shan Granite*

The Tsing Shan Granite overlays the western part of the Study Area in the Castle Peak. This granitic pluton forms the mountainous topography at the western Study Area. The western boundary is defined by the Deep Bay Fault and eastern boundary of the Tuen Mun Fault. The Tsing Shan Granite is variably deformed, and equigranular to inequigranular in texture. It is typically strongly deformed and recrystallised except that the southernmost exposures are only weakly deformed. The degree of deformation generally increases from southwest to northeast.

### **2.1.2.2 Superficial Deposits**

Thick succession of superficial deposit of Quaternary age occupies large, flat-lying areas in the centre of the northwest of the Study Area and extends to the offshore area. In the hilly areas, debris flow deposits are commonly lying in valleys and grading downslope into large fans. Alluvium forms small deposits in the hilly area, but is generally restricted to areas downslope of the debris flow deposits and is widespread in the flat low-lying area. The marine and estuarine deposits can be found near the shoreline area. Reclamation area can also be found near the original coastline near developed new towns in Tuen Mun and Tin Shui Wai.

#### ***Alluvium***

Alluvium is the most widespread superficial deposit overlying bedrock of the Study Area. Alluvial deposits are further divided by the age of deposition: late Pleistocene deposits are found in extensive fluvial terraces, while Holocene alluvium mainly occurs along the recent stream courses. The late Pleistocene alluvial deposit often occurs as inter-layers of clayey silt and sand. The Holocene alluvium comprises mainly gravelly sand in the upper stream courses and clayey sand or silt in the lower courses. The general thickness of the whole alluvial deposit is about 5 - 15 m (GCO, 1990).

#### ***Debris flow deposits***

The debris flow deposit is generally referred to as colluvium in Hong Kong. The large area of deposit can be found below Tsing Shan in the Tuen Mun valley in the Study Area. The composition varies from silt, sand, gravel, cobbles to boulders depending on the original topography and source.

#### ***Estuarine/Marine deposits***

Marine deposit comprises mainly very soft to soft clays. It can be found in the near-shore area like the north of Tin Shui Wai. The estuarine deposit is mainly comprised of brownish grey clayey silts with plant remains and organic clays containing shell fragments.

#### ***Fill (Reclamation)***

Fill can be found in the reclamation area in the south and west of Tuen Mun. The composition varies significantly from clay to cobbles.

### **2.1.2.3 Structure**

The structure of the Study Area is dominated by northeast-trending faults, including the San Tin Thrust Fault between the Palaeozoic and Mesozoic rocks. The Carboniferous strata are thrust from the northwest over the Jurassic volcanic rocks to the southeast at the San Tin Thrust Fault. Tuen Mun fault zone consists of at least four major faults, bounded by the Deep Bay Fault (Lau Fau Shan Fault) in northwest and the San Tin Fault in the southeast. The Palaeozoic strata thrust over from the northwestern side and overlying tuff of the Tai Mo Shan Formation at the northwest dipping San Tin Fault. The overthrusting of Palaeozoic strata onto the Jurassic strata contributes the metamorphism in the Study Area. The northwest-trending

fault is also dominant within the Study Area.

### **2.1.3 Available Borehole Data**

A total of 13 cross-sections have been plotted in the Yuen Long alluvial plain and the Tuen Mun Valley area (see the location plan in Figure 2.2), based on the existing borehole information obtained from the AGS borehole database. The cross-sections, as shown in Figures 2.3 to 2.15, provide information of the soil strata, including the thickness and stiffness of soil layers, for site response analyses.

## **2.2 Ground Investigation**

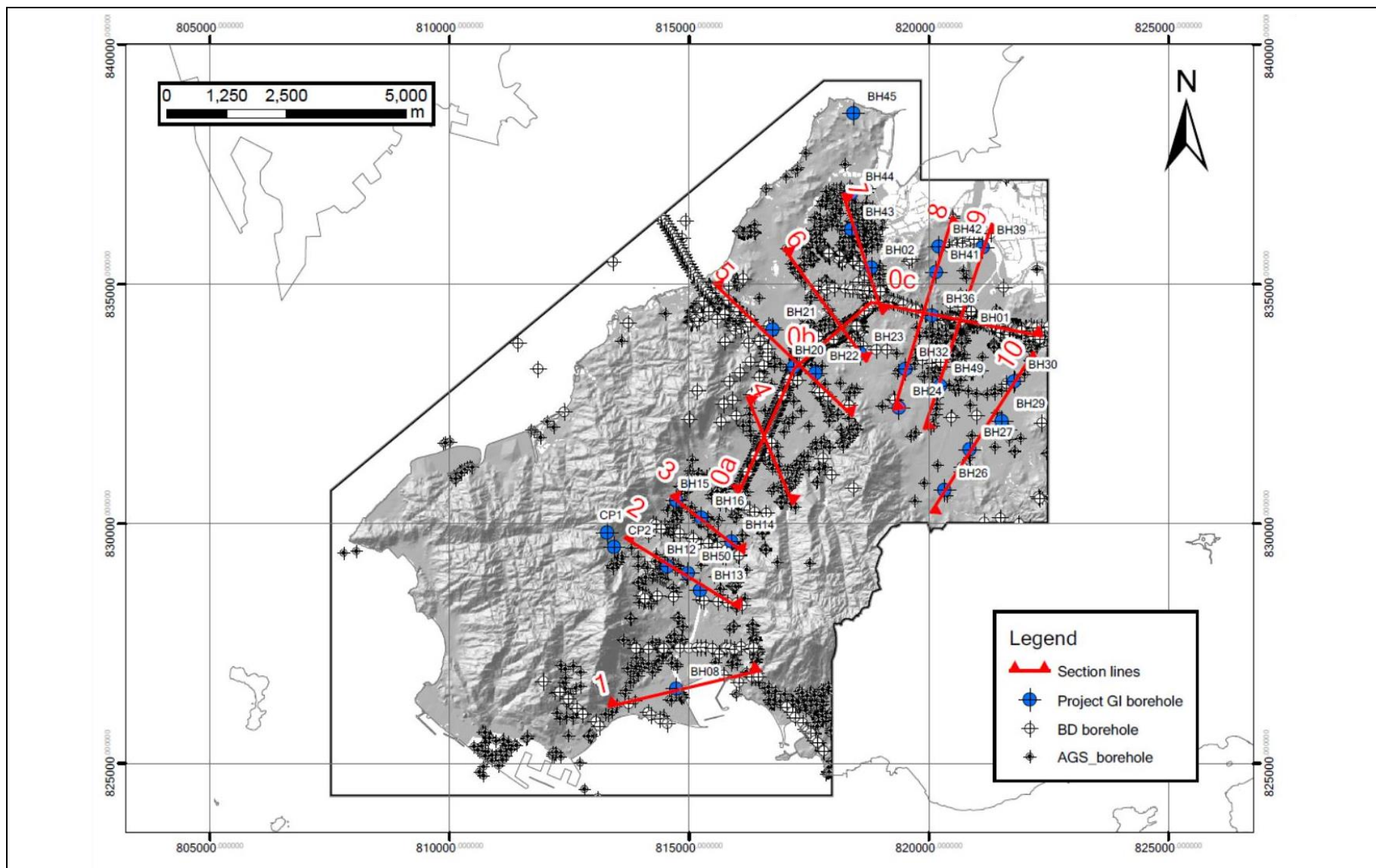
Site-specific GI works comprising 27 vertical boreholes were undertaken by Fugro Geotechnical Services Ltd from May to December 2010. Figure 2.16 shows the borehole locations on the geological map of the Study Area. SPT, in accordance with BSI (1990), GEO (2017) and the Contract Specification, have been carried out at all boreholes. Details of the geological log descriptions are presented in the final fieldwork report (Fugro, 2011a).

Based on the geographical locations and the rock types revealed by the GI works, the boreholes can be categorised into three areas:

- (a) Area 1: Yuen Long alluvial plain overlying metasedimentary bedrock,
- (b) Area 2: Yuen Long alluvial plain overlying igneous bedrock, and
- (c) Area 3: Tuen Mun valley overlaying volcanic rock.

Table 2.1 summarises the bedrock type, the ground level, the approximate thickness of fill and the approximate depth to bedrock, and the approximate depth the SPT-N value exceeding 100 (indicating the depth to very stiff soils) for the 27 boreholes. It is noted that some locations have a significant thickness of very stiff soil over the bedrock.

The majority of boreholes are located within Area 1 in the Yuen Long alluvial plain, underlain by metasedimentary bedrock comprising metasiltstone, metamudstone, metaconglomerate and marble. While the location of BH21 is shown on the geological map as being within Tuen Mun Formation, metasiltstone and metaconglomerate bedrock is retrieved and it is also classified as part of Area 1.



**Figure 2.2 A Plan Showing the Locations of the Section Lines**

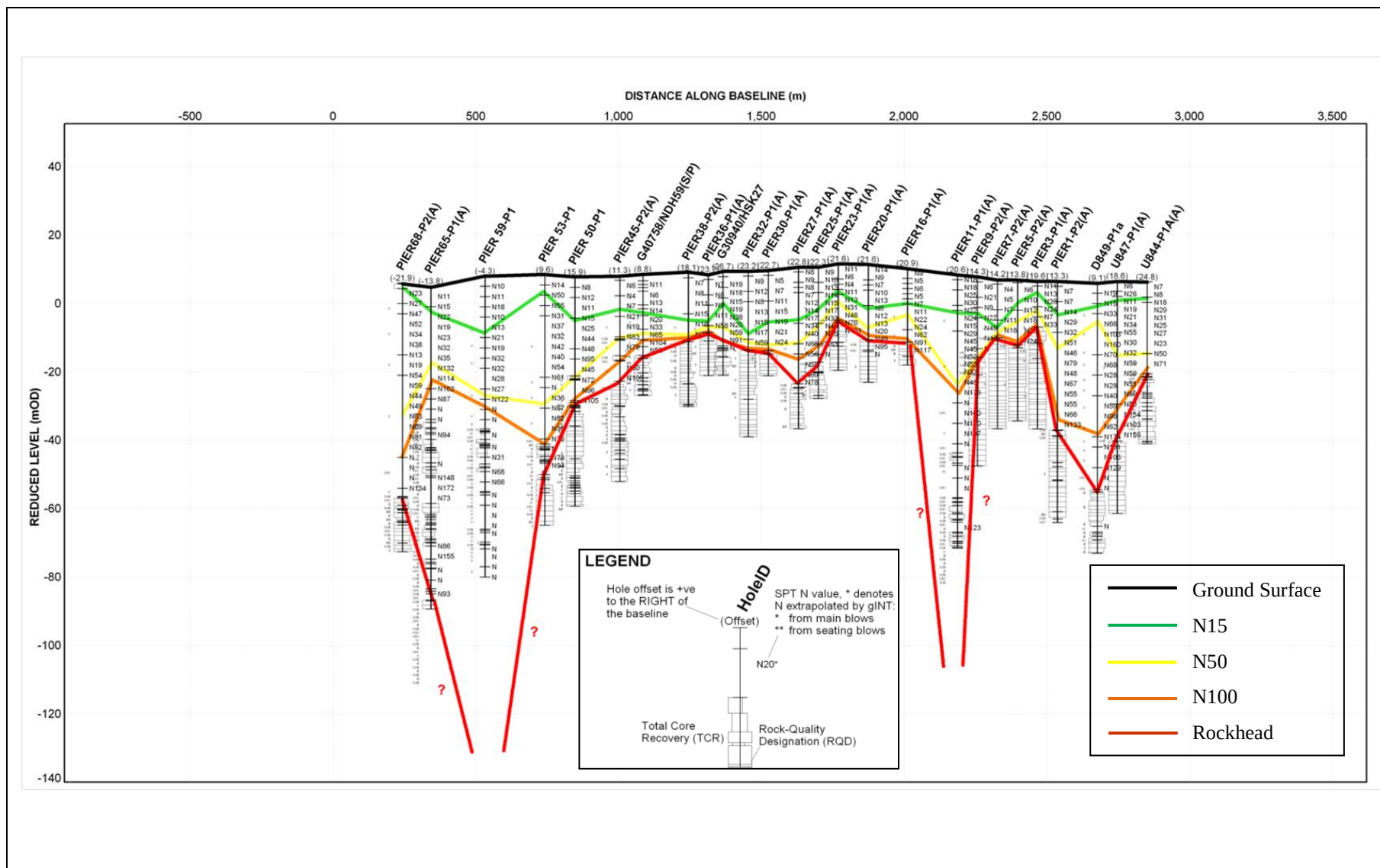


Figure 2.3 Soil Strata Classified According to SPT-N Value of Section 0a



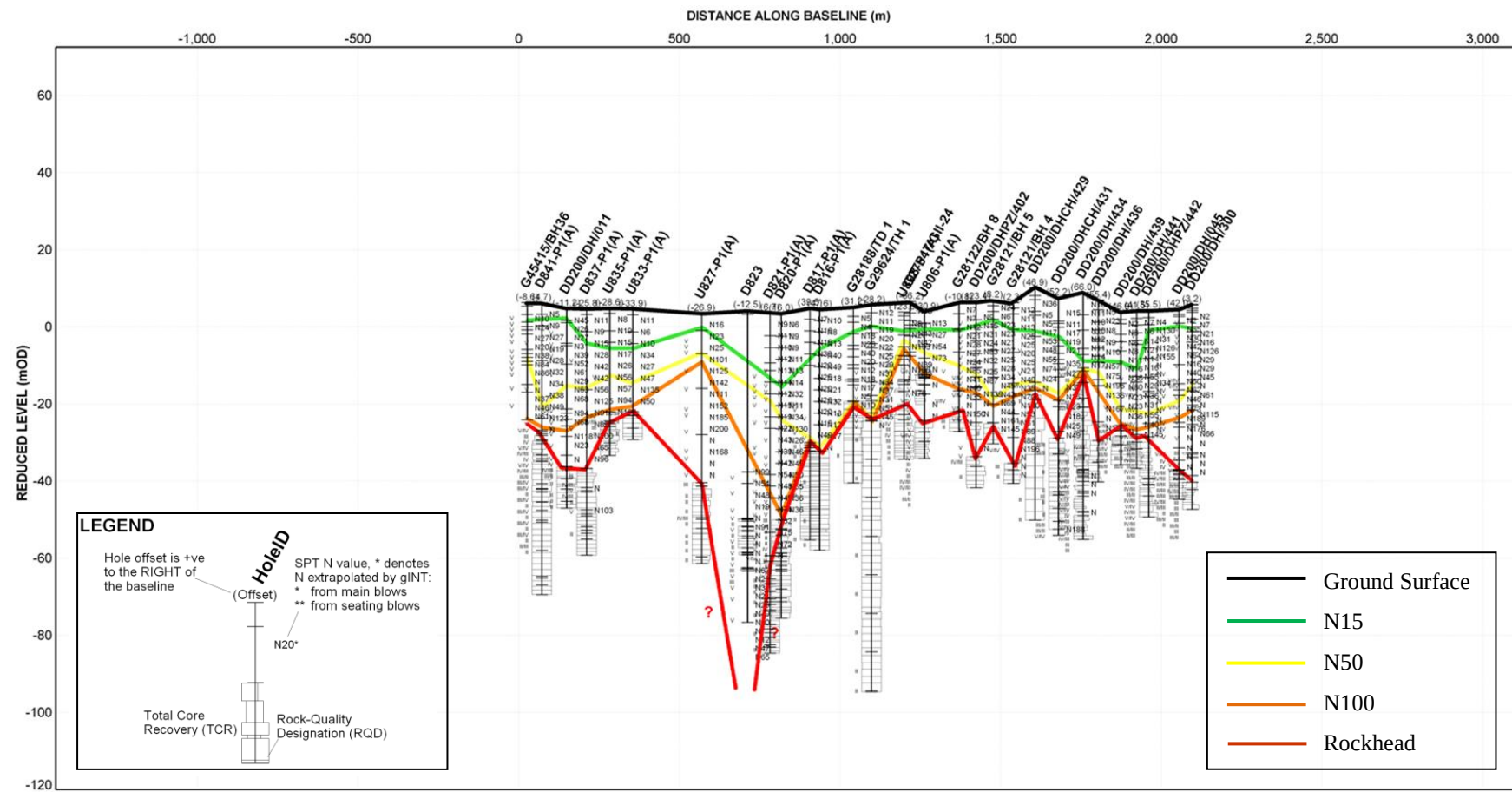
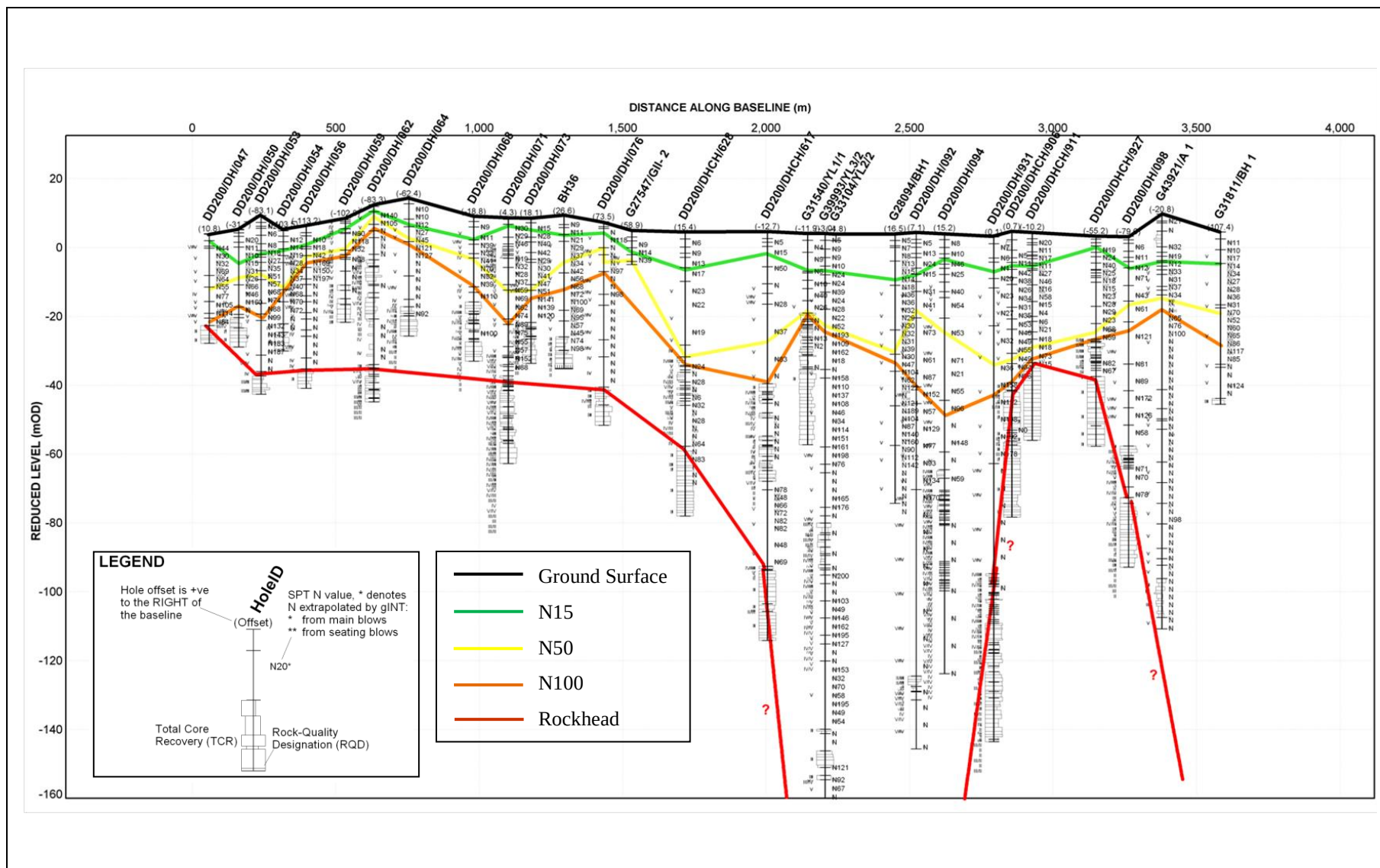


Figure 2.4 Soil Strata Classified According to SPT-N Value of Section 0b



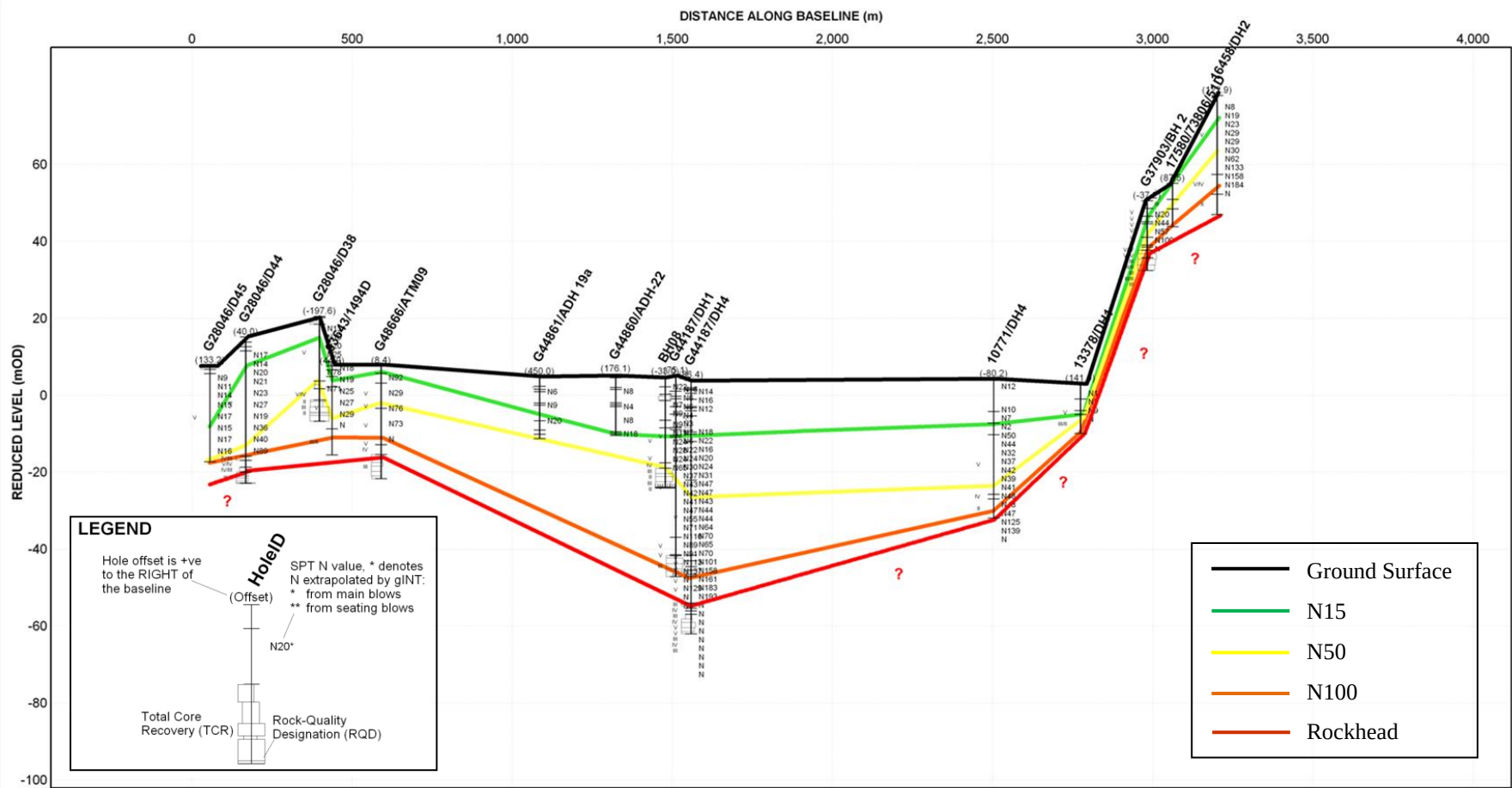


Figure 2.6 Soil Strata Classified According to SPT-N Value of Section 1

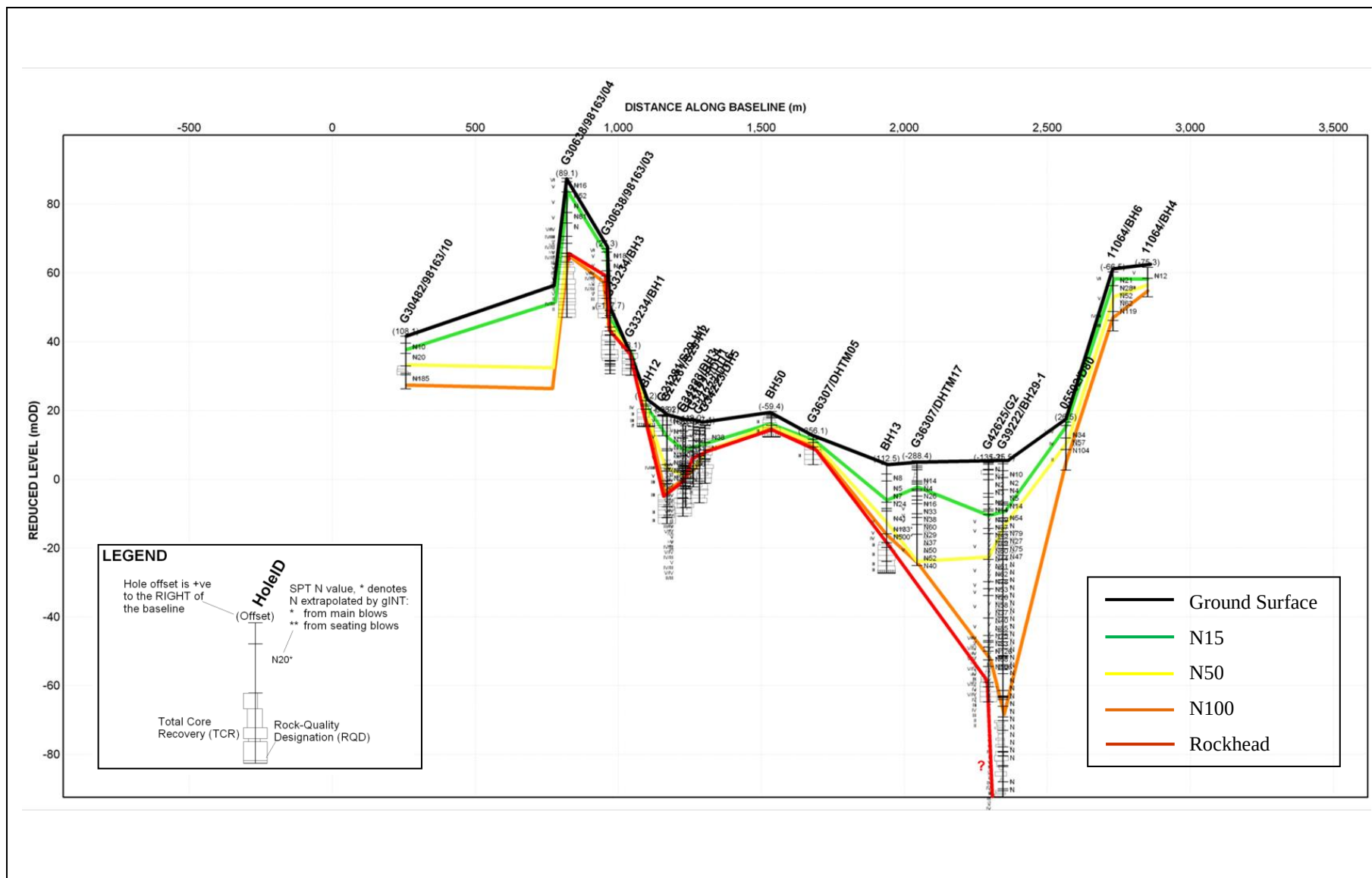


Figure 2.7 Soil Strata Classified According to SPT-N Value of Section 2

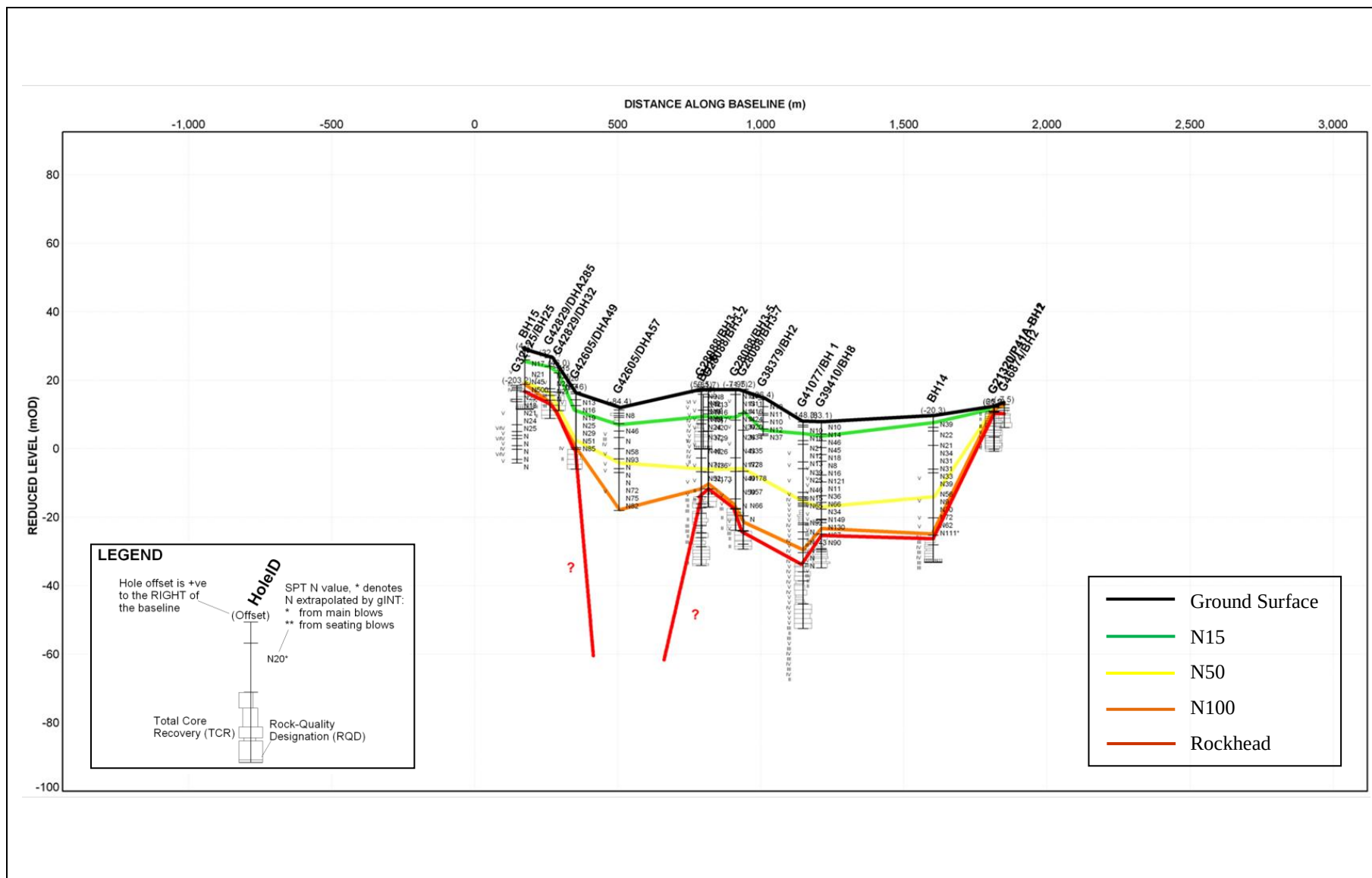
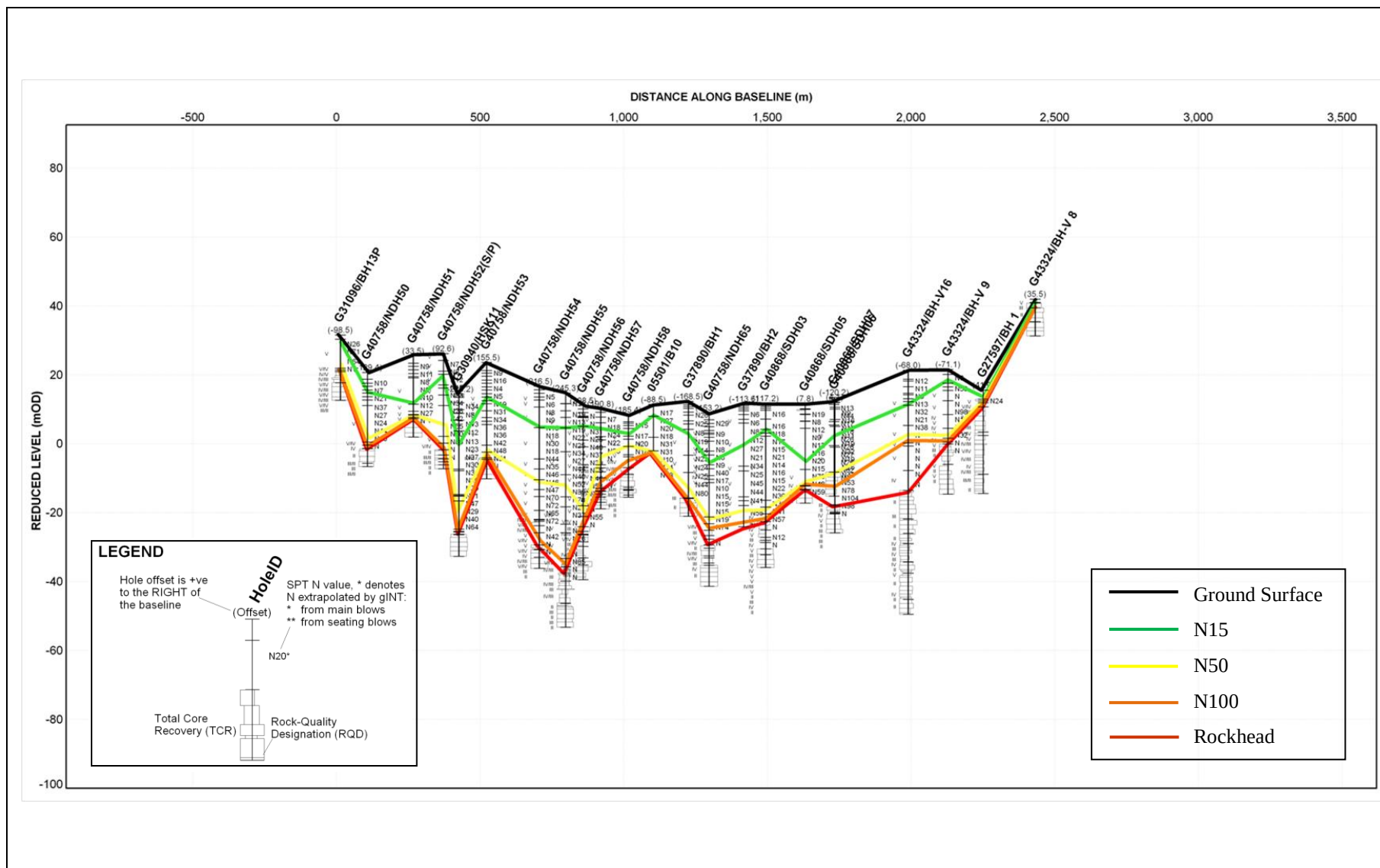


Figure 2.8 Soil Strata Classified According to SPT-N Value of Section 3





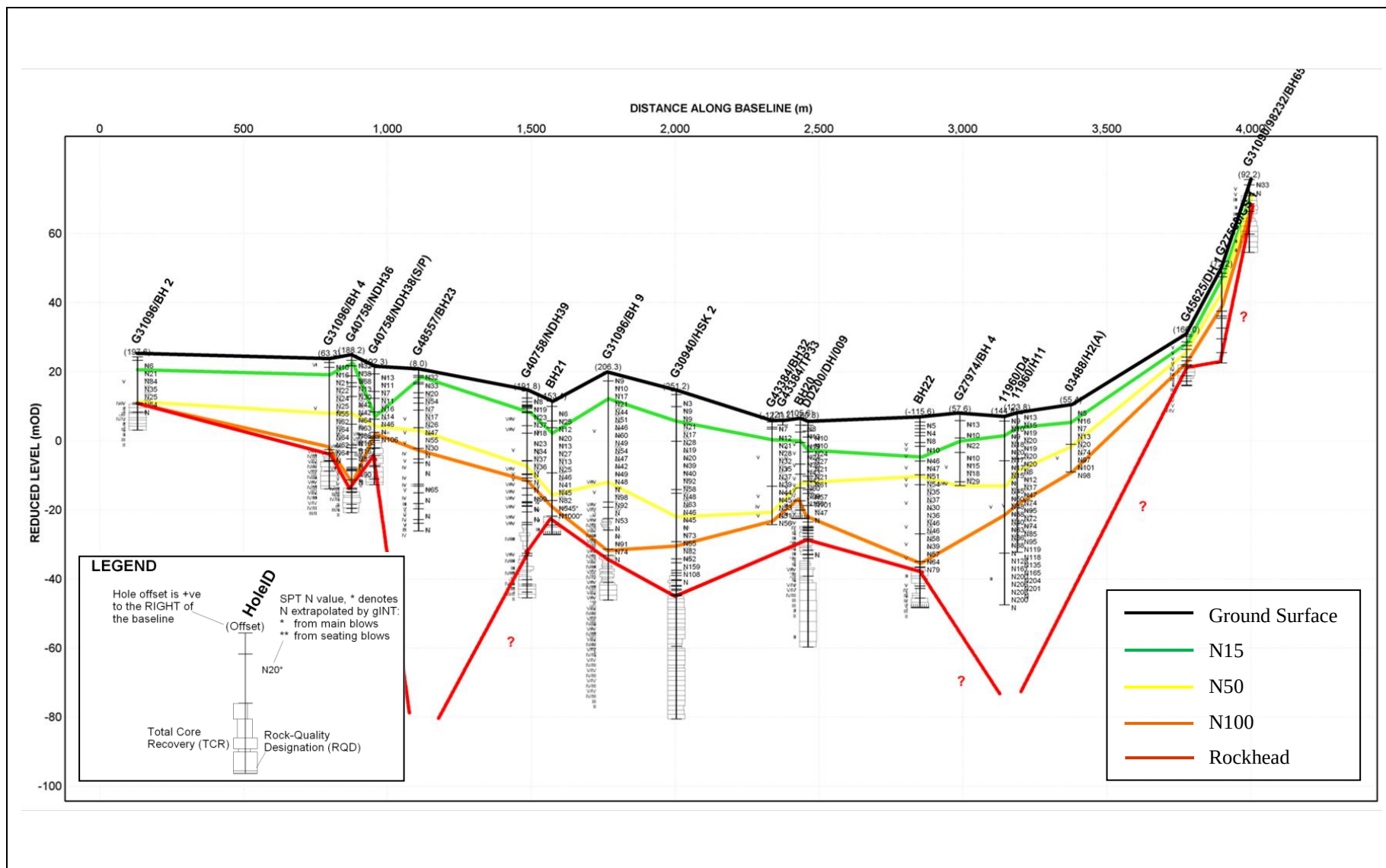


Figure 2.10 Soil Strata Classified According to SPT-N Value of Section 5

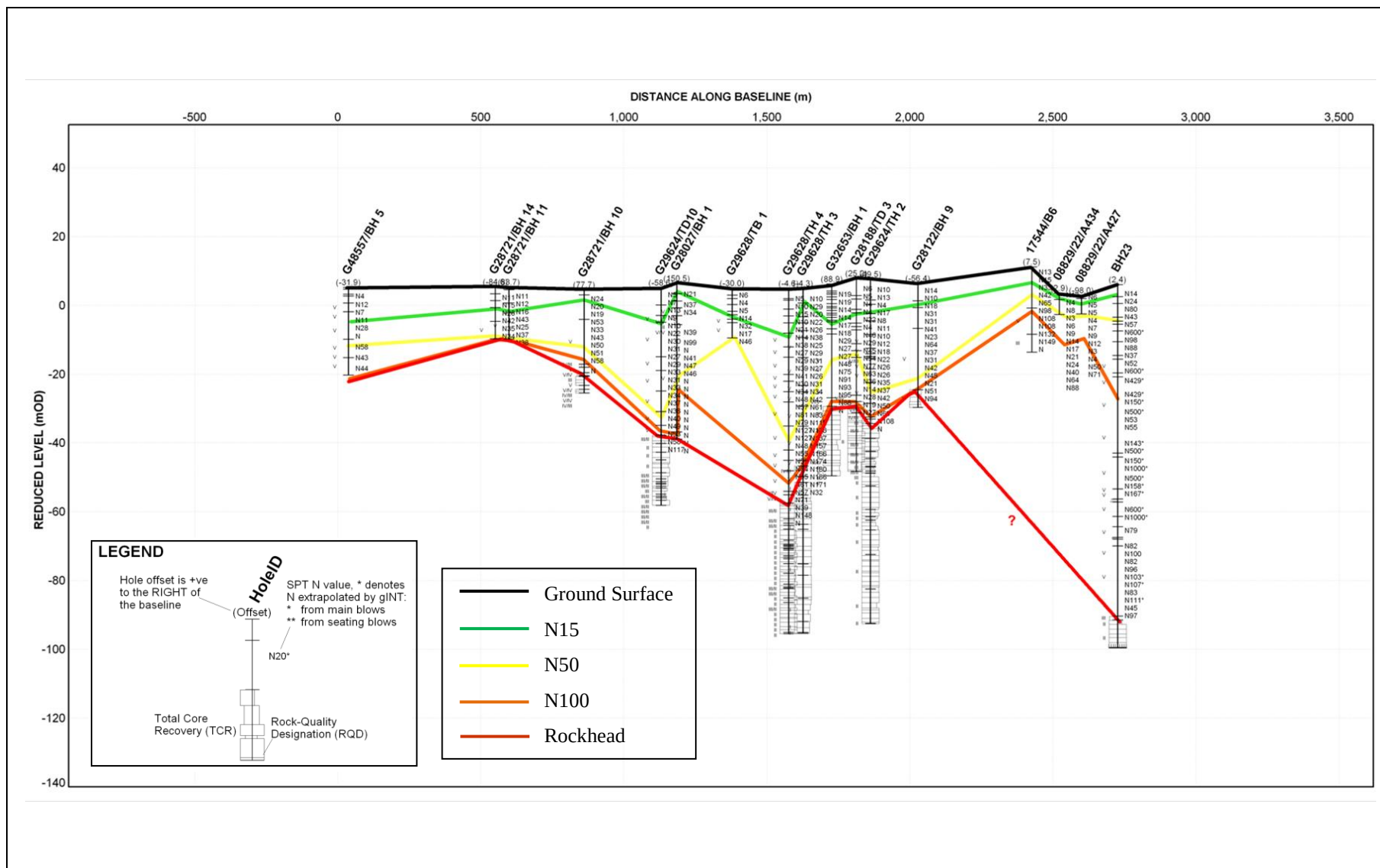
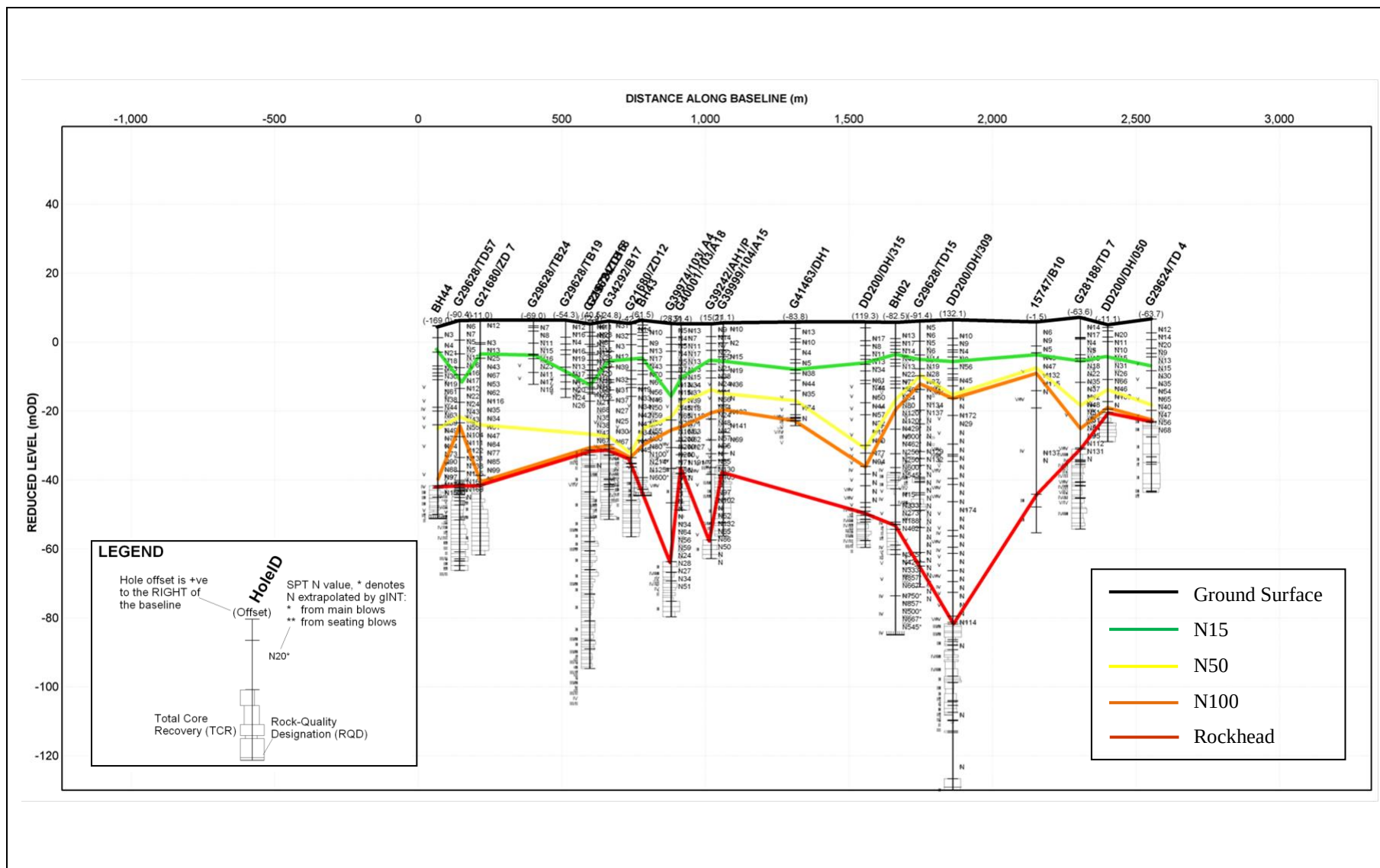


Figure 2.11 Soil Strata Classified According to SPT-N Value of Section 6





**Figure 2.12 Soil Strata Classified According to SPT-N Value of Section 7**

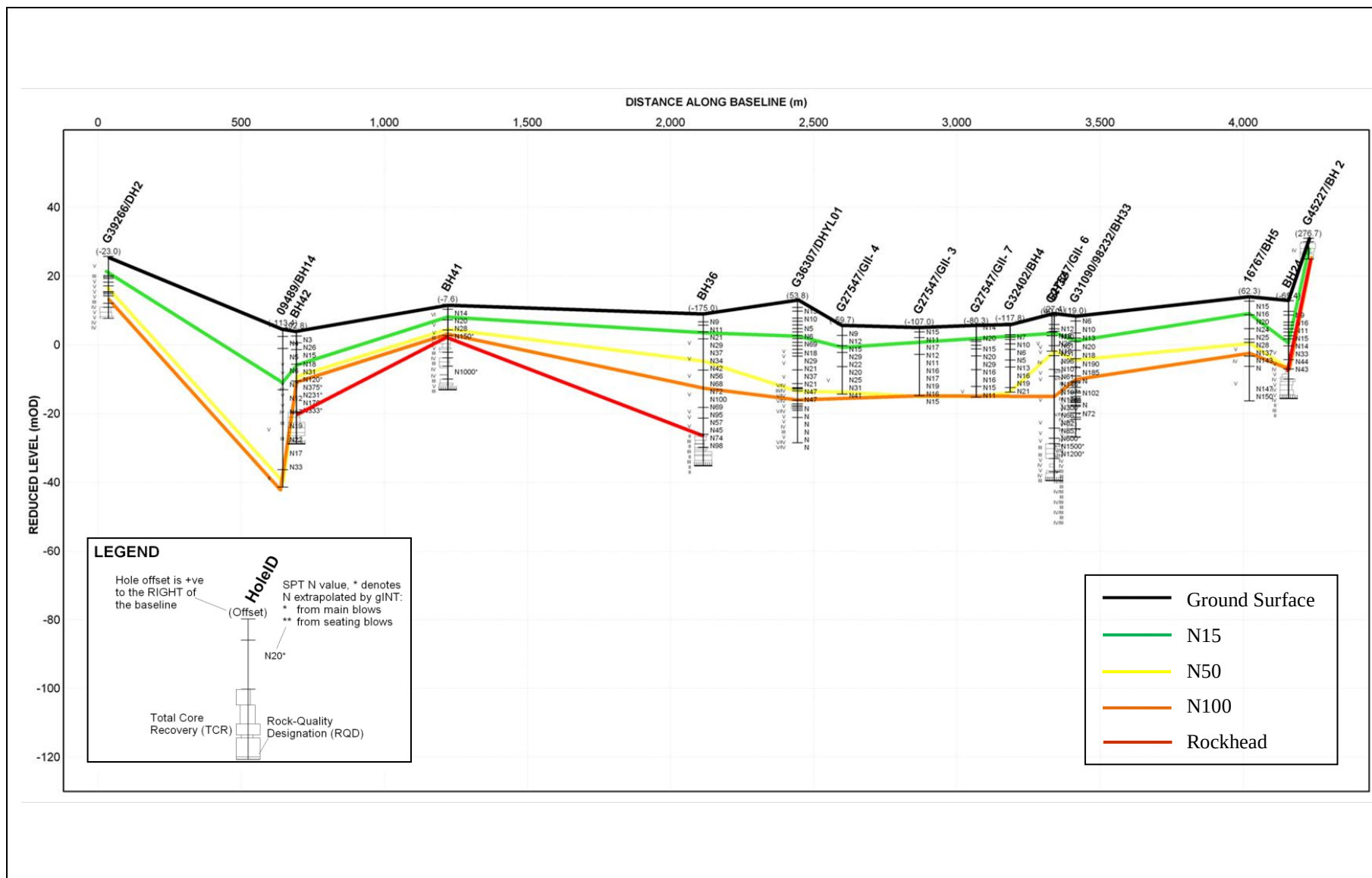


Figure 2.13 Soil Strata Classified According to SPT-N Value of Section 8

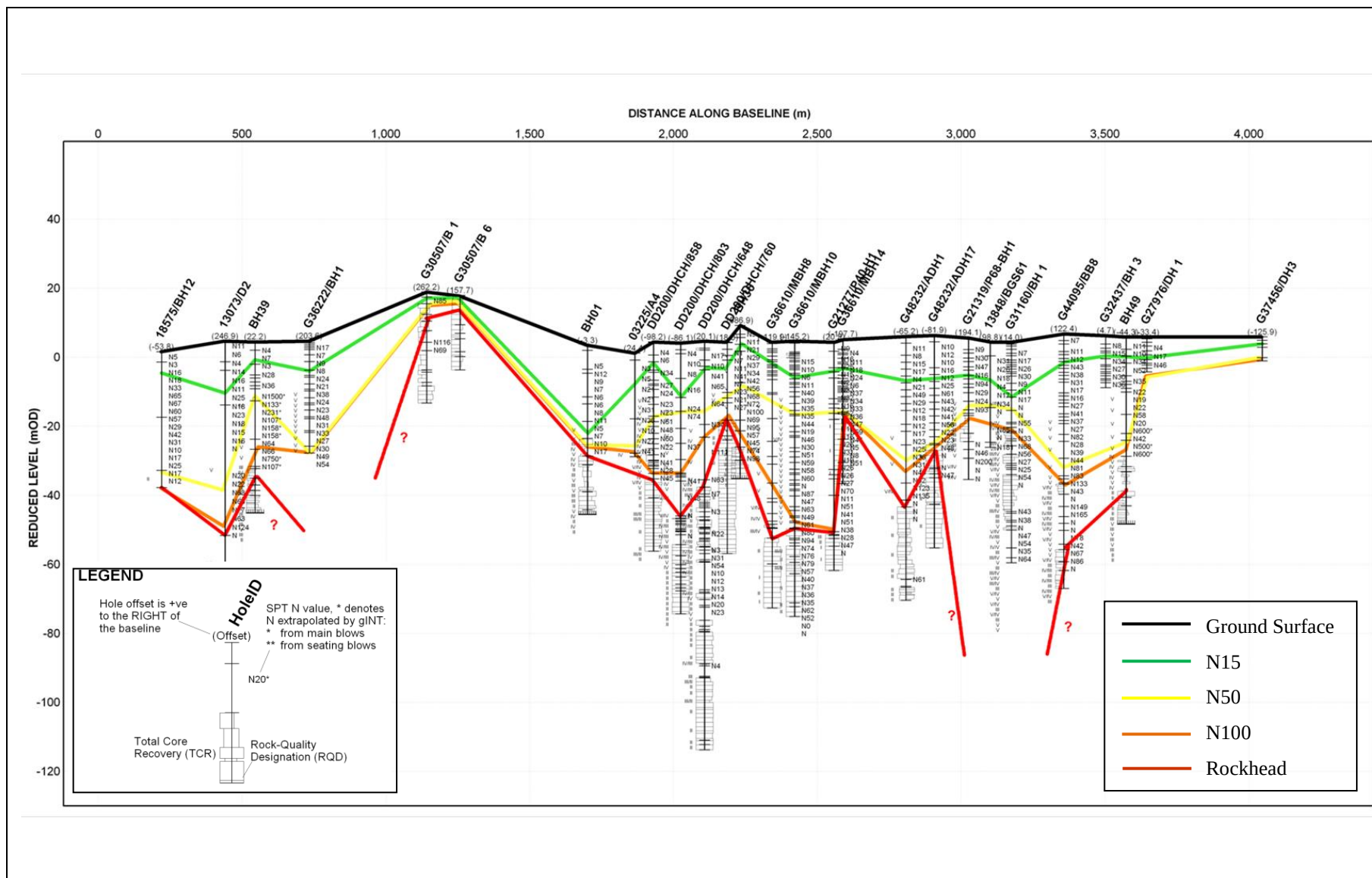


Figure 2.14 Soil Strata Classified According to SPT-N Value of Section 9

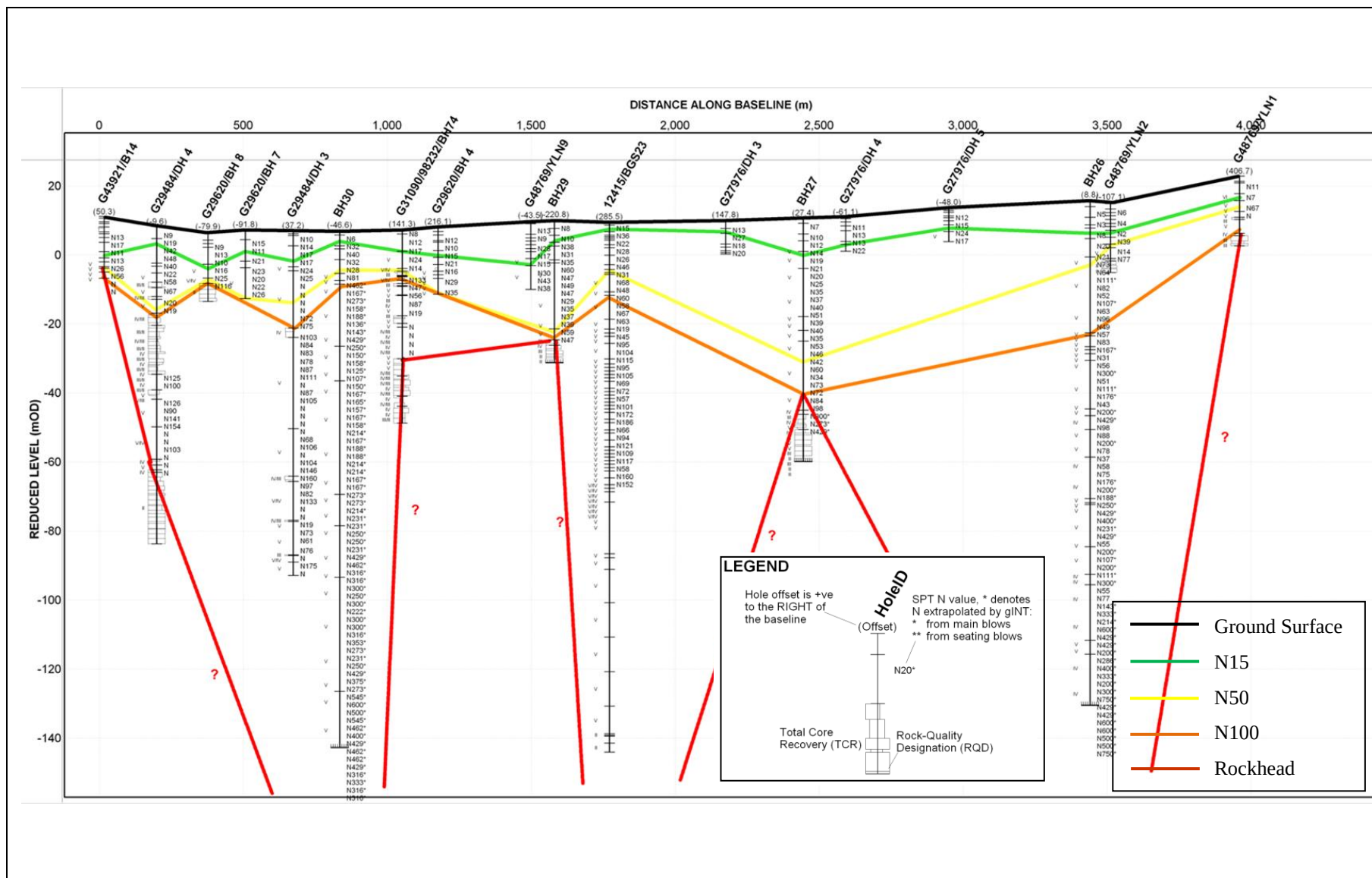


Figure 2.15 Soil Strata Classified According to SPT-N Value of Section 10

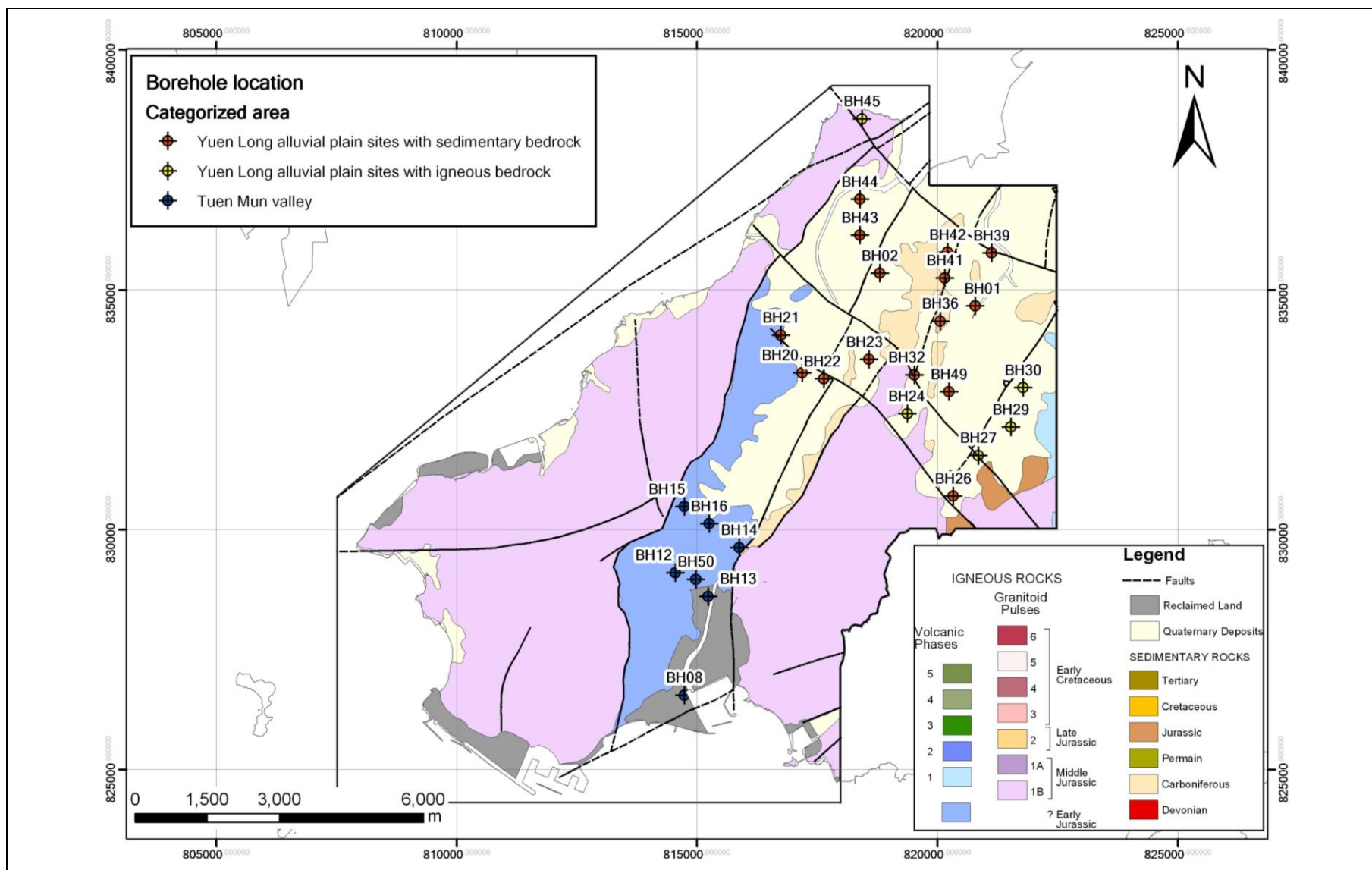


Figure 2.16 Location of the Boreholes on the Geological Map in the Study Area

**Table 2.1 Categorisation of the Boreholes According to the Bedrock Type and Locality**

| Borehole | Area   | Bedrock Type *                     | Surface Level (mPD) | Fill Thickness (m) | Depth to SPT-N > 100 (m) | Depth to Bedrock (m) |
|----------|--------|------------------------------------|---------------------|--------------------|--------------------------|----------------------|
| BH01     | Area 1 | Metasiltstone                      | 3.5                 | 1.5                | 27                       | 32.5                 |
| BH02     |        |                                    | 6.1                 | 7.0                | 25                       | 59.0                 |
| BH22     |        |                                    | 7.0                 | 5.5                | 43                       | 43.7                 |
| BH32     |        |                                    | 8.9                 | 5.0                | 14                       | 37.7                 |
| BH39     |        |                                    | 4.6                 | 2.5                | 15                       | 36.2                 |
| BH41     |        |                                    | 11.9                | 1.5                | 8                        | 9.2                  |
| BH42     |        |                                    | 4.1                 | 1.5                | 13                       | 23.9                 |
| BH44     |        |                                    | 4.8                 | 3.5                | 42                       | 47.1                 |
| BH20     |        | Metasiltstone/<br>Metasandstone    | 6.6                 | 2.0                | 23                       | 23.9                 |
| BH21     |        | Metasiltstone/<br>Metaconglomerate | 11.5                | 1.5                | 29                       | 33.3                 |
| BH26     |        | Metamudstone                       | 16.0                | 2.0                | 74                       | > 146                |
| BH36     |        |                                    | 9.3                 | 2.6                | 35                       | 35.3                 |
| BH43     |        | Metamudstone/<br>Metaconglomerate  | 6.5                 | 5.7                | 37                       | 45.8                 |
| BH23     |        | Marble                             | 6.0                 | 3.5                | 24                       | 96.4                 |
| BH49     |        |                                    | 5.8                 | 3.5                | 29                       | 37.5                 |
| BH24     | Area 2 | Granite                            | 12.8                | 3.1                | 19                       | 22.8                 |
| BH45     |        |                                    | 8.4                 | 1.5                | 16                       | 38.6                 |
| BH27     |        | Tuff                               | 10.7                | 0.0                | 50                       | 61.3                 |
| BH29     |        |                                    | 10.3                | 2.6                | 34                       | 34.9                 |
| BH30     |        |                                    | 7.2                 | 0.0                | 15                       | > 150                |
| BH08     | Area 3 | Metatuff                           | 4.8                 | 11.3               | 19                       | 23.7                 |
| BH12     |        | Tuff Breccia                       | 22.8                | 0.0                | 2                        | 2.5                  |
| BH13     |        |                                    | 4.6                 | 3.1                | 18                       | 23.1                 |
| BH14     |        | Metaandesite                       | 9.8                 | 4.6                | 34                       | 37.8                 |
| BH15     |        | Metatuff                           | 28.6                | 1.5                | 9                        | 11.9                 |
| BH16     |        |                                    | 15.9                | 0.0                | 7                        | 10.9                 |
| BH50     |        | Tuff                               | 19.1                | 1.9                | 2                        | 2.0                  |

Notes: (1) Area 1: Yuen Long alluvial plain sites with sedimentary bedrock;  
Area 2: Yuen Long alluvial plain sites with igneous bedrock;  
Area 3: Tuen Mun valley.

(2) \* Inferred when the bedrock is not reached in BH26 and BH30.



For Area 1, the thickness of alluvial soils ranges from 2 m to 16 m. The depth to bedrock ranges from 9 m (BH41) to more than 146 m (BH26). It is also worth to note in BH26 that very stiff soil with SPT-N value  $> 100$  is encountered at a depth of 74 m and continues for more than 70 m until reaching the terminated depth.

Five boreholes in Area 2 are underlain by igneous bedrock and they are located around the perimeter of the Yuen Long valley. The thickness of alluvial soils ranges from 2 m to 15 m. Though BH45 is located on granitic area with a very thin soil cover according to the geological map, it has been added to this area because of its 12 m thick layer of alluvium. The depth to bedrock varies from 23 m (BH24) to more than 150 m in BH30. However, very stiff soil (SPT-N  $> 100$ ) has already been encountered at a shallow depth of 15 m.

There are seven boreholes in the Tuen Mun valley area i.e. Area 3. They are located on the Tuen Mun formation. Two boreholes (BH08 and BH13), having a fill thickness of 11 m and 3 m respectively, are in reclamation area in the geological map.

On the hillsides, no alluvium has been found except BH14 which is located near the river channel in the Tuen Mun valley. It contains an alluvial layer of about 4 m thick.

### **2.3 In-situ Shear Wave Velocity Tests**

In-situ shear wave velocity measurements have been carried out at all 27 boreholes. The following four geophysics tests have been carried out at different locations:

- (a) Downhole seismic,
- (b) PS logging,
- (c) Crosshole seismic, and
- (d) Multi-analysis of surface wave (MASW).

Table 2.2 indicates the testing locations. Figure 2.17 illustrates the distribution of the PS logging, Downhole seismic and MASW tests in the Study Area. A Crosshole seismic test was carried out at BH36.

The range of soil and rock layer thickness, SPT-N values and measured shear wave velocities for each soil type encountered in all testing locations are summarised in Table 2.3. All the raw data and detailed results can be found in the final factual reports of geophysics works (Fugro, 2011b & 2011c).

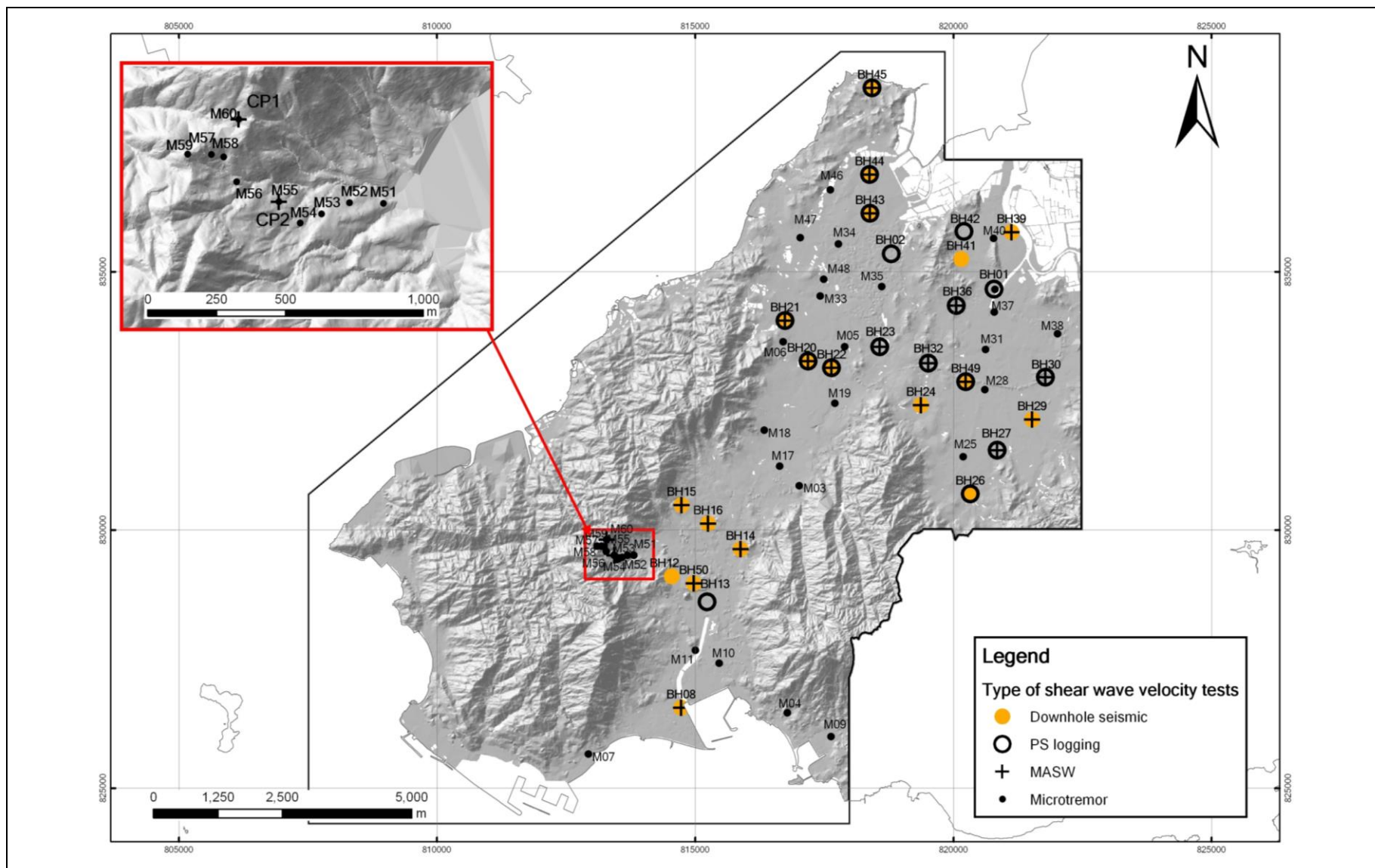
**Table 2.2 Summary of the Tests Conducted and their Locations**

| Borehole     | Downhole Seismic | PS Logging | MASW | Crosshole Seismic |
|--------------|------------------|------------|------|-------------------|
| BH1          |                  | ✓          |      |                   |
| BH2          |                  | ✓          |      |                   |
| BH8          | ✓                |            | ✓    |                   |
| BH12         | ✓                |            |      |                   |
| BH13         |                  | ✓          |      |                   |
| BH14         | ✓                |            | ✓    |                   |
| BH15         | ✓                |            | ✓    |                   |
| BH16         | ✓                |            | ✓    |                   |
| BH20*        | ✓                | ✓          | ✓    |                   |
| BH21*        | ✓                | ✓          | ✓    |                   |
| BH22*        | ✓                | ✓          | ✓    |                   |
| BH23         |                  | ✓          | ✓    |                   |
| BH24         | ✓                |            | ✓    |                   |
| BH26*        | ✓                | ✓          |      |                   |
| BH27         |                  | ✓          | ✓    |                   |
| BH29         | ✓                |            | ✓    |                   |
| BH30         |                  | ✓          | ✓    |                   |
| BH32         |                  | ✓          | ✓    |                   |
| BH36*        | ✓                | ✓          | ✓    | ✓                 |
| BH39         | ✓                |            | ✓    |                   |
| BH41         | ✓                |            |      |                   |
| BH42         |                  | ✓          |      |                   |
| BH43*        | ✓                | ✓          | ✓    |                   |
| BH44*        | ✓                | ✓          | ✓    |                   |
| BH45*        | ✓                | ✓          | ✓    |                   |
| BH49*        | ✓                | ✓          | ✓    |                   |
| BH50         | ✓                |            | ✓    |                   |
| Castle Peak  |                  |            | ✓    |                   |
| Castle Peak  |                  |            | ✓    |                   |
| Total Number | 19               | 17         | 22   | 1                 |

Legend:

\* Two holes at the same location





**Figure 2.17** Location Map for the Geophysics Field Tests

**Table 2.3 Overall Characterisation of the Soils for All Sites**

| All Sites                 | Number of Sites                   |                 | Depth (m) |       | Thickness (m) |       | SPT-N |       | V <sub>s</sub> Measurements (m/s) |     |
|---------------------------|-----------------------------------|-----------------|-----------|-------|---------------|-------|-------|-------|-----------------------------------|-----|
|                           | with the Considered Soil Material | Tested with SPT | Min       | Max   | Min           | Max   | Min   | Max   | Min                               | Max |
| Fill                      | 23                                | 9               | 0         | 11.3  | 0             | 11.3  | 3     | 39    | 130                               | 350 |
| Marine/ Estaurine Deposit | 5                                 | 5               | 1.5       | 11.3  | 2             | 8.2   | 3     | 21    | 150                               | 200 |
| Alluvium Sand             | 22                                | 21              | 1.5       | 22    | 2             | 15.4  | 3     | 98    | 150                               | 450 |
| Alluvium Clay             | 7                                 | 7               | 1.5       | 16.8  | 0.9           | 8     | 3     | 34    | 200                               | 400 |
| In-situ Sedimentary Rock  | 14                                | 14              | 4.6       | 146.5 | 4.57          | 131.1 | 5     | > 100 | 160                               | 632 |
| In-situ Tuff              | 10                                | 9               | 1.5       | 150   | 1             | 137.4 | 10    | > 100 | 153                               | 700 |
| In-situ Granite           | 2                                 | 2               | 13.2      | 51.3  | 9.7           | 37.8  | 33    | > 100 | 325                               | 800 |

### 2.3.1 Downhole Seismic

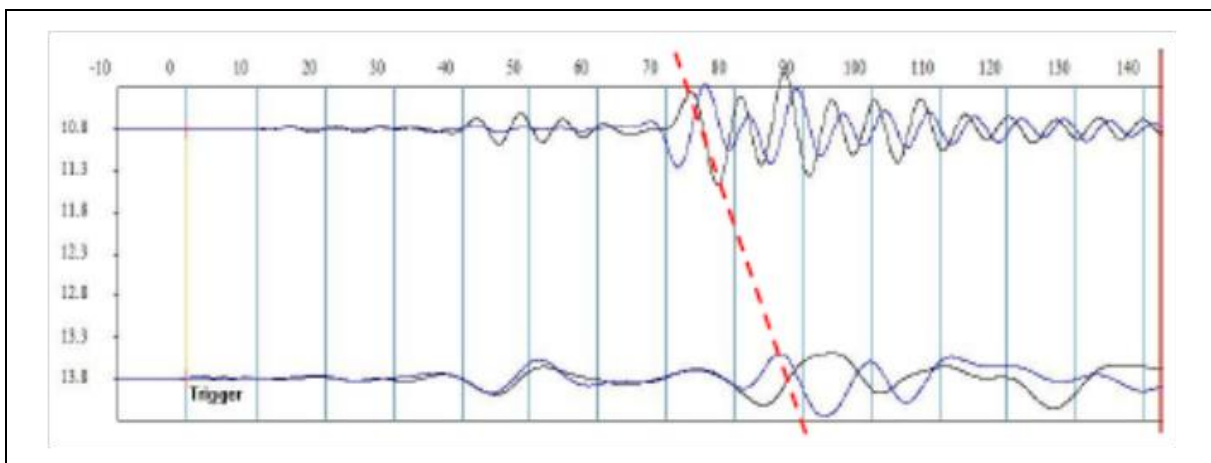
Downhole seismic tests have been carried out at 19 boreholes. The records of seismic shots from ‘left’ and ‘right’ source activations have been overlain so that incident shear wave energy could be identified by characteristic shear wave (S-wave) polarisation for the arrival time as shown in Figure 2.18. The incident S-wave arrival time can be recognised by the polarity reversal at approximately 70 ms.

Two methodologies have been used to process the data.

- (a) The determination of interval S-wave velocities can be made by ‘picking’ the arrival time of the incident S-wave energy on each geophone. The interval time and distance information can be used to calculate interval velocities. With correct channel geometry, the same process can be achieved by drawing a velocity line through the same phase on each trace (i.e. peak to peak or trough to trough) as shown in Figure 2.18. This procedure is considered (theoretically) to be the most accurate means of determining interval velocities as it is independent of trigger (time zero) errors. However, it requires that the characteristics of both signals are similar (so that the same phase may be picked) from each receiver.

Where the source signature between receivers is not consistent (due to, for example, changes in ground material, changes in grout bond quality, variations in mechanical coupling with the borehole wall, equipment performance related issues, etc.), it may not be possible to determine the accurate interval velocities in this manner. In addition, measurements of interval velocities (from low frequency signals typical in downhole shot records) over relatively short distances are prone to errors induced as a function of picking resolution (i.e. a time pick error could be a high percentage of the absolute travel time between receivers).

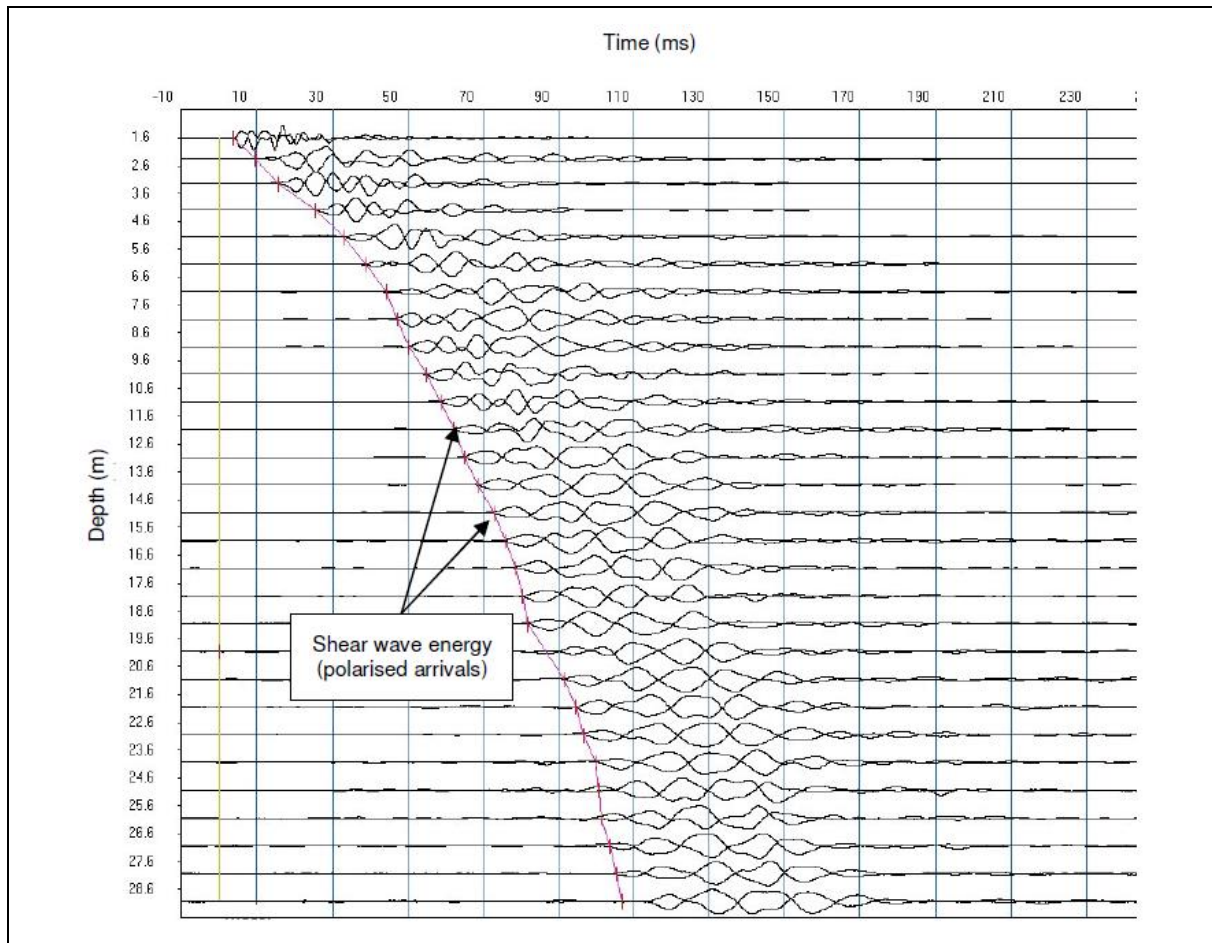
Where data do not exhibit consistent signal characteristics for top and bottom receivers, the method described above is not appropriate and could have led to inaccurate determination of velocities.



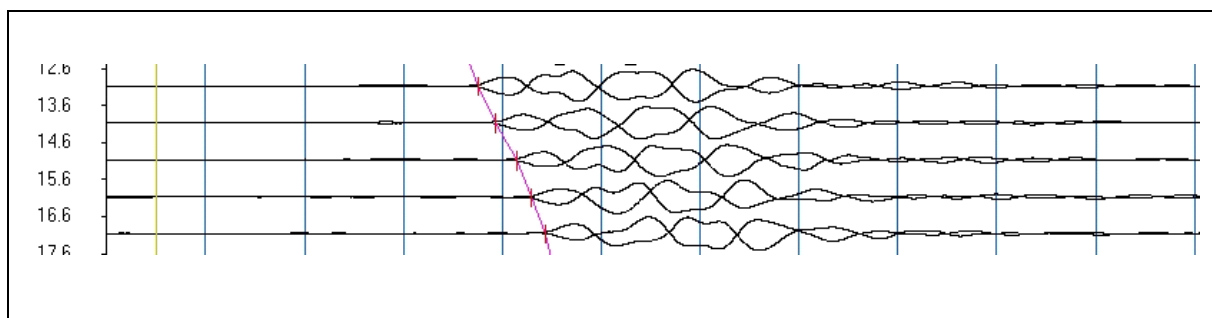
**Figure 2.18 Example of Downhole Seismic Shot Record**

- (b) An alternative analysis has been carried out to determine velocity profiles by an assessment of velocity gradients from time-distance plots of all picked arrival times. This procedure has been carried out by combining shot records from each individual test depths into a complete depth section. The data has appropriately been filtered to remove unwanted frequencies and analysed to pick incident S-wave energy at each test depth. An example of a complete depth data record (shot gather) is provided in Figure 2.19.

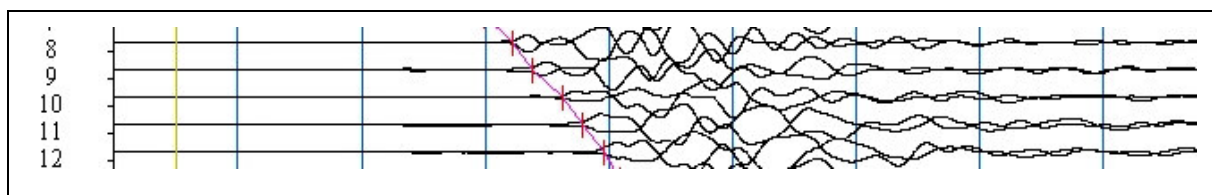
Figure 2.19 illustrates a good quality shot gather, but noise can make the analysis of the data more difficult, and therefore, the data have been classified within four quality rankings labelled from Q1 (best) to Q4 (worst). Figures 2.20 to 2.23 illustrate typical examples for each quality ranking.



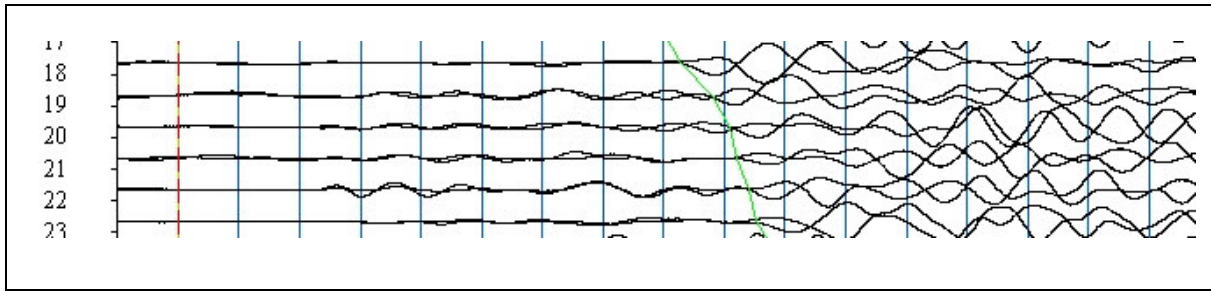
**Figure 2.19 Downhole Seismic Shot Gather and Interpretation Example**



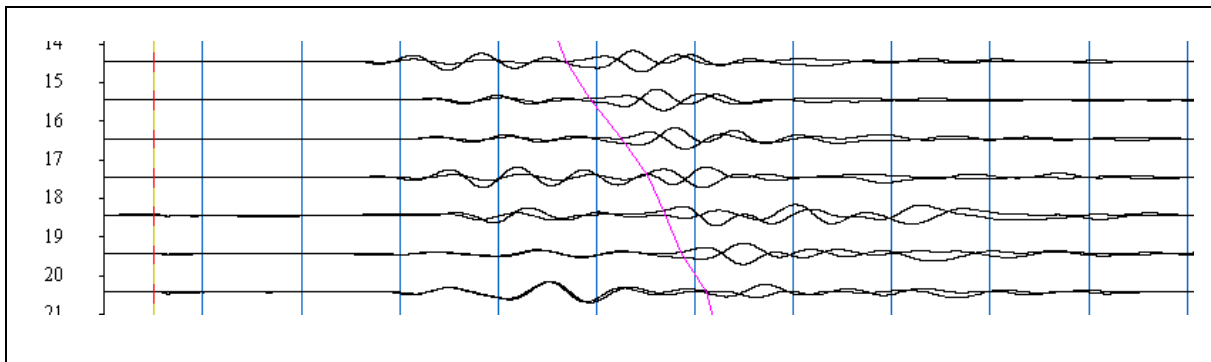
**Figure 2.20 Q1 Downhole Seismic Shot Record Example**



**Figure 2.21 Q2 Downhole Seismic Shot Record Example**



**Figure 2.22 Q3 Downhole Seismic Shot Record Example**



**Figure 2.23 Q4 Downhole Seismic Shot Record Example**

### 2.3.2 PS Logging

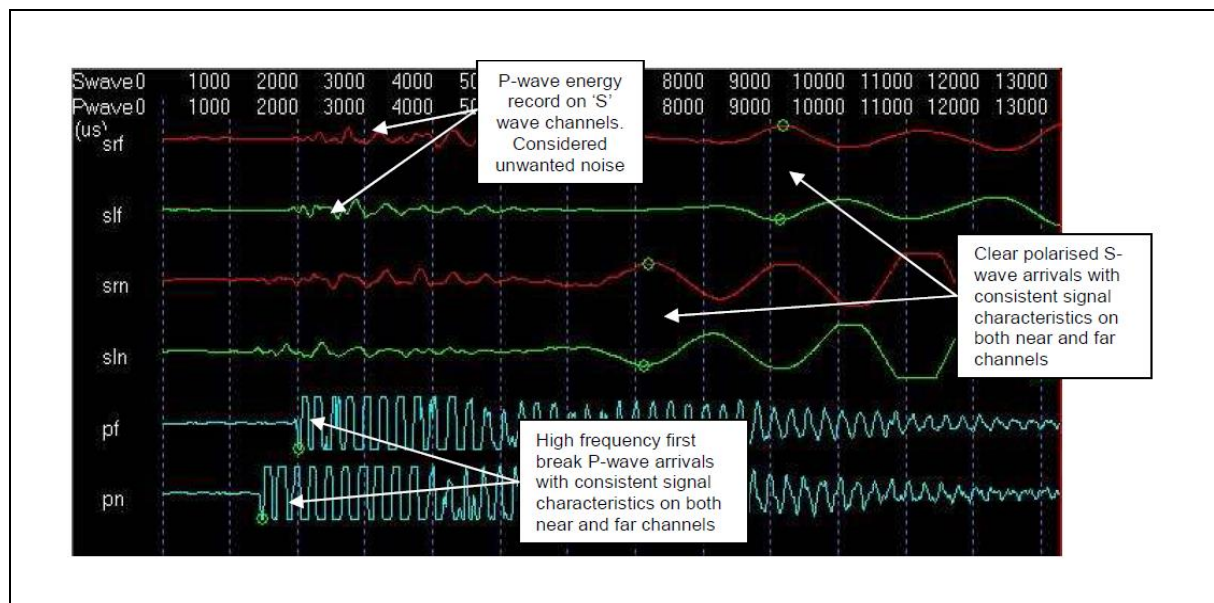
PS logging tests have been carried out at 17 borehole locations. A ranking from Q1 to Q4 has been designated to each velocity measurement as a function of the data quality and confidence in signal recognition. The criteria to determine the interval velocities for the different quality rankings are summarised in Table 2.4. Where a confident identification of compression or shear wave arrivals could not be made based upon those criteria, the data are rejected and no velocity is calculated. Examples of Q1 and Q2 shot record characteristics are shown in Figures 2.24 and 2.25 respectively.

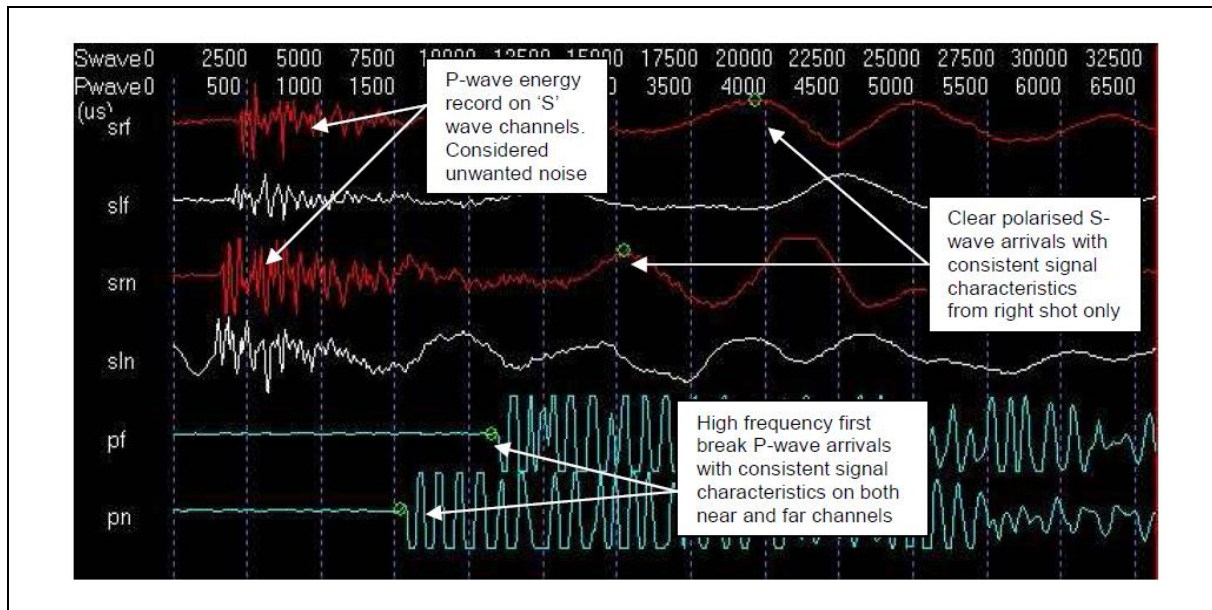
Only Q1 and Q2 data are considered for the determination of the shear wave velocity design profile used in the site response analysis (see Section 4).



**Table 2.4 Quality Rankings Criteria for PS Logging**

| Q Index | Software Platform | Comments                                                                                                                                                                                                                           |
|---------|-------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1       | Glog-sus          | Interval velocities determined from a visual assessment of raw data without the need for data processing/filtering. Confident identification of polarised signals for left and right shots on both near and far channels.          |
| 2       | Glog-sus          | Interval velocities determined from a visual assessment of raw data without the need for data processing/filtering. Confident identification of polarised signals for either the left or right shot on both near and far channels. |
| 3       | Seislmager        | Interval velocities determined from by identification of polarised signals for both left and right shots on both near and far channels after appropriate frequency filtering and channel remapping.                                |
| 4       | Seislmager        | Direct velocities determined from by identification of polarized signals for left and right shots on either the near or far channels Subject to phase, trigger and borehole geometry errors.                                       |

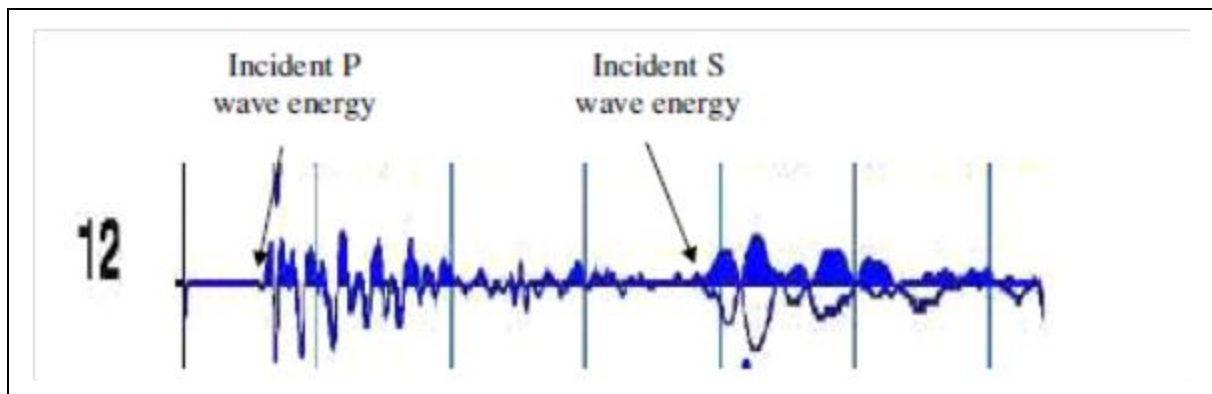
**Figure 2.24 Q1 PS Logging Record Example**



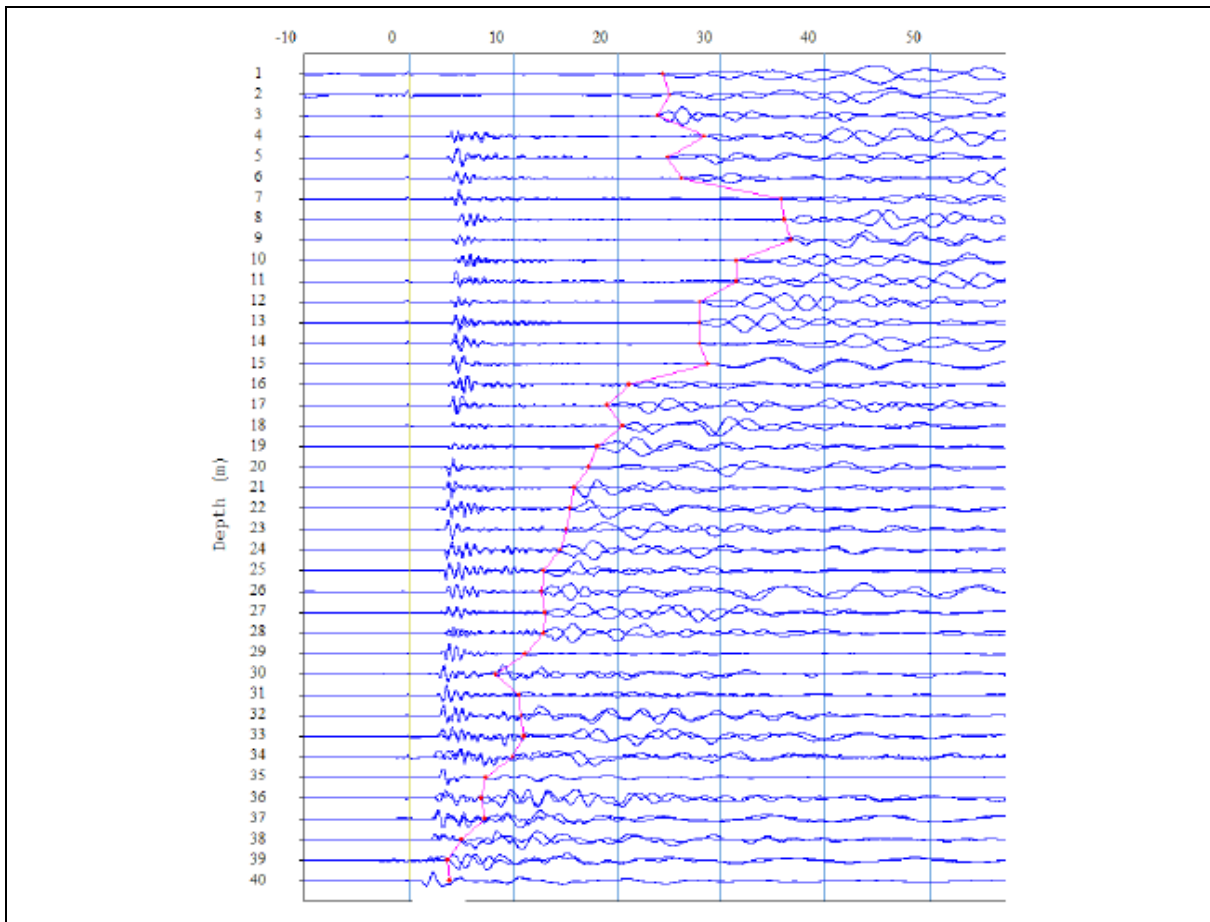
**Figure 2.25 Q2 PS Logging Record Example**

### 2.3.3 Crosshole Seismic

A Crosshole seismic test has been carried out at BH36. In this technique, two boreholes (BH36 & BH36A) have been sunk at about 5 m apart. Shot records from 'left' and 'right' or 'up' and 'down' source activations are overlain so that incident shear wave energy could be identified by characteristic shear wave polarisation. An example of the combined shot record and crosshole shot gather are provided in Figures 2.26 and 2.27. Determination of the *P*- and *S*-wave velocities at each test depth is made by 'picking' the arrival time of the incident *P*- or *S*-wave energy on each combined shot record. Where confident identification of *P*- or *S*-wave energy could not be determined based upon these criteria, the data are rejected and no velocity is calculated.



**Figure 2.26 Single Depth, Combined Crosshole Seismic Shot Record Example**



**Figure 2.27 Crosshole Shot Gather (Horizontally Polarised Source) Example**

A notable difference in signal clarity is identified between the Downhole seismic tests for BH36 and BH36A. Shot records for BH36 generally exhibit clear polarisation of shear wave energy (mainly quality classification 1 and 2). Shot records for BH36A exhibit significantly reduced signal clarity (mainly quality classification 2 to 4). The reason for the variation in data quality is not clear but is likely to be related to localised ground/hole conditions specifically around BH36A.

In general, velocities measured for shear wave energy primarily in the horizontal plane are slightly higher than those velocities derived for shear wave energy primarily in a vertical plane. The divergence between horizontal and vertical plane velocities is the greatest between a depth of 20 to 26 m in completely decomposed Metamudstone, Sandy Silt, as logged in BH36. This difference between the vertical and horizontal plane velocities indicates a degree of anisotropic behaviour of the material with the shear stiffness being greater on the horizontal plane.

The shear wave velocity measurements derived from the Crosshole seismic test are broadly consistent with the velocities derived from the PS logger and Downhole seismic measurements. Clearly, the vertical plane velocity from the Crosshole seismic test, rather than that from the horizontal plane, should be comparable with the velocity results from the PS logger and Downhole seismic tests.



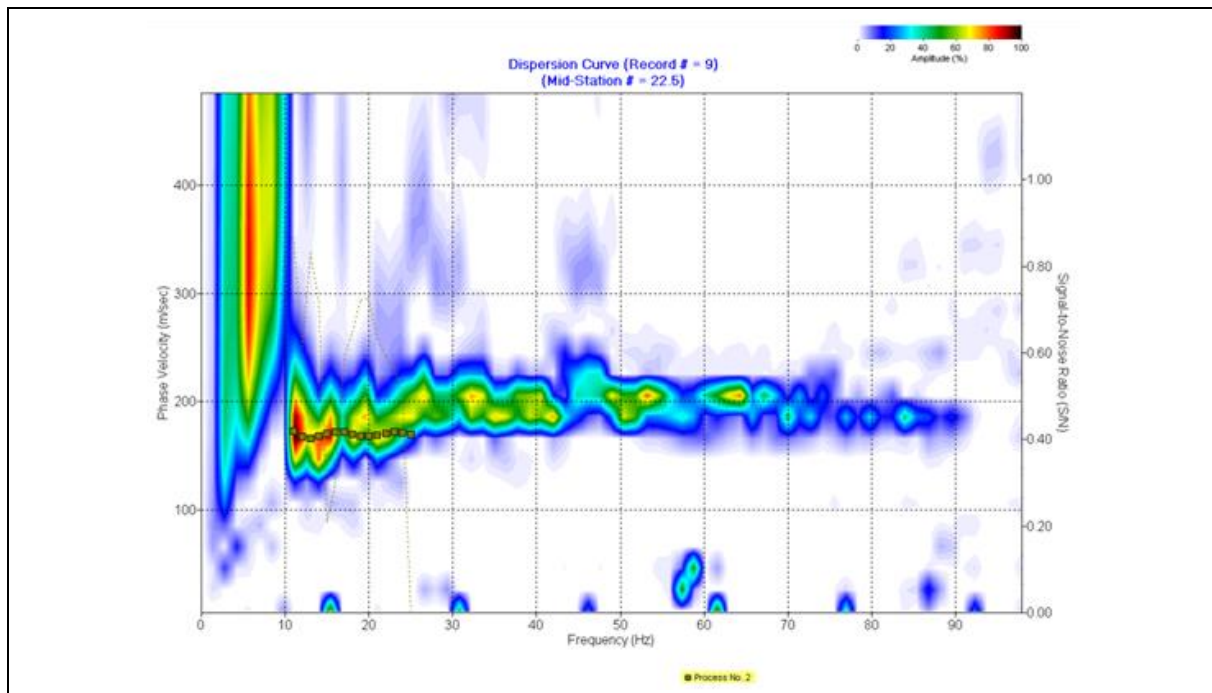
### 2.3.4 Multi-analysis of Surface Wave (MASW)

The 22 MASW testing locations as listed in Table 2.2 are shown in Figure 2.17. 20 tests have been located adjacent to the boreholes sunk as part of this project and 2 additional tests have been undertaken at the lower slopes of the Castle Peak.

The inferred shear wave velocity profiles are determined from Rayleigh waves based on the algorithms described in Xia et al (1999). Rayleigh waves, assuming a Poisson's Ratio of 0.25, travel at a speed of about 0.9 times that of the S-wave velocity. A typical overtone image exhibiting dispersive behaviour is provided in Figure 2.28. Only the fundamental mode was considered when using this dispersion curve to derive shear wave velocities. The fundamental mode is defined as the lowest dispersive, coherent phase velocity at any particular frequency. The MASW test results are considered to be reliable down to a depth of about 10 m from the ground based on the quality of resolution of the dispersion curve. Also, the MASW technique is based upon acquisition at small strains ( $< 10^{-5}$ ).

### 2.3.5 Comments on PS Logging Relative to Downhole Seismic Tests

Based on the large dataset of shear wave velocities available from PS logging and Downhole seismic tests and the quality rankings of the data, a qualitative comparison between both techniques has been made. As shown in Table 2.5, the PS logging data seem to be of better overall quality than the Downhole seismic processed data. The average percentage of Q1 and Q2 data over the total amount of data is indeed 73% for PS logging against 55% for Downhole seismic testing.



**Figure 2.28 Typical Dispersion Curve for MASW Test for BH20**

**Table 2.5 Summary of Quality Rankings for PS Logging and Downhole Seismic Tests**

| Borehole | Area   | Depth to Bedrock (m) | PS Logging Quality |                   |                 |                 | Downhole Seismic Quality |                   |                 |                 |    |    |
|----------|--------|----------------------|--------------------|-------------------|-----------------|-----------------|--------------------------|-------------------|-----------------|-----------------|----|----|
|          |        |                      | No. of Q1 & Q2     | Total No. of Data | % Q1-Q2         | Average % Q1-Q2 | No. of Q1 & Q2           | Total No. of Data | % Q1-Q2         | Average % Q1-Q2 |    |    |
| BH01     | Area 1 | 32.1                 | 22                 | 26                | 85*             | 72              | 73                       | NE                |                 |                 | 57 | 55 |
| BH02     |        | 59.0                 | 83                 | 88                | 94*             |                 |                          |                   |                 |                 |    |    |
| BH20     |        | 23.9                 | 15                 | 20                | 75              |                 |                          | 14                | 29              | 48              |    |    |
| BH21     |        | 33.3                 | 27                 | 30                | 90*             |                 |                          | 12                | 38              | 32              |    |    |
| BH22     |        | 43.7                 | 64                 | 64                | 100*            |                 |                          | 14                | 41              | 34              |    |    |
| BH23     |        | 96.4                 | 8                  | 11                | 73              |                 |                          | NE                |                 |                 |    |    |
| BH26     |        | > 146                | 5                  | 30                | 17 <sup>#</sup> |                 |                          | 26                | 29              | 90*             |    |    |
| BH32     |        | 37.7                 | 52                 | 55                | 95*             |                 |                          | NE                |                 |                 |    |    |
| BH36     |        | 35.3                 | 19                 | 21                | 90*             |                 |                          | 29                | 40              | 73              |    |    |
| BH39     |        | 36.2                 | NE                 |                   |                 |                 |                          | 20                | 45              | 44              |    |    |
| BH41     |        | 9.2                  |                    |                   |                 |                 |                          | 21                | 25              | 84*             |    |    |
| BH42     |        | 23.9                 | 14                 | 35                | 40              |                 |                          | NE                |                 |                 |    |    |
| BH43     |        | 45.8                 | 53                 | 56                | 95*             |                 |                          | 23                | 49              | 47              |    |    |
| BH44     |        | 47.1                 | 16                 | 28                | 57              |                 |                          | 31                | 53              | 58              |    |    |
| BH49     |        | 37.5                 | 18                 | 66                | 27              |                 |                          | 23                | 37              | 62              |    |    |
| BH24     | Area 2 | 22.8                 | NE                 |                   |                 | 85              | 19                       | 28                | 68              | 56              |    |    |
| BH27     |        | 61.3                 | 86                 | 86                | 100*            |                 | NE                       |                   |                 |                 |    |    |
| BH29     |        | 10.3                 | NE                 |                   |                 |                 | 33                       | 41                | 80*             |                 |    |    |
| BH30     |        | > 150                | 129                | 131               | 98*             |                 | NE                       |                   |                 |                 |    |    |
| BH45     |        | 38.6                 | 23                 | 41                | 56              |                 | 13                       | 68                | 19 <sup>#</sup> |                 |    |    |
| BH08     | Area 3 | 23.7                 | NE                 |                   |                 | 48              | 21                       | 25                | 84*             | 55              |    |    |
| BH12     |        | 2.5                  |                    |                   |                 |                 | 3                        | 6                 | 50              |                 |    |    |
| BH13     |        | 23.1                 | 19                 | 40                | 48              |                 | NE                       |                   |                 |                 |    |    |
| BH14     |        | 37.8                 | NE                 |                   |                 |                 | 2                        | 36                | 6 <sup>#</sup>  |                 |    |    |
| BH15     |        | 11.9                 |                    |                   |                 |                 | 15                       | 17                | 88*             |                 |    |    |
| BH16     |        | 10.9                 |                    |                   |                 |                 | 7                        | 15                | 47              |                 |    |    |
| BH50     |        | 2.0                  |                    |                   |                 |                 | 2                        | 7                 | 29              |                 |    |    |

Notes:

- (1) Area 1: Yuen Long alluvial plain sites with sedimentary bedrock;  
Area 2: Yuen Long alluvial Plain sites with igneous bedrock;  
Area 3: Tuen Mun valley.
- (2) \* Q1-Q2% > 80%;  
<sup>#</sup> Q1-Q2% < 20%.

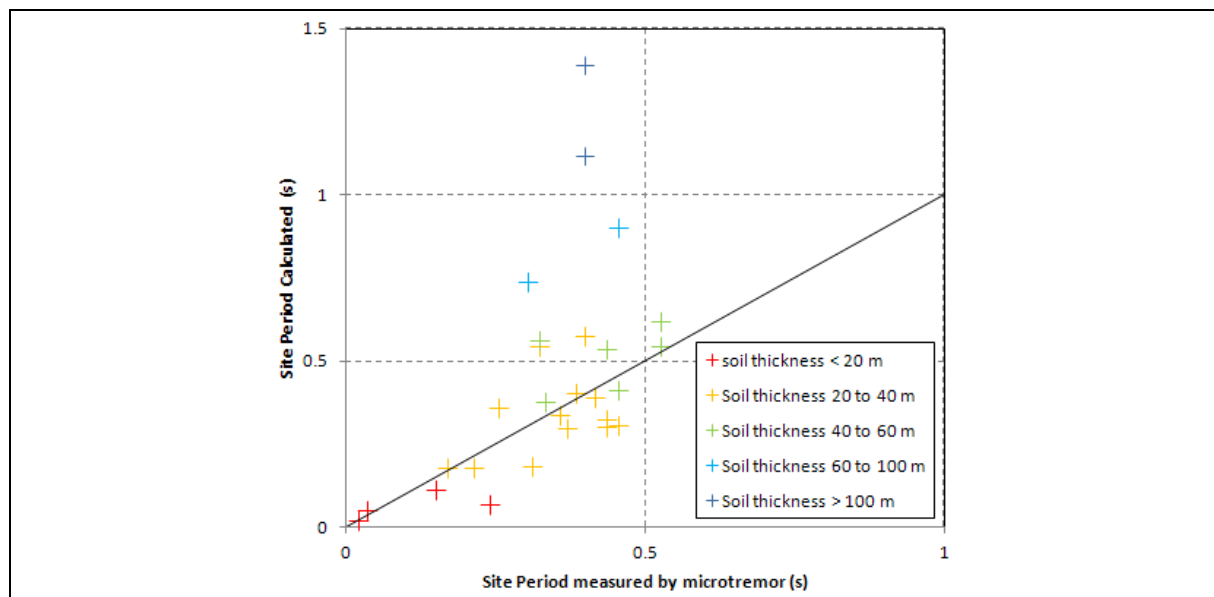
PS logging seismic test is originally expected to give better result than downhole test for sites with a deeper rockhead. However, by comparing the percentage of good quality data between PS logging and Downhole seismic tests relative to the soil thickness, no such trend is observed. For example, for BH26 where the rockhead was not reached after 146 m of investigation, the Downhole seismic test obtained more good quality measurements (with 90% good quality data) than the PS logging, which endured significant collapses due to the removal of borehole casing during the PS logging test.

## 2.4 Microtremor Tests

Microtremor tests have been carried out at all borehole locations, with an addition of 23 tests carried out at other locations in urban/suburban areas within Tuen Mun, Tin Shui Wai and Yuen Long (see Figure 2.17). Ten other tests have also been carried out on natural terrain at the west of Leung King Estate, Tuen Mun. The microtremor tests have been performed from late July to early November 2010 by the CityU Professional Services Ltd (CityU, 2010).

The instrumentation consists of a micro-*g* resolution force-balanced accelerometer and a high precision signal conditioning recorder that have been used to acquire digitally triaxial acceleration time histories at the designated site under ambient conditions. Measurement has been taken at each location for fifteen minutes, from which the power spectra of accelerations and the resulting site spectra have been produced for investigation on site.

The microtremor tests have been carried out as part of the study to explore the applicability and effectiveness of this non-destructive and economic means to determine the dominant period of a site. In Figure 2.29, the measured natural periods of the sites are plotted against the calculated ones based on the interpreted soil profiles of each borehole (see Section 4).



**Figure 2.29 Comparison between Site Periods Measured by Microtremor Tests and those Calculated for the Whole Soil Profile**

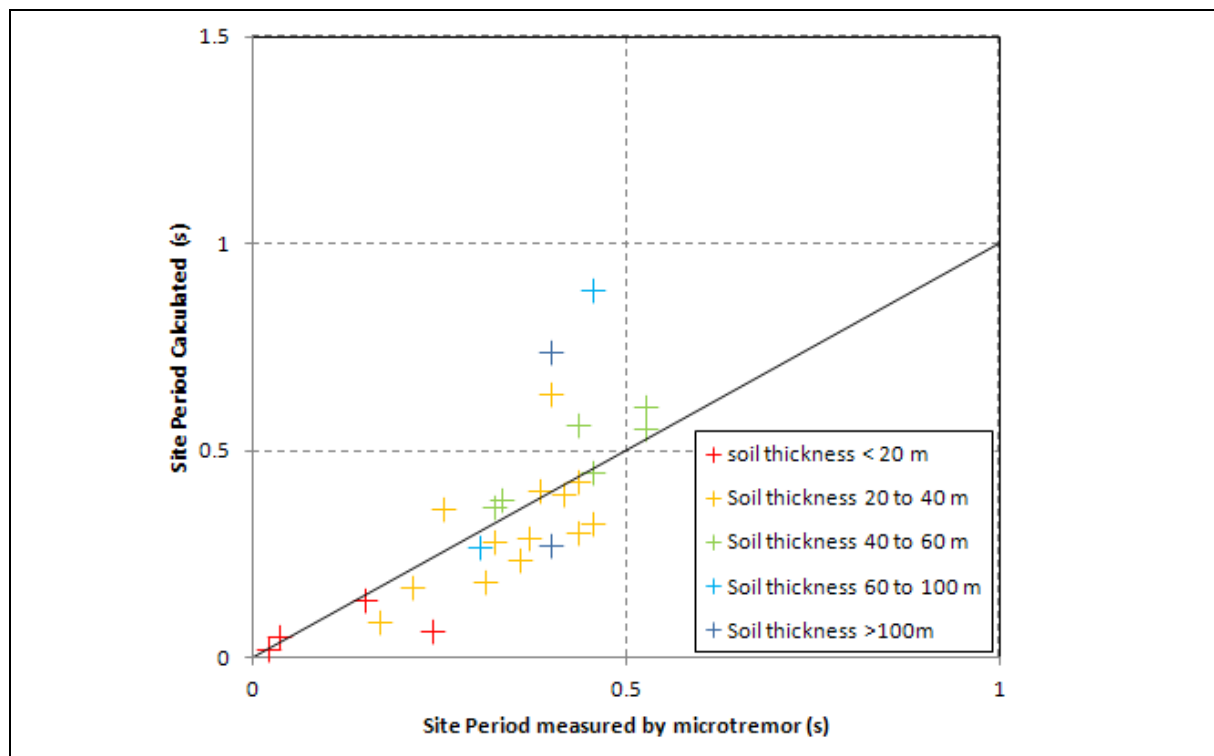
The calculation of the site period is based on the following commonly used theoretical equation developed in the United States (EERA, 2000):

$$T = \frac{4H^2}{\sum_i h_i V_{s_i}} \dots\dots\dots(2.1)$$

where  $T$  = site period (in s)  
 $H$  = thickness of soil deposits (in m)  
 $h_i$  = thickness for layer  $i$  (in m)  
 $V_{s_i}$  = shear velocity for layer  $i$  (in m/s).

Apart from boreholes with very thick soil layer (greater than 50 m), the site period measurements by the microtremor method are found to match the theoretically calculated values quite consistently (see Figure 2.29).

A further set of site period calculations has been made by only considering the soil profile down to approximately the depth where the SPT-N value exceeds 100. The results are compared to the microtremor measurements as shown in Figure 2.30. Again, the calculated and measured site periods for the shallower boreholes generally agree well. For deeper sites, the agreement is also generally quite good. The measured peak of site period determined by the microtremor tests, therefore, appears to be dominated by the resonance of the relatively softer soils of the shallower strata.



**Figure 2.30 Comparison between Site Periods Measured by Microtremor Tests and those Calculated for Soil Profile down to Where the SPT-N Value > 100**

### 3 Laboratory Testing Results

#### 3.1 Bulk Density Tests

A total of 78 soil samples and 25 rock samples have been tested for bulk density by the Public Works Central Laboratory (PWCL), Gammon Construction Ltd. (GCL) and FT Laboratories Ltd. (FT). Tables 3.1 and 3.2 summarise the number of samples tested for each type of rock and soil, the range of the measured bulk densities and the design values considered for site response analyses. Detailed summary tables for all the tests are presented in Appendix A. The raw data can be found in PWCL (2011), GCL (2011) and FT (2011).

**Table 3.1 Summary of the Bulk Density Test Results for Rock**

| Rock Type        | Rock Description | Number of Samples | Range of Measured Bulk Density (t/m <sup>3</sup> ) | Design Bulk Density (t/m <sup>3</sup> ) |
|------------------|------------------|-------------------|----------------------------------------------------|-----------------------------------------|
| Sedimentary Rock | Metasiltstone    | 7                 | 2.49 - 2.75                                        | 2.6                                     |
|                  | Metaconglomerate | 2                 | 2.52 - 2.78                                        |                                         |
|                  | Metamudstone     | 3                 | 2.68 - 2.91                                        | 2.8                                     |
|                  | Marble           | 3                 | 2.72 - 2.82                                        |                                         |
| Igneous Rock     | Tuff             | 8                 | 2.62 - 2.89                                        | 2.6                                     |
|                  | Granite          | 2                 | 2.49 - 2.65                                        |                                         |

**Table 3.2 Summary of the Bulk Density Test Results for Soil**

| Soil Type                              | Soil Description  | Number of Samples |    | Range of Measured Bulk Density (t/m <sup>3</sup> ) | Design Bulk Density (t/m <sup>3</sup> ) |
|----------------------------------------|-------------------|-------------------|----|----------------------------------------------------|-----------------------------------------|
| Residual Soil                          | Silt              | 2                 |    | 1.85 - 1.92                                        | 1.9                                     |
| Top Soil                               | Silt              | 1                 |    | 2.12                                               | 2.1                                     |
| Debris Flow                            | Silt              | 1                 |    | 2.18                                               | 2.2                                     |
| Fill                                   | All types         | 8                 |    | 1.80 - 2.06                                        | 2.0                                     |
| Colluvium                              | Sandy Clayey Silt | 1                 |    | 2.42                                               | 2.0                                     |
| Alluvium                               | Clay              | 26                | 7  | 1.91 - 2.05                                        | 1.9                                     |
|                                        | Silt and sand     |                   | 19 | 1.75 - 2.20                                        |                                         |
| Marine/Estuarine                       | All types         | 5                 |    | 1.59 - 1.91                                        | 1.7                                     |
| Completely Decomposed Sedimentary Rock | Metasiltstone     | 34                | 8  | 1.94 - 2.23                                        | 2.0                                     |
|                                        | Metasandstone     |                   | 2  | 2.04 - 2.06                                        |                                         |
|                                        | Metaconglomerate  |                   | 3  | 1.69 - 1.99                                        |                                         |
|                                        | Metamudstone      |                   | 4  | 1.90 - 2.07                                        |                                         |
|                                        | Metaandesite      |                   | 1  | 1.77                                               |                                         |
| Completely Decomposed Igneous Rock     | Tuff              |                   | 8  | 1.86 - 2.25                                        |                                         |
|                                        | Granite           |                   | 3  | 1.83 - 2.10                                        |                                         |
|                                        | Rhyolite          |                   | 2  | 1.73 - 1.90                                        |                                         |
| Fault Zone Breccia                     | Silt              |                   | 3  | 1.67 - 2.08                                        |                                         |

A design value of  $2.0 \text{ t/m}^3$  has been chosen for the completely decomposed rocks and the soil densities vary from  $1.7 \text{ t/m}^3$  for marine/estuarine deposits to  $2.2 \text{ t/m}^3$  for debris flow deposits. For slightly to highly decomposed rocks, the bulk density values have been taken in between the average bulk density measured for completely decomposed rock and moderately to slightly decomposed rock. That of the moderately to slightly decomposed rock is taken to be in between  $2.6 \text{ t/m}^3$  and  $2.8 \text{ t/m}^3$ .

### 3.2 Fines and Clay Content

A total of 110 numbers of samples have been tested by the PWCL and GCL for particle size distribution. The fines and clay content are defined as the percentage of particles with a size of less than  $0.074 \text{ mm}$  (Seed et al, 2001) and  $0.005 \text{ mm}$  (Chinese Seismic Code, 2010) respectively. Tables 3.3 and 3.4 summarise the number of samples tested for each type of soils and in-situ decomposed rock, the range of fines and clay contents, and the corresponding average values that will be considered in the liquefaction assessment. Detailed summary tables for all the tests are presented in Appendix B. For a more realistic assessment of the liquefaction susceptibility of the more critical soils i.e. alluvial sand and fill, the outlier values of 5 soil samples remarked by a star in the tables have been excluded from the calculations of the average values of fines and clay content.

According to the measured clay content, for values less than 16% in accordance with Chinese Seismic Code (2010) up to Intensity 9, three types of soils can be identified as being potentially liquefiable: Sand Fill, Alluvial Sand and Silt, as well as the Silty Debris Flow deposits identified in BH23. Table 3.5 shows the depth of potentially liquefiable soil layers in each borehole.

### 3.3 Plasticity Index

The plasticity index (PI) is one of the key parameters of fines materials for the liquefaction and site response analyses. Table 3.6 indicates the range and the average value of PI for different soils tested, as well as the number of samples tested for each soil type. The alluvial clay samples exhibit an average PI of 26% and the PI of Estuarine/Marine deposits is 20%. The average PI of residual soils is 19%.

Plasticity index tests have been carried out by PWCL and GCL for a total of 61 samples. Detailed summary tables for all of the test results are presented in Appendix C.

### 3.4 Triaxial Tests

Three series of tests have been carried out at the Hong Kong University of Science and Technology (HKUST). These tests include six cyclic triaxial tests with shear wave velocity measurements by bender elements (Series 1), four static shear to failure triaxial tests (Series 2) and four cyclic shear to failure triaxial tests (Series 3). The details of the testing procedures can be referred to the HKUST factual report (HKUST, 2011). The results of Series 2 and 3 are related to a separate study on earthquake-induced natural terrain landslides, and are thus not discussed here.

**Table 3.3 Fines and Clay Content Summary for Soil**

| Soil Type            | Soil Description       | Number of Samples | Range of Fines Content (%) | Average Fines Content (%) | Range of Clay Content (%) | Average Clay Content (%) |
|----------------------|------------------------|-------------------|----------------------------|---------------------------|---------------------------|--------------------------|
|                      |                        |                   | P.S. < 0.074 mm            |                           | P.S. < 0.005 mm           |                          |
| Debris Flow          | Sandy Silt             | 1                 | -                          | 34                        | -                         | 10                       |
| Fill                 | Sand                   | 2                 | 2 - 19                     | 11                        | 0 - 12                    | 6                        |
|                      | Silt                   | 2                 | 49 - 59                    | 54                        | 28 - 28                   | 28                       |
| Alluvium             | Silt                   | 17                | 17 - 82                    | 54                        | 8 - 47                    | 21                       |
|                      | Silty Clay             | 6                 | 46 - 96                    | 76                        | 28 - 72                   | 51                       |
|                      | Sandy Clay             | 6                 | 20 - 62                    | 46                        | 27 - 37                   | 32                       |
|                      | Sand                   | 13                | 8 - 66                     | 23                        | 7 - 17                    | 11                       |
| Marine/<br>Estuarine | Sandy Clayey Silt      | 1                 | -                          | 34                        | -                         | 10                       |
|                      | Clayey Silt/Silty Clay | 2                 | 2 - 19                     | 11                        | 0 - 12                    | 6                        |

**Table 3.4 Fines and Clay Content Summary for Completely Decomposed Rock**

| Soil Type     | Soil Description             | Number of Samples | Range of Fines Content (%) | Average Fines Content (%) | Range of Clay Content (%) | Average Clay Content (%) |
|---------------|------------------------------|-------------------|----------------------------|---------------------------|---------------------------|--------------------------|
|               |                              |                   | P.S. < 0.074 mm            |                           | P.S. < 0.005 mm           |                          |
| Sedimentary   | Silt                         | 20                | 28 - 97                    | 60                        | 4 - 47                    | 17                       |
|               | Sand                         | 2                 | 29 - 48                    | 39                        | 10 - 12                   | 11                       |
|               | Gravel                       | 4                 | 23 - 72                    | 48                        | 6 - 20                    | 11                       |
| Igneous       | Clayey Silt                  | 10                | 54 - 98                    | 73                        | 11 - 27                   | 18                       |
|               | Sandy Silt/Sandy Clayey Silt | 8                 | 27 - 73                    | 51                        | 8 - 27                    | 17                       |
|               | Sand/Gravel                  | 2                 | 20 - 28                    | 24                        | 8 - 11                    | 10                       |
| Fault Breccia | Sandy Silt                   | 3                 | 39 - 70                    | 56                        | 12 - 30                   | 19                       |

**Table 3.5 Summary of Potentially Liquefiable Soil**

| Borehole | Area   | Depth of the Potentially Liquefiable Soils (m) |          |        |             |        |
|----------|--------|------------------------------------------------|----------|--------|-------------|--------|
|          |        | Fill                                           | Alluvial |        | Debris Flow |        |
|          |        |                                                | Top      | Bottom | Top         | Bottom |
| BH01     | Area 1 | 1.5                                            | 6.6      | 22.0   | NE          |        |
| BH02     |        | 7.1                                            | 7.1      | 17.4   |             |        |
| BH20     |        | 2.0                                            | 2.1      | 7.2    |             |        |
| BH21     |        | 1.5                                            | 5.7      | 7.7    |             |        |
| BH22     |        | 5.5                                            | 5.5      | 7.5    |             |        |
| BH23     |        | 3.5                                            | 3.5      | 16.6   | 16.6        | 20.6   |
| BH26     |        | 2.0                                            | 2.0      | 7.3    | NE          |        |
|          |        |                                                | 8.2      | 15.4   |             |        |
| BH32     |        | 5.0                                            | 5.0      | 9.6    |             |        |
| BH36     |        | 2.6                                            | 5.5      | 7.5    |             |        |
| BH39     |        | 2.5                                            | 6.6      | 17.2   |             |        |
| BH41     |        | 1.5                                            | NE       |        |             |        |
| BH42     |        | 1.5                                            | 3.5      | 9.7    |             |        |
| BH43     |        | 5.7                                            | 7.7      | 19.9   |             |        |
| BH44     |        | 3.5                                            | 7.7      | 15.7   |             |        |
| BH49     |        | 3.5                                            | 3.5      | 15.9   |             |        |
| BH24     | Area 2 | 3.2                                            | 3.2      | 13.2   | NE          |        |
| BH27     |        | NE                                             | 1.5      | 9.7    |             |        |
| BH29     |        | 2.6                                            | 6.6      | 12.6   |             |        |
| BH30     |        | NE                                             | 1.5      | 8.6    |             |        |
|          |        |                                                | 19.3     | 21.4   |             |        |
| BH45     |        | 1.5                                            | 1.5      | 13.5   |             |        |
| BH08     | Area 3 | 11.3                                           | 11.3     | 14.3   | NE          |        |
| BH12     |        | NE                                             |          |        |             |        |
| BH13     |        | 3.1                                            | 11.3     | 13.9   |             |        |
| BH14     |        | 4.6                                            | 4.6      | 8.8    |             |        |
| BH15     |        | 1.5                                            | NE       |        |             |        |
| BH16     |        | NE                                             |          |        |             |        |
| BH50     |        | 2.0                                            |          |        |             |        |

Note: Area 1: Yuen Long alluvial plain sites with sedimentary bedrock;  
Area 2: Yuen Long alluvial Plain sites with igneous bedrock; and  
Area 3: Tuen Mun valley.



**Table 3.6 Summary of the Plasticity Index Test Results**

| Soil Type        |                     | Number of Soil Samples | Range of PI (%) | Average PI (%) |
|------------------|---------------------|------------------------|-----------------|----------------|
| Residual Soil    |                     | 3                      | 12 - 29         | 17             |
| Fill             |                     | 2                      | 8 - 18          | 13             |
| Marine           |                     | 4                      | 13 - 31         | 20             |
| Alluvium         | Clay                | 11                     | 19 - 40         | 26             |
|                  | Silt                | 11                     | 9 - 24          | 16             |
|                  | Sand                | 1                      | 8               | 8              |
| Sedimentary Rock | CD Metasilstone     | 7                      | 12 - 30         | 17             |
|                  | CD Metamudstone     | 2                      | 11 - 16         | 14             |
|                  | CD Metaconglomerate | 3                      | 12 - 14         | 13             |
|                  | CD Metasandstone    | 2                      | 10 - 43         | 27             |
| Igneous Rock     | CD Tuff             | 6                      | 7 - 14          | 11             |
|                  | CDG                 | 2                      | 8 - 20          | 14             |
|                  | CD Rhyolite         | 4                      | 14 - 27         | 21             |
| Fault Breccia    |                     | 3                      | 11 - 26         | 17             |

### 3.4.1 Cyclic Triaxial Tests with Shear Wave Velocity Measurements (Series 1)

#### (a) *Factual report summary*

Different consolidation stages for the Series 1 tests are presented in Table 3.7. The soil information for each tested sample is presented in Tables 3.8 to 3.10. The stress paths in the deviatoric stress – mean effective stress ( $q$ - $p'$ ) space and the stress-strain curves in the deviatoric stress – deviatoric strain ( $\Delta q$ - $\Delta \varepsilon_q$ ) space for each stage of cyclic loading as well as the shear modulus degradation curves and normalised shear modulus degradation curves have been plotted. Details can be found in the HKUST factual report (HKUST, 2011).

The shear modulus at very small strains ( $G_0$ ) between stages of cyclic loading is determined by bender elements, defined for an engineering shear strain ( $\gamma$ ) of 0.001% according to Dyvik & Madshus (1985).

The secant shear modulus ( $G$ ) is determined from the  $\Delta q$ - $\Delta \varepsilon_q$  stress-strain curve of each cyclic loading stage as:

$$G = \frac{q_{\max} - q_{\min}}{3(\varepsilon_{q\max} - \varepsilon_{q\min})} \dots\dots\dots (3.1)$$

where  $G$  =  $\Delta q$ - $\Delta \varepsilon_q$  stress-strain curve of each cyclic loading  
 $q_{\max, \min}$  = the peak and trough deviatoric stresses of each cyclic loading stage  
 $\varepsilon_{q\max, \min}$  = the shear strains of the unloading curve of the fifth cycle.

**Table 3.7 Consolidation Stages for Cyclic Triaxial Tests in Series 1**

| Test ID | Consolidation Stage | Axial Effective Stress, $\sigma_a$ (kPa) | Radial Effective Stress, $\sigma'_r$ (kPa) | Mean Effective Stress, $p'$ (kPa) | Deviatoric Stress, $q$ (kPa) |
|---------|---------------------|------------------------------------------|--------------------------------------------|-----------------------------------|------------------------------|
| CW1     | 1                   | 123                                      | 52                                         | 76                                | 71                           |
|         | 2                   | 246                                      | 104                                        | 152                               | 142                          |
| CW2     | 1                   | 43                                       | 22                                         | 29                                | 21                           |
|         | 2                   | 85                                       | 45                                         | 58                                | 40                           |
|         | 3                   | 170                                      | 105                                        | 127                               | 65                           |
| CW3     | 1                   | 50                                       | 29                                         | 36                                | 21                           |
|         | 2                   | 95                                       | 51                                         | 66                                | 44                           |
|         | 3                   | 191                                      | 98                                         | 129                               | 93                           |
| CW4     | 1                   | 40                                       | 27                                         | 31                                | 13                           |
|         | 2                   | 67                                       | 43                                         | 51                                | 24                           |
|         | 3                   | 134                                      | 76                                         | 95                                | 58                           |
| CW5     | 1                   | 25                                       | 16                                         | 19                                | 9                            |
|         | 2                   | 45                                       | 29                                         | 34                                | 16                           |
| CW6     | 1                   | 50                                       | 30                                         | 37                                | 20                           |
|         | 2                   | 98                                       | 63                                         | 75                                | 35                           |

**Table 3.8 Soil Information for Samples Tested in Series 1**

| Test ID | Borehole Number | Sampling Depth (m) | Soil Type                | Classification             |
|---------|-----------------|--------------------|--------------------------|----------------------------|
| CW1     | BH20            | 12.2 - 13.2        | CD-metasiltsone          | Sandy clayey silt          |
| CW2     | BH24            | 7.1 - 8.1          | Alluvium                 | Clayey fine to coarse sand |
| CW3     | BH22            | 8.6 - 9.6          | CD-metasiltsone          | Clayey silt                |
| CW4     | BH24            | 5.1 - 6.1          | Alluvium                 | Silty find sand            |
| CW5     | BH39            | 3.5 - 4.5          | Estuarine/Marine deposit | Clayey silt                |
| CW6     | BH43            | 9.7 - 10.7         | Alluvium                 | Silty clay                 |

Figure 3.1 illustrates how these values are determined for Stage 5 of the CW1 test as an example.

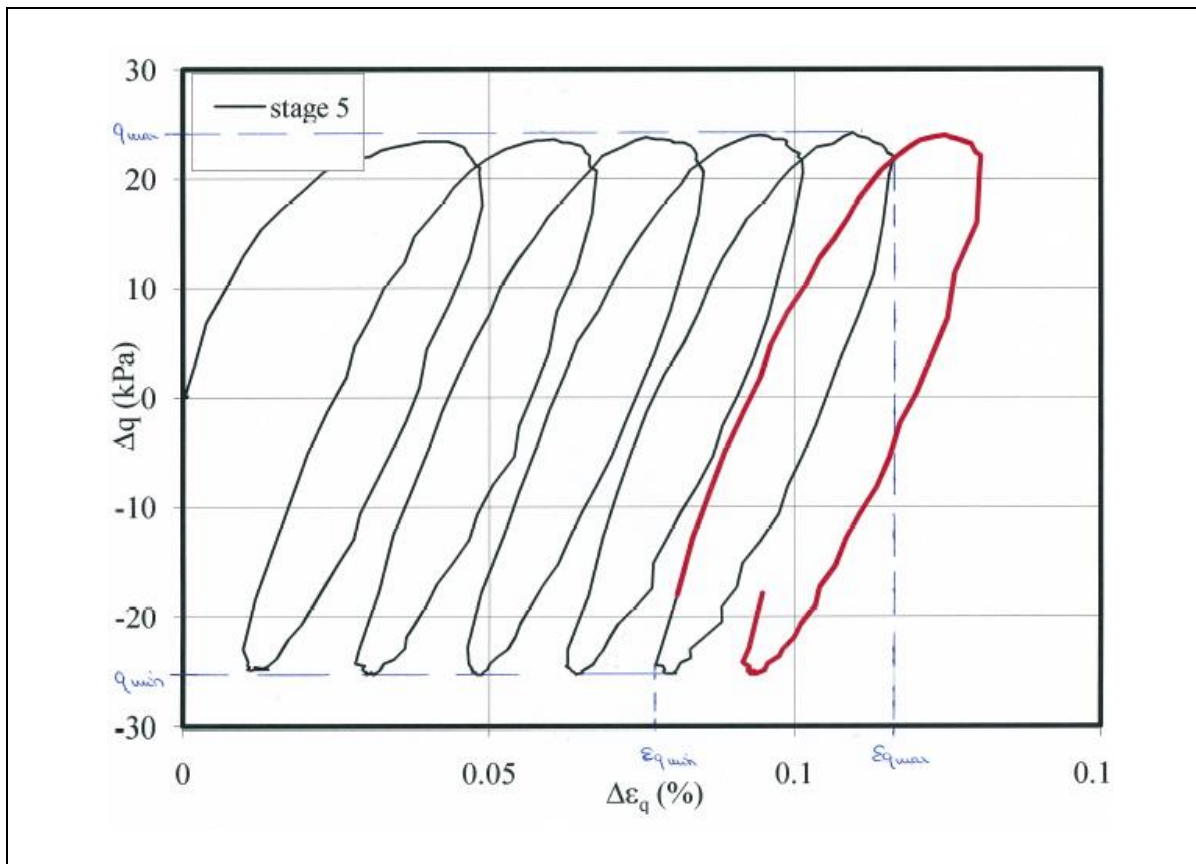
The shear modulus degradation curves are plotted against the engineering shear strain amplitude ( $\gamma$ ), with  $\gamma$  (%) determined as:

$$\gamma = 1.5\varepsilon_q = 1.5 \times \frac{\varepsilon_{q\max} - \varepsilon_{q\min}}{2} \dots\dots\dots (3.2)$$

The normalised shear modulus degradation curves are plotted as  $G/G_0$  versus  $\gamma$ .

It should be noted that the secant shear moduli have not been calculated for some stages when the interpretation of the  $\Delta q$ - $\Delta\varepsilon_q$  curves are found to lead to inaccurate results. Those inaccurate results happened at very small strain and stress levels at Stages 1, 2 and even 3 for CW<sub>5</sub>-S<sub>1</sub> or in the case of CW<sub>3</sub>-S<sub>3</sub>, Stage 6, due to the radial Hall Effect transducer being out of range in the first cycle.

All the data curves as well as the photographs of each specimen after the test completion can be found in the HKUST factual report (HKUST, 2011).



**Figure 3.1 Illustration of the Determination of  $q_{\min}$ ,  $q_{\max}$ ,  $\varepsilon_{\min}$  and  $\varepsilon_{\max}$  for the Cyclic Triaxial Test CW1, Stage 5**

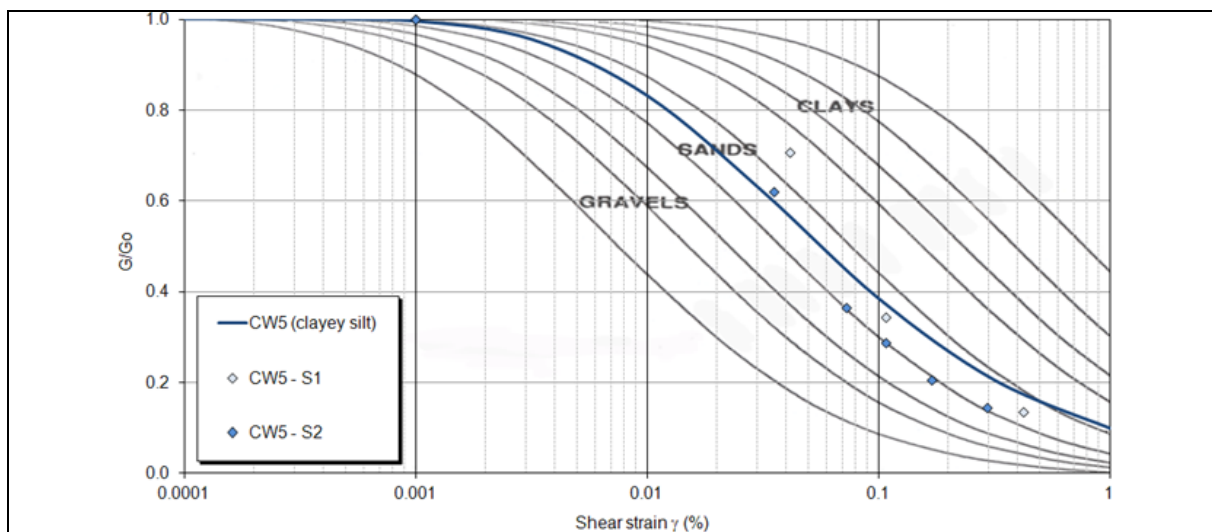
**(b) Interpretation of the tests for the site response analyses**

The site response analyses require determination of the dynamic soil properties in terms of small-strain shear modulus degradation curves for different soil types encountered. A set of six curves has been defined for this study. Four curves, for the following materials, are directly derived from the cyclic triaxial tests (CW1 to CW6) as best-fit lines of the data:

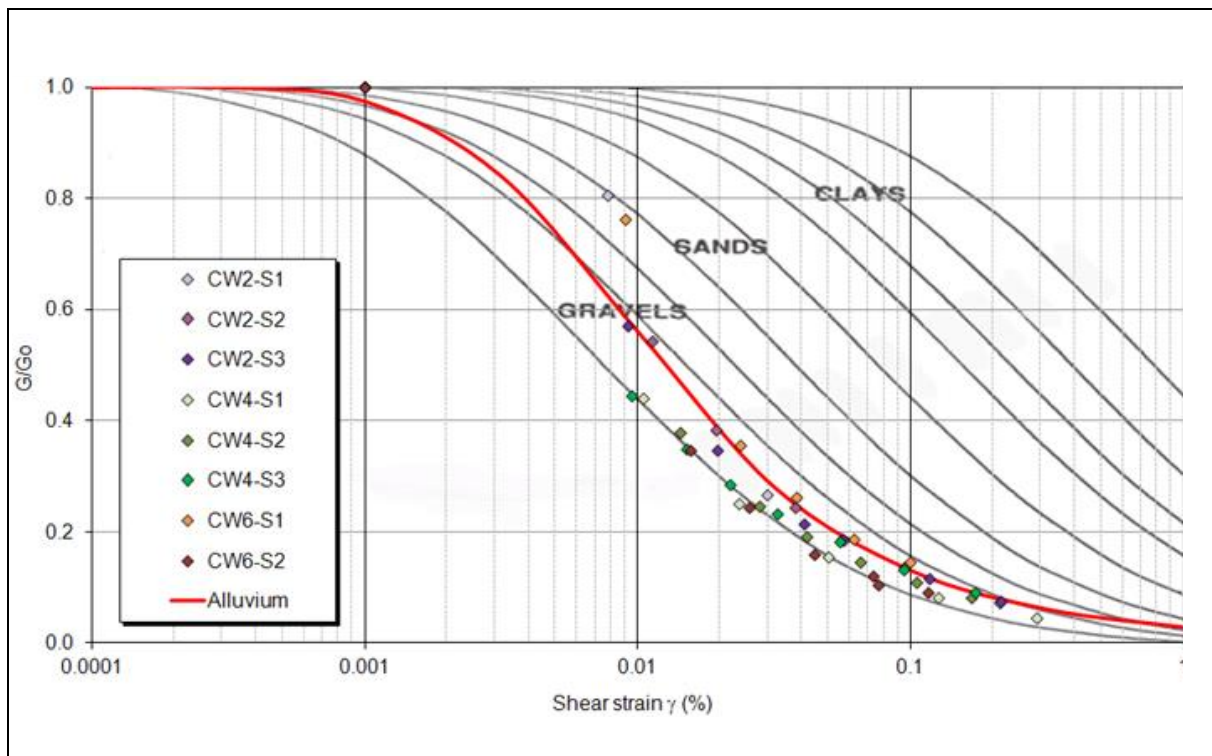
- (i) Estuarine/Marine deposits,
- (ii) Alluvium (all types),
- (iii) Completely decomposed sedimentary rock (clayey silt), and
- (iv) Completely decomposed sedimentary rock (sandy clayey silt).

The design degradation curves are plotted against the cyclic triaxial test results in Figures 3.2 to 3.4 for different soil materials. The degradation curves ranging from gravels to clays from EPRI (1993) resulted from a broad European cyclic triaxial testing dataset are plotted in the background. According to those curves, the alluvium tested in this study has a similar dynamic shear modulus degradation behaviour to that of gravels from EPRI (1993) from 0.01% to 1% strain, but has a greater degradation rate than the soils tested in EPRI (1993) for very small strains. The Estuarine/Marine deposits follow a trend similar to the upper bound of the sand behaviour. This is consistent with the relatively low plasticity index of the Estuarine/Marine deposits samples tested (see Section 3.3). Finally, the cyclic triaxial tests on completely decomposed metasiltstone show a behaviour ranging from the lower bound of sand behaviour to a gravel behaviour, which is consistent with the general soil descriptions and a relatively low average plasticity index of 17% (see Section 3.3).

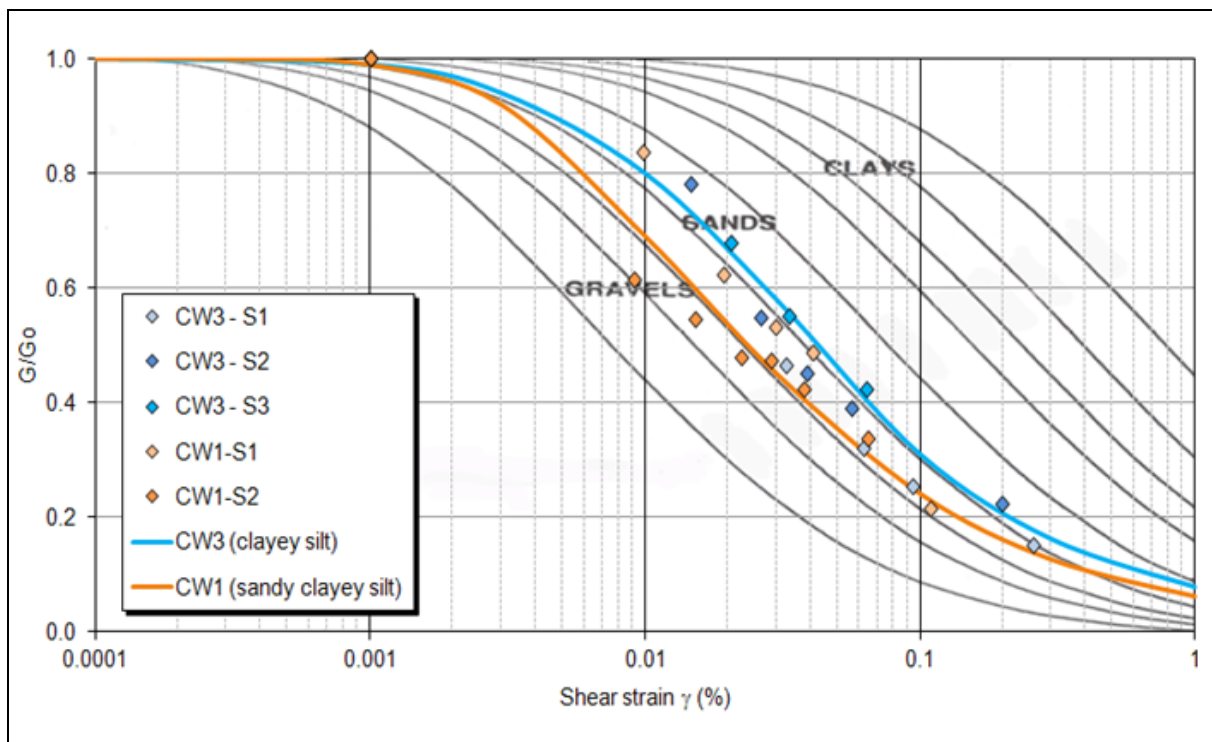
For the purpose of site response analyses, two additional curves for fill and completely decomposed granite and volcanic rocks have been defined based on previous testing dataset and literature review in Hong Kong.



**Figure 3.2 Shear Modulus Degradation Curve for Estuarine and Marine Deposits**



**Figure 3.3 Shear Modulus Degradation Curve for Alluvium (All Types)**



**Figure 3.4 Shear Modulus Degradation Curve for Decomposed Sedimentary Rock (Clayey Silt and Sandy Clayey Silt)**

### 3.4.2 Static Shear to Failure Triaxial Tests (Series 2)

The stress path in the  $q$ - $p'$  space and the stress-strain curve in the  $\Delta q$ - $\Delta \varepsilon_q$  space for each static shear to failure test are shown in the HKUST factual report. The variations of pore water pressure ( $u_w$ ) and stress ratio ( $q/p'$ ) versus  $\varepsilon_q$  for each static shear to failure test are also provided. The report also includes photographs of each specimen after tests. Table 3.9 summarises the soil information for the samples tested in this Series of tests. The results of these tests are only relevant to the earthquake-induced natural terrain landslide hazard assessment and will be presented separately.

**Table 3.9 Soil Information for Samples Tested in Series 2**

| Test ID | Borehole Number | Sampling Depth (m) | Soil Type       | Classification                                                                   |
|---------|-----------------|--------------------|-----------------|----------------------------------------------------------------------------------|
| SF1     | BH22            | 19.7 - 20.7        | CD-metasiltsone | Clayey silt                                                                      |
| SF2     | BH24            | 15.1 - 16.1        | CDG             | Sandy silt                                                                       |
| SF3     | BH27            | 10.8 - 11.8        | CDV             | Clayey silt                                                                      |
| SF4     | UKS-TP5         | 1.8                | Colluvium       | Slightly sandy clayey silt with medium to coarse sized tuff and quartz fragments |

### 3.4.3 Cyclic Shear to Failure Triaxial Tests (Series 3)

The stress path in the  $q$ - $p'$  space and the stress-strain curve in the  $\Delta q$ - $\Delta \varepsilon_q$  space for each stage of cyclic shear to failure test are shown in the figures of the HKUST factual report. The variations of excess pore water pressure ( $\Delta u_w$ ) versus cyclic number for each stage of cyclic shear to failure test are also provided. The report also includes the photographs of each specimen after tests.

As indicated in Table 3.10, the samples tested are the same as the ones tested in Series 2, apart from the CD-metasiltsone sample from BH22. The results of the Series 2 and 3 tests are only relevant to the earthquake-induced natural terrain landslide hazard assessment and will be presented separately.

**Table 3.10 Soil Information for Samples Tested in Series 3**

| Test ID | Borehole Number | Sampling Depth (m) | Soil Type        | Classification                                                                   |
|---------|-----------------|--------------------|------------------|----------------------------------------------------------------------------------|
| SF1     | BH22            | 19.7 - 20.7        | CD-metasiltstone | Clayey silt                                                                      |
| SF2     | BH24            | 15.1 - 16.1        | CDG              | Sandy silt                                                                       |
| SF3     | BH27            | 10.8 - 11.8        | CDV              | Clayey silt                                                                      |
| SF4     | UKS-TP5         | 1.8                | Colluvium        | Slightly sandy clayey silt with medium to coarse sized tuff and quartz fragments |

#### 4 Soil Profiles

As mentioned in Section 1, a total of 27 soil profiles have been investigated with SPT and in-situ shear-wave velocity ( $V_s$ ) measurements by Downhole seismic, PS logging, Crosshole seismic and MASW tests. Figures 4.1 to 4.27 show the design profiles defined in terms of soil types, shear wave velocity and small-strain shear modulus versus depth for each borehole. In each case, the profile extends into moderately to slightly decomposed rock.

The measured  $V_s$  of rock is generally about 1,000 m/s, apart from:

- (i) BH22 with  $V_s$  of rock being about 800 m/s based on good quality PS logging data, and
- (ii) BH26 and BH30 which the rock level is not reached, with  $V_s$  at the bottom of the profile being about 750 m/s.

The design lines of  $V_s$  correspond to the best-fit lines from good quality in-situ measurements (Q1 and Q2) (see Section 2.3), taking also into account the velocities calculated from the SPT-N and  $V_s$  correlations at depths where there were very few or no good quality in-situ measurements.

The SPT-N and  $V_s$  correlations, as shown in Figure 4.28, have been derived from good quality in-situ measurements (Q1 and Q2). The soil-specific correlations derived from this dataset are listed as follows:

- CDG:  $V_s = 90.043 N^{0.304}$
- CDS:  $V_s = 138.17 N^{0.2244}$
- Alluvium:  $V_s = 198.04 N^{0.0643}$
- Clay:  $V_s = 125.81 N^{0.1852}$

- Fill:  $V_s = 111.07 N^{0.2082}$

For Fill, the study dataset is limited and has been expanded with regional data from Singapore and Hong Kong to come up with a sensible correlation. The following datasets have been additionally considered:

- CPT from Shum (2003);
- Downhole seismic tests from Wong et al (1998 & 2000) and the Kai Tak Airport Site Investigation Report (Europeene de Geophysique (Asia) (2003));
- Spectral analysis of surface wave from Lee et al (1998);
- PS logging from Kwong (1998) and Ng et al (2000); and
- Crosshole and Downhole seismic tests from Veijayaratnam et al (1993) for Singapore.

Also, a correlation based on the dataset from all soil types has been derived as:

- All soils:  $V_s = 122.37 N^{0.2409}$

Two additional correlations that are commonly used in China have been suggested by GEERRI as follows:

The “GEERRI 1” correlation is defined as:

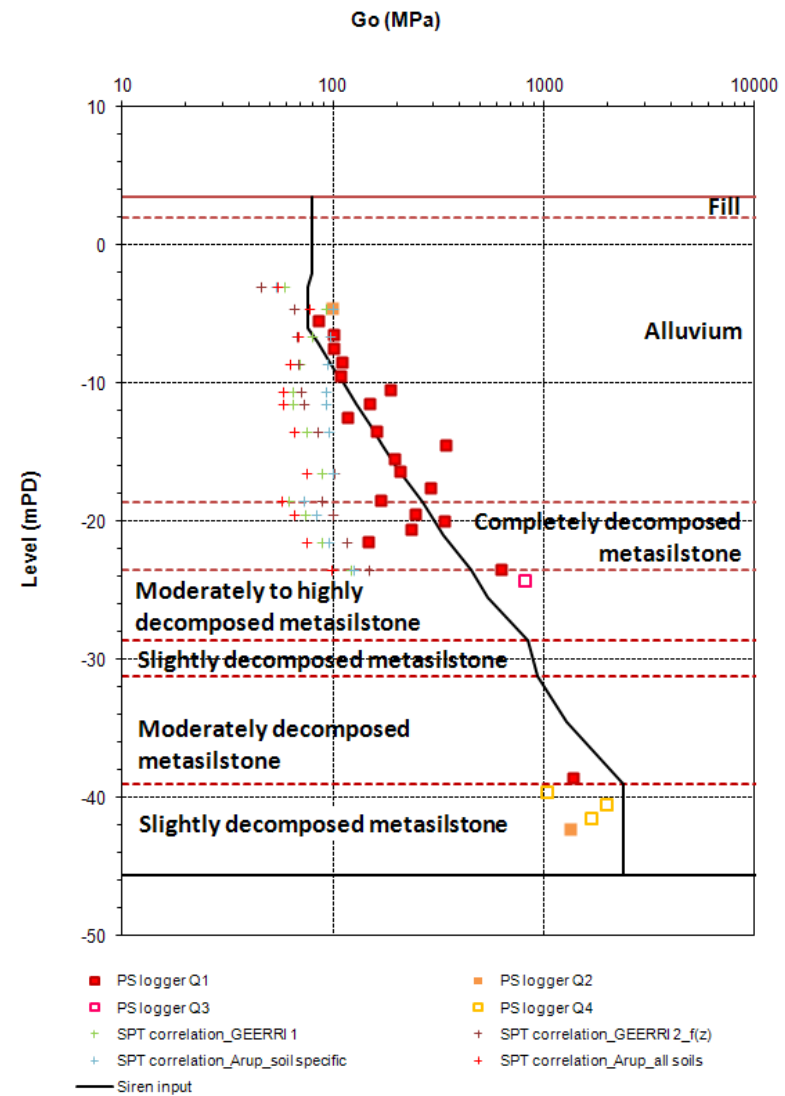
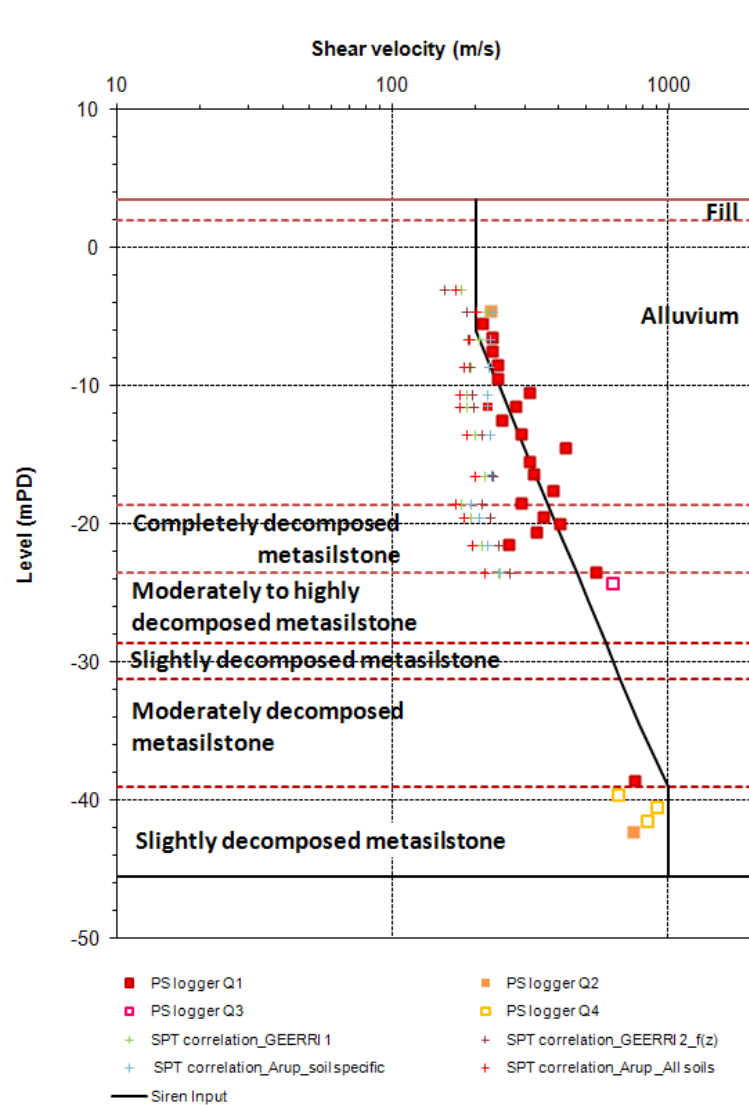
- All soils:  $V_s = 116 N^{0.258}$

The “GEERRI 2” is depth dependent and is:

- All soils:  $V_s = 75.67 N^{0.1436} Z^{0.2563}$  (with  $Z$  in metres)

All of the above correlations have also been plotted on the  $V_s$  and  $G_0$  profiles for individual borehole in Figures 4.1 to 4.27 for comparison with the measured data. It can be seen from these figures that the correlations are generally consistent with the in-situ measurements.





**Figure 4.1  $V_s$  and  $G_0$  Profile for BH01**

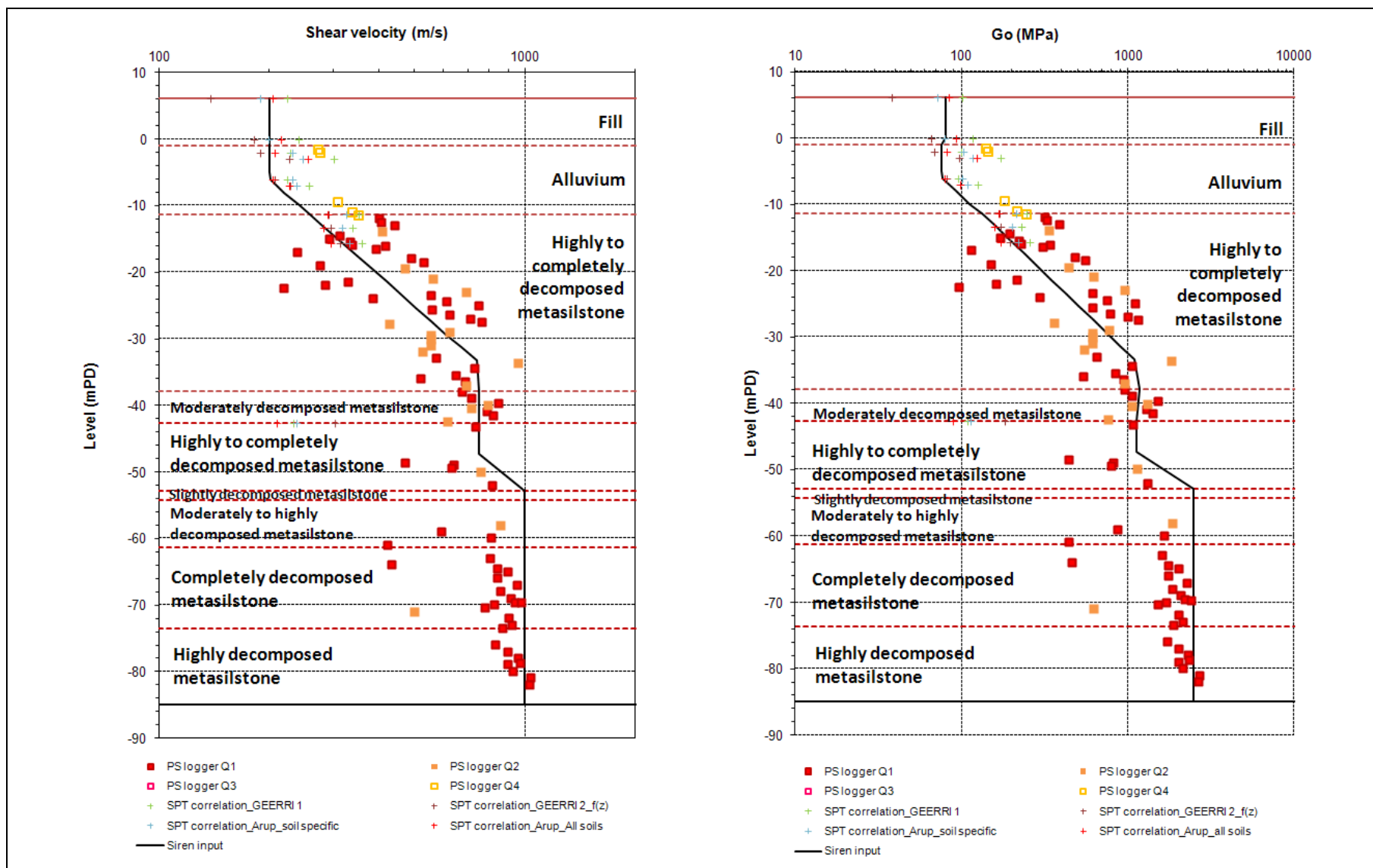


Figure 4.2 Vs and Go Profile for BH02

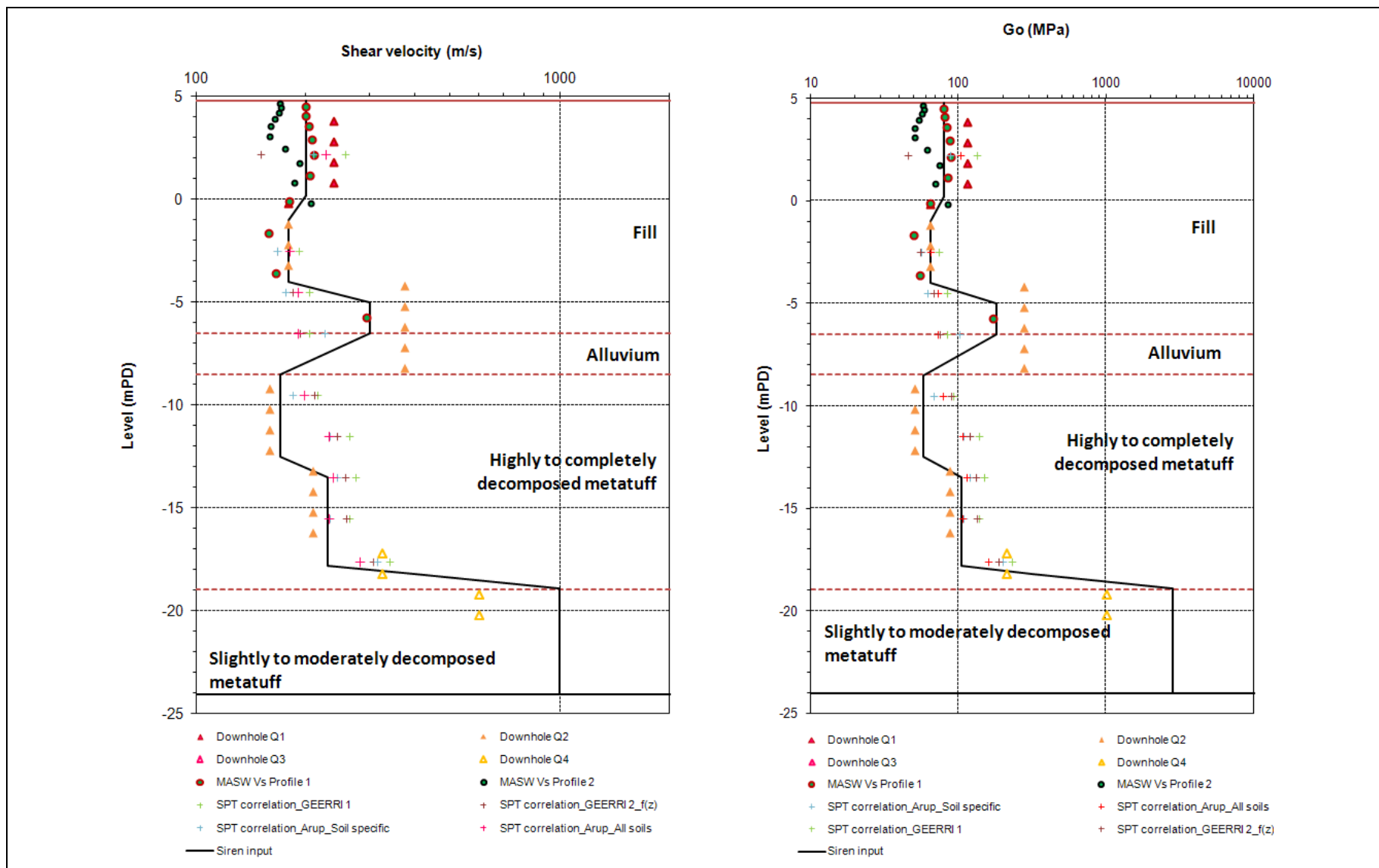


Figure 4.3 Vs and  $G_0$  Profile for BH08

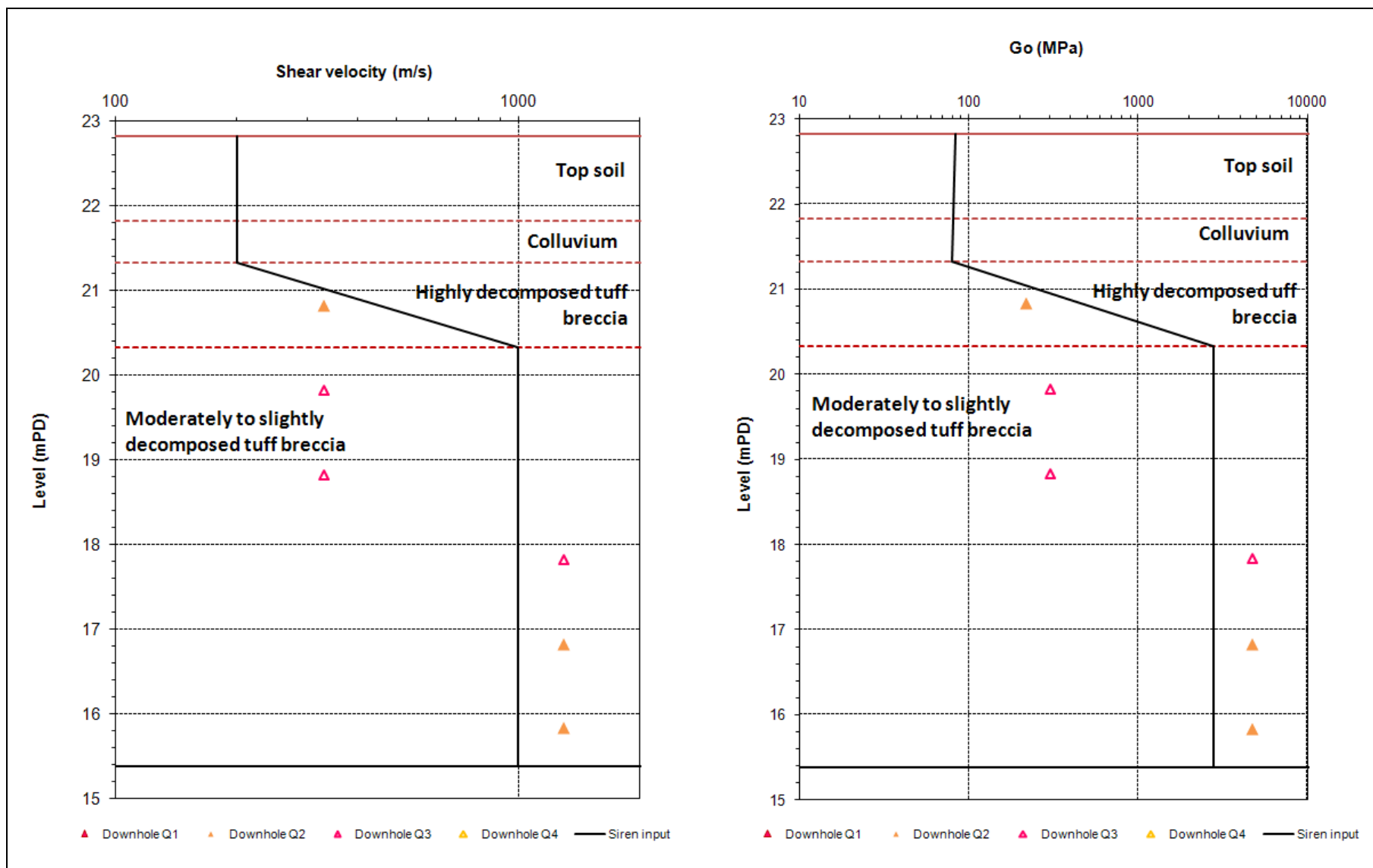


Figure 4.4 Vs and Go Profile for BH12

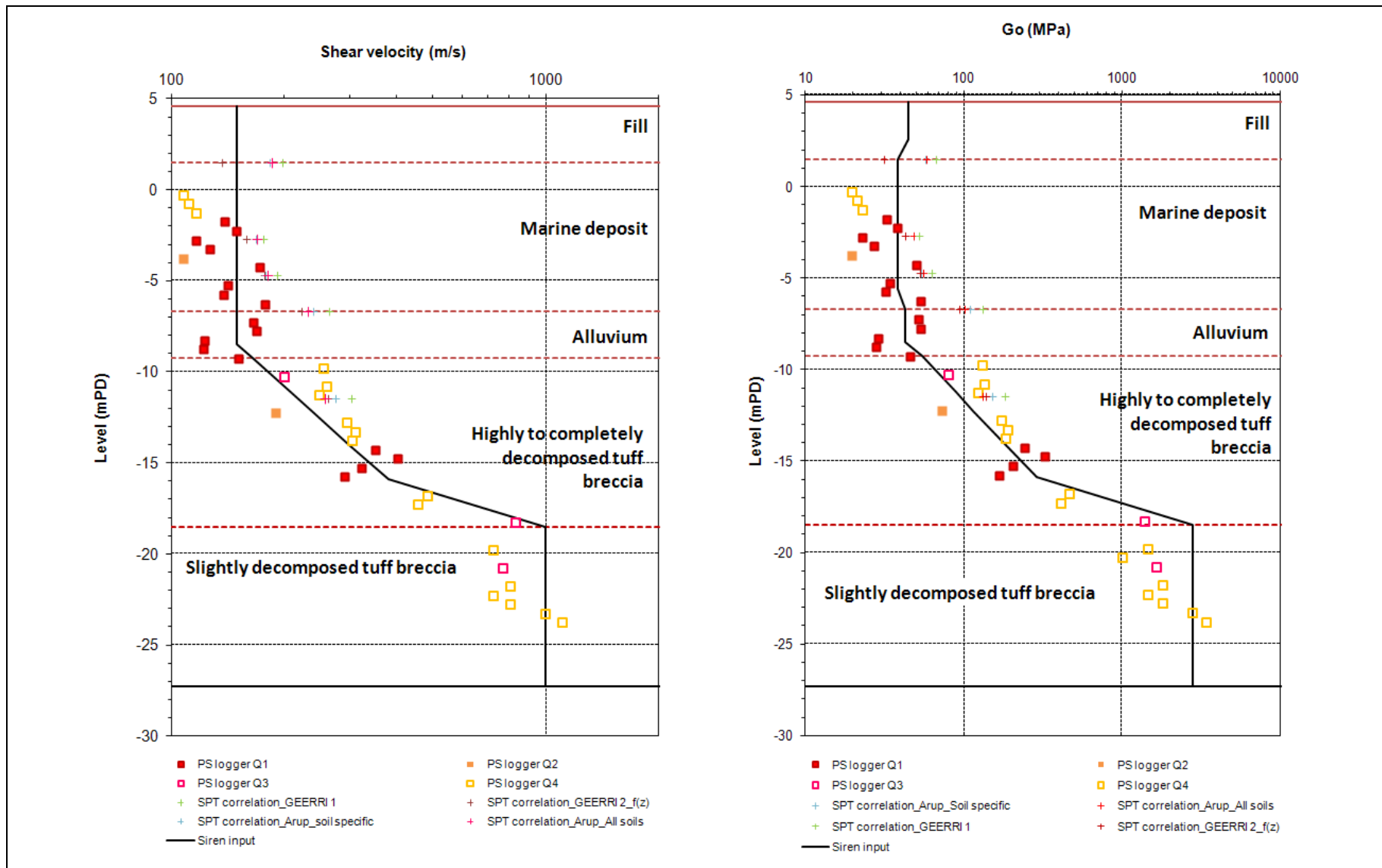


Figure 4.5 Vs and Go Profile for BH13

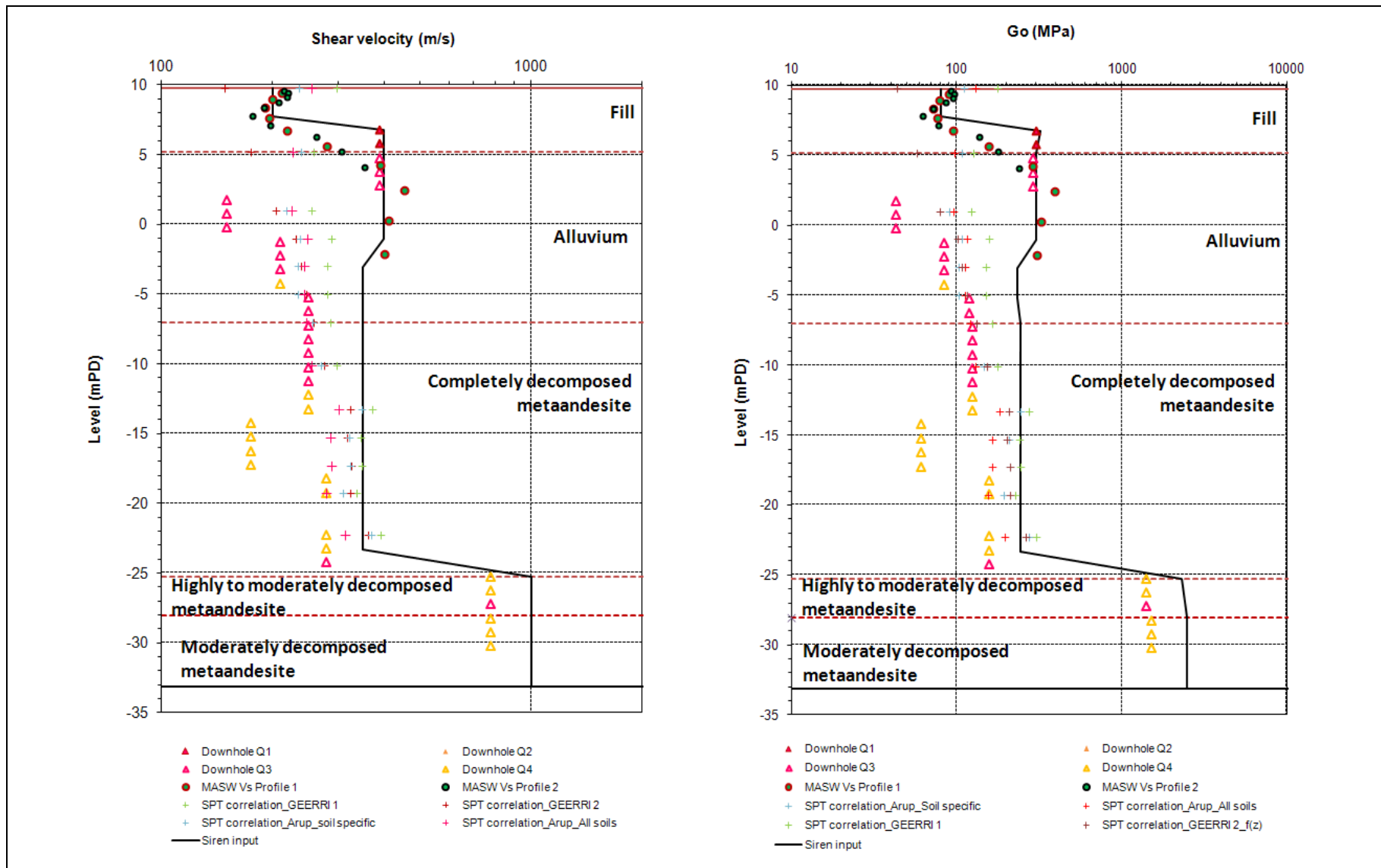


Figure 4.6 Vs and Go Profile for BH14

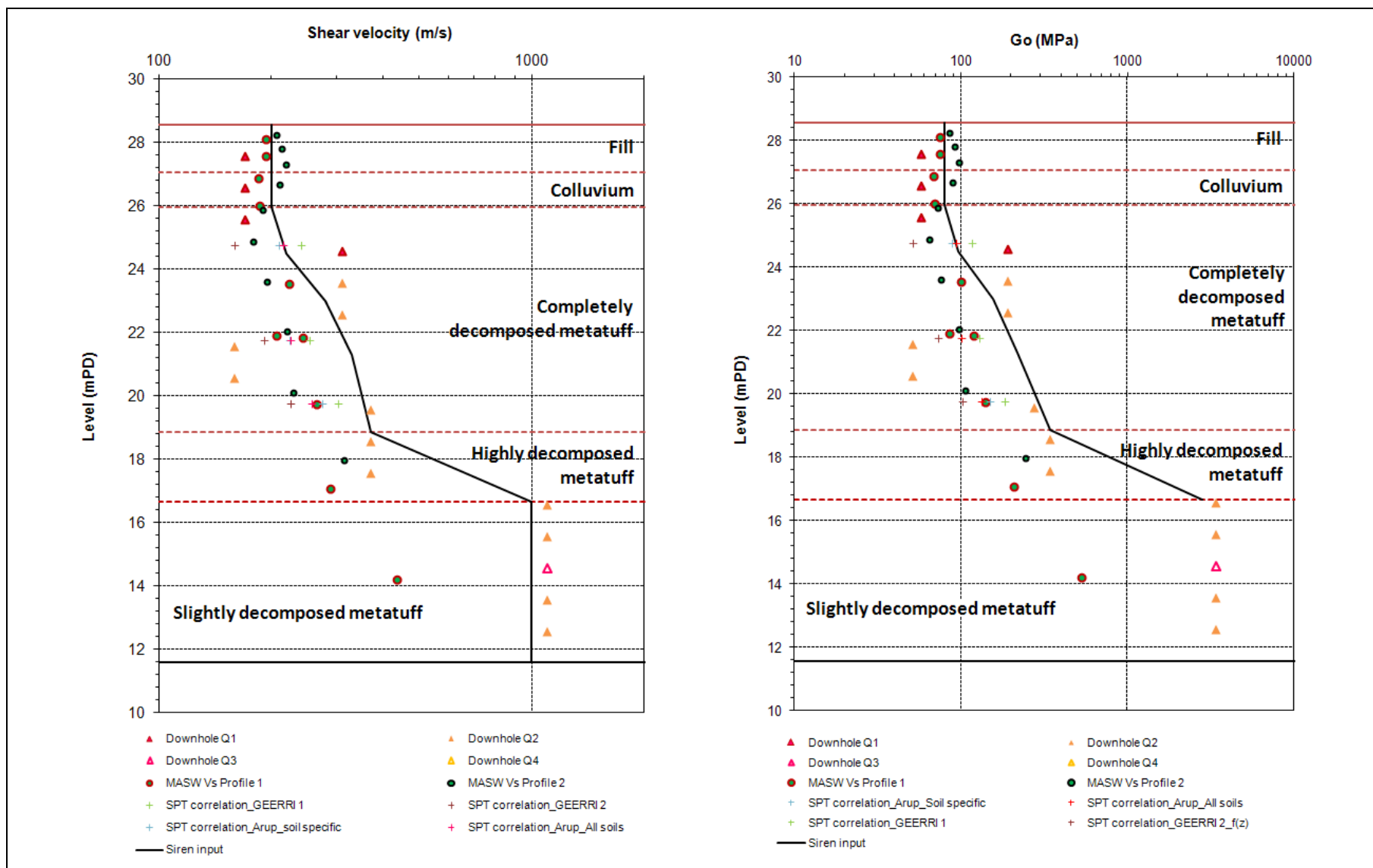
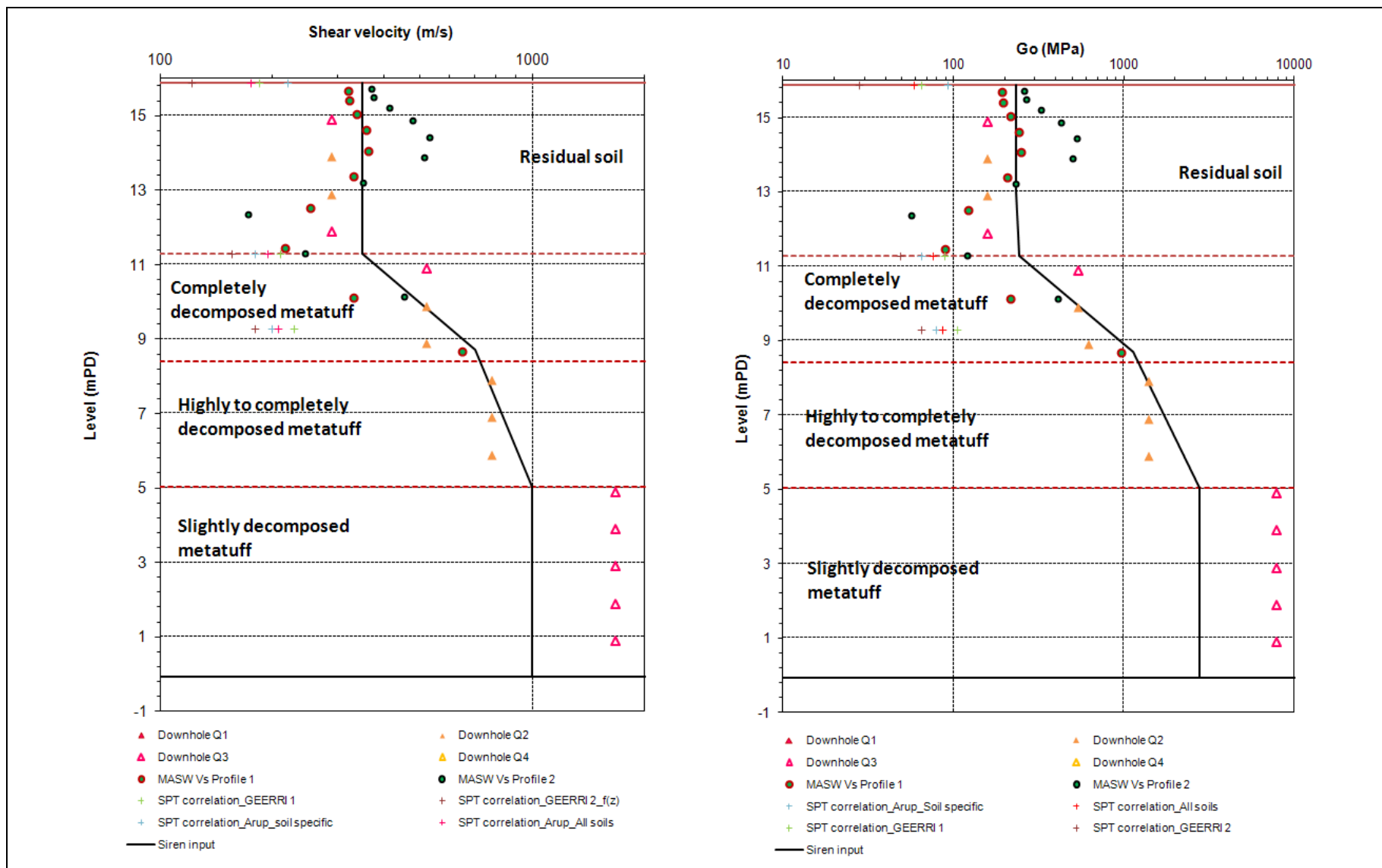


Figure 4.7  $V_s$  and  $G_0$  Profile for BH15



**Figure 4.8 Vs and Go Profile for BH16**



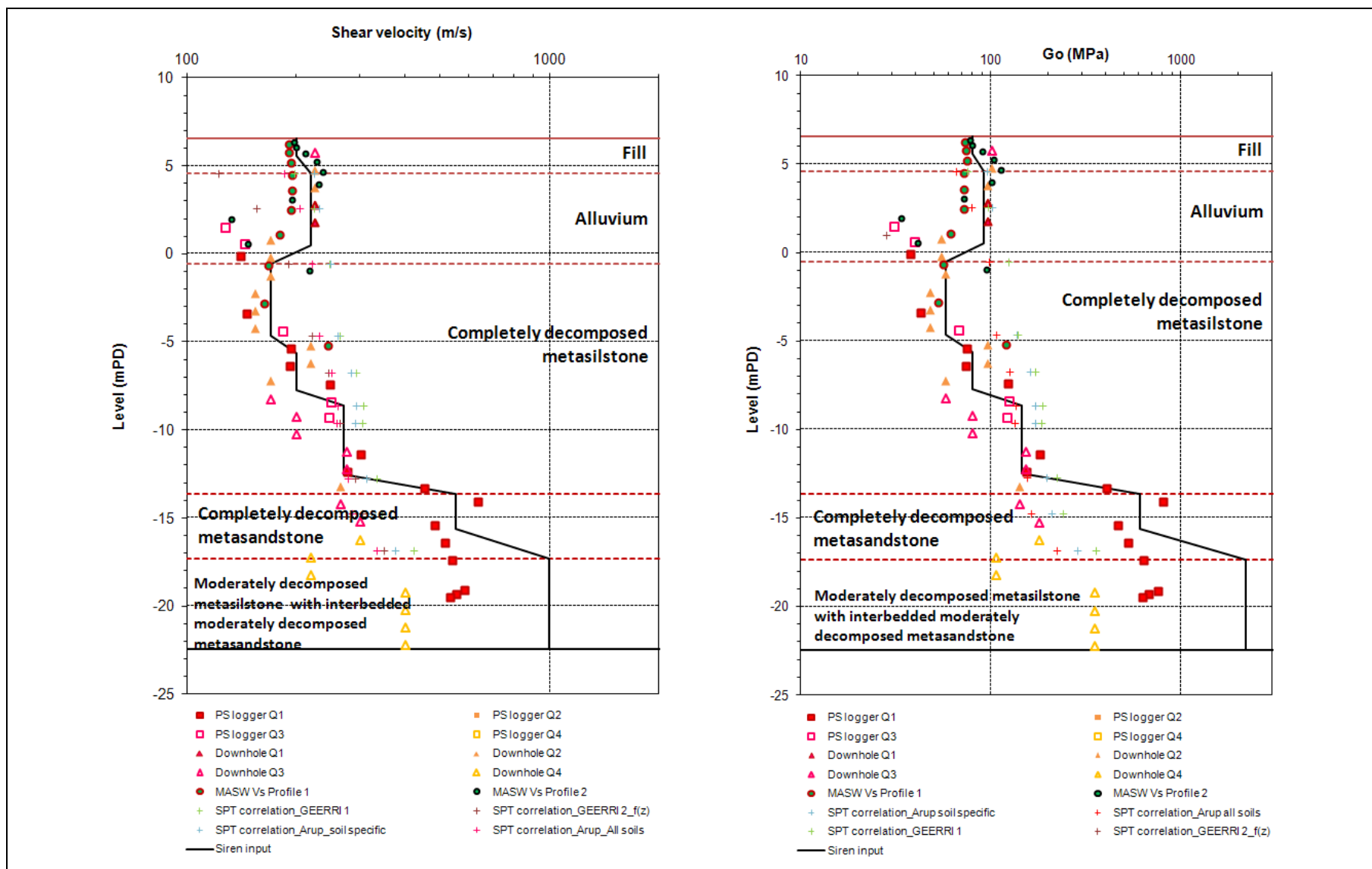


Figure 4.9 Vs and  $G_0$  Profile for BH20

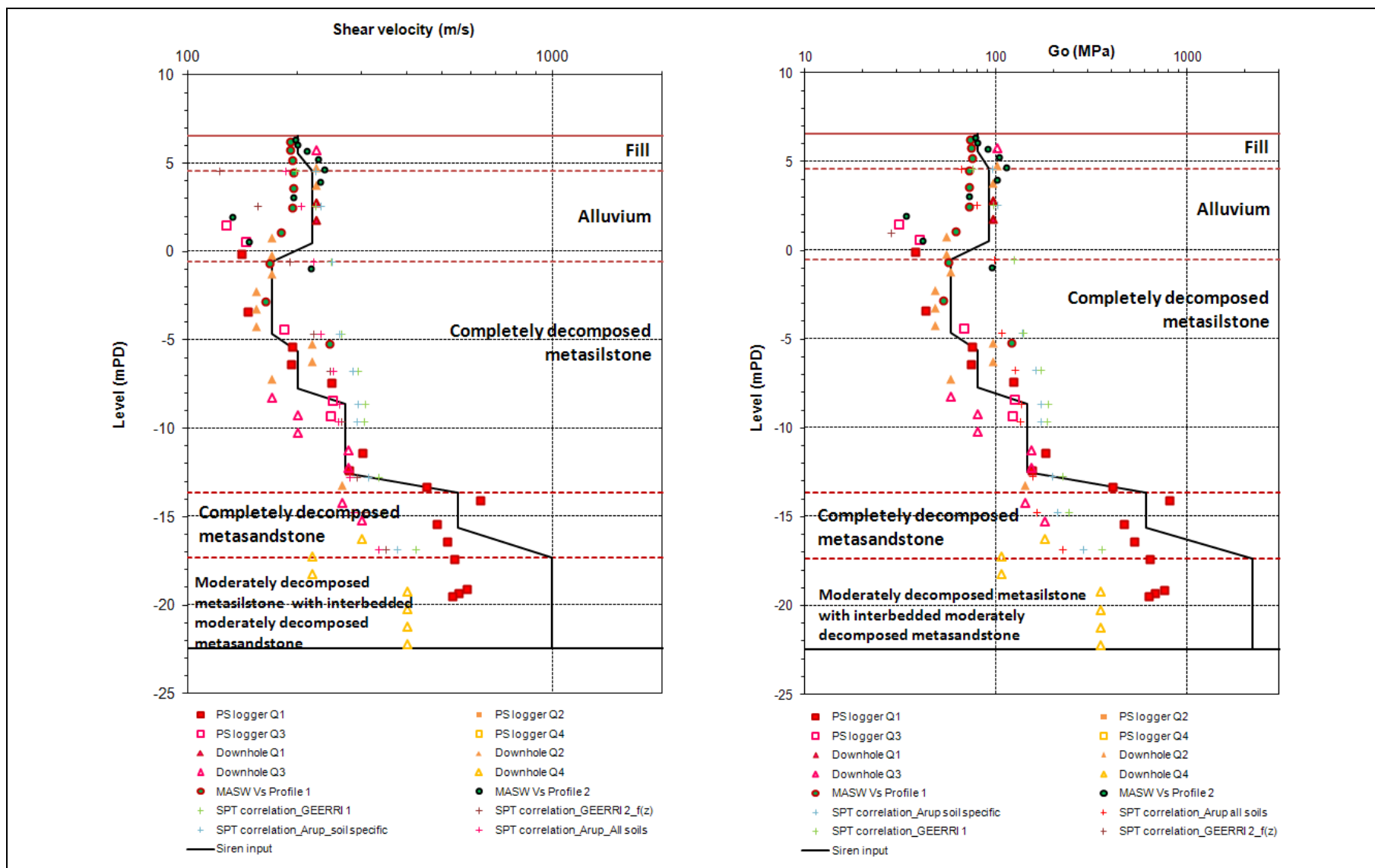


Figure 4.10  $V_s$  and  $G_0$  Profile for BH21

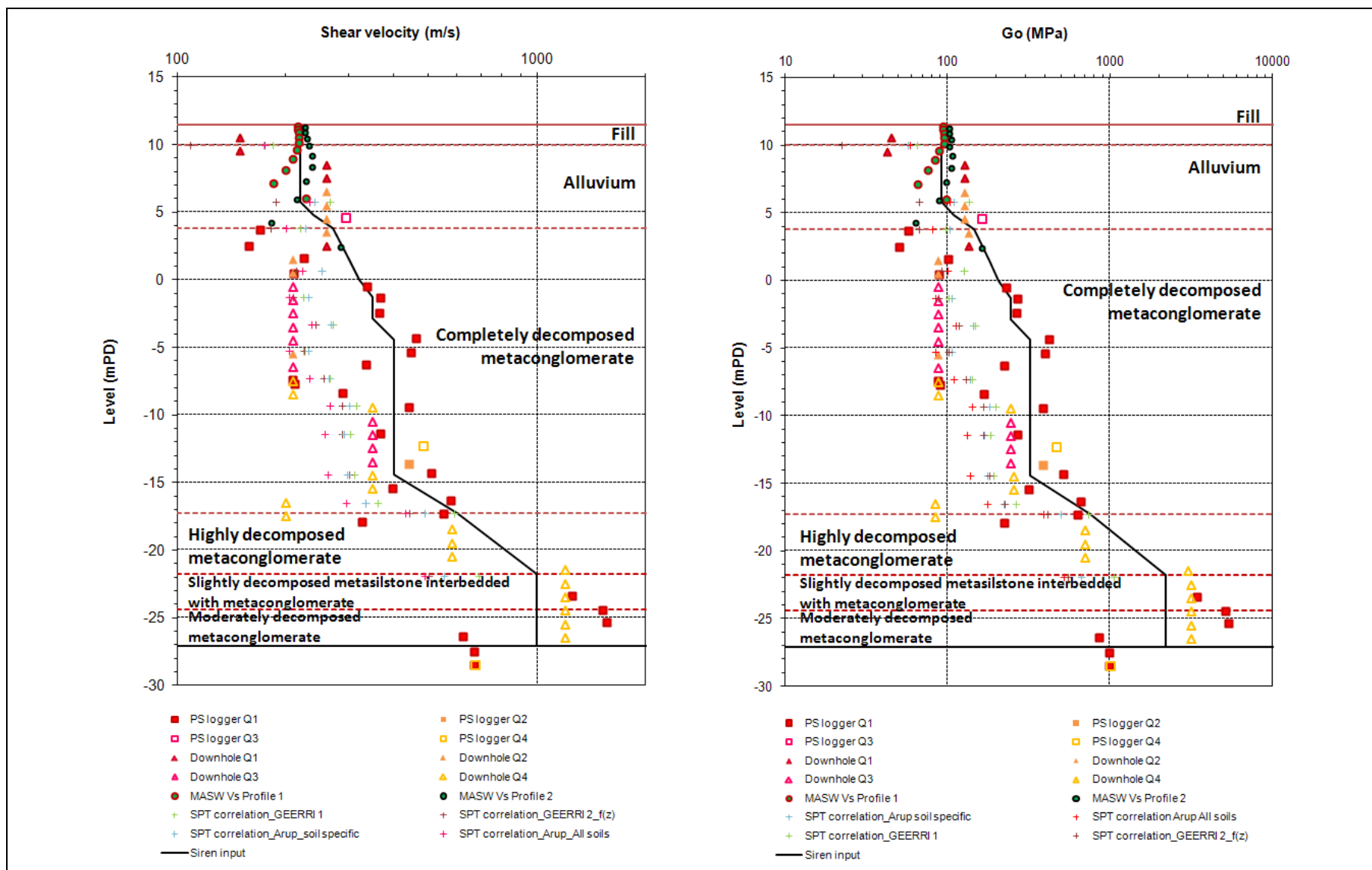


Figure 4.11 Vs and  $G_0$  Profile for BH22

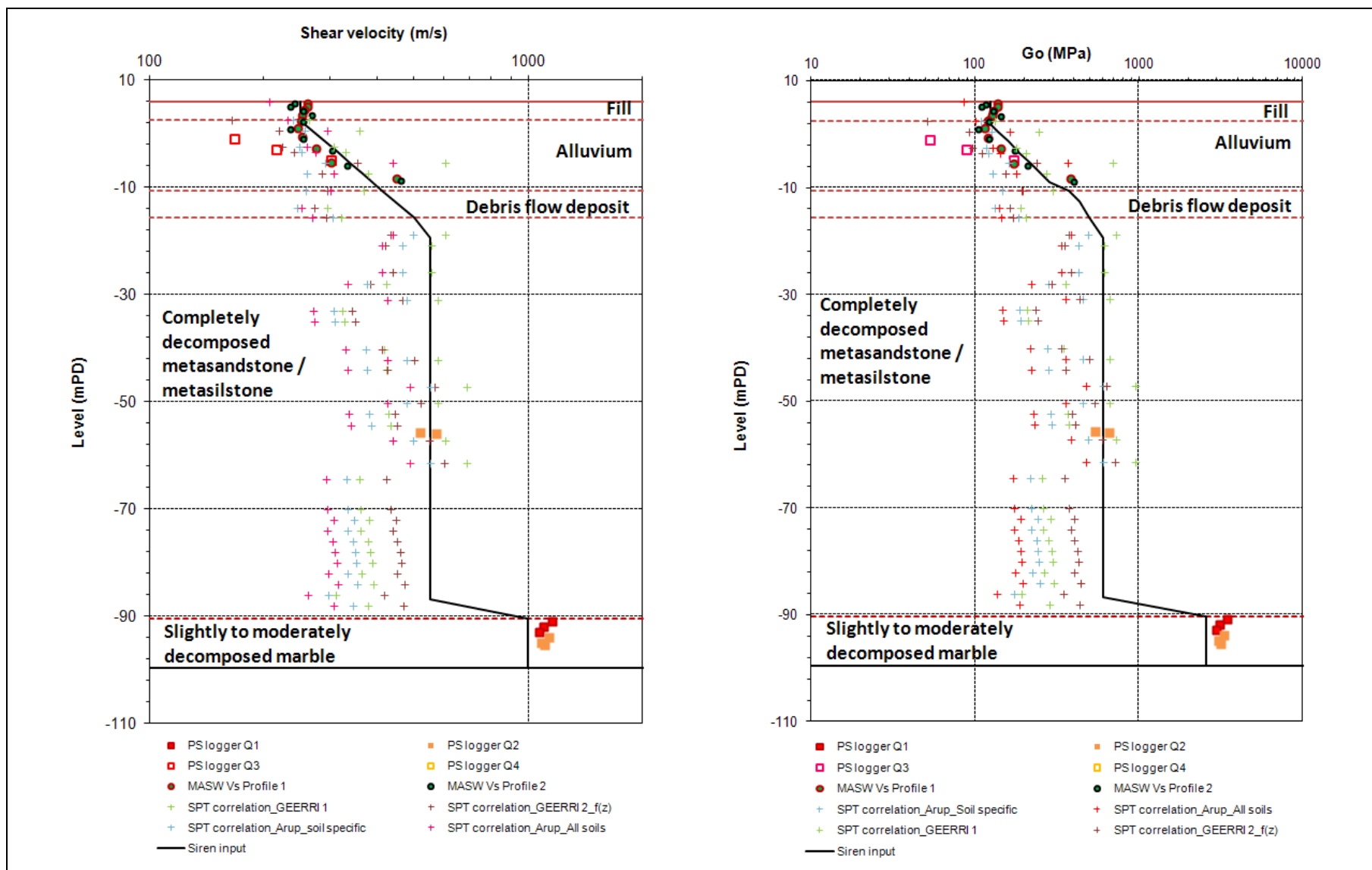
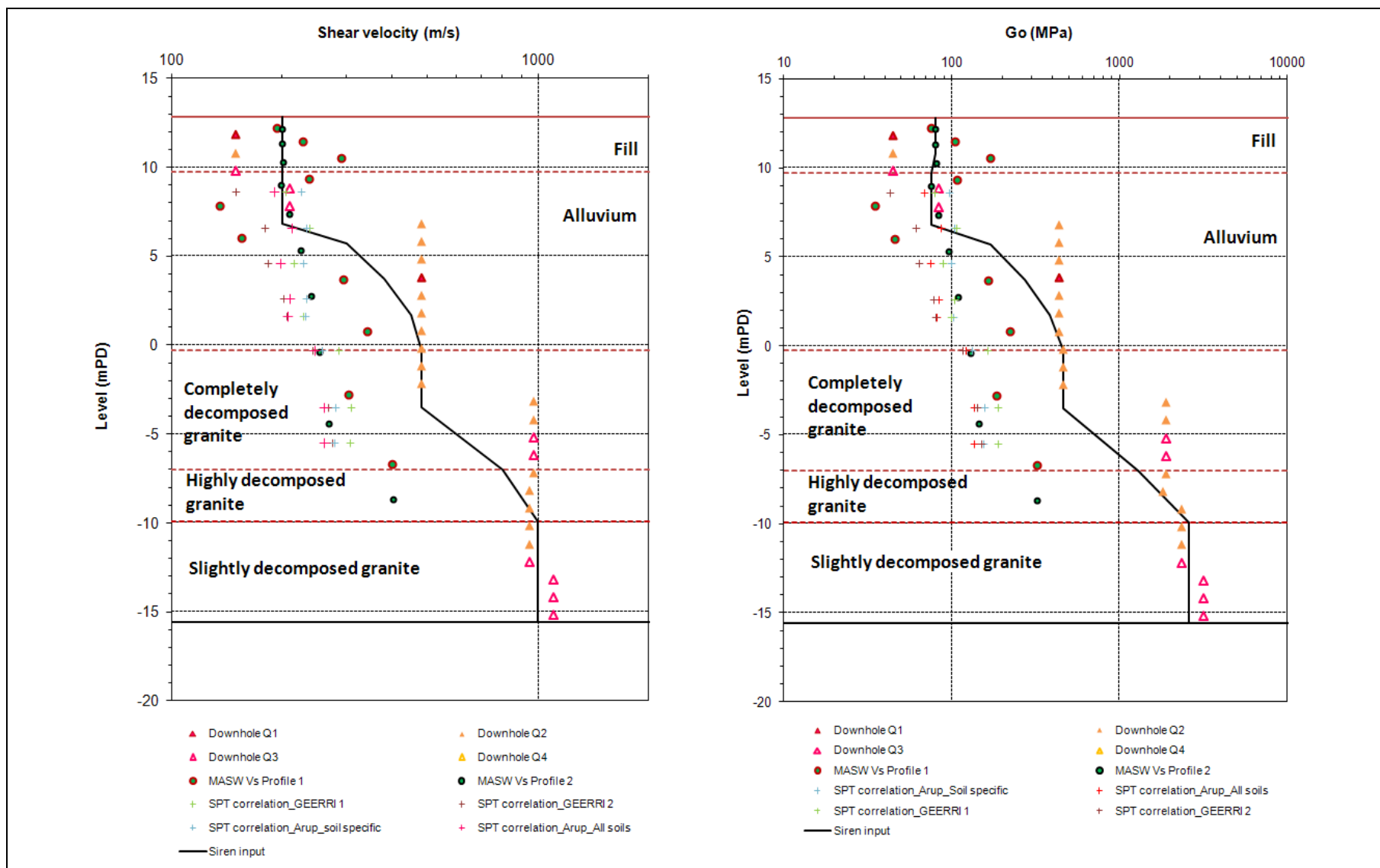


Figure 4.12 Vs and Go Profile for BH23



**Figure 4.13 Vs and  $G_0$  Profile for BH24**

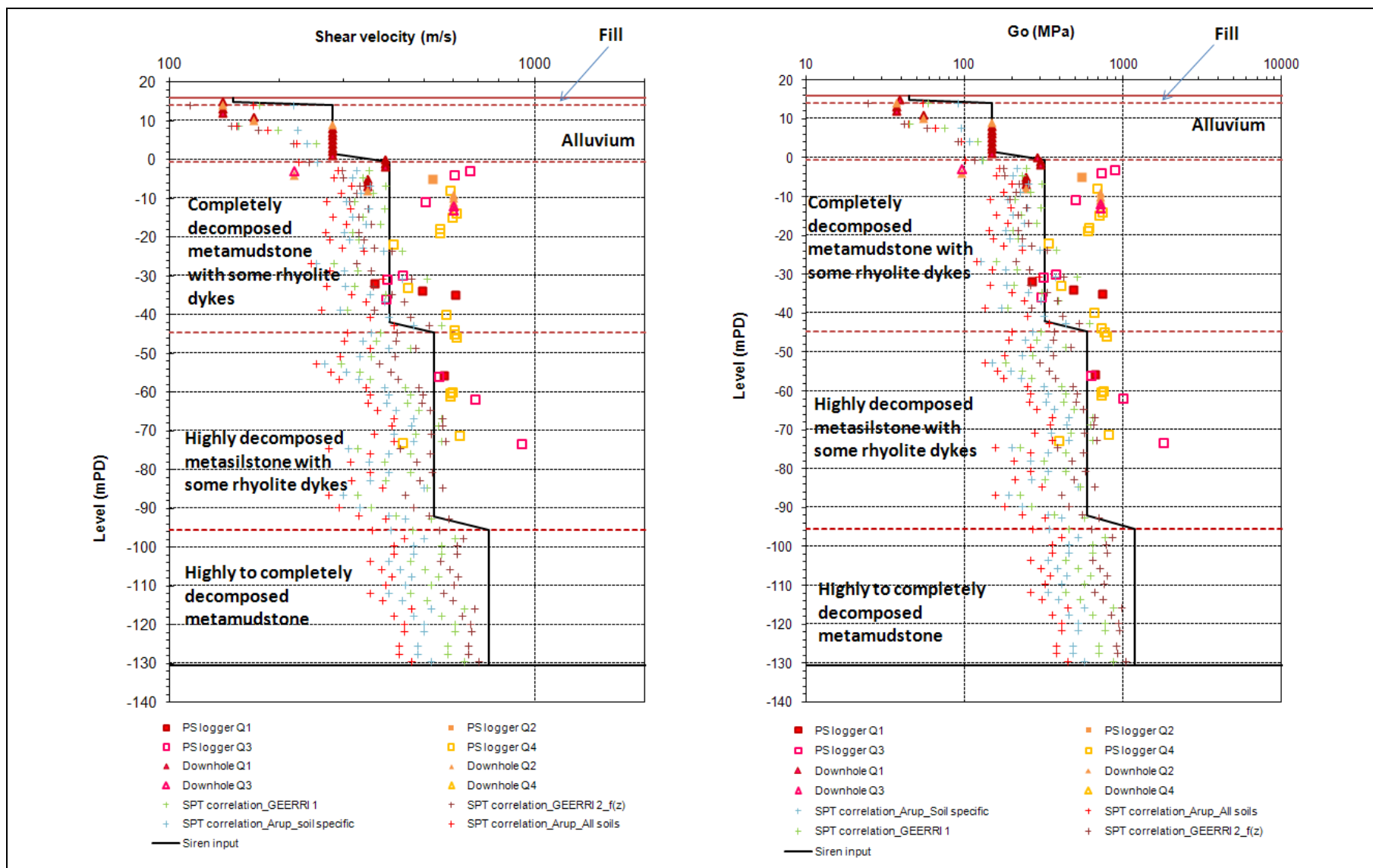


Figure 4.14 Vs and G<sub>0</sub> Profile for BH26

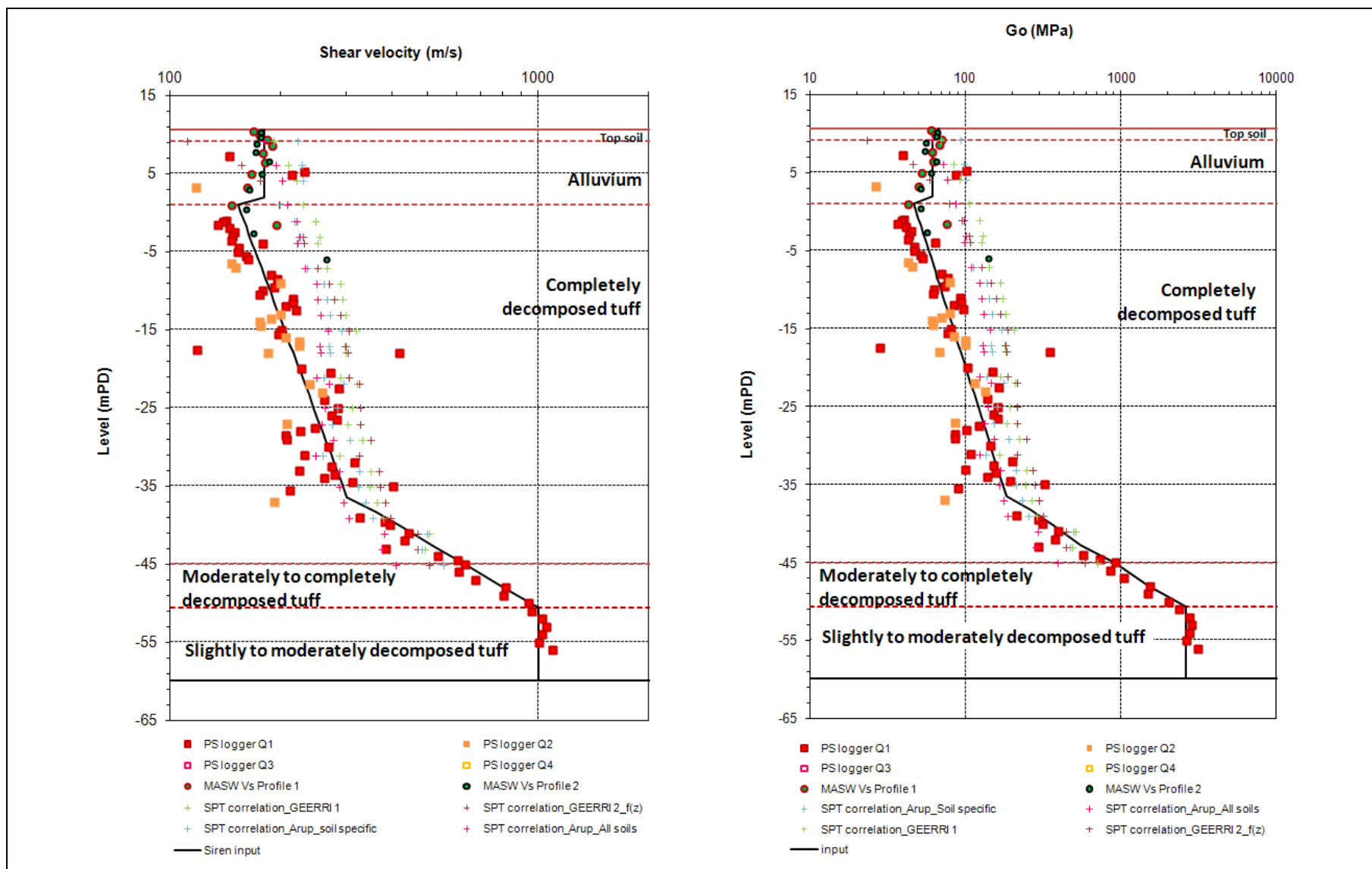


Figure 4.15 Vs and  $G_0$  Profile for BH27

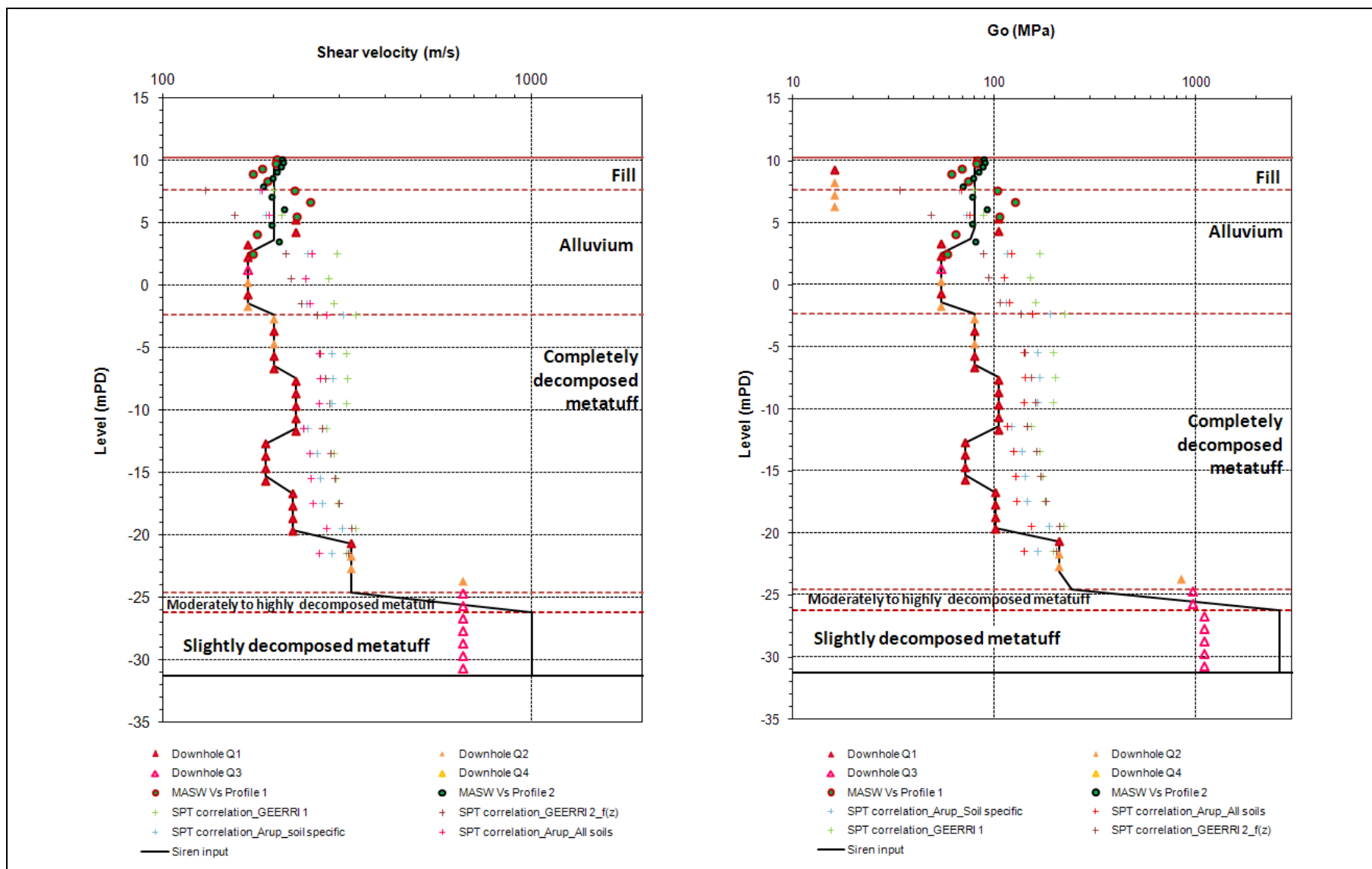
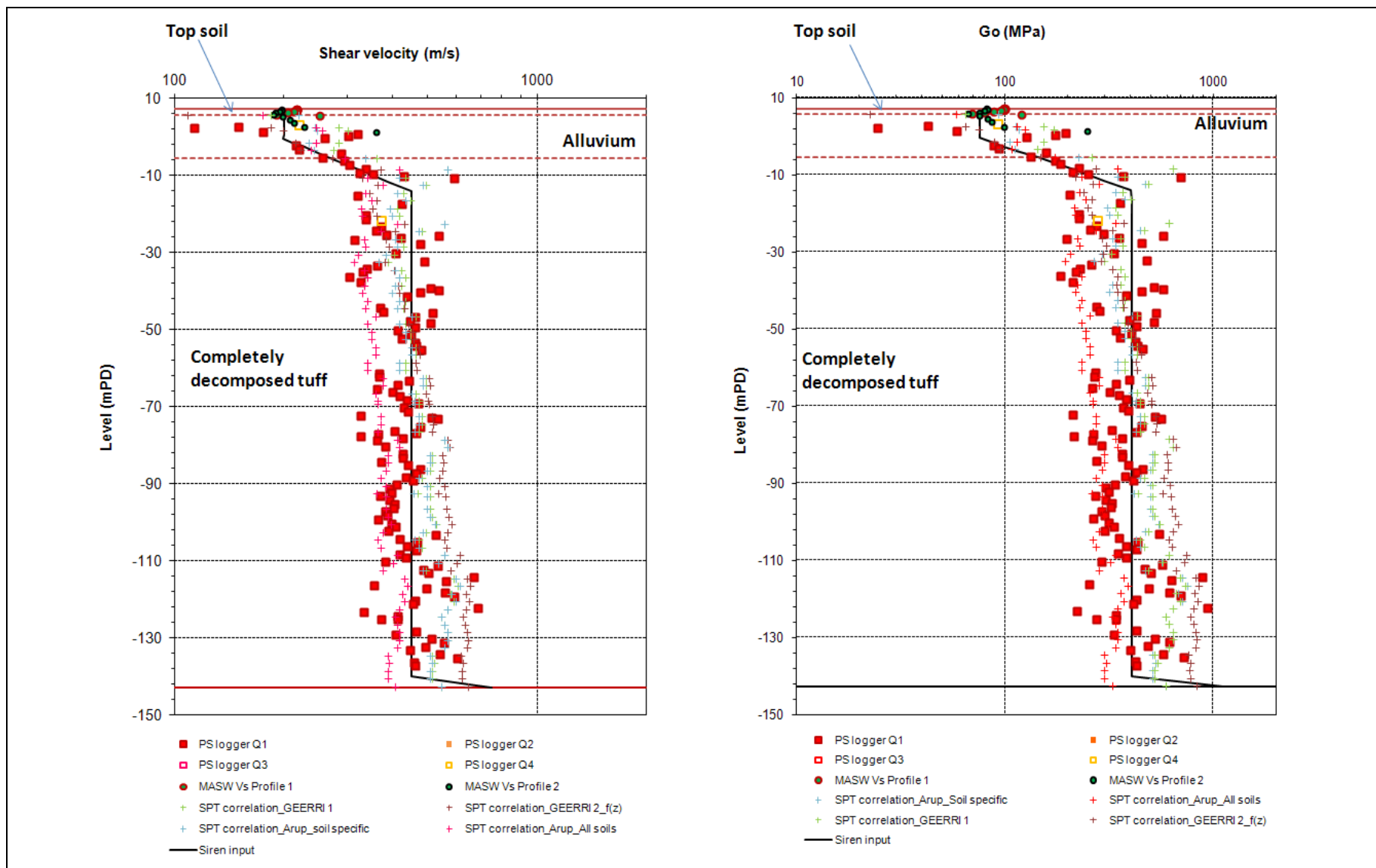


Figure 4.16 Vs and Go Profile for BH29





**Figure 4.17 Vs and G<sub>0</sub> Profile for BH30**

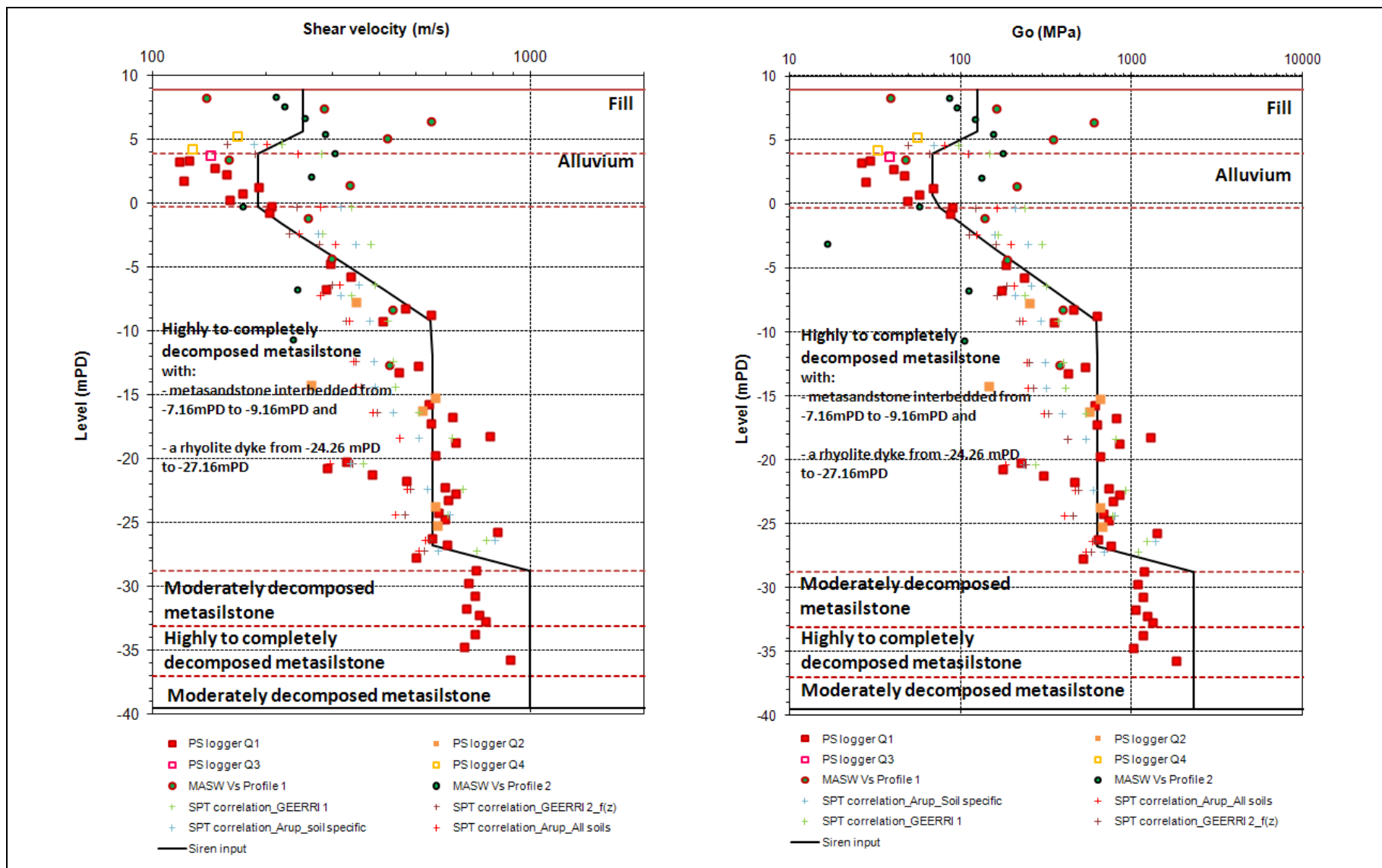


Figure 4.18 Vs and G<sub>0</sub> Profile for BH32

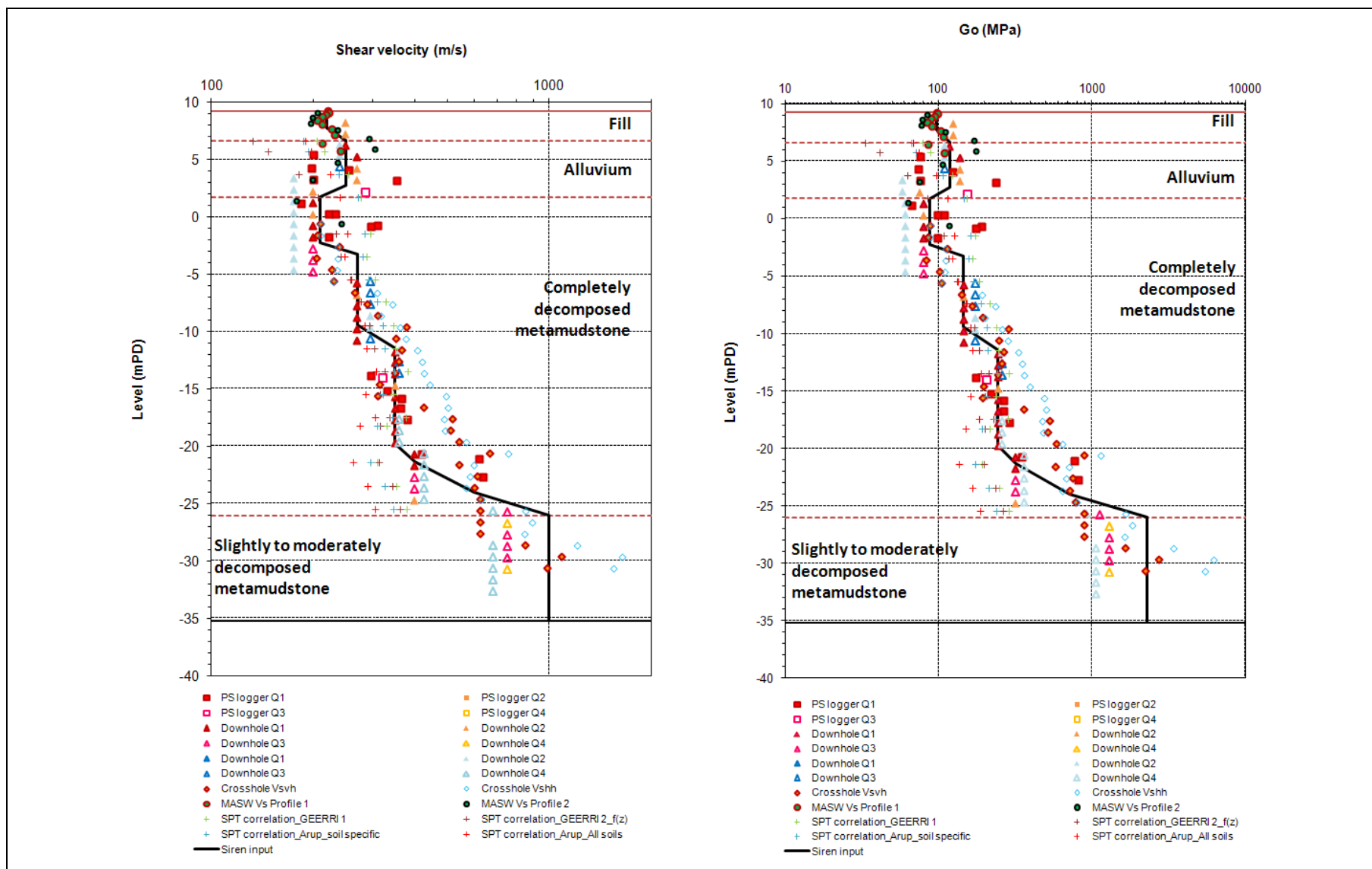


Figure 4.19 Vs and G<sub>0</sub> Profile for BH36

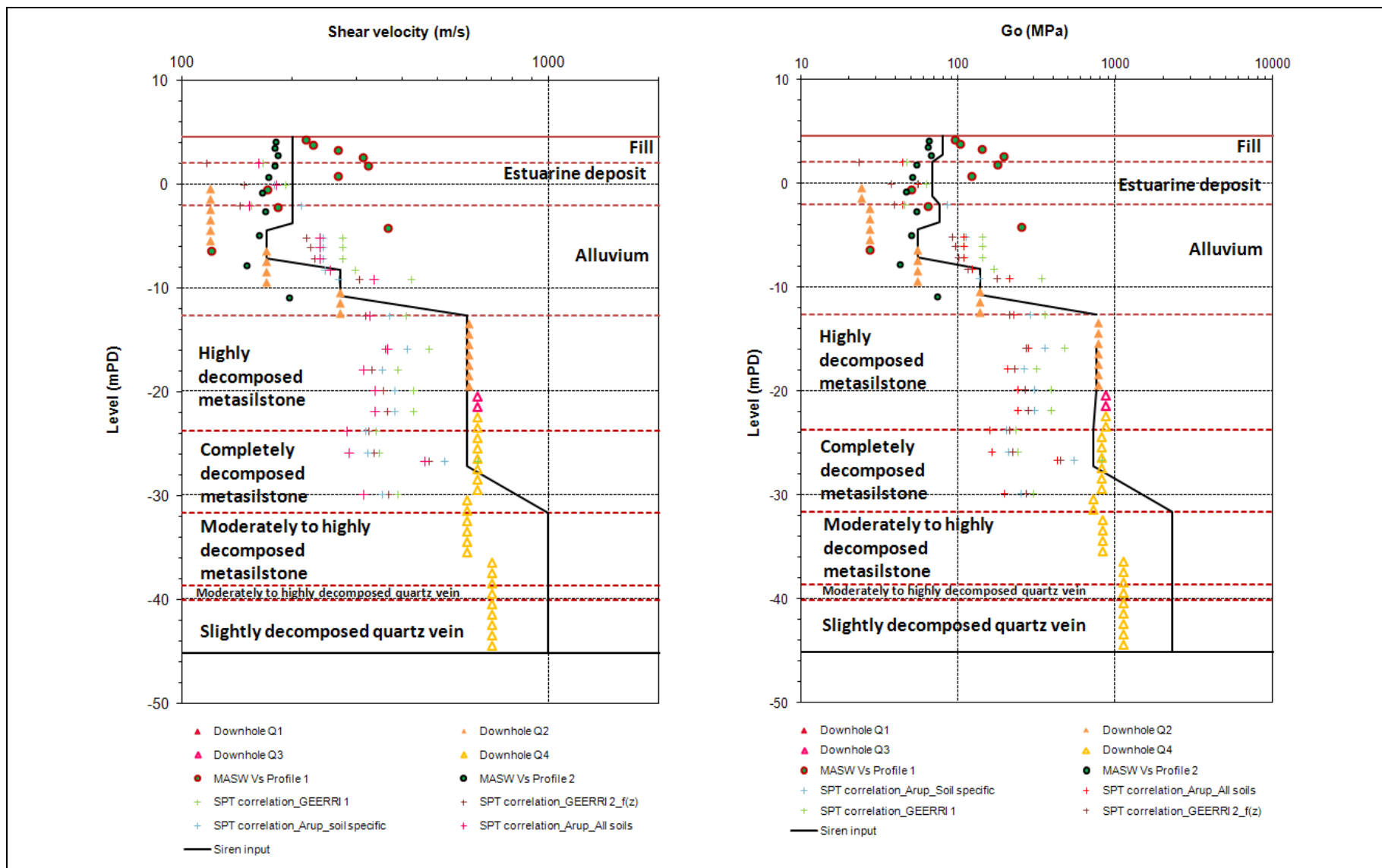


Figure 4.20 Vs and Go Profile for BH39

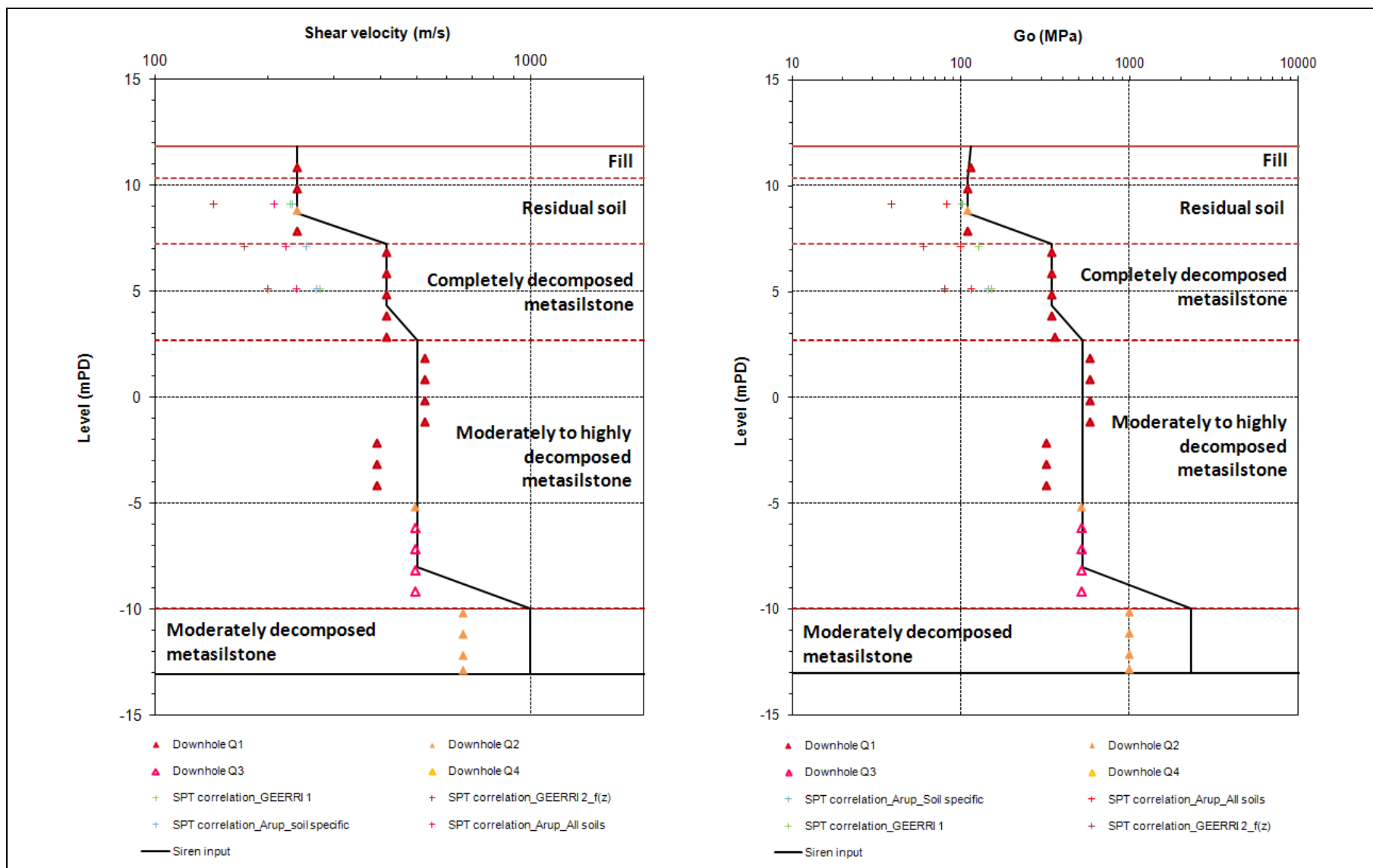


Figure 4.21 Vs and Go Profile for BH41

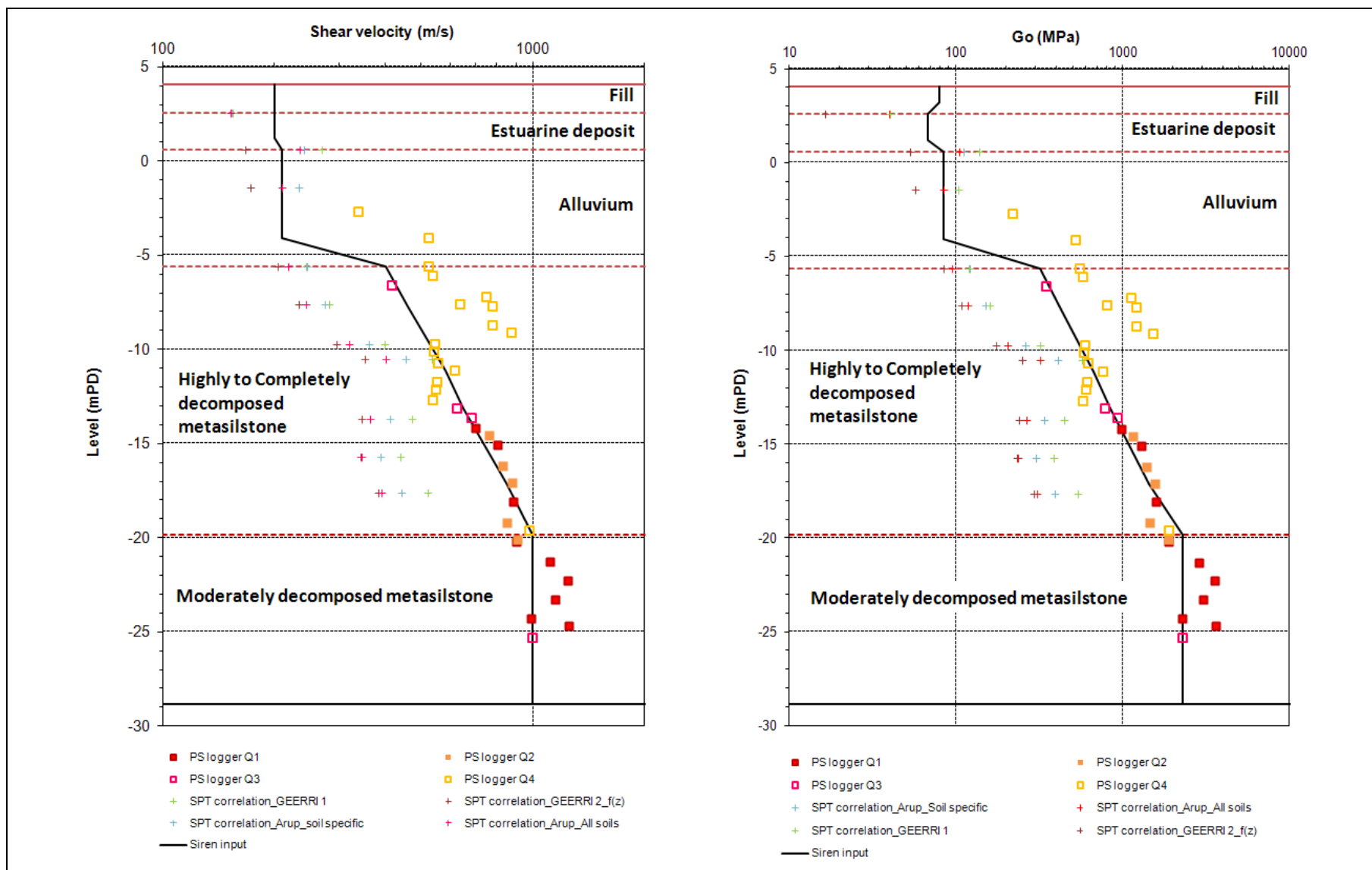


Figure 4.22  $V_s$  and  $G_0$  Profile for BH42

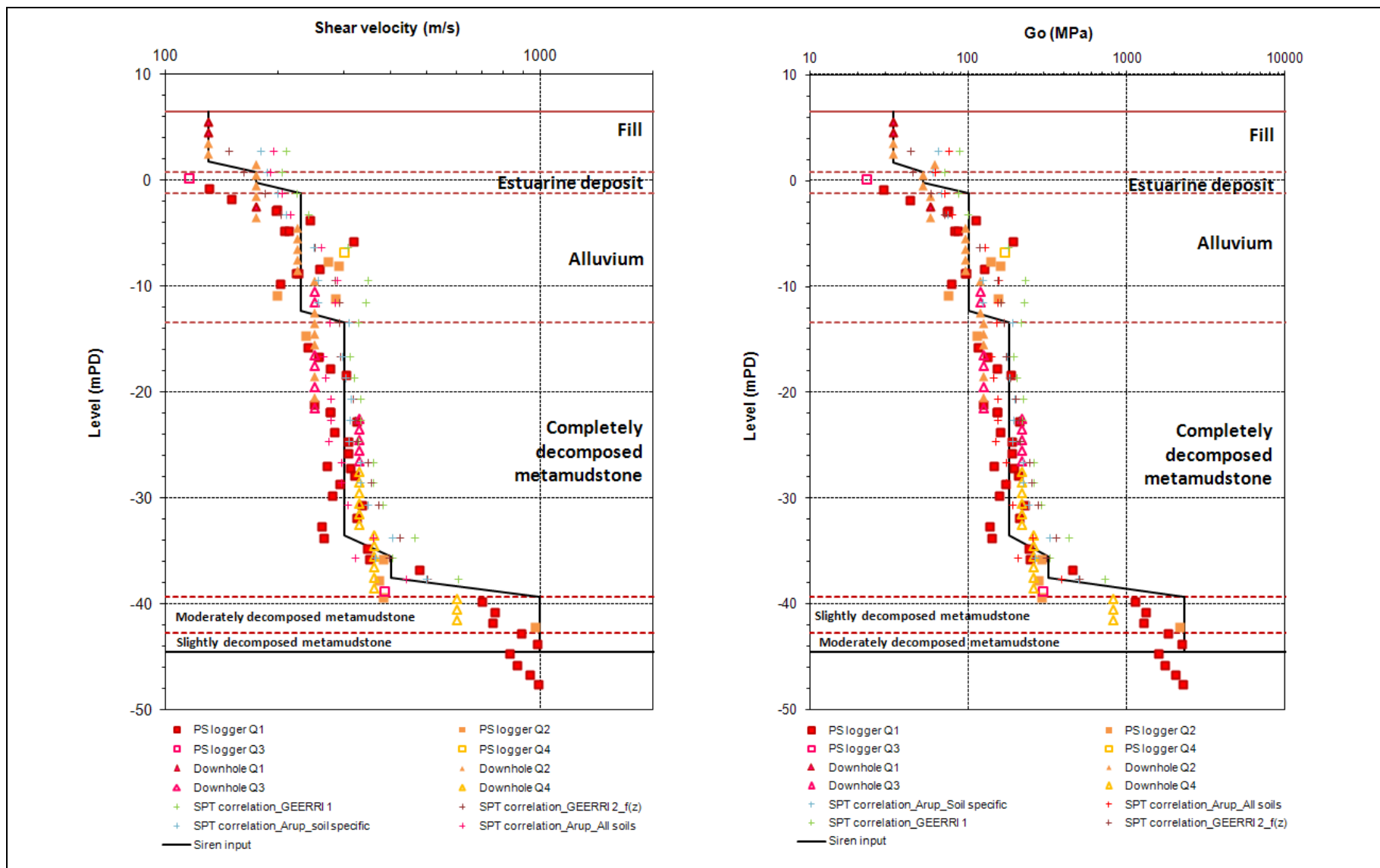


Figure 4.23  $V_s$  and  $G_o$  Profile for BH43

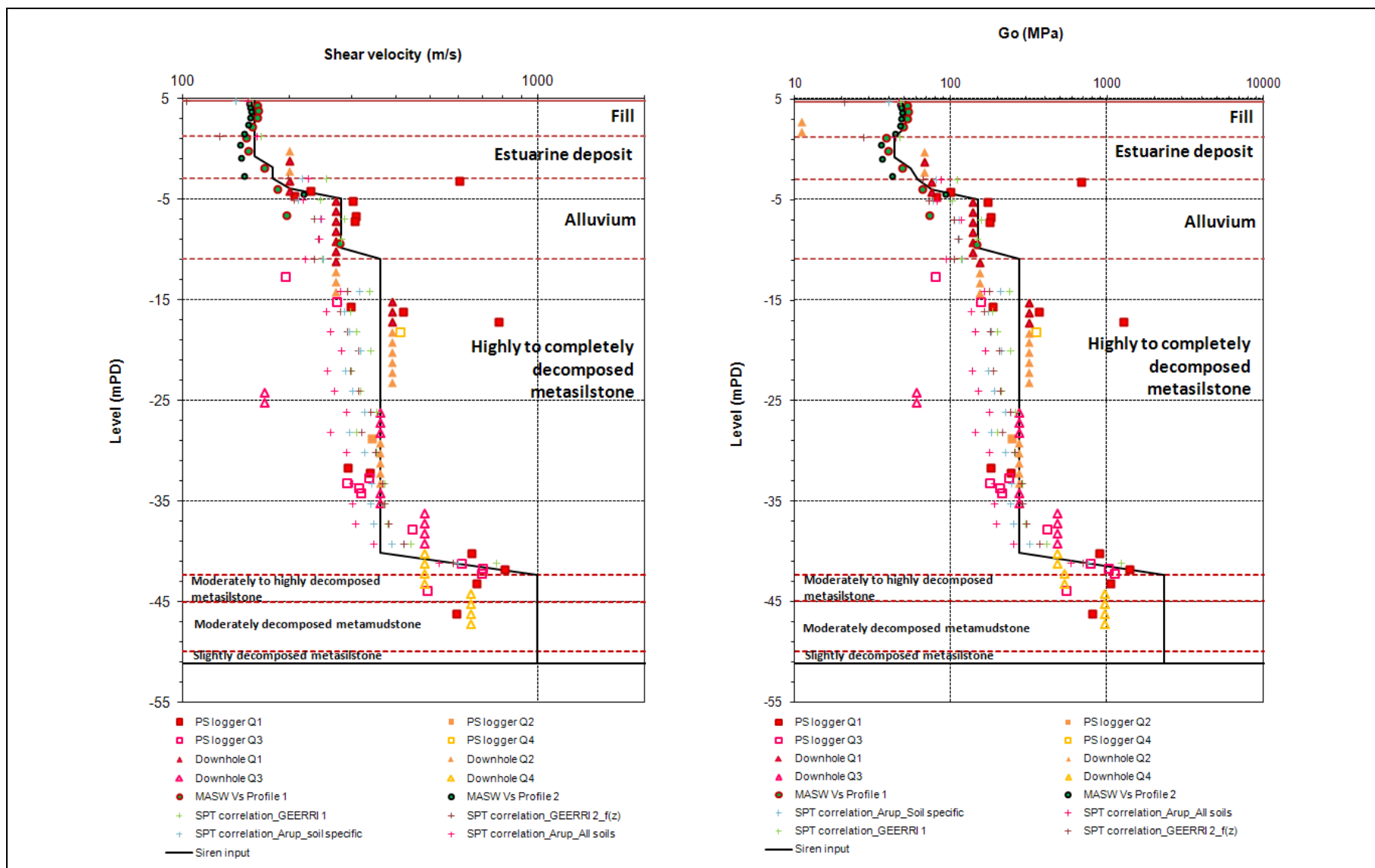


Figure 4.24 Vs and Go Profile for BH44



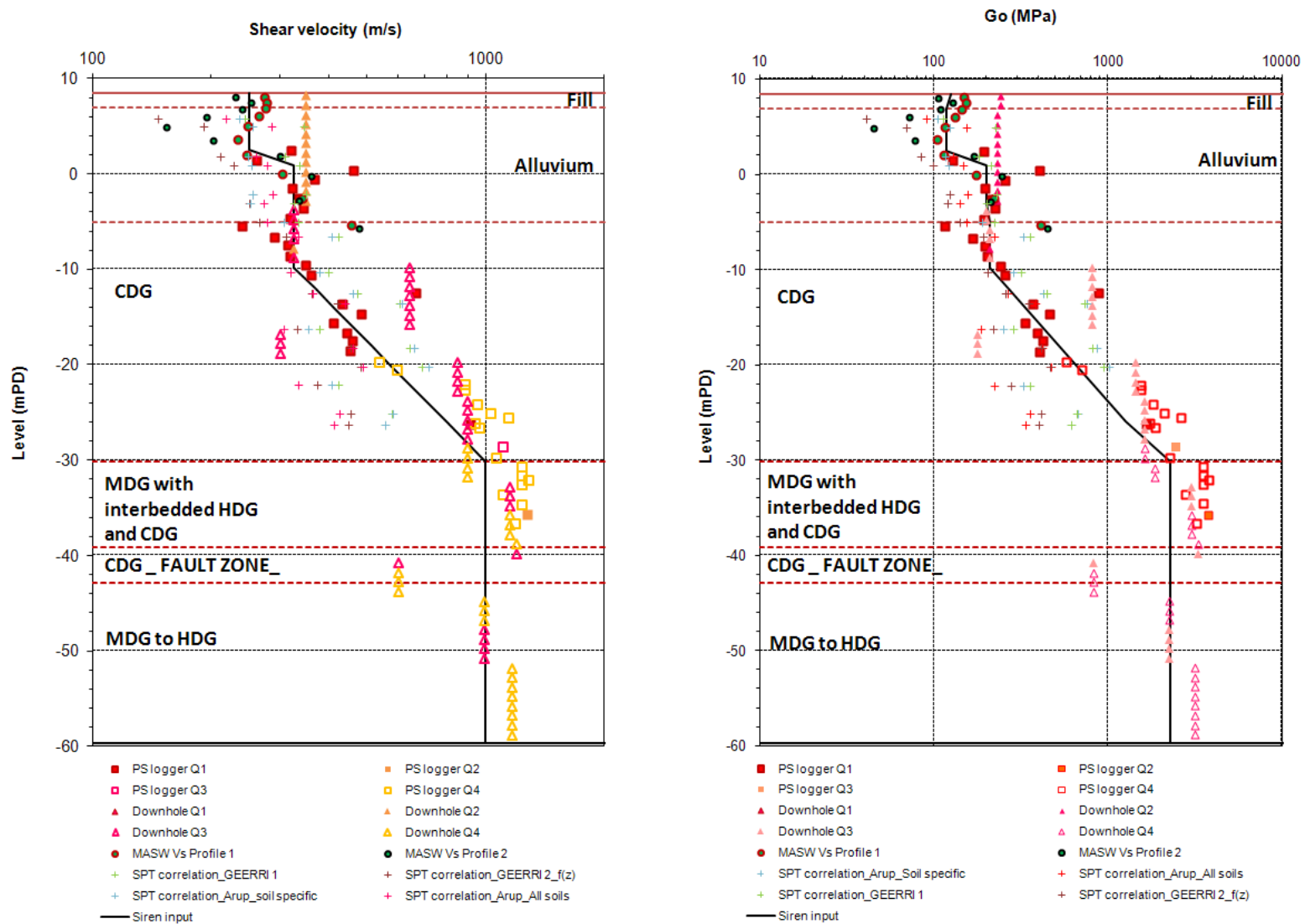


Figure 4.25 Vs and Go Profile for BH45

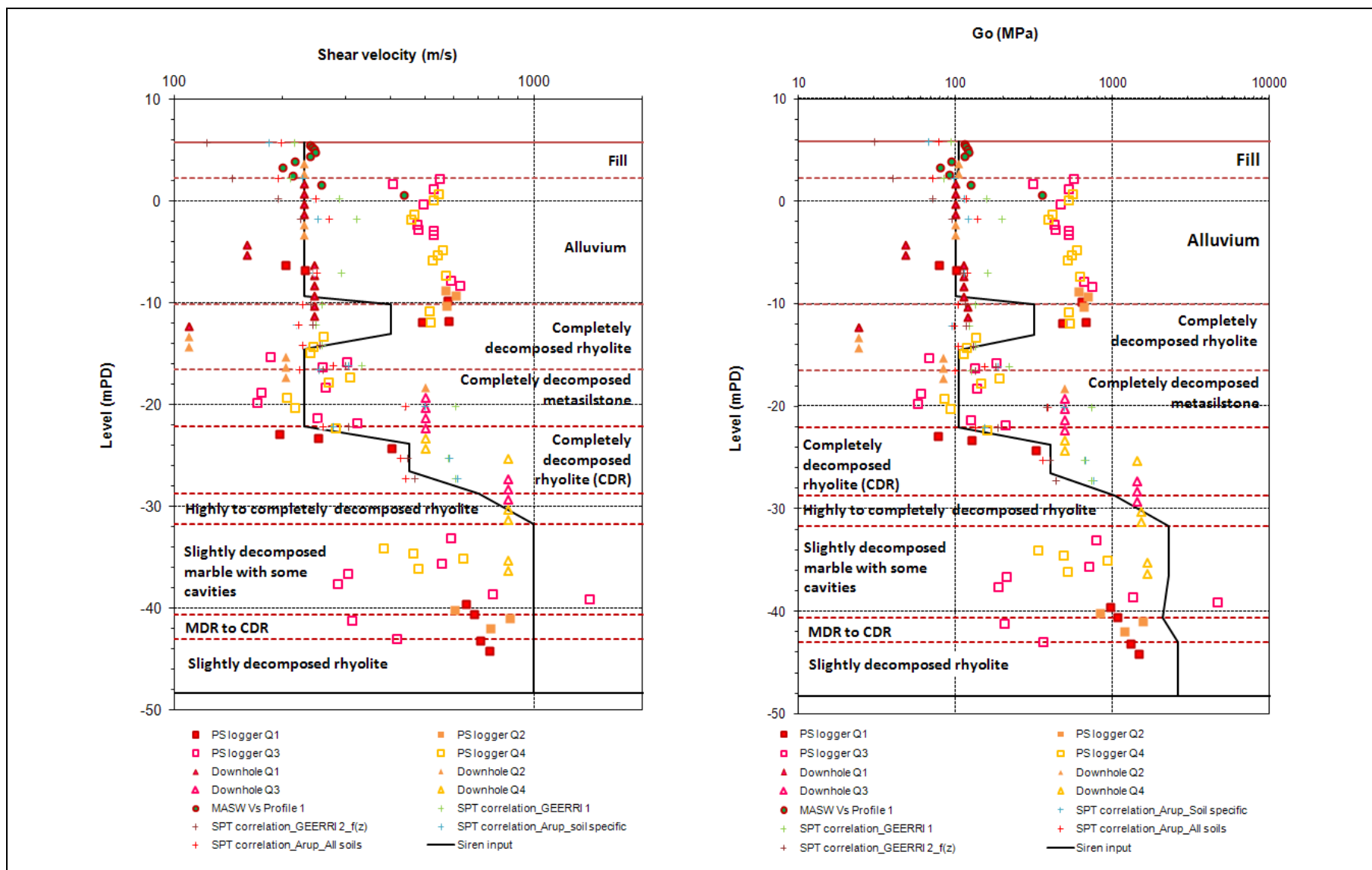
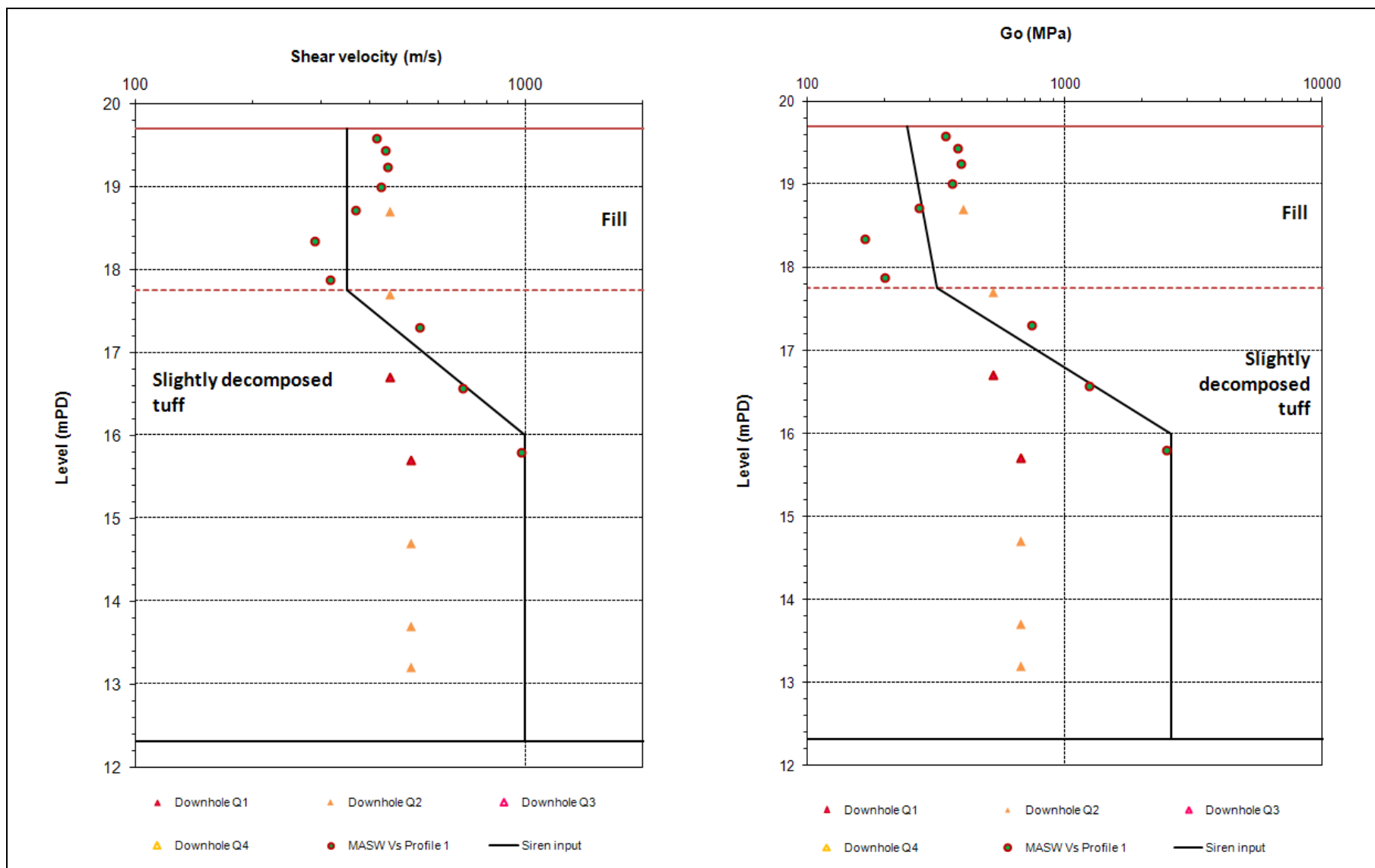
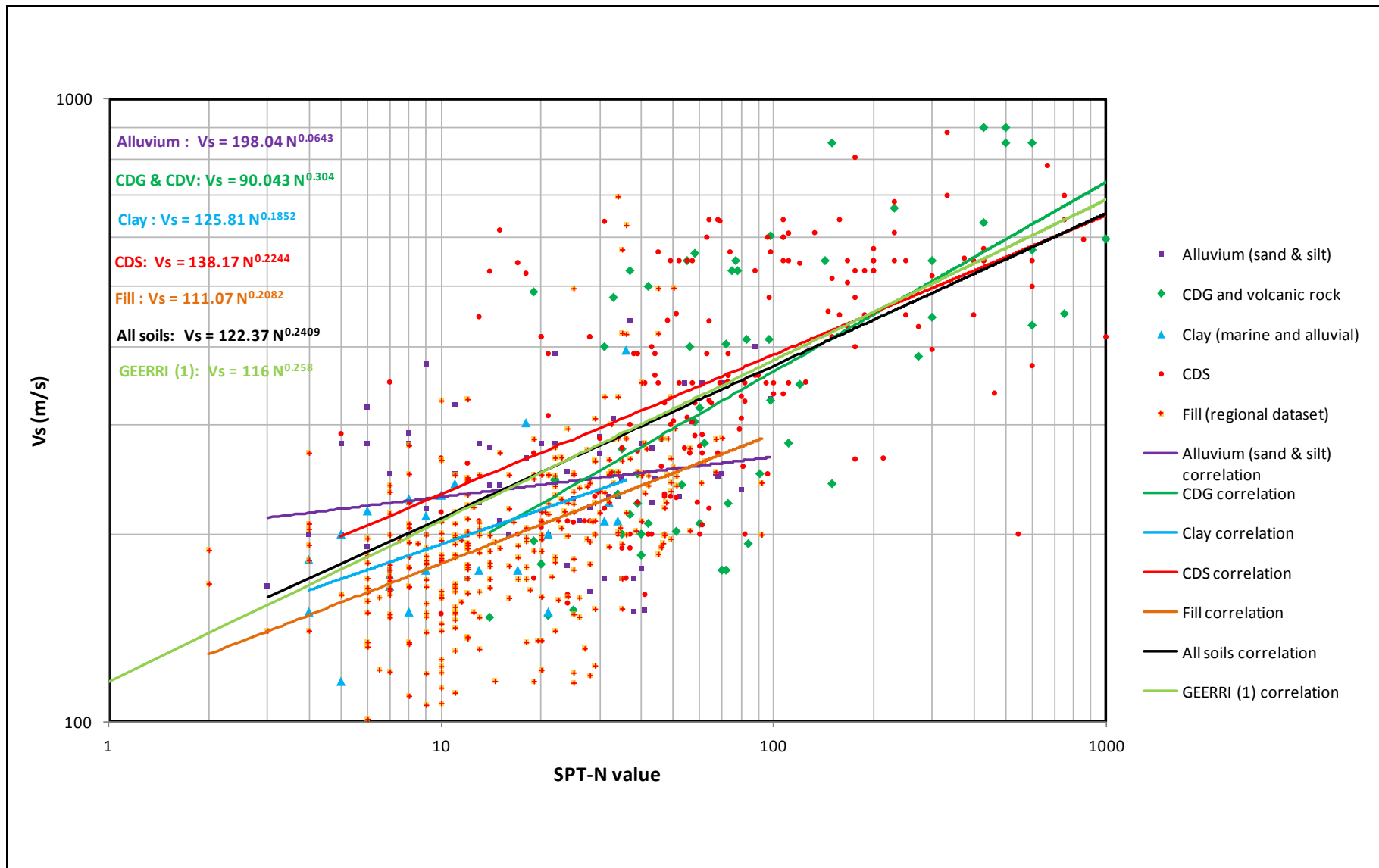


Figure 4.26 Vs and  $G_0$  Profile for BH49



**Figure 4.27** Vs and Go Profile for BH50



**Figure 4.28 Shear Wave Velocity to SPT-N Value Correlations**

## 5 Development of Rock Time Histories for Site Response Analyses

The propagation of the seismic ground motions through the soil profile requires input motions for bedrock in form of acceleration time histories. The ground motion records used for subsequent site response analyses are derived to be compatible with the uniform hazard response spectra (UHRs) for bedrock as derived in Arup (2015).

### 5.1 Target Design Rock Horizontal Response Spectra

The design bedrock spectra obtained from probabilistic seismic hazard analysis are described in Arup (2015). The UHRs is shown in Figure 5.1 for ground motions having 63%, 10% and 2% probabilities of being exceeded in the next 50 years. A de-aggregation process was then applied to the UHRs to define earthquakes that contributed the most significantly to different portions of the UHRs curves. These earthquake scenarios are defined in terms of their magnitudes and distances with a scaling factor applied such that the amplitude of the scenario earthquake spectrum matches the amplitude of the UHRs over an appropriate range.

The de-aggregation procedure defined combinations of magnitudes and distances for each UHRs, representing approximately the peak ground acceleration (PGA), and response spectral ordinate values in the 0.2 s, 0.5 s to 1.0 s and > 2.0 s portions of the UHRs. The de-aggregated combinations of magnitude and distance for each UHRs are summarised in Table 5.1. It was found that only two discrete combinations of magnitude and distance were required to provide a reasonable match to the UHRs. The 0.2 s and 1.0 s portions of UHRs have therefore been considered. This finding is consistent with the current IBC Code Provisions (ICC, 2009) developed in the United States, which present two spectral ordinate ranges (0.2 s and 1.0 s). As a remark, this de-aggregation procedure is not mentioned in the current Chinese Seismic Code GB 50011-2010 (Chinese Seismic Code, 2010).

**Table 5.1 De-aggregated Combinations of Magnitude and Distance for Each UHRs**

| Probability of Ground Motion in the Next 50 Years | Short Period Ground Motion |               | Long Period Ground Motion                     |               |                                     |               |          |               |
|---------------------------------------------------|----------------------------|---------------|-----------------------------------------------|---------------|-------------------------------------|---------------|----------|---------------|
|                                                   | 0.2 s                      |               | 0.5 s - 1 s (Near-source EQ less than 250 km) |               | 0.5 s - 1 s (Distance EQ at 250 km) |               | 5 s      |               |
|                                                   | <i>M</i>                   | <i>R</i> (km) | <i>M</i>                                      | <i>R</i> (km) | <i>M</i>                            | <i>R</i> (km) | <i>M</i> | <i>R</i> (km) |
| 63%                                               | 5.5                        | 50            | 6.5                                           | 150           | -                                   | -             | 6.5      | 150           |
| 10%                                               | 5.5                        | 30            | 6.5                                           | 60            | -                                   | -             | 7        | 90            |
| 2%                                                | 5.5                        | 10            | 7                                             | 60            | 8                                   | 250           | 7.5      | 90            |

The scenario earthquake combinations of magnitude and distance are used to compute the scenario earthquake response spectrum based on different weightings of the attenuation models as presented in Arup (2015). The scenario earthquake response spectrum is then scaled to the spectral ordinate values of the UHRS shown in Figure 5.1.

The scenario spectra are illustrated in Figures 5.2 to 5.4. The results show that the scenario spectra scaled to the UHRS spectral ordinate values are similar and match the whole target UHRS quite well. It was therefore decided that the whole rock UHRS should be used for the design rock horizontal response spectra rather than to separate them into short and long period motions for design response spectra.

## 5.2 Selection of Rock Time Histories

In the absence of appropriately measured strong ground motions from the South China region, existing time histories have been modified to match the frequency contents of the target bedrock response spectra. The distance and magnitude of the selected earthquakes match the possible earthquake occurrences which give rise to the target ground motion hazard. Three sets of recorded strong motion records have been selected from suitable strong motion record database to represent the bedrock outcrop excitation having 63%, 10% and 2% probabilities of being exceeded in the next 50 years for Hong Kong. Also, it is a conventional way of codes of practice to select real earthquake records and scale them up to the target response spectrum for design purposes (e.g. IBC-2009 (ICC, 2009) and GB50011-2010 (Chinese Seismic Code, 2010)). Supplementary artificial time history is allowed, if no appropriate real records are available.

Without modification, the response spectra of the selected time histories in most cases will not closely match the target design response spectrum. Since the purpose of the site response analysis is to capture the average (expected) soil response rather than the variability of it, it is desirable to modify the selected time histories such that the response spectra of the modified recorded time histories match the target UHRS for the design return period reasonably well.

Historically, modification of the selected recorded time histories has been carried out in a frequency-domain. However, in the last decade with advances in the wavelet theory, a time-domain method has emerged as the preferred approach for spectral matching. Frequency-domain methods have the disadvantage of adding harmonic components to a recorded time history throughout the whole duration of the record. In contrast, the time-domain method has the advantage of adding wave packets of various periods having discrete durations. These wave packets are added to the recorded time history within small and discontinuous time windows where there is a significant amplitude of motion of the same period. Hence, the time-domain method preserves better the original features of the recorded time histories. The selected recorded earthquake time histories have been modified in the time-domain in order to match the target UHRS closely, particularly at long periods. The computer program RSPMATCH (Hancock et al, 2006) has been used for this purpose.

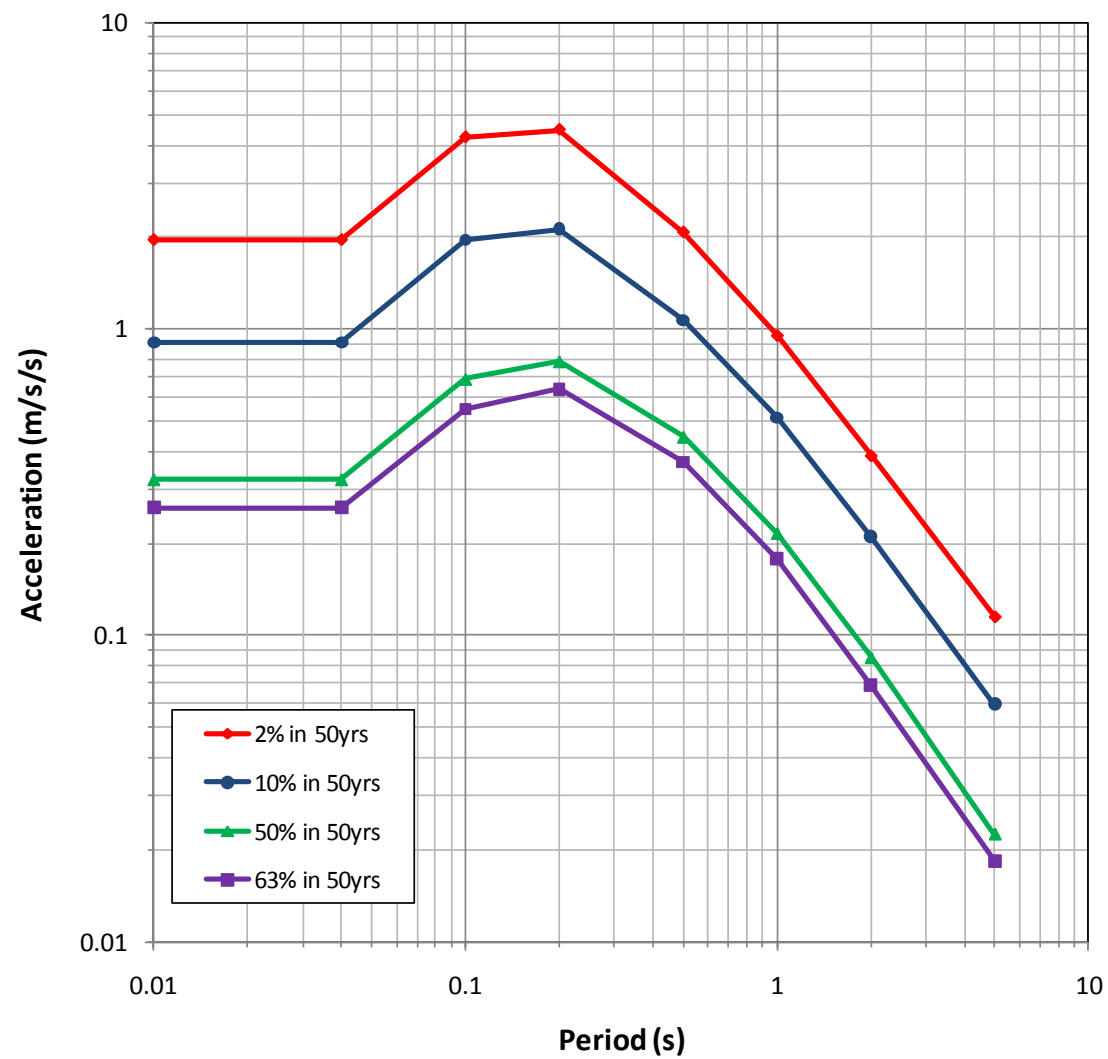


Figure 5.1 Horizontal Acceleration Response Spectra for Rock Sites

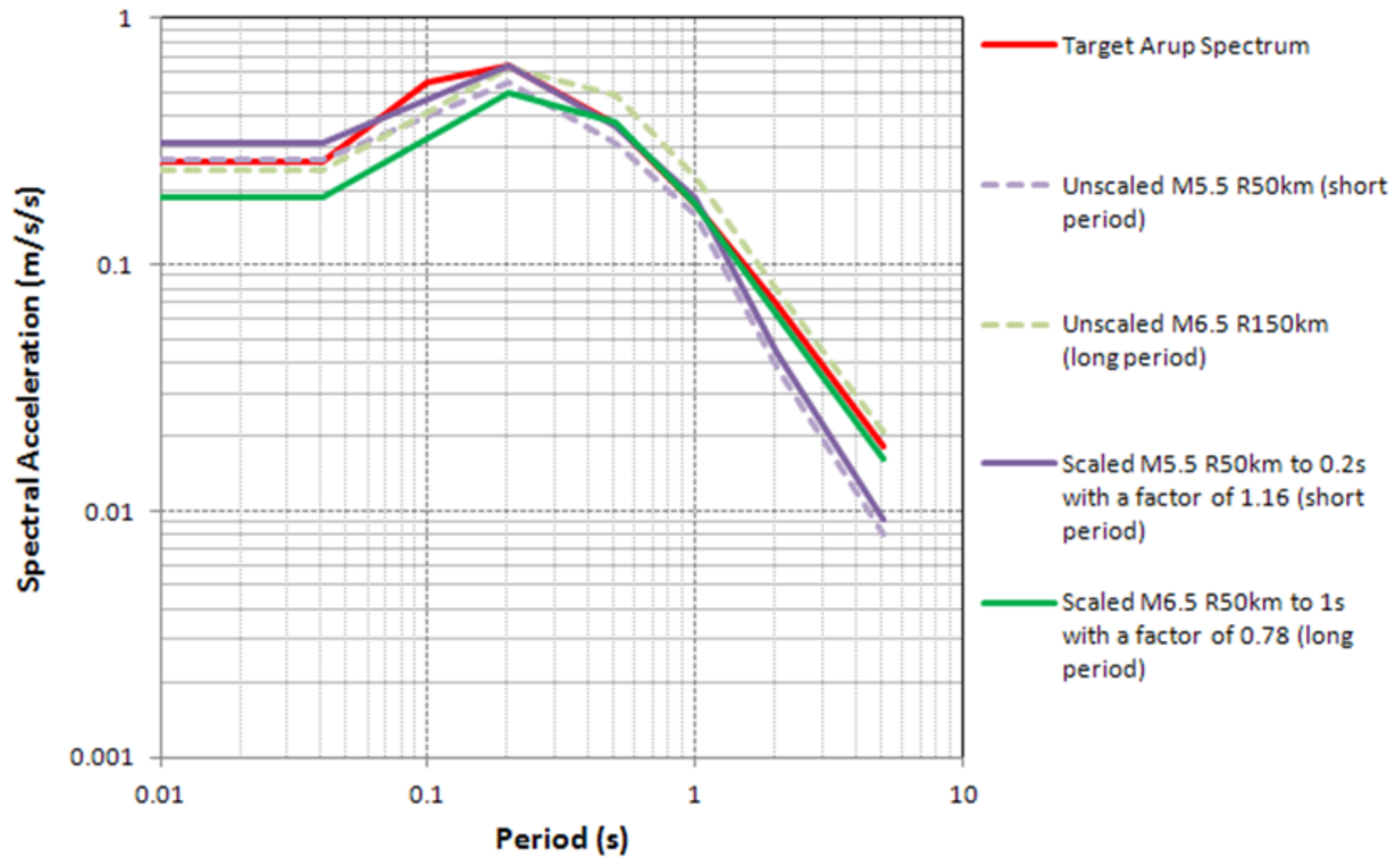


Figure 5.2 Scenario Response Spectra for 63% in the Next 50 Years Ground Motion



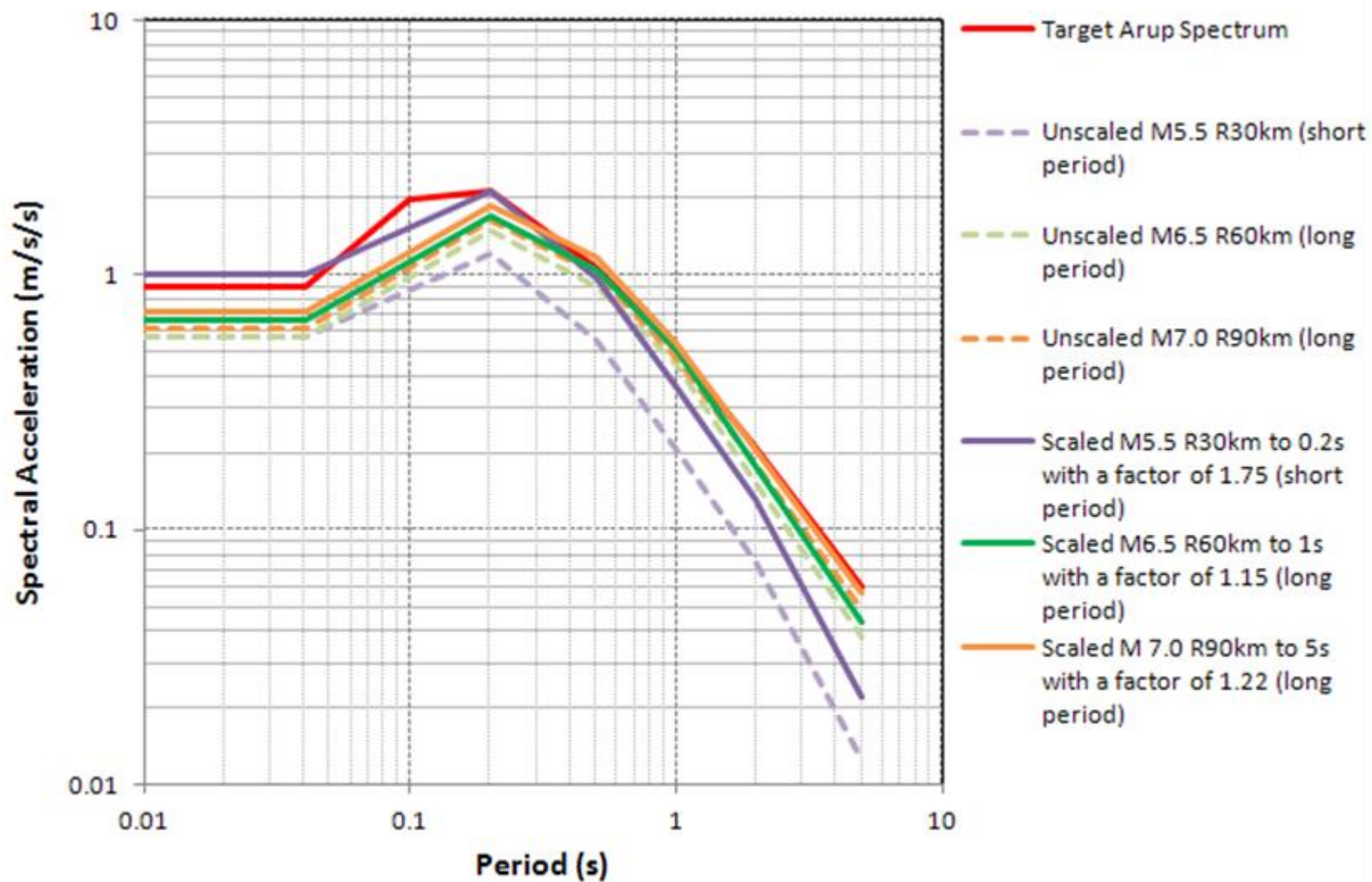


Figure 5.3 Scenario Response Spectra for 10% in the Next 50 Years Ground Motion

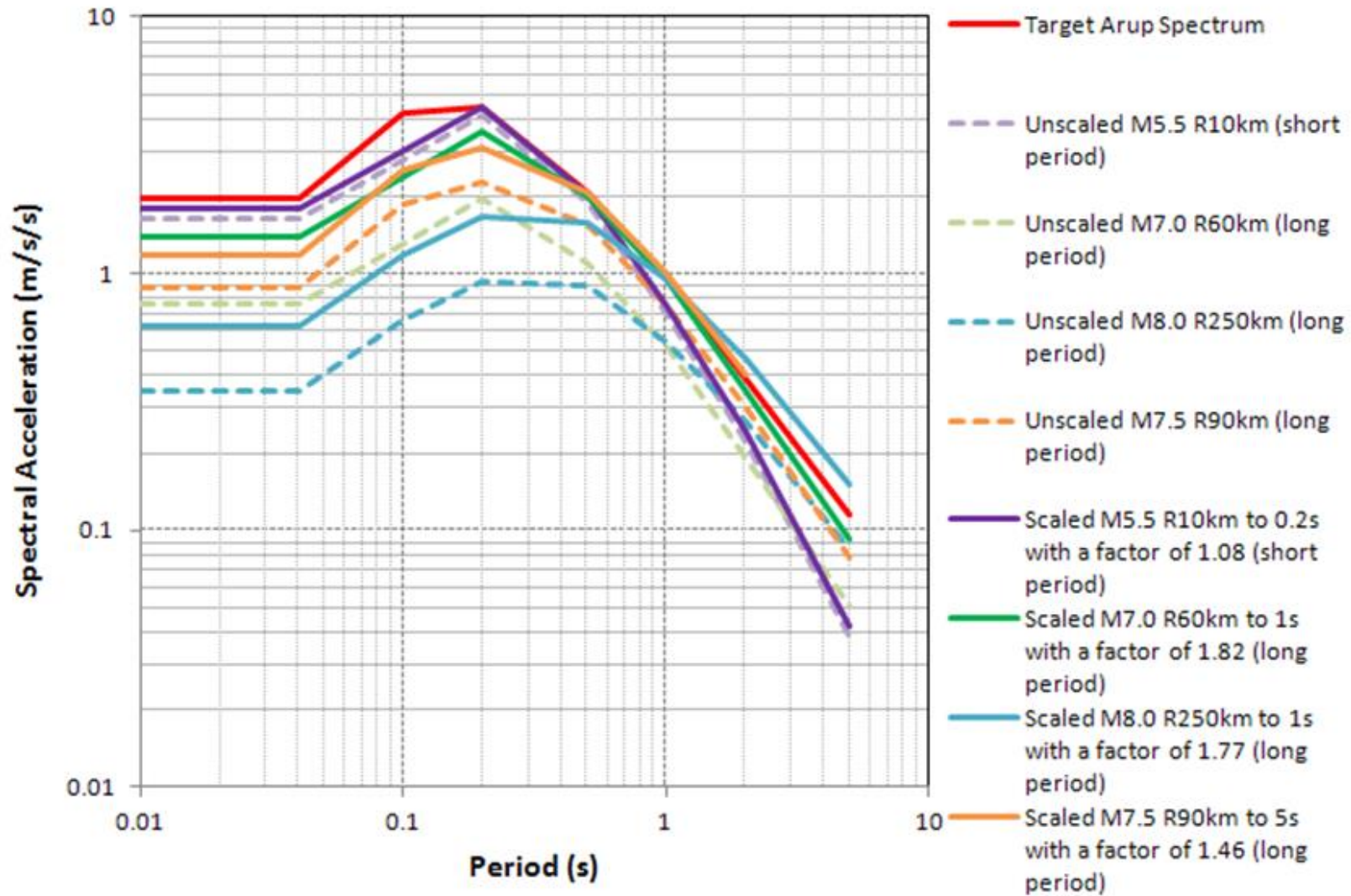


Figure 5.4 Scenario Response Spectra for 2% in the Next 50 Years Ground Motion

The following selection criteria have been considered:

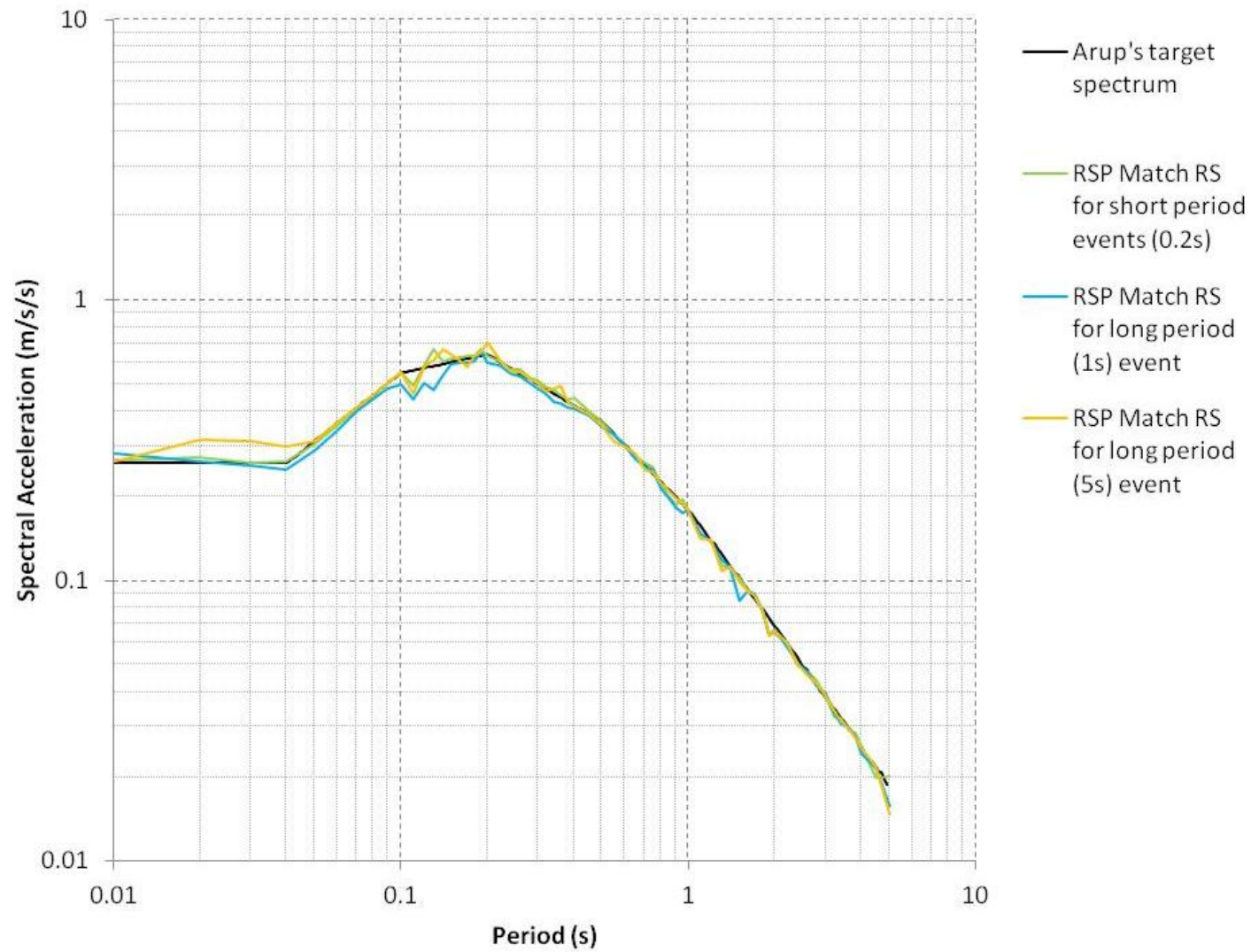
- (a) Magnitude and distance pair similar to the de-aggregated combinations.
- (b) Minimum scaling required to match the amplitude of the target spectral shape.
- (c) Time-histories recorded at rock sites.

Table 5.2 shows three selected bedrock time histories that have been obtained from the Pacific Earthquake Engineering Research (PEER) strong motion database to represent each ground motion of having 63%, 10% and 2% probabilities of being exceeded in the next 50 years for Hong Kong. Since the current PEER earthquake database is only available for earthquake less than 200 km, ground motions of distant earthquake with a moment magnitude of 8 and a distance of 250 km have been artificially generated from the theoretical HKU-Arup attenuation model (Lam et al, 2000; Chandler et al, 2006).

Figures 5.5 to 5.7 show the spectrally matched target response spectra using the RSPMATCH method for 63%, 10% and 2% in 50 years respectively. The generated time histories are shown in Figures 5.8 to 5.10.

**Table 5.2 List of Selected Rock Time History Records**

| Source from PEER Strong Motion Database | Earthquake Event      | Date       | Magnitude | Closest Distance to Surface Projection of Rupture (km) | Target Period for <i>M-R</i> Combinations (Refer to Table 5.1) | Target Level Probability of the Ground Motion in 50 years |
|-----------------------------------------|-----------------------|------------|-----------|--------------------------------------------------------|----------------------------------------------------------------|-----------------------------------------------------------|
| NGA2245                                 | Chi-Chi-Taiwan-02     | 1999-09-20 | 5.9       | 54                                                     | 0.2 s                                                          | 63%                                                       |
| NGA3137                                 | Chi-Chi-Taiwan-05     | 1999-09-22 | 6.2       | 135                                                    | 1 s                                                            |                                                           |
| NGA3130                                 | Chi-Chi-Taiwan-05     | 1999-09-22 | 6.2       | 136                                                    | 5 s                                                            |                                                           |
| NGA210                                  | Livermore-01          | 1980-01-24 | 5.8       | 30                                                     | 0.2 s                                                          | 10%                                                       |
| NGA3171                                 | Chi-Chi-Taiwan-05     | 1999-09-22 | 6.2       | 63                                                     | 1 s                                                            |                                                           |
| NGA1112                                 | Kobe, Japan           | 1995-01-16 | 6.9       | 100                                                    | 5 s                                                            |                                                           |
| NGA133                                  | Friuli-Italy-02       | 1976-09-15 | 5.9       | 14                                                     | 0.2 s                                                          | 2%                                                        |
| NGA734                                  | Loma Prieta           | 1989-10-18 | 6.9       | 53                                                     | 1 s                                                            |                                                           |
| Arup-HKU                                | Shantou (theoretical) | -          | 8.0       | 250                                                    | 1 s                                                            |                                                           |
| NGA1392                                 | Chi-Chi-Taiwan        | 1999-09-20 | 7.6       | 87                                                     | 5 s                                                            |                                                           |



**Figure 5.5 Spectra for 63% in the Next 50 Years Ground Motion**

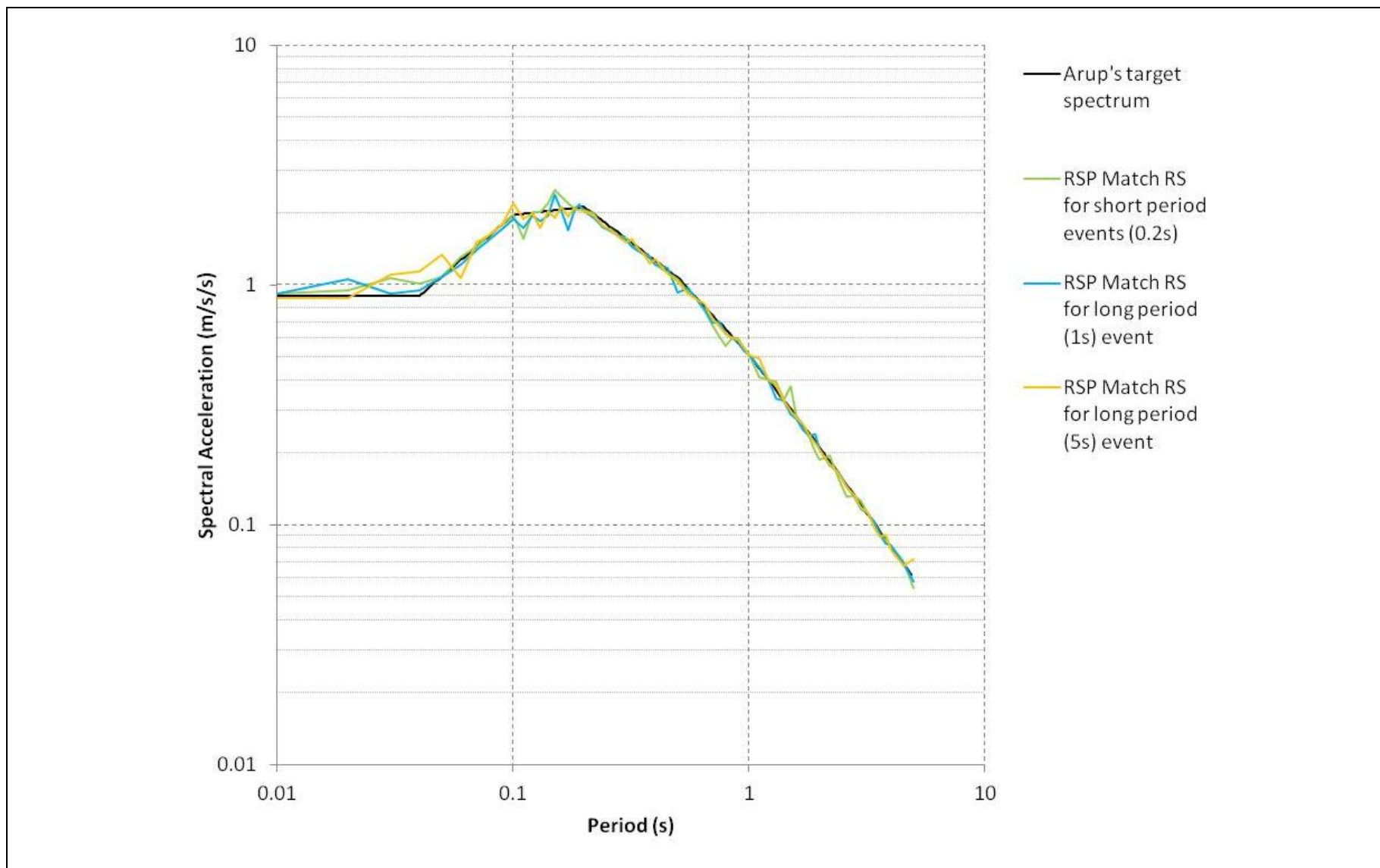


Figure 5.6 Spectra for 10% in the Next 50 Years Ground Motion



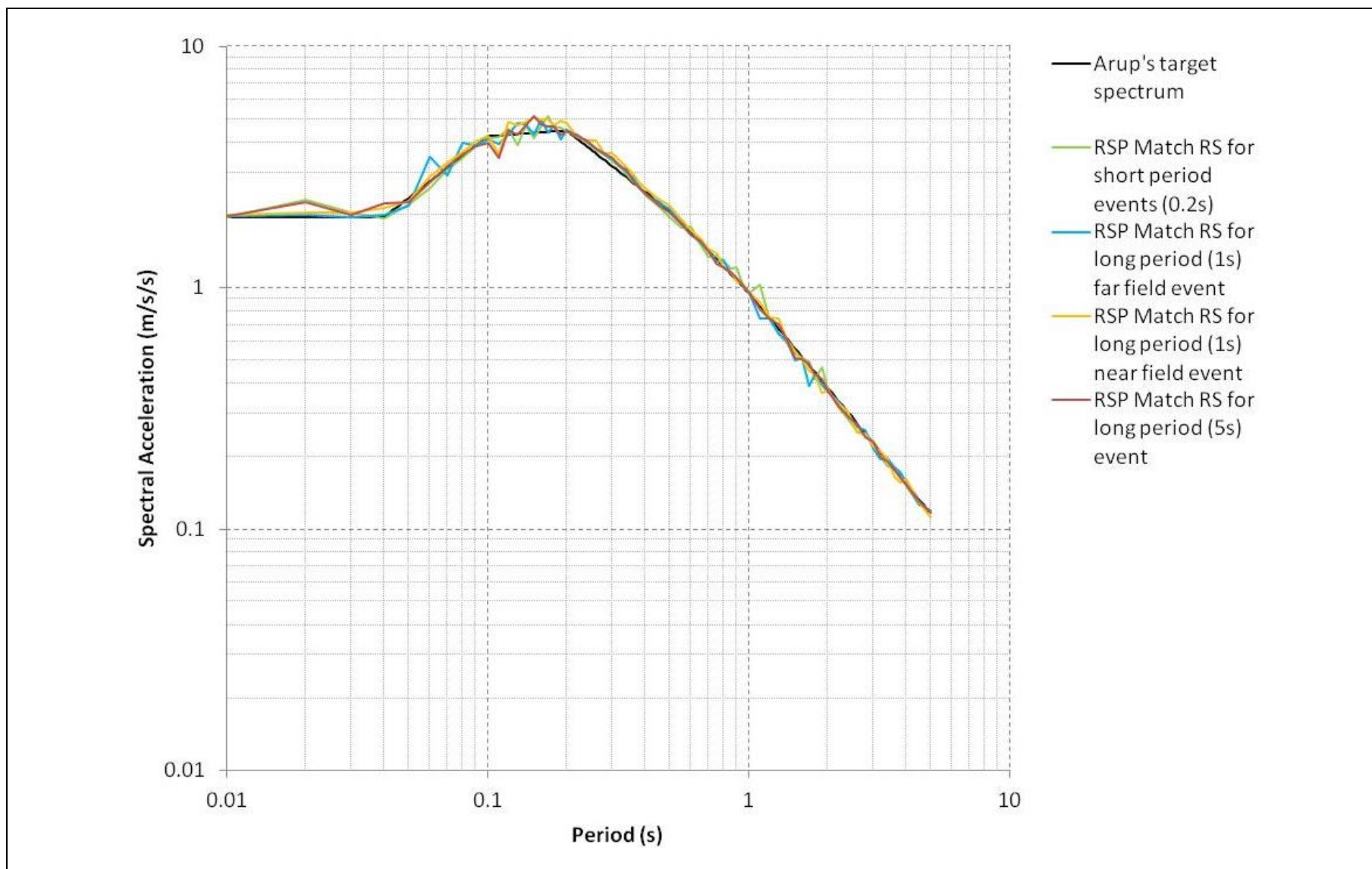
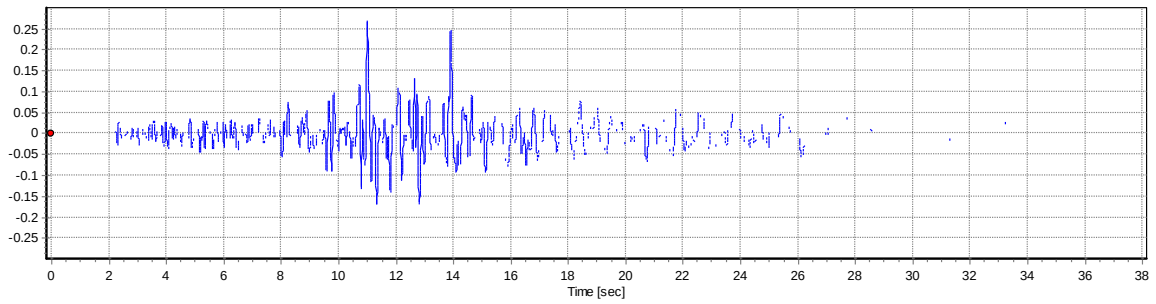
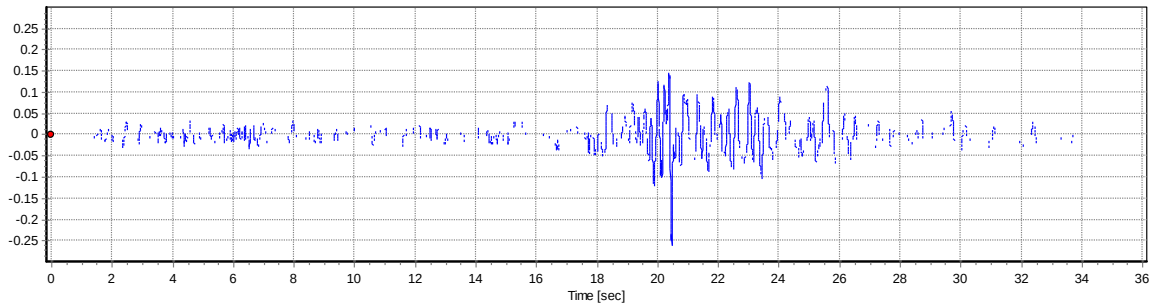


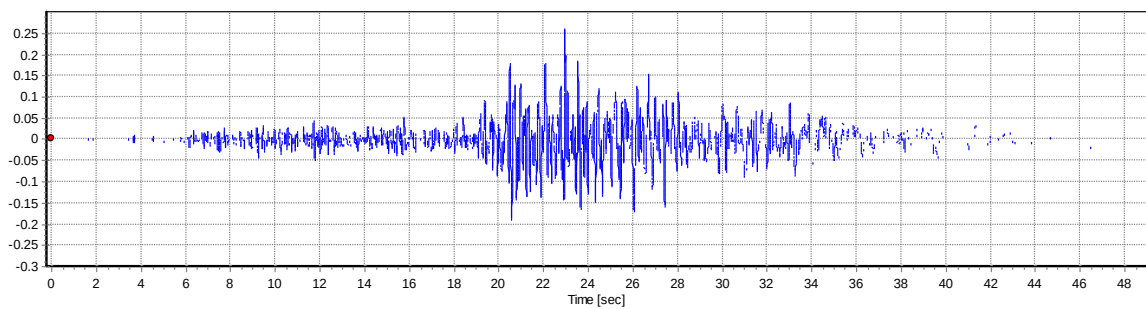
Figure 5.7 Spectra for 2% in the Next 50 Years Ground Motion



Short period motion (0.2 s)

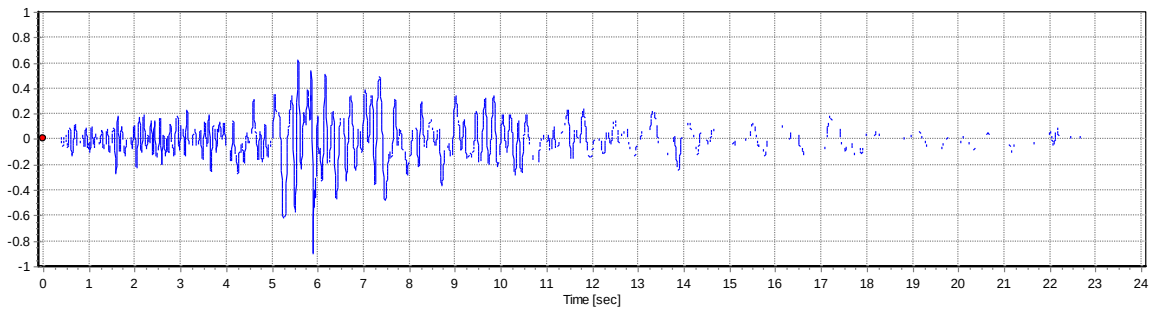


Long period motion (1 s)

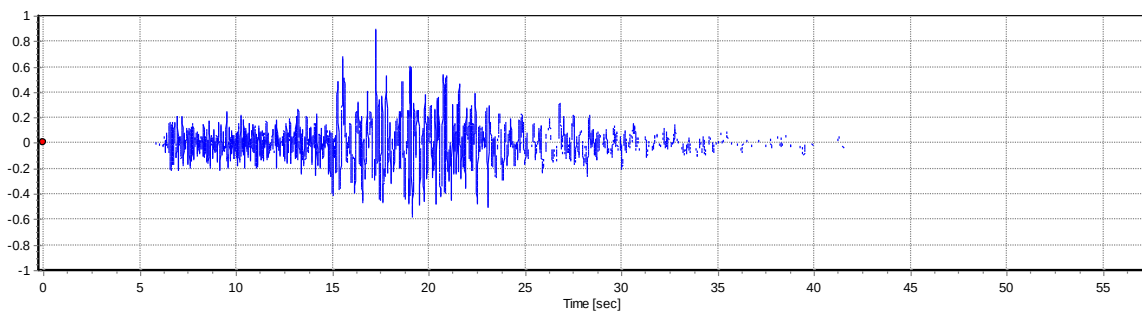


Long period motion (5 s)

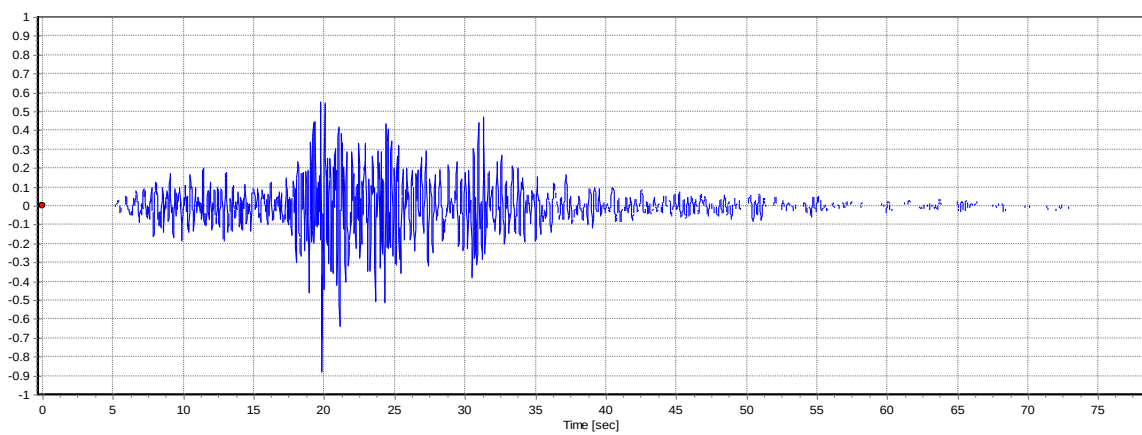
**Figure 5.8 Spectrally Matched Rock Input Time Histories for 63% in the Next 50 Years Ground Motion**



Short period motion (0.2 s)



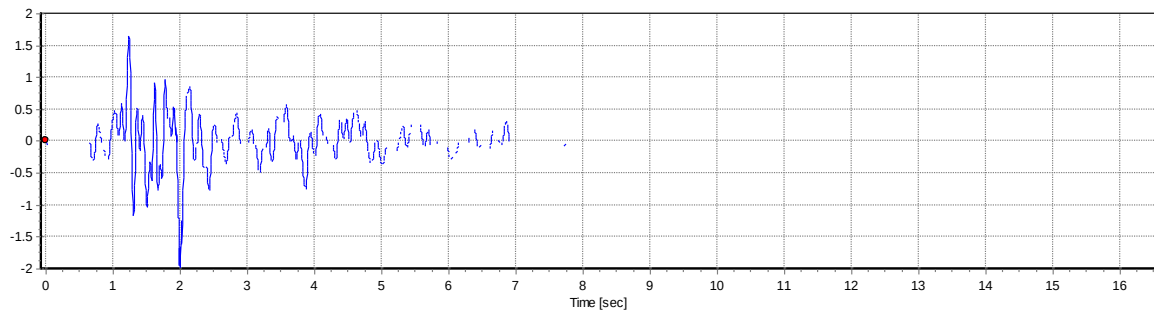
Long period motion (1 s)



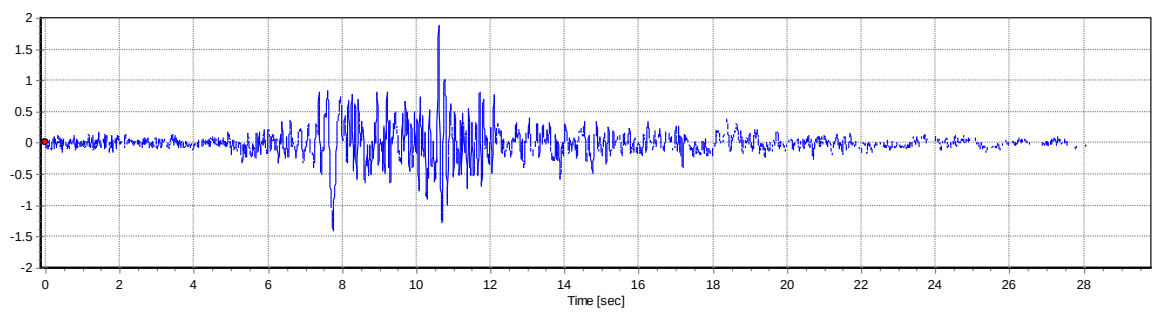
Long period motion (5 s)

**Figure 5.9 Spectrally Matched Rock Input Time Histories for 10% in the Next 50 Years Ground Motion**

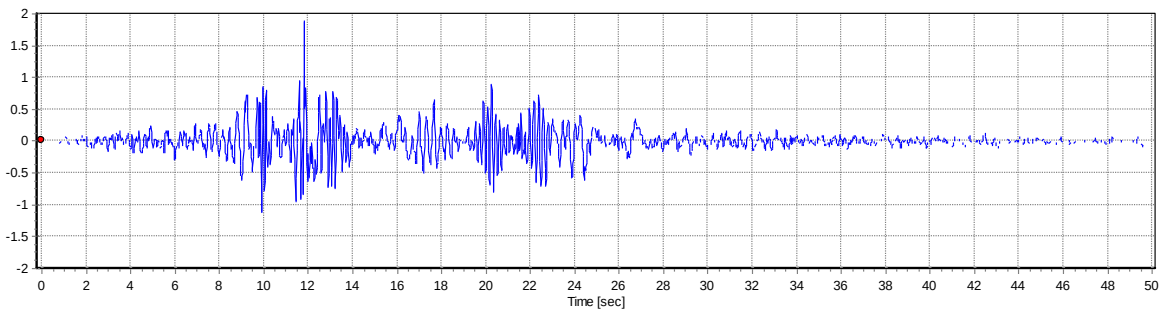




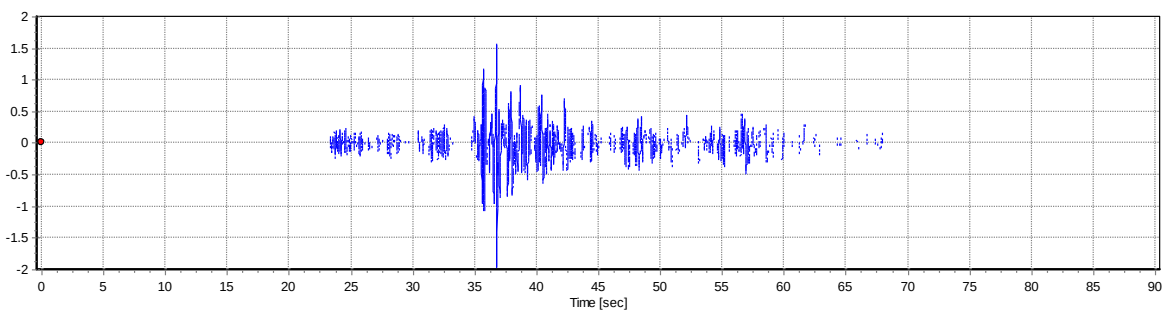
Short period motion (0.2 s)



Long period motion (1 s)



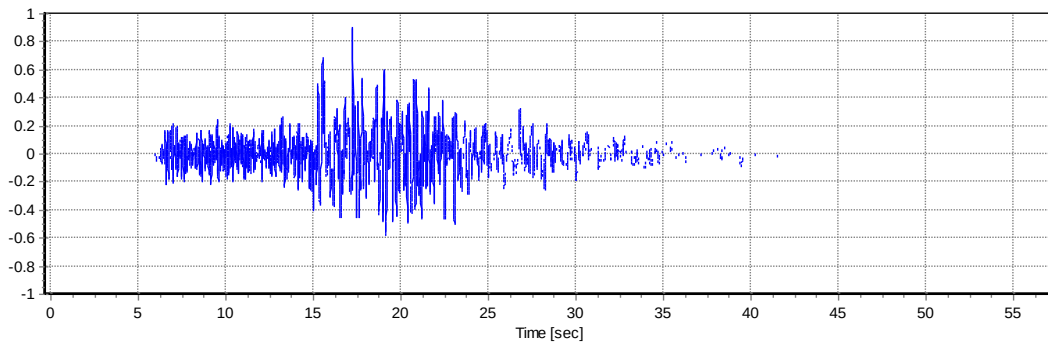
Long period motion (5 s)



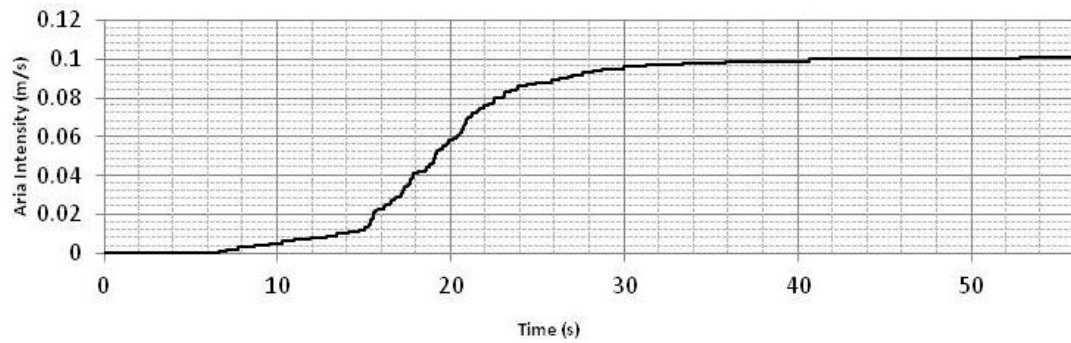
**Figure 5.10 Spectrally Matched Rock Input Time Histories for 2% in the Next 50 Years Ground Motion**

### 5.3 GEERRI Time History Selection

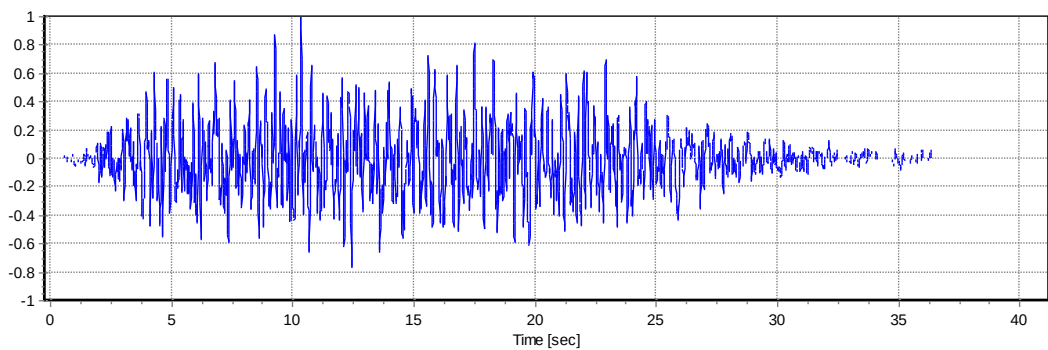
GEERRI generated rock input time histories using artificial Green's function simulations to produce a tri-linear shape of time history in order to spectrally match the target spectrum in the frequency-domain (see Appendix E). The Green's function is used to solve inhomogeneous differential equations subject to specific initial conditions or boundary conditions. The shortcoming of this artificial method is that the time history is not generated based on the characteristics of any real records, as discussed in Section 5.2. Also, the distinct characteristics of individual frequency and energy content of a real earthquake cannot be represented. Figure 5.11 shows a comparison of Arias Intensity (cumulative square of acceleration against time) between the 10% in the next 50 years time histories generated by Arup and GEERRI. It shows that the energy content of the real time history generated by Arup increases more rapidly when the main shear wave arrives and then quickly reduces. However, that of the artificial time history generated by GEERRI linearly increases with time, which is not representing a real characteristic of the earthquake energy content.



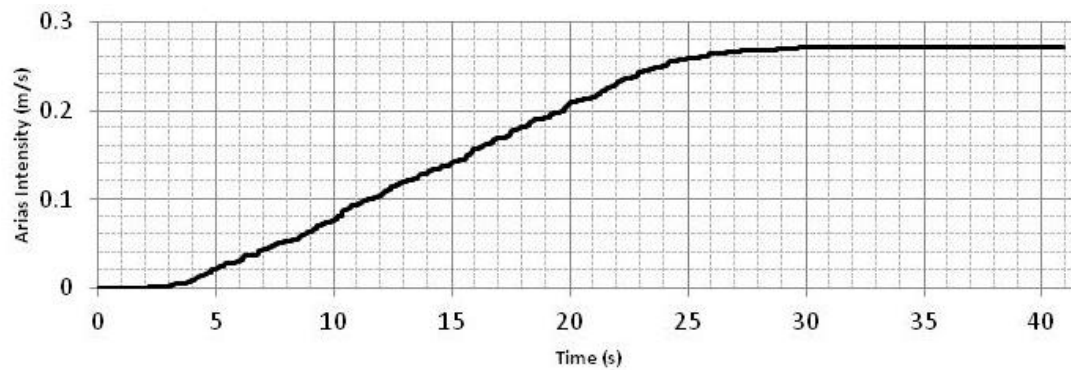
Arup acceleration time history (10% in 50 years ground motion, 1 s)



Arias Intensity curve for Arup time history (10% in 50 years ground motion, 1 s)



GEERRI acceleration time history TH1 (10% in 50 years ground motion)



Arias Intensity curve for GEERRI time history TH1 (10% in 50 years)

**Figure 5.11 Comparison of Arias Intensity for Rock Time History between Arup and GEERRI for 10% in the Next 50 Years Ground Motion**

## 6 Site Response Analyses

### 6.1 General

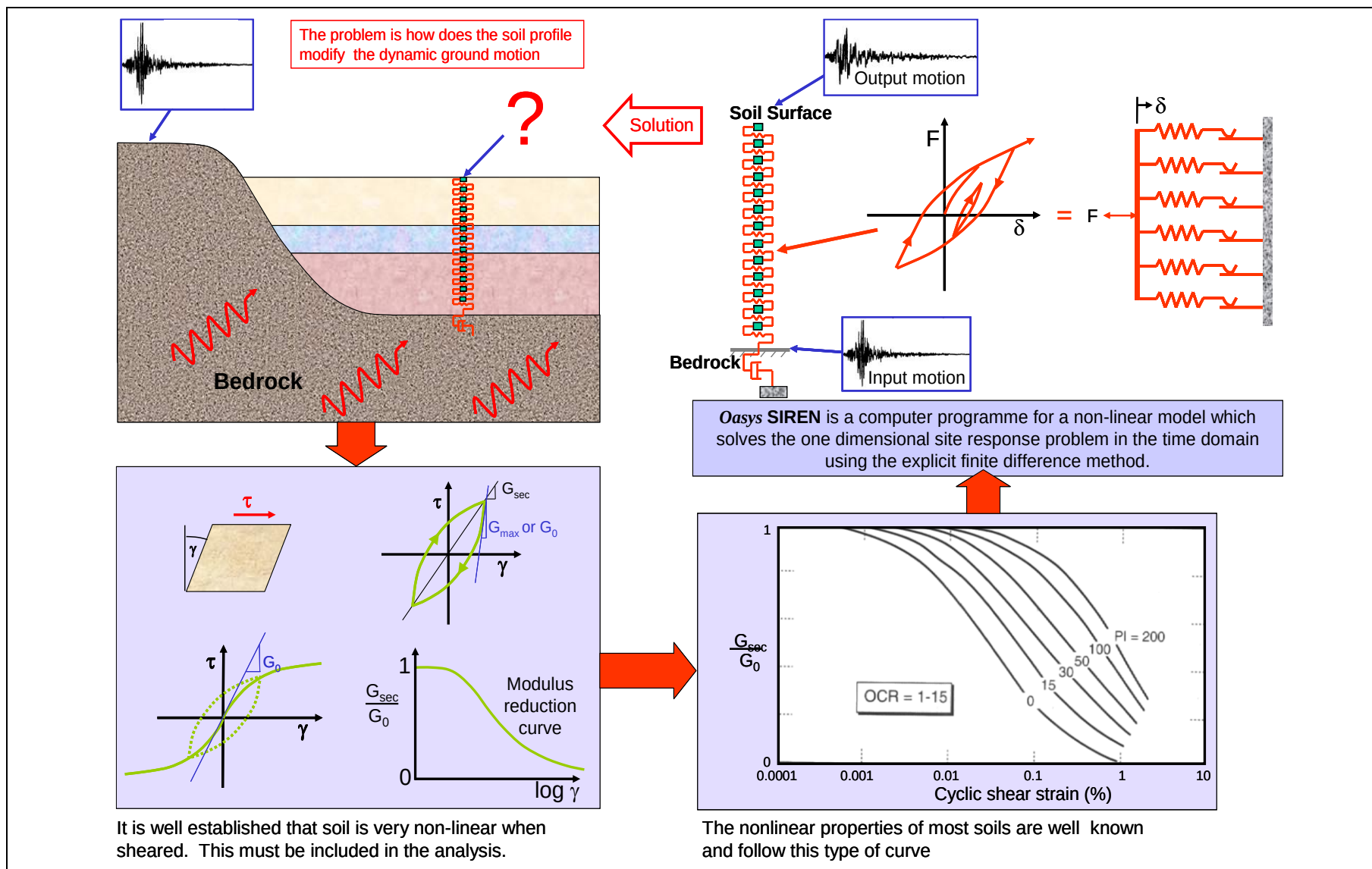
Although earthquake site response analyses have been carried out previously for a number of specific sites in Hong Kong, there are no existing recommendations for design soil response spectrum that can be applied throughout Hong Kong for the purpose of regional site classification. In order to better understand the potential regional earthquake-induced soil amplification trends in the Study Area, a series of one-dimensional site response analyses have been undertaken for all 27 boreholes with in-situ shear wave velocity measurements. These results have been used to determine the ground motion amplitude and period-dependent factors for various Site Classes in microzonation. These factors are specific for the ground conditions in the North-west New Territories and can be applied systematically across this Study Area.

### 6.2 Arup Methodology

The site response analysis methodology is illustrated in Figure 6.1 and involves the following stages:

- (a) Define the profiles of each borehole in terms of soil types and profiles of small-strain shear modulus versus depth based on the measured in-situ shear wave velocity (see Section 2). In each case, the profile extends into bedrock.
- (b) Derive the shear modulus degradation curves, which represent the reduction of shear modulus with increasing shear strain, for each soil type based on the laboratory testing results (see Section 3).
- (c) Define the appropriate earthquake acceleration time-histories from the bedrock spectra of Arup (2015) for input into the site response analyses (see Section 5).
- (d) Carry out one-dimensional site response analyses using the program *Oasys SIREN*.
- (e) Determine spectral ratios (output response/input response) from the analyses for a suite of soil profiles.
- (f) Determine the design surface response spectra by multiplying the bedrock response spectra by the amplitude-dependent spectral ratios for a range of periods.

The program *Oasys SIREN* has been used to perform the calculations for the site response analyses. It is a finite difference program analysing the response of a one-dimensional soil column subjected to an earthquake motion at its base. The earthquake ground motion is modelled as vertically propagating shear waves. The soil column is specified as a series of horizontal layers, each layer being modelled as a non-linear material with hysteretic



**Figure 6.1 Methodology of Site Response Analysis**

damping. The soil damping is derived as a function of the shear modulus degradation curve. Detailed calibration analyses by *Oasys SIREN* can be found in Henderson et al (1990) and Heidebrecht et al (1990). Theoretically, the soil model used in *Oasys SIREN* can more accurately reflect the actual hysteretic soil behaviour in comparison to the pseudo-non-linear soil models used in other site response analysis programs e.g. SHAKE (Schnabel et al, 1972) and EERA (2000) developed in the United States.

The maximum shear stress at each soil layer is also generated by *Oasys SIREN* and can be used for the study of liquefaction analysis (see Section 8).

### 6.3 GEERRI Methodology

GEERRI has carried out independent site response analyses using their computer program ESE (2005), which has been developed and approved by the China Earthquake Administration. The results have been checked by Arup. The program performs one-dimensional site response analysis and assumes that the cyclic soil behaviour can be simulated using an equivalent linear model. A vertical harmonic shear wave propagates in a one-dimensional layered system. The basic concept is the same as SHAKE (Schnabel et al, 1972) and EERA (2000).

The “equivalent-linear” method adopted by GEERRI is commonly used in earthquake engineering for modelling wave transmission in layered sites and dynamic soil-structure interaction. On the contrary, the fully non-linear method embodied in *Oasys SIREN* is less commonly used. As such, it is worth discussing some differences between the two methods as follows.

In the equivalent-linear method, a linear analysis is performed, with some initial values assumed for damping ratios and shear moduli in various layers of the model. The maximum cyclic shear strain is recorded for each layer and a fraction of it (0.65 in GEERRI’s case) is used to determine new values for damping ratios and shear moduli. It is done by making reference to the laboratory-derived curves that relate damping ratios and secant moduli to the amplitude of cycling shear strain. GEERRI adopted the same derived  $G/G_0$  curves developed by Arup (see Section 3). The whole process is repeated several times until there is no further change in the material properties. At this point, the “strain-compatible” values of damping and modulus are found, and the simulation using these values is representative of the response of a real site. Details of GEERRI’s analyses are presented in Appendix E.

In *Oasys SIREN*, a single analysis is undertaken using a fully non-linear method, because non-linearity in the stress-strain law is followed directly by each element as the solution marches on in time. Provided that an appropriate non-linear law is used, the dependence of damping and apparent modulus on strain level is automatically modelled. This fully non-linear method correctly represents the physics and real soil hysteresis curves as well as the energy-absorbing characteristics under earthquake excitation. When subject to a large earthquake excitation, *Oasys SIREN* should calculate a more realistic result than that from an equivalent-linear program, such as ESE (2005). However, for the relatively small level of earthquake ground motions in Hong Kong, the use of non-linear time-domain or equivalent linear frequency-domain programs should not result in a significant difference.

## 6.4 Comparison with GEERRI Site Response Results

GEERRI has used the average rock response spectra between that adopted by Arup and that derived from their previous seismic hazard study (Arup, 2015) as shown in Figure 6.2 as the input target rock response spectra. The soil design parameters presented in Sections 3 and 4 have also been used by GEERRI in their site response analyses. The resulted ground surface response spectrum output for each borehole for ground motions having 63%, 10% and 2% chance of being exceeded in the next 50 years have been presented in their seismic microzonation report as presented in Appendix E.

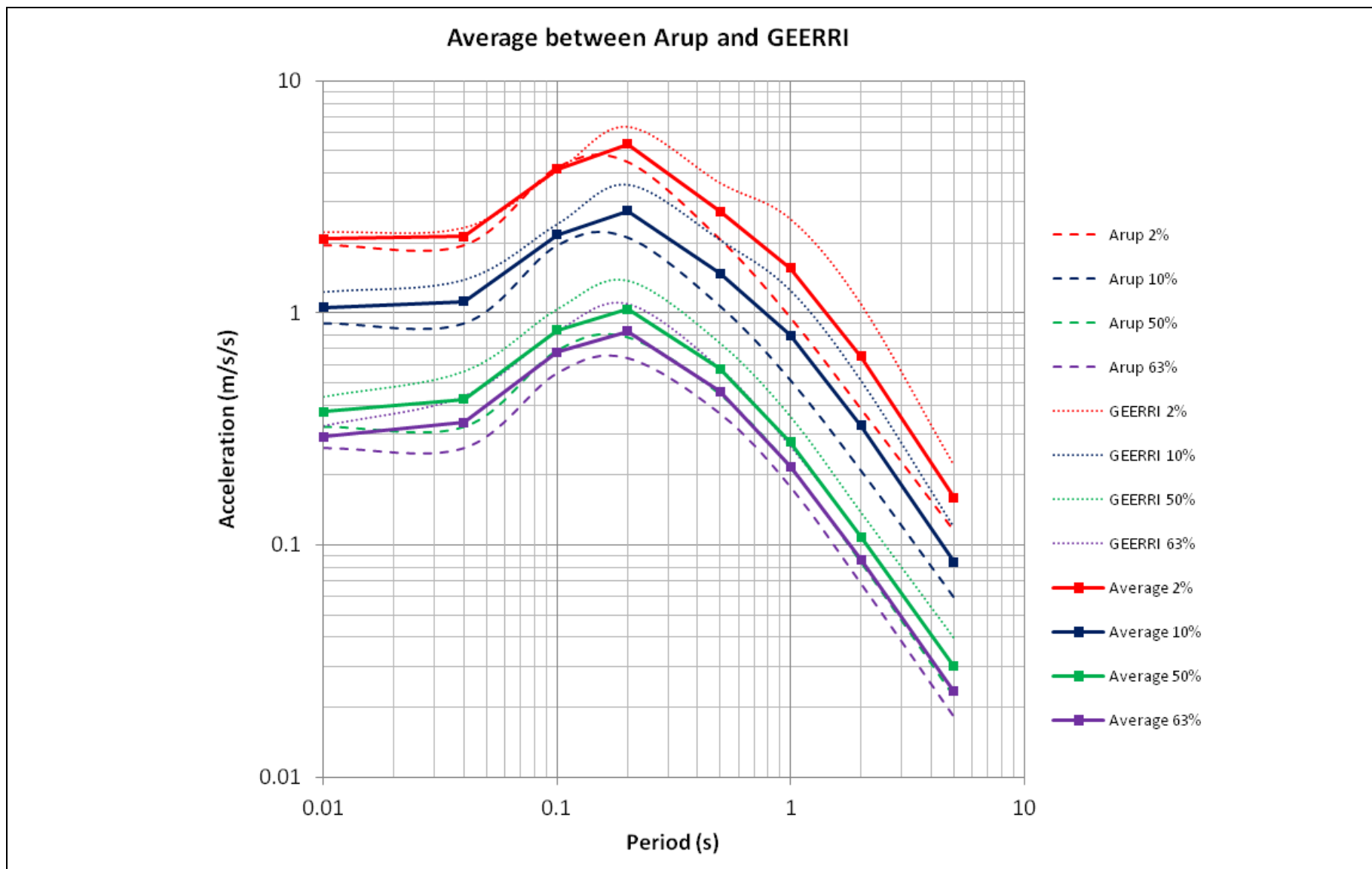
Comparisons of the spectral ratios calculated by Arup and GEERRI are presented in Figures 6.3 to 6.29 for the 10% in the next 50 years ground motion. The comparisons show that the calculated spectra ratios as a function of structural period by Arup and GEERRI are very similar. An exception is BH50, which represents a rock site.

## 6.5 Comparison with Microtremor Results

Microtremor tests at 60 sites have been carried out (see Section 2.4), among which 50 sites are in urban/suburban areas within Tuen Mun, Tin Shui Wai and Yuen Long, and 10 sites are on natural terrain in the West of Leung King Estate, Tuen Mun. This method provides a non-destructive and economic means to determine the dominant period of a site. It uses surface waves generated by ambient environmental disturbances, e.g. traffic, machines, wind, etc., to estimate subsurface soil characteristics.

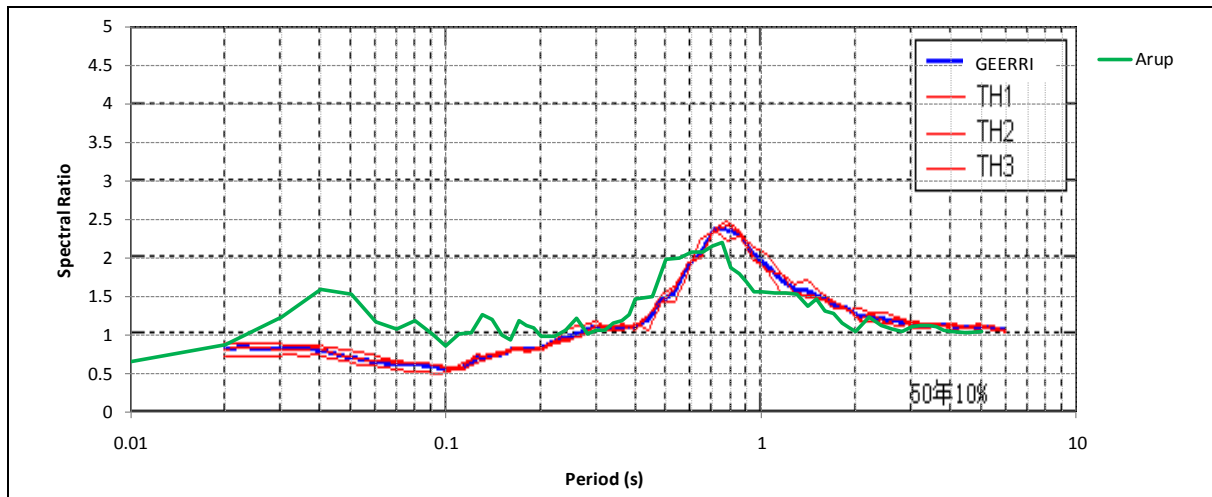
The microtremor method is based on the Nakamura method (Nakamura, 1989). In this method, the dominant site period can be estimated from the period at which the largest  $H/V$  (horizontal/vertical) ratio of the power spectral density occurs. The premise is that the soil layer tends to amplify horizontal ground motion at its dominant period, while vertical motion is not significantly affected by site response effects in a relatively low frequency regime of horizontal resonance.

In order to compare the measured dominant period by microtremor tests with the results of site response analyses by *Oasys* SIREN, the measured vertical acceleration time history has been used as the input motion of site response analysis for each borehole. The output SIREN surface  $H/V$  (horizontal/vertical) ratio of the power spectral density can then be directly compared with the measured results of microtremor tests. The comparisons are shown in Figures 6.30 to 6.56. The results broadly agree with each other. For the sake of completeness, the calculated theoretical site dominant periods as discussed in Section 2.3 for the entire soil profile and for the depth to where SPT-N value is about 100 are also presented in the figures.

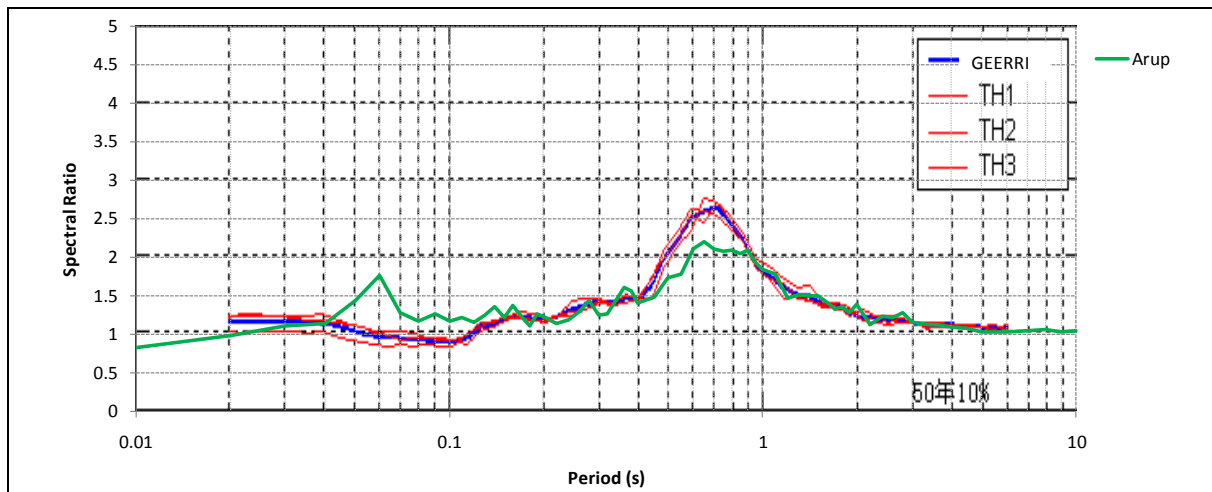


**Figure 6.2 Target Rock Response Spectra Used by GEERRI**

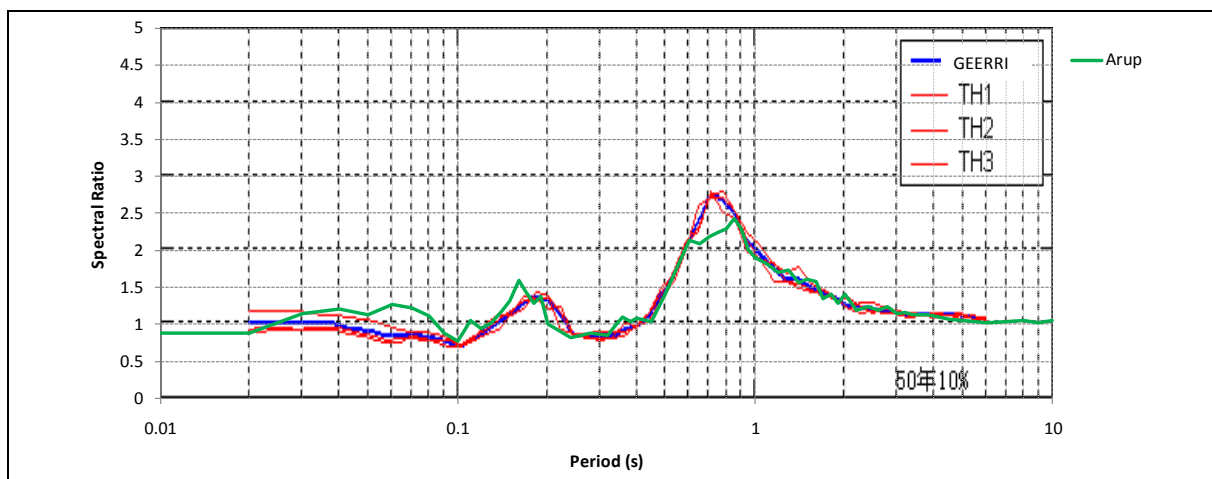




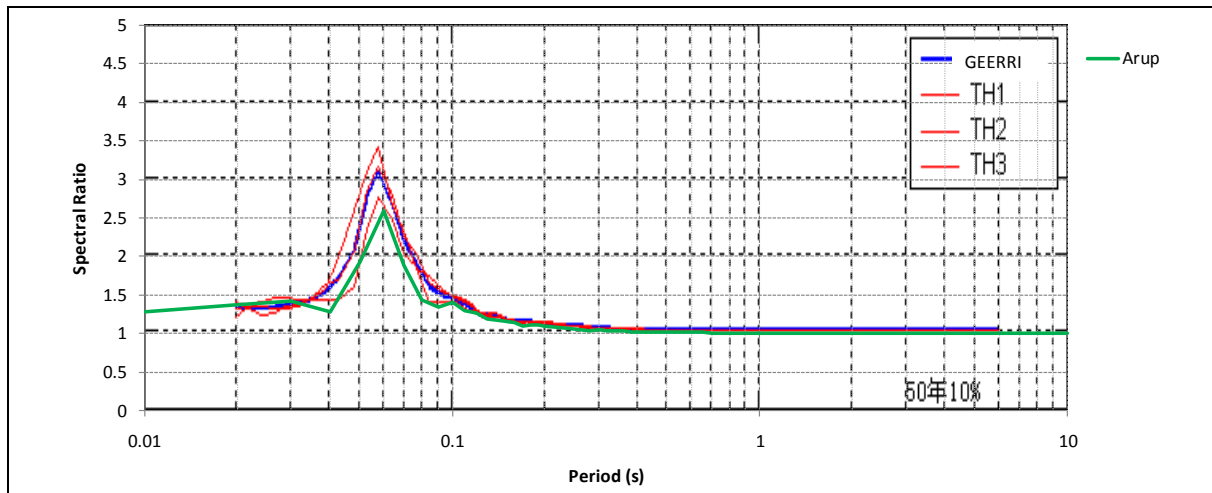
**Figure 6.3 Spectral Ratios for BH01 for 10% in the Next 50 Years Ground Motion**



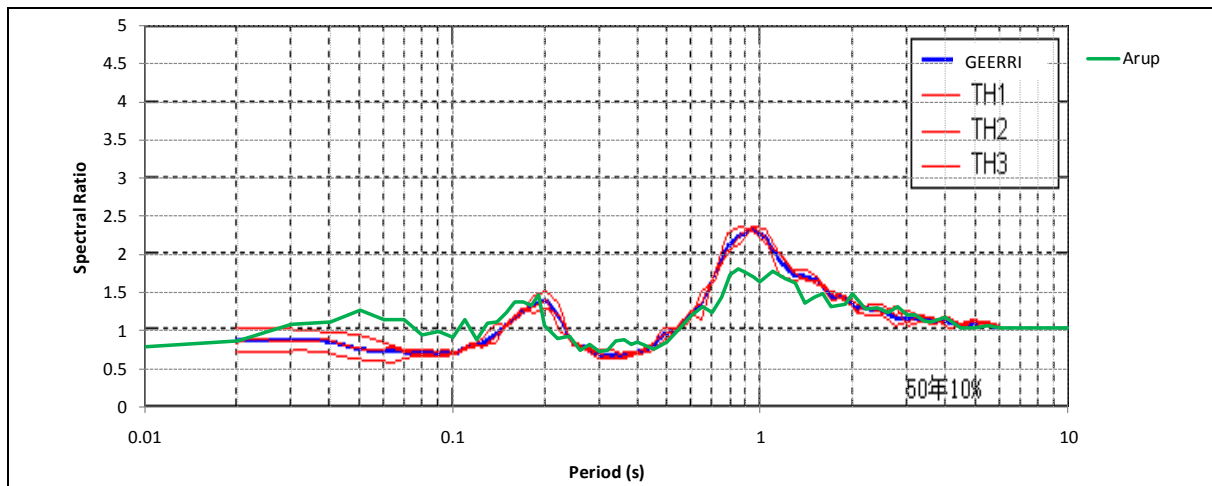
**Figure 6.4 Spectral Ratios for BH02 for 10% in the Next 50 Years Ground Motion**



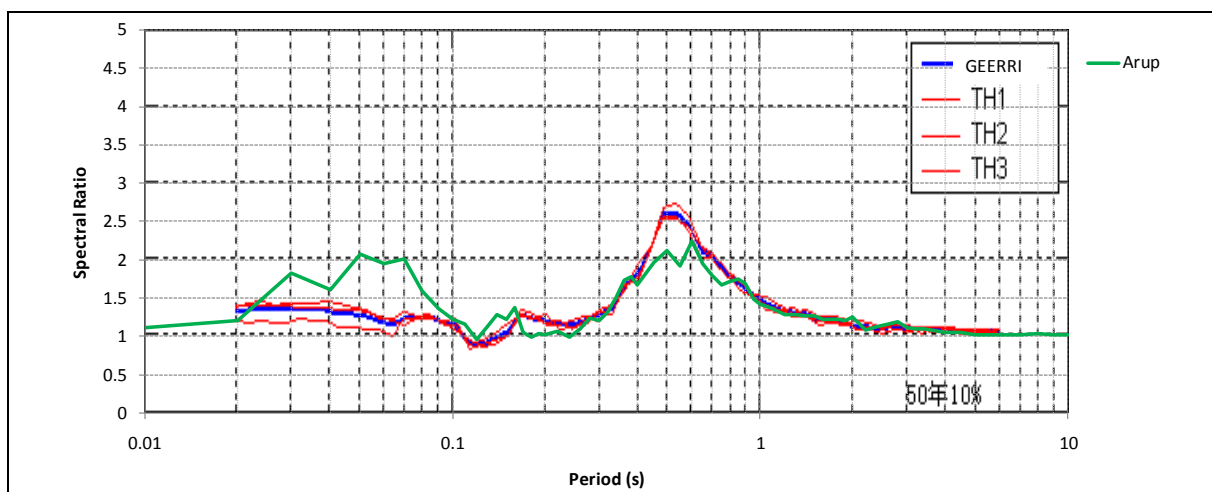
**Figure 6.5 Spectral Ratios for BH08 for 10% in the Next 50 Years Ground Motion**



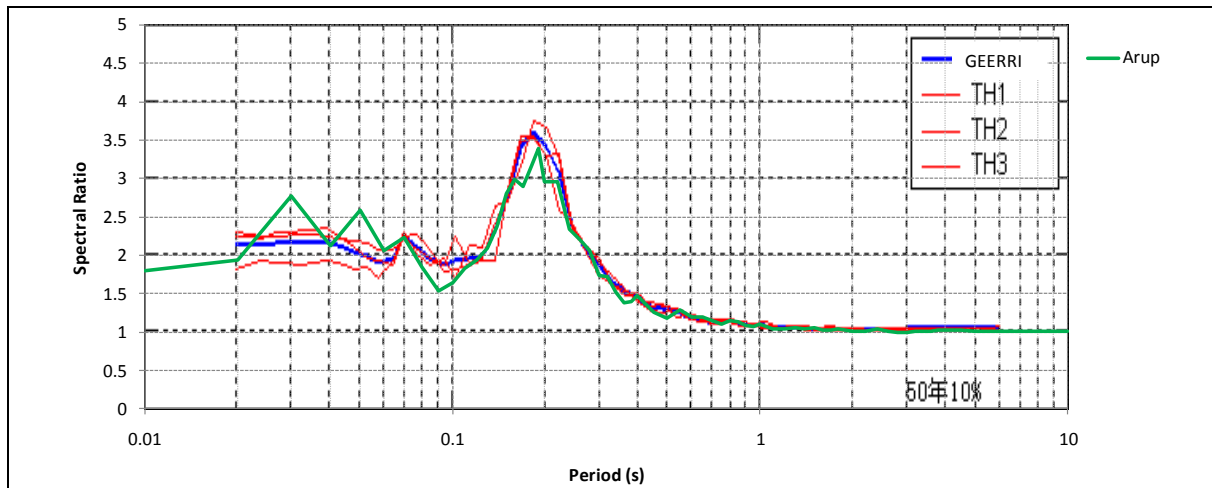
**Figure 6.6 Spectral Ratios for BH12 for 10% in the Next 50 Years Ground Motion**



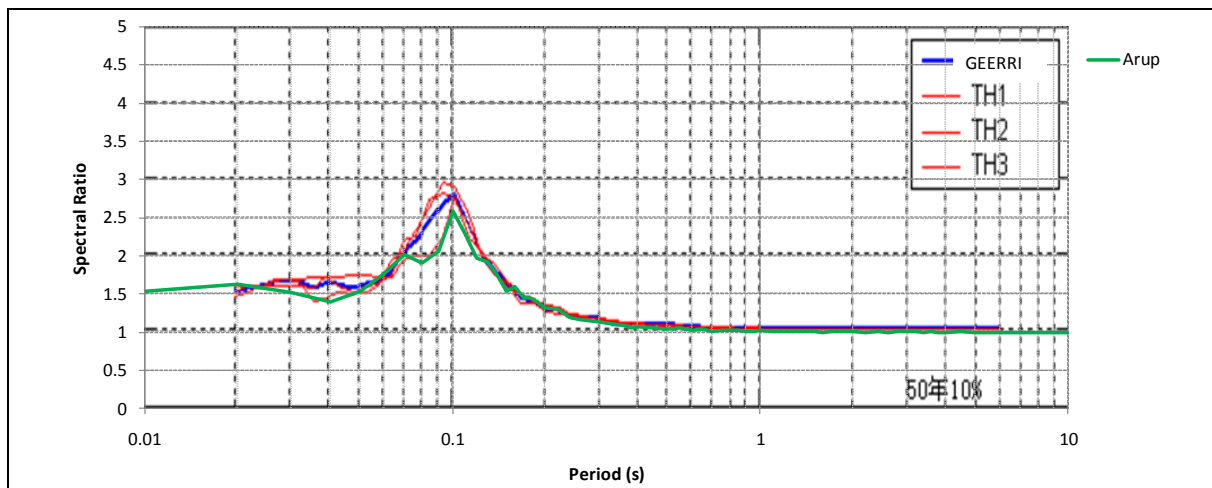
**Figure 6.7 Spectral Ratios for BH13 for 10% in the Next 50 Years Ground Motion**



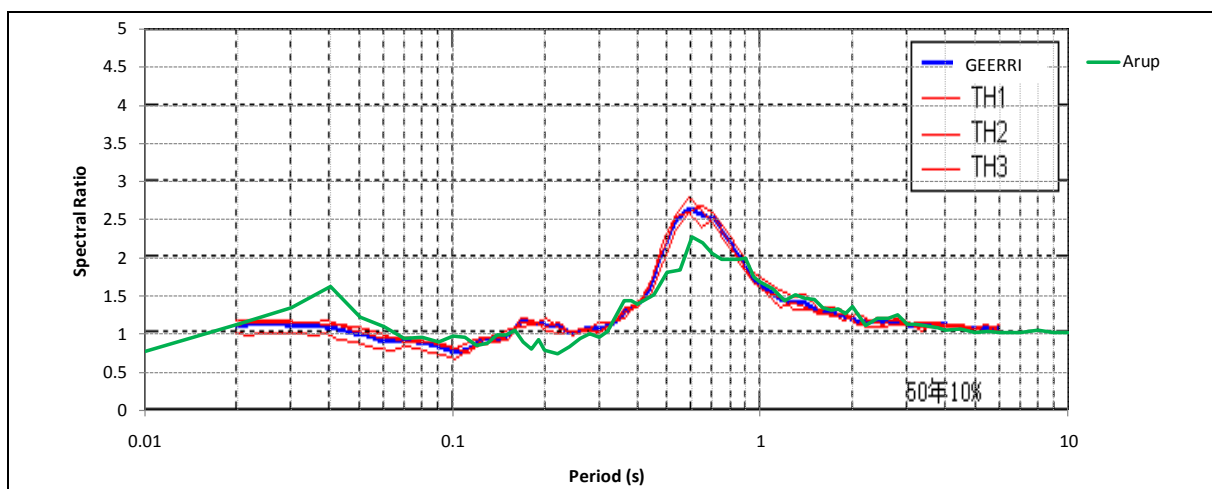
**Figure 6.8 Spectral Ratios for BH14 for 10% in the Next 50 Years Ground Motion**



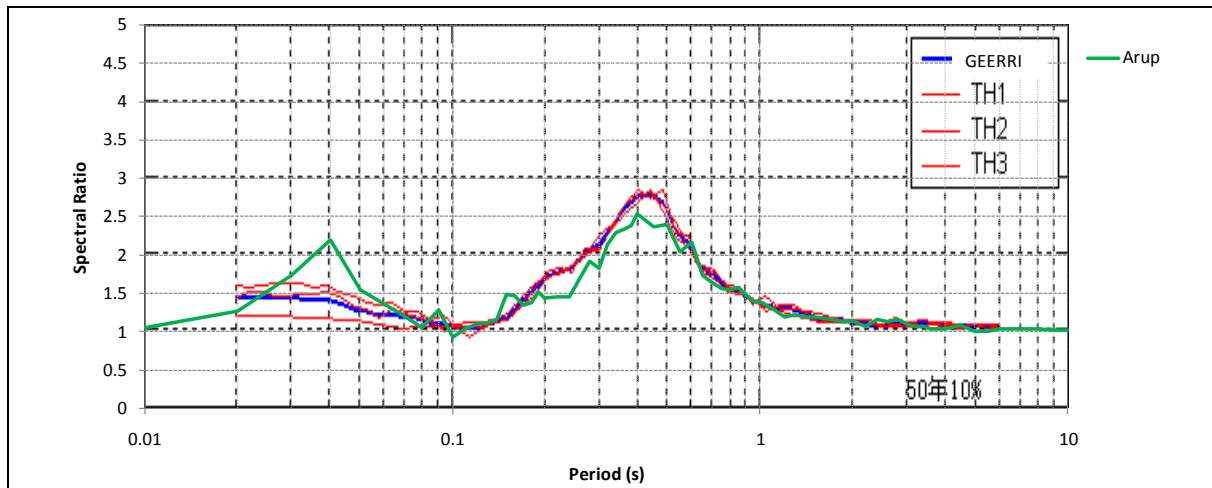
**Figure 6.9 Spectral Ratios for BH15 for 10% in the Next 50 Years Ground Motion**



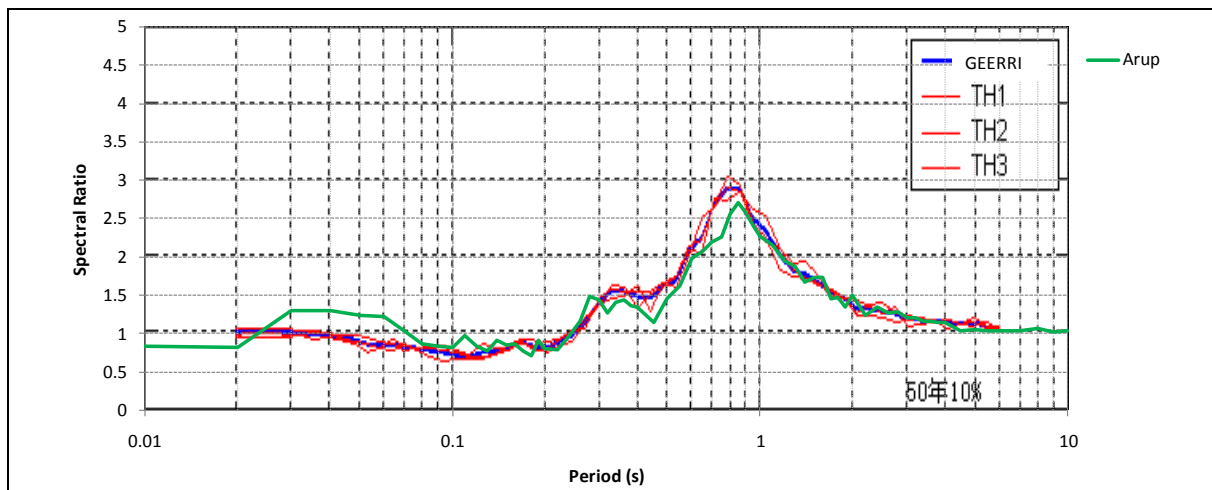
**Figure 6.10 Spectral Ratios for BH16 for 10% in the Next 50 Years Ground Motion**



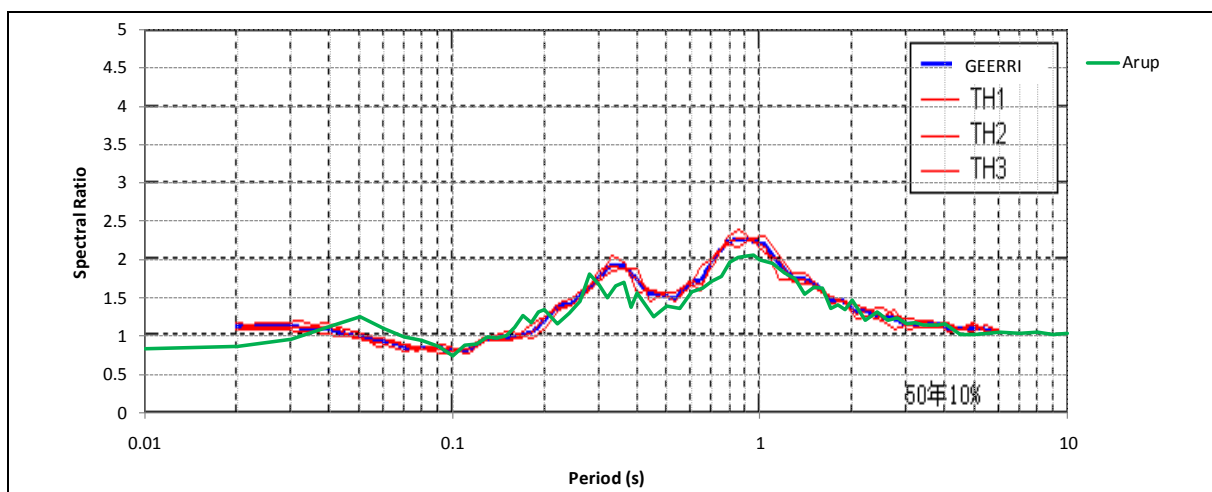
**Figure 6.11 Spectral Ratios for BH20 for 10% in the Next 50 Years Ground Motion**



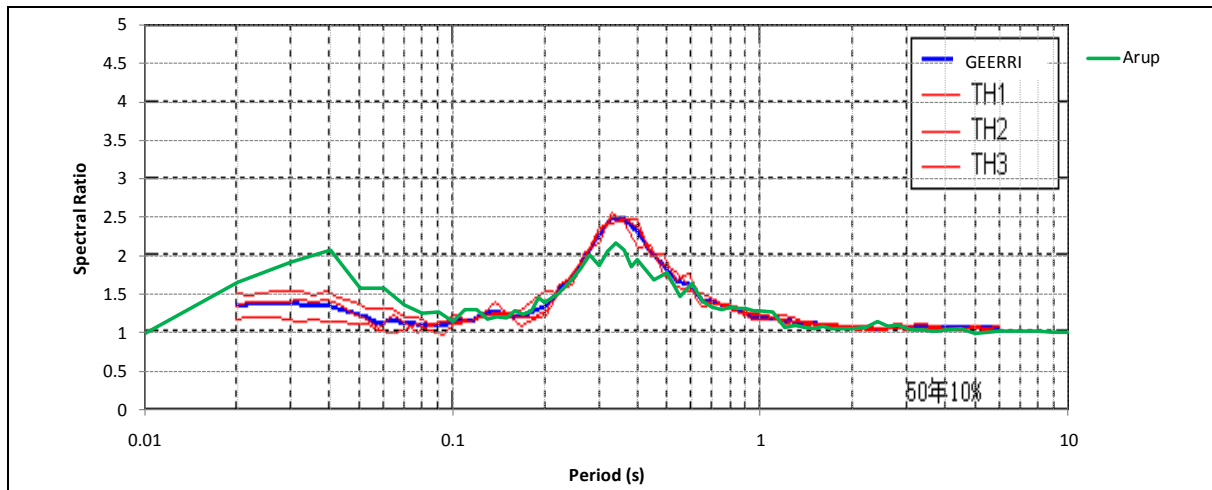
**Figure 6.12 Spectral Ratios for BH21 for 10% in the Next 50 Years Ground Motion**



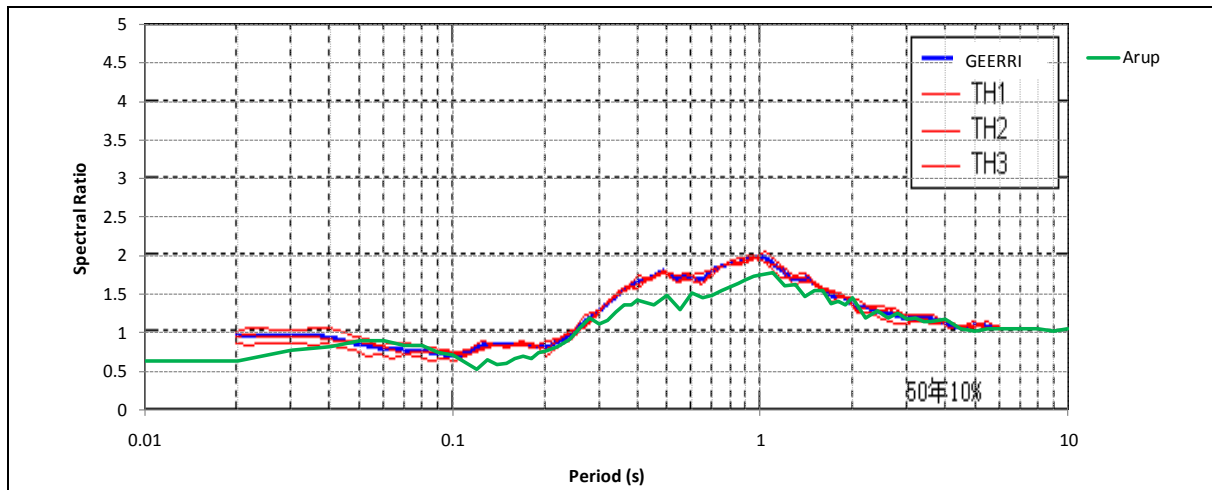
**Figure 6.13 Spectral Ratios for BH22 for 10% in the Next 50 Years Ground Motion**



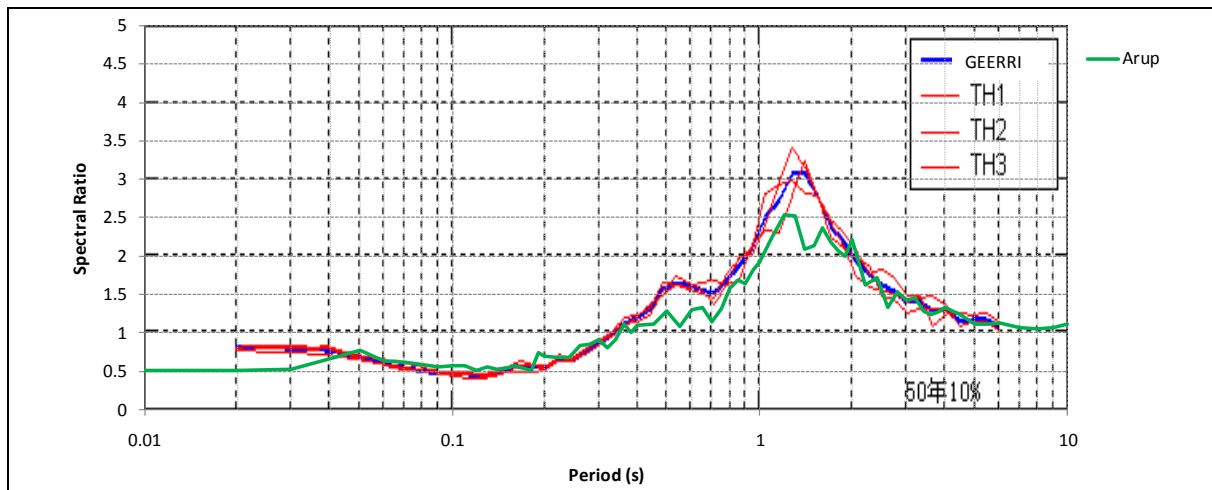
**Figure 6.14 Spectral Ratios for BH23 for 10% in the Next 50 Years Ground Motion**



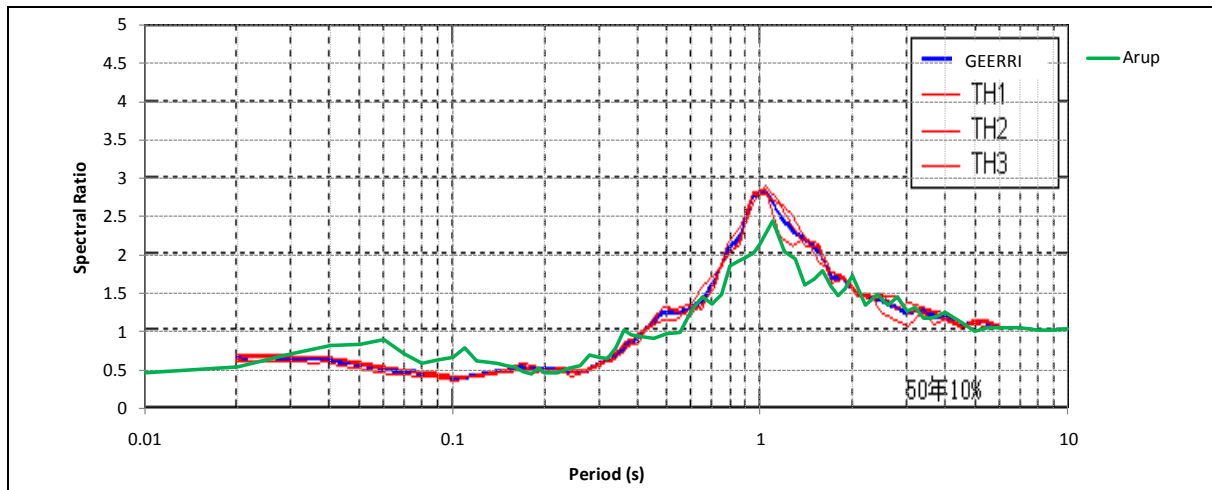
**Figure 6.15 Spectral Ratios for BH24 for 10% in the Next 50 Years Ground Motion**



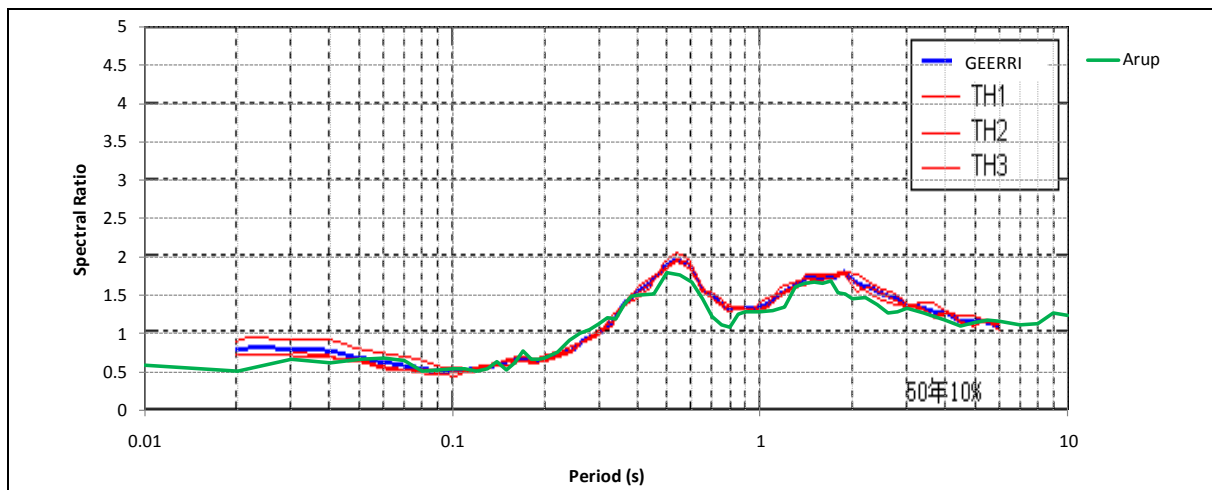
**Figure 6.16 Spectral Ratios for BH26 for 10% in the Next 50 Years Ground Motion**



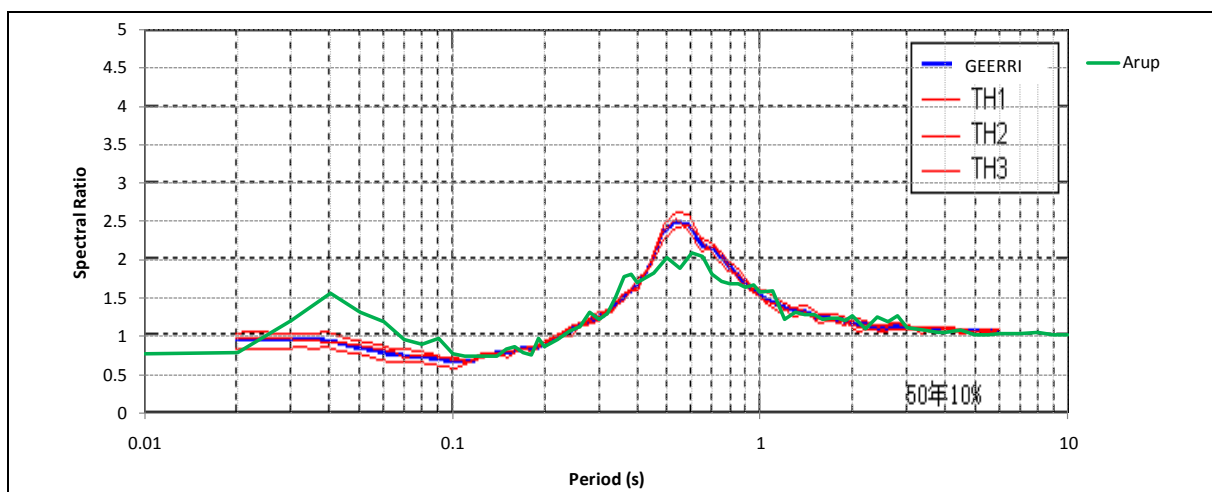
**Figure 6.17 Spectral Ratios for BH27 for 10% in the Next 50 Years Ground Motion**



**Figure 6.18 Spectral Ratios for BH29 for 10% in the Next 50 Years Ground Motion**

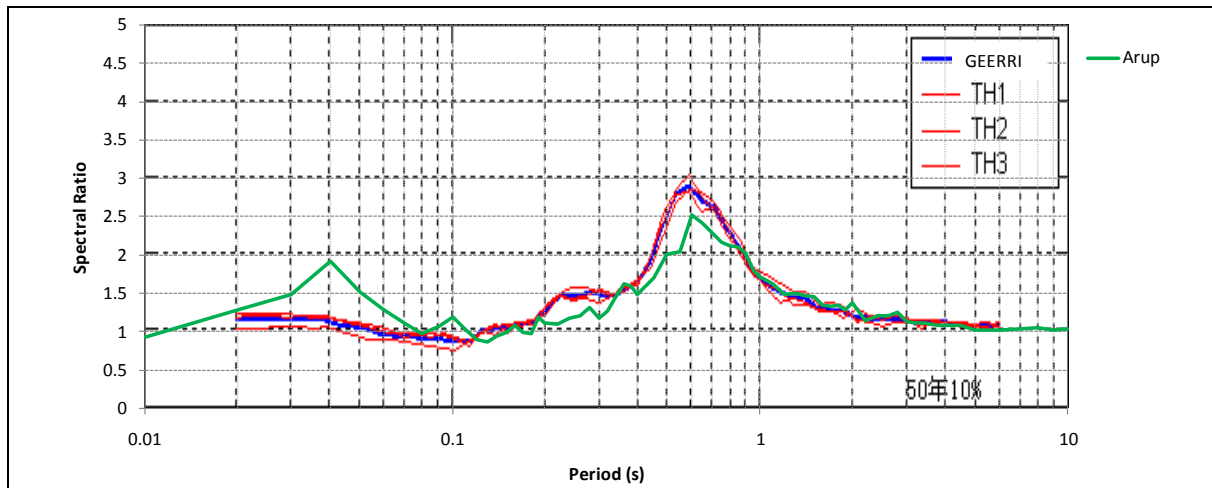


**Figure 6.19 Spectral Ratios for BH30 for 10% in the Next 50 Years Ground Motion**

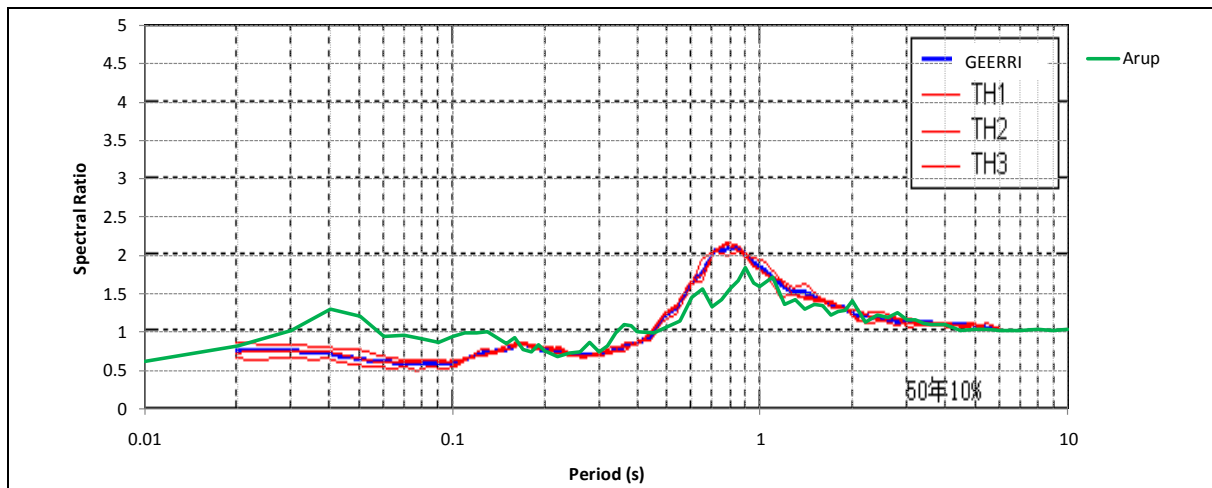


**Figure 6.20 Spectral Ratios for BH32 for 10% in the Next 50 Years Ground Motion**

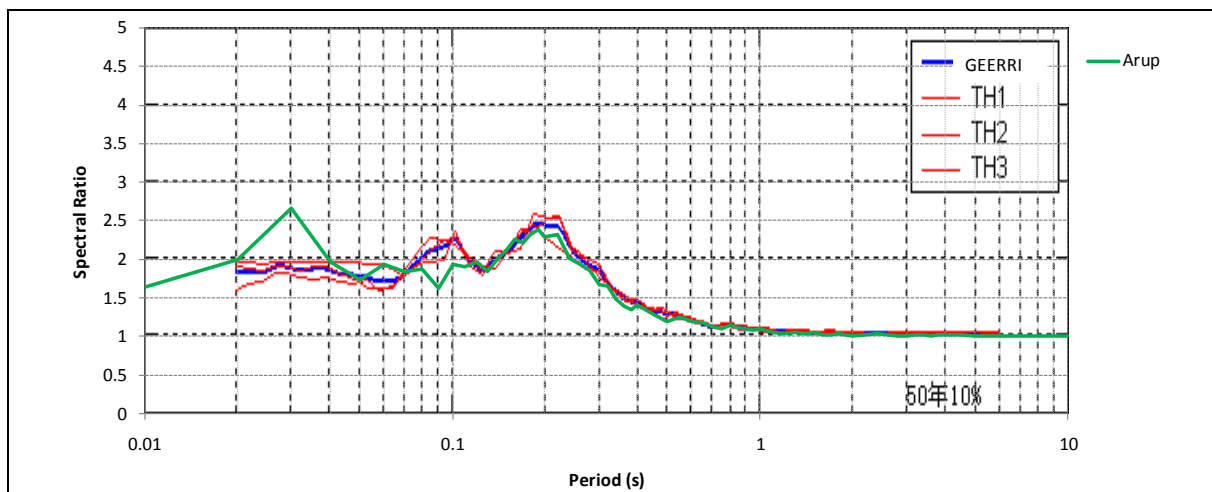




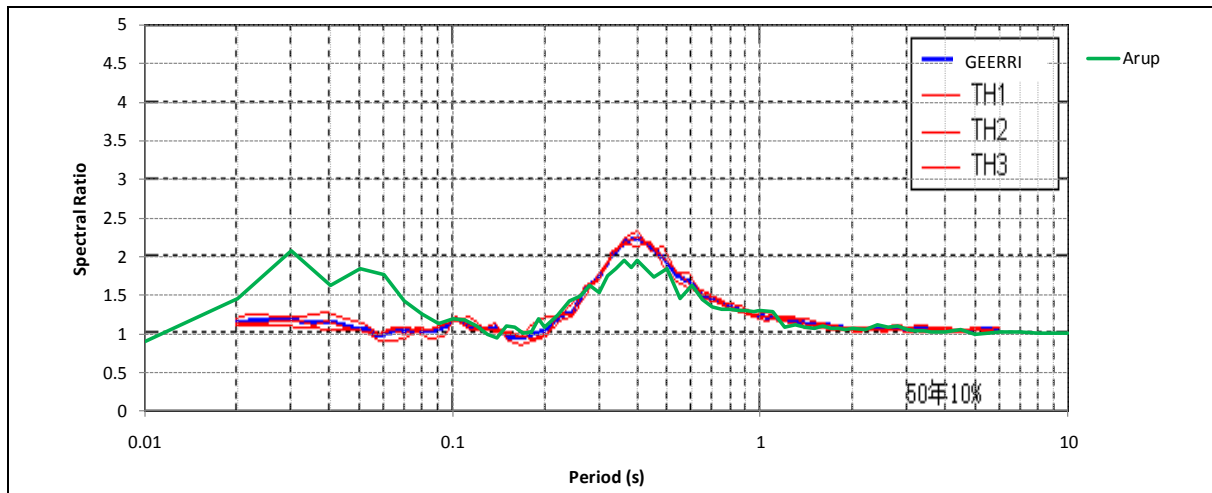
**Figure 6.21 Spectral Ratios for BH36 for 10% in the Next 50 Years Ground Motion**



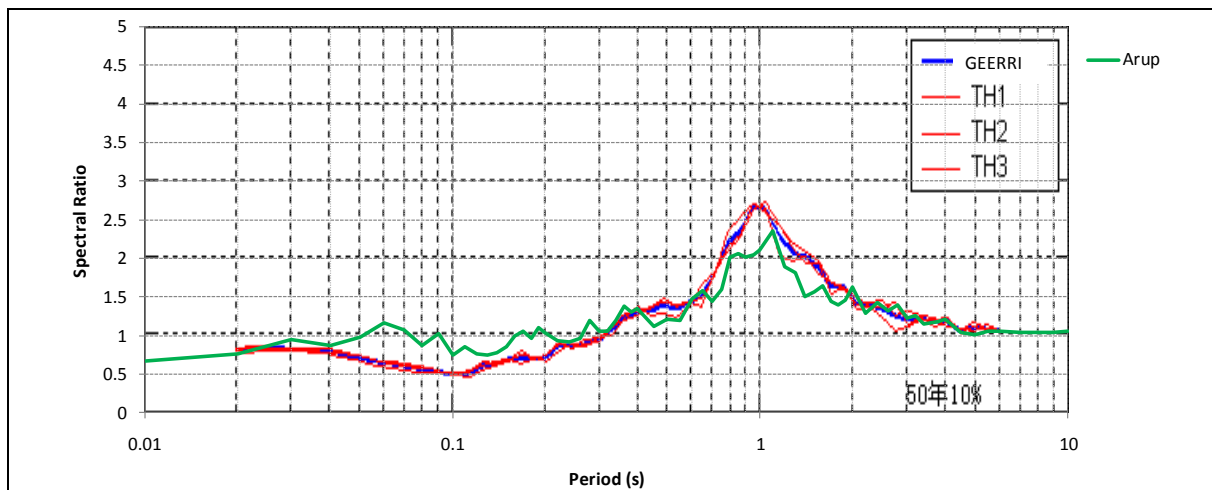
**Figure 6.22 Spectral Ratios for BH39 for 10% in the Next 50 Years Ground Motion**



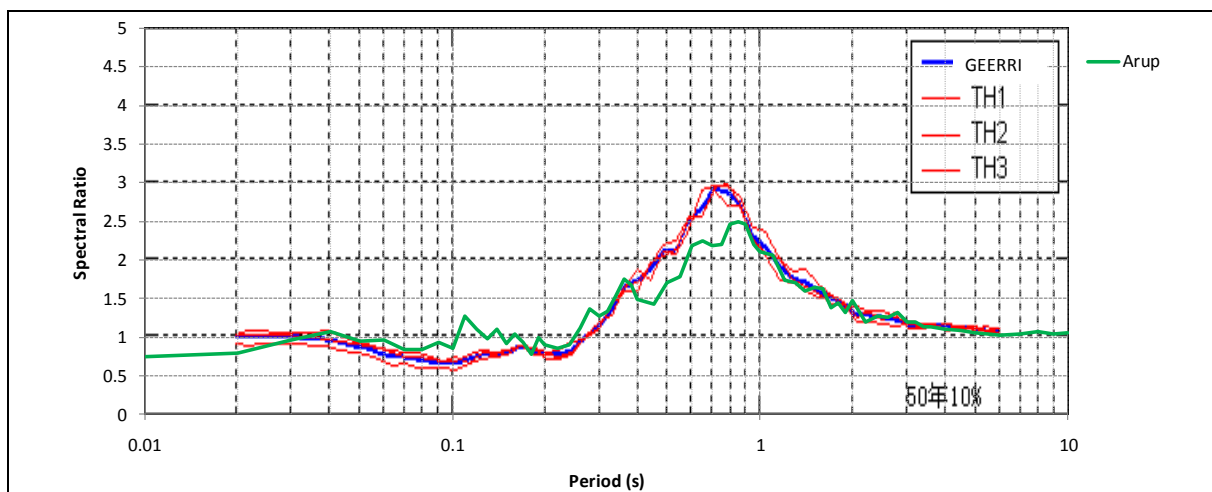
**Figure 6.23 Spectral Ratios for BH41 for 10% in the Next 50 Years Ground Motion**



**Figure 6.24 Spectral Ratios for BH42 for 10% in the Next 50 Years Ground Motion**



**Figure 6.25 Spectral Ratios for BH43 for 10% in the Next 50 Years Ground Motion**



**Figure 6.26 Spectral Ratios for BH44 for 10% in the Next 50 Years Ground Motion**



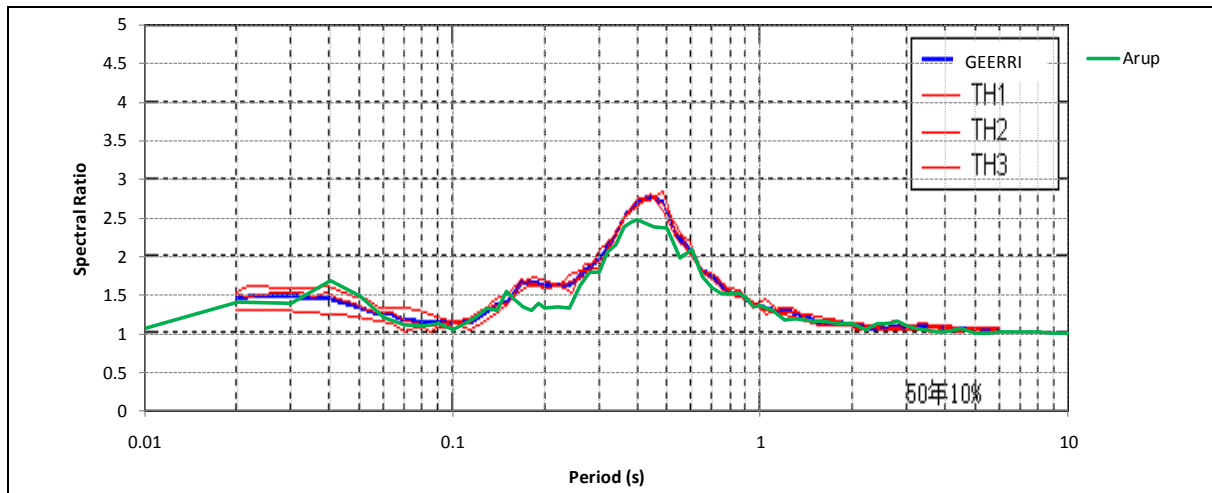


Figure 6.27 Spectral Ratios for BH45 for 10% in the Next 50 Years Ground Motion

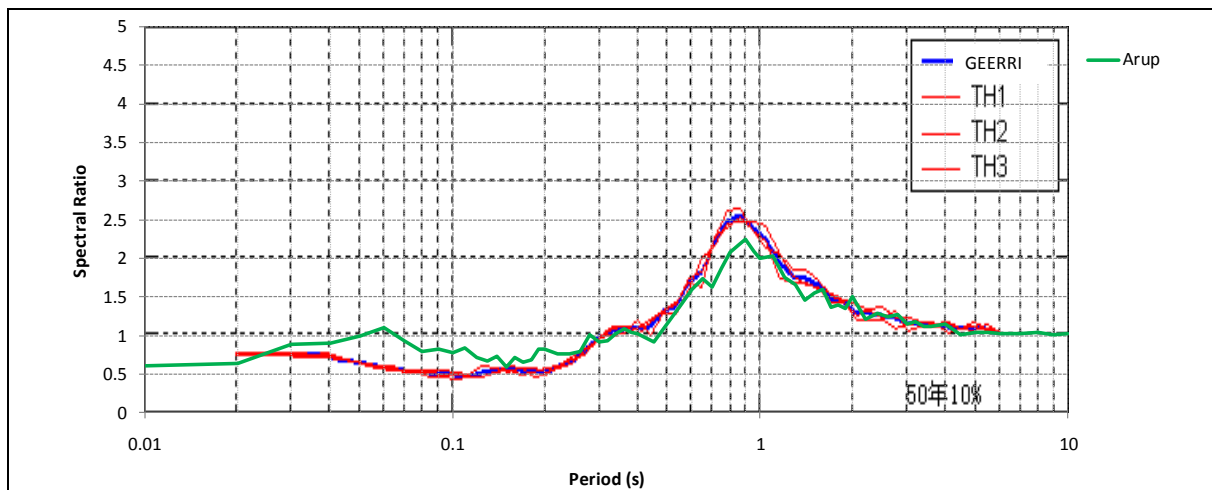


Figure 6.28 Spectral Ratios for BH49 for 10% in the Next 50 Years Ground Motion

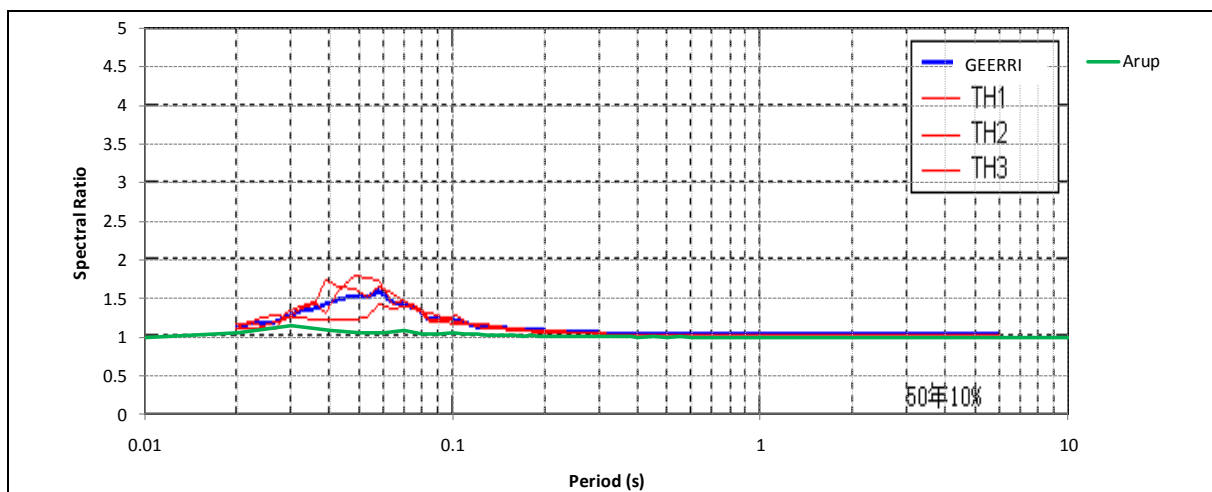
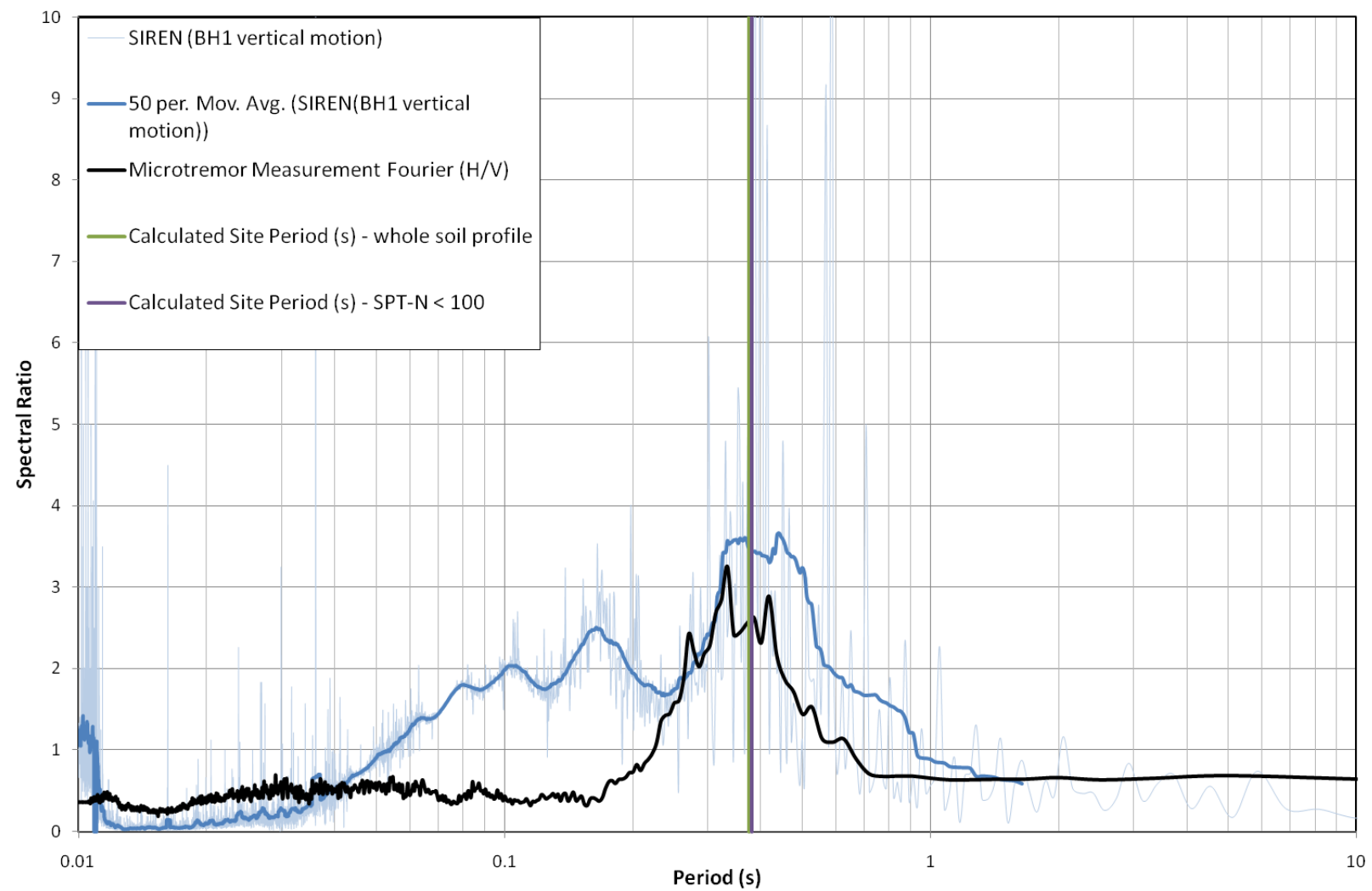
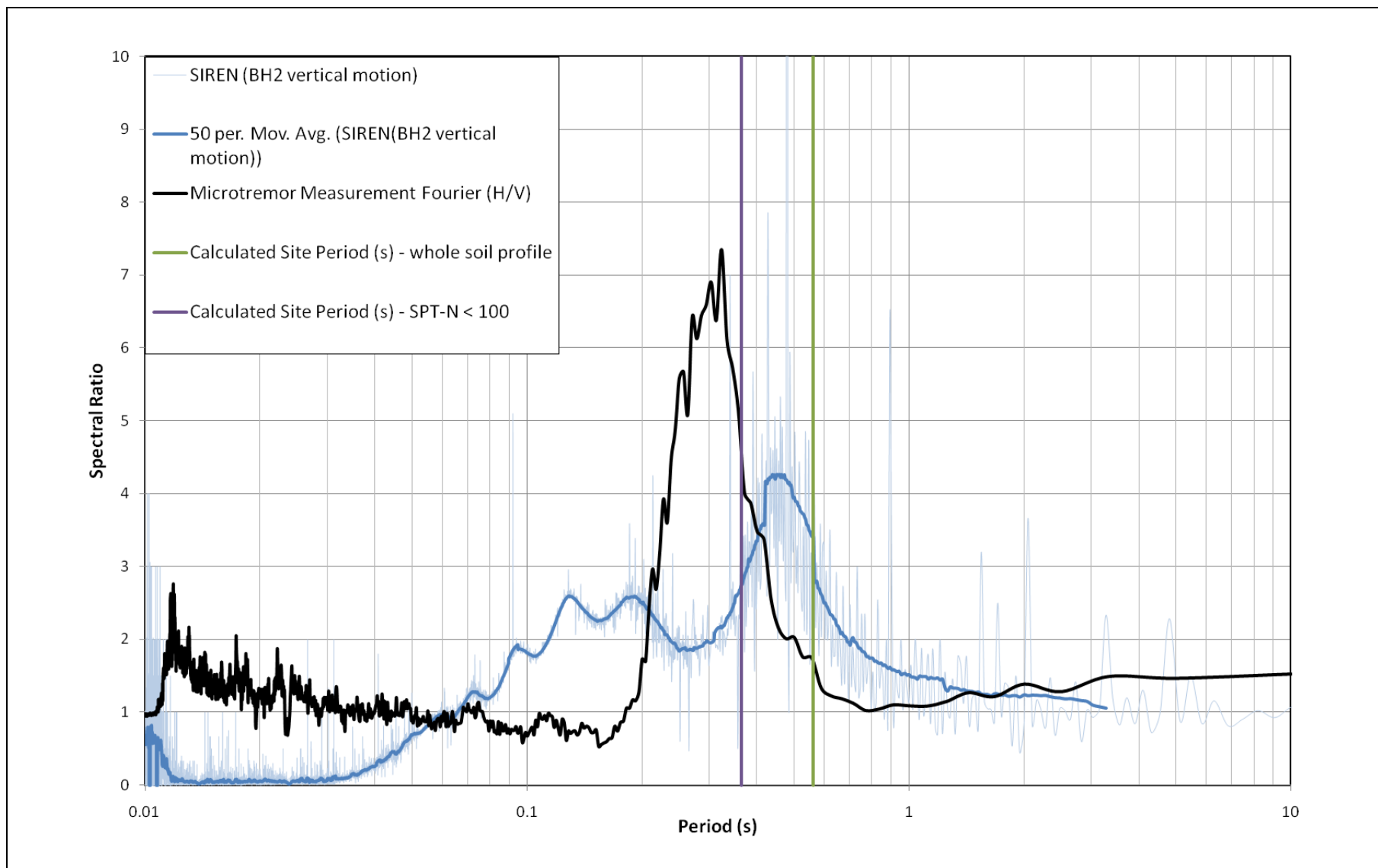


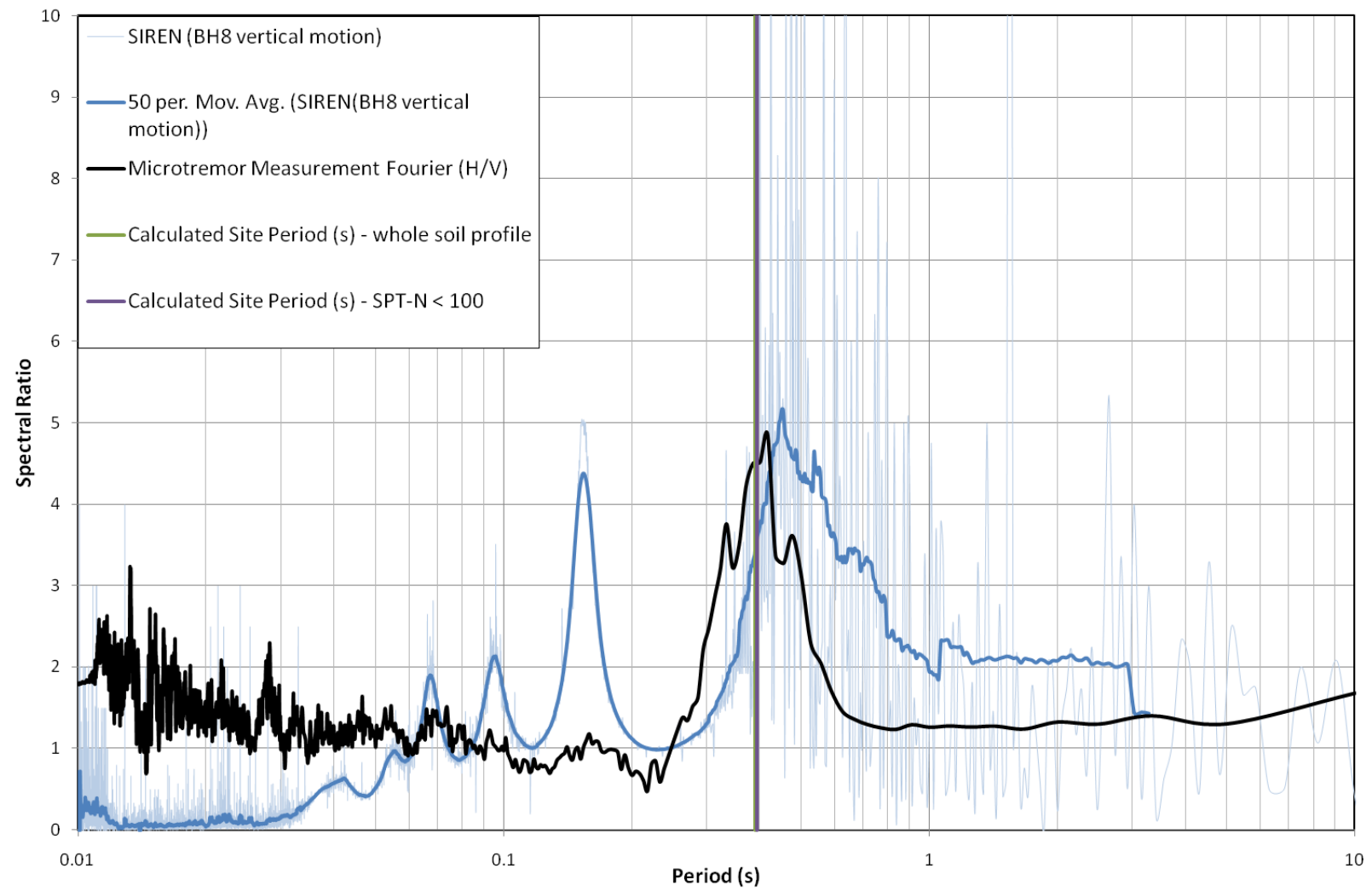
Figure 6.29 Spectral Ratios for BH50 for 10% in the Next 50 Years Ground Motion



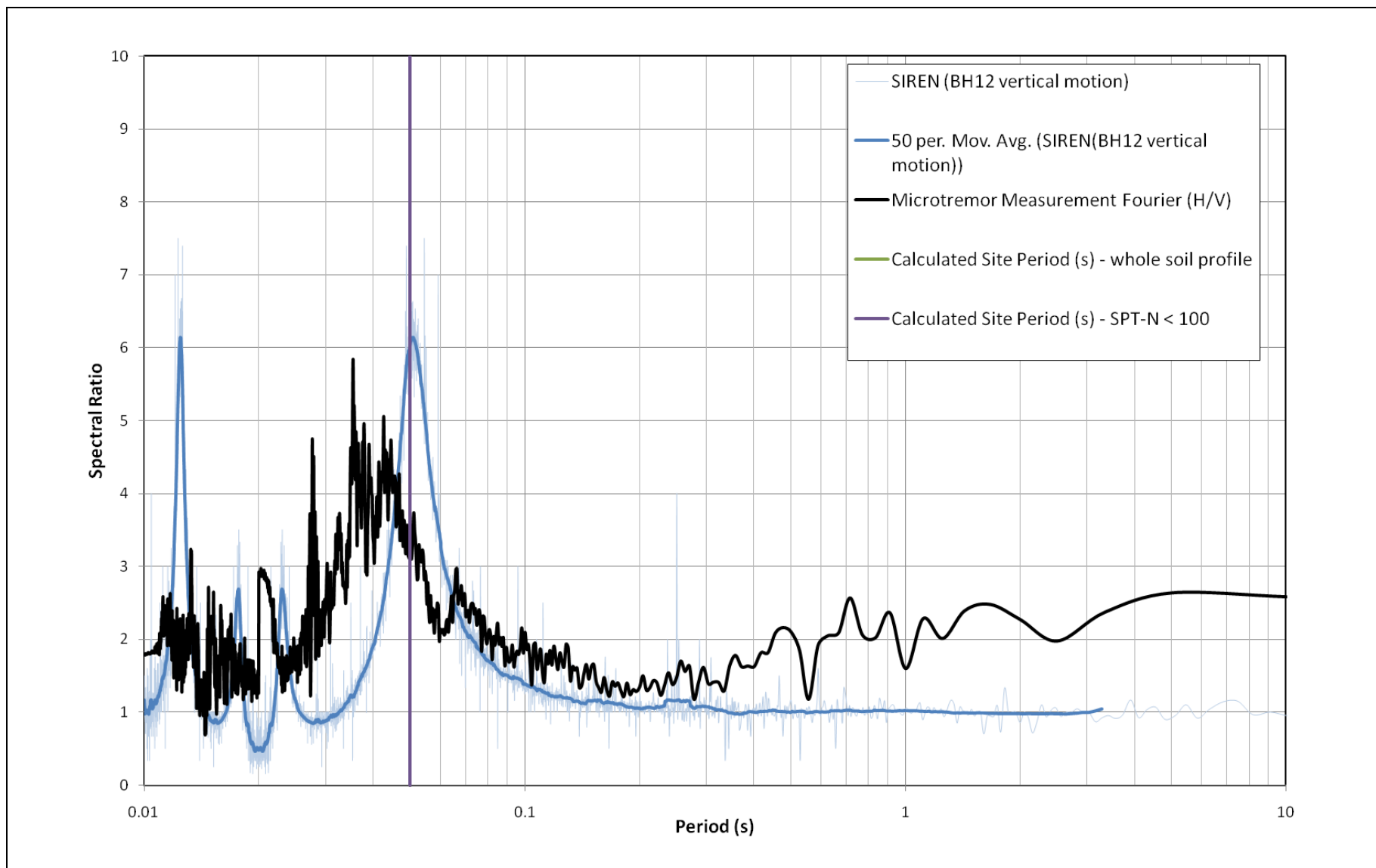
**Figure 6.30 BH01 - Fourier Amplitude Spectral Ratio**



**Figure 6.31 BH02 - Fourier Amplitude Spectral Ratio**



**Figure 6.32 BH08 - Fourier Amplitude Spectral Ratio**



**Figure 6.33 BH12 - Fourier Amplitude Spectral Ratio**

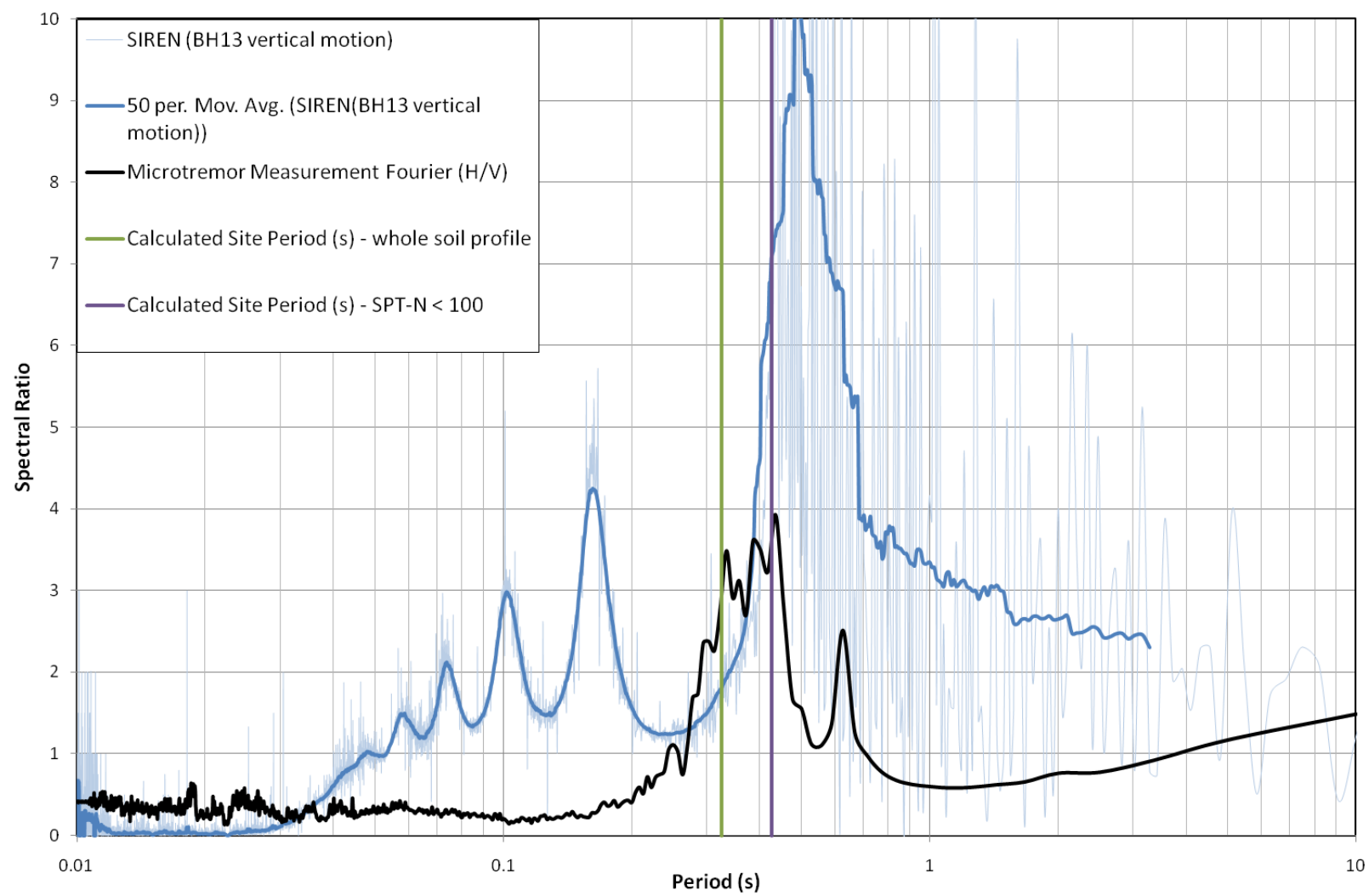


Figure 6.34 BH13 - Fourier Amplitude Spectral Ratio

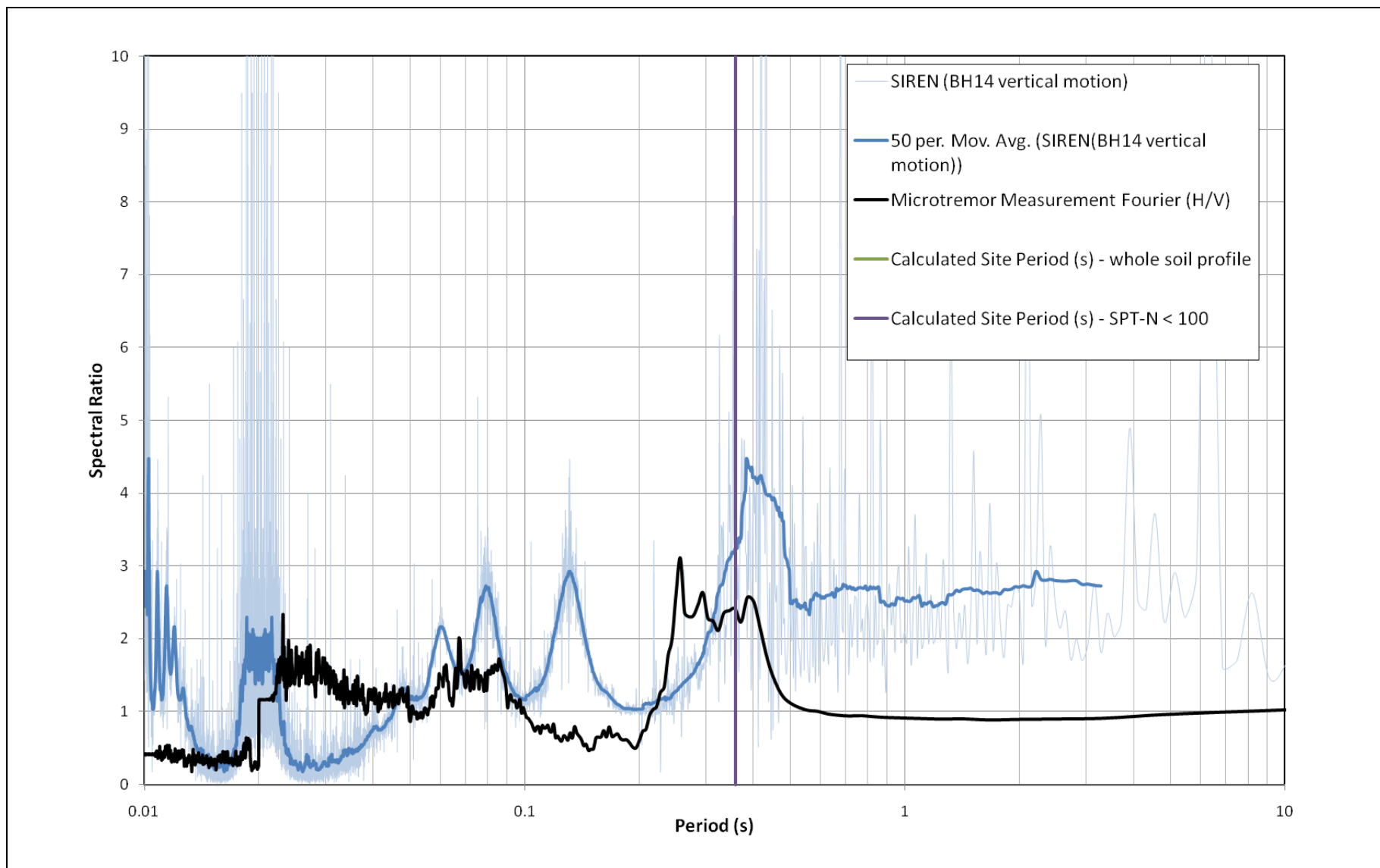
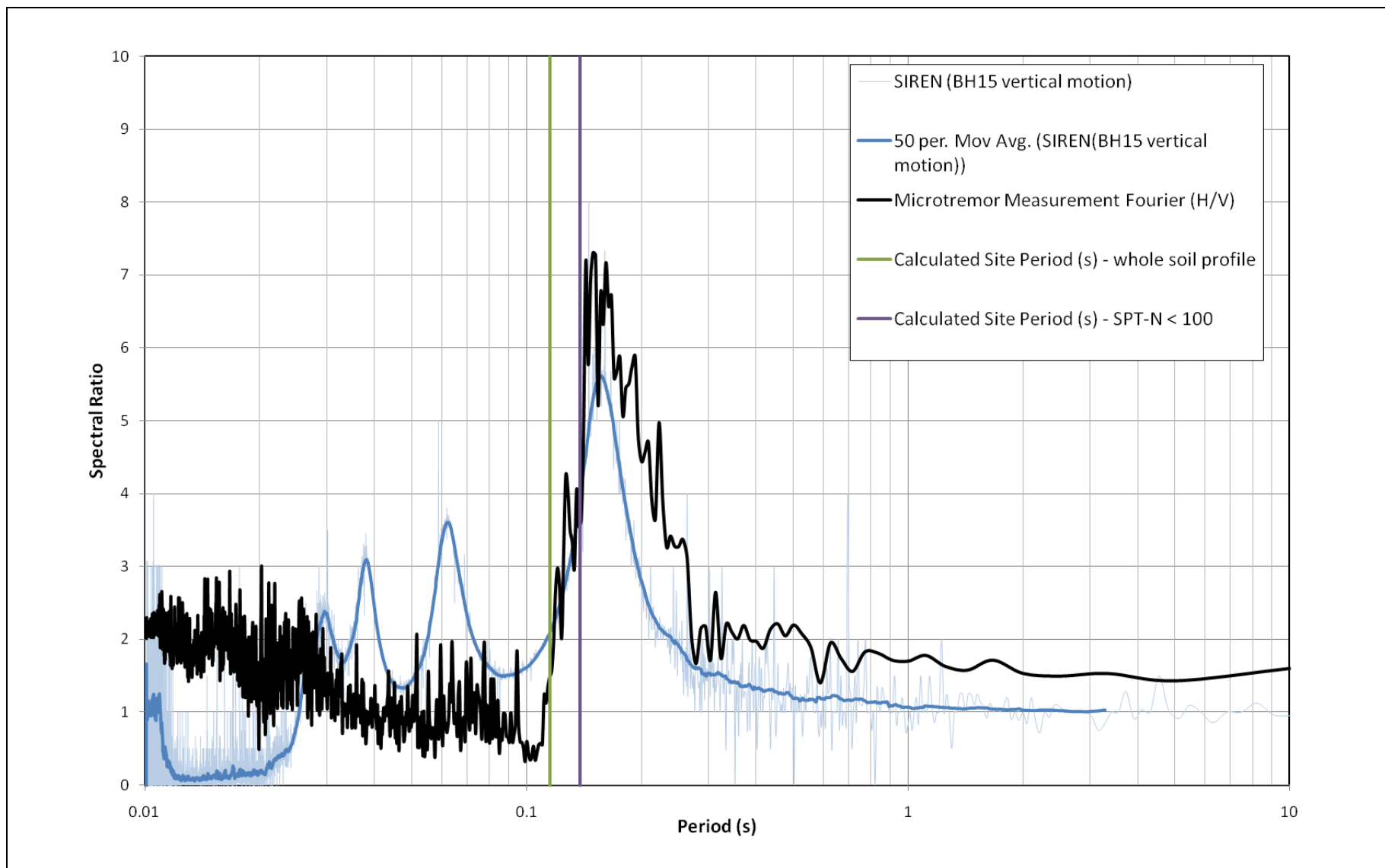
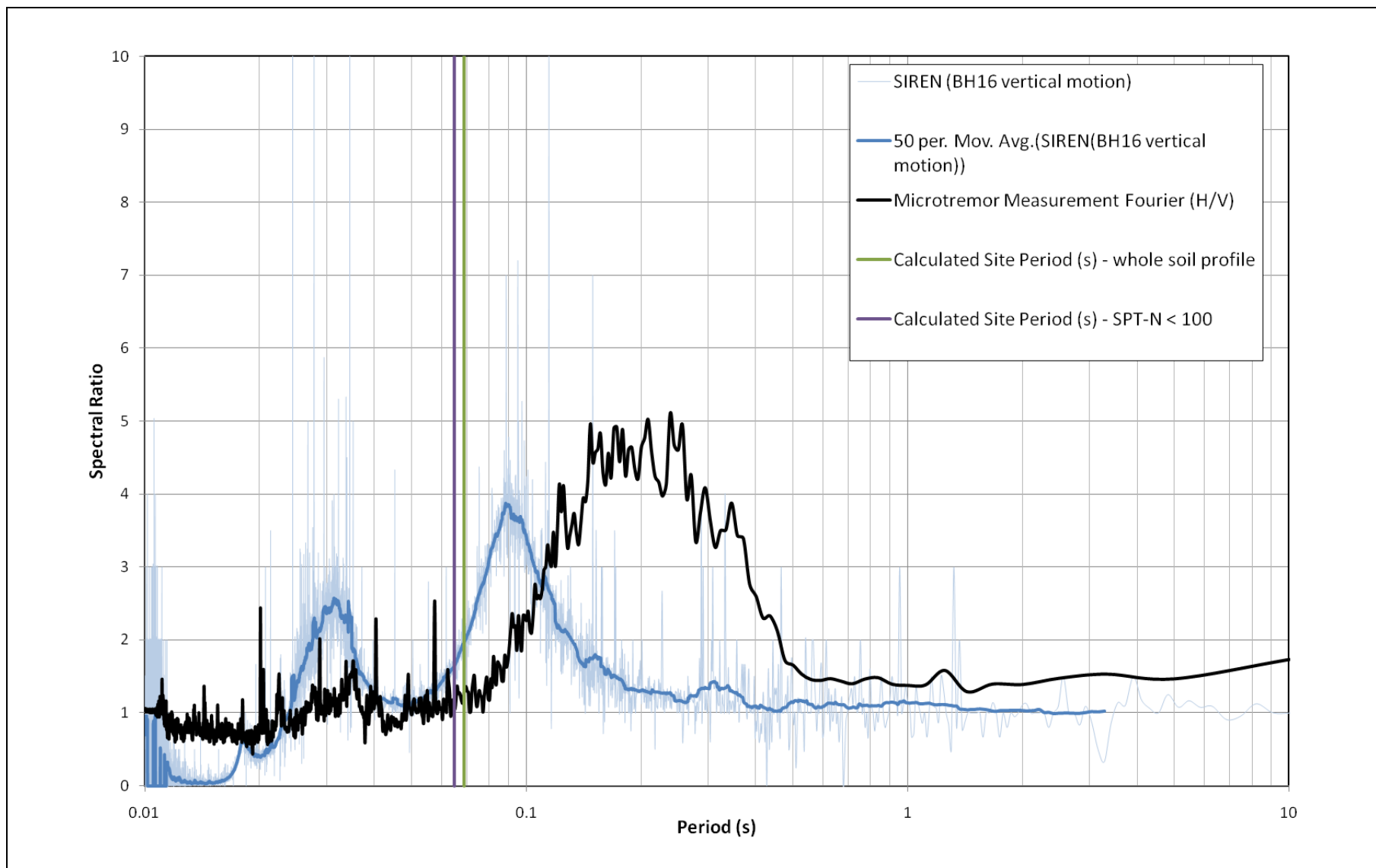


Figure 6.35 BH14 - Fourier Amplitude Spectral Ratio



**Figure 6.36 BH15 - Fourier Amplitude Spectral Ratio**





**Figure 6.37 BH16 - Fourier Amplitude Spectral Ratio**

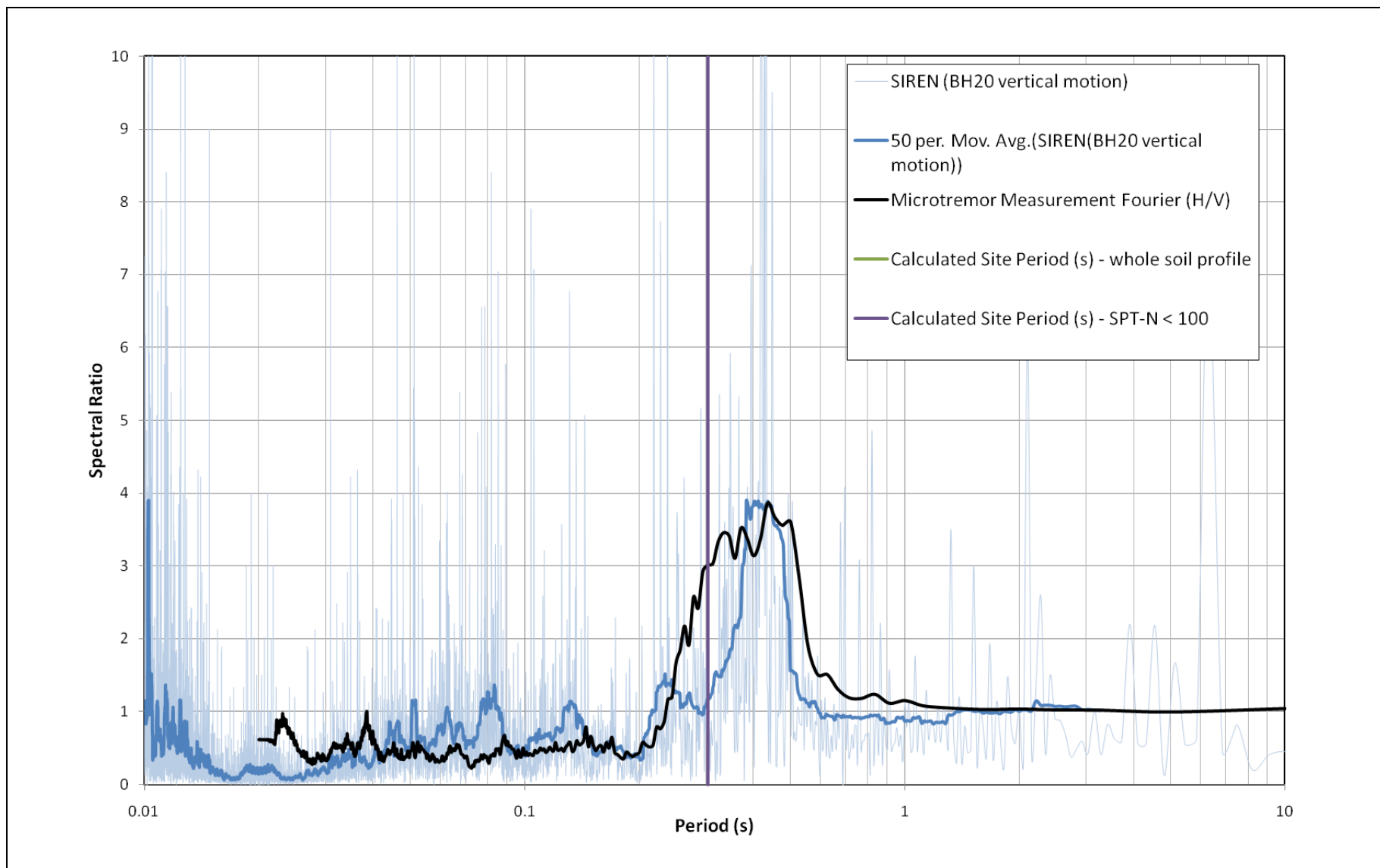
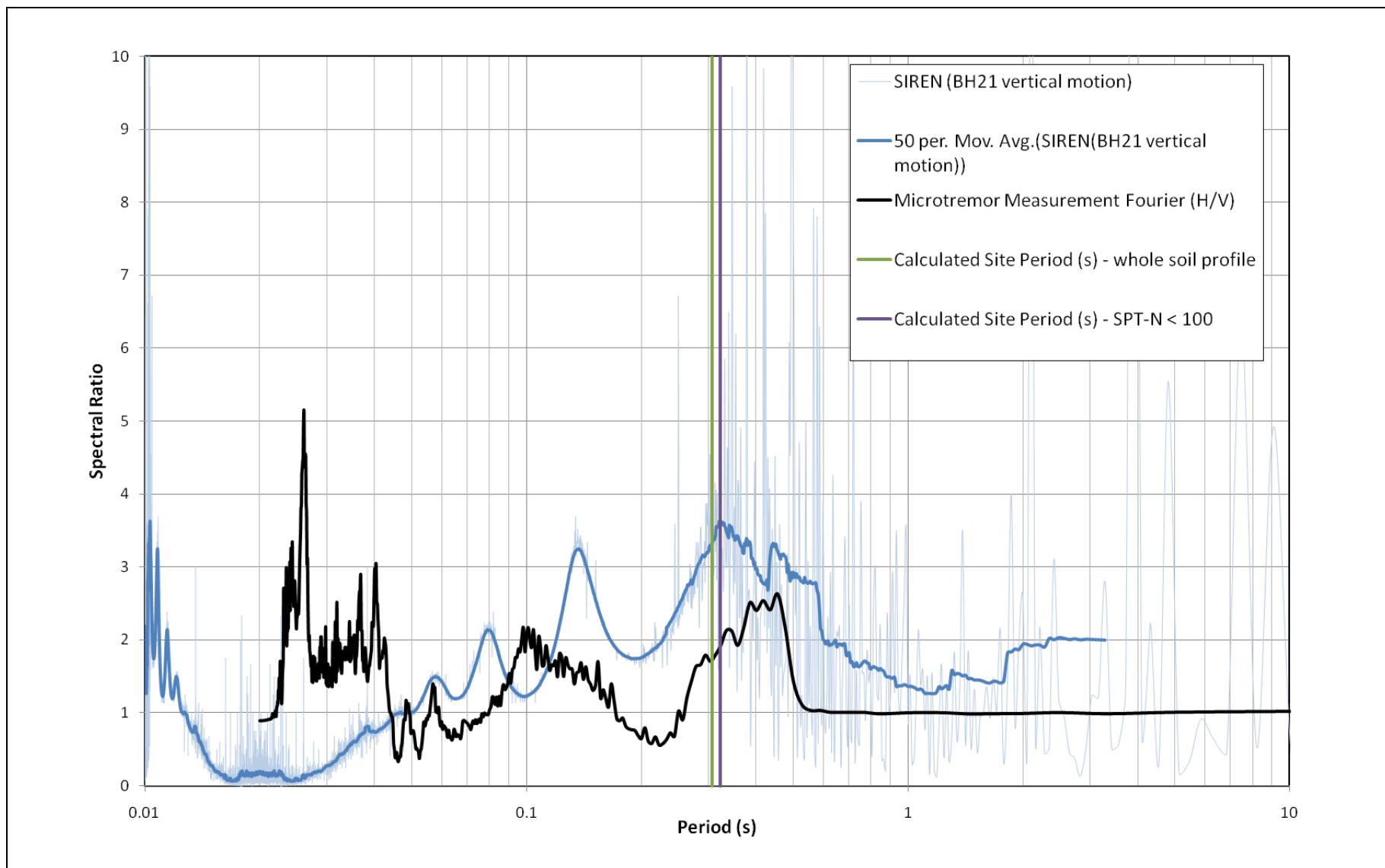
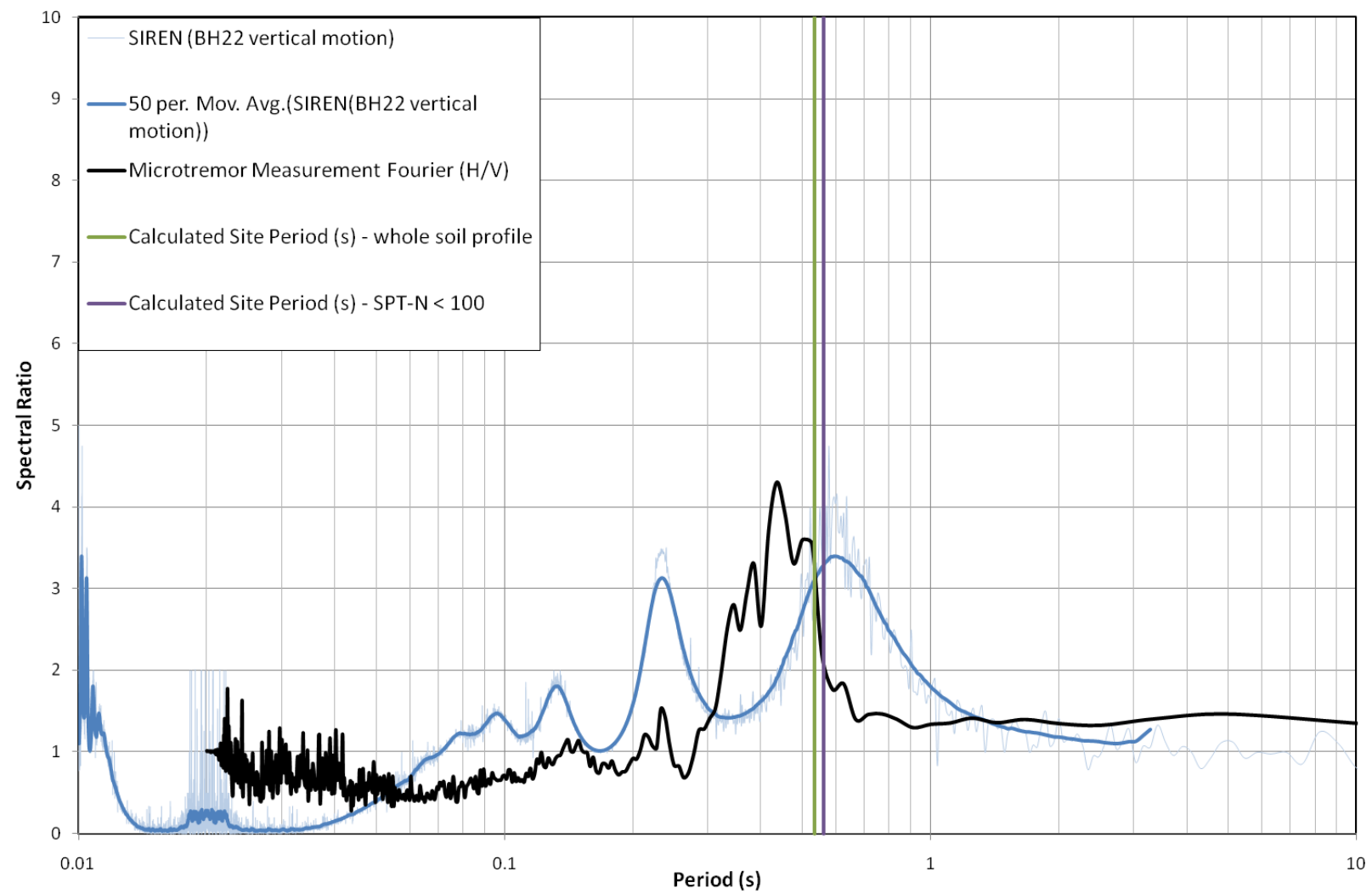


Figure 6.38 BH20 - Fourier Amplitude Spectral Ratio



**Figure 6.39 BH21 - Fourier Amplitude Spectral Ratio**



**Figure 6.40 BH22 - Fourier Amplitude Spectral Ratio**

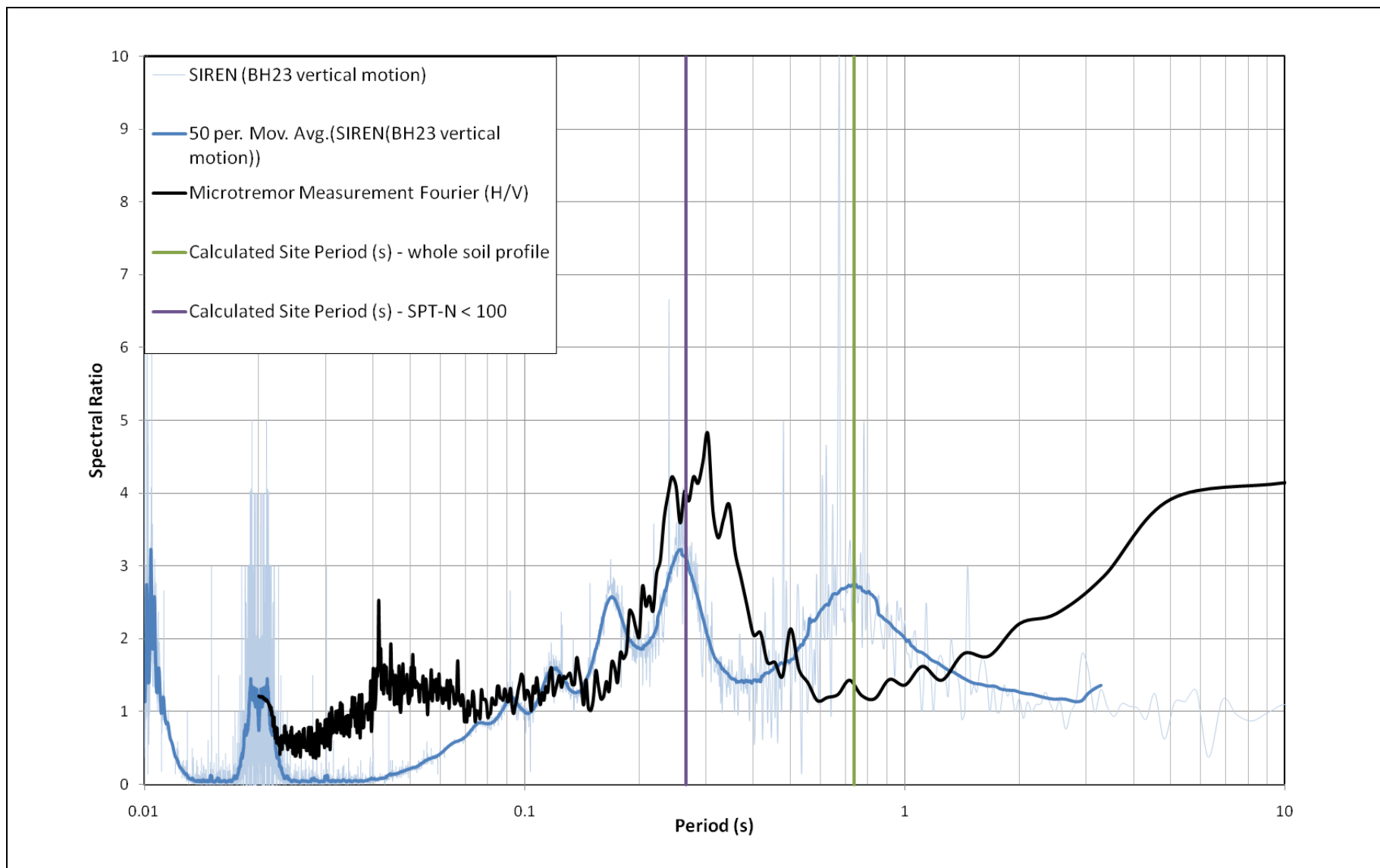


Figure 6.41 BH23 - Fourier Amplitude Spectral Ratio

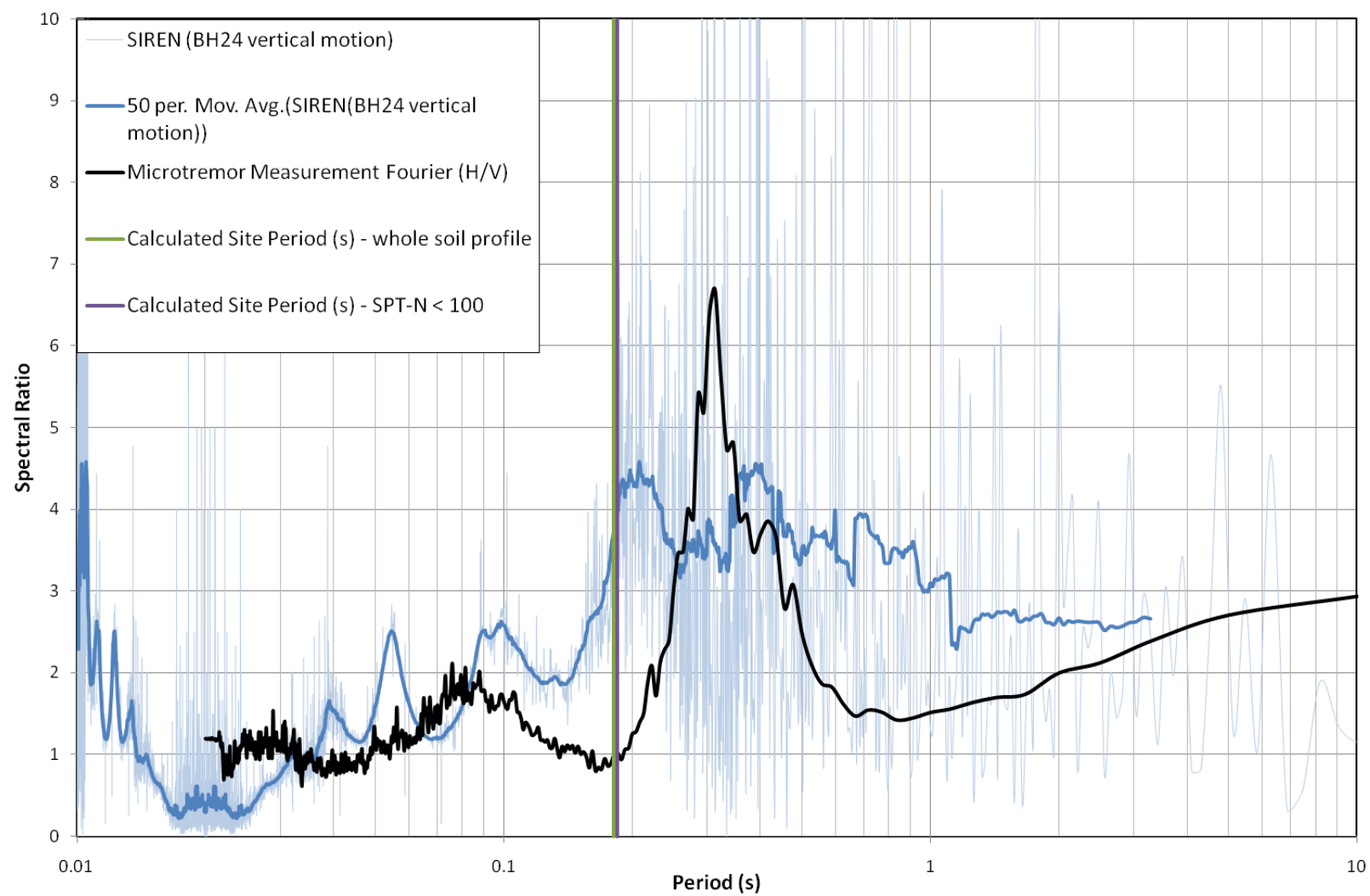
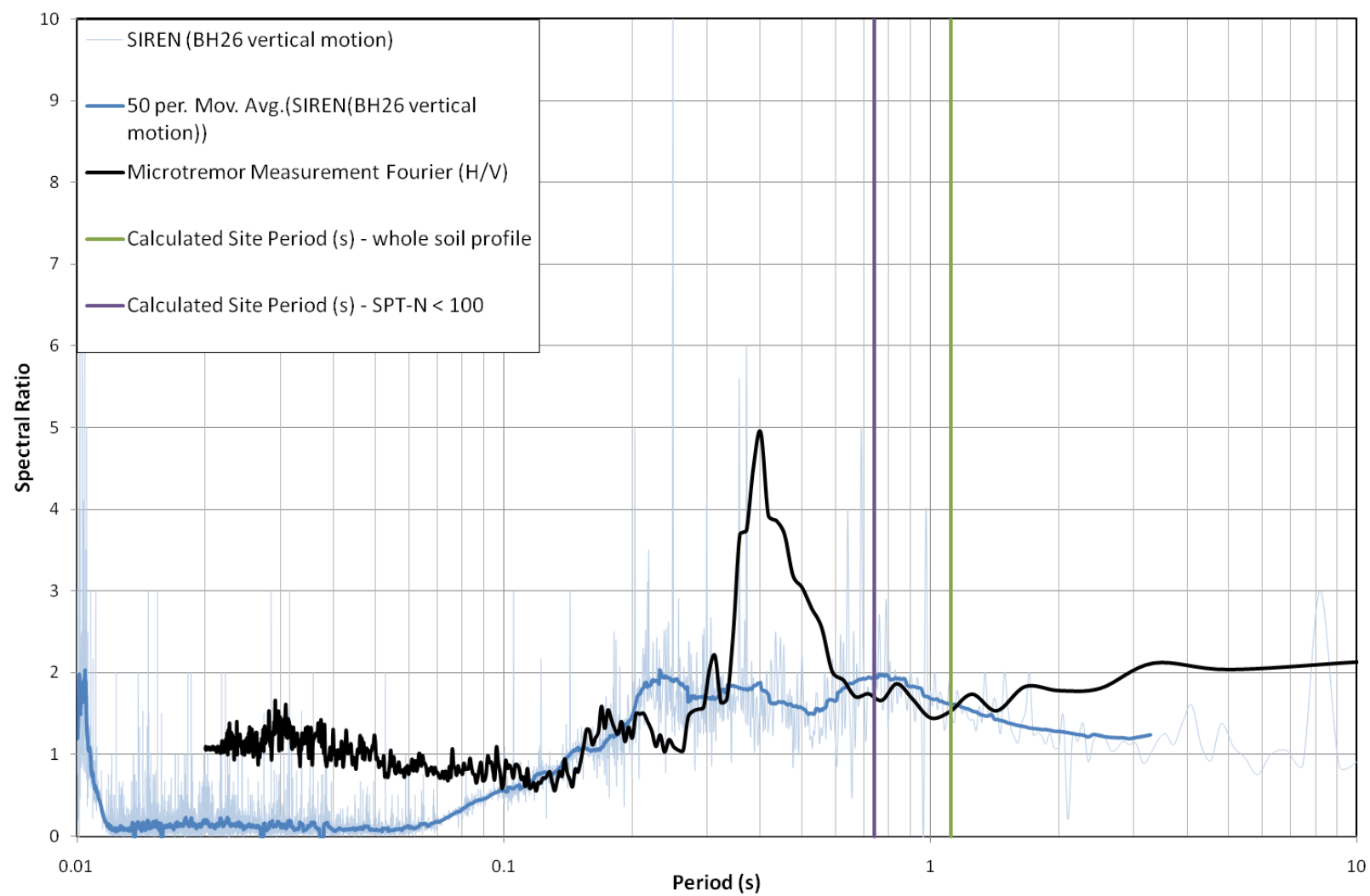
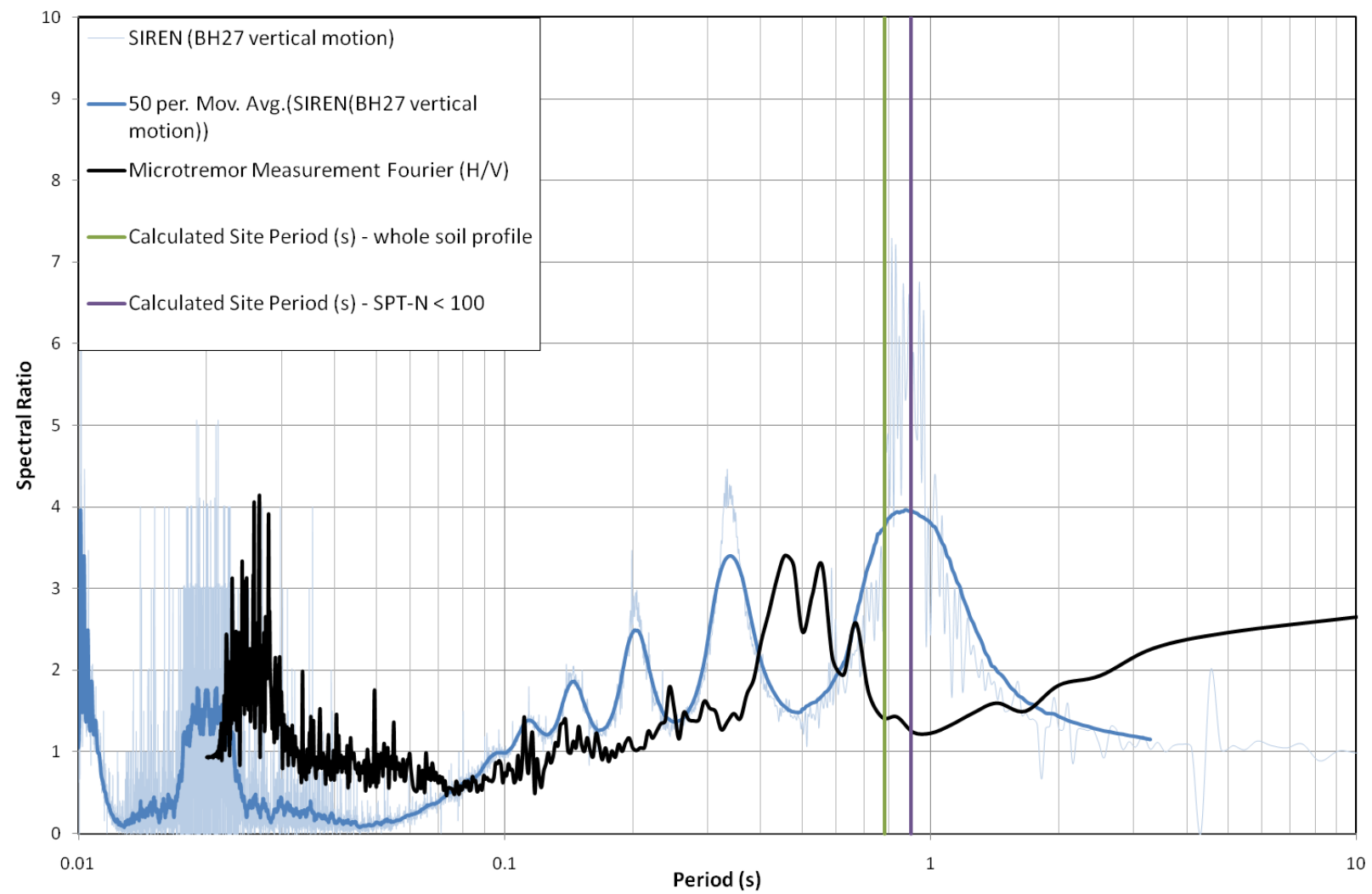


Figure 6.42 BH24 - Fourier Amplitude Spectral Ratio



**Figure 6.43 BH26 - Fourier Amplitude Spectral Ratio**



**Figure 6.44 BH27 - Fourier Amplitude Spectral Ratio**



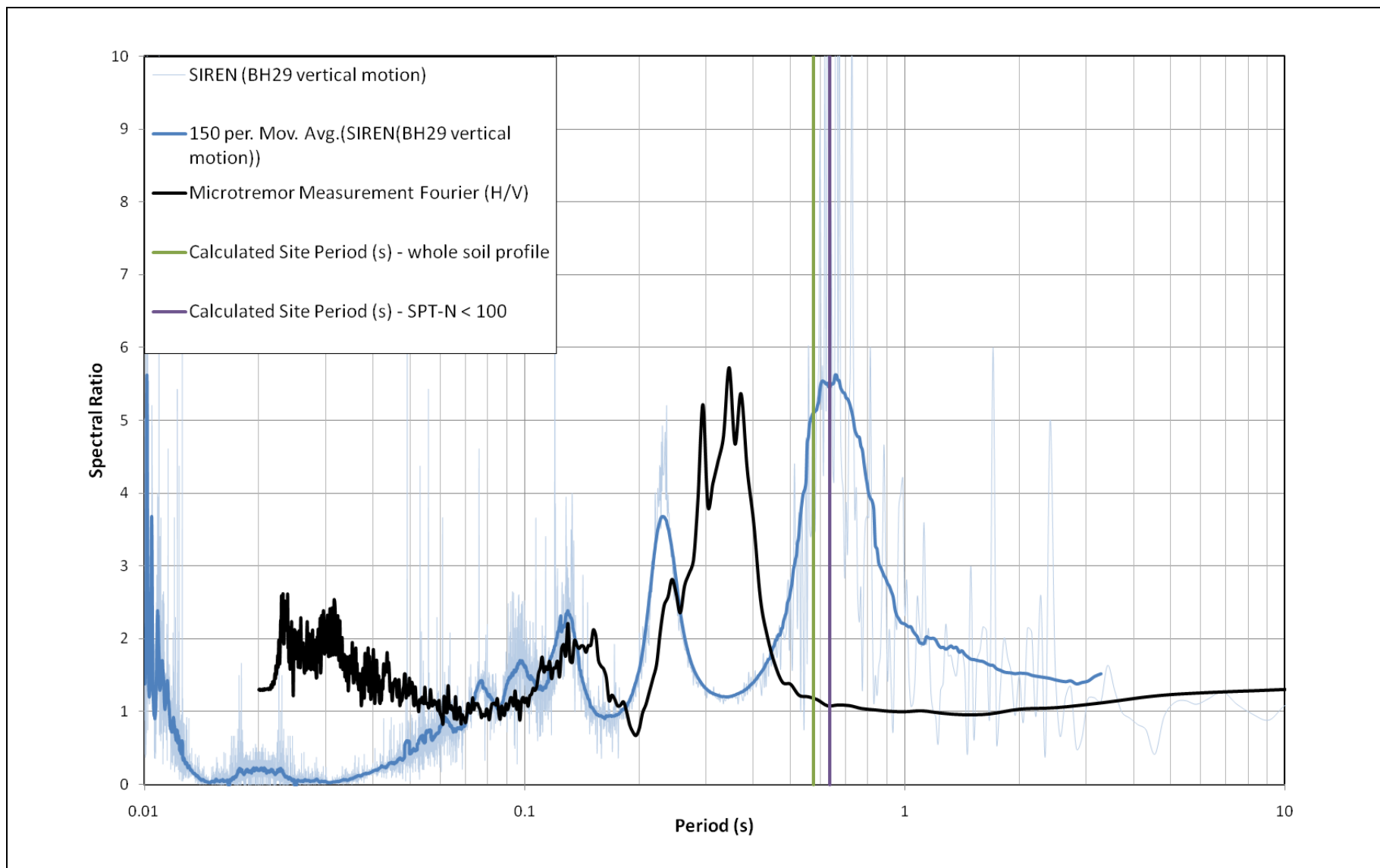
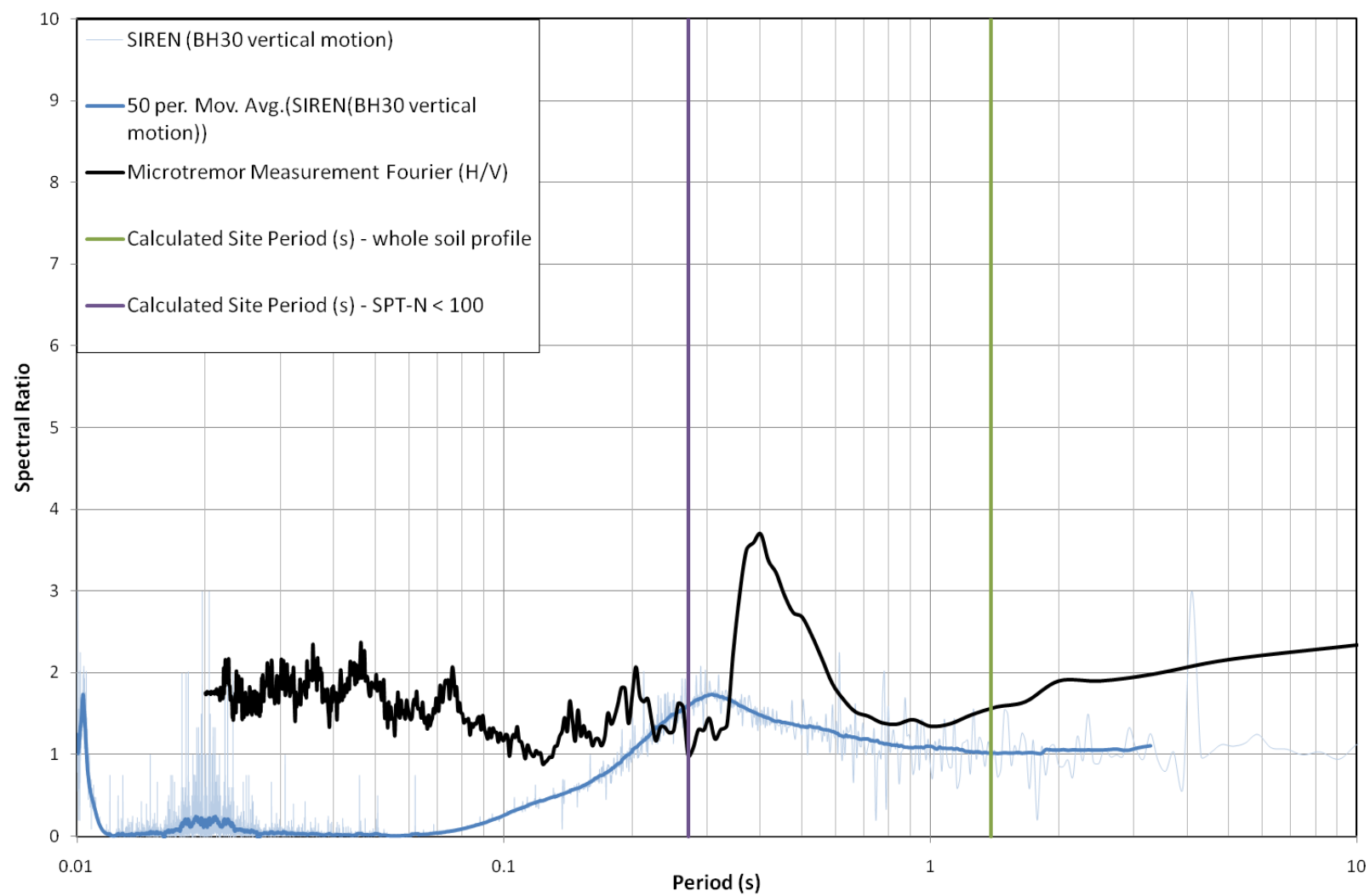


Figure 6.45 BH29 - Fourier Amplitude Spectral Ratio



**Figure 6.46 BH30 - Fourier Amplitude Spectral Ratio**

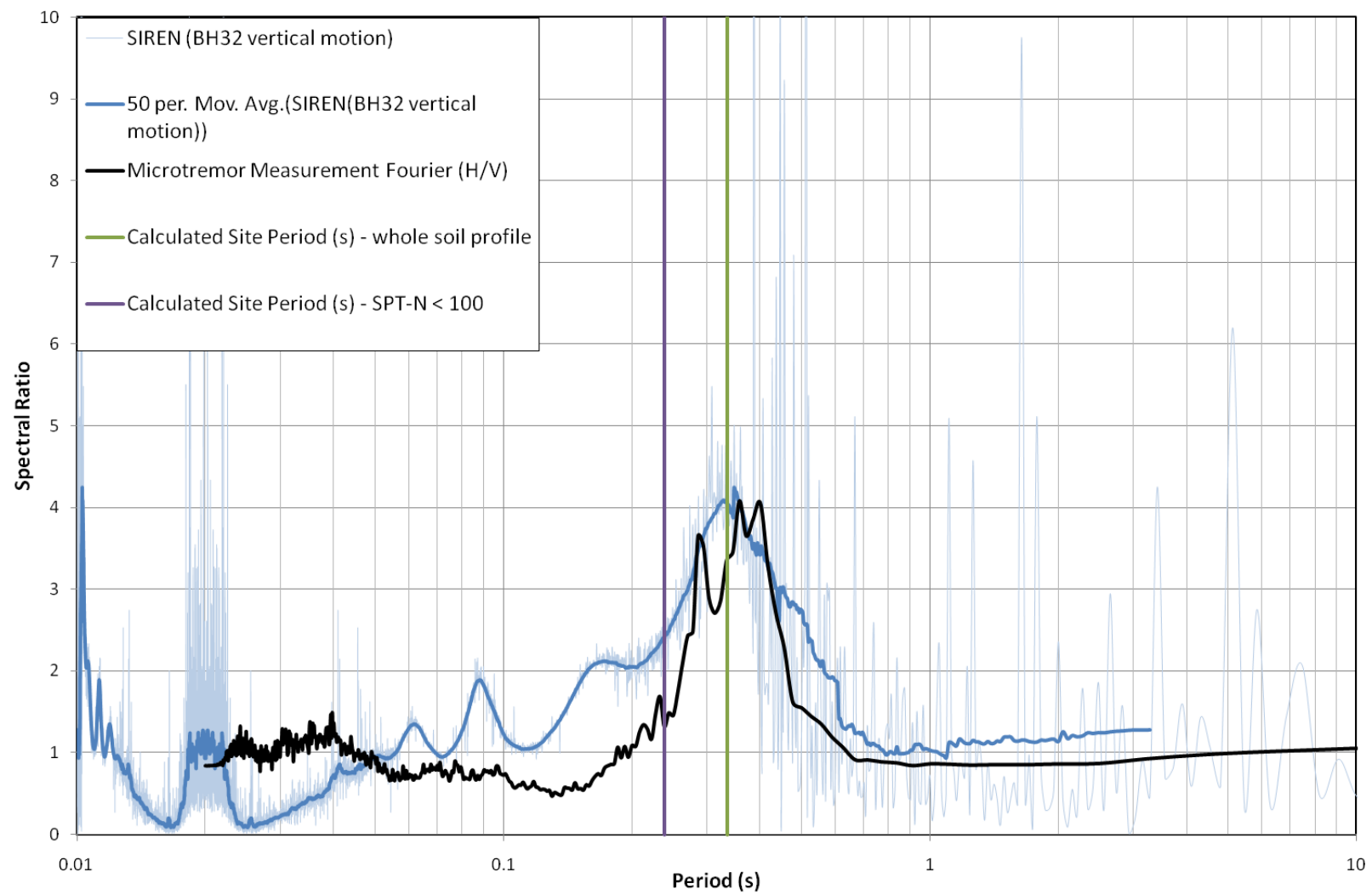
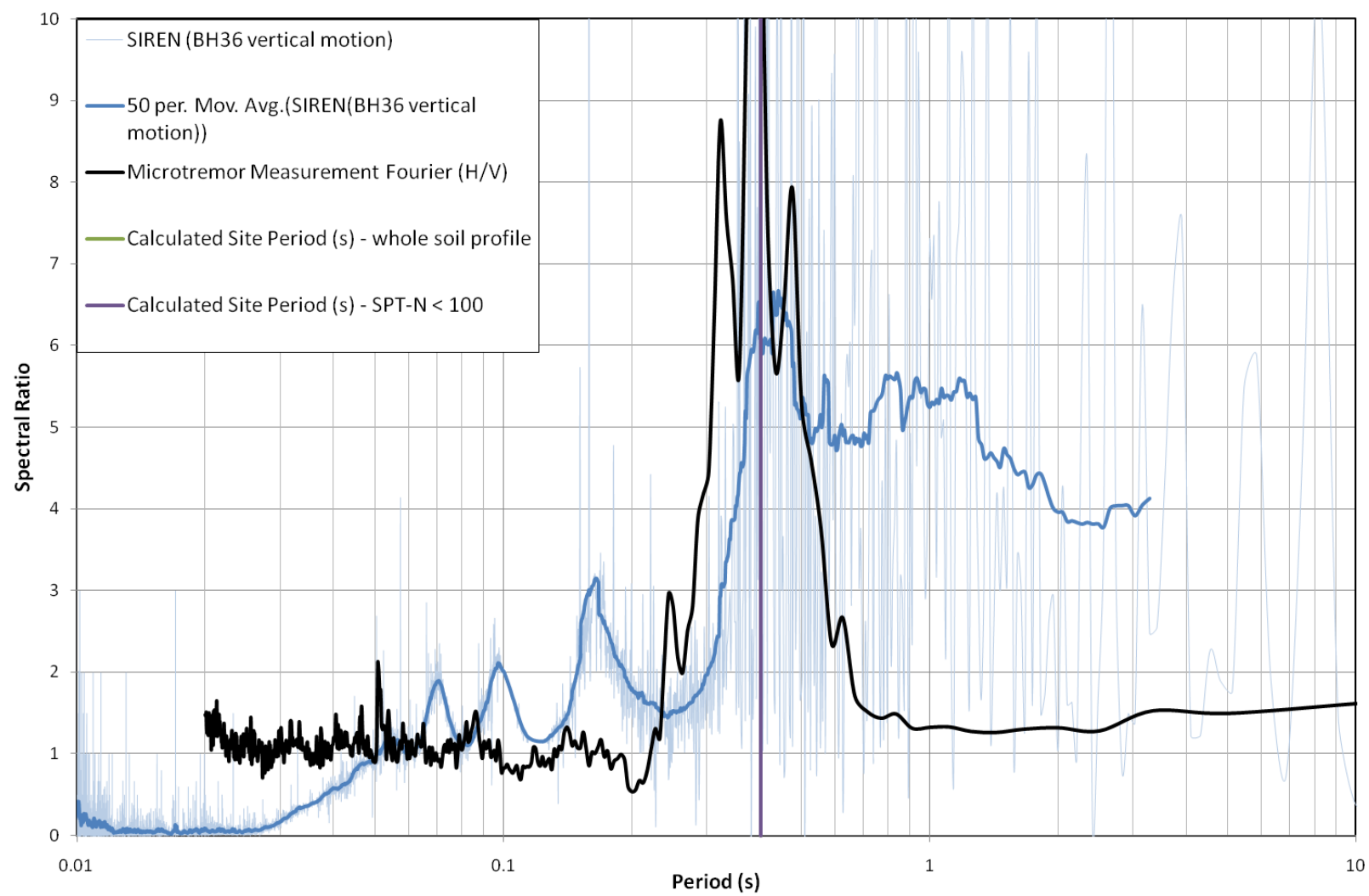


Figure 6.47 BH32 - Fourier Amplitude Spectral Ratio



**Figure 6.48 BH36 - Fourier Amplitude Spectral Ratio**

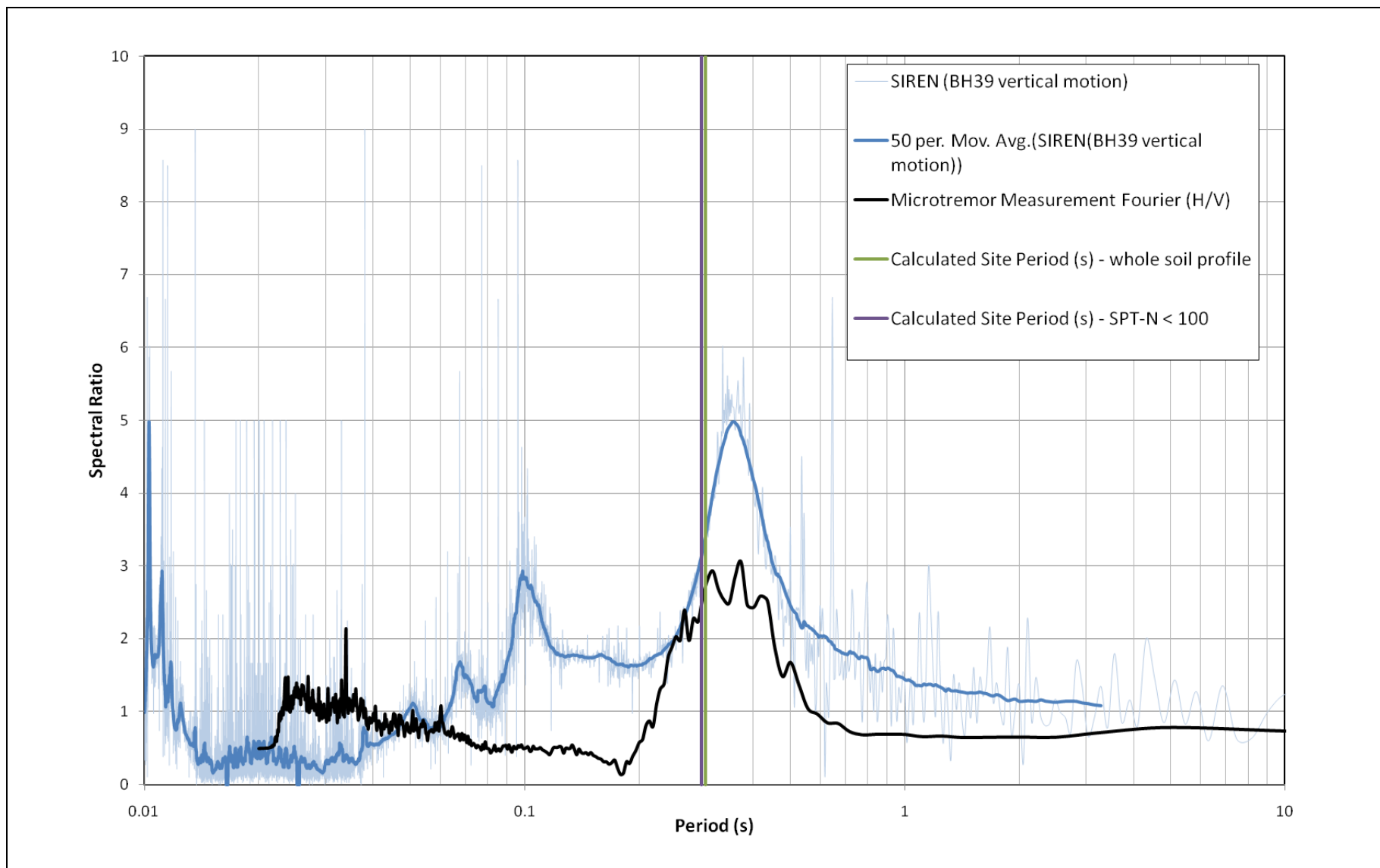
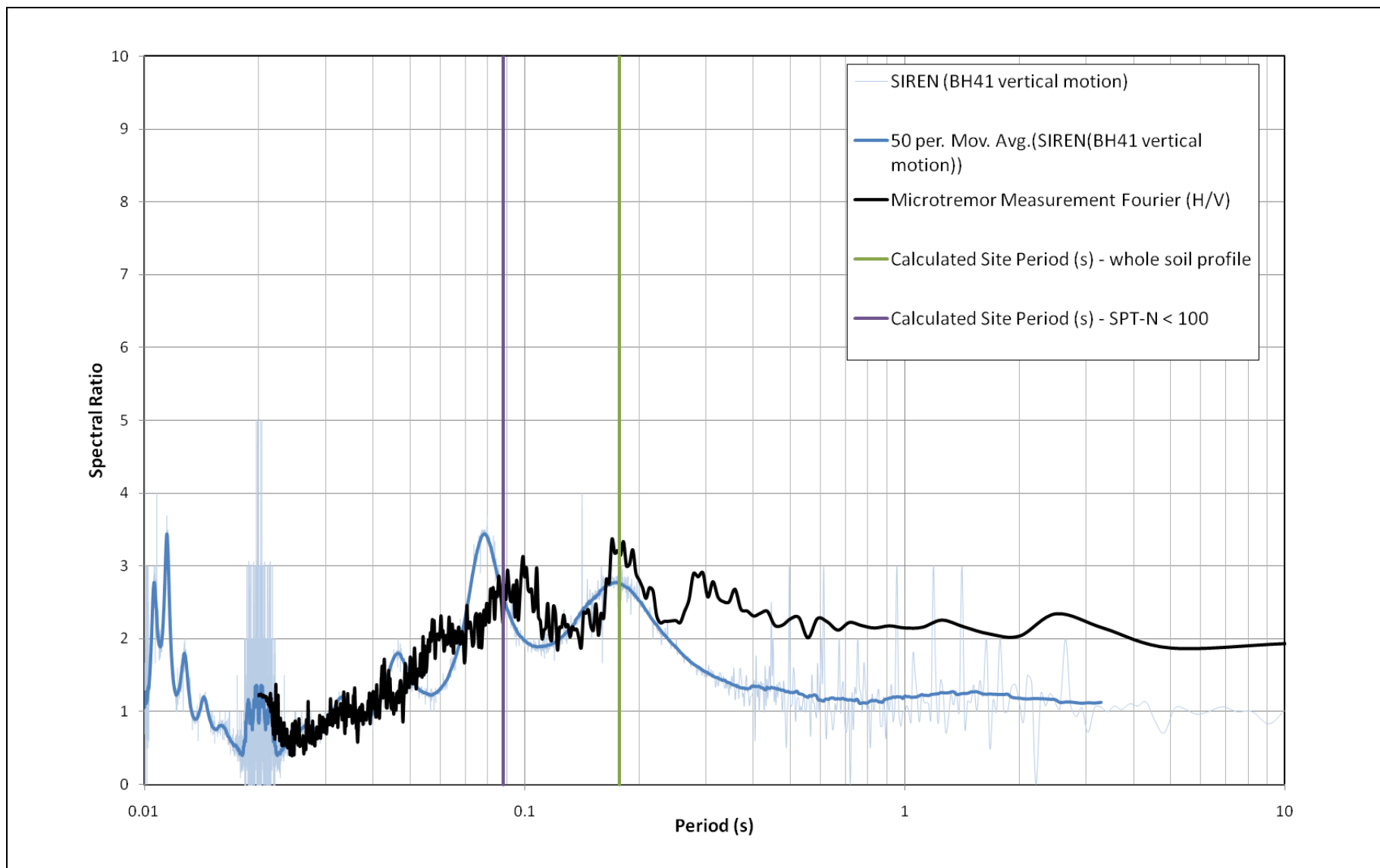
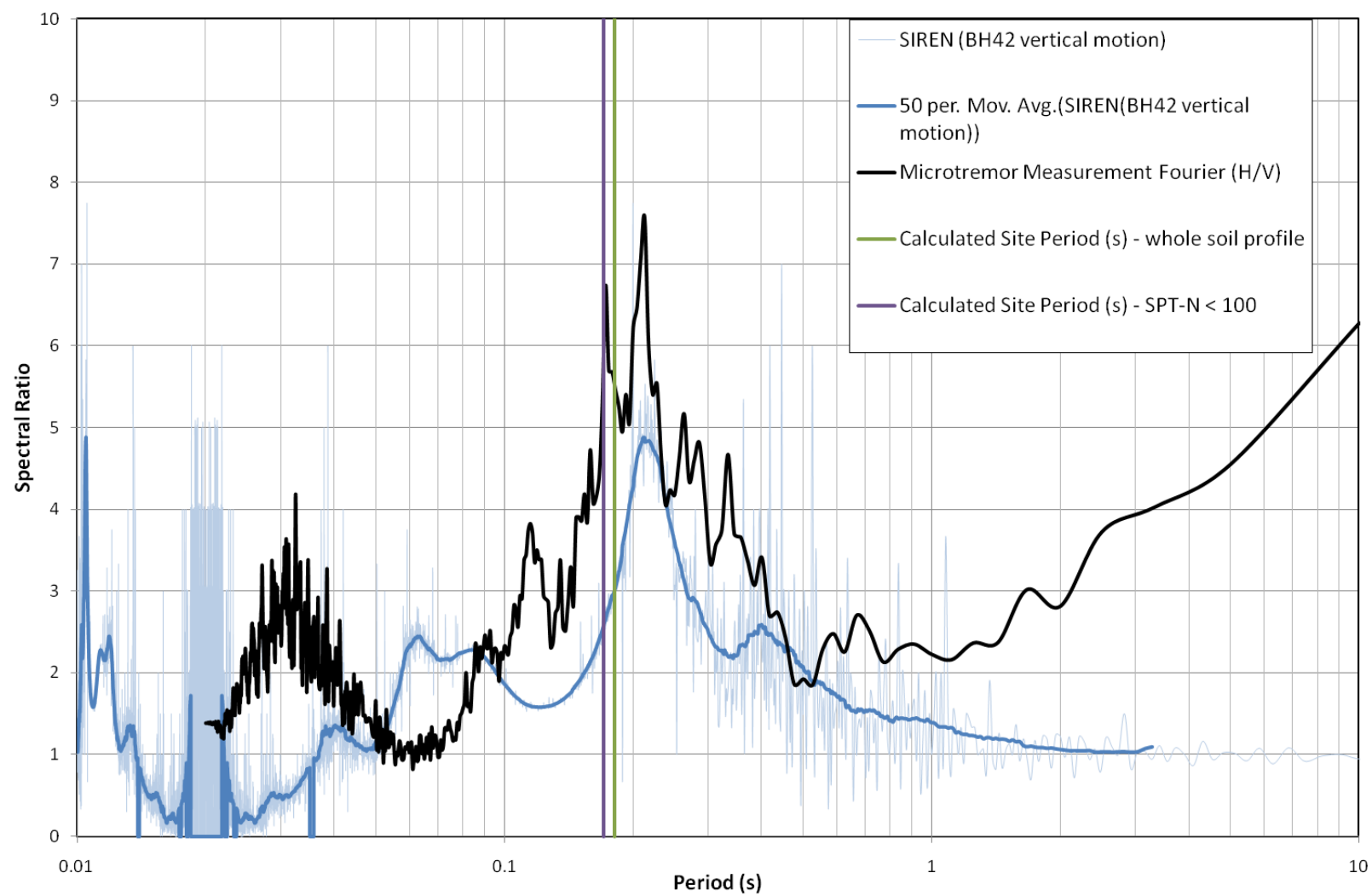


Figure 6.49 BH39 - Fourier Amplitude Spectral Ratio



**Figure 6.50 BH41 - Fourier Amplitude Spectral Ratio**



**Figure 6.51 BH42 - Fourier Amplitude Spectral Ratio**

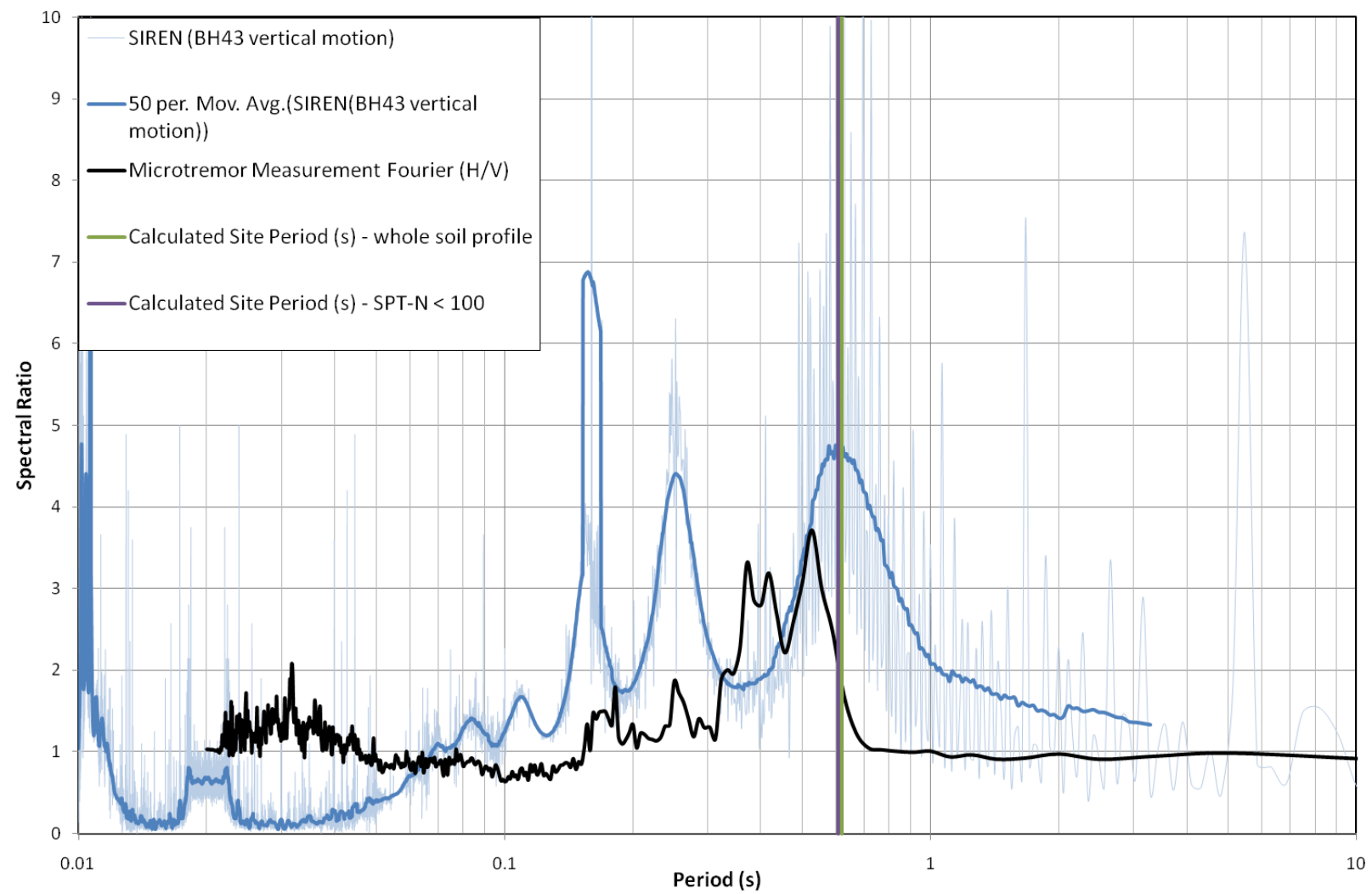
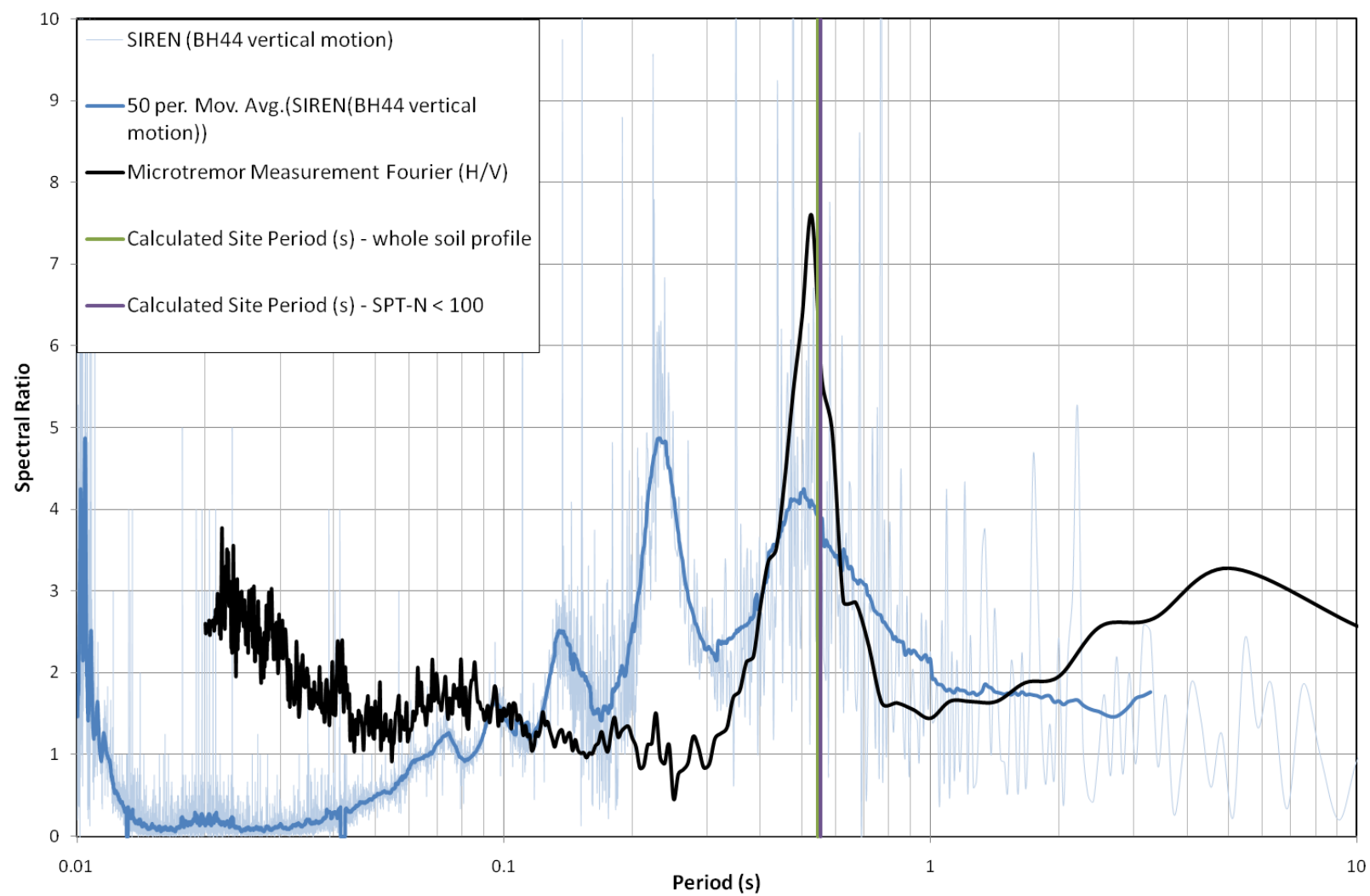


Figure 6.52 BH43 - Fourier Amplitude Spectral Ratio





**Figure 6.53 BH44 - Fourier Amplitude Spectral Ratio**

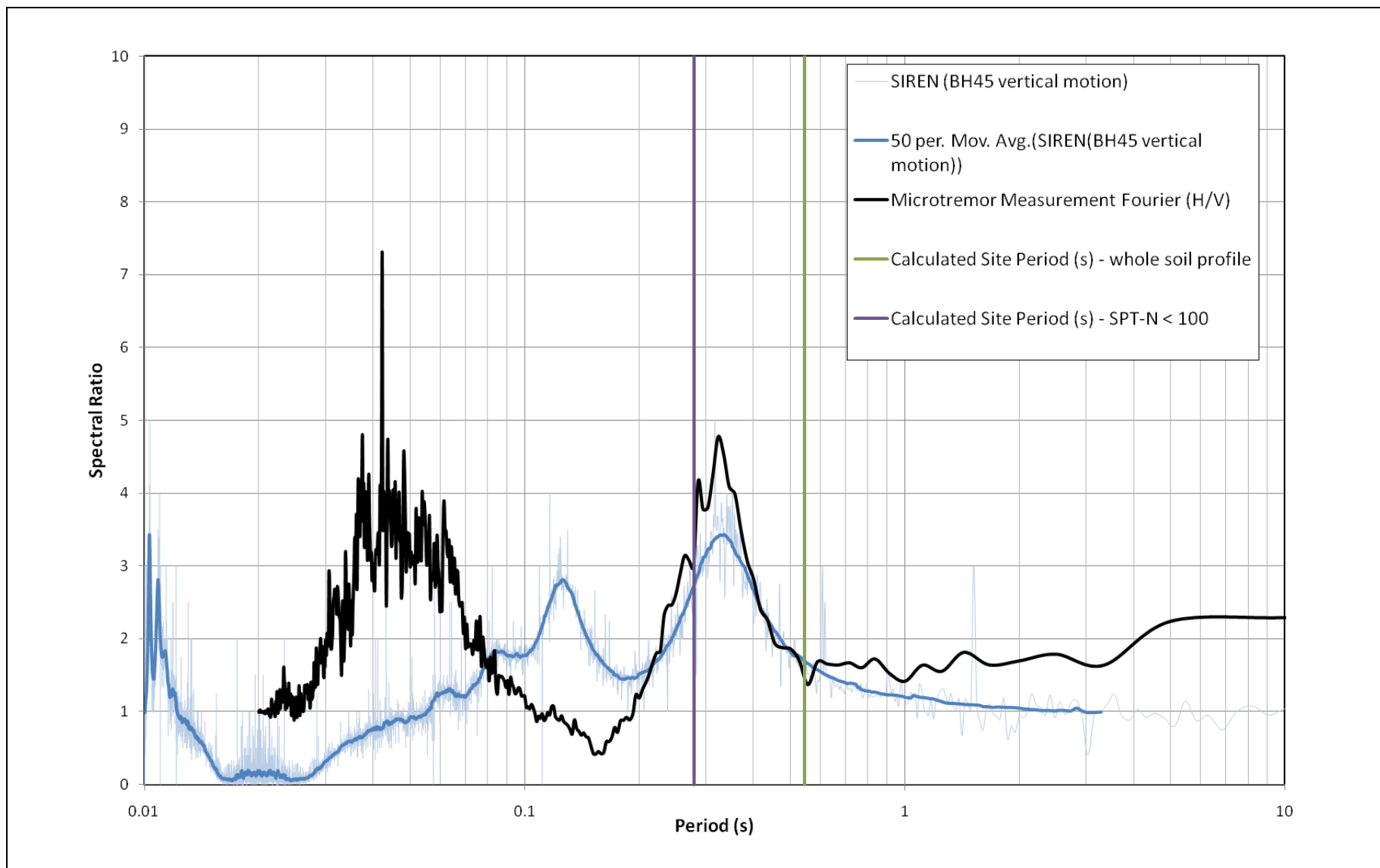


Figure 6.54 BH45 - Fourier Amplitude Spectral Ratio

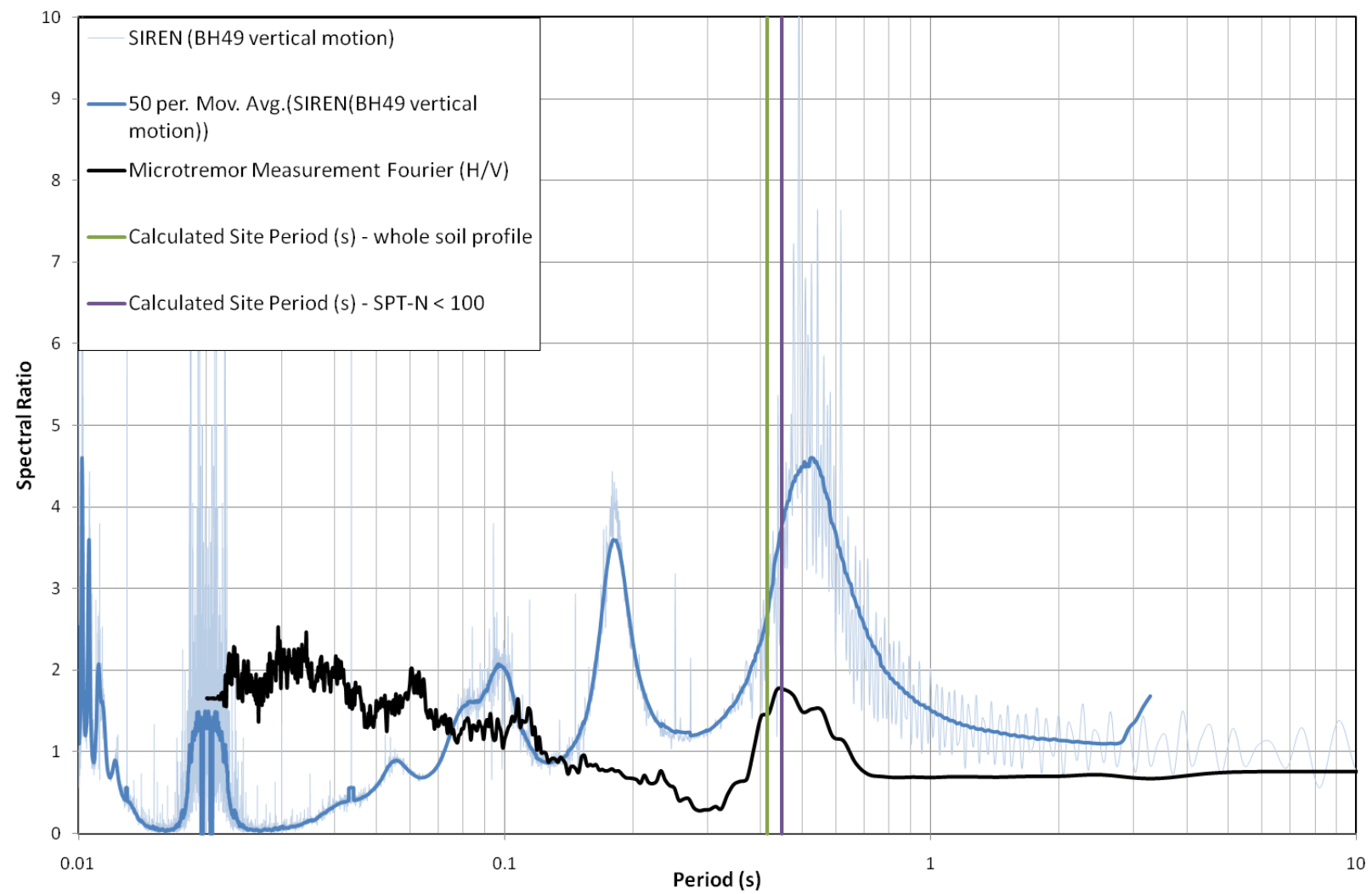


Figure 6.55 BH49 - Fourier Amplitude Spectral Ratio

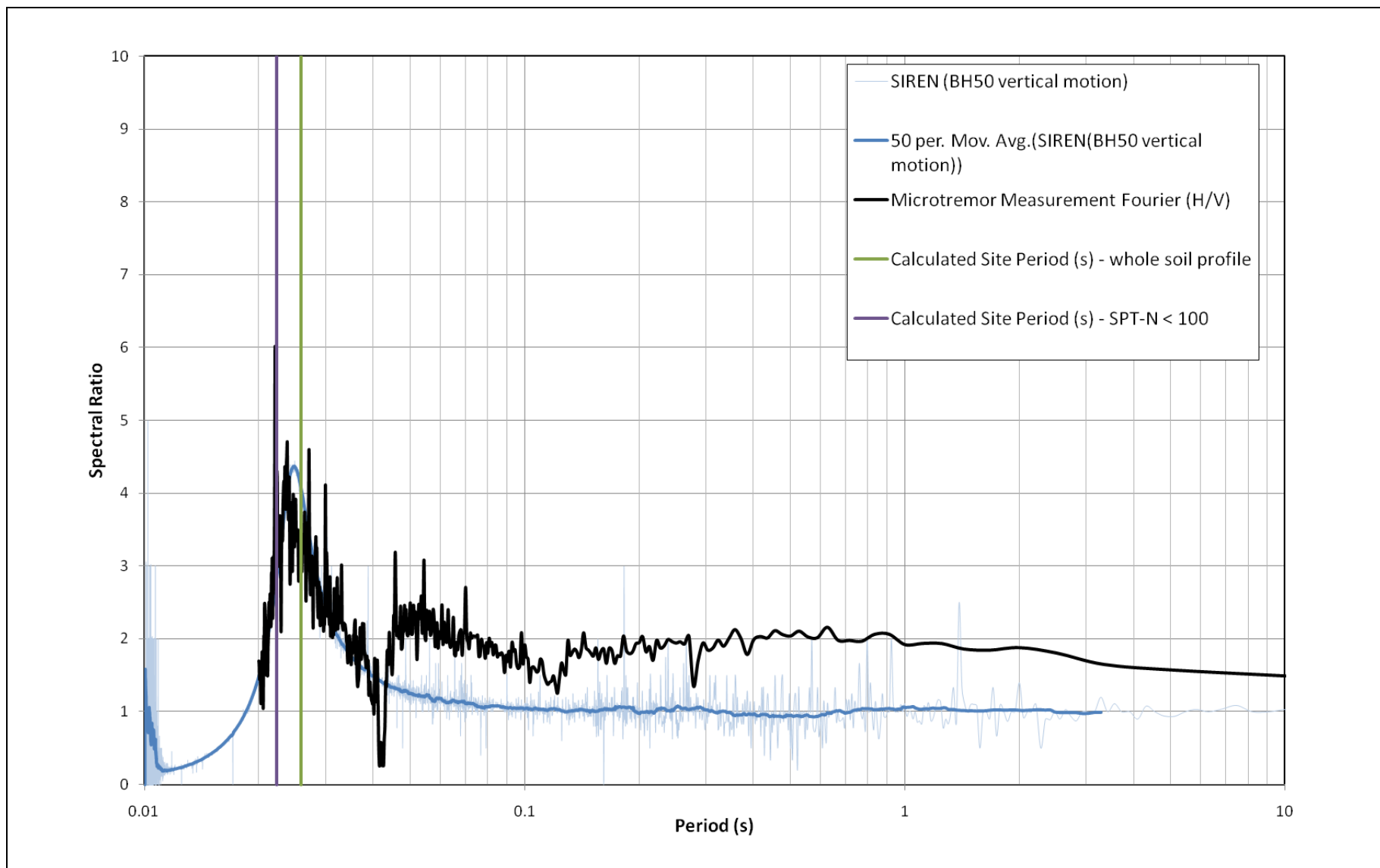


Figure 6.56 BH50 - Fourier Amplitude Spectral Ratio

## 7 Seismic Ground Motion Microzonation

This section presents how the ground surface response spectra produced by the site response analyses (see Section 6) have been studied and classified such that a systematic seismic ground motion microzonation methodology can be applied to the whole Study Area. It concludes by comparing the microzonation recommendations with those of GEERRI.

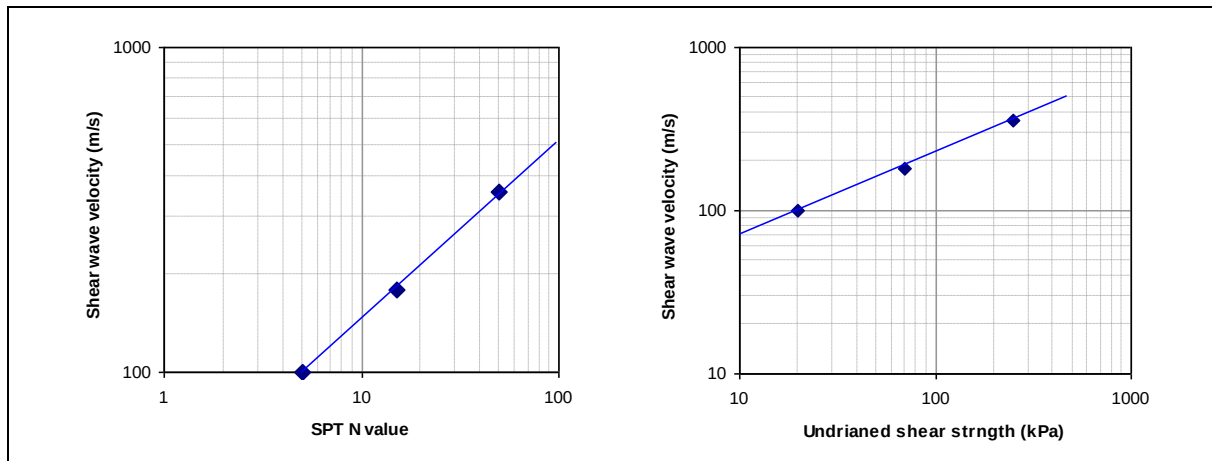
### 7.1 Established Classification Methods

It has long been recognised that local soil conditions can have a significant effect on the seismic ground motions at the ground surface. Codes of Practice in different countries address this issue by defining Site Classes based on the in-situ shear wave velocity of the soil profile. For example, the Eurocode (BSI, 2004a) and the International Building Code of the United States (ICC, 2009) adopt a site classification system based on an average shear wave velocity down to a depth of 30 m ( $V_{S,30}$ ).

Eurocode 8 (BSI, 2004a) defines Site Classes from A to D as shown in Table 7.1. As can be seen, in addition to depth and soil type, there are three parameters used for site classification, including shear-wave velocity ( $V_S$ ), SPT-N value, and undrained shear strength ( $S_U$ ).  $V_S$  is the preferred parameter. If it is not available, the Site Classes can also be derived based on the SPT-N or  $S_U$  profile in the top 30 m (or down to hard material or rock). If rock is encountered above 30 m, a value of  $V_S$  appropriate to the rock type should be used. It should be noted that the International Building Code of the United States (ICC, 2009) also denotes that an SPT-N value of 100 can be used for the rock portion. Where there is a combination of SPT-N values and  $S_U$  at various depths, they should be converted to  $V_S$  using Figure 7.1, which are derived from Table 7.1.

**Table 7.1 Definitions of Site Classes in Eurocode 8**

| Site Class | Soil Profile Description      | Average Properties in Top 30 m   |                      |                                       |
|------------|-------------------------------|----------------------------------|----------------------|---------------------------------------|
|            |                               | Shear-wave Velocity, $V_S$ (m/s) | SPT-N (Blows/300 mm) | Undrained Shear Strength, $S_U$ (kPa) |
| A          | Rock or thin (< 5 m) soil     | $800 < V_{S,30}$                 | Not applicable       | Not applicable                        |
| B          | Very dense or very stiff soil | $360 < V_{S,30} \leq 800$        | $N > 50$             | $S_U > 250$                           |
| C          | Medium to dense or stiff soil | $180 < V_{S,30} \leq 360$        | $15 < N \leq 50$     | $70 < S_U \leq 250$                   |
| D          | Loose or soft to firm soil    | $V_{S,30} \leq 180$              | $N \leq 15$          | $S_U \leq 70$                         |



**Figure 7.1 Conversion of Shear Wave Velocity from SPT-N Values and Undrained Shear Strengths (Eurocode 8)**

The representative soil property  $P_{30}$  ( $V_{S,30}$ ,  $SPT-N_{30}$  or  $S_{U,30}$ ) in the upper 30 m is calculated as:

$$P_{30} = \frac{\sum_{i=1}^n d_i}{\sum_{i=1}^n \frac{d_i}{P_i}} \dots\dots\dots (7.1)$$

where  $\sum_{i=1}^n d_i = 30 \text{ m}$

$P_i$  = soil parameter ( $V_s$ ,  $SPT-N$  or  $S_U$ )

$d_i$  = thickness of layer  $i$  between 0 and 30 m.

The Chinese Seismic Code (2010) considers a depth of 20 m to derive an average soil shear wave velocity. Its soil classification system is based on four types of soils defined by the effective shear wave velocity  $V_{S,20}$  defined as follows (see Table 7.2):

$$V_{S,20} = \frac{d_0}{t} \dots\dots\dots (7.2)$$

$$t = \sum_{i=1}^n \frac{d_i}{v_{si}} \dots\dots\dots (7.3)$$

where  $V_{S,20}$  = effective shear wave velocity (in m/s)

$d_0$  = depth of soil layer, applying minimum value of depth of overlying soil or 20 m soil (in m)

$t$  = time to transfer shear wave velocity from ground surface to the depth of soil layer,  $d_0$

$d_i$  = thickness of the  $i$ -th soil layer (in m)

- $v_{si}$  = shear wave velocity of the  $i$ -th soil layer (in m/s)  
 $n$  = number of soil layers.

The site classification system adopted by the Chinese Seismic Code (2010) is based on  $V_{S,20}$  of the soil and the depth of overlying soil is presented in Table 7.3.

**Table 7.2 Classification of Soil and Shear Wave Velocity Range,  $V_{S,20}$**

| Soil Type              | Shear Wave Velocity (m/s) |
|------------------------|---------------------------|
| Hard rock              | $V_{S,20} > 800$          |
| Firm soil or soft rock | $800 \geq V_{S,20} > 500$ |
| Medium firm soil       | $500 \geq V_{S,20} > 250$ |
| Medium soft soil       | $250 \geq V_{S,20} > 140$ |

**Table 7.3 Site Classification Based on Effective Shear Wave Velocity and Depth of Overlying Soil**

| Effective Shear Wave Velocity (m/s) | Site Classification |            |           |        |
|-------------------------------------|---------------------|------------|-----------|--------|
|                                     | I                   | II         | III       | IV     |
| $V_{S,20} > 800$                    | 0 m                 |            |           |        |
| $800 \geq V_{S,20} > 500$           | 0 m                 |            |           |        |
| $500 \geq V_{S,20} > 250$           | < 5 m               | $\geq 5$ m |           |        |
| $250 \geq V_{S,20} > 140$           | < 3 m               | 3 - 50 m   | > 50 m    |        |
| $V_{S,20} \leq 140$                 | < 3 m               | 3 - 15 m   | 15 - 80 m | > 80 m |

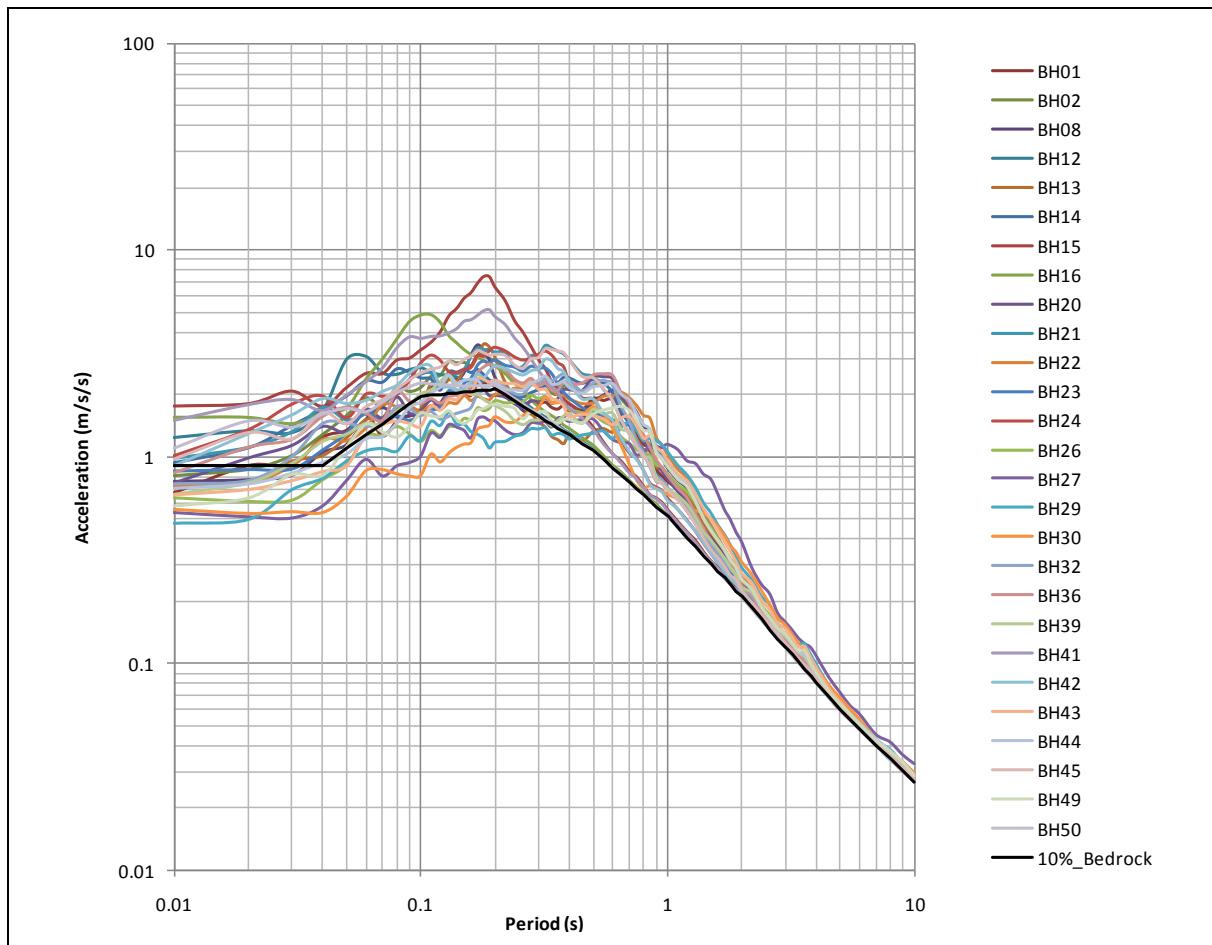
Another approach of site classification is based on the site period. In Section 3, it is shown that there was a reasonable agreement between the site period measured by the microtremor tests and those calculated from the shear wave velocities measured down to the depth of where the SPT-N value reached a value of 100.

## 7.2 Grouping of Borehole Ground Motion Spectra

In this study, the ground surface spectra have been studied and grouped according to their shape. This exercise is mainly focused on the ground motions having a 10% chance of being exceeded in the next 50 years. A check has been carried out for those having a 2% and 63% chance of being exceeded in the next 50 years. Figure 7.2 shows all ground surface response spectra for the ground motions having a 10% chance of being exceeded in the next 50 years. As can be seen, there is a fair amount of variation between them. Therefore, rational

ways of dividing the boreholes based on their various ground surface spectra have to be derived.

To provide a rational basis for grouping the boreholes, different methods have been tried to divide them into different groups based on four different parameters. Following the recommendations by the codes of practice as discussed above, these parameters include  $V_{S,30}$ ,  $V_{S,20}$ , the site periods calculated using  $V_S$  down to a depth where the SPT-N values reached 100 ( $T_{N100}$ ), and the ratio of maximum spectral acceleration to the 1-second spectral acceleration ( $S_{\max}/S_1$ ). The  $S_{\max}/S_1$  ratio is analogous to the inverse of the corner period  $T_g$ , used by GEERRI and the Chinese Code, which defines the period where the design acceleration spectrum changes from a constant maximum value to a decreasing value.



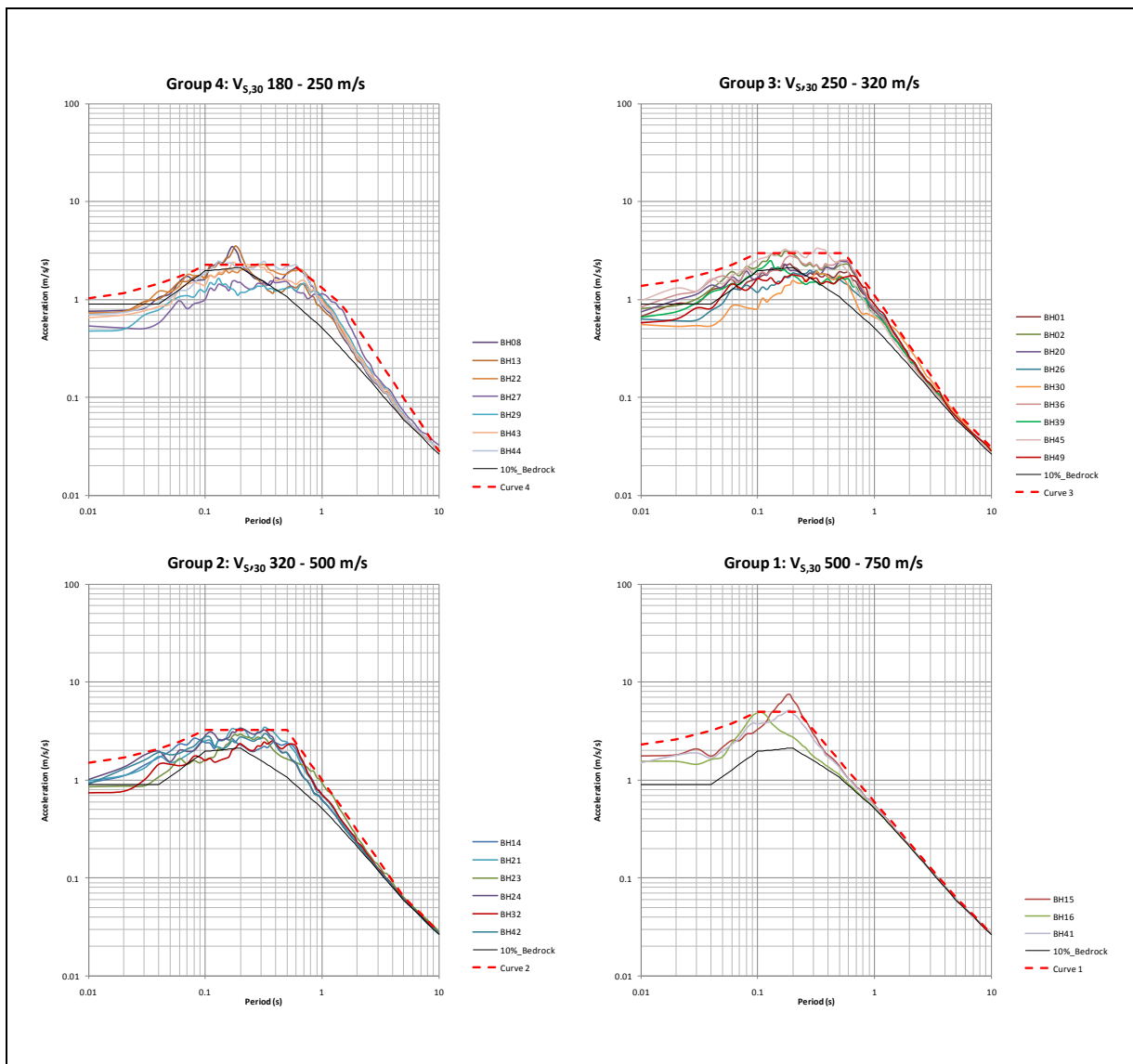
**Figure 7.2 Calculated Ground Surface Acceleration Response Spectra Having a 10% Chance of Being Exceeded in the Next 50 Years**

Figures 7.3 to 7.6 show the resulted groupings based on  $V_{S,30}$ ,  $V_{S,20}$ ,  $T_{N100}$  and  $S_{\max}/S_1$  respectively. The dashed red straight lines represent the design lines for each group (they are the same on all figures for each group). The controlling values for each of four parameters have been selected so that the groupings on each of the figures are as similar as possible.

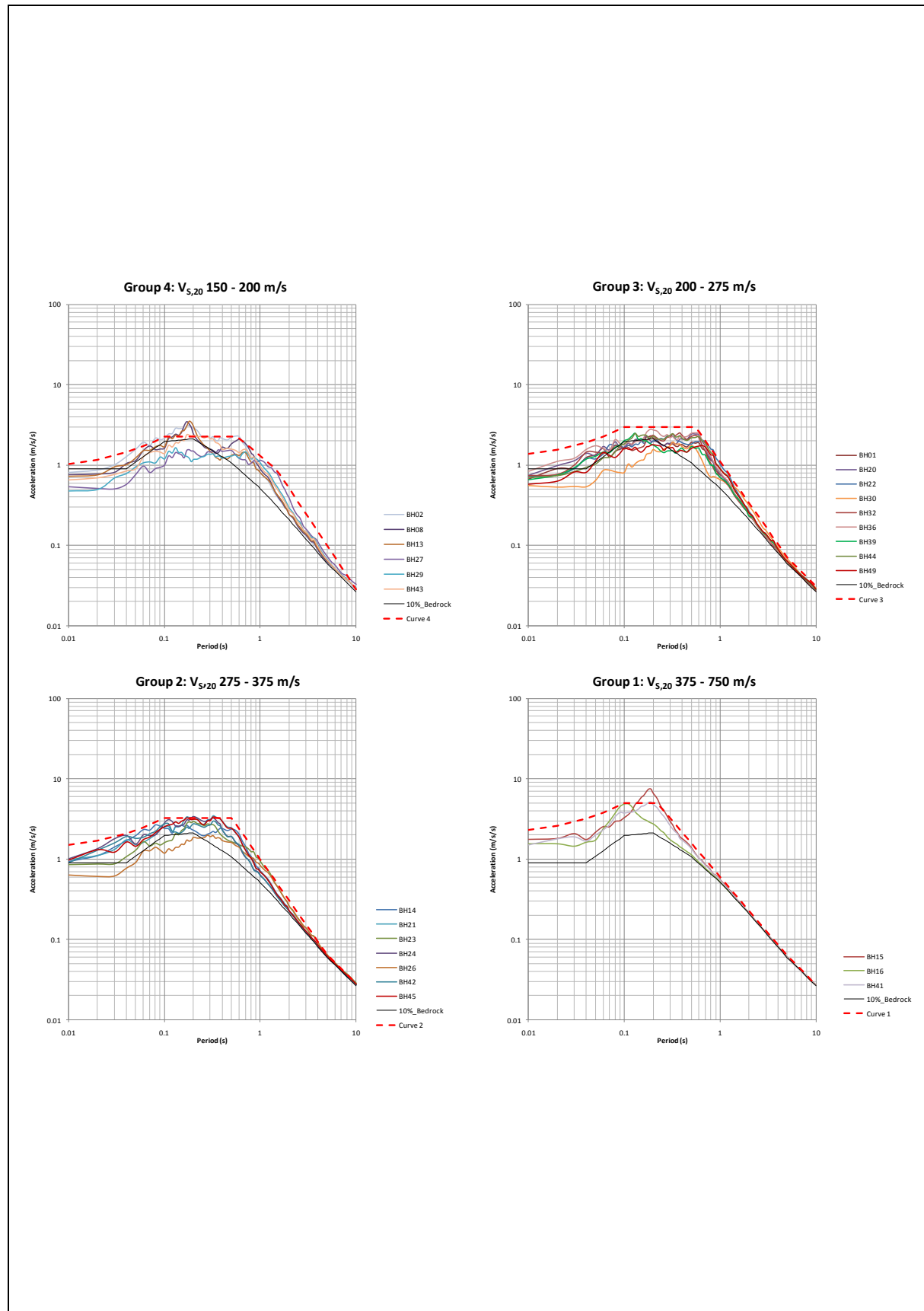


By comparing Figures 7.3 to 7.6, the most consistent grouping is the one based on the  $S_{\max}/S_1$  ratios (see Figure 7.6). It can be seen that the maximum spectral values tend to increase with  $S_{\max}/S_1$  and that the  $S_1$  values tend to reduce. Although both terms are grouped by the same single parameter, the overall match is still reasonable. The problem with this method, however, is that it cannot be solely used to assess boreholes on the basis of their logs. Also, borehole-specific site response analysis is required to determine its value. Other parameters ( $V_{S,30}$ ,  $V_{S,20}$  and  $T_{N100}$ ), on the other hand, can be determined directly from borehole logs and used to extrapolate the grouping to the AGS borehole database available within the Study Area. As such, among the remaining three parameters, it is considered that the  $T_{N100}$  grouping shown on Figure 7.5 gives the most consistent result.

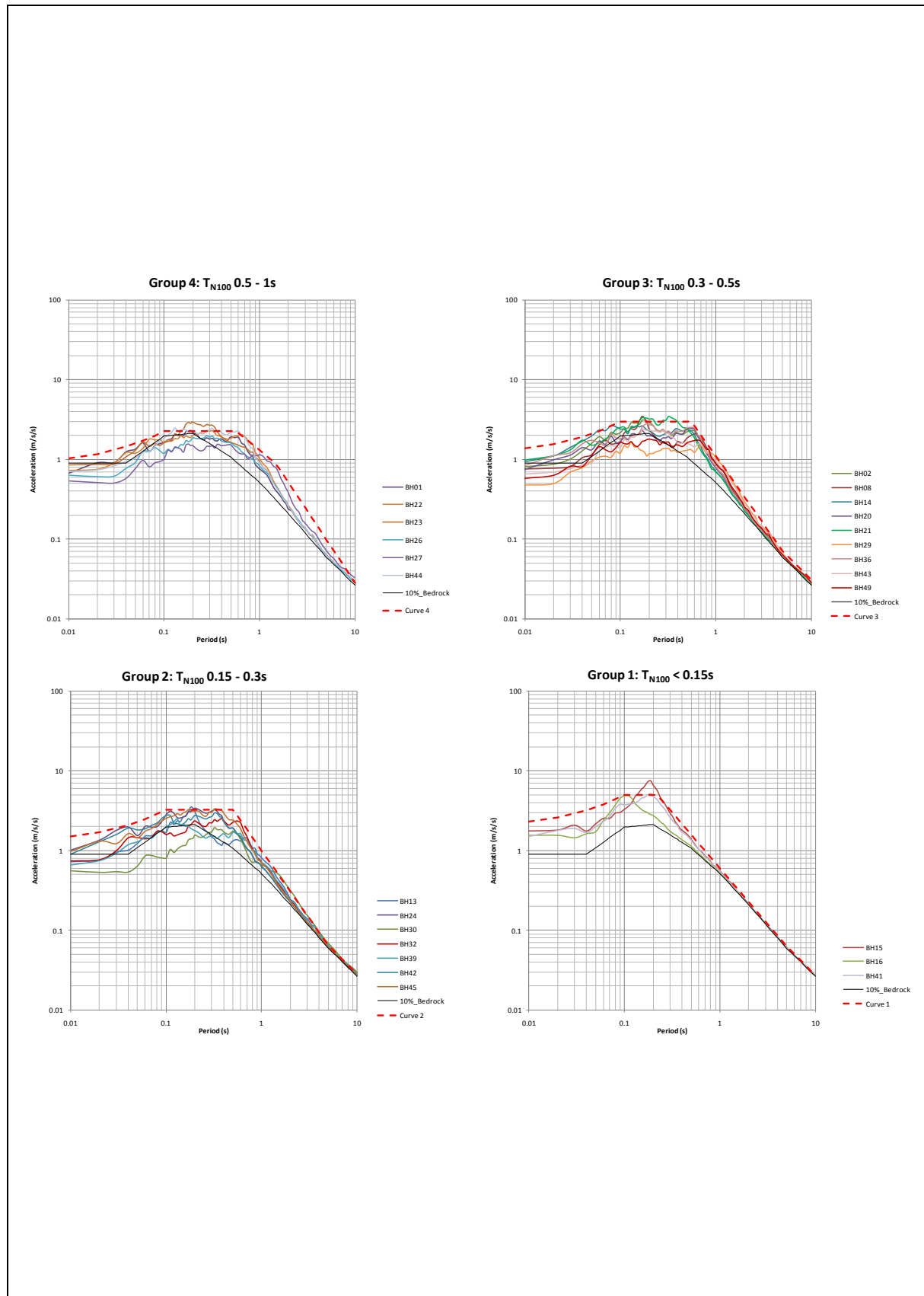
The same groupings are shown in Figures 7.7 to 7.10 for the ground motion having a 2% chance of being exceeded in the next 50 years and in Figures 7.11 to 7.14 for the ground motion having a 63% chance of being exceeded in the next 50 years.



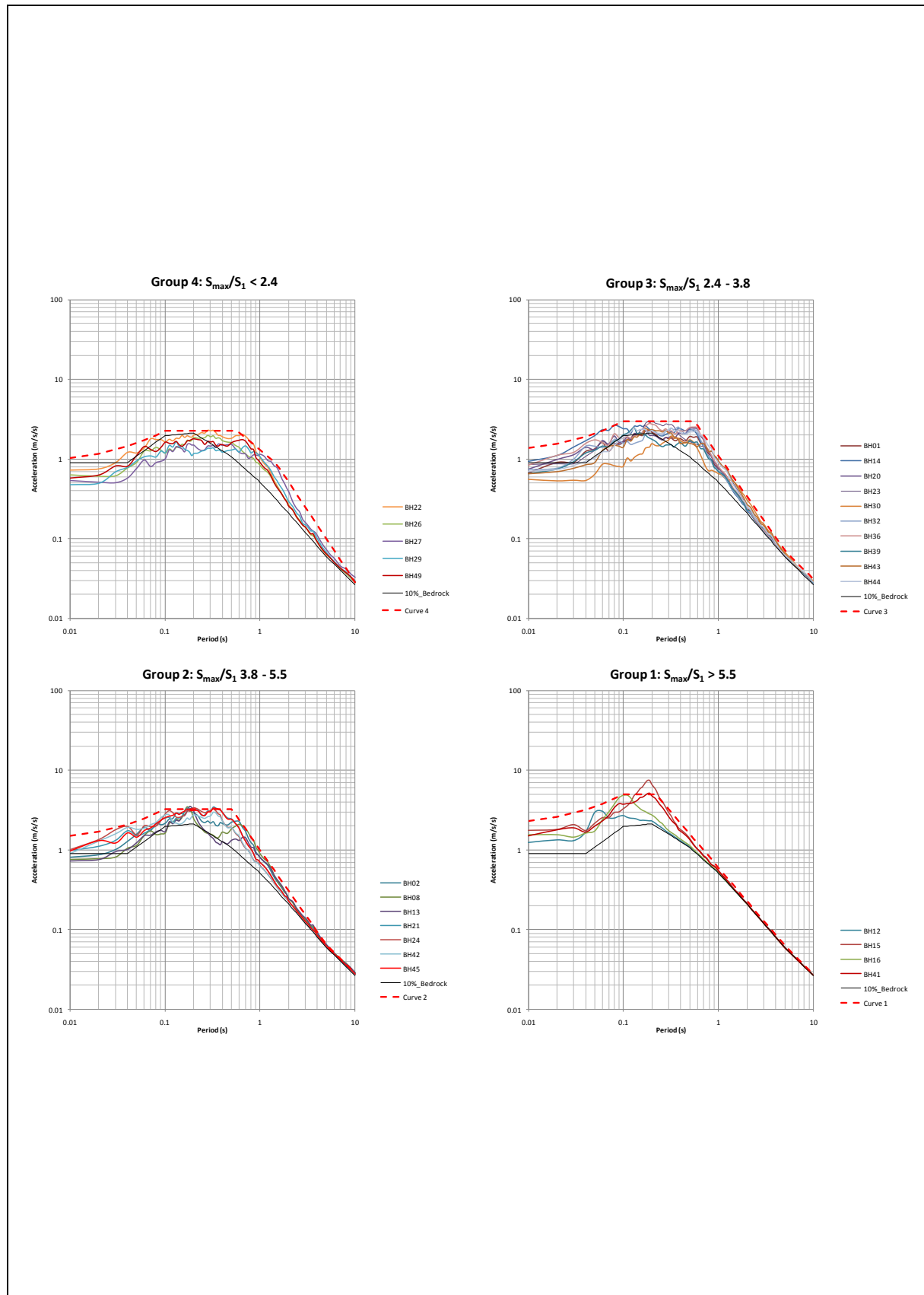
**Figure 7.3 10% in 50 Years Spectra Grouped on the Basis of their  $V_{S,30}$  Values**



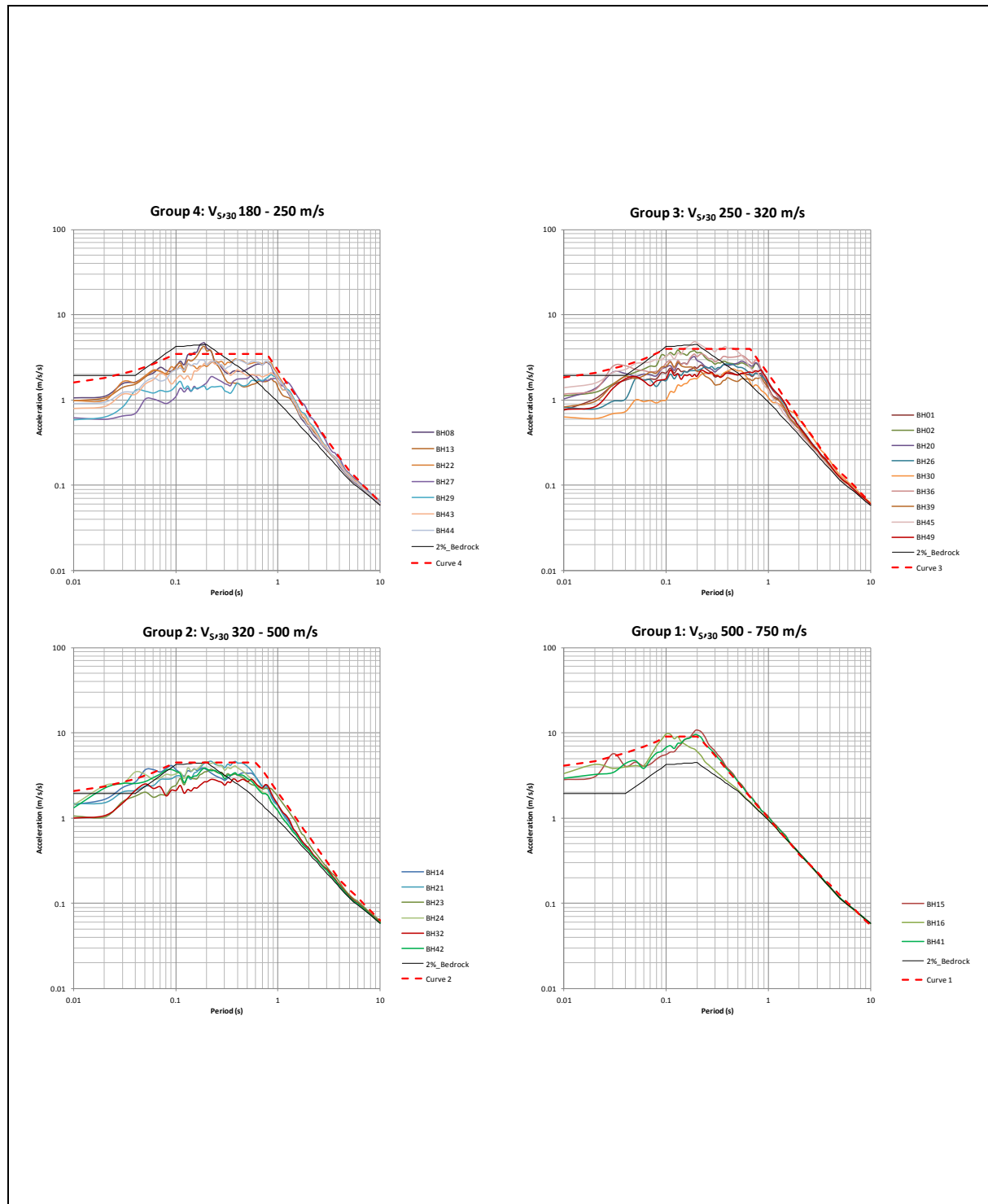
**Figure 7.4 10% in 50 Years Spectra Grouped on the Basis of their  $V_{s,20}$  Values**



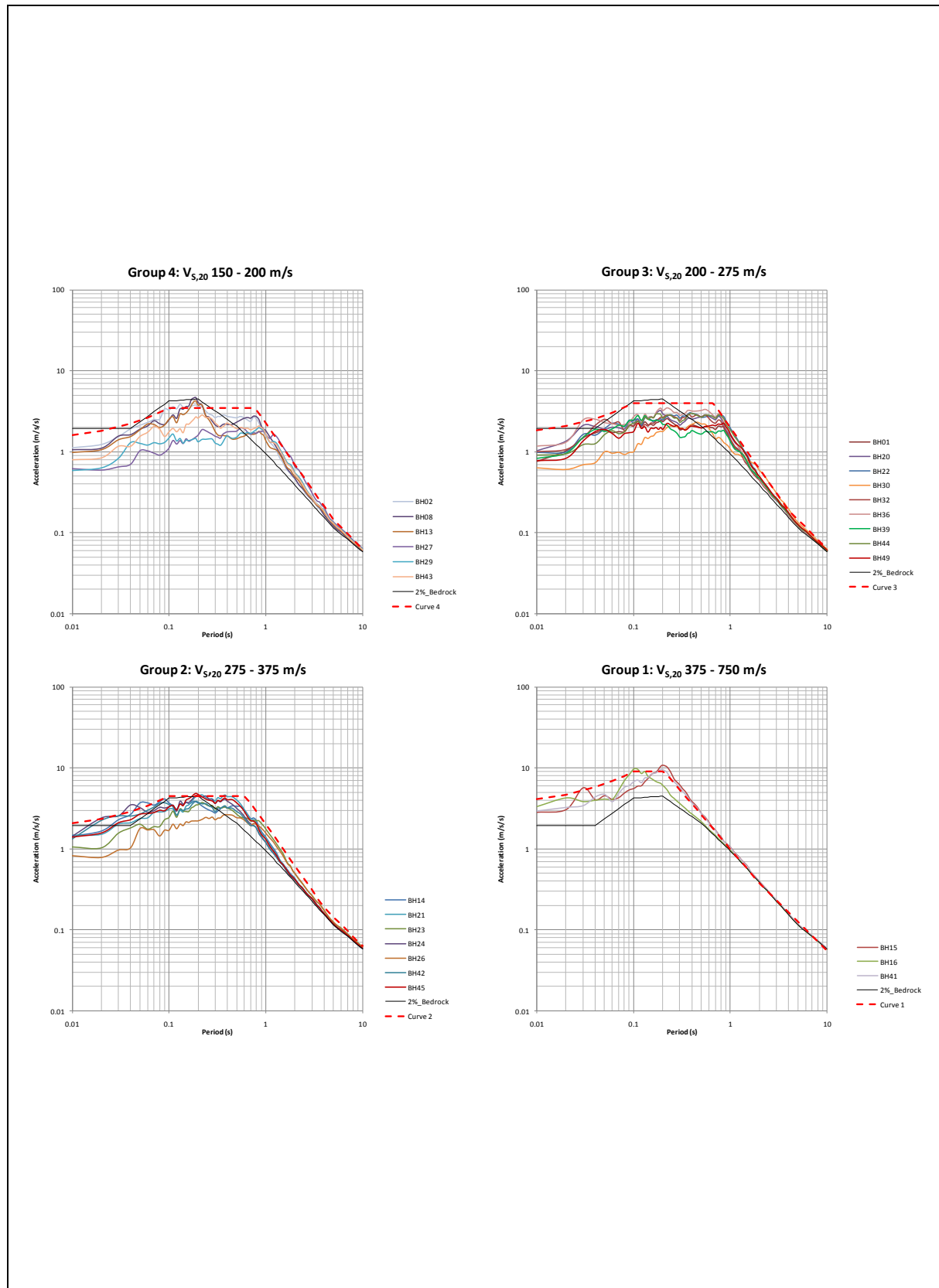
**Figure 7.5 10% in 50 Years Spectra Grouped on the Basis of their  $T_{N100}$  Values**



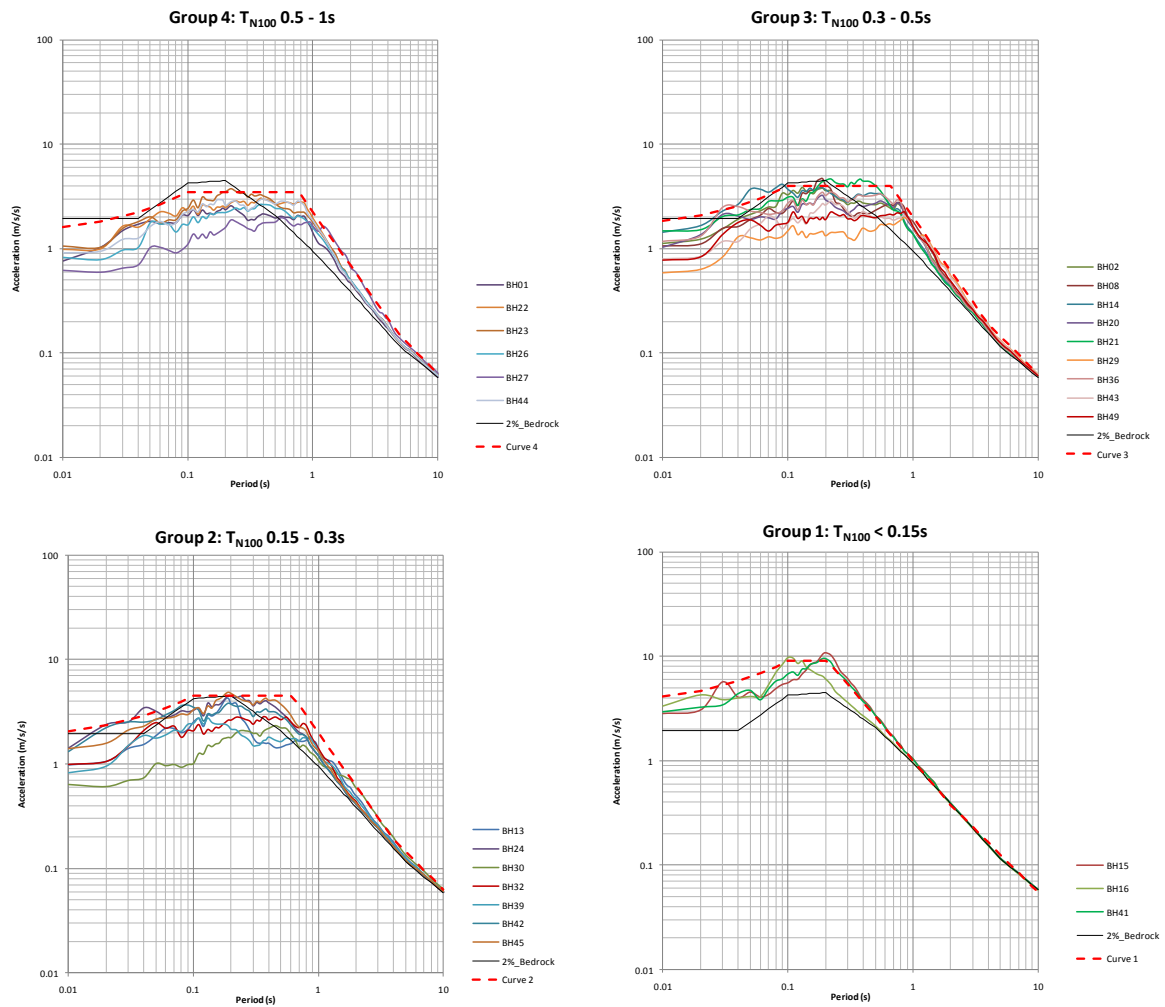
**Figure 7.6 10% in 50 Years Spectra Grouped on the Basis of their  $S_{max}/S_1$  Ratios**



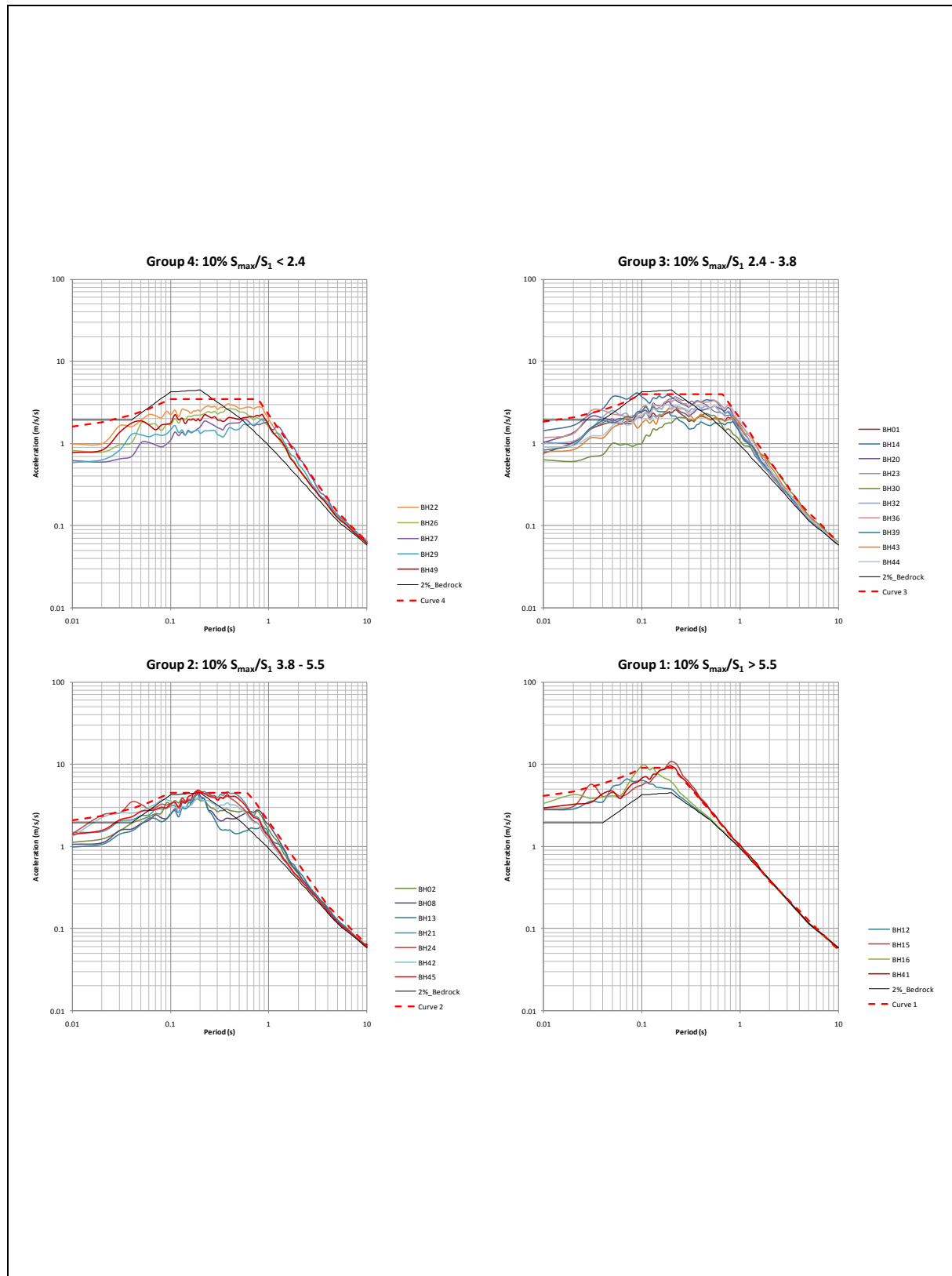
**Figure 7.7 2% in 50 Years Spectra Grouped on the Basis of their  $V_{s,30}$  Values**



**Figure 7.8 2% in 50 Years Spectra Grouped on the Basis of their  $V_{s,20}$  Values**

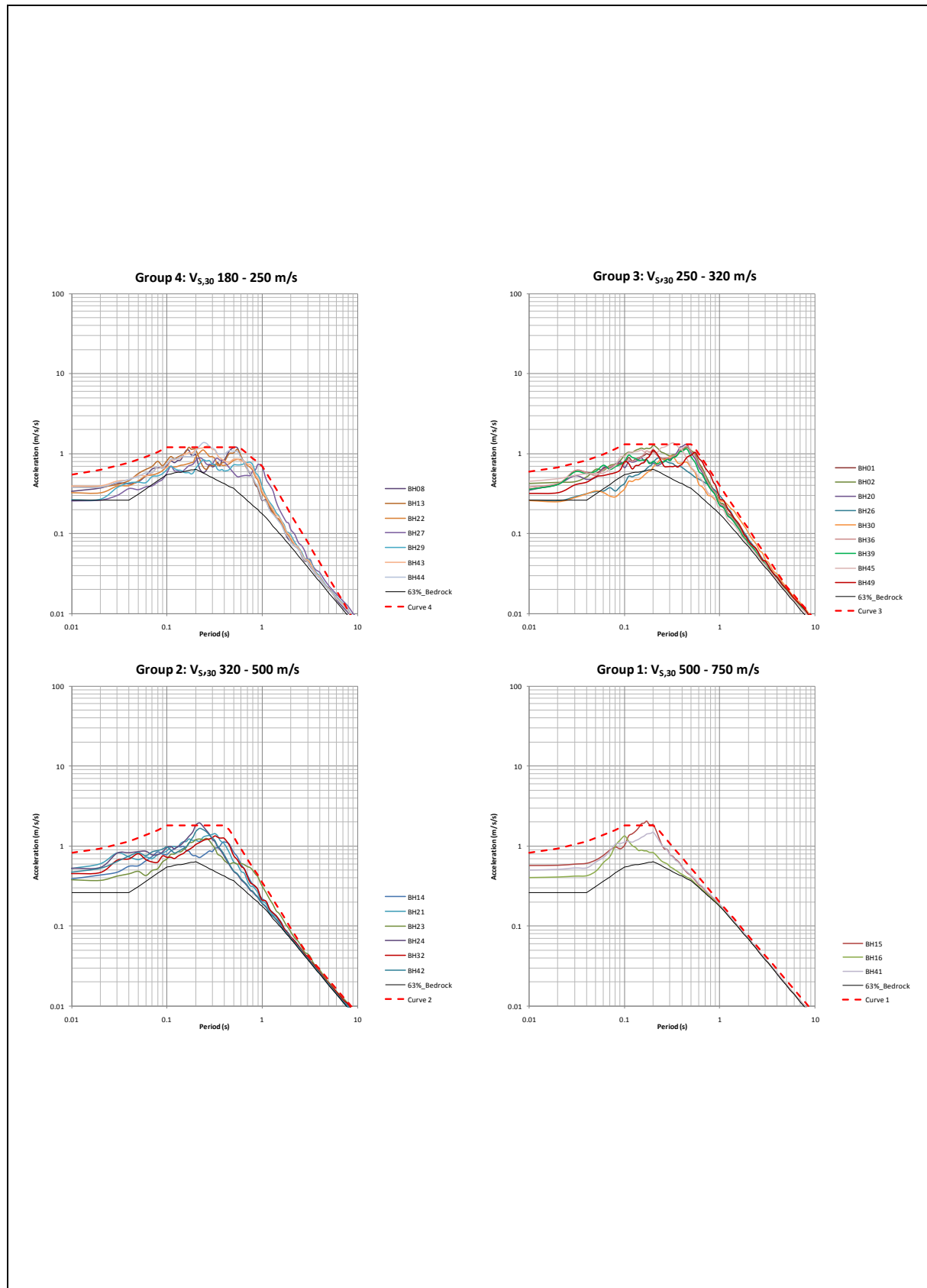


**Figure 7.9 2% in 50 Years Spectra Grouped on the Basis of their  $T_{N100}$  Values**

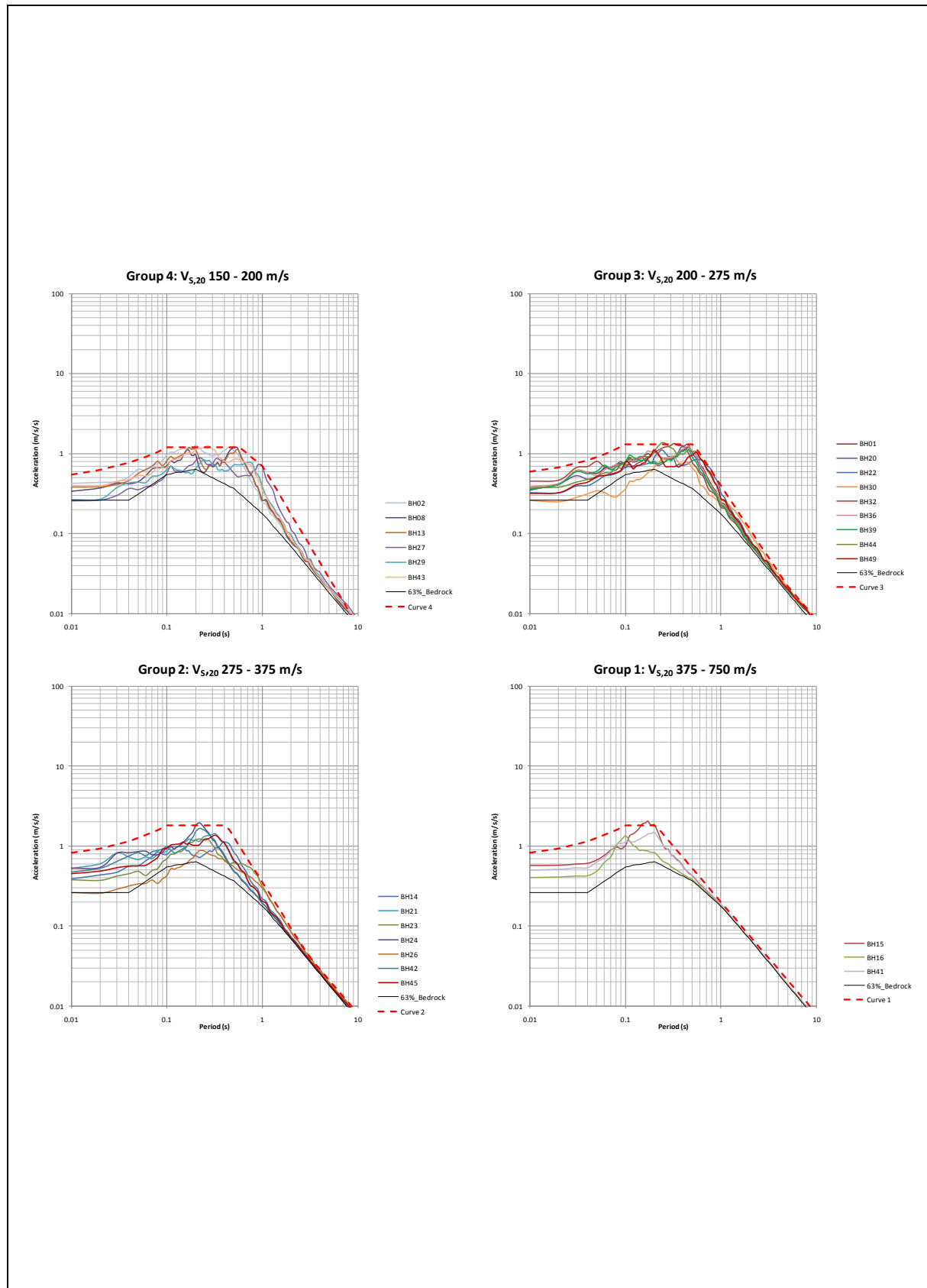


**Figure 7.10 2% in 50 Years Spectra Grouped on the Basis of their 10% in 50 Years Spectra  $S_{\max}/S_1$  Ratios**

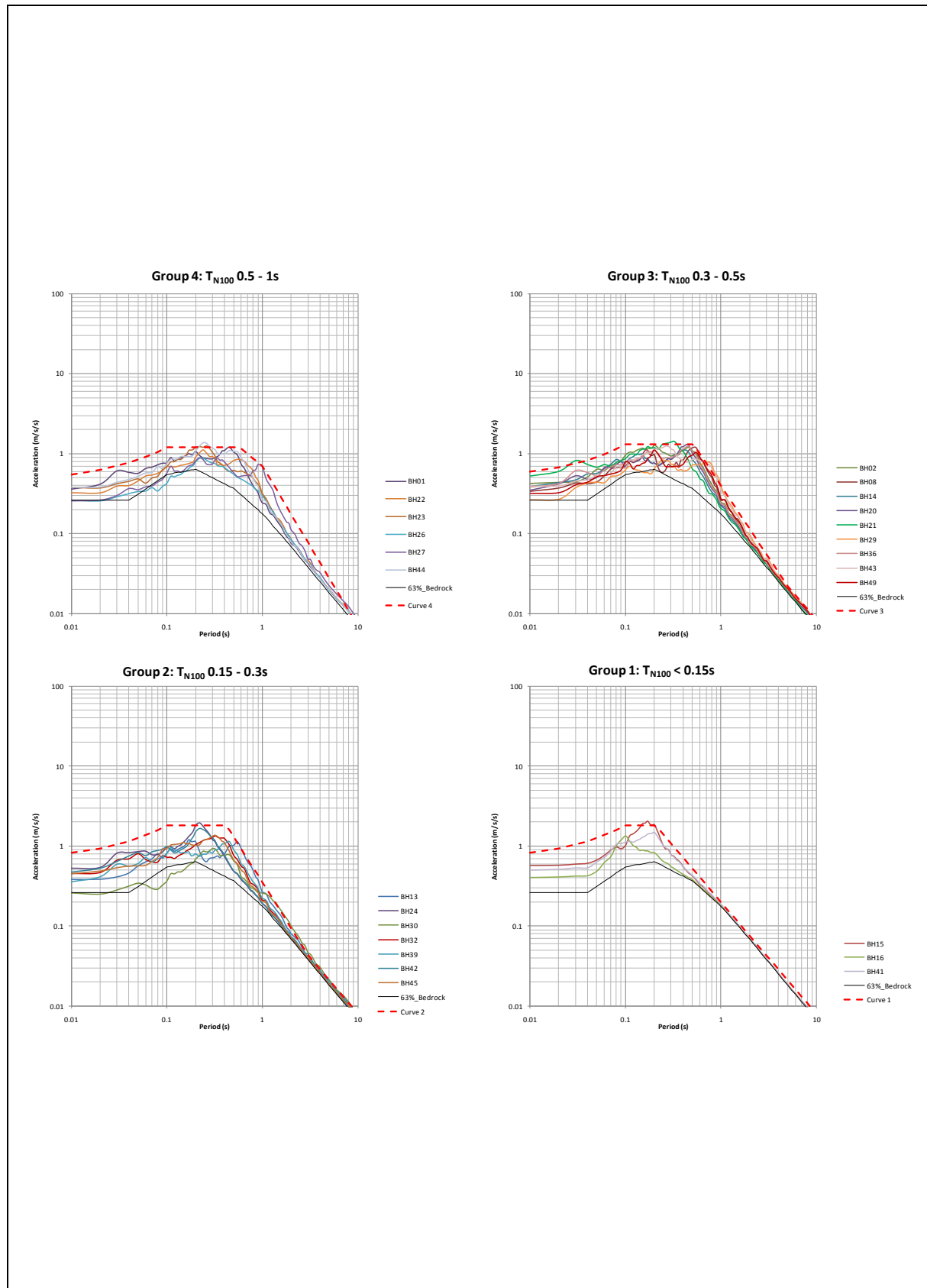




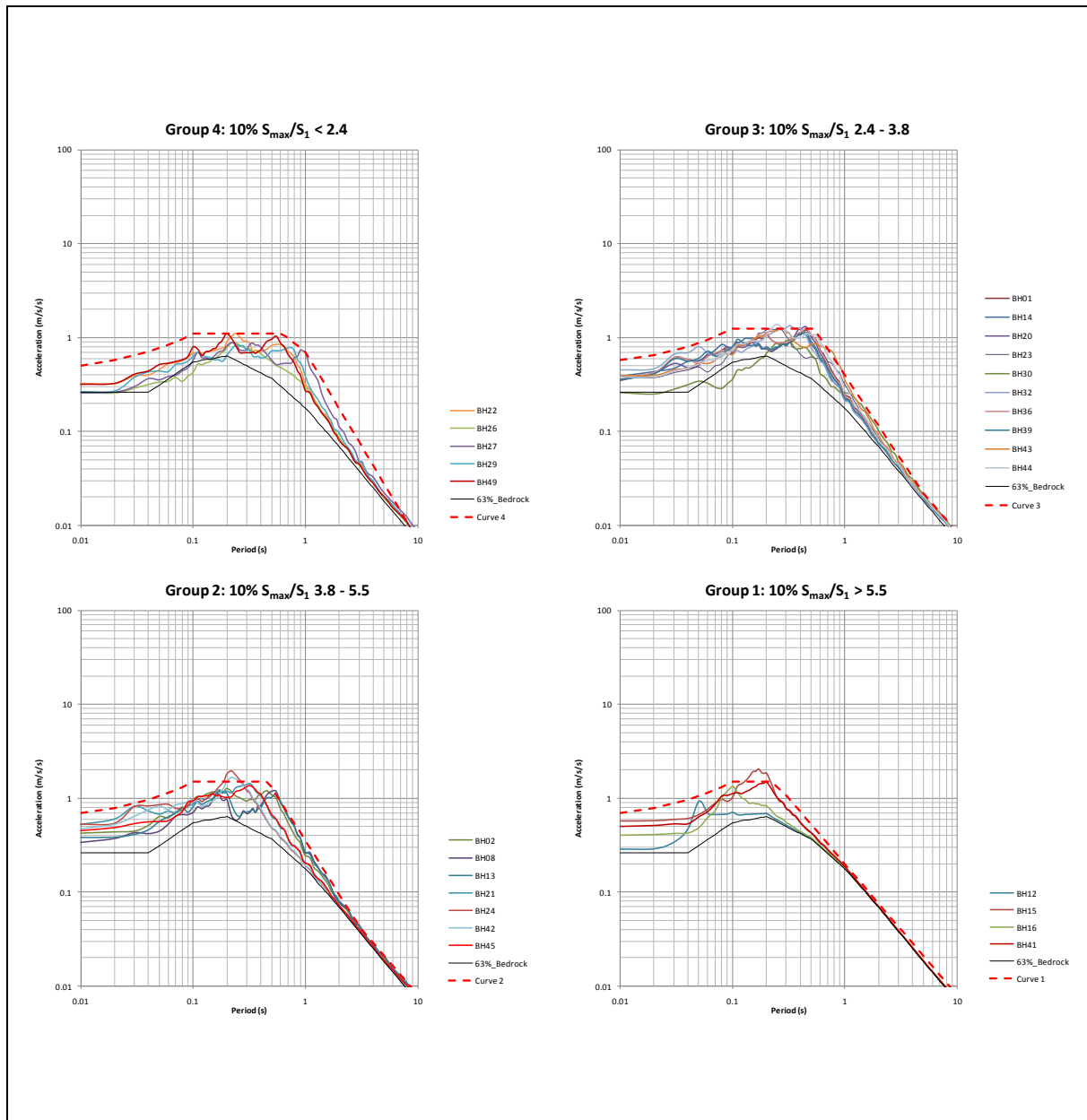
**Figure 7.11 63% in the Next 50 Years Spectra Grouped on the Basis of their  $V_{s,30}$  Values**



**Figure 7.12 63% in the Next 50 Years Spectra Grouped on the Basis of their  $V_{s,20}$  Values**



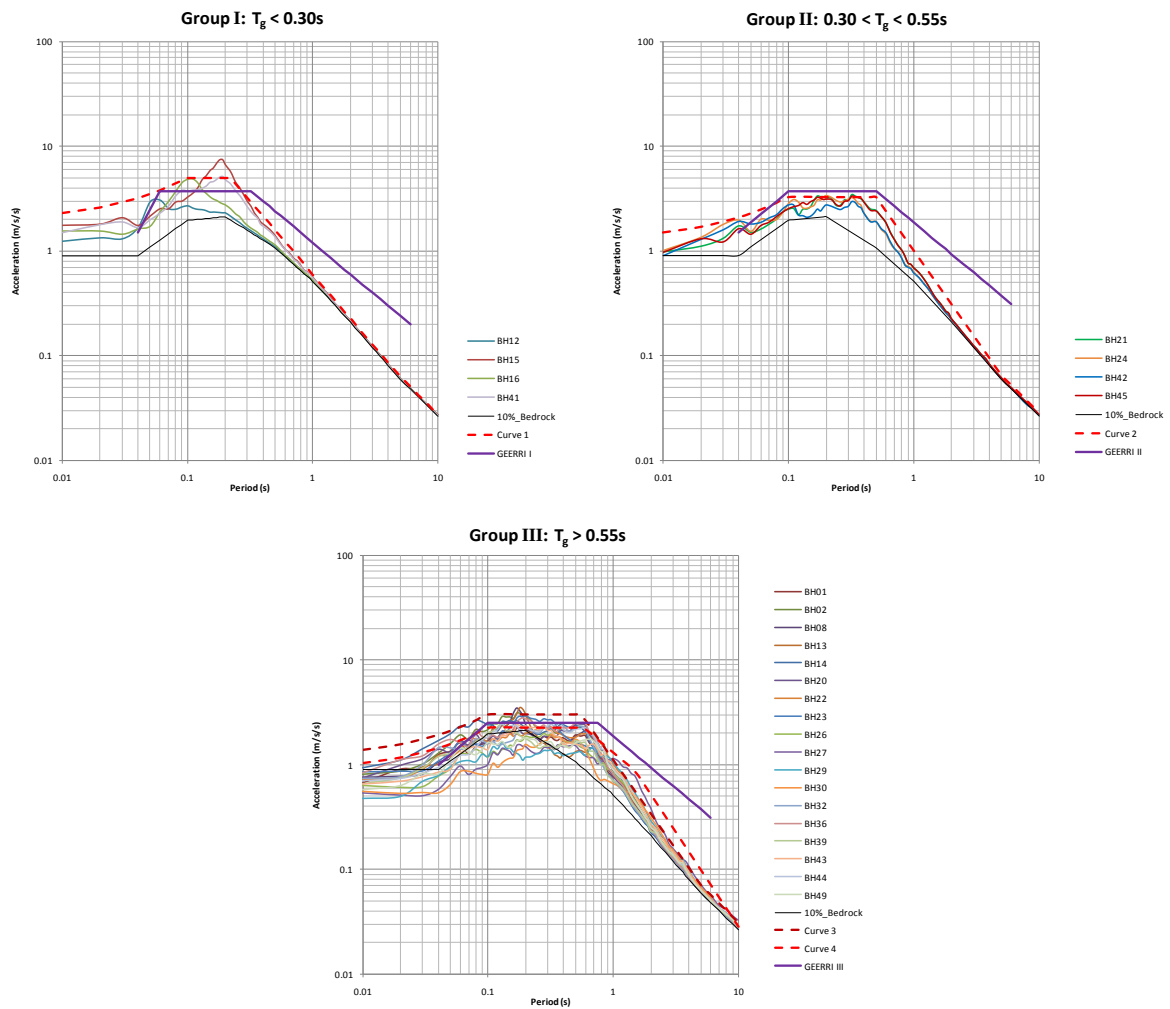
**Figure 7.13 63% in 50 Years Spectra Grouped on the Basis of their  $T_{N100}$  Values**



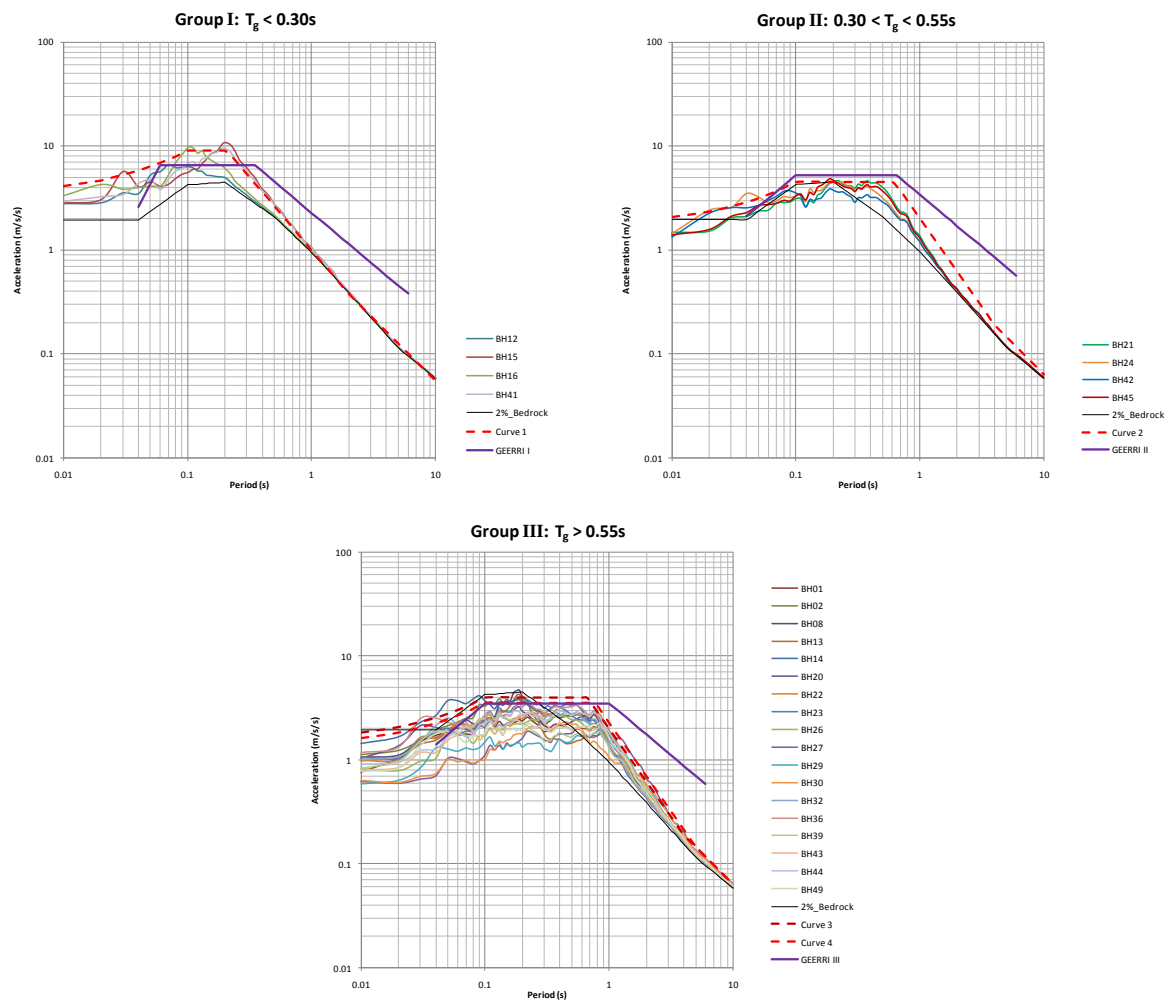
**Figure 7.14 63% in 50 Years Spectra Grouped on the Basis of their 10% in 50 Years Spectra  $S_{max}/S_1$  Ratios**

### 7.3 Comparison with the GEERRI Borehole Classification

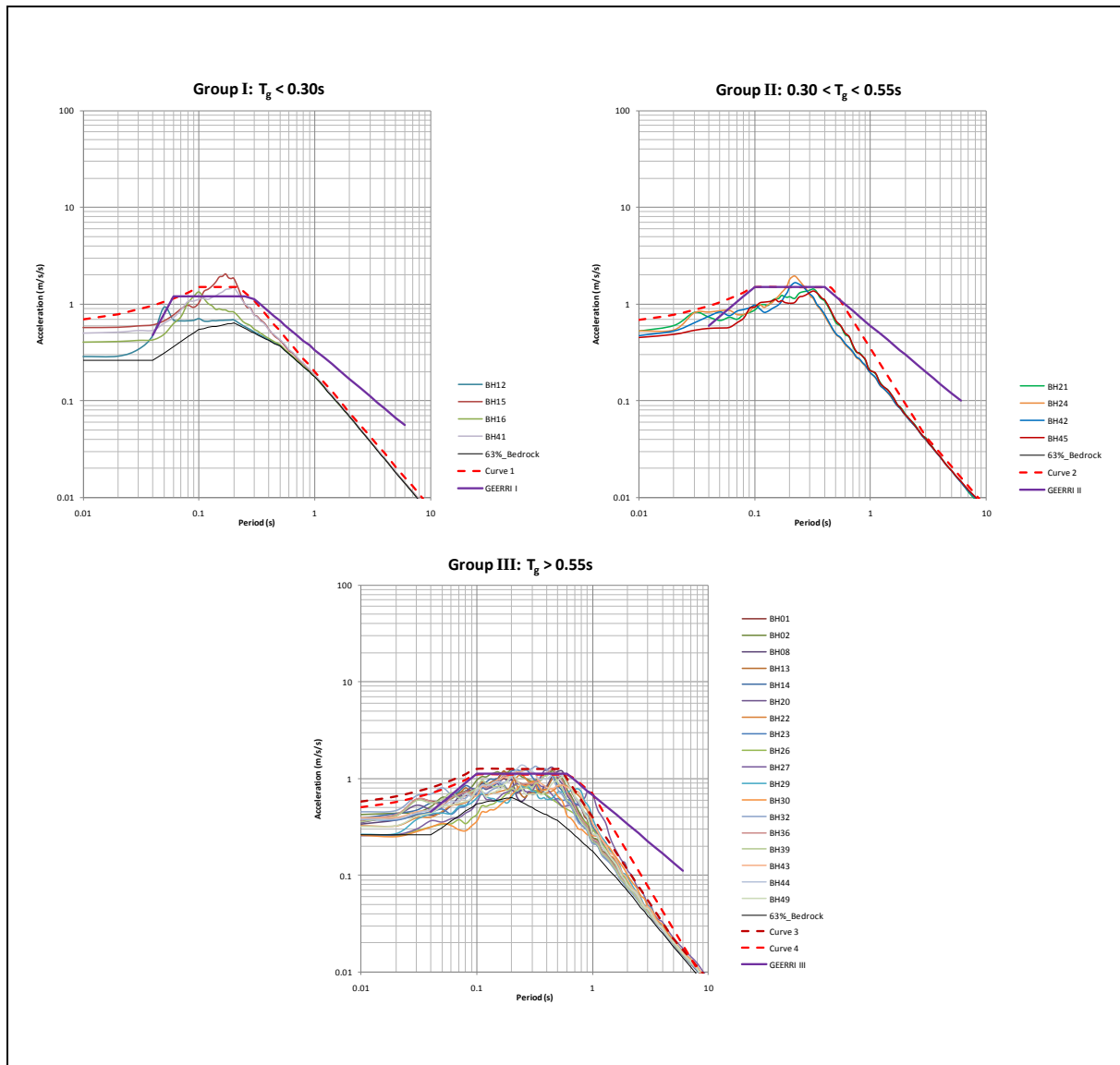
As can be seen in Appendix E, the GEERRI study resulted in three site classes, denoted as Site Classes I, II and III. Their borehole classification and the design envelopes for each site class for the 10%, 2% and 63% chance of being exceeded in the next 50 years are shown in Figures 7.15, 7.16 and 7.17 respectively. As can be seen, the design envelopes are quite similar with design lines derived above in terms of the peak spectral values. The major difference is the larger spectral values of the GEERRI curves at long periods because GEERRI used an exponent of 1 for all curves at structural periods larger than the  $T_g$  values.



**Figure 7.15 10% in 50 Years Spectra Compared to the GEERRI Design Curves**



**Figure 7.16 2% in 50 Years Spectra Compared to the GEERRI Design Curves**



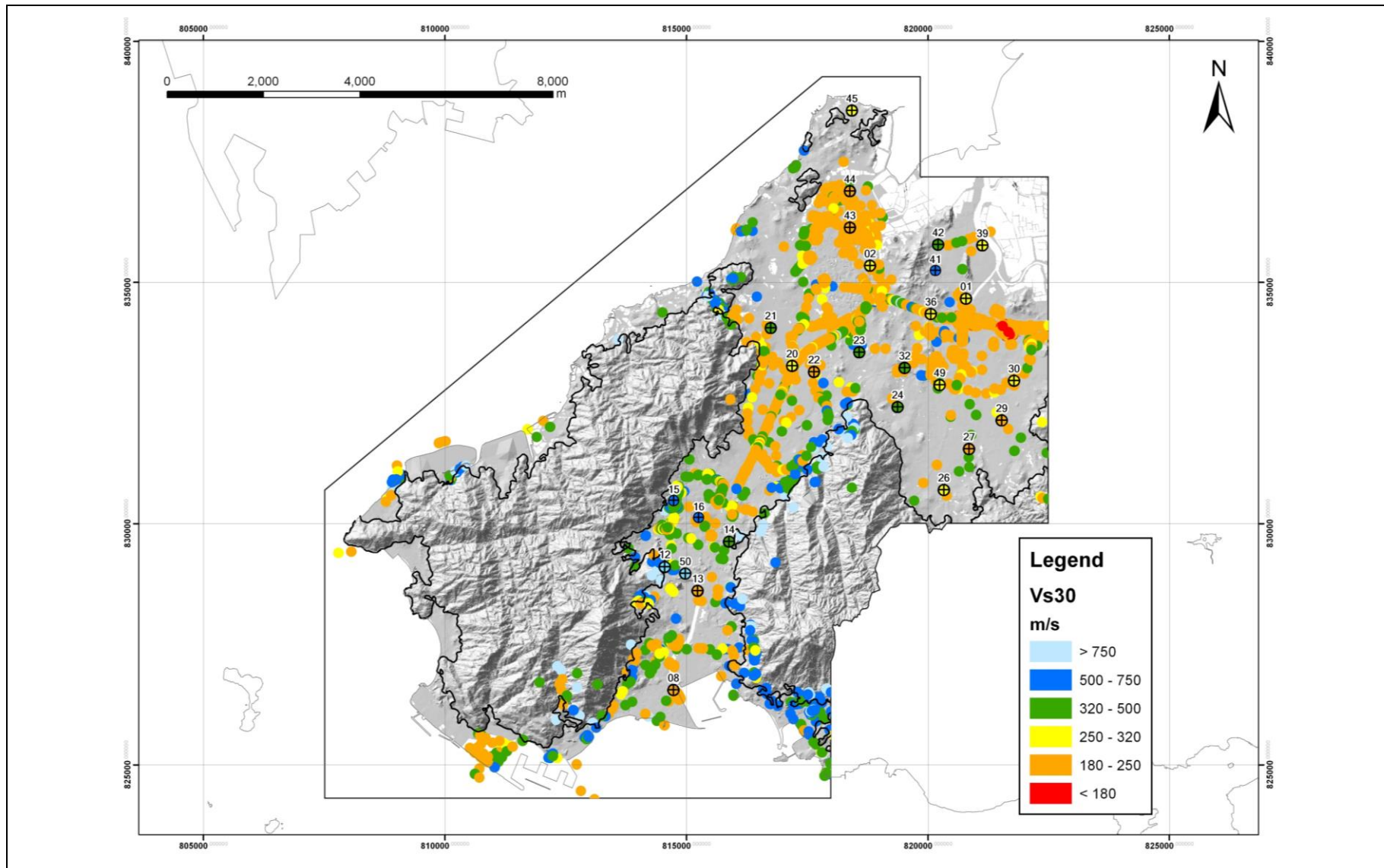
**Figure 7.17 63% in 50 Years Spectra Compared to the GEERRI Design Curves**

## 7.4 Extrapolation of the Borehole Classes to the Study Area

Extrapolation has been carried out in two ways, one using the AGS borehole database and one using the slope data, as described in the following sections.

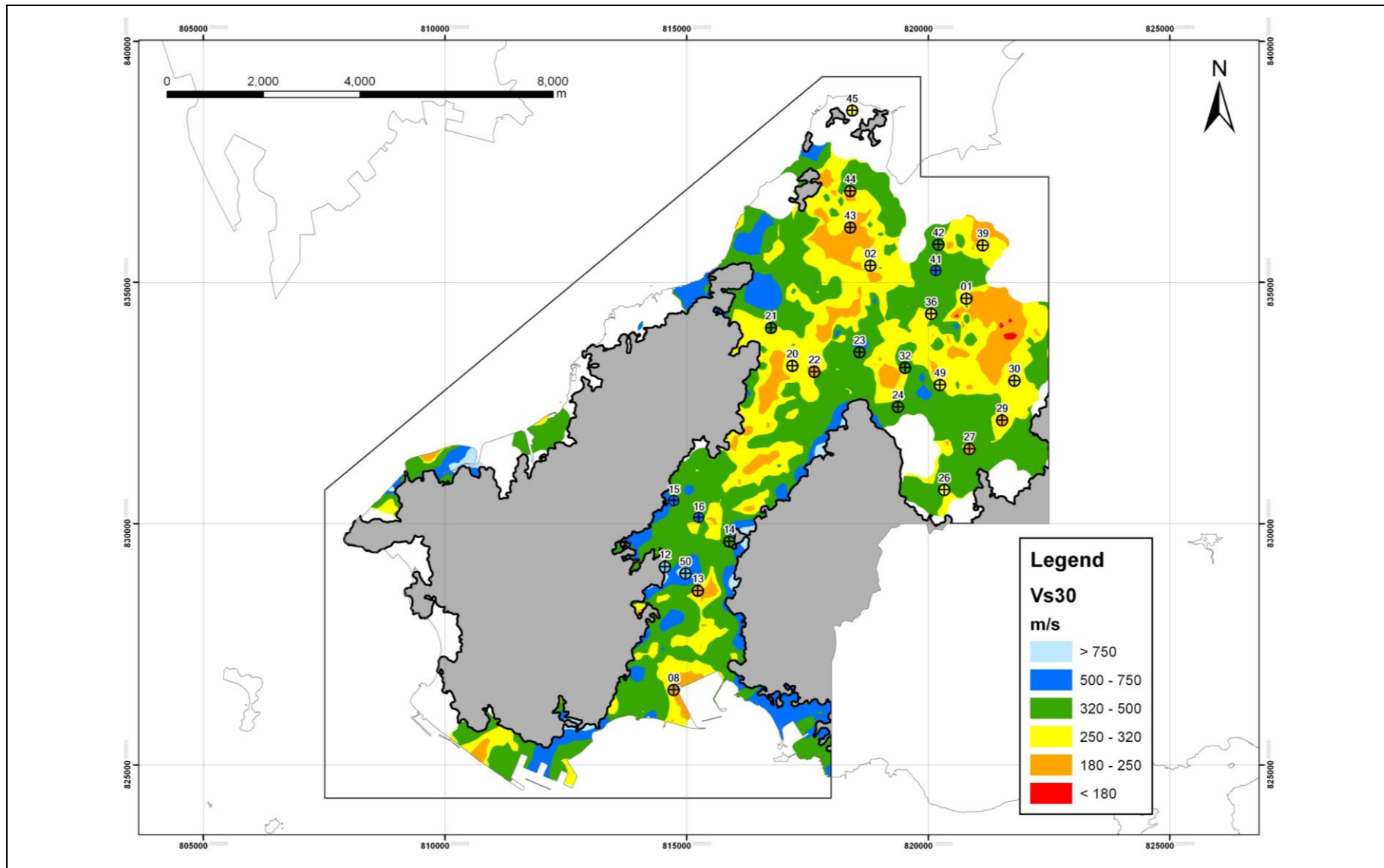
### 7.4.1 Extrapolation Using the AGS Database

The available AGS borehole data has been analysed to generate the above parameters ( $V_{S,30}$ ,  $V_{S,20}$  and  $T_{N100}$ ). The results are plotted in Figures 7.18 and 7.19 for  $V_{S,30}$ , Figures 7.20 and 7.21 for  $V_{S,20}$  and Figures 7.22 and 7.23 for  $T_{N100}$ . For each pair of figures, the first one shows the classification of each borehole in the AGS data shown as a coloured circle at the location of the AGS borehole. The second one shows a contour diagram developed from these

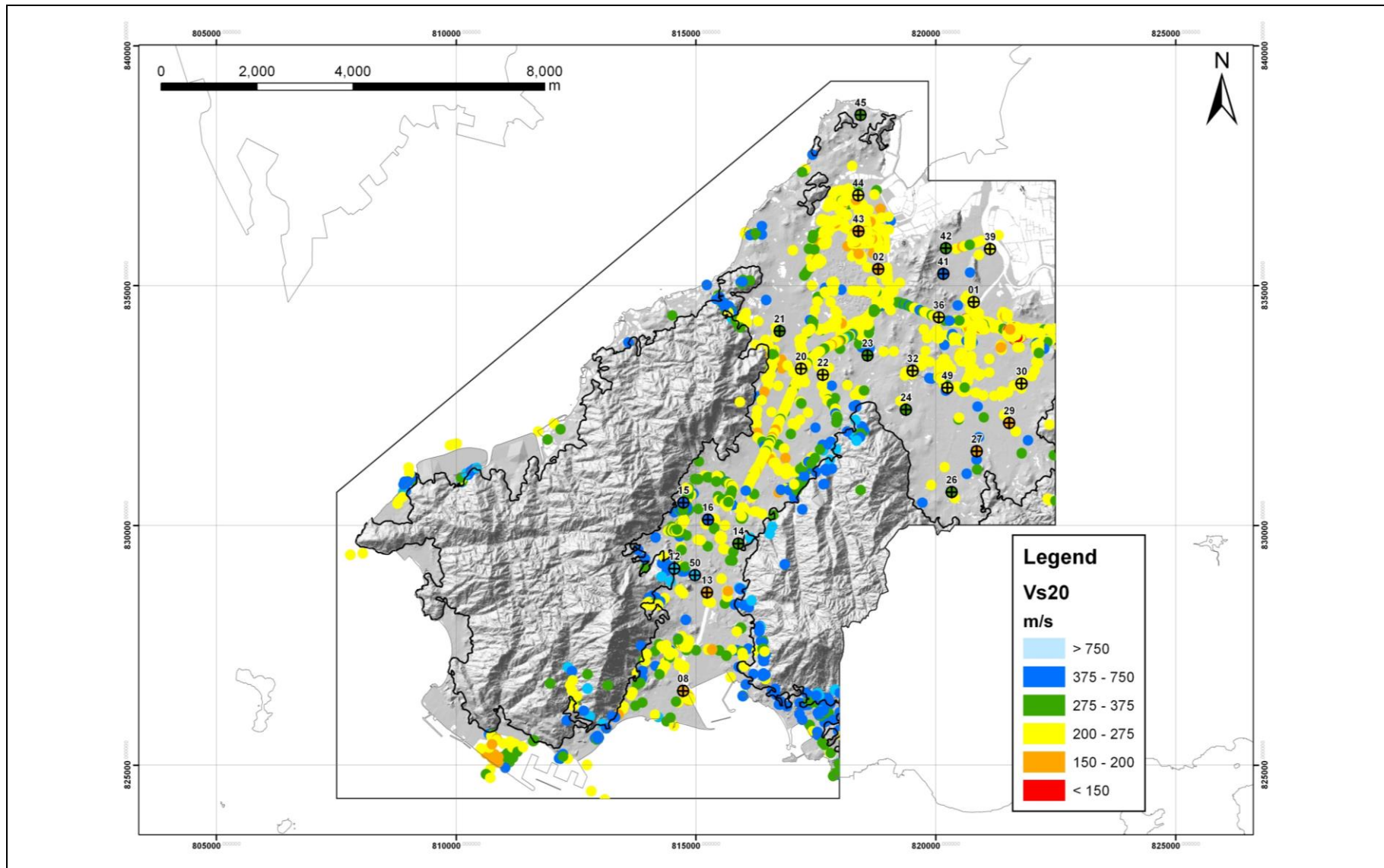


**Figure 7.18 Classification of AGS Database Based on  $V_{s,30}$**

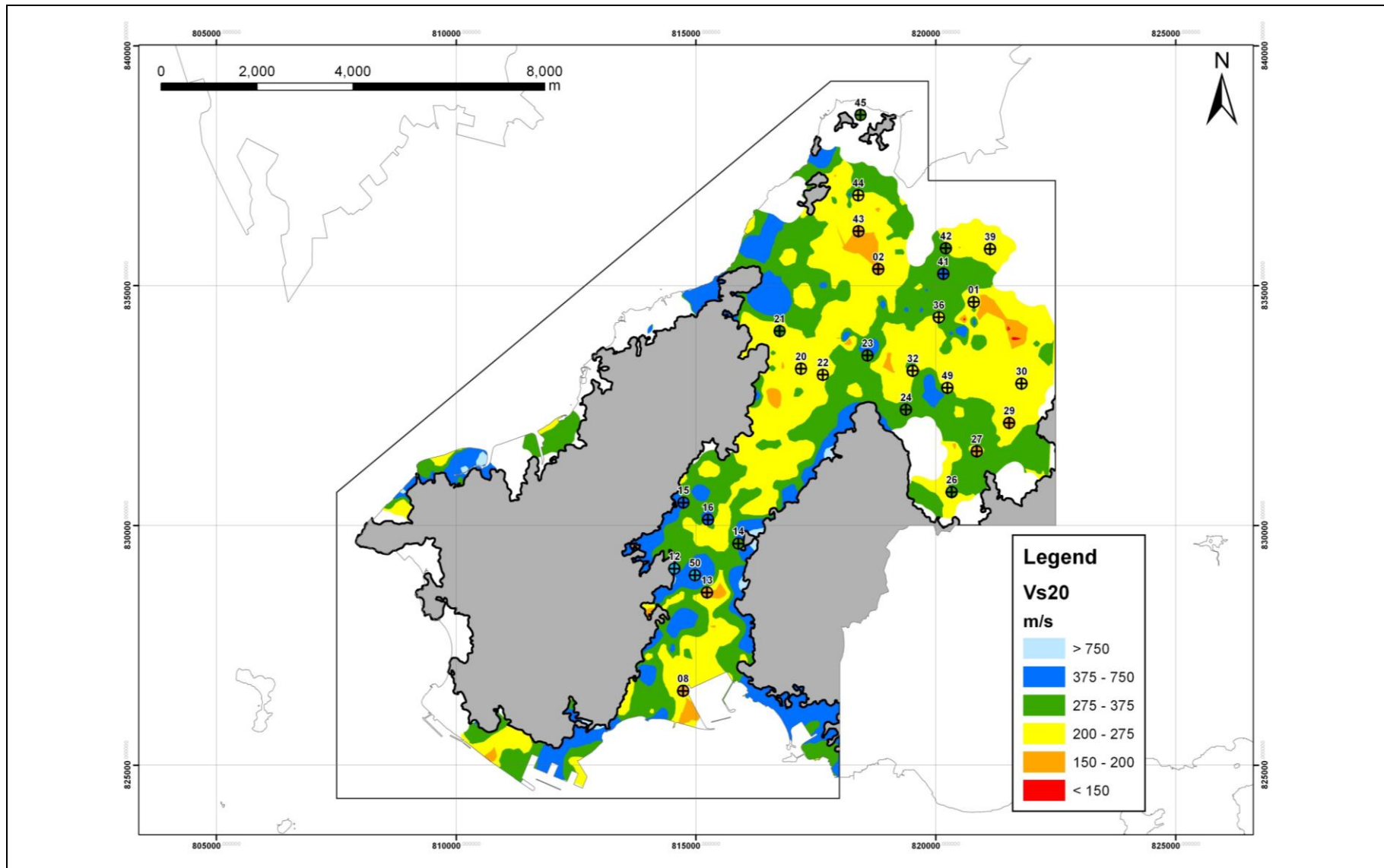




**Figure 7.19** Microzonation Map for Seismic Ground Motion Based on  $V_{s,30}$



**Figure 7.20 Classification of AGS Database Based on  $V_{s,20}$**



**Figure 7.21 Microzonation Map for Seismic Ground Motion Based on  $V_{s,20}$**

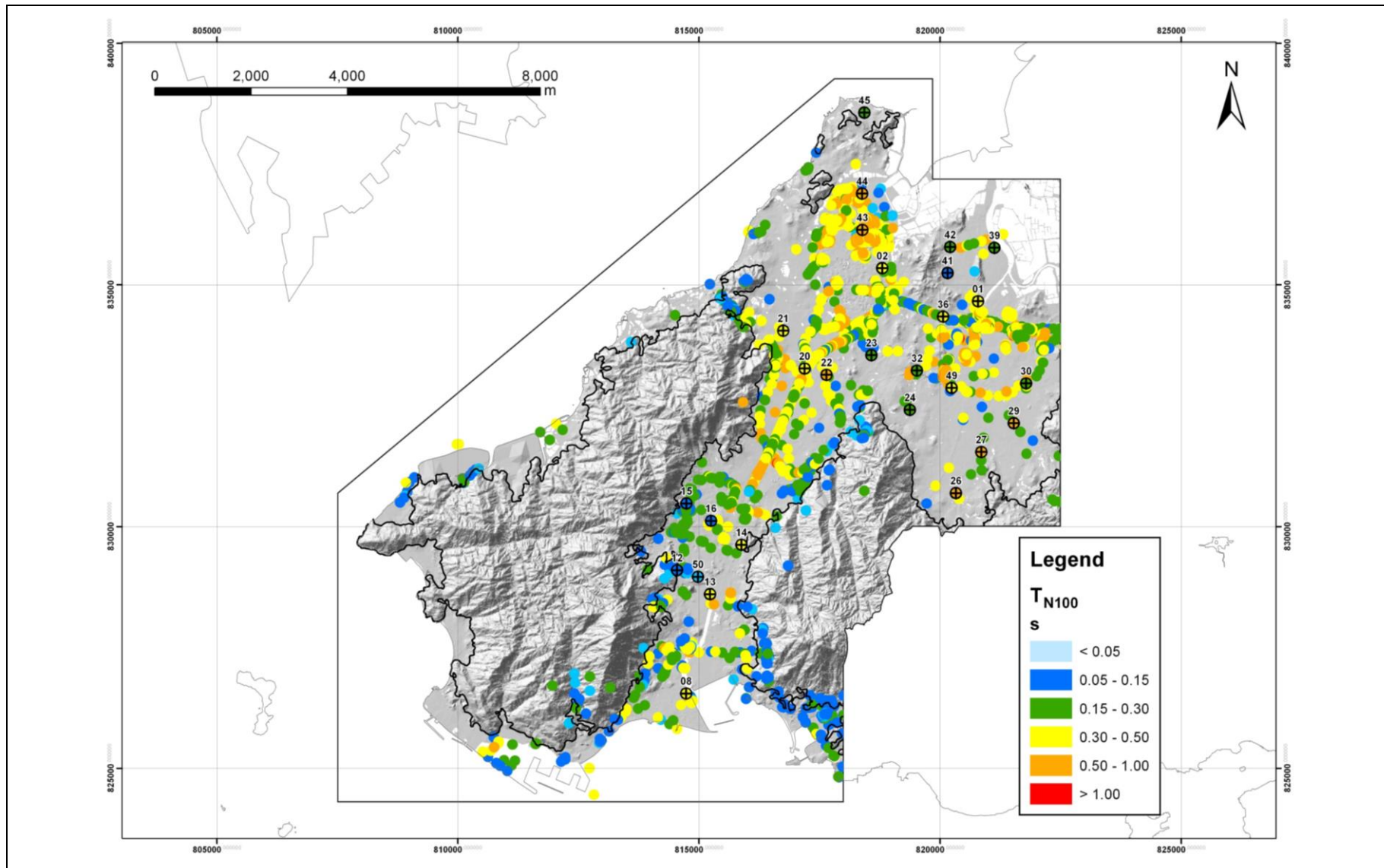
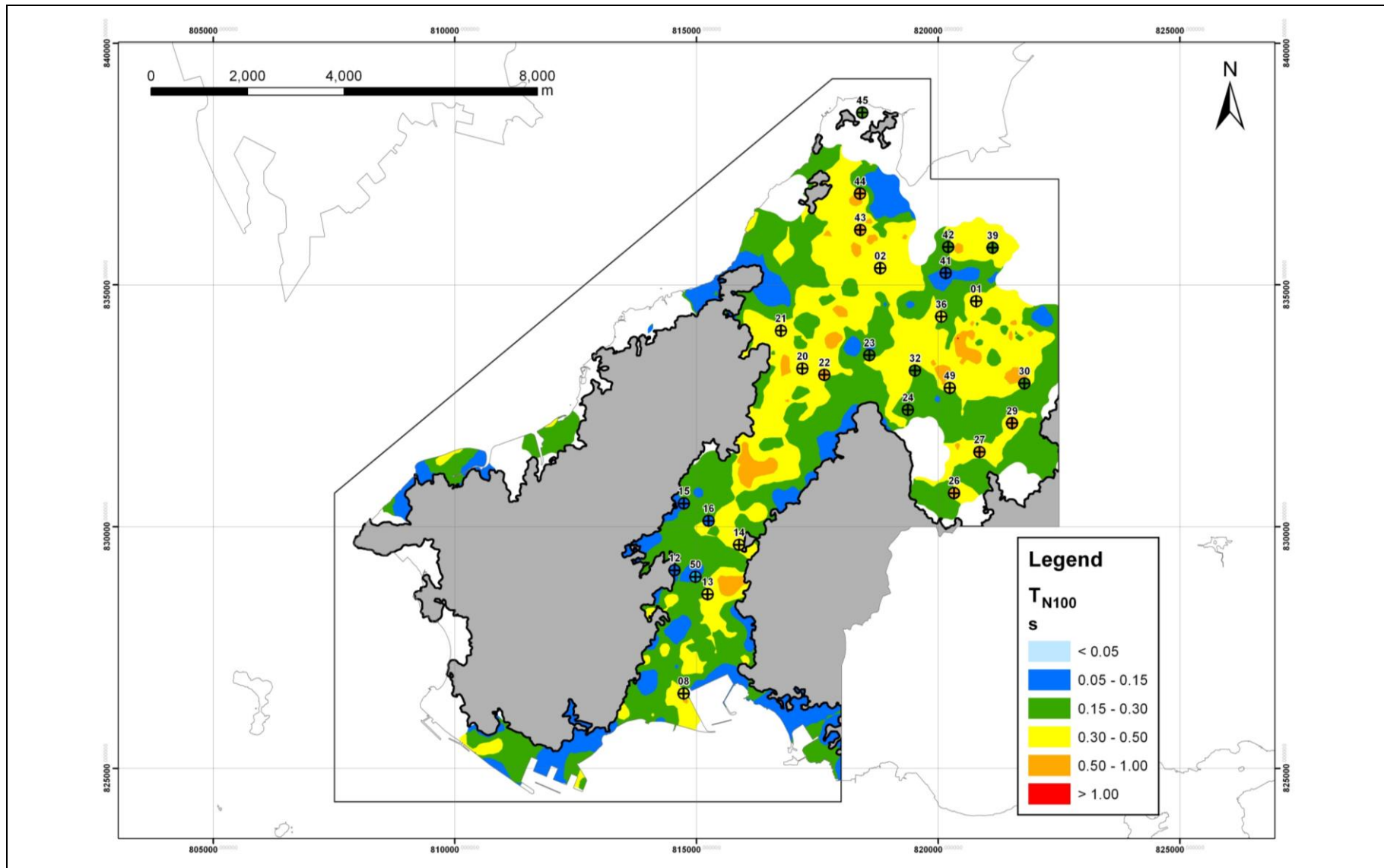


Figure 7.22 Classification of AGS Database Based on  $T_{N100}$





**Figure 7.23 Microzonation Map for Seismic Ground Motion Based on  $T_{N100}$**

values. The results of the site-specific boreholes, as shown in the figures, have also been used in generating the contours. The white areas represent an absence of boreholes that can reasonably generate contours. The edge of the area that encloses the 15° average topographic slope angle is also shown. It is suggested that the area within this line be considered to be rock for microzonation purposes. The following section describes the derivation of the average topographic slope angle.

It should be noted that the colours of the contours in these figures are consistent in that they all represent the same groups of data as follows:

- (a) Group 1 - dark blue,
- (b) Group 2 - green,
- (c) Group 3 - yellow, and
- (d) Group 4 - orange.

Pale blue is used for rock and red is used when the variable is beyond the range of the site-specific boreholes. Overall, it can be seen that the three contour figures show broadly consistent trends.

To consider how the microtremor results may influence the ground motion microzonation, their measured periods have been classified in the same way as the  $T_{N100}$  values and compared with the contours of the  $T_{N100}$  periods derived from the site-specific boreholes and the AGS data in Figure 7.24. It can be seen that there is generally very good agreement between them. It indicates that the measured periods from microtremor tests are consistent with the  $T_{N100}$  values. Therefore, the microtremor results can also be used for microzonation studies.

#### 7.4.2 Extrapolation Using Slope Angle

The USGS published correlations between  $V_{S,30}$  and topographic slope angle (Allen & Wald, 2007). Two regions, namely active tectonic and stable continental regions, were defined. Figure 7.25 shows their data ranges and their measured data in these two regions. The  $V_{S,30}$  values obtained from this study have been plotted in a similar fashion against the slope angle as shown in Figure 7.26 together with the two mean curves derived from the USGS data. In the figure, the straight black line represents an average  $V_{S,30}$  – slope angle correlation derived using the site-specific borehole data. The AGS data for the Study Area are also shown. Here, the slope angle is defined as the average slope of the ground within 40 m of the borehole.

Figure 7.26 shows that the correlation between the average slope angle and the  $V_{S,30}$  value is quite loose i.e. there is a significant scatter among the data. However, both datasets (site-specific boreholes and AGS data) are found to possess a similar mean value. It is worth noting that the figure implies that Hong Kong is more active than what the USGS refer to as the ‘active tectonic’ regions. On questioning the USGS about this, they advised that Hong Kong is definitely not a ‘stable continental’ region such as Australia. This implies that the time scale being used by the USGS in their definition is in an excess of 100 million years.

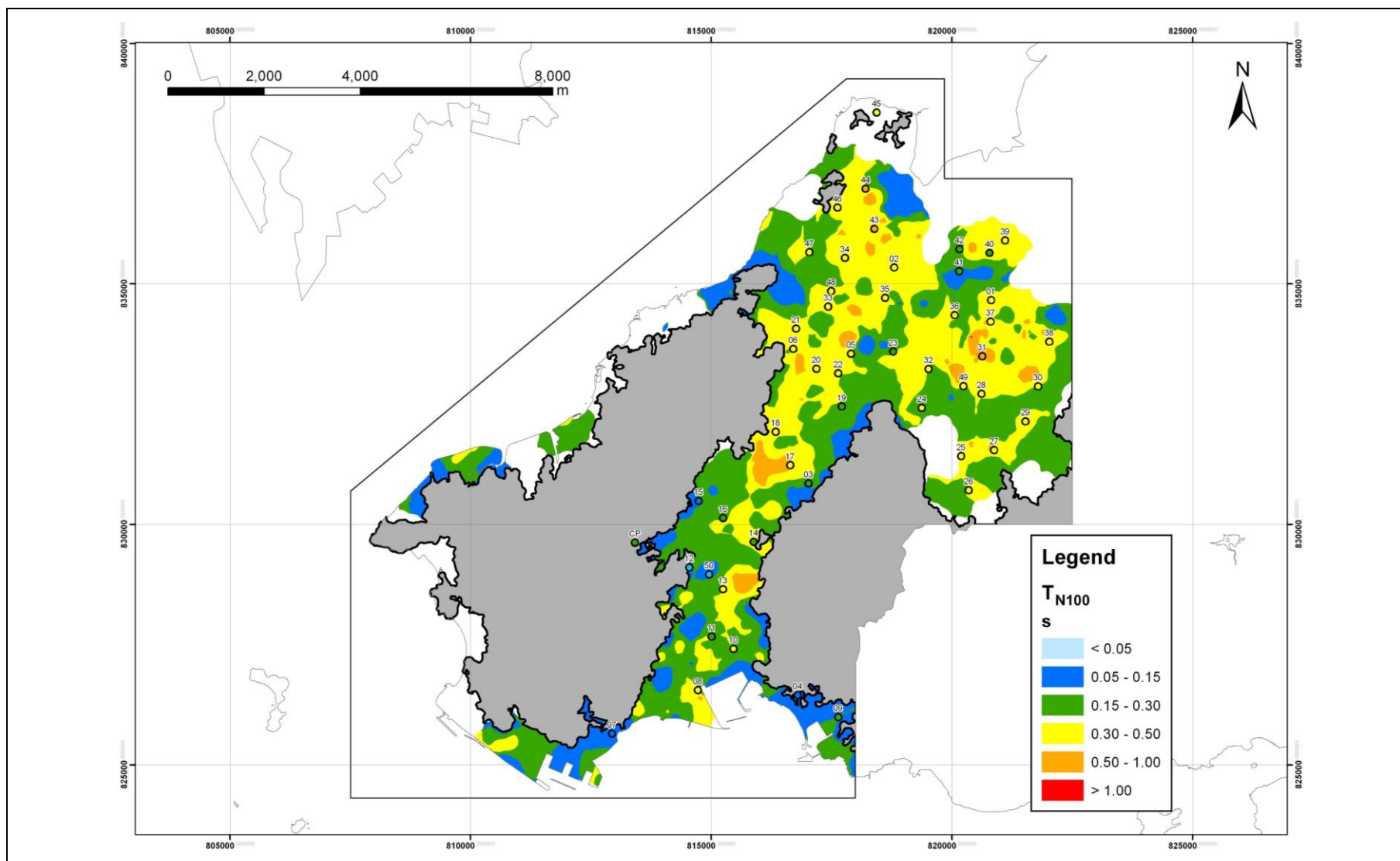
Using the average  $V_{S,30}$  – slope angle correlation (i.e. the straight black line) derived from Figure 7.26 and relating this to the  $V_{S,30}$  classes shown in Figure 7.3, various site classes can be determined as a function of the average slope angle. The resulted zoning is shown in Figure 7.27. It should be noted that man-made activities exert an effect on this zoning. For example, the blue/green strip between BH49 and BH30 is due to the road embankment forming the Yuen Long ring road.

Comparing Figure 7.27 with Figures 7.19, 7.21 and 7.23, it can be seen that the same overall trend is evident regardless of some significant differences. An advantage of this map is that it is derived based on a relatively uniformly distributed dataset whereas the maps derived based on AGS data are more variable in terms of its distribution.

## 7.5 Discussion

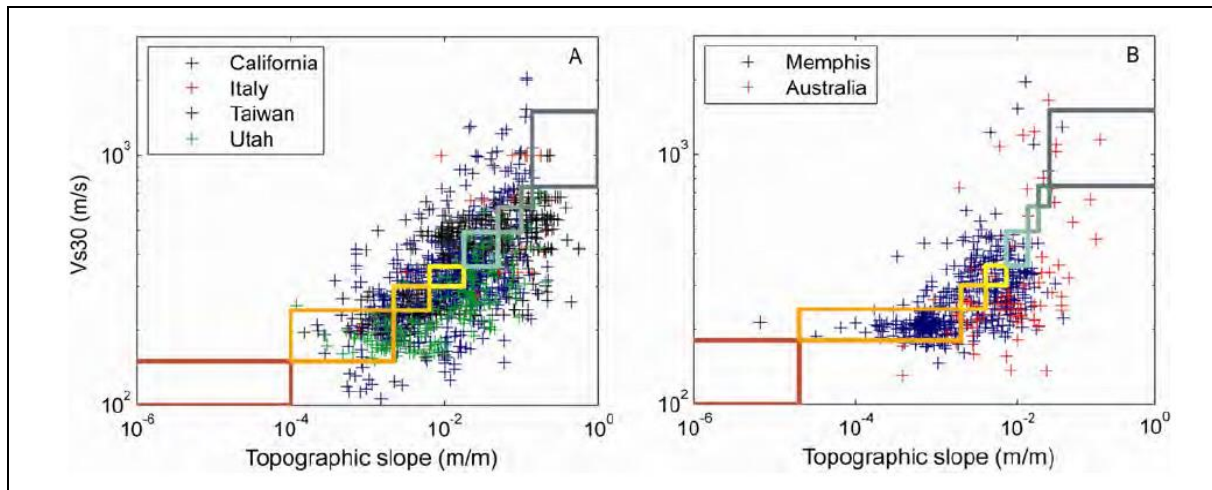
Figure 7.28 shows the differences in the design curves for the four groups using the same colour system as that used in Figures 7.19, 7.21, 7.23 and 7.27. As can be seen, the variation between the groups is not significant. For instance, Groups 2 and 3 are similar for 2% and 10% in the next 50 years whilst Groups 2, 3 and 4 are quite similar for the 2% and 63% in the next 50 years. Comparing with the variations among boreholes in each group (Figures 7.3 to 7.14), the differences between these group design curves (Figure 7.28) are considered less remarkable.

The microzonation maps produced above are, inevitably, very dependent on their underlying data distribution. For example, microzonation maps for flatter valleys containing deeper soils, of which soil properties and characteristics are highly variable, could not be considered as sufficiently precise for site-specific design purposes. In essence, the microzonation maps are not used directly in engineering design practice as overseas codes of practice generally demand site-specific site classification to be done using borehole data. Also, the codes allow for site-specific site response analyses which can be readily undertaken using computer programs that are freely available. However, the microzonation maps could be used for planning purpose as they provide useful information about the seismic effects on different types of buildings situated at different geological and topographic settings. For example, this study shows that low-rise buildings will be less affected by earthquakes on flatter soil areas, and that high-rise buildings will be less affected on steeper thin soil and rock areas. However, the final planning decision is still subject to a spectrum of factors.

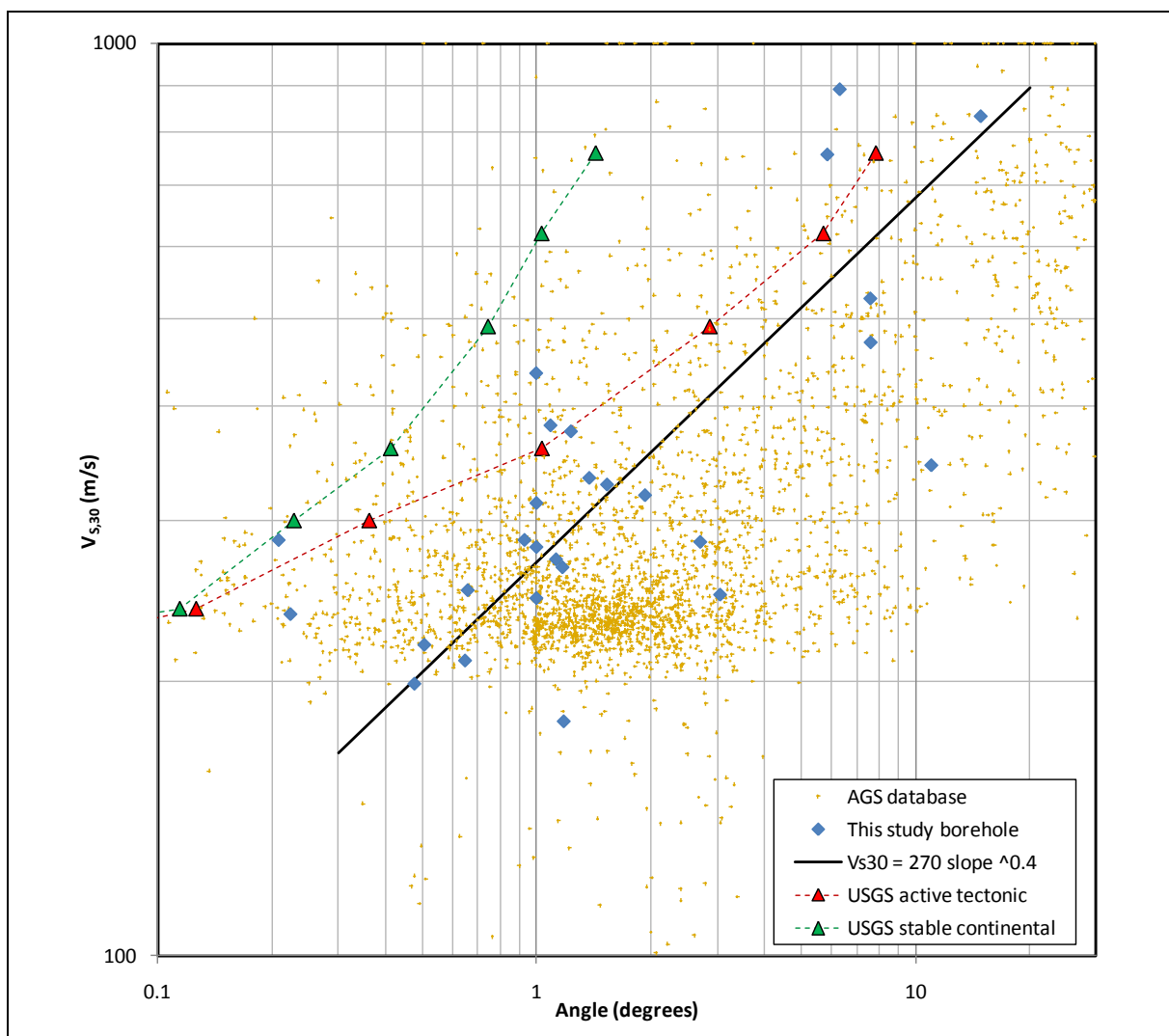


**Figure 7.24 Microzonation Map for Seismic Ground Motion Based on the AGS Database  $T_{N100}$  Compared to the Microtremor Results**

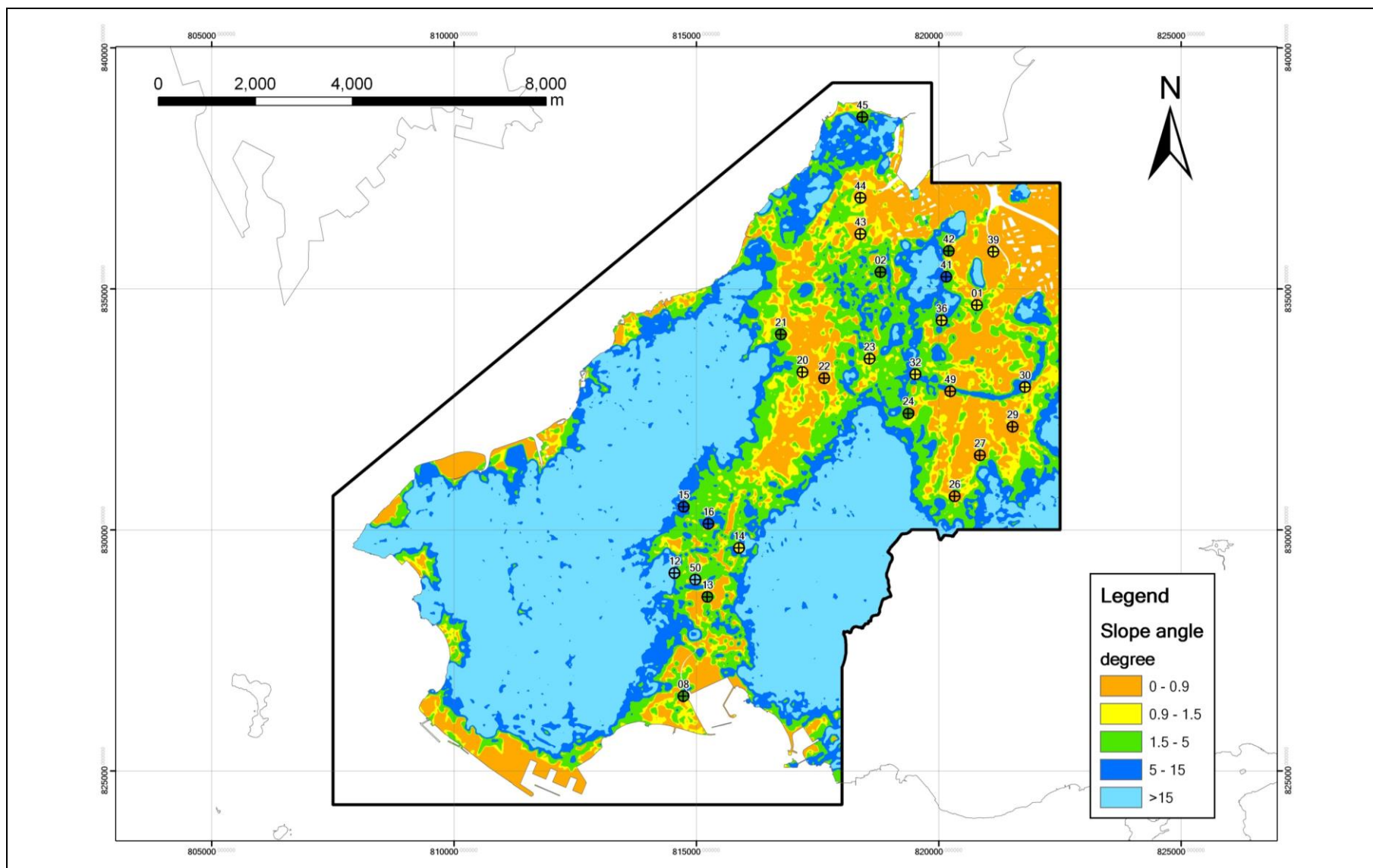




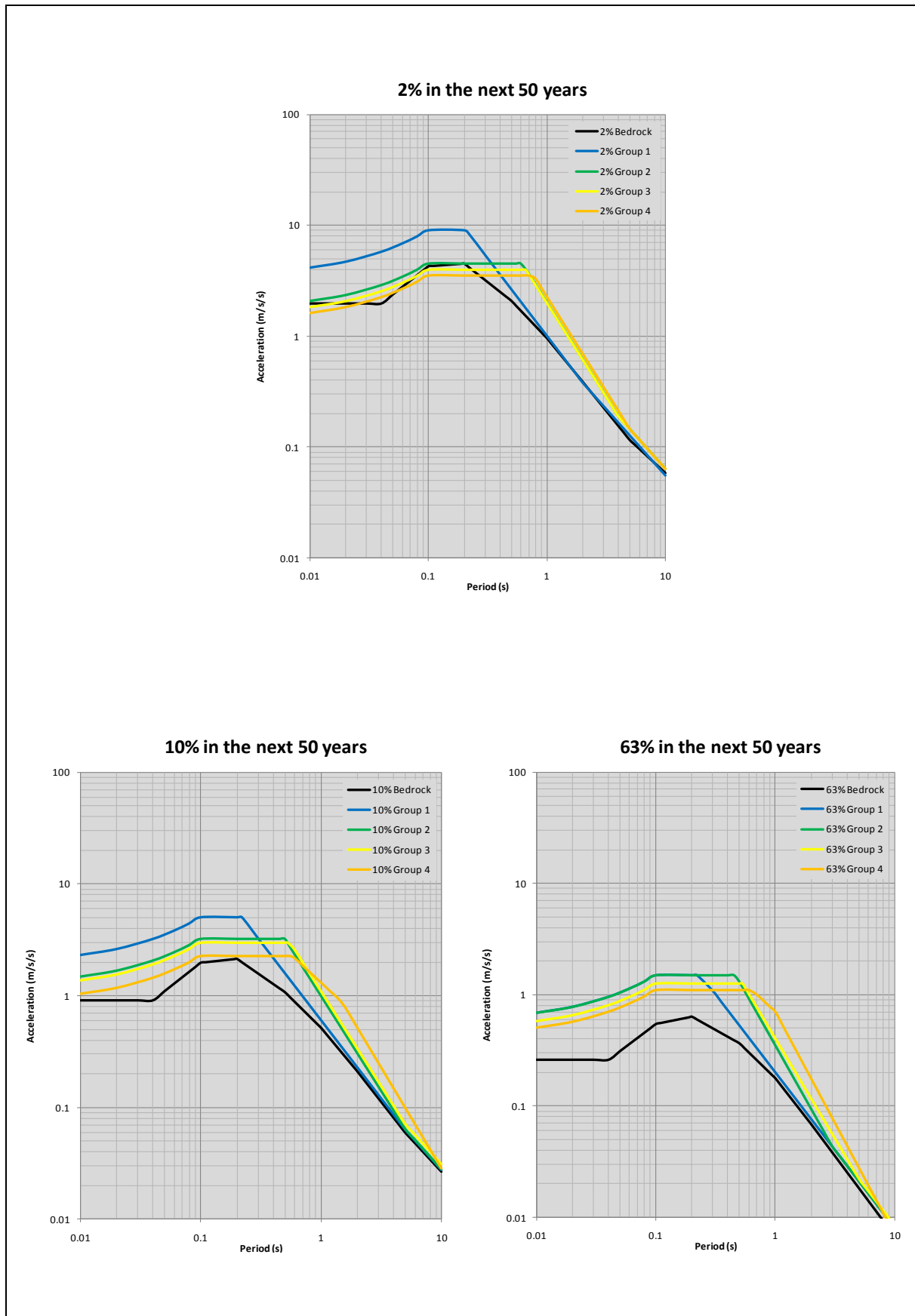
**Figure 7.25 USGS Correlations between  $V_{s,30}$  and Topographic Slope for Active Tectonic (A) and Stable Continental (B) Regions**



**Figure 7.26 Correlations between  $V_{s,30}$  and Topographic Slope in this Study**



**Figure 7.27 Microzonation Map for Seismic Ground Motion Based on Average Slope Angle**



**Figure 7.28 Comparison of the Ground Motion Design Groups**

## 8 Liquefaction

### 8.1 General

Liquefaction generally refers to the cyclic generation of large pore water pressure in saturated granular soils and the resulted reduction in effective stress leading to a rapid strength loss of the soils.

Variables that influence the onset of liquefaction include the presence of ground water, the particle size distribution of the soils, the in-situ relative density of the soils, the effective confining stress and the amplitude and duration of shaking. For soils with a high percentage of fine-grained particles, such as clays, the rate of build-up of excess pore water pressure is much slower than that in sands. Therefore, liquefaction of this type of soils is less probable. In very coarse-grained soils such as gravels, the excess pore water pressure is generally rapidly dissipated. As a result, liquefaction is less probable. There are exceptions to both of these cases, but generally sandy soils are considered to have the greatest susceptibility to liquefaction.

Liquefaction has a potential to cause bearing capacity failure and settlements of shallow foundations, and to a lesser extent, possible damages to piled foundations due to either a loss of support or an additional lateral loading near embankments or cuttings. The loss of strength of foundation soils, and the associated horizontal and/or vertical displacements could cause damages to buildings and infrastructure.

### 8.2 Definition of Susceptible Soils

As mentioned above, sandy soils are relatively more susceptible to liquefaction in an earthquake event. Considering the compositions of soils in the Study Area, Reclamation Fill, Alluvial Sands and Silts, and sandy or silty Marine Deposits are considered prone to liquefaction and are thus included in the liquefaction assessment in this study. For Reclamation Fill, clean sandy fill is considered. The fact that Alluvial Silts are also considered is because it is now generally agreed that low-plasticity silts have a potential to liquefy whilst moderate-plasticity silts may liquefy under certain conditions (Seed et al, 2001).

The following deposits have been assumed not to be susceptible to liquefaction or any other cyclic strength loss behaviour:

- (a) Marine Clays and Alluvial Clays: the basis for this assumption is that plastic soils with high clay contents are generally considered to be non-liquefiable. The Chinese Code GB50011-2010 (Chinese Seismic Code, 2010) also specifies that soils with a clay content (particle diameter size < 0.005 mm) of 10% and 13% can be considered not liquefiable under Intensities 7 and 8 earthquakes respectively.
- (b) Colluvium: this soil typically comprises gravel, cobbles and boulders in a silt/clay matrix and is rarely predominantly sand.
- (c) Saprolite (Completely to Highly Decomposed Rocks): this

soil typically has a very low likelihood of liquefaction due to its age, relative density, fines content and strength. The Chinese Seismic Code (2010) also specifies that for any geological age of soil condition originally formed in the Late Quaternary Period or before, it can be considered not liquefiable under Intensities 7 and 8 earthquakes.

In this study, the liquefaction assessment is extended to a depth of 40 m below ground level. It is assumed that below this depth, liquefaction is improbable and also unlikely to influence the surface behaviour of structures nor slopes.

### 8.3 Arup Methodology

Common engineering practice in the assessment of liquefaction potential is to use empirical correlations. These correlations were derived based upon field observations of liquefaction, or absence of liquefaction in past earthquakes, and in-situ soil properties measured from, for example, the standard penetration test (SPT), cone penetration test (CPT), or in-situ shear-wave velocity ( $V_s$ ) measurements. One of the most widely applied correlations is the SPT-based correlation proposed by Seed & Idriss (1971), as shown in Figure 8.1. This is essentially a deterministic relationship, which allows the designer to determine a factor of safety against liquefaction for a corrected SPT-N value and a cyclic shear stress ratio. More recently, Seed et al (2001) presented probabilistic relationships, which was also SPT-N value based, as shown in Figure 8.2. The use of these relationships contains a number of advantages over that shown in Figure 8.1:

- (a) They make use of a greater body of empirical data, including data from earthquakes occurring since 1984.
- (b) They make use of numerous improvements in the understanding of the variables affecting liquefaction, such as the interpretation of SPT data and the evaluation of the cyclic shear stress ratio.
- (c) The use of Bayesian probabilistic methods has reduced uncertainty and improved understanding of variability.

The relationships presented by Seed et al (2001) are summarised in the following equation:

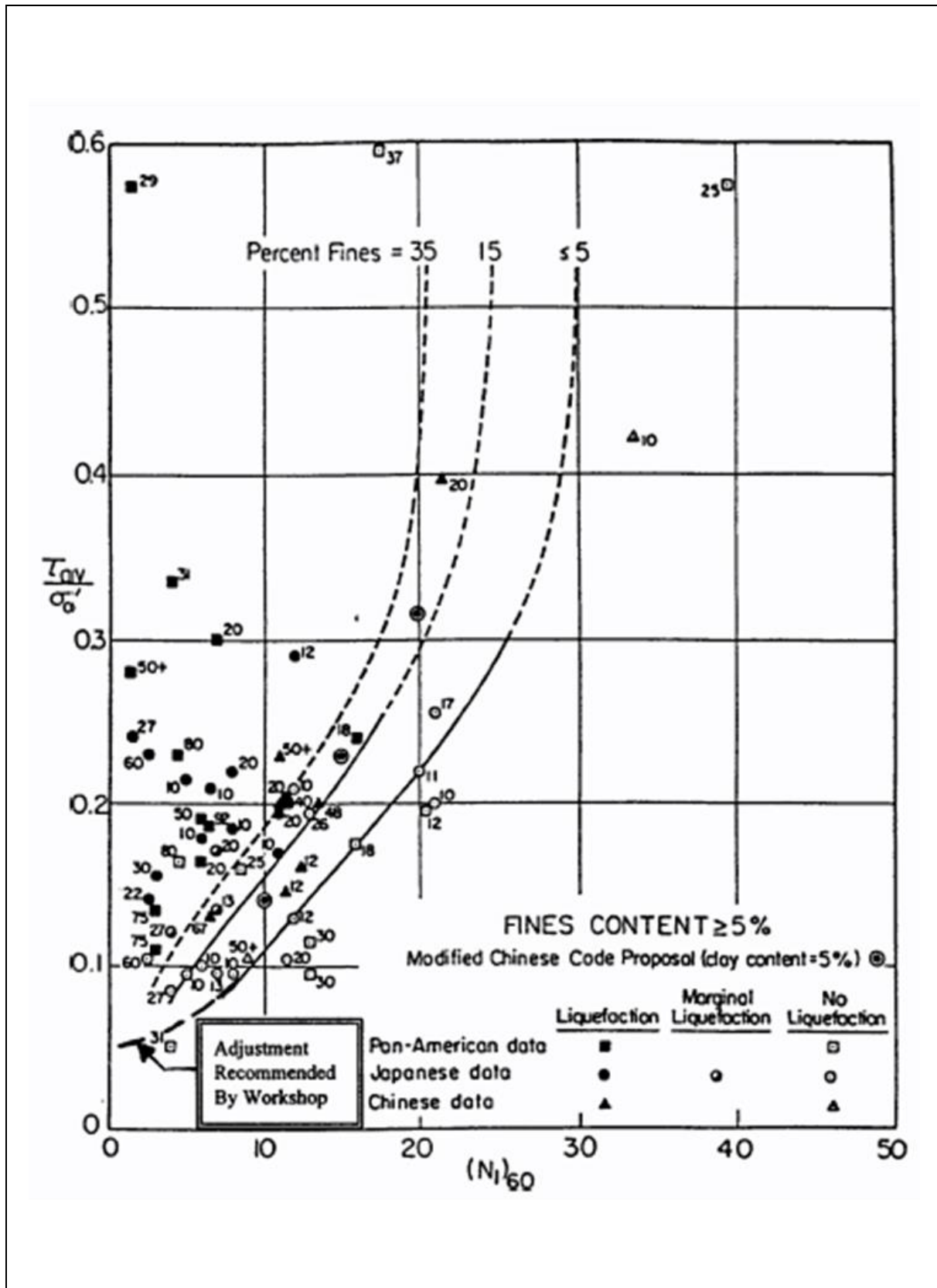
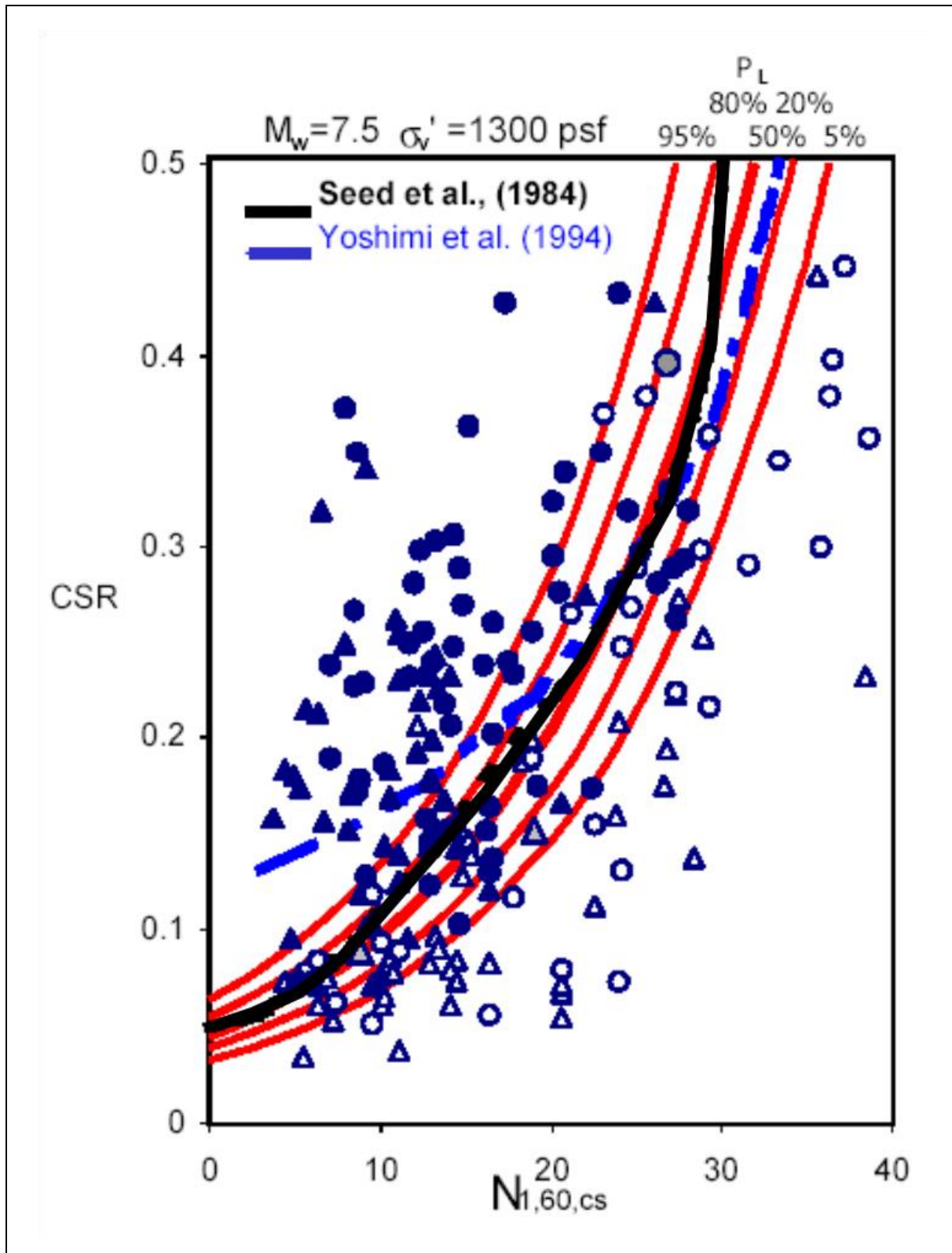


Figure 8.1 Correlation between Equivalent Uniform Cyclic Stress Ratio and SPT Data for  $M_w = 7.5$  Earthquakes with Adjustments at Low Cyclic Stress Ratio (Seed & Idriss, 1971)



**Figure 8.2 Recommended “Probabilistic” SPT-based Liquefaction Triggering Correlation (for  $M_w = 7.5$  and  $\sigma_v' = 0.65$  atm) “Clean Sands” ( $FC \leq 5\%$ ) (Seed et al, 2001)**

$$P_L = \Phi \left[ -\frac{\left( N_{1,60} \times (1 + 0.004FC) - 13.32 \times \ln(CSR) - 29.53 \times \ln(M_w) - 3.70 \times \ln(\sigma_v') + 0.05FC + 33.73 \right)}{2.7} \right] \dots\dots\dots (8.1)$$

where  $P_L$  = probability of liquefaction  
 $\Phi$  = standard cumulative normal distribution  
 $N_{1,60}$  = SPT-N corrected for overburden effects and for energy.  $N_1$  is corrected for overburden and  $N_{1,60}$  is corrected for energy and equipment, using the following correction factors:

$$N_I = \left( \frac{100}{\sigma_v'} \right)^{0.5} N$$

$$N_{1,60} = N_I, C_R, C_S, C_B, C_E$$

where  $C_R$  = correction for rod lengths shorter than 10 m  
 $C_S$  = correction for non-standard SPT samplers  
 $C_B$  = correction for borehole diameters greater than 115 mm  
 $C_E$  = correction for energy efficiency of SPT hammer

$FC$  = fines content (percent finer than 0.074 mm)  
 $M_w$  = moment magnitude of the earthquake for which the liquefaction probability is being assessed  
 $\sigma_v'$  = vertical effective stress (in kPa)  
 $CSR$  = 'equivalent uniform cyclic shear stress ratio'. This has been evaluated by means of site-specific seismic site response analyses using *Oasys SIREN*. *Oasys SIREN* computes the peak shear stress ( $\tau_{max}$ ) at each soil element in the profile, and the 'equivalent uniform' CSR is assumed to be equal to 65% of the peak, where

$$CSR = 0.65 \times \frac{\tau_{max(SIREN)}}{\sigma_v'}$$

Figure 8.2 illustrates the resulting probability curves normalised to  $M_w = 7.5$ ,  $\sigma_v' = 65$  kPa for a 'clean sand' ( $FC \leq 5\%$ ).

As an alternative to using the site response analysis to estimate shear stresses and  $CSR$ , a simplified equation is frequently used, where:

$$CSR = \frac{\tau_{av}}{\sigma_v'} = 0.65 \times \frac{a_{max}}{g} \times \frac{\sigma_v}{\sigma_v'} \times r_d \times M_f \dots\dots\dots (8.2)$$

where  $a_{max}$  = peak surface horizontal ground acceleration  
 $g$  = acceleration due to gravity



- $\sigma_v$  = total vertical stress  
 $M_f$  = magnitude reduction factor  
 $r_d$  = stress reduction coefficient.

The definition of the stress reduction coefficient ( $r_d$ ) has a significant uncertainty since this parameter has a high variability, and has been found to be dependent on earthquake magnitude, intensity of shaking and site stiffness as well as the depth below ground level. There are simplified relationships relating  $r_d$  to depth (Youd & Idriss, 2001), but they are considered potentially unconservative. For this reason, Seed et al (2001) recommended the use of the in-situ CSR calculated by means of site-specific site response analysis, and this approach has been used in this study.

The following  $N_{1,60}$  correction factors have been assumed:

- (a) The values for  $C_R$  presented in Youd & Idriss (2001) are used, where rod length < 3 m,  $C_R = 0.75$ ; for rod length = 3 to 4 m,  $C_R = 0.8$ ; for rod length = 4 to 6 m,  $C_R = 0.85$ ; for rod length = 6 to 10 m,  $C_R = 0.95$  and for rod length > 10 m,  $C_R = 1.0$ . It has been nominally assumed that the rod length is 1.0 m above ground level.
- (b)  $C_S = 1.0$ .
- (c)  $C_B = 1.0$ .
- (d)  $C_E = 1.0$  for standard automatic trip hammers used in Hong Kong.

The fines contents of the soils have been used based on the laboratory testing results presented in Section 3 and summarised in Table 3.3.

The results of site-specific site response analysis have been used to compute the profile of shear stresses versus depth for each case using *Oasys SIREN*. The input earthquake time-histories have been selected to represent de-aggregated magnitude and distance combinations for the three ground motion levels (see Section 5). The following cases have been analysed using *Oasys SIREN* to determine the site response coefficients, and these have been considered in terms of liquefaction potential:

- (a) 10% in 50 years,  $M_w = 6.5$ .
- (b) 2% in 50 years, near-field earthquake event < 250 km,  $M_w = 7.0$ .
- (c) 2% in 50 years, far-field earthquake event at 250 km,  $M_w = 7.5$ .

The effective vertical stresses have been calculated using the ground water level measured in the site-specific boreholes, which is generally about 2 m below the ground surface. It is assumed that liquefaction will not occur above the ground water level.

## 8.4 GEERRI Methodology

GEERRI calculates the potential of liquefaction based on the provisions in Chinese Code (Chinese Seismic Code, 2010) (see Appendix E). The code specifies that the potential of liquefaction needs not to be considered for the following soil conditions:

- (a) When the geological age of soil condition is originally formed in the Late Quaternary Period or before, in Intensity 7 and Intensity 8 regions.
- (b) Soil comprising more than 8%, 13% and 16% clay particles ( $< 0.005$  mm particle diameter size) in earthquake intensities of 7, 8 and 9 respectively.
- (c) The following conditions regarding the thickness of covering soil and the level of ground water table, under which the assessment of the liquefaction potential can be ignored:

$$d_u > d_0 + d_b - 2$$

$$d_w > d_0 + d_b - 3$$

$$d_u + d_w > 1.5 d_0 + 2 d_b - 4.5$$

where  $d_w$  = highest recorded level of ground water table (in m)

$d_u$  = thickness of the covering soil without marine clay and silty clay

$d_b$  = depth of shallow footing, not exceeding 2 m

$d_0$  = depth of the characteristic SPT-N value.

The critical SPT-N value for liquefaction,  $N_{CR}$ , can be calculated as follows:

$$0 - 20 \text{ m depth: } N_{CR} = N_0 \beta [\ln(0.6d_s + 1.5) - 0.1d_w] (3/\rho_c)^{0.5}$$

where  $d_s$  = depth of SPT layer

$d_w$  = depth of ground water table

$\rho_c$  = percentage of clay content

$N_0$  = characteristic SPT-N for liquefaction

$\beta$  = 0.8 for Hong Kong (Earthquake Design Group 1).

The design  $N_0$  value is based on the recommended  $N_0$  range for different earthquake ground motions in the Chinese Code. Table 8.1 summarises the recommended  $N_0$  values for this study.

**Table 8.1 Characteristic SPT-N Values for Liquefaction,  $N_0$** 

| Probability of Being Exceeded<br>in the Next 50 years | Earthquake<br>Intensity | Design Peak Ground<br>Acceleration ( $g$ ) | $N_0$ |
|-------------------------------------------------------|-------------------------|--------------------------------------------|-------|
| 10%                                                   | 7                       | 0.10                                       | 7     |
| 2%                                                    | 8                       | 0.20                                       | 12    |

The soil layers are identified to liquefy if their measured uncorrected  $N$  value is smaller than the calculated  $N_{CR}$ . If this occurs for one or more layers, the following equation is used to calculate the Liquefaction Index,  $I_{IE}$ , according to the Chinese Code:

$$I_{IE} = \sum_{i=1}^n \left( 1 - \frac{N_i}{N_{CRi}} \right) d_i W_i \dots\dots\dots (8.3)$$

where

- $I_{IE}$  = liquefaction Index
- $N$  = depth of measured SPT-N value
- $N_i$  = measured uncorrected SPT-N value
- $N_{CRi}$  = critical SPT-N for liquefaction
- $d_i$  = thickness of representing SPT-N layer, can take average thickness between each of the two SPT-N values
- $W_i$  = depth coefficient, when depth less than 5 m taken as 10 and when depth is 20 m taken to be zero and for 5 m to 20 m can be taken value as having a linear reduction with depth.

Three levels of Liquefaction Index are classified in the Chinese Code:

- (a) Slight liquefaction potential  $0 < I_{IE} \leq 6$
- (b) Moderate liquefaction potential  $6 < I_{IE} \leq 18$
- (c) Severe liquefaction potential  $I_{IE} > 18$ .

## 8.5 Liquefaction Results

Figures 8.3 to 8.24 show the results of liquefaction assessment using the Seed method (Seed et al, 2001) and the Chinese Code method (Chinese Seismic Code, 2010). It is considered that the soil layer will be liquefied when the liquefaction probability calculated by the Seed method exceeds 50% and when the  $N_{CR}$  to  $N$  ratio calculated by the Chinese Code method is greater than 1.

The calculated maximum liquefaction probability by the Seed method of any single soil layer and the Liquefaction Index by the Chinese Code method are summarised in Table 8.2. In general, the two methods have similar findings on the level of liquefaction potential for the boreholes. The key factors causing differences in the results are the use of fines content in the Seed method and clay content in the Chinese Code method. This explains the resulted zero liquefaction potential by the Chinese Code method for boreholes BH24, BH39 and BH42.

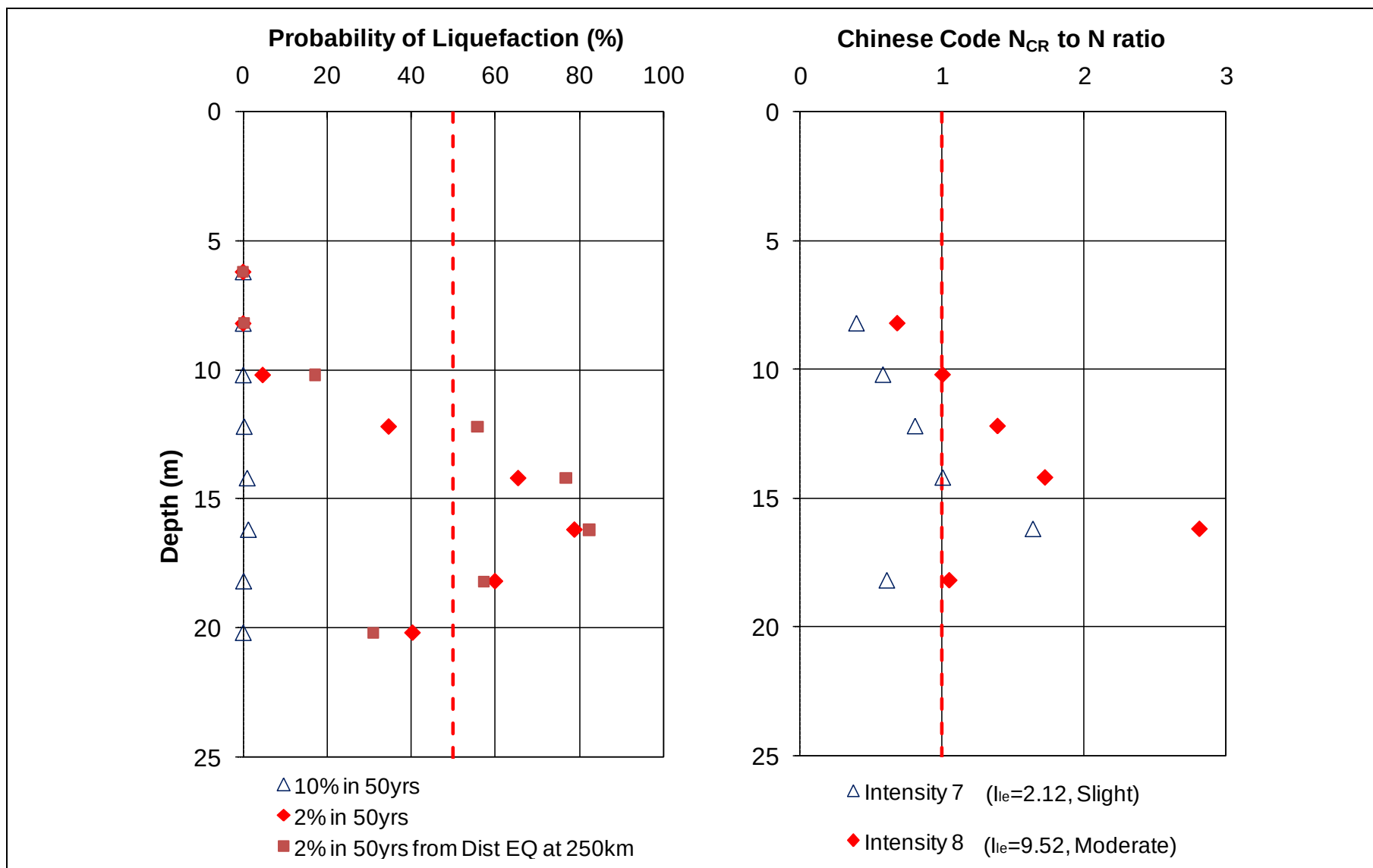


Figure 8.3 Liquefaction Chart for BH01 for 10% in 50 Years Ground Motion

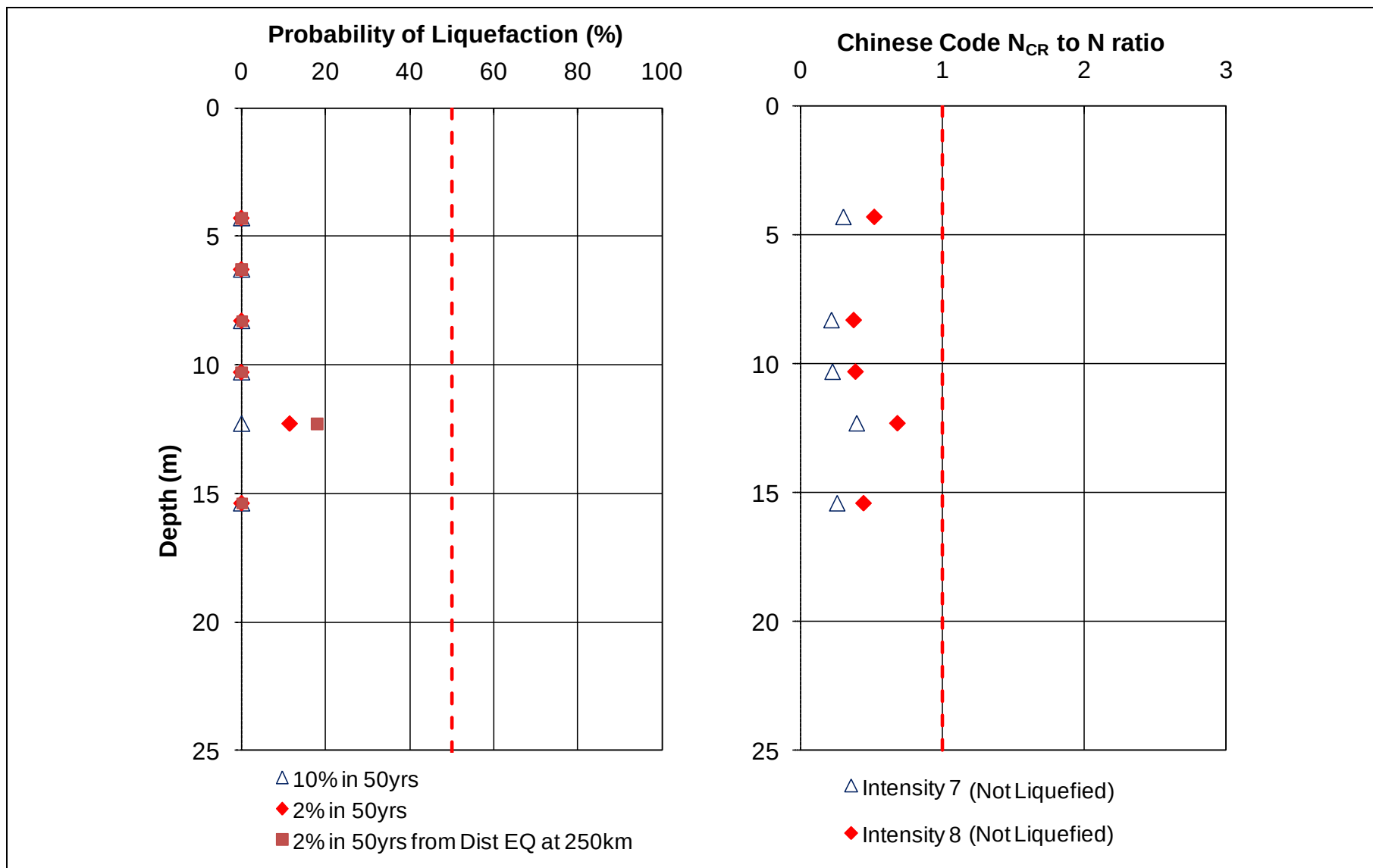


Figure 8.4 Liquefaction Chart for BH02 for 10% in 50 Years Ground Motion

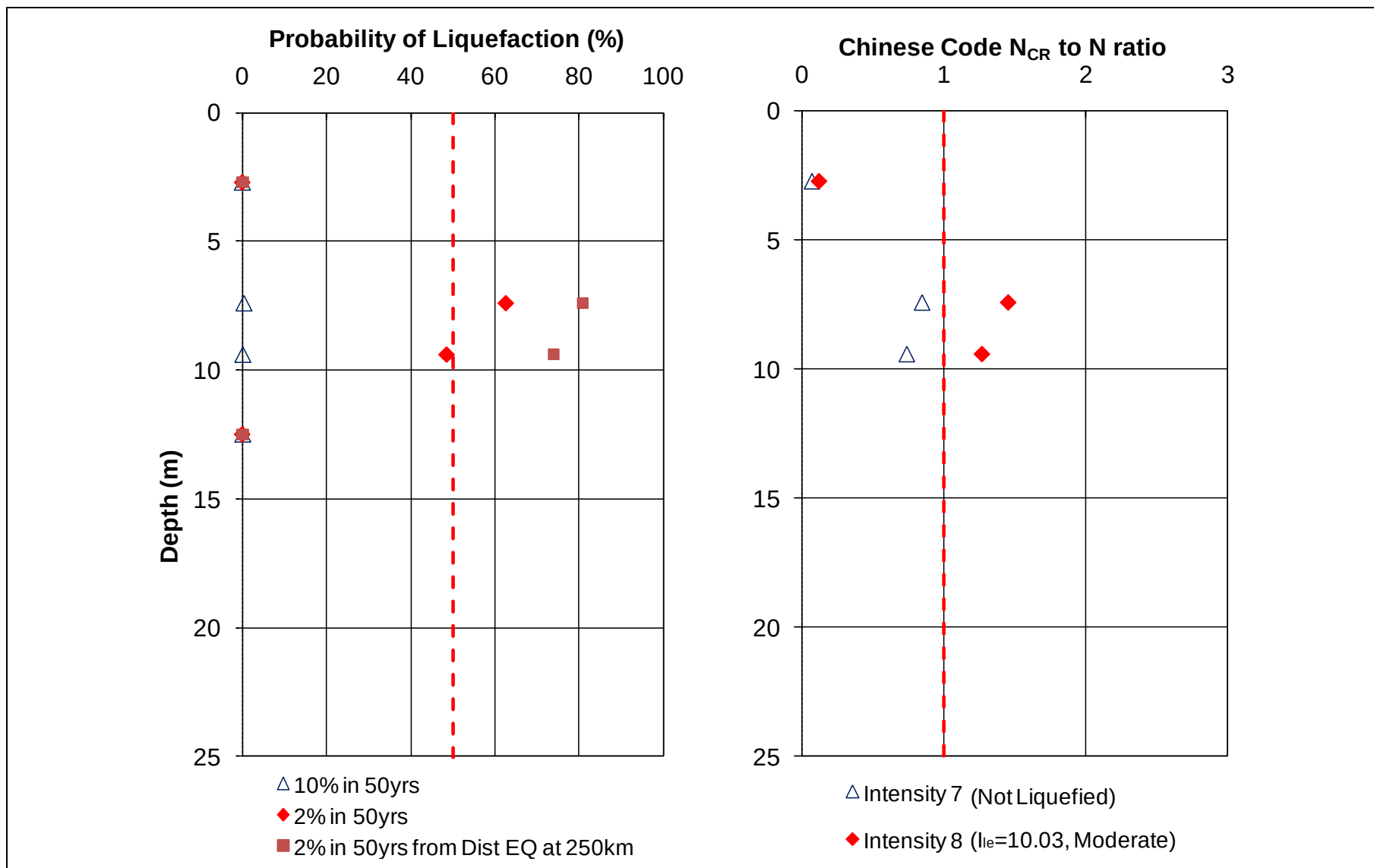


Figure 8.5 Liquefaction Chart for BH08 for 10% in 50 Years Ground Motion

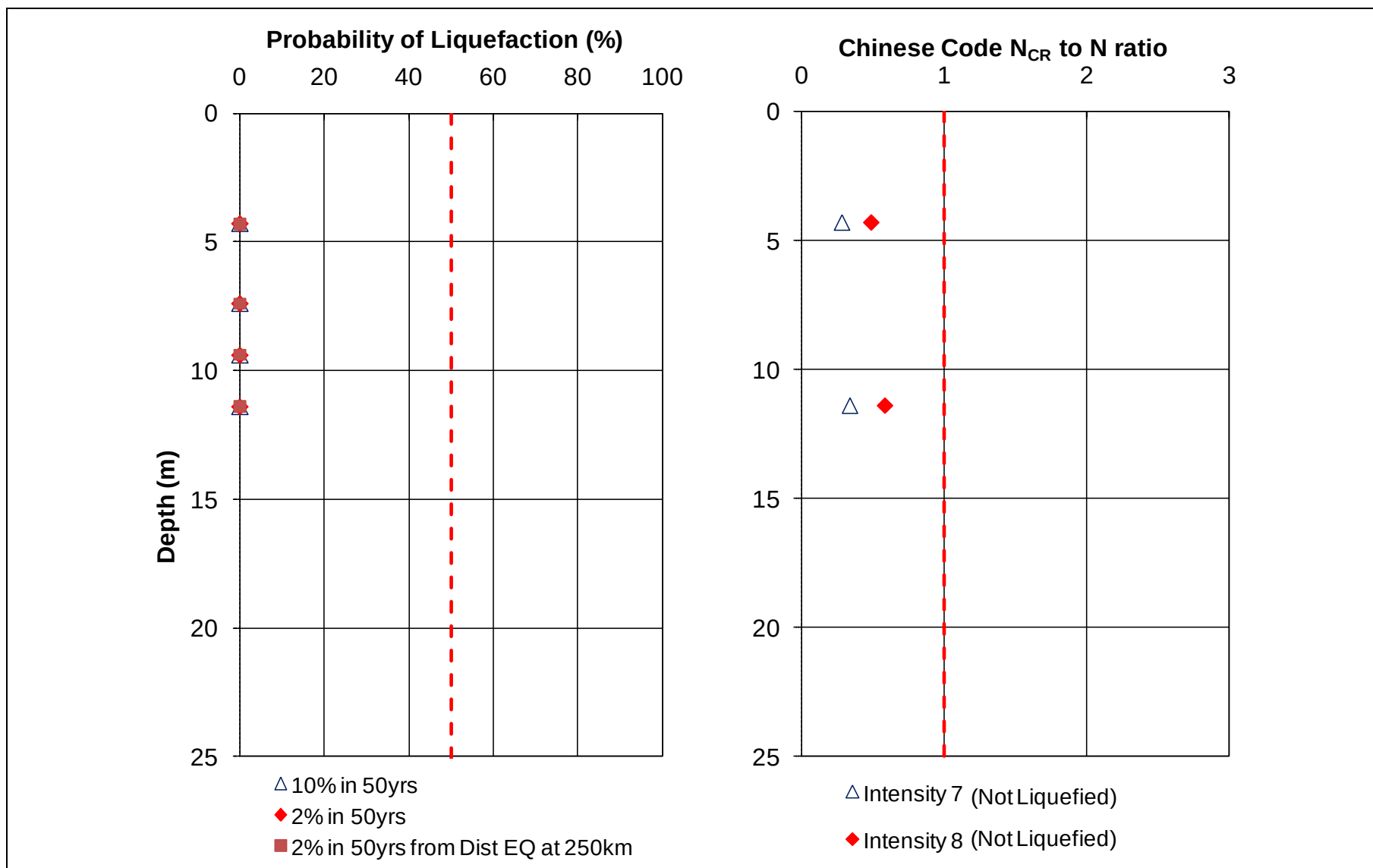


Figure 8.6 Liquefaction Chart for BH13 for 10% in 50 Years Ground Motion

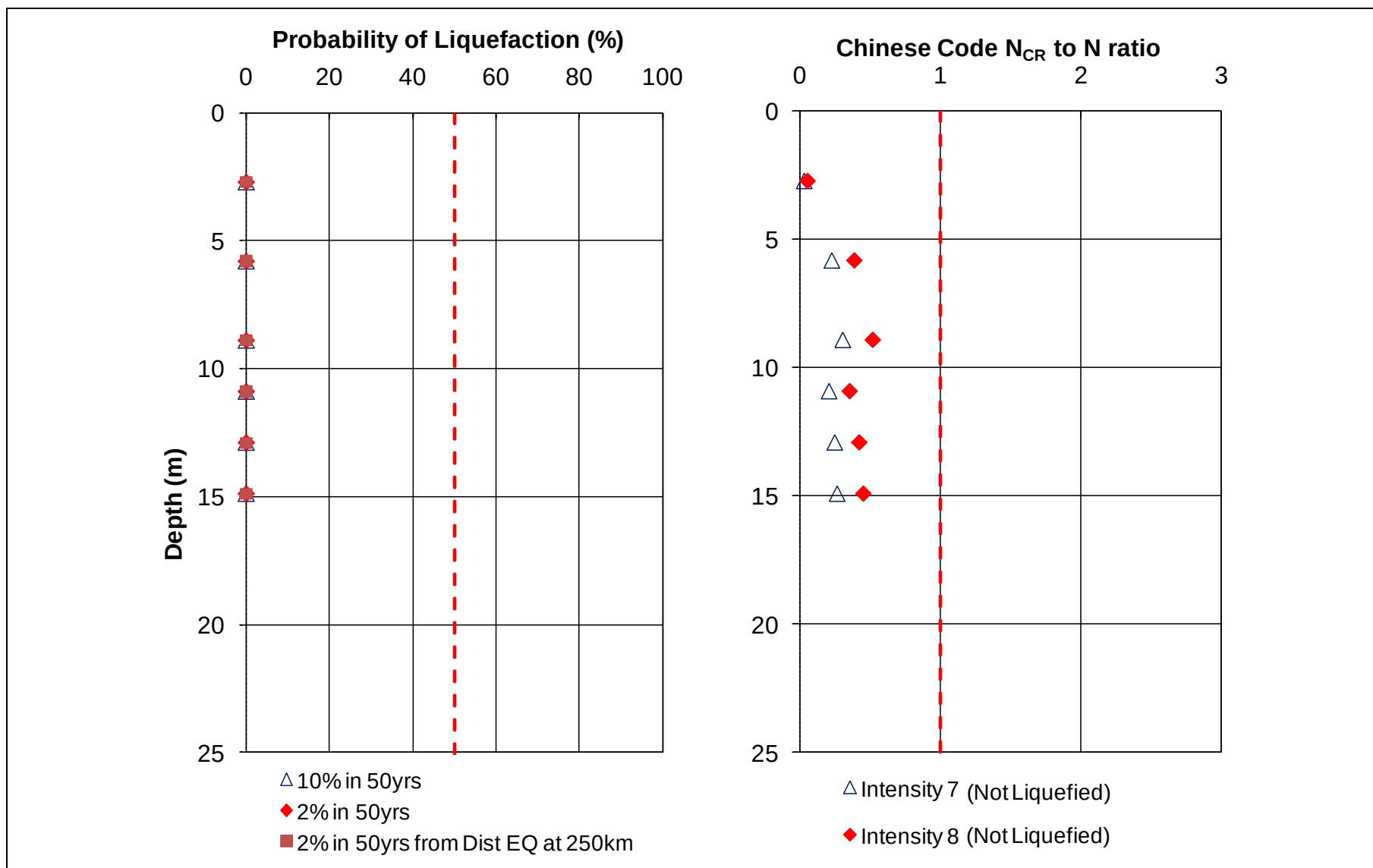


Figure 8.7 Liquefaction Chart for BH14 for 10% in 50 Years Ground Motion



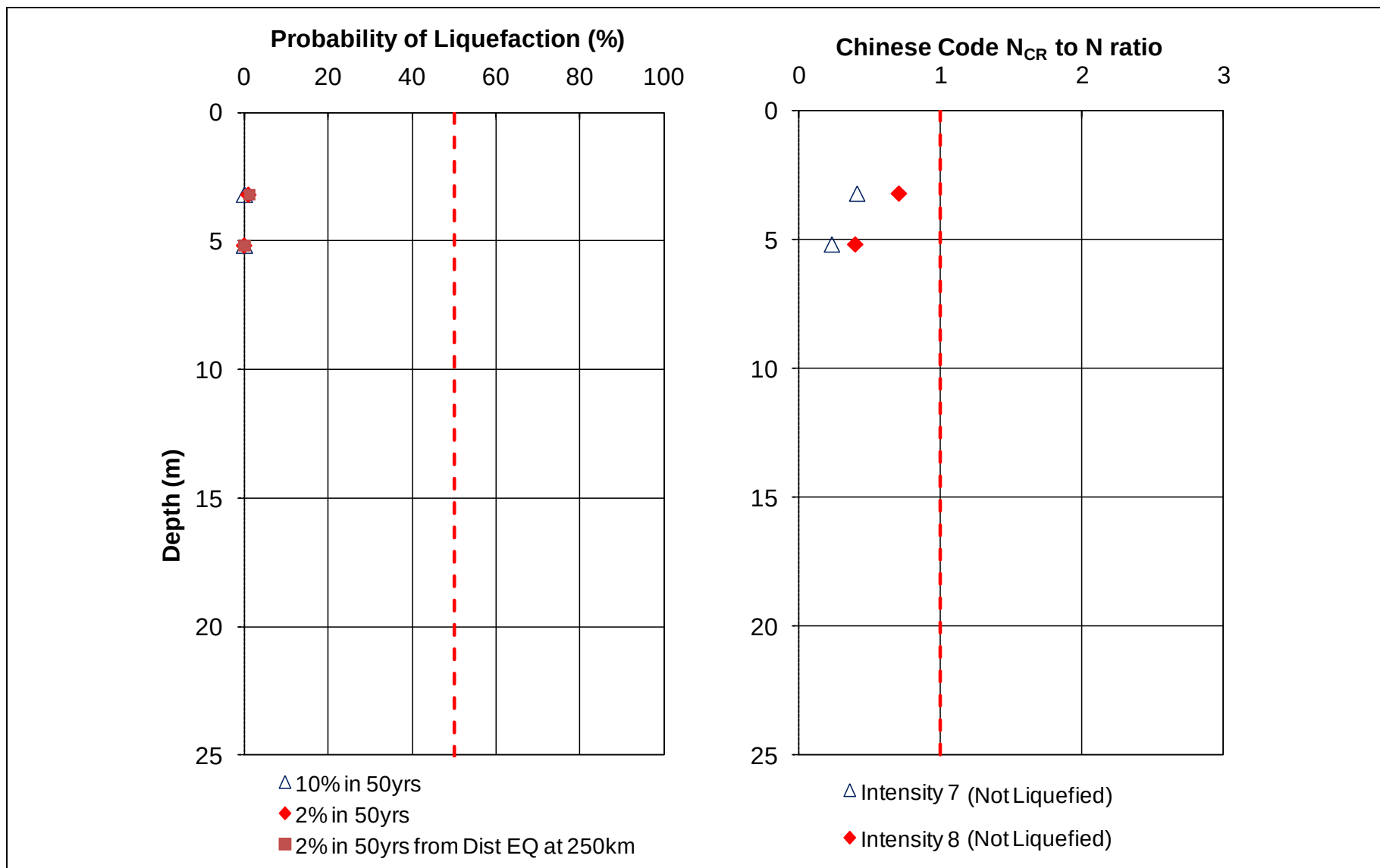


Figure 8.8 Liquefaction Chart for BH20 for 10% in 50 Years Ground Motion

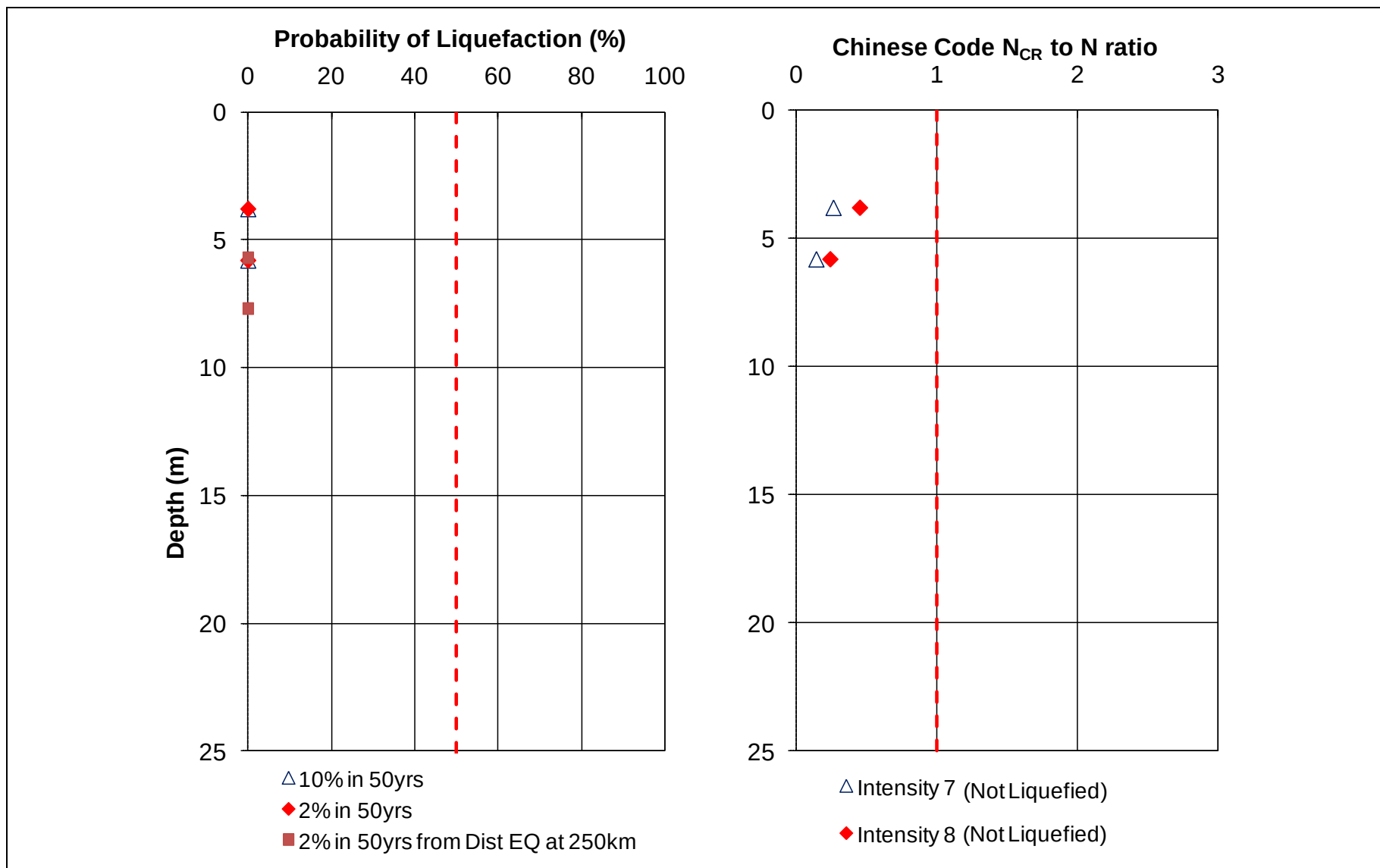


Figure 8.9 Liquefaction Chart for BH21 for 10% in 50 Years Ground Motion

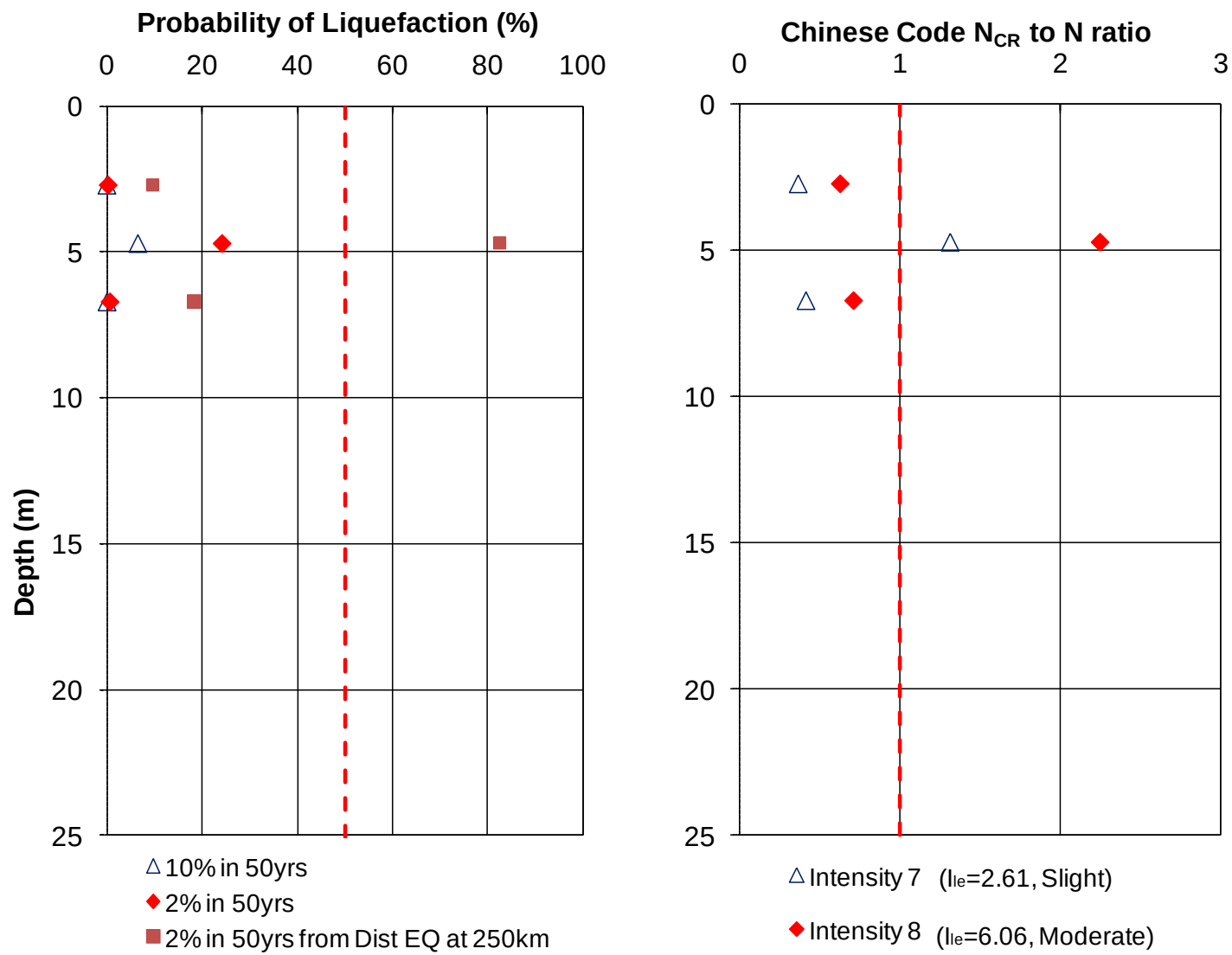


Figure 8.10 Liquefaction Chart for BH22 for 10% in 50 Years Ground Motion

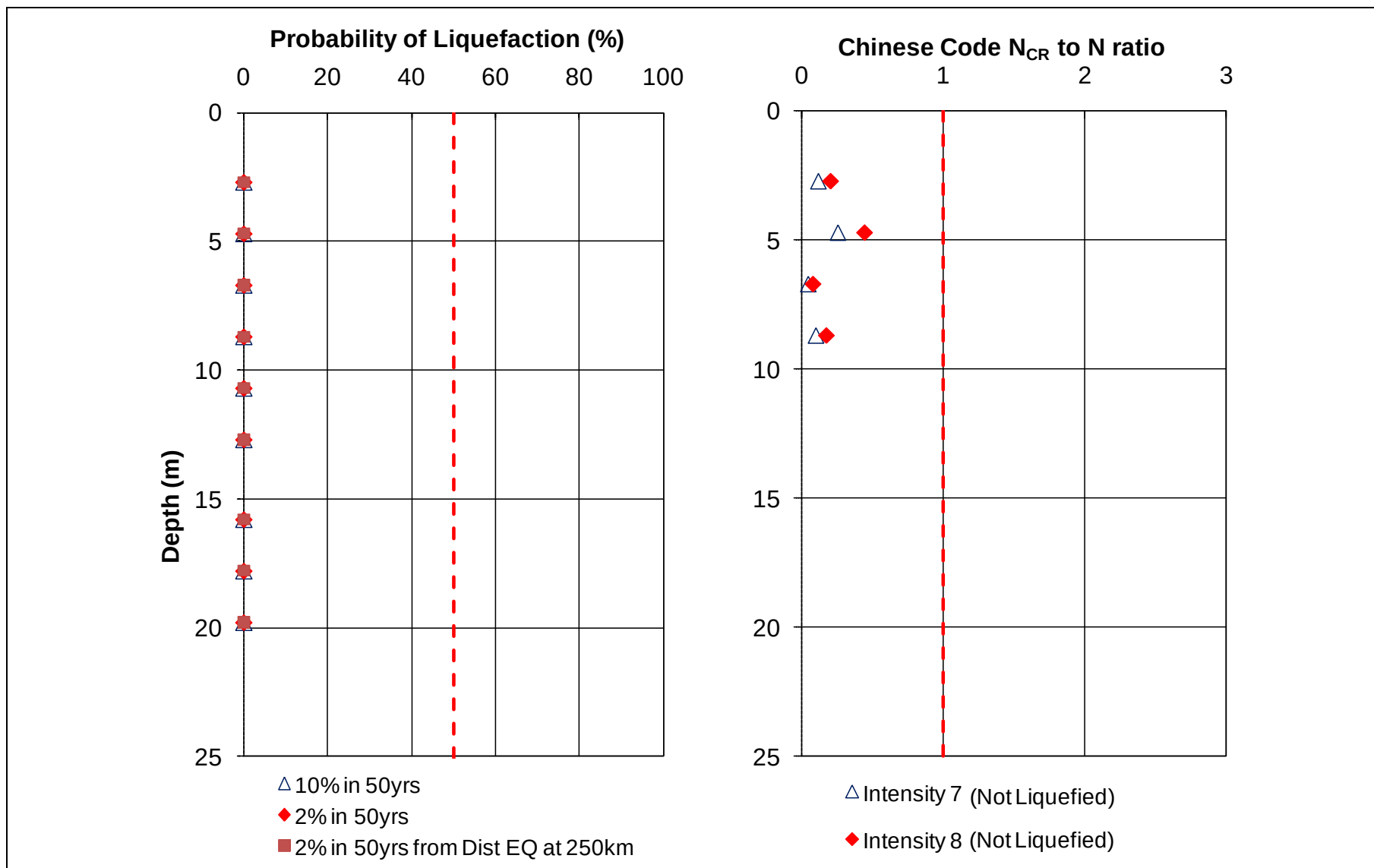


Figure 8.11 Liquefaction Chart for BH23 for 10% in 50 Years Ground Motion

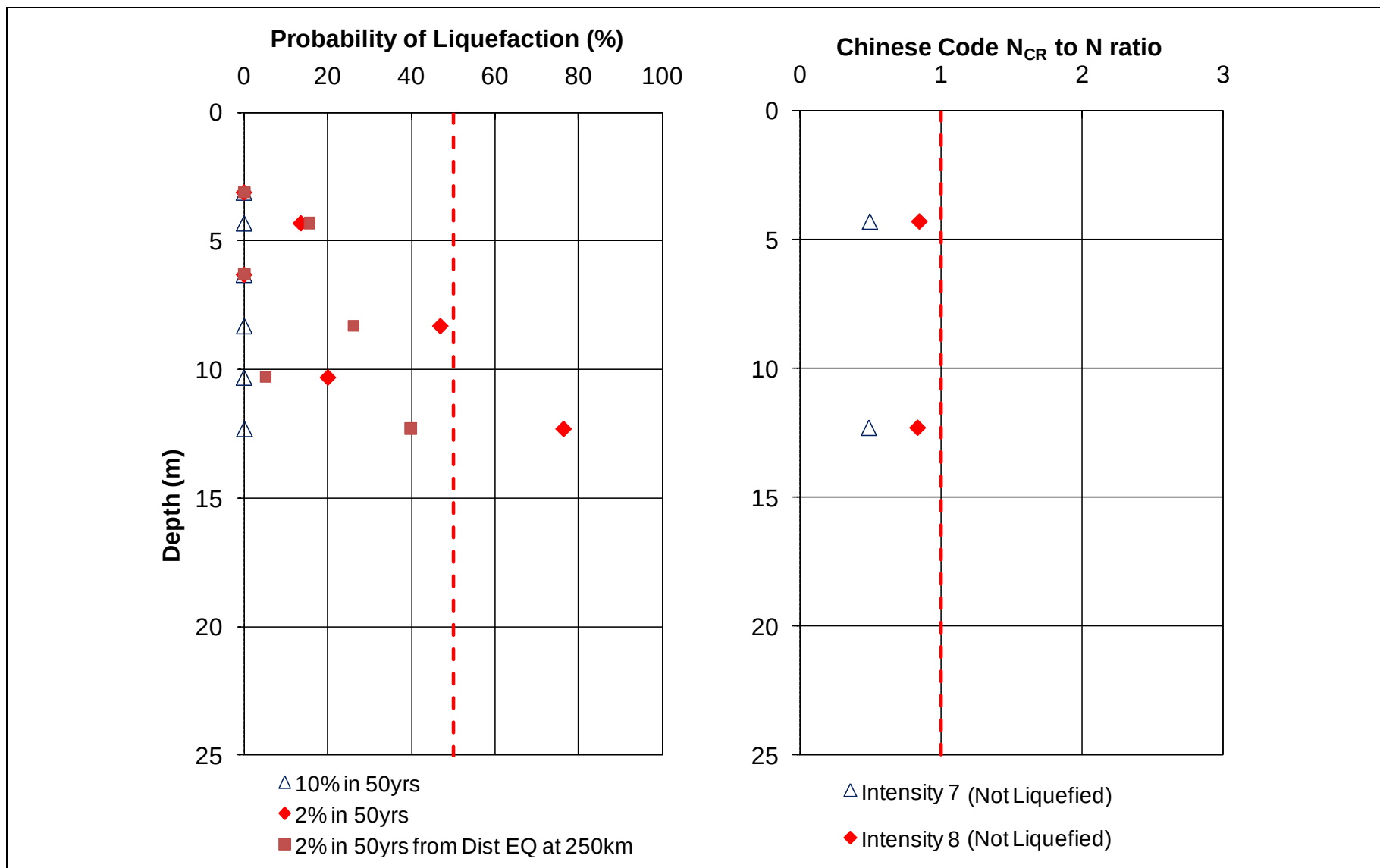


Figure 8.12 Liquefaction Chart for BH24 for 10% in 50 Years Ground Motion

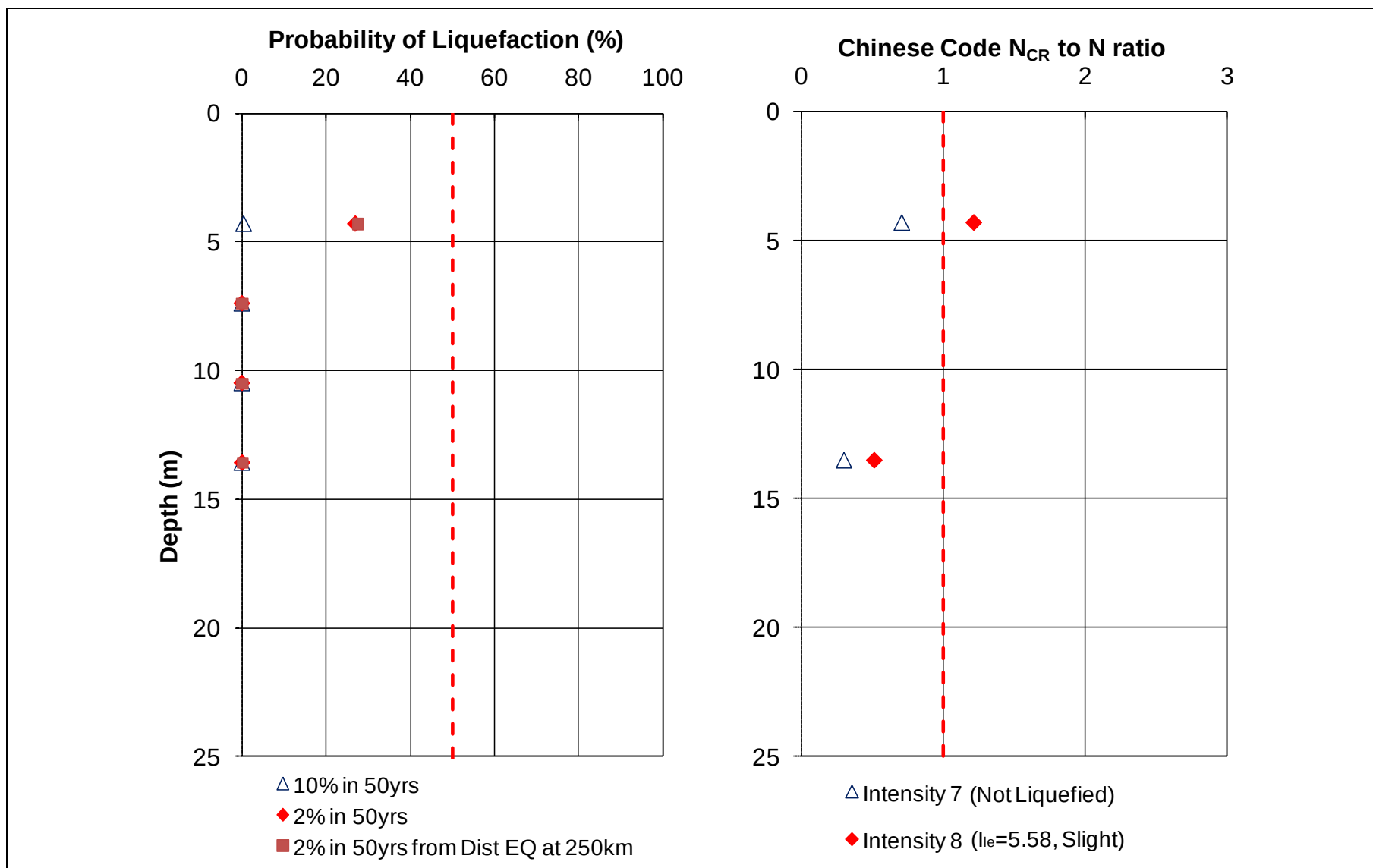


Figure 8.13 Liquefaction Chart for BH26 for 10% in 50 Years Ground Motion

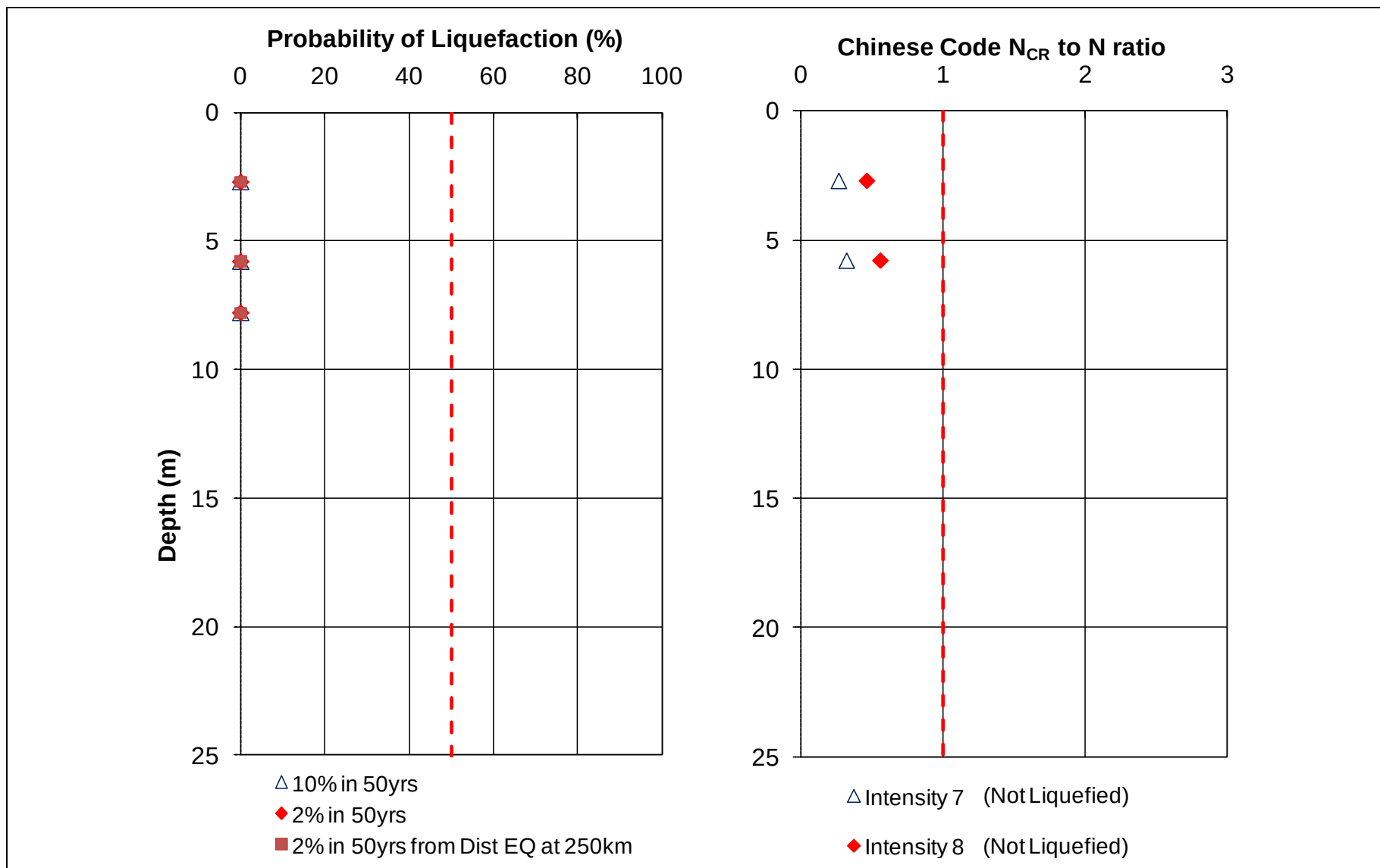


Figure 8.14 Liquefaction Chart for BH27 for 10% in 50 Years Ground Motion

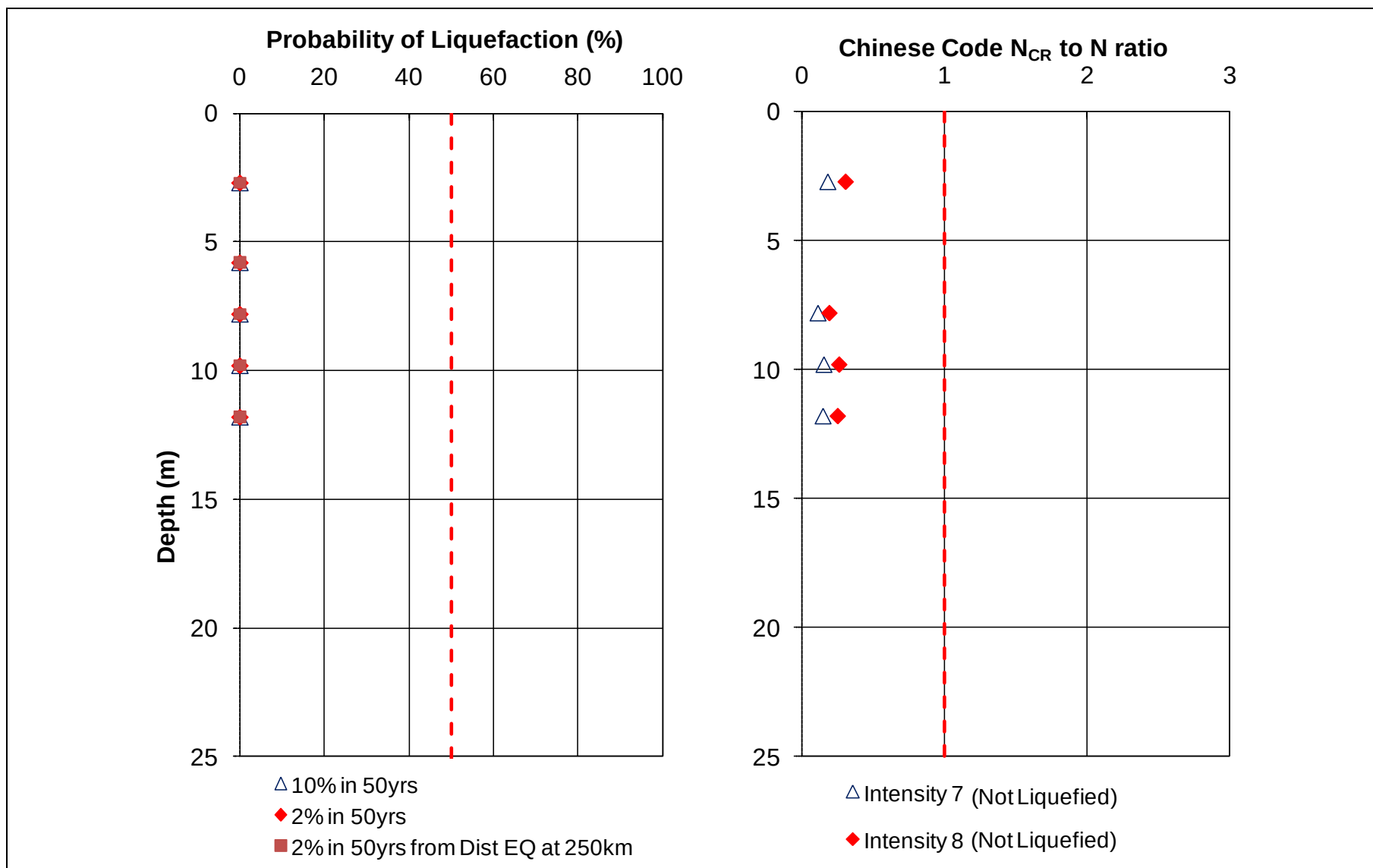


Figure 8.15 Liquefaction Chart for BH29 for 10% in 50 Years Ground Motion



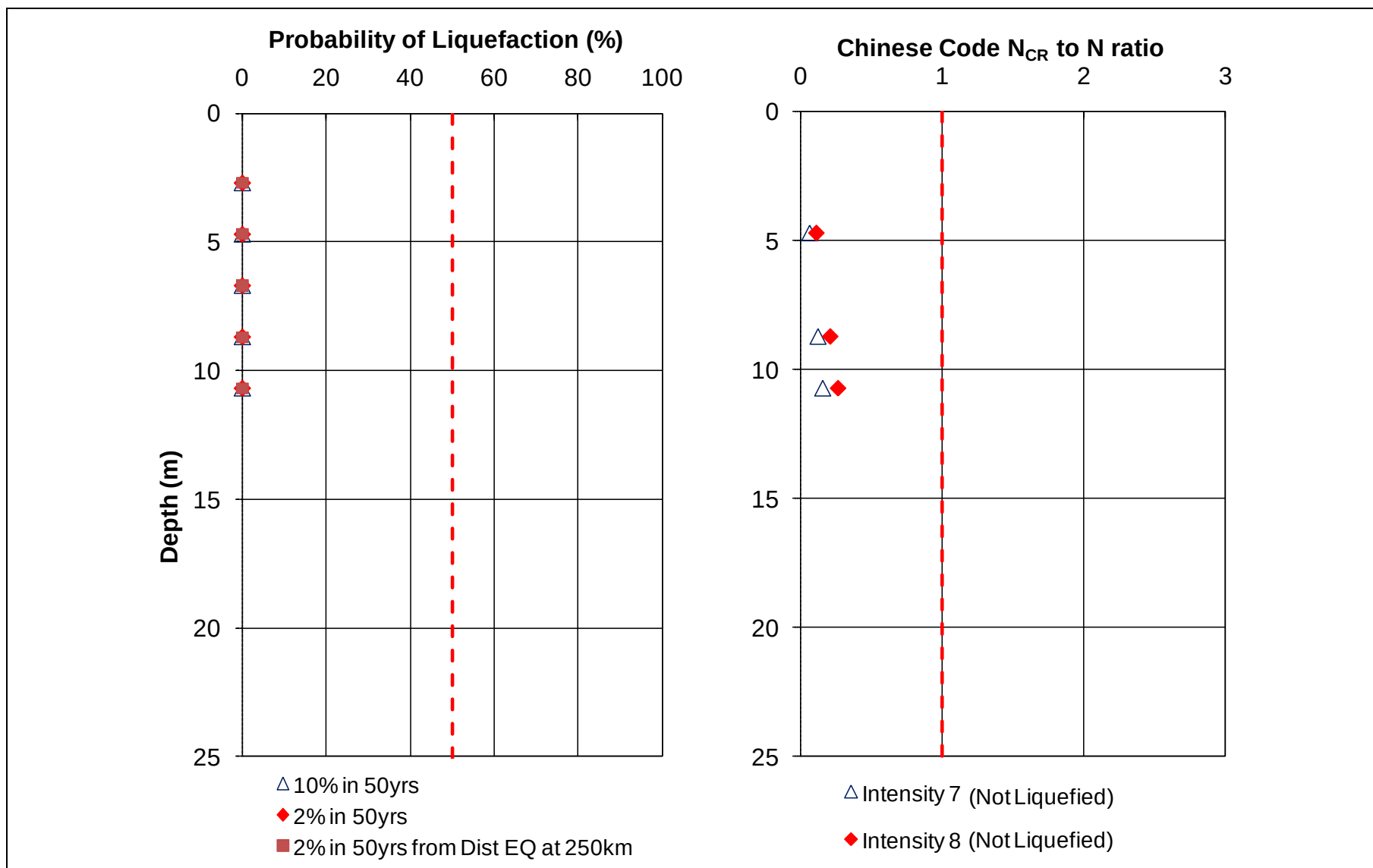


Figure 8.16 Liquefaction Chart for BH30 for 10% in 50 Years Ground Motion

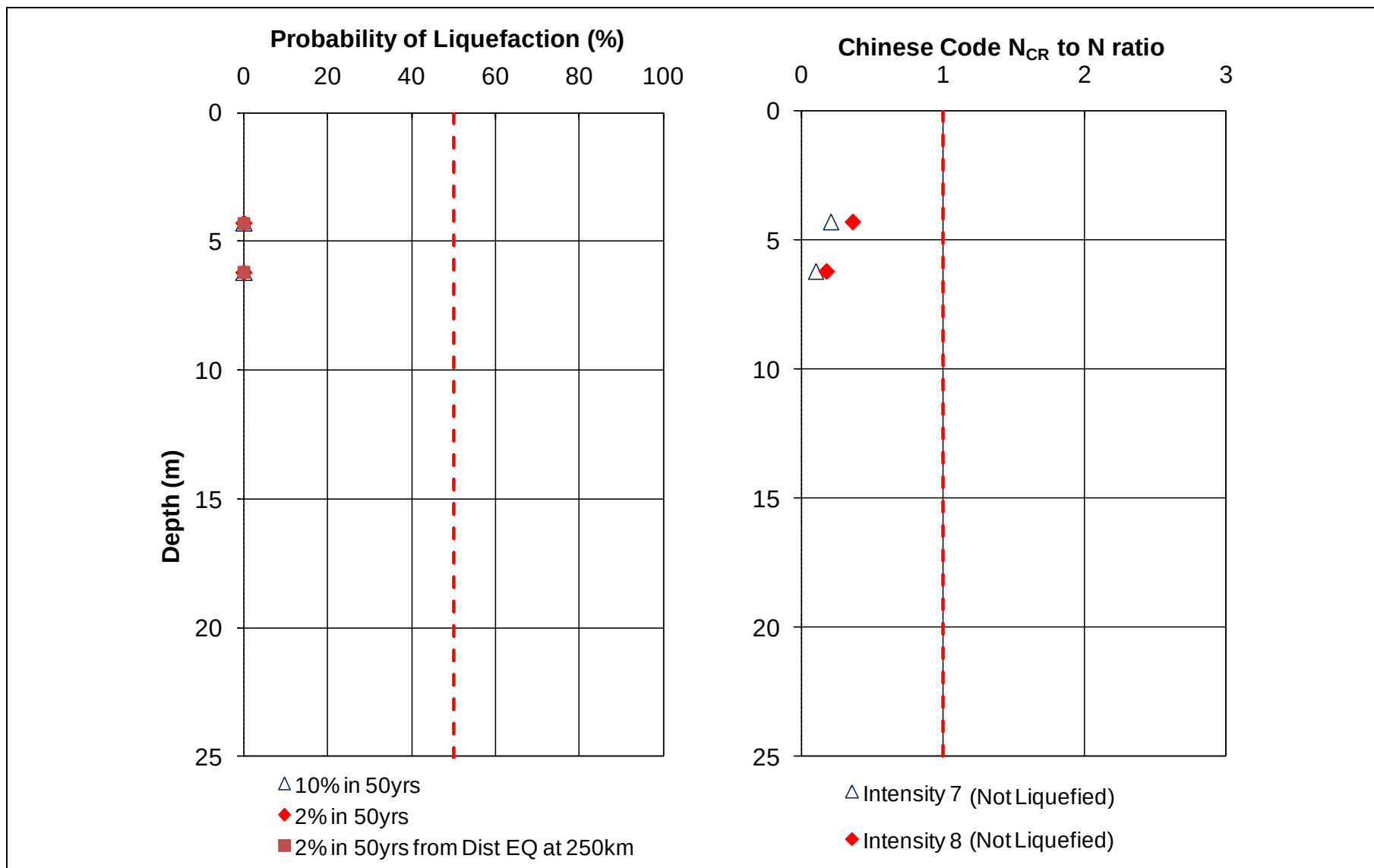


Figure 8.17 Liquefaction Chart for BH32 for 10% in 50 Years Ground Motion

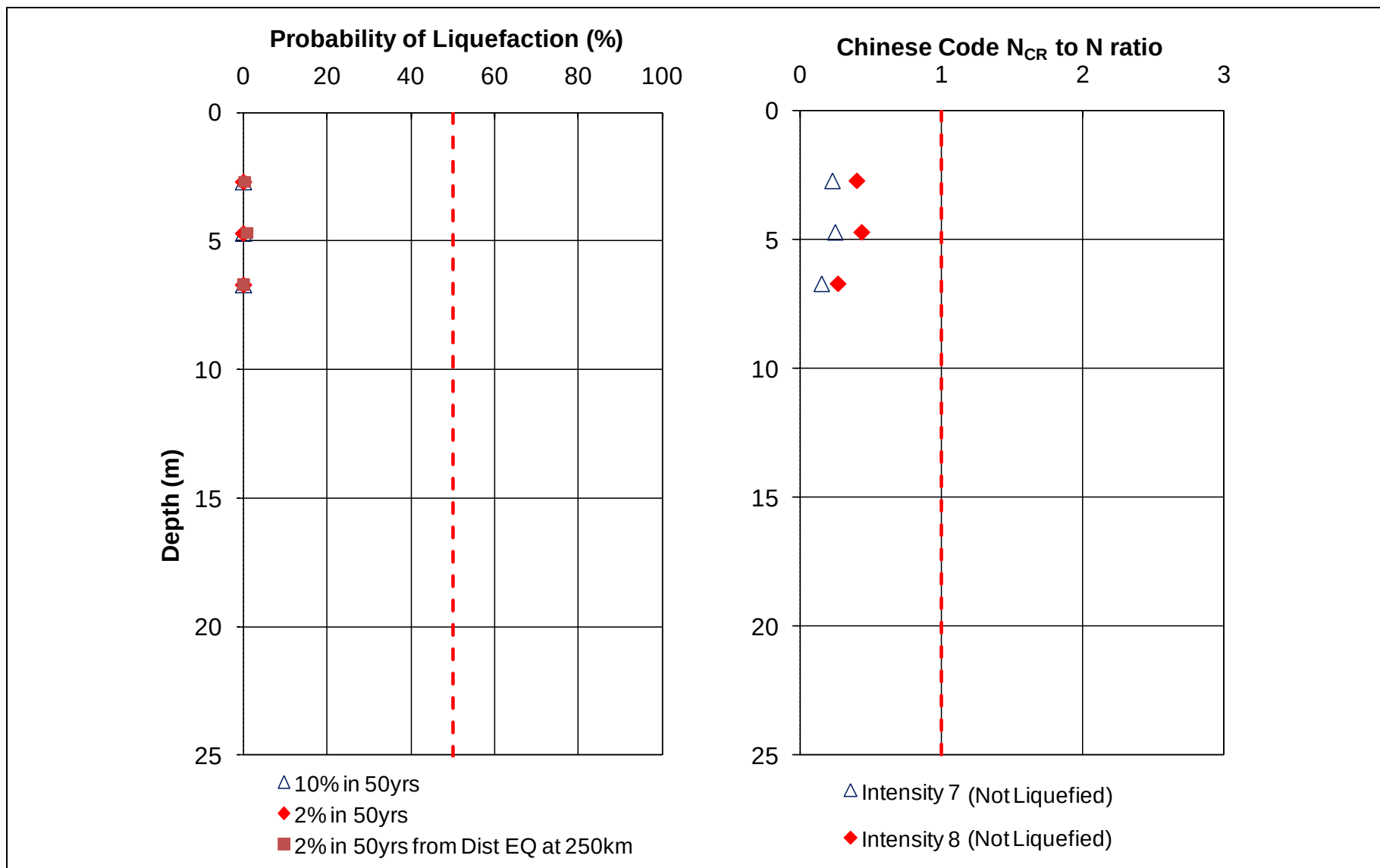


Figure 8.18 Liquefaction Chart for BH36 for 10% in 50 Years Ground Motion

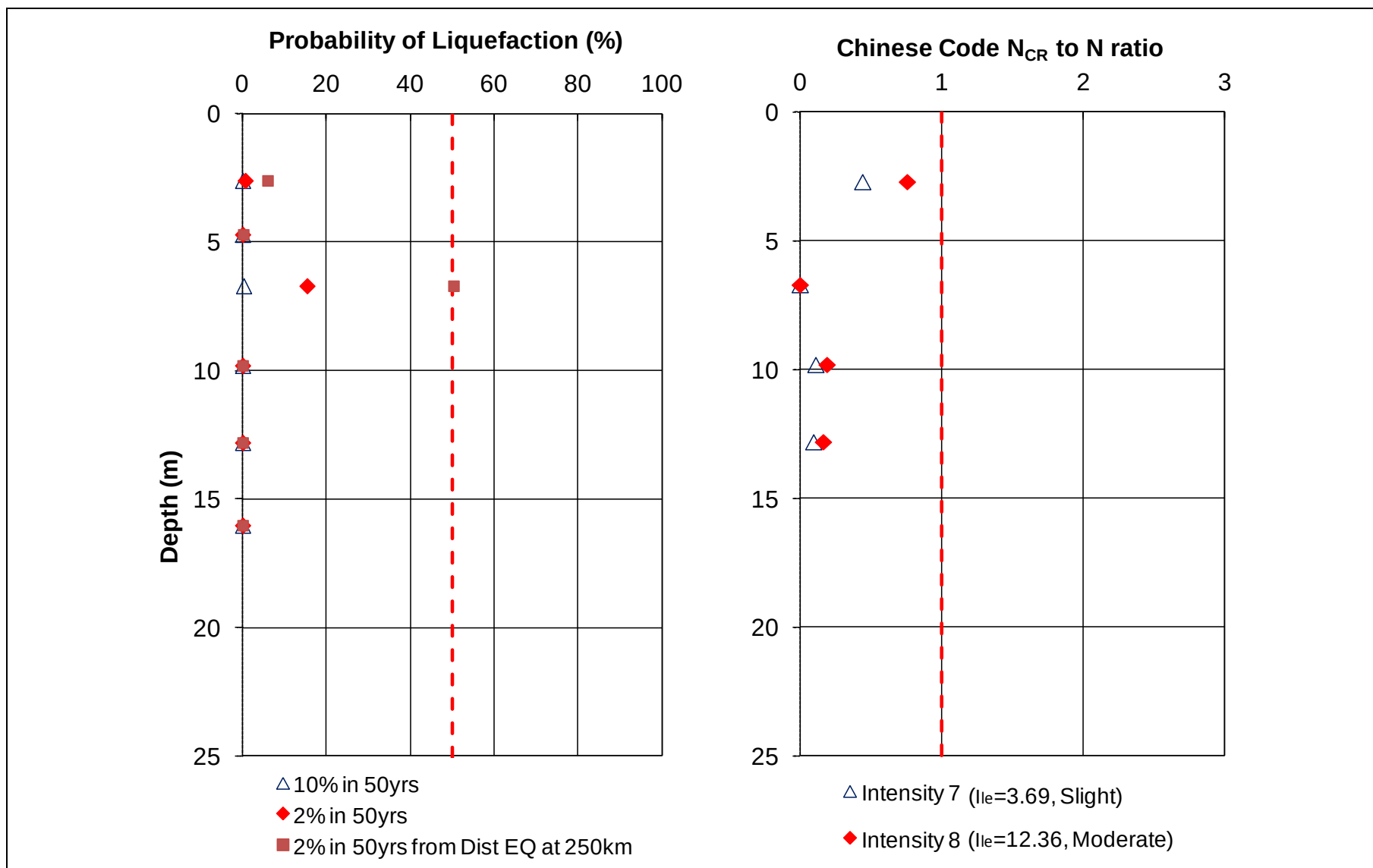


Figure 8.19 Liquefaction Chart for BH39 for 10% in 50 Years Ground Motion

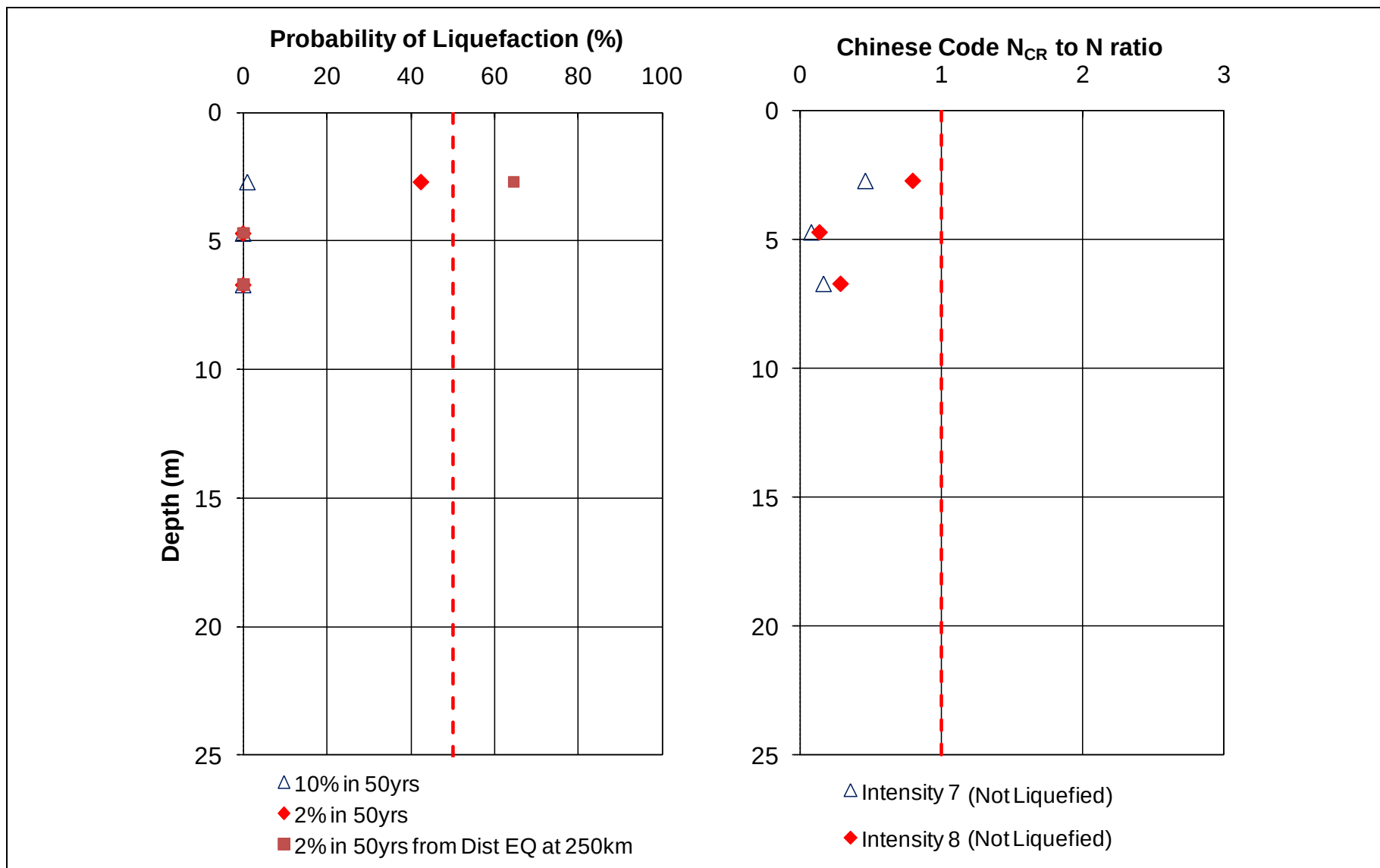


Figure 8.20 Liquefaction Chart for BH42 for 10% in 50 Years Ground Motion

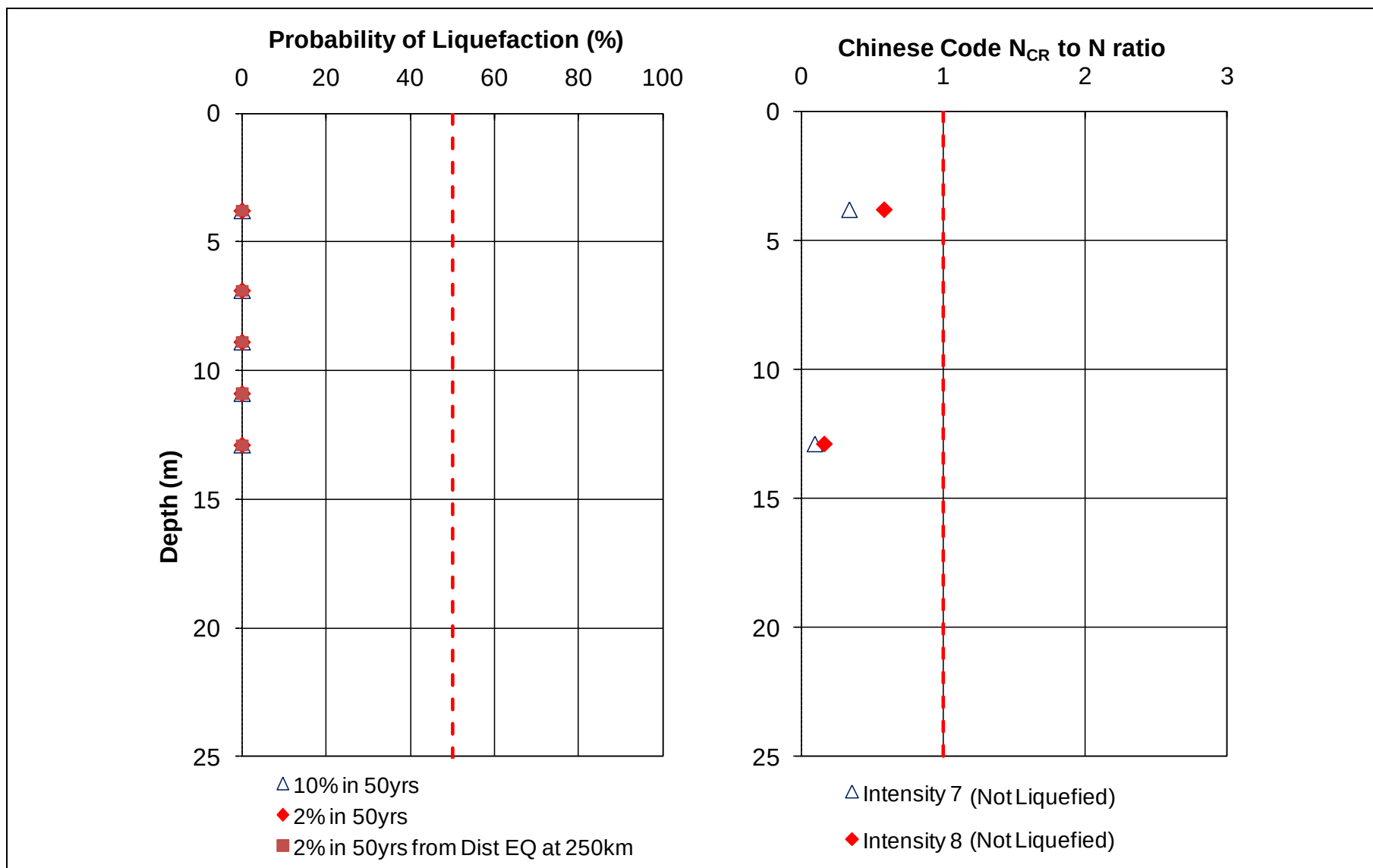


Figure 8.21 Liquefaction Chart for BH43 for 10% in 50 Years Ground Motion

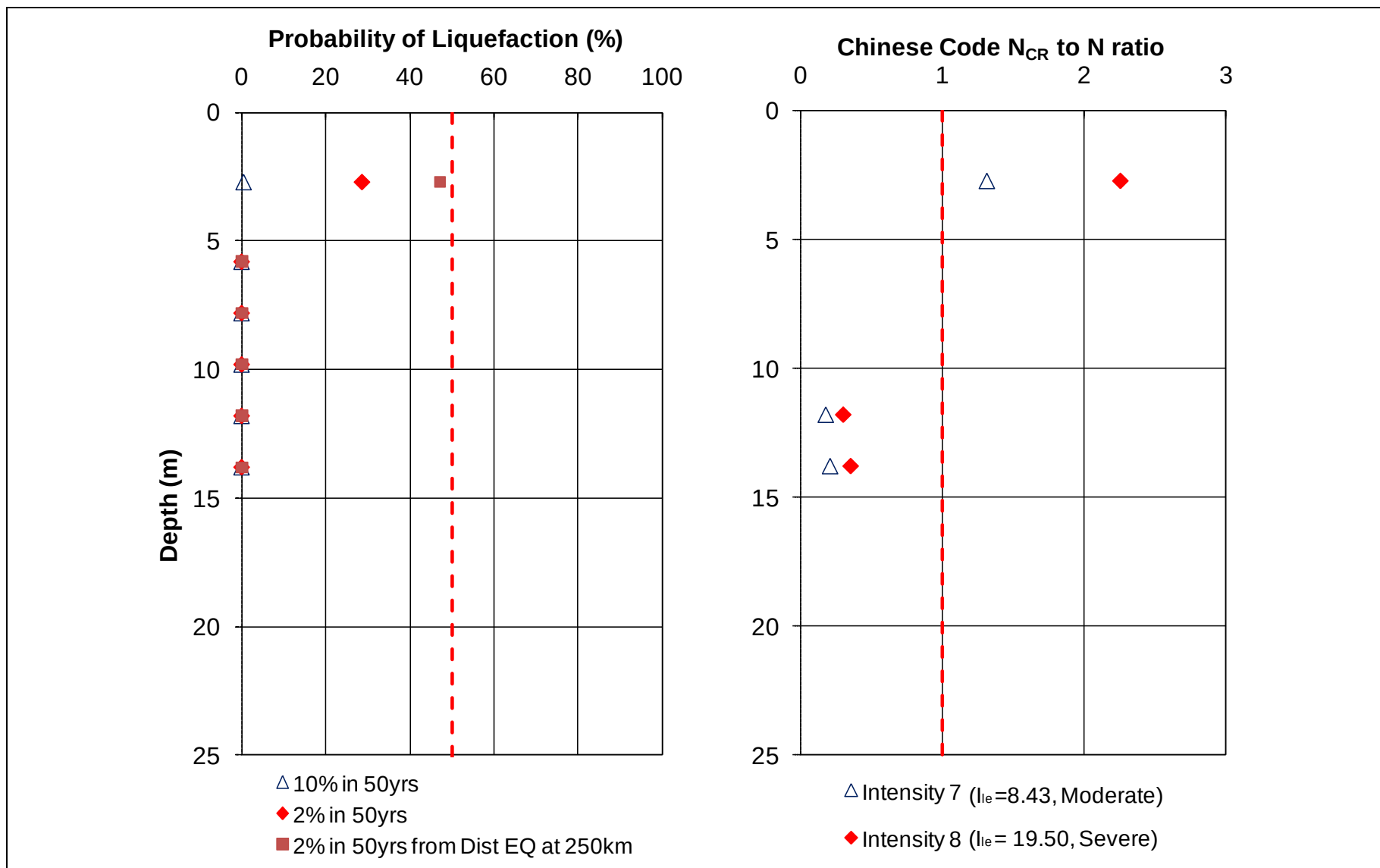


Figure 8.22 Liquefaction Chart for BH44 for 10% in 50 Years Ground Motion

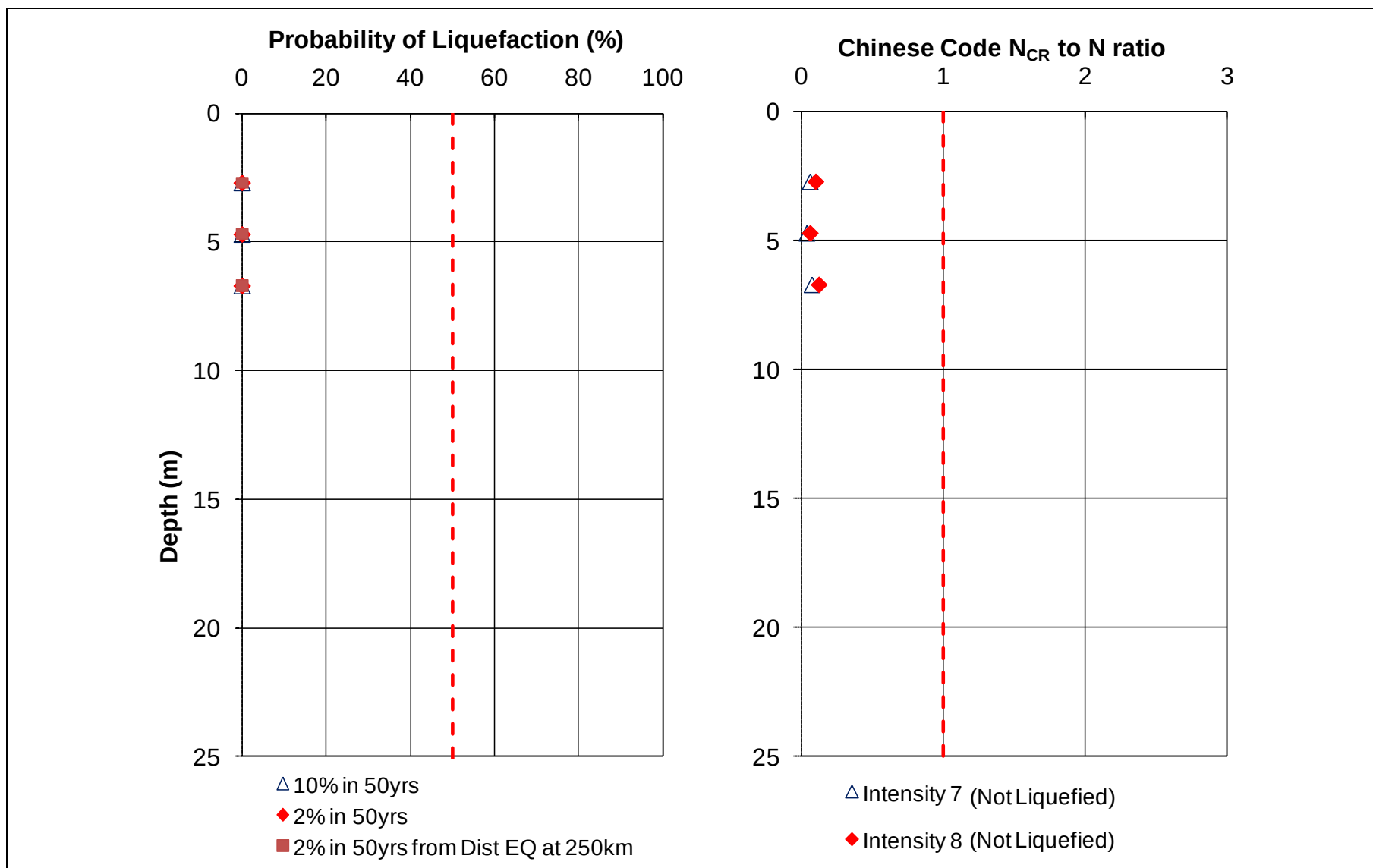


Figure 8.23 Liquefaction Chart for BH45 for 10% in 50 Years Ground Motion



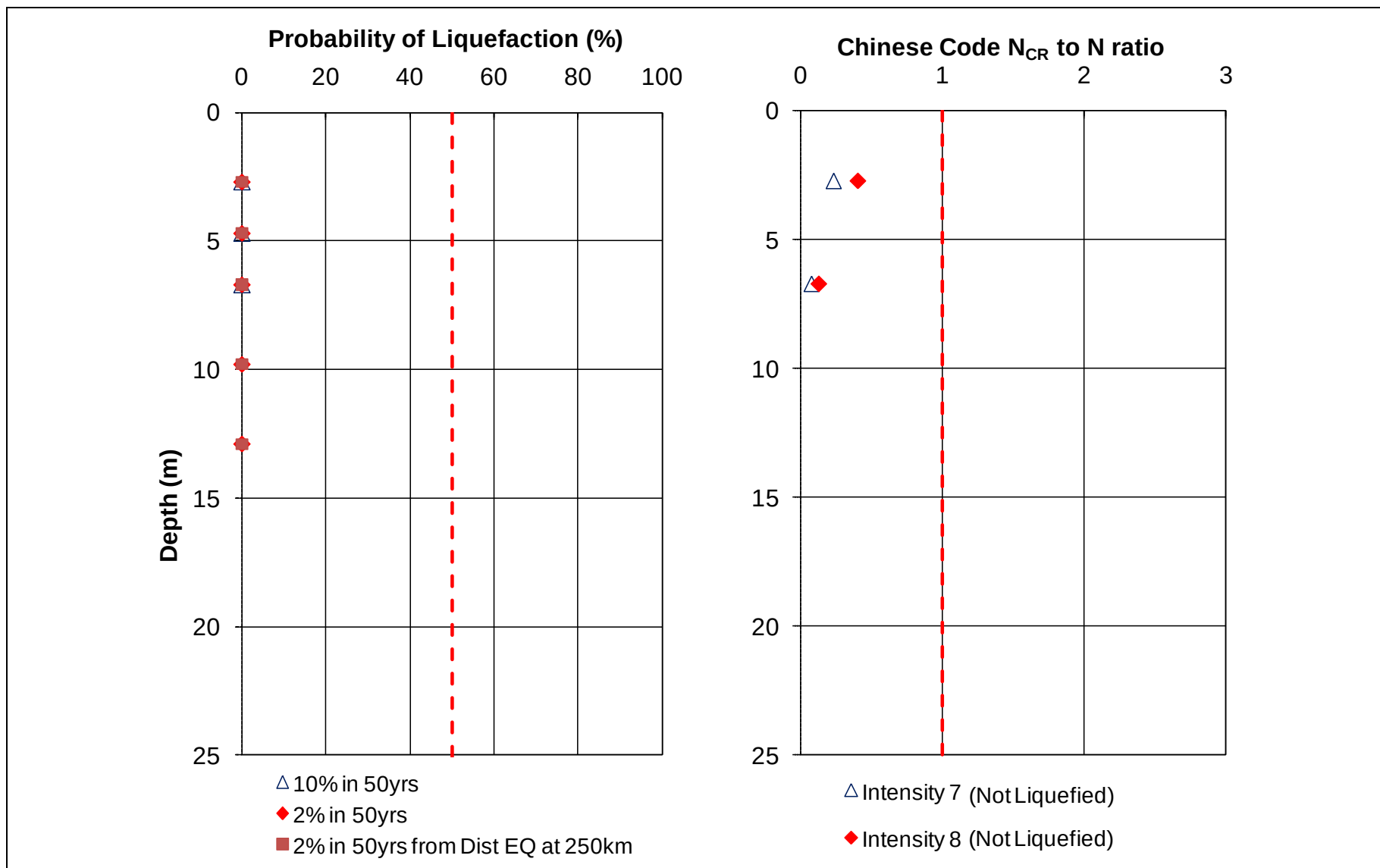


Figure 8.24 Liquefaction Chart for BH49 for 10% in 50 Years Ground Motion



## 8.6 Liquefaction Zoning

The available AGS borehole data (around 2000) have been used to analyse the liquefaction potential under the ground motion of 10% and 2% chance of being exceeded in 50 years for Hong Kong respectively. The liquefaction probability of each AGS borehole is calculated using the Seed method (Seed et al, 2001) as presented in Section 8.3.

In the analysis, the ground water table is assumed to be 1.5 m below the existing ground level for simplicity. The earthquake induced maximum shear stress against depth is obtained from the best-estimate and upper-estimate design lines of the site response analysis results for all boreholes in the Study Area. The maximum depth of liquefaction is considered to be 40 m below ground level because the chance of liquefaction for depth greater than 40 m is very unlikely considering the geology in the Study Area. Also, only alluvial sand and silty sand are considered in the liquefaction analysis. Although fill containing loose sand may also be susceptible to liquefaction, it is considered that its composition can be highly variable and localised. Therefore, a site-specific liquefaction analysis for any significantly filled-up man-made areas should be considered.

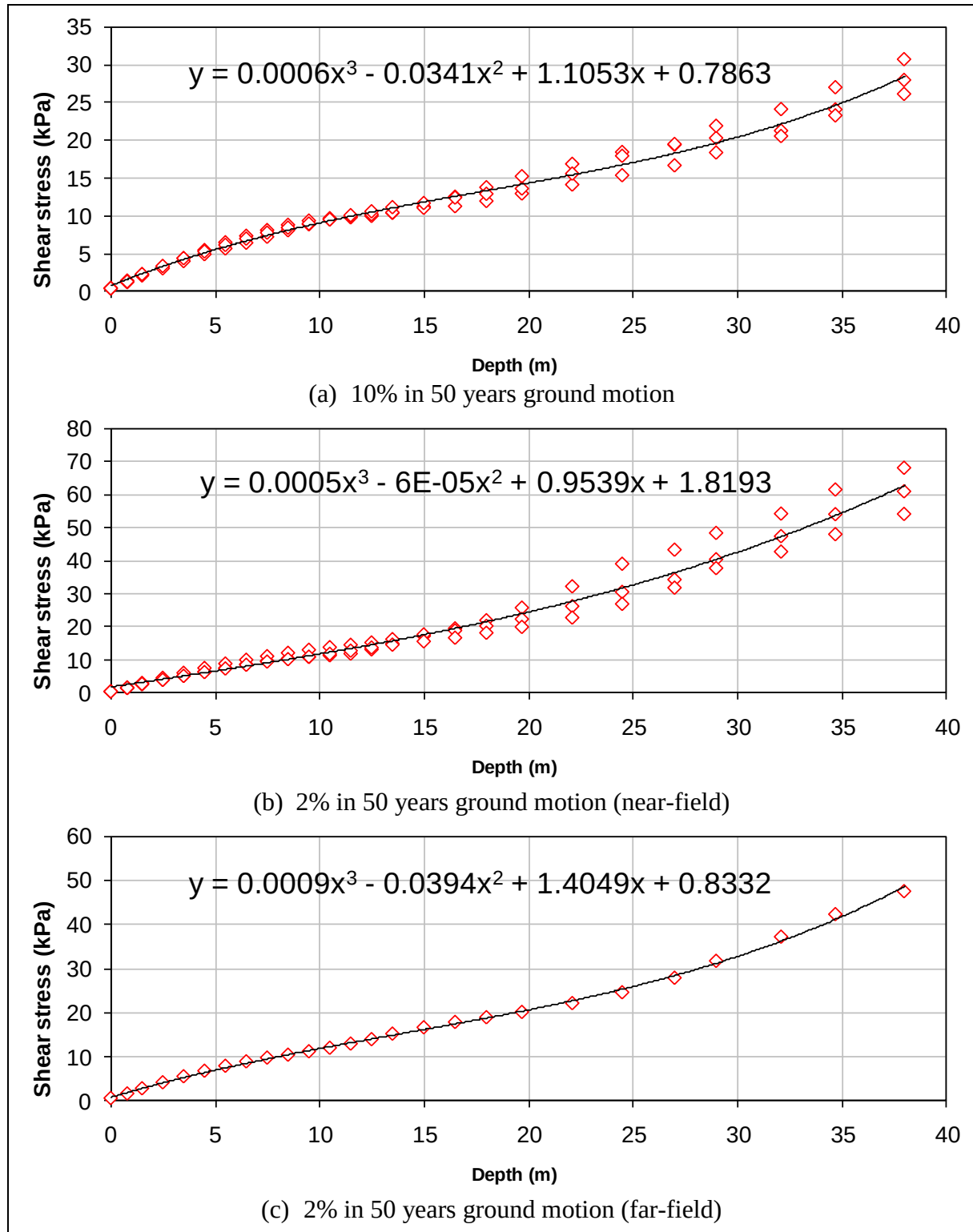
The results from *Oasys SIREN* analyses have been used to estimate the shear stress at various depths. The average maximum shear stress against depth for each borehole from the site response analyses are presented in Figures 8.25 to 8.46. The three curves represent the three different input time histories matching the 0.2 s, 1 s and 5 s spectral accelerations of the design response spectra as discussed in Section 5. Figures 8.47 to 8.49 show the best-estimate and upper-estimate curves of the maximum shear stress against depth for ground motions of the 10% and 2% chance being exceeded in the next 50 years respectively.

The results of liquefaction potential assessment show that the maximum probability of liquefaction for the 10% chance being exceeded in the next 50 years ground motion is less than 10% even the upper-estimate design line of maximum shear stress is applied. Therefore, it is concluded that liquefaction of the Study Area is very unlikely for ground motion having a chance of 10% of being exceeded in the next 50 years. However, when the ground motion increases to 2% chance of being exceeded in the next 50 years, quite a significant number of boreholes would have a liquefaction probability exceeding 60% for at least one layer. This can be considered as having a moderate chance of liquefaction.

The liquefaction probability of each borehole for the 2% in 50 years are presented in Figures 8.50 to 8.53 for the best-estimate and upper-estimate design lines under near-field and far-field earthquake events respectively. Liquefaction contours are then generated based of these maps and divided into four zones of probability 0 - 40%, 40 - 60%, 60 - 80% and 80 - 100% as shown in Figures 8.54 to 8.56. Since the results of liquefaction probability between the upper- and best-estimate design lines for far-field earthquake events are similar, only liquefaction contour maps for the best-estimate design line is produced. Also, the best-estimate design line seems more reasonable when compared to the site-specific borehole liquefaction potential probability discussed in Section 8.5.

GEERRI also produced a liquefaction index zoning map for Earthquake Intensity 7 and Intensity 8 using the Chinese Code method as described in Section 8.4. Intensities 7 and 8 are approximately equivalent to the ground motions having a 10% and 2% chance of being exceeded in the next 50 years respectively. The GEERRI liquefaction index zoning maps are

presented in their report enclosed in Appendix E (see Figures 8.1 & 8.2 in the appendix). It generally shows that the Chinese Code gives a higher chance of liquefaction for the 10% in the next 50 years ground motion. However, the results are similar to that obtained from Seed et al (2001) for the 2% in the next 50 years ground motion.



**Figure 8.25 Maximum Shear Stress against Depth for BH1**

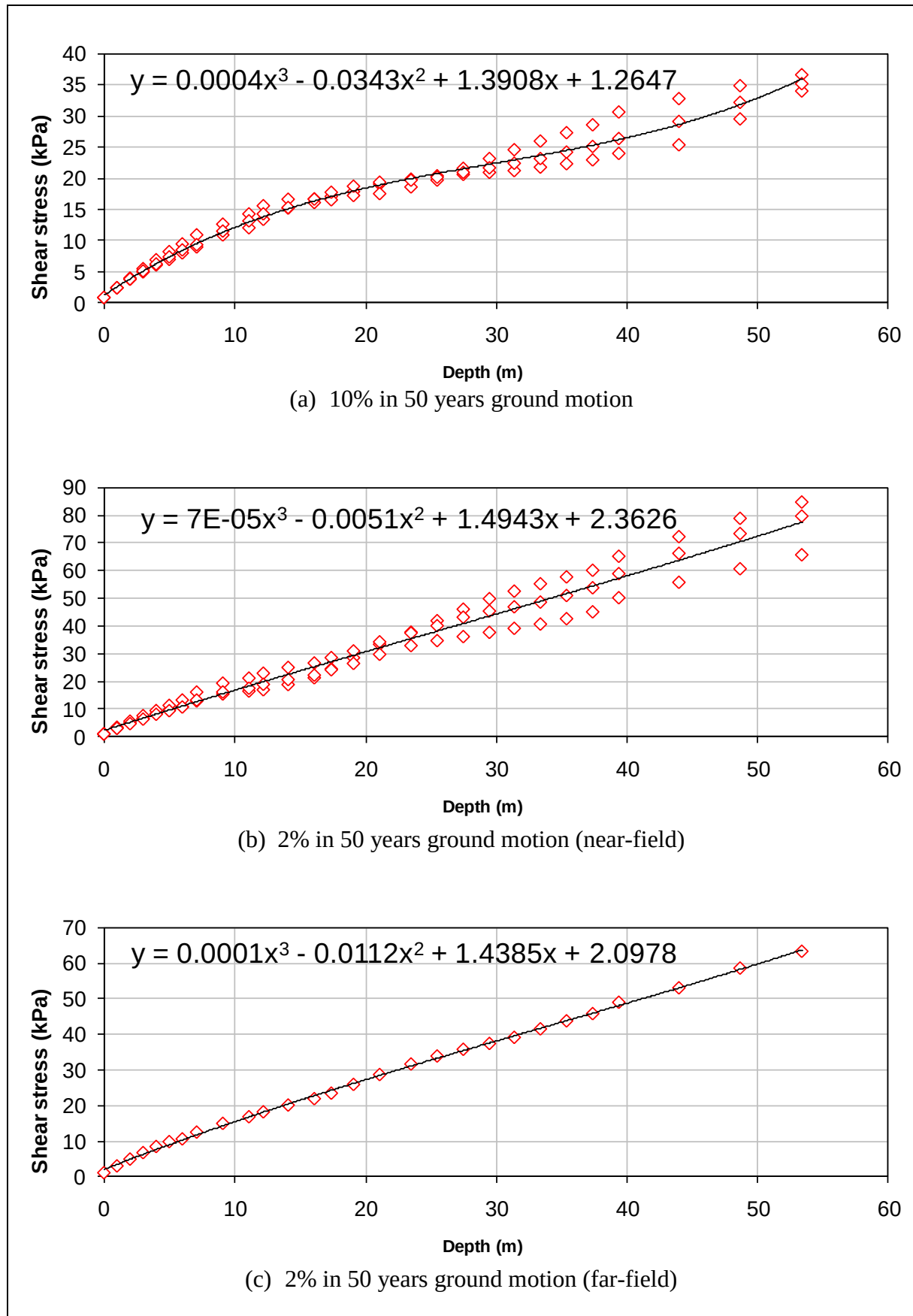


Figure 8.26 Maximum Shear Stress against Depth for BH2

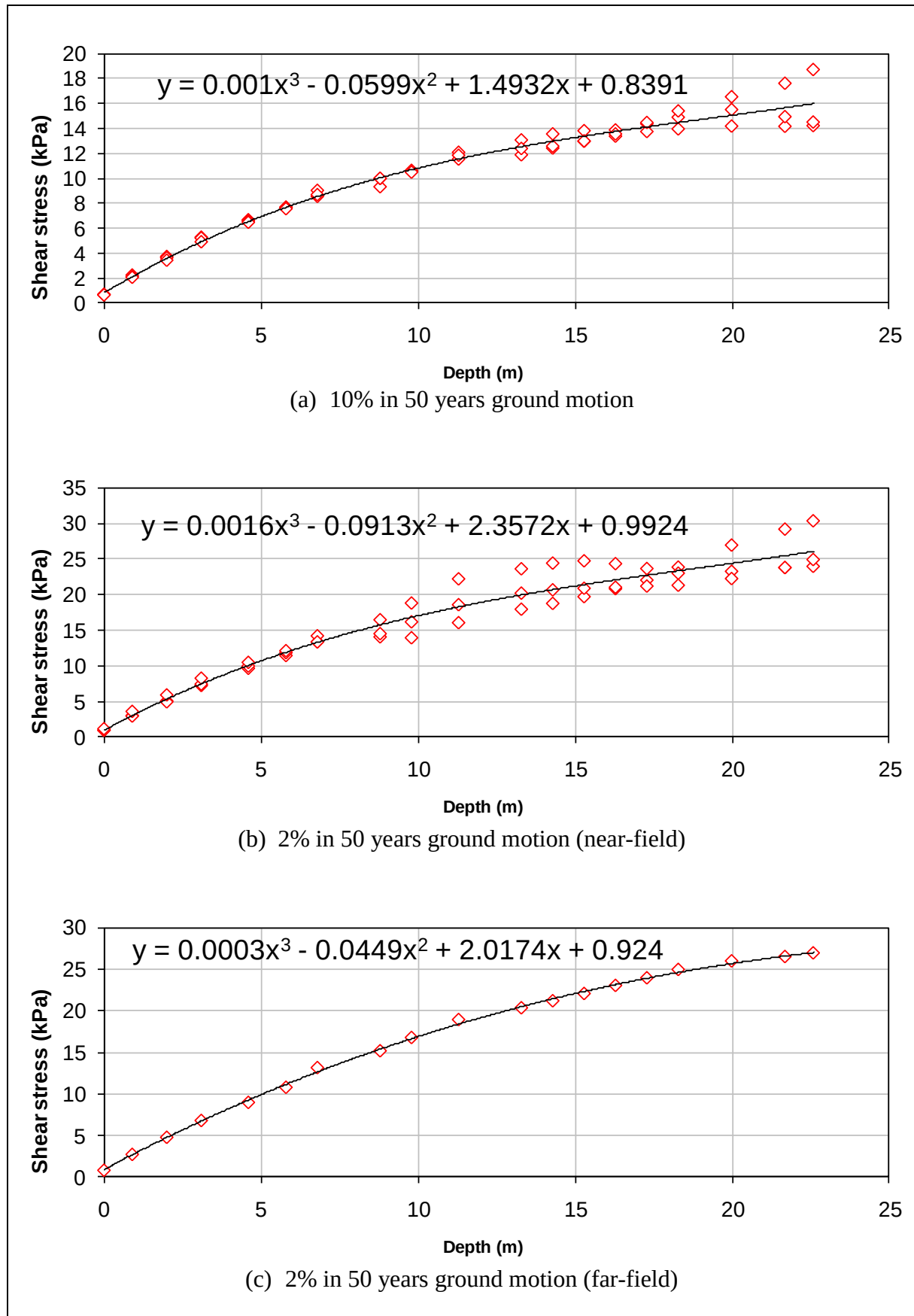


Figure 8.27 Maximum Shear Stress against Depth for BH8

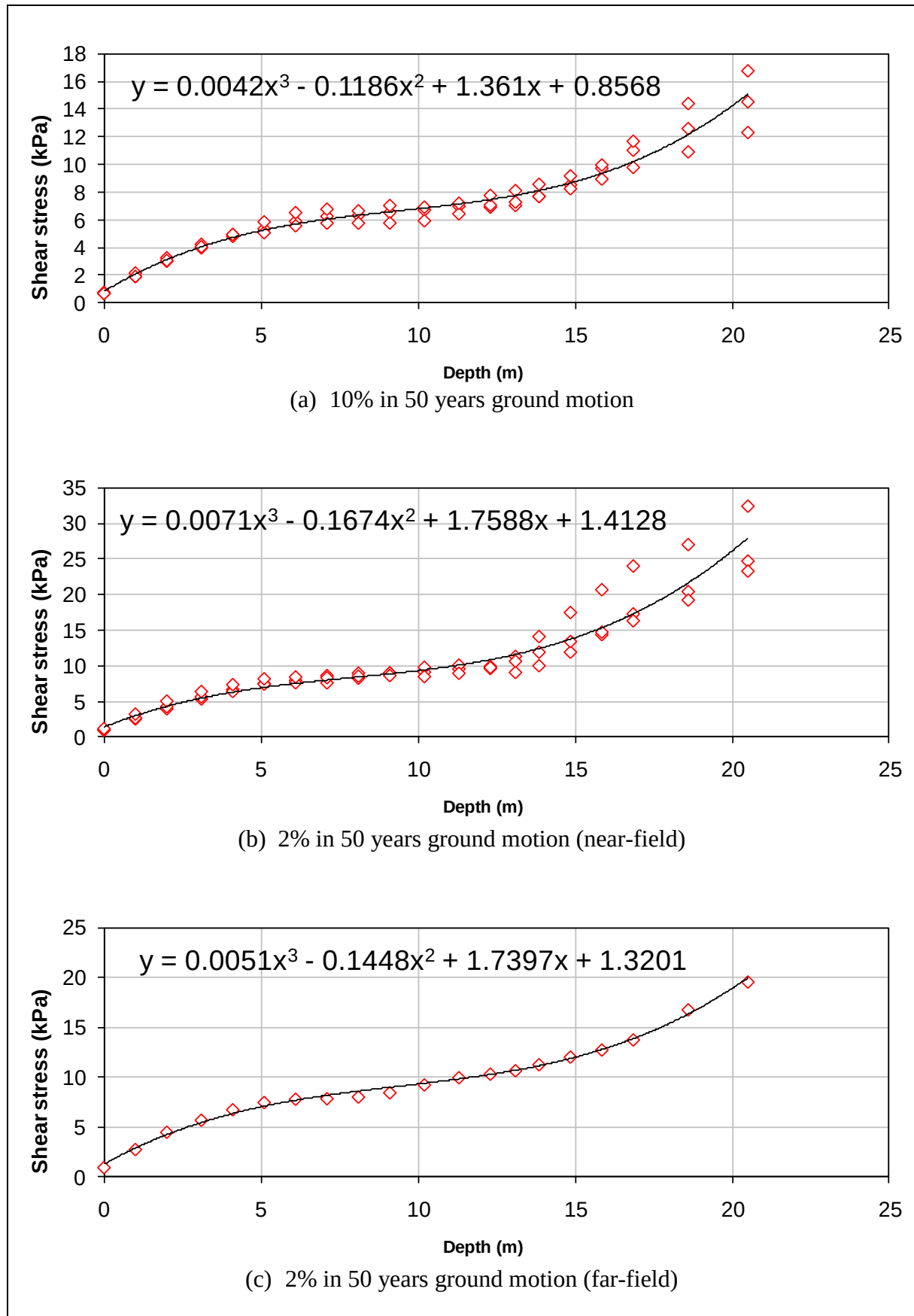


Figure 8.28 Maximum Shear Stress against Depth for BH13

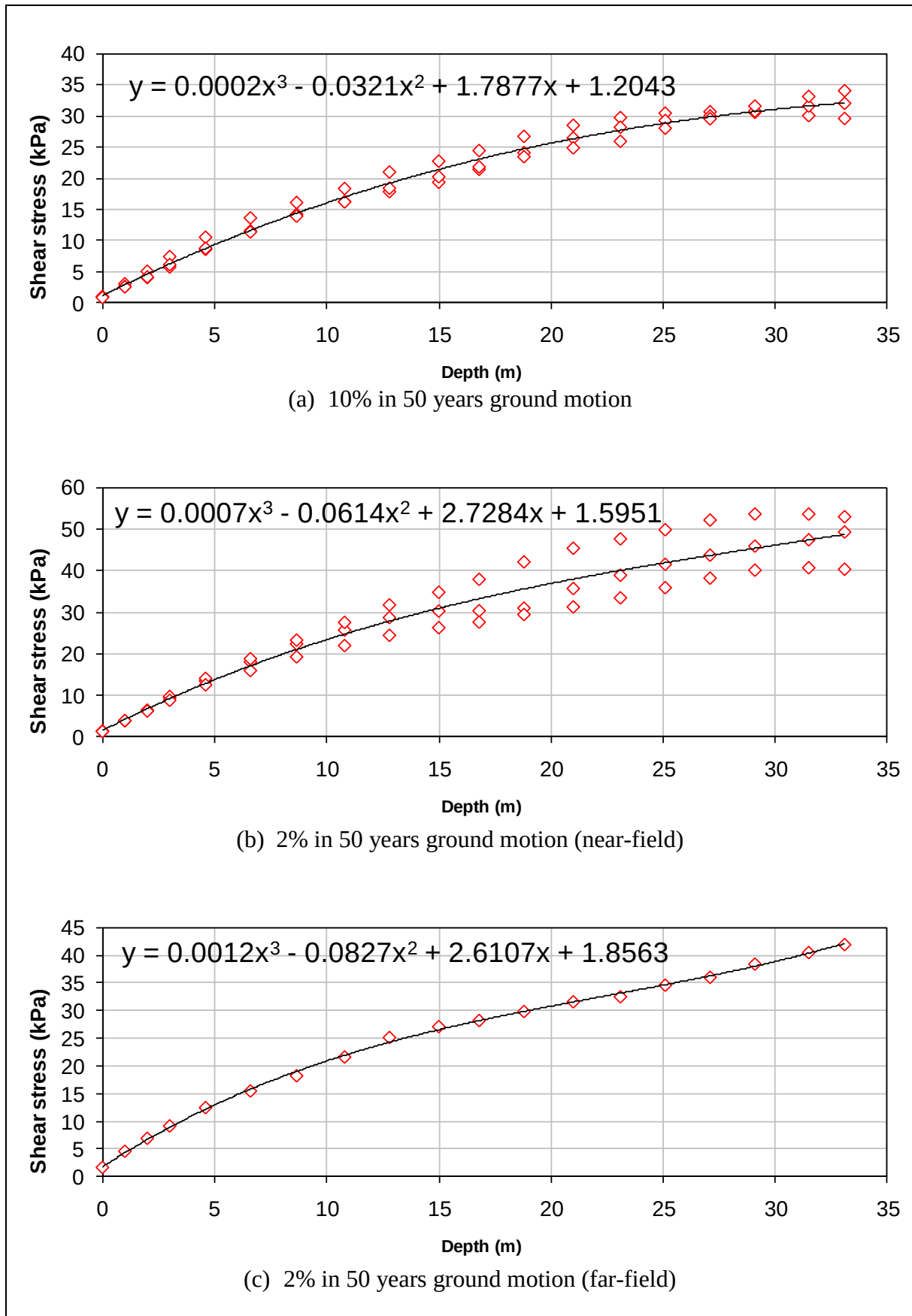
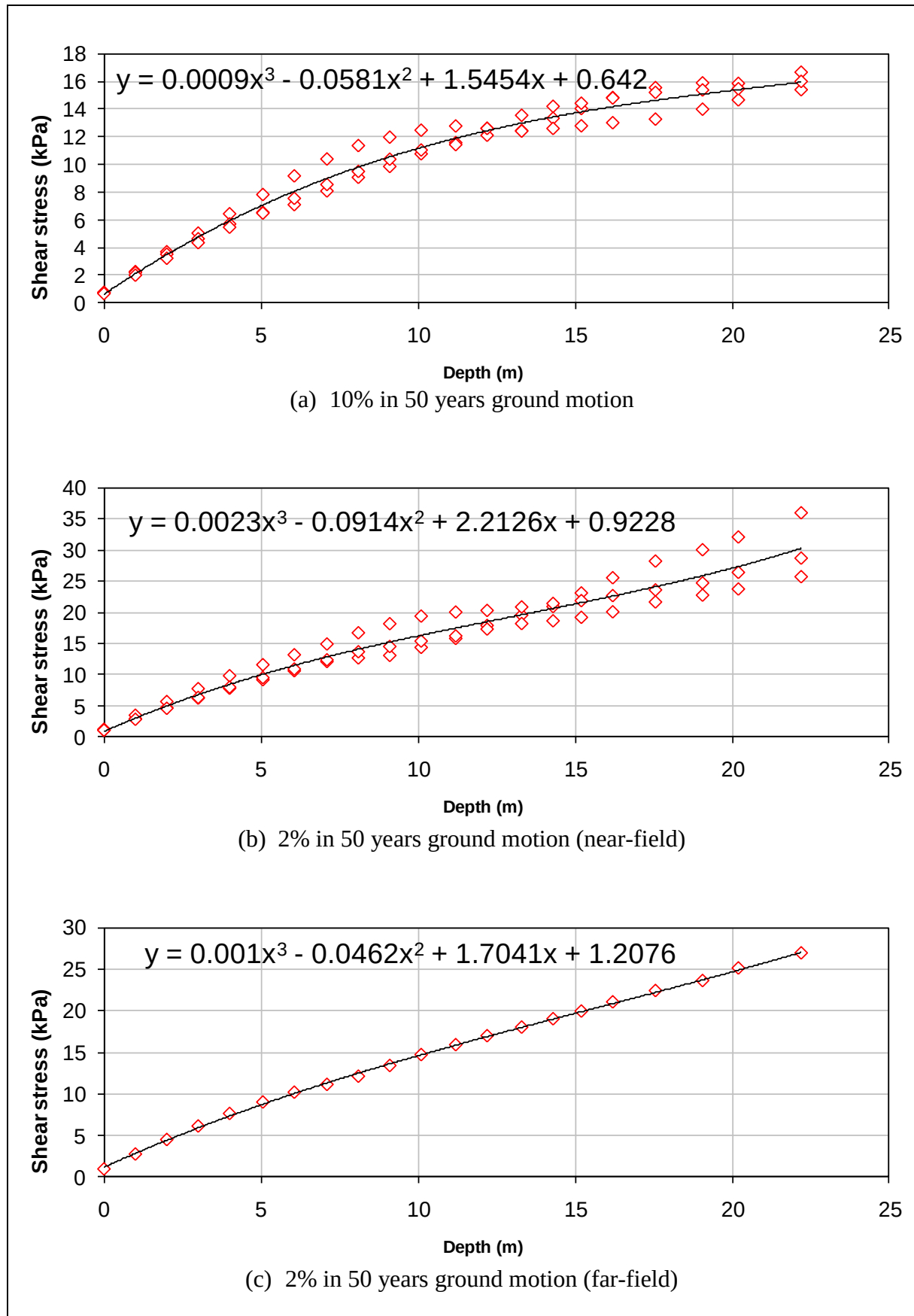


Figure 8.29 Maximum Shear Stress against Depth for BH14





**Figure 8.30 Maximum Shear Stress against Depth for BH20**

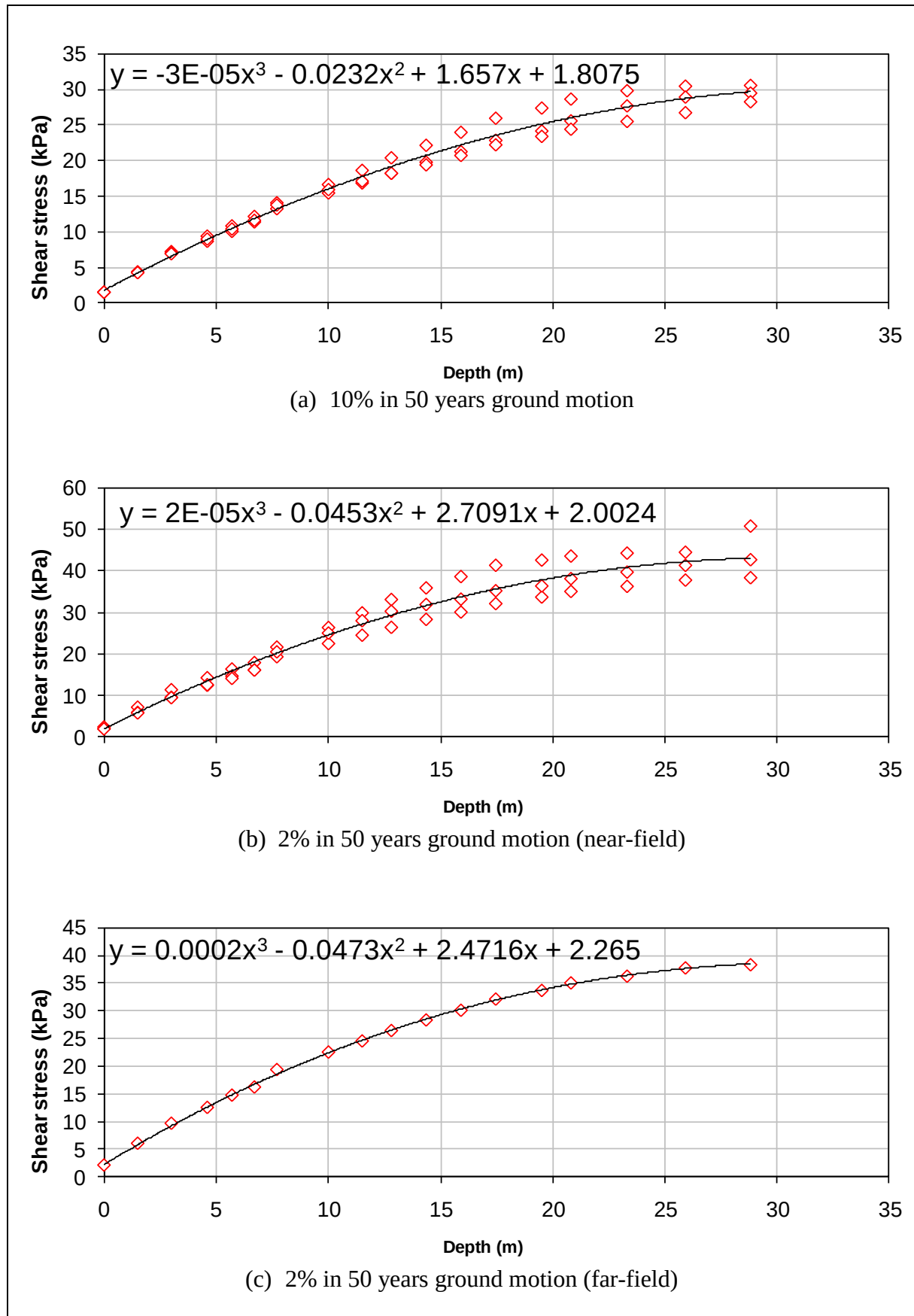


Figure 8.31 Maximum Shear Stress against Depth for BH21

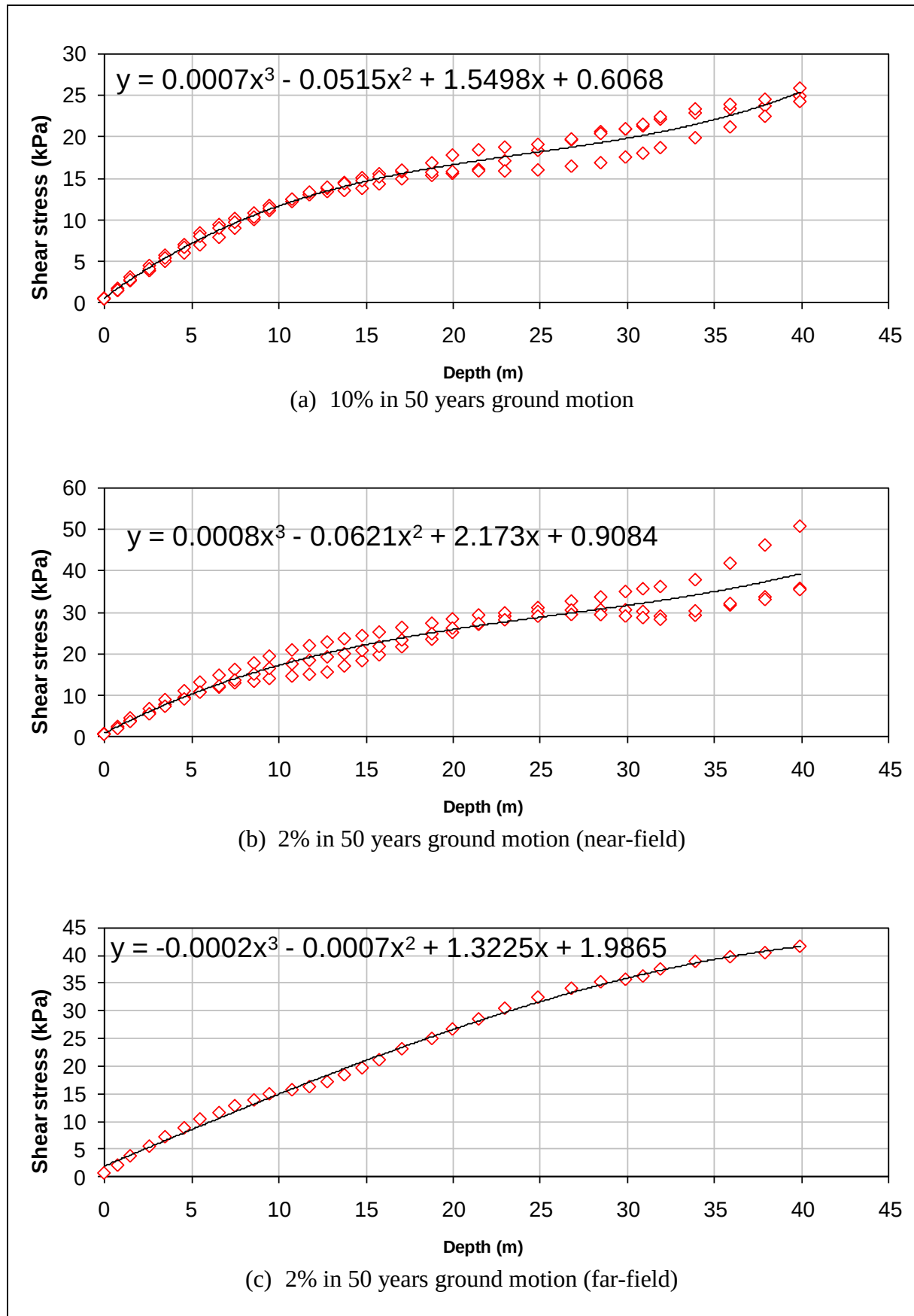


Figure 8.32 Maximum Shear Stress against Depth for BH22

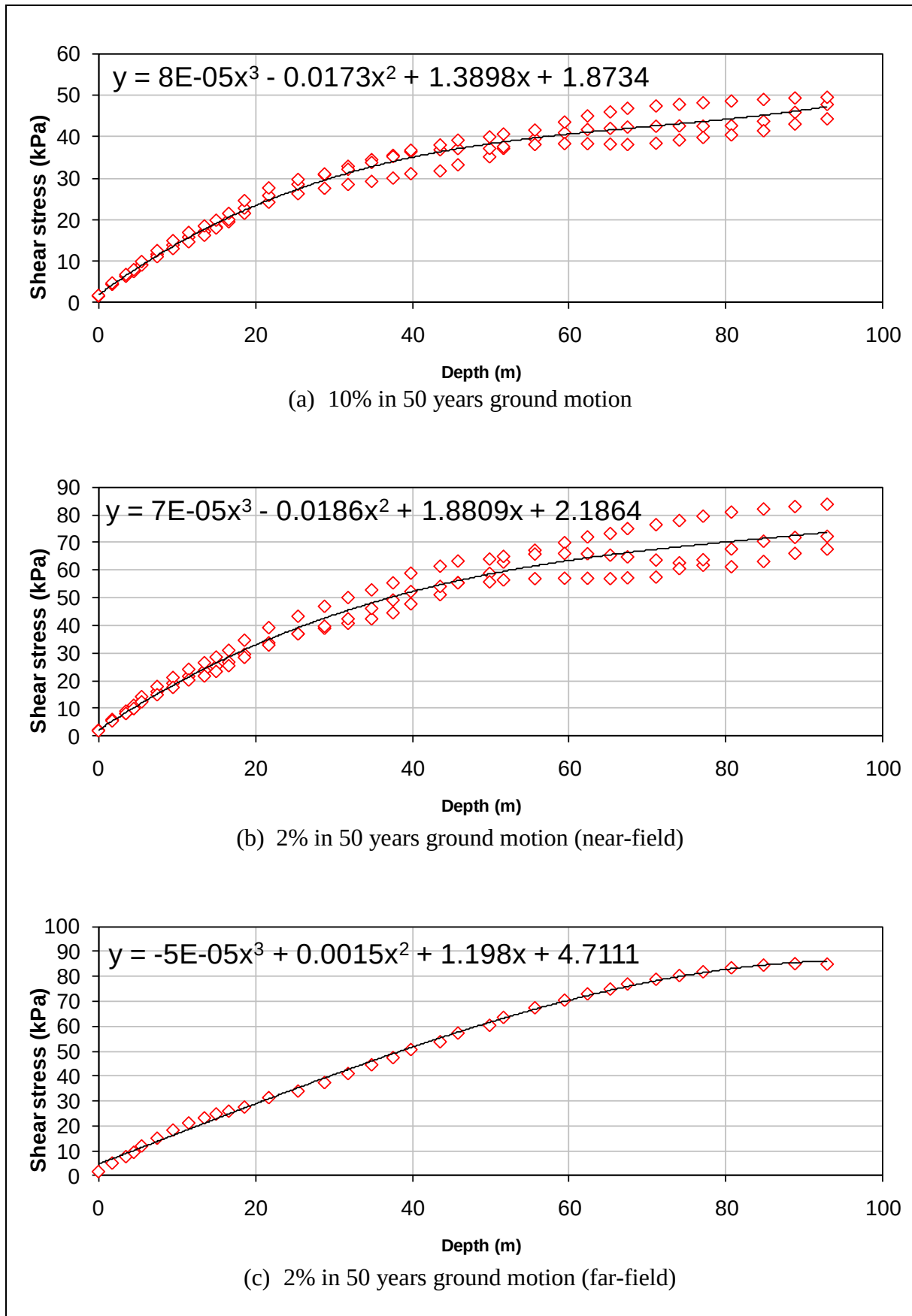


Figure 8.33 Maximum Shear Stress against Depth for BH23

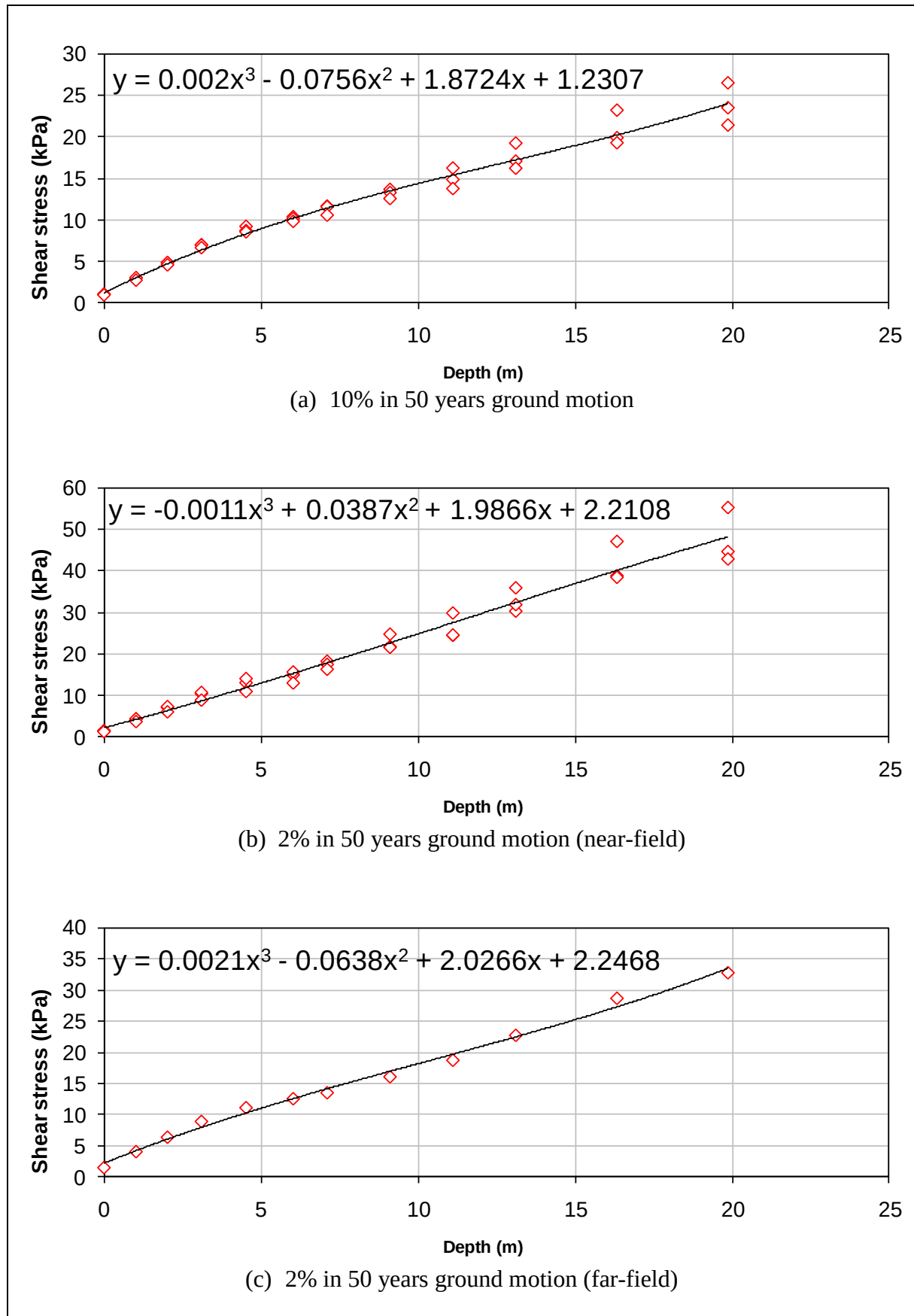


Figure 8.34 Maximum Shear Stress against Depth for BH24

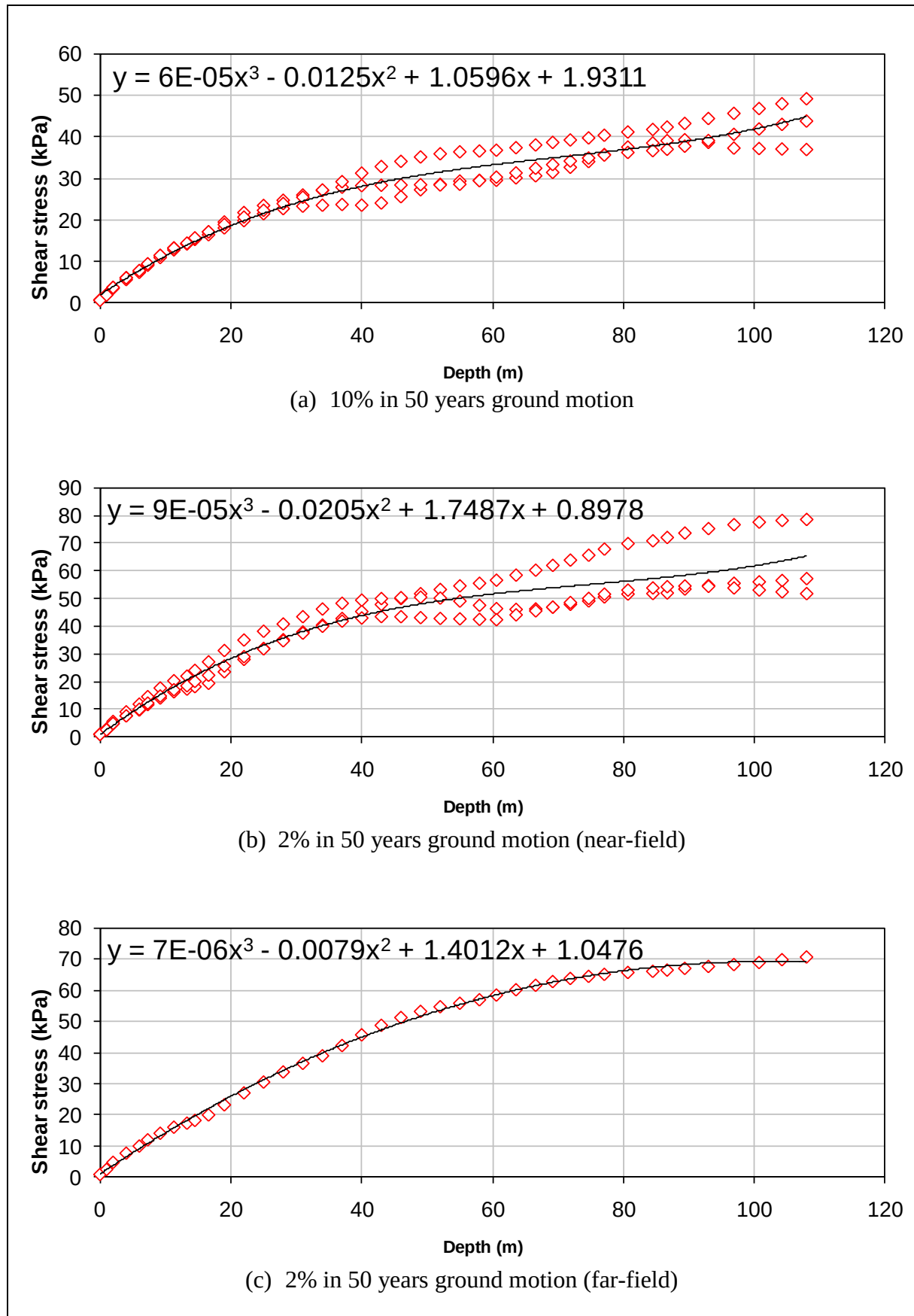


Figure 8.35 Maximum Shear Stress against Depth for BH26

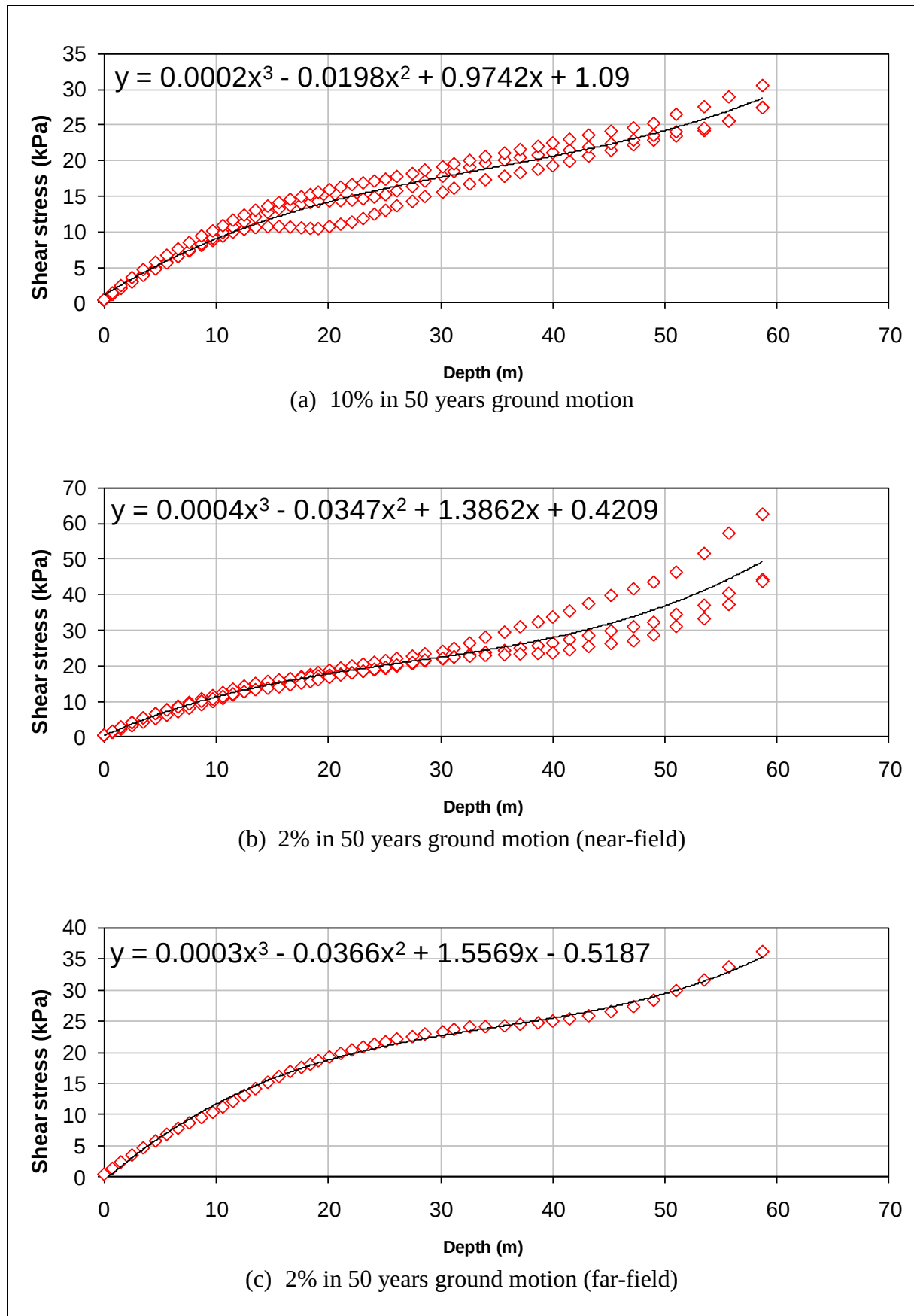


Figure 8.36 Maximum Shear Stress against Depth for BH27

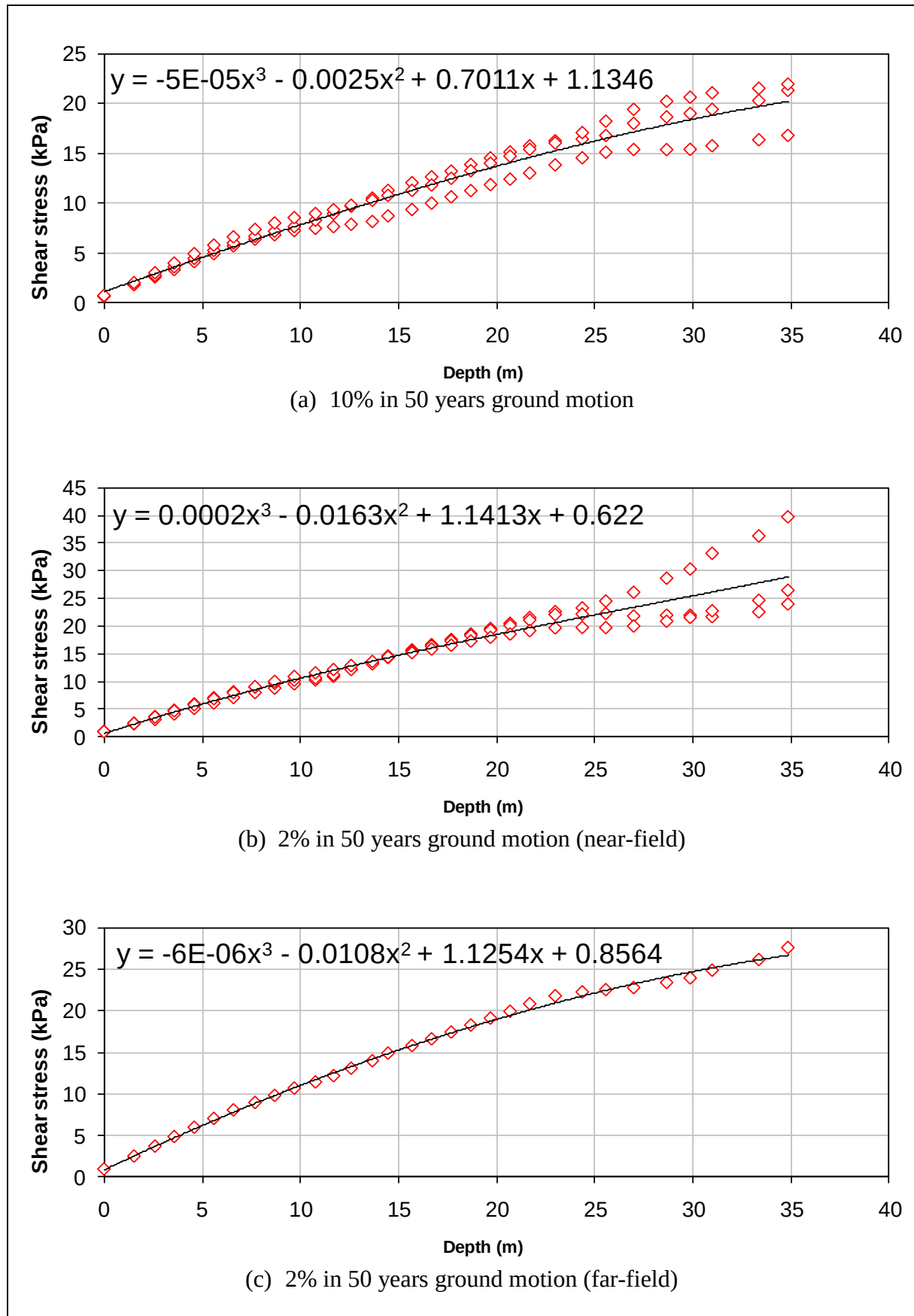


Figure 8.37 Maximum Shear Stress against Depth for BH29



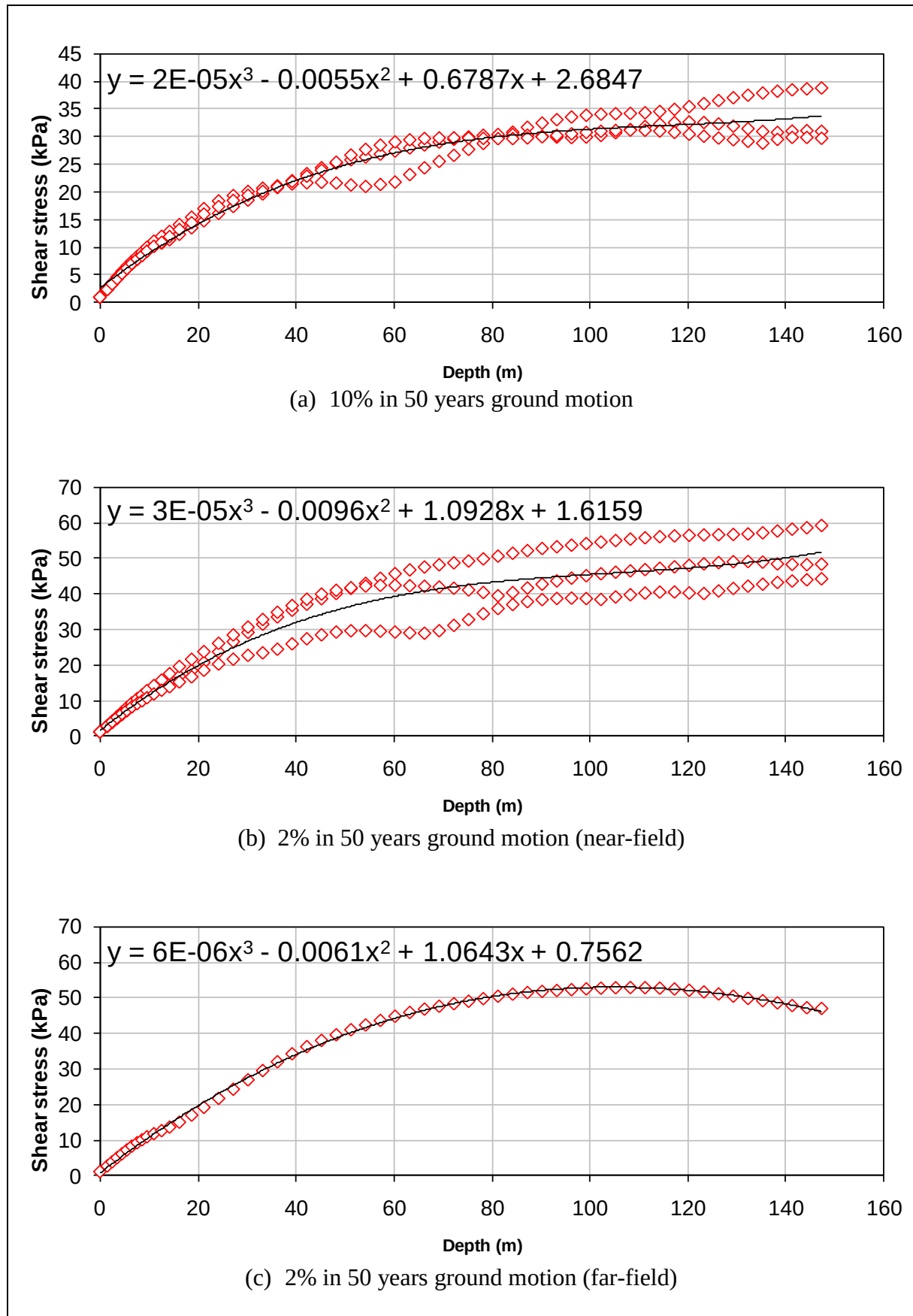


Figure 8.38 Maximum Shear Stress against Depth for BH30

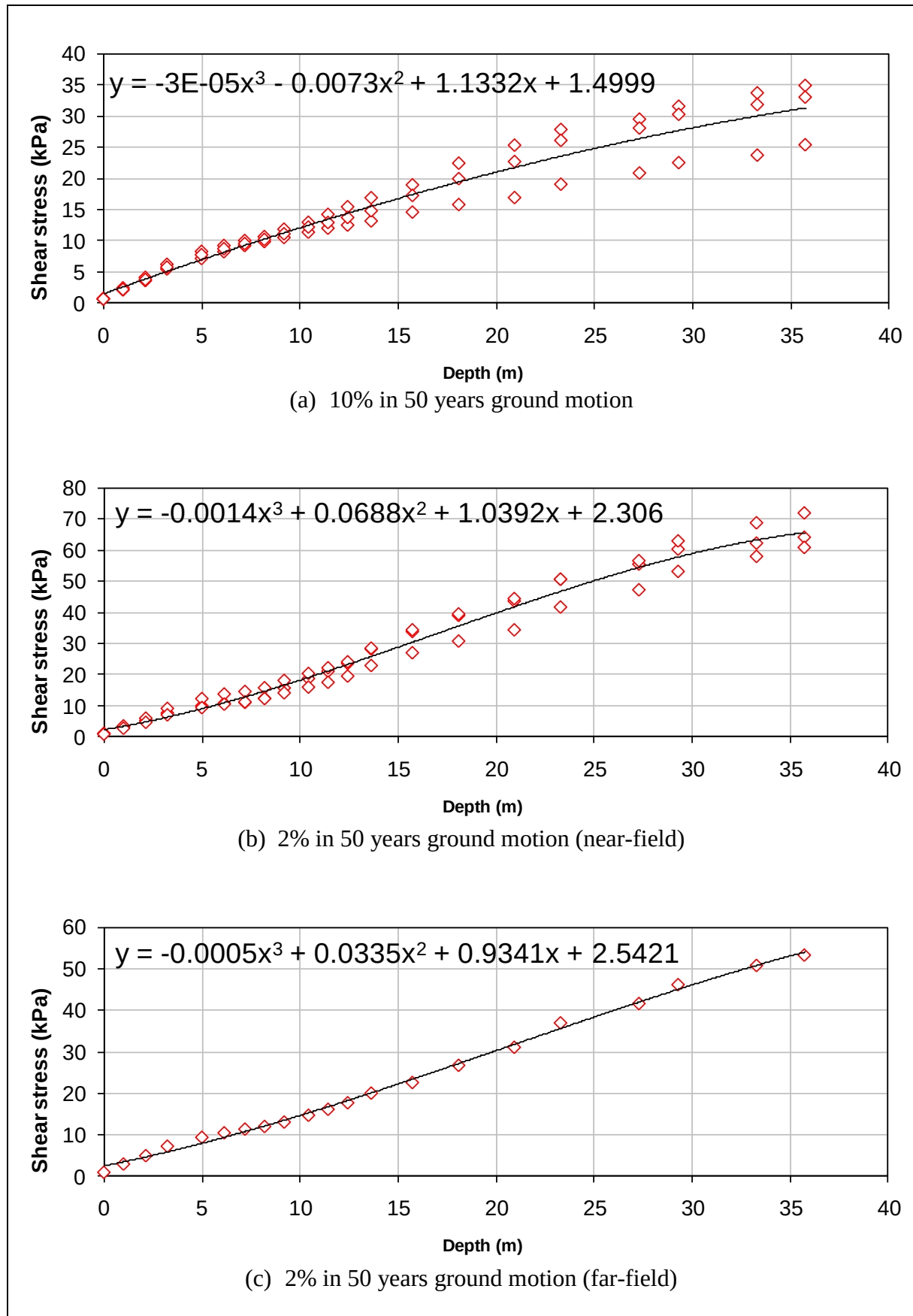
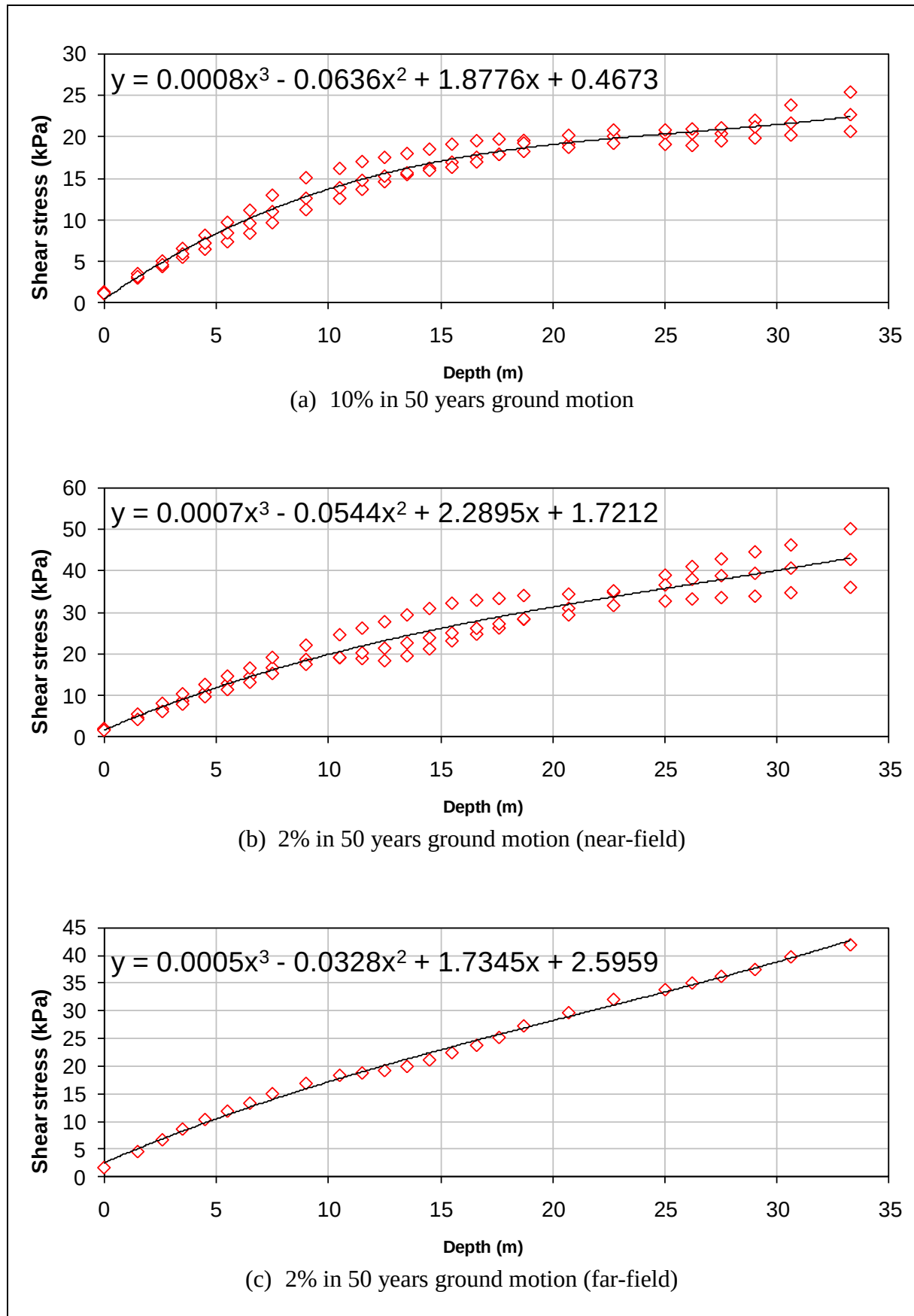


Figure 8.39 Maximum Shear Stress against Depth for BH32



**Figure 8.40 Maximum Shear Stress against Depth for BH36**

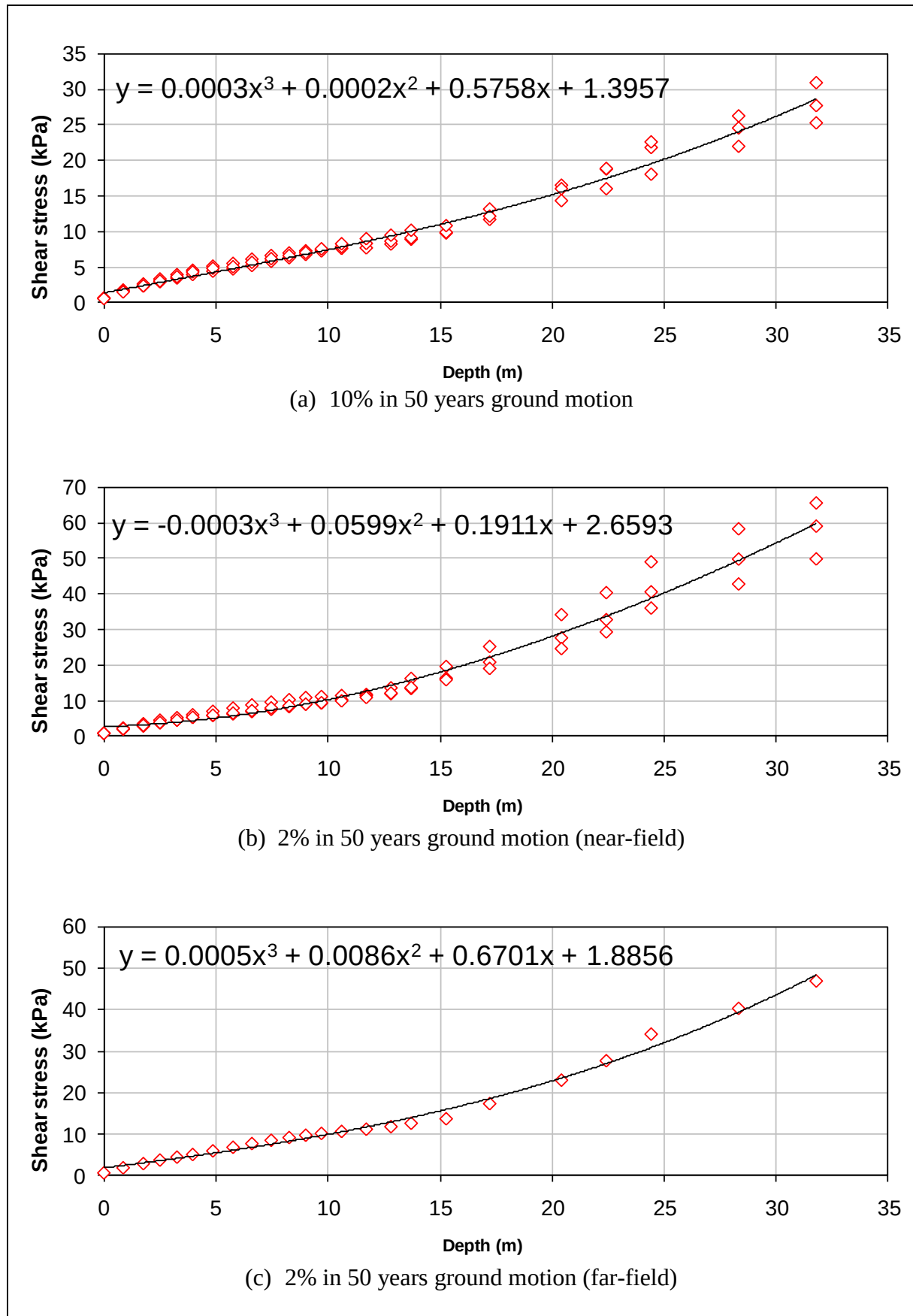


Figure 8.41 Maximum Shear Stress against Depth for BH39

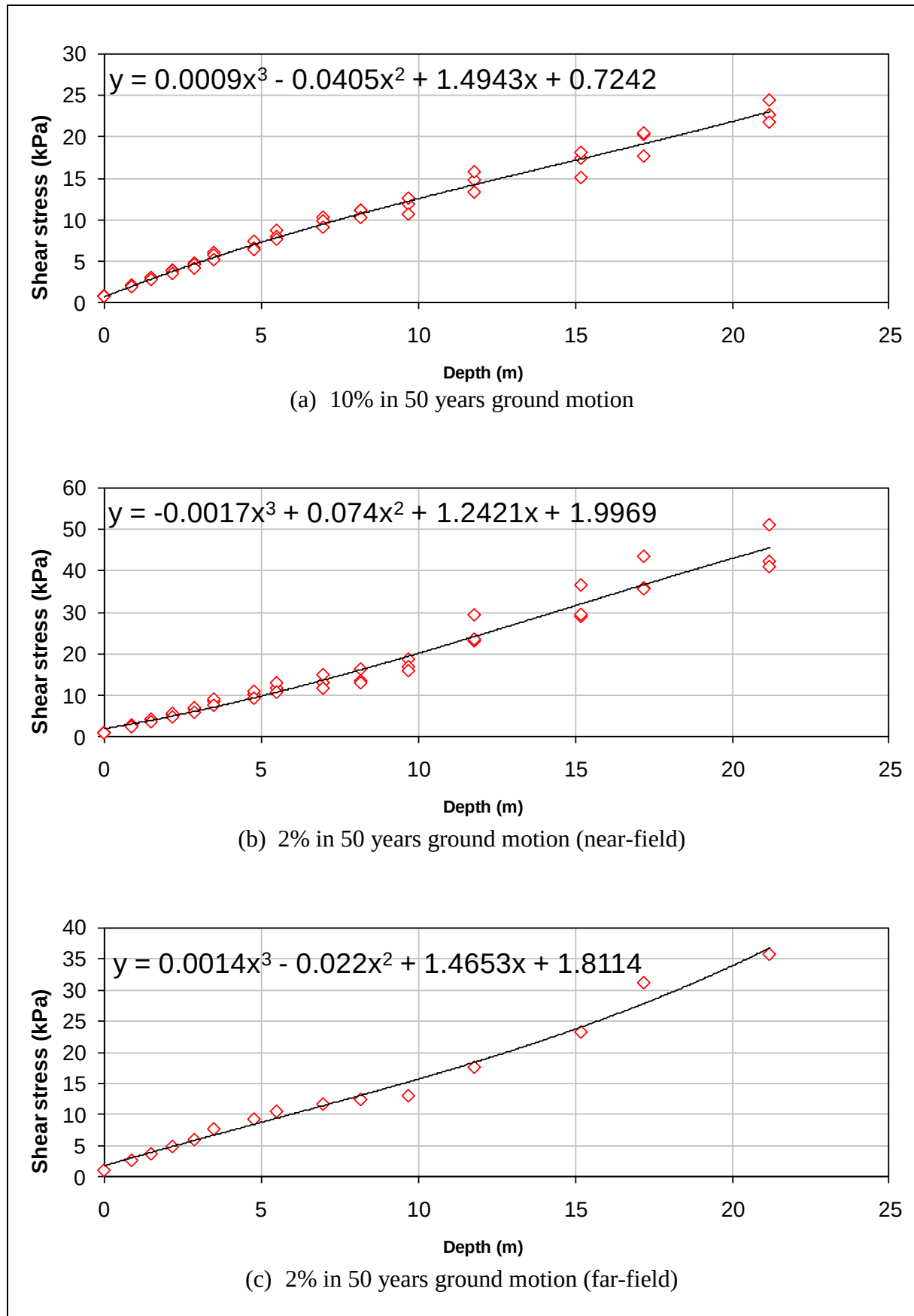


Figure 8.42 Maximum Shear Stress against Depth for BH42

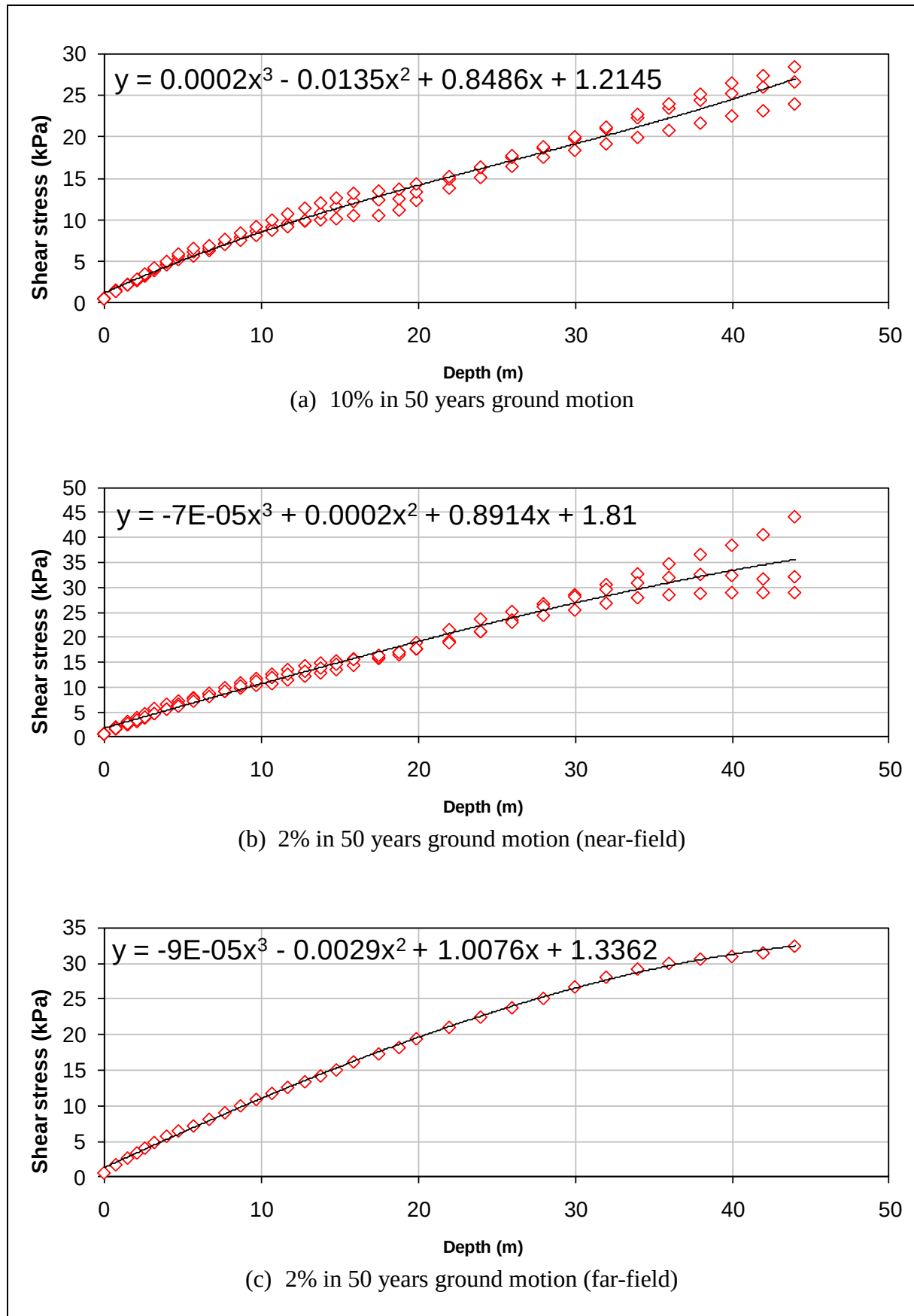


Figure 8.43 Maximum Shear Stress against Depth for BH43

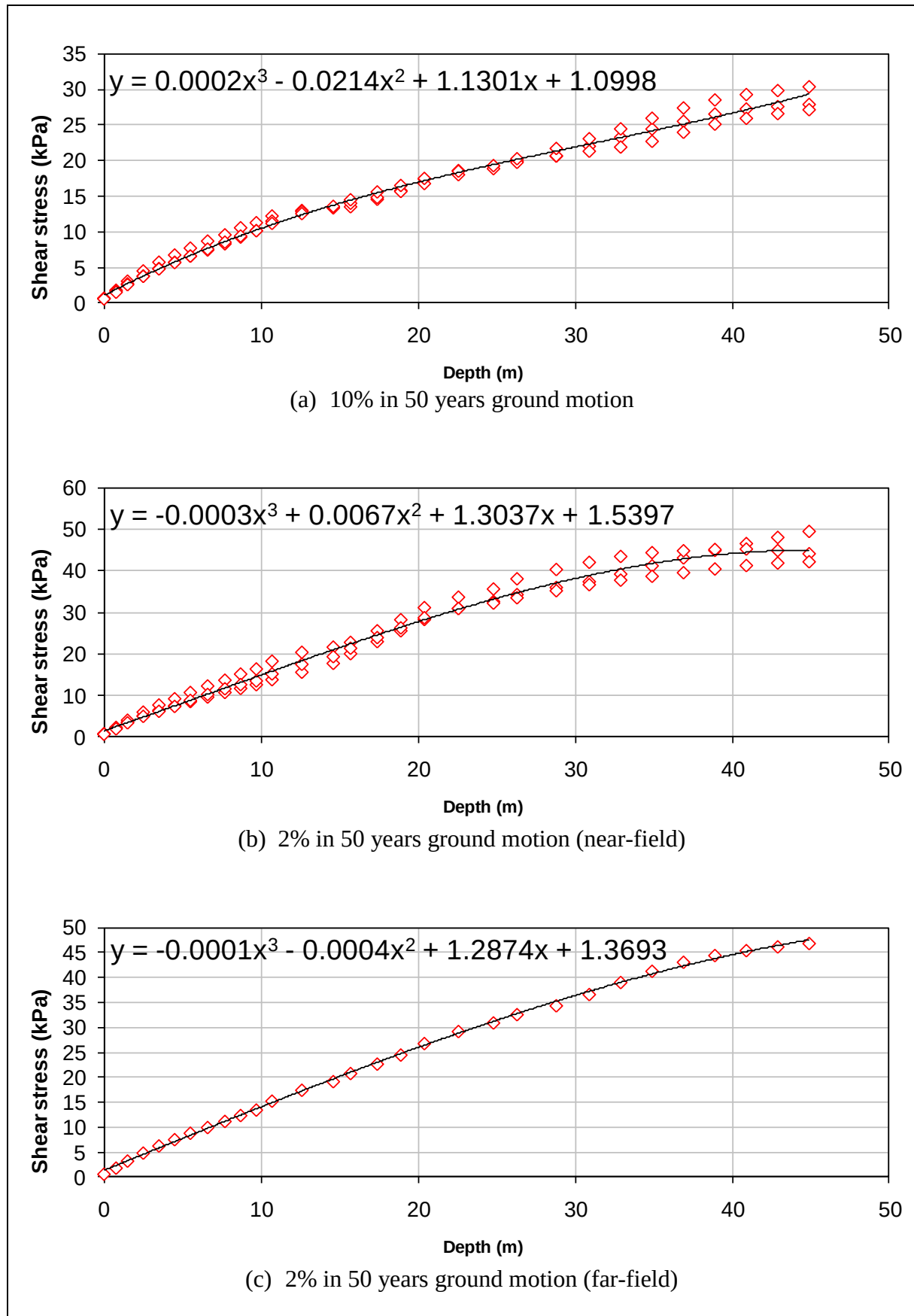


Figure 8.44 Maximum Shear Stress against Depth for BH44

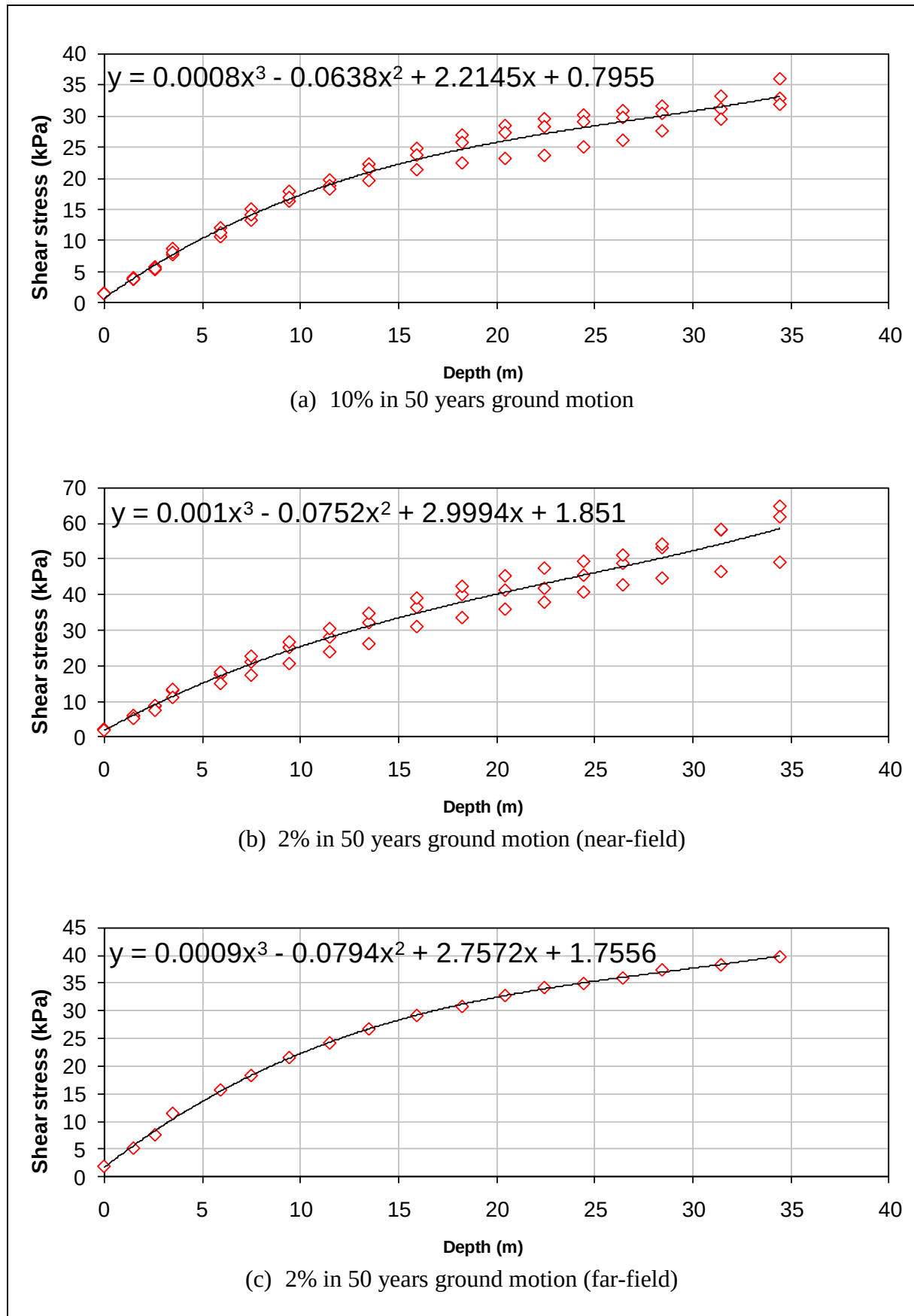


Figure 8.45 Maximum Shear Stress against Depth for BH45



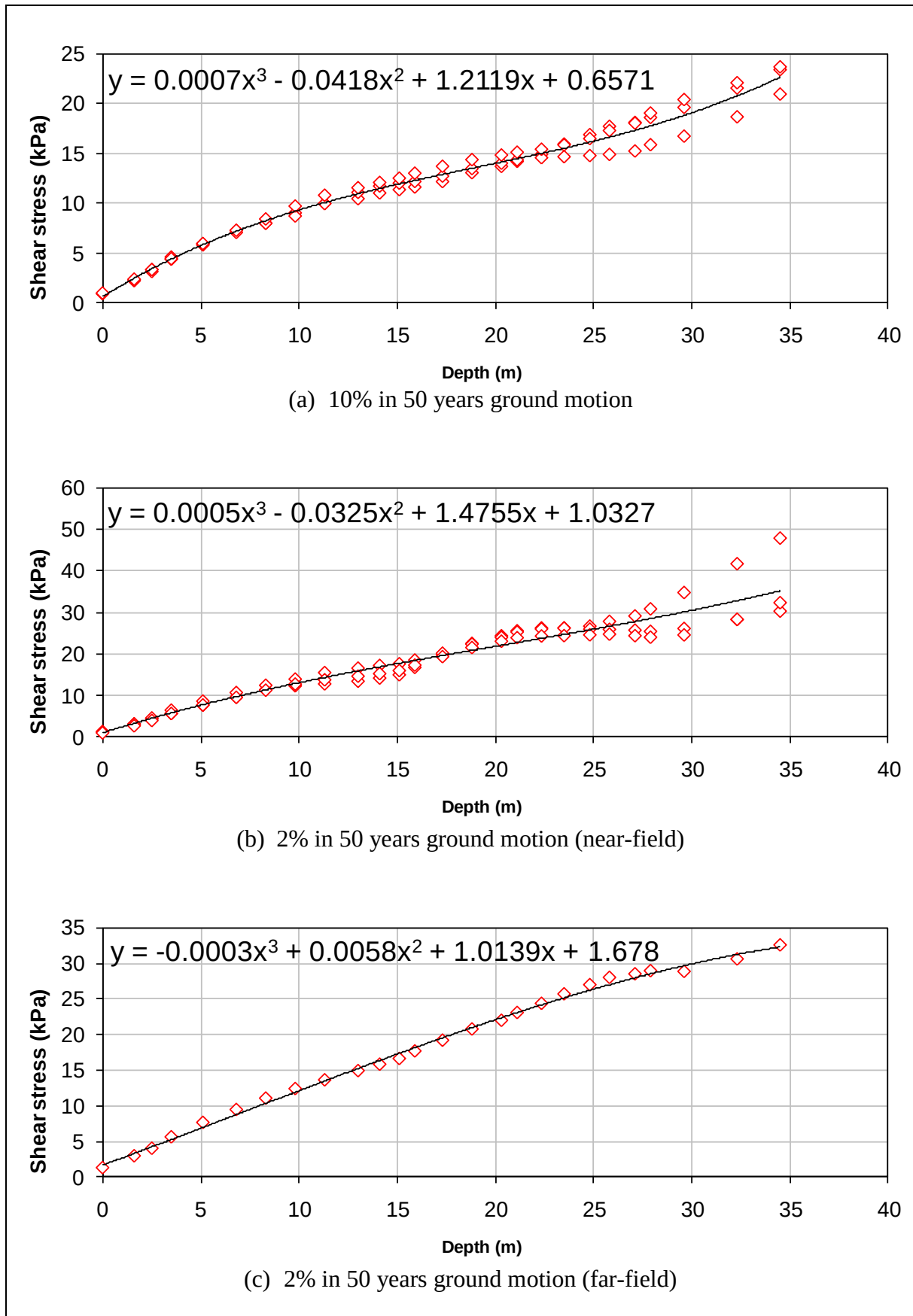


Figure 8.46 Maximum Shear Stress against Depth for BH49

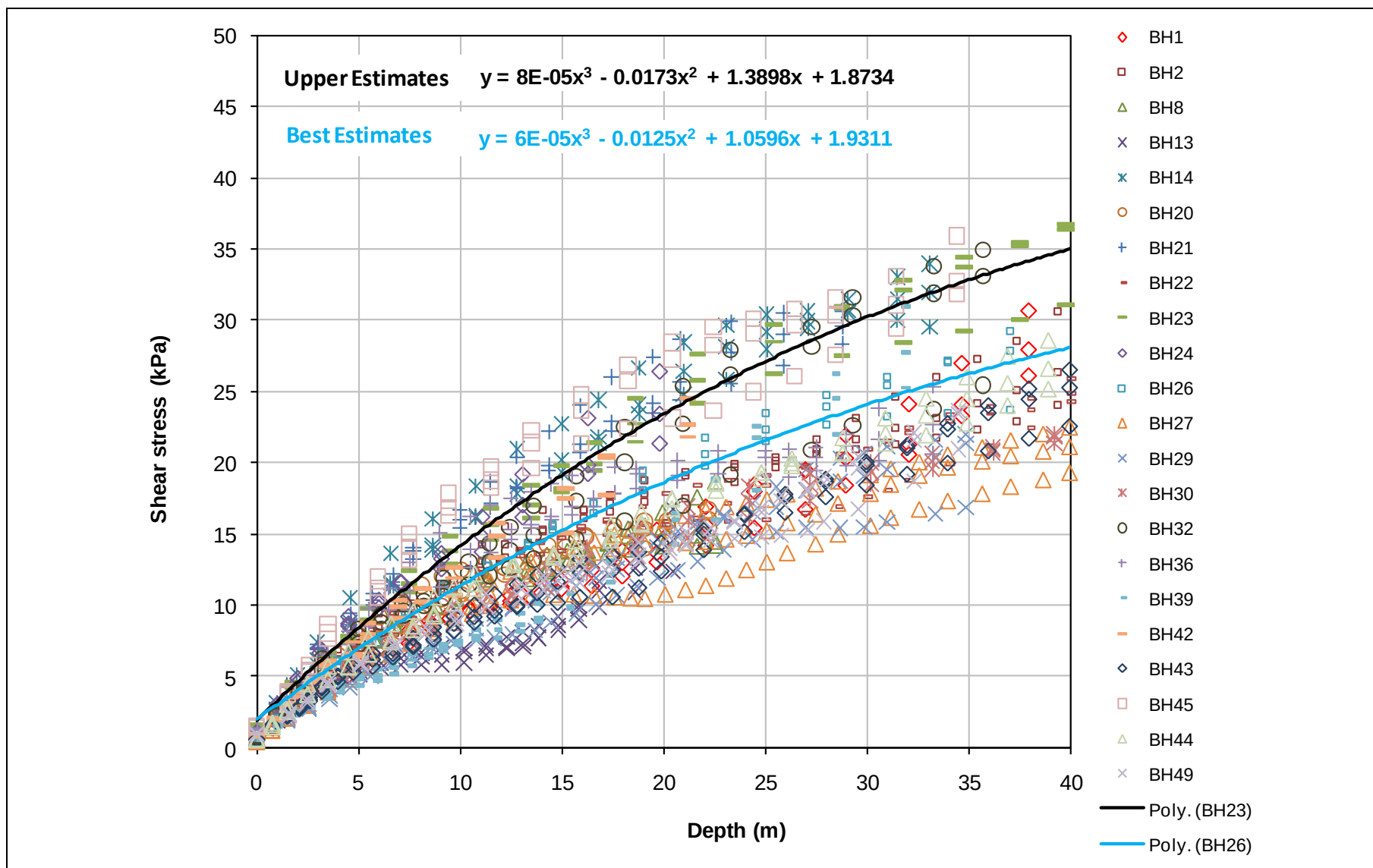
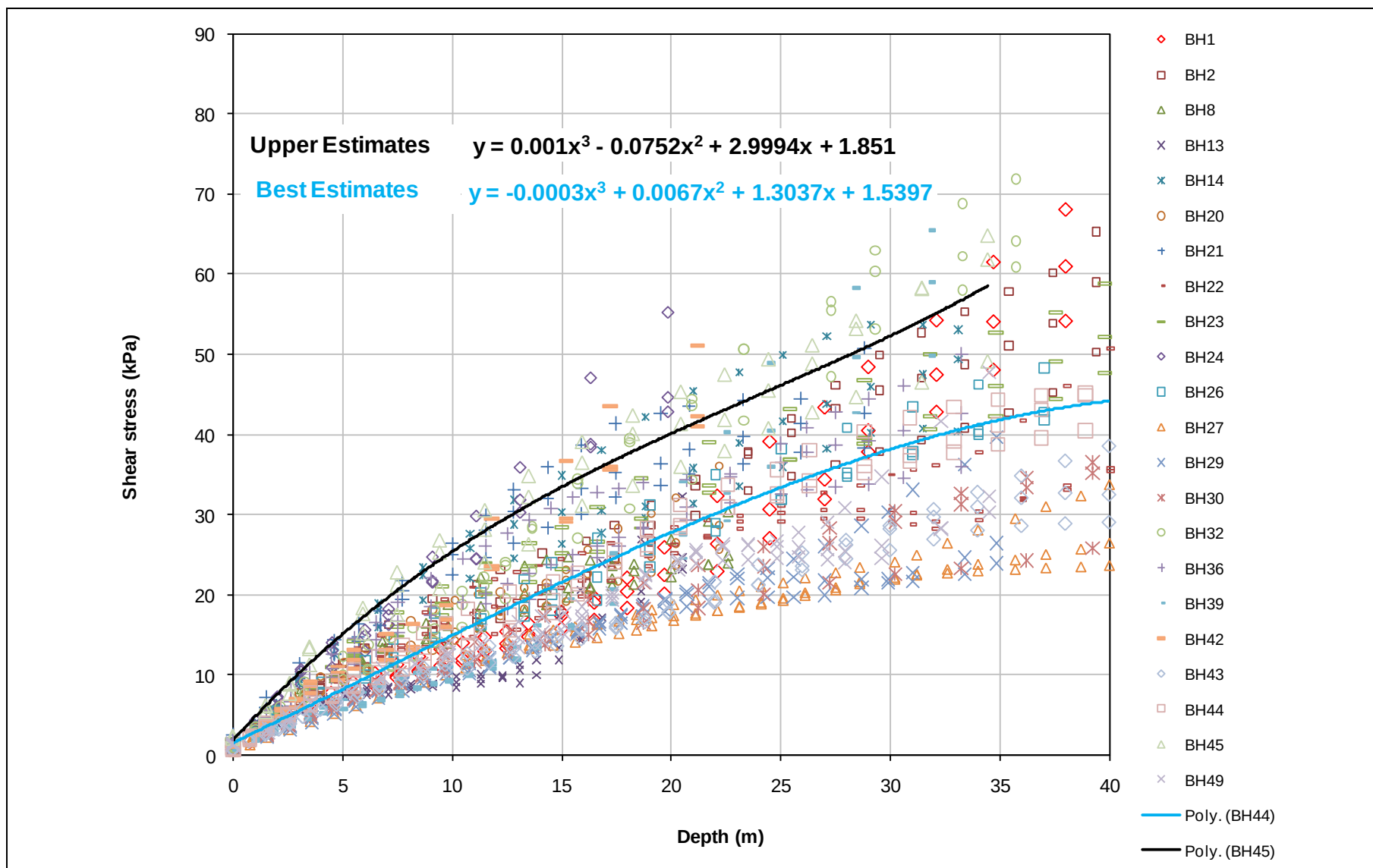


Figure 8.47 Maximum Shear Stress against Depth for All Boreholes with 10% in 50 Years Ground Motion



**Figure 8.48 Maximum Shear Stress against Depth for All Boreholes with 2% in 50 Years Near-field Ground Motion**

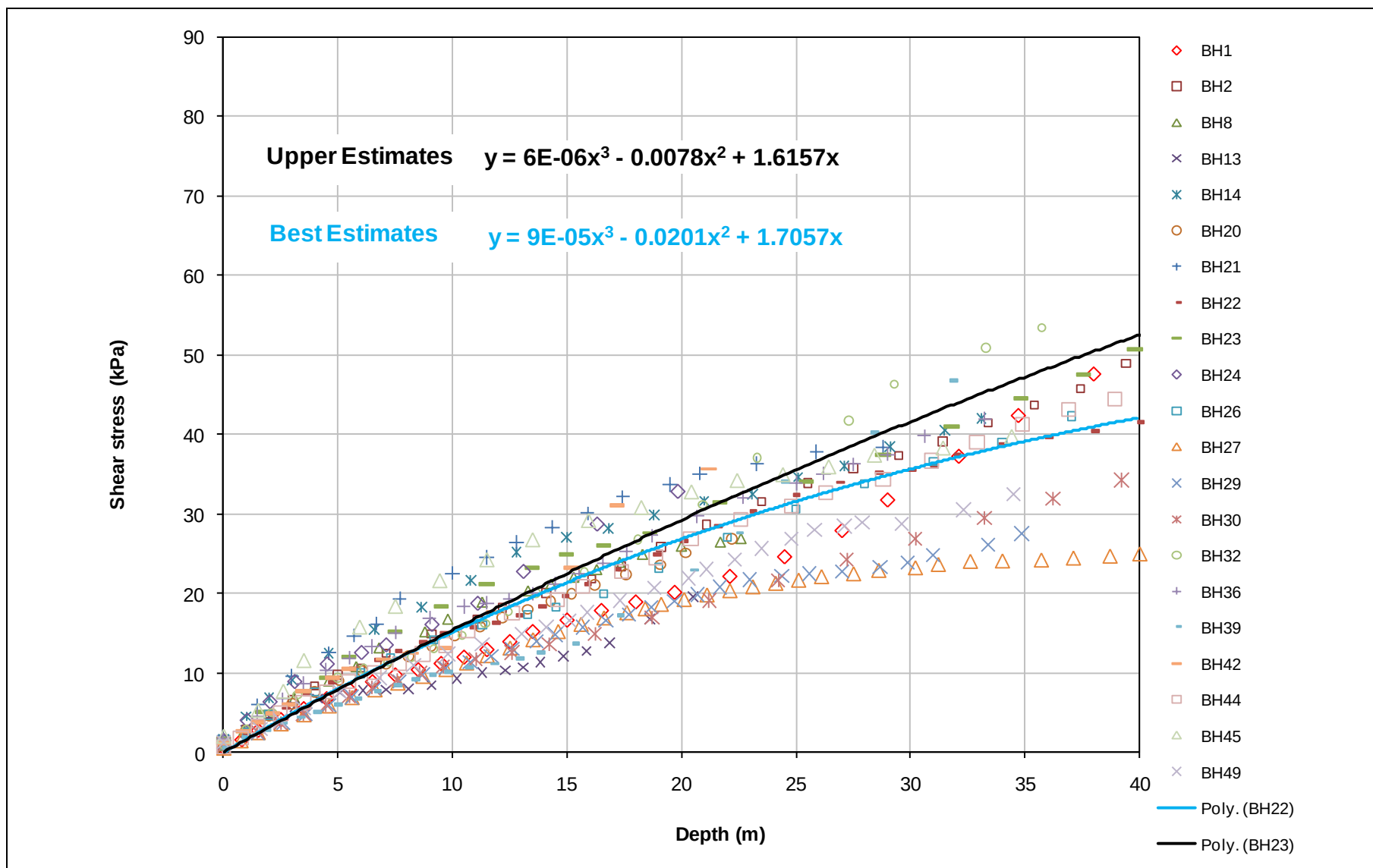
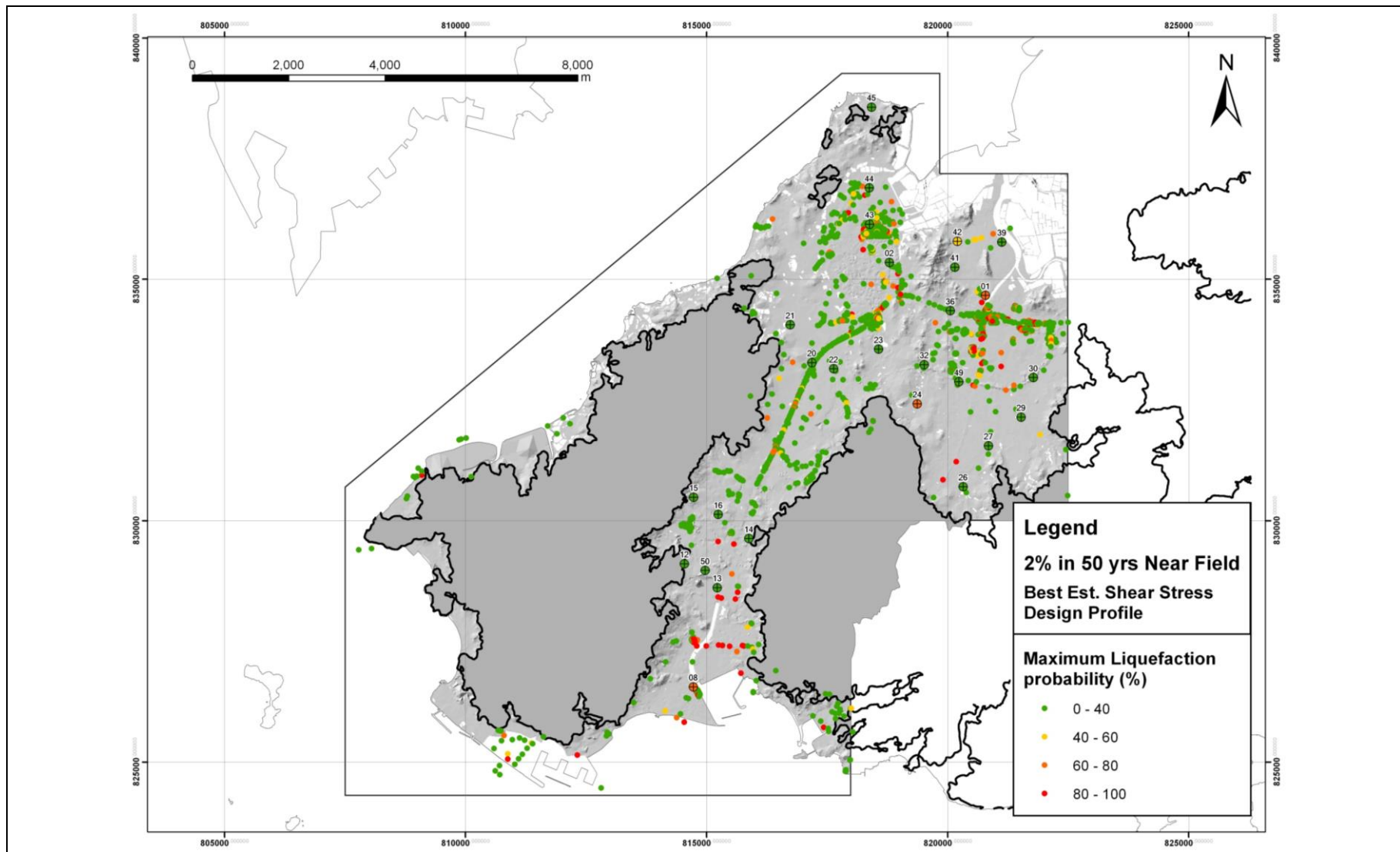
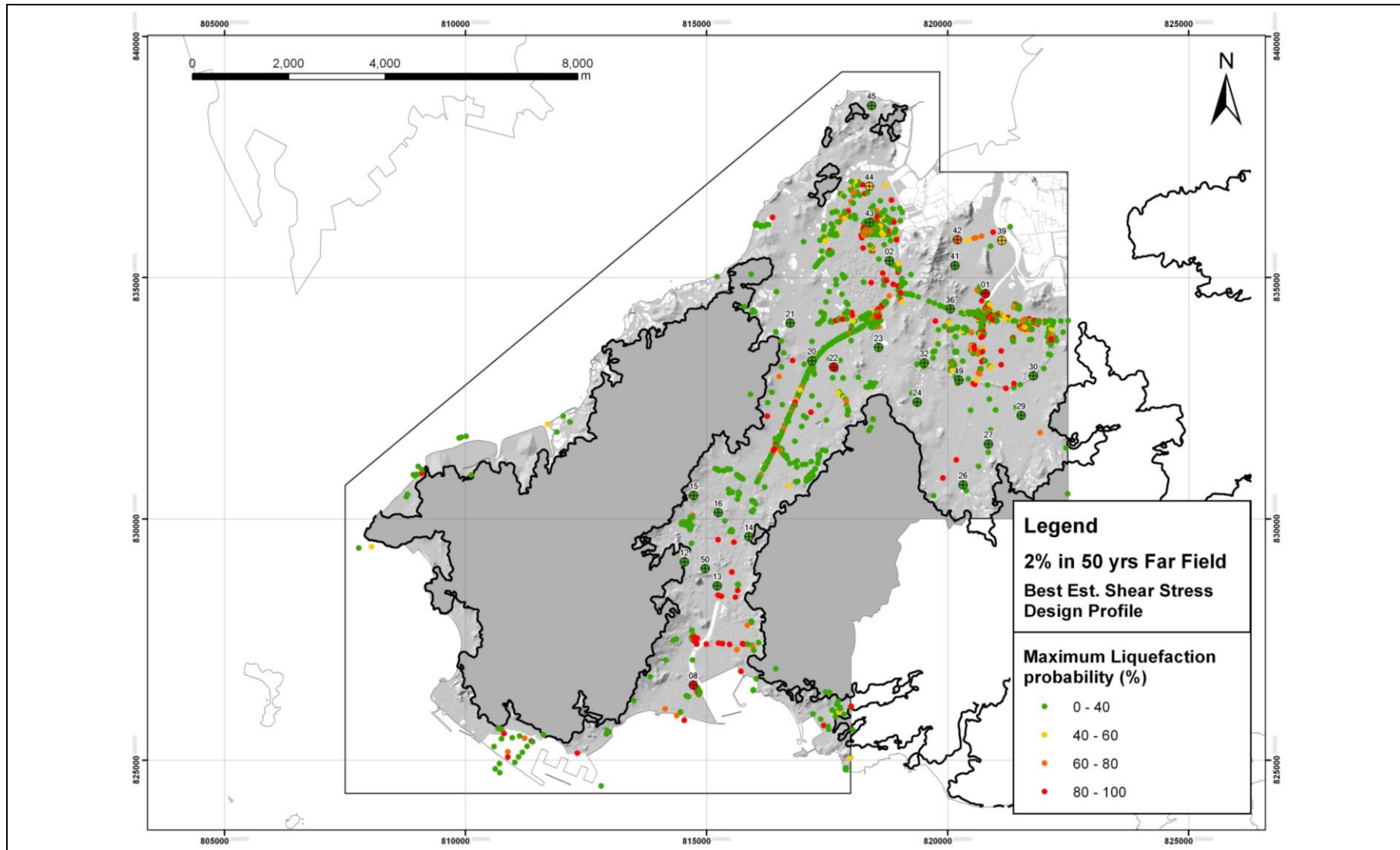


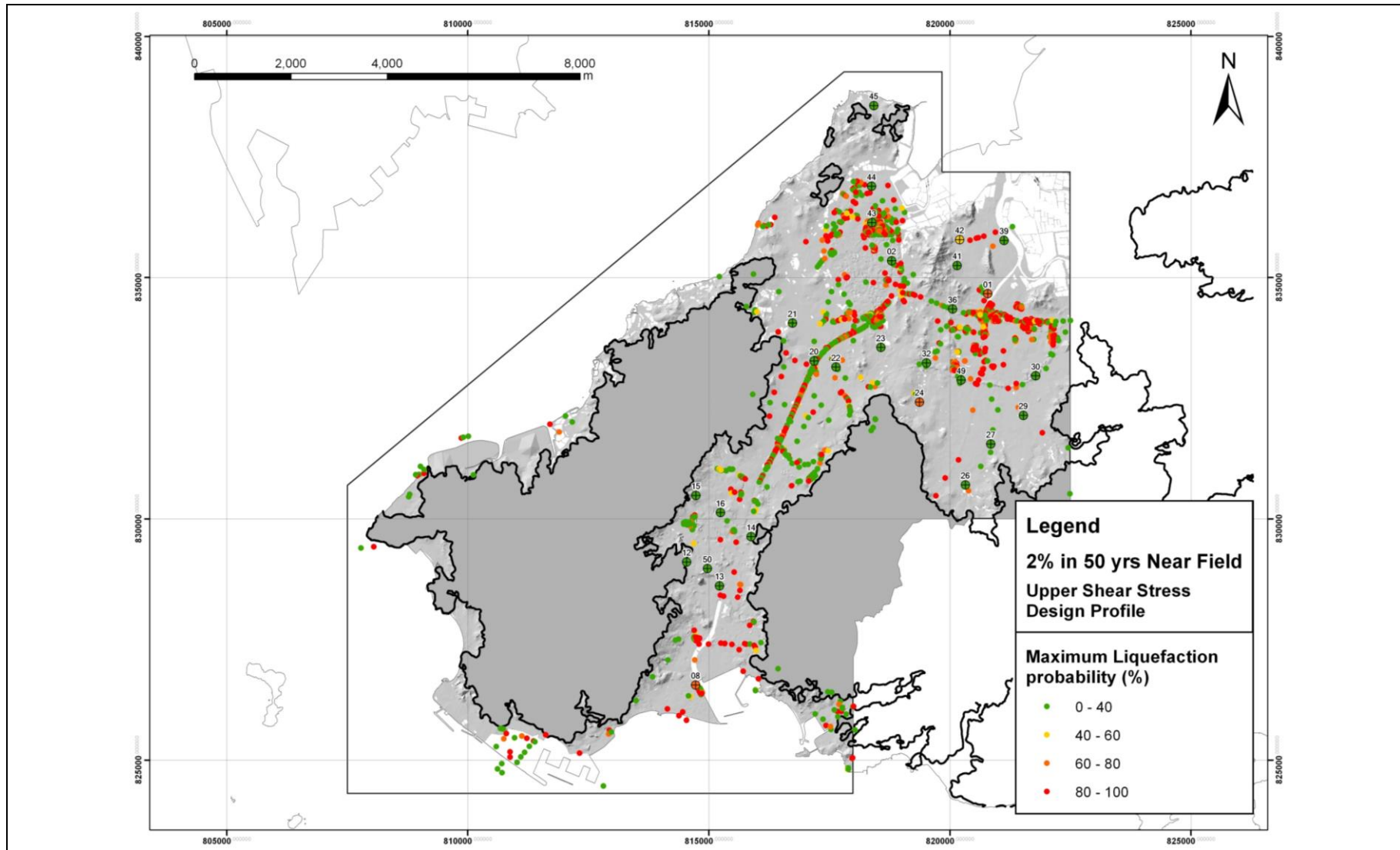
Figure 8.49 Maximum Shear Stress against Depth for All Boreholes with 2% in 50 Years Far-field Ground Motion



**Figure 8.50 Liquefaction Probability of Each Boreholes Based on Best Estimate Design Lines for Near-field Earthquake for 2% in 50 Years Ground Motion**

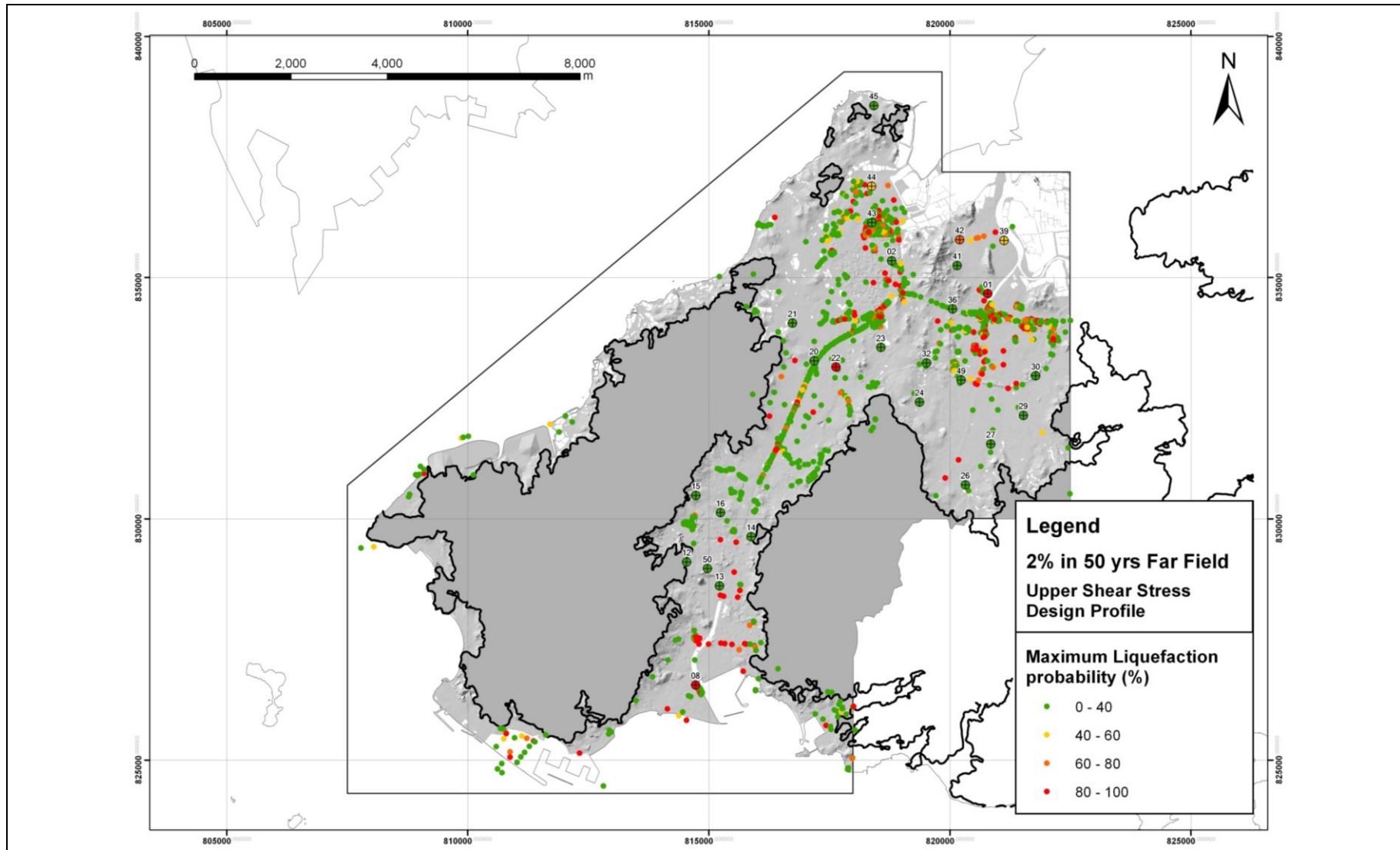


**Figure 8.51 Liquefaction Probability of Each Boreholes Based on Best Estimate Design Lines for Far-field Earthquake for 2% in 50 Years Ground Motion**



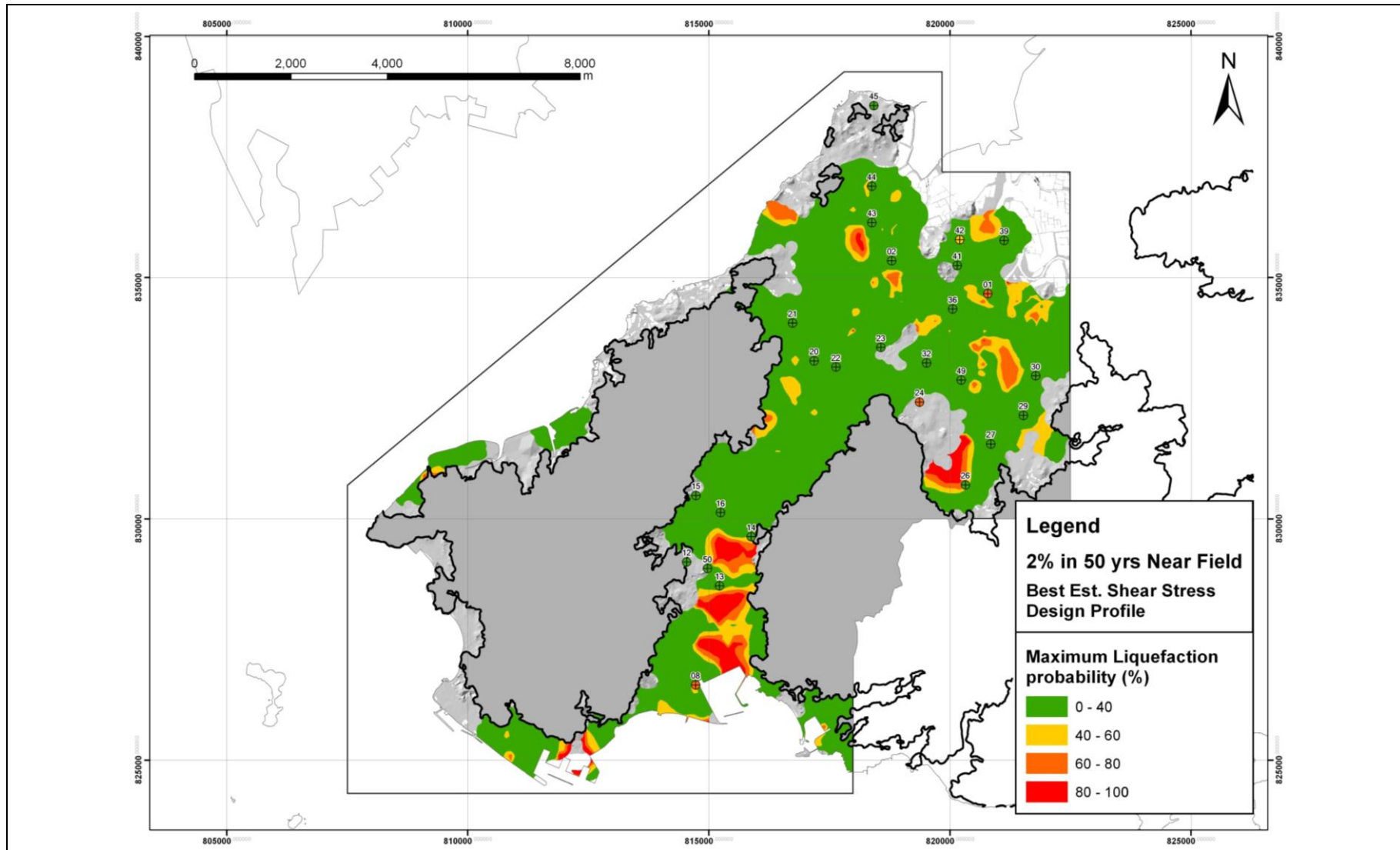
**Figure 8.52 Liquefaction Probability of Each Boreholes Based on Upper Estimate Design Lines for Near-field Earthquake for 2% in 50 Years Ground Motion**



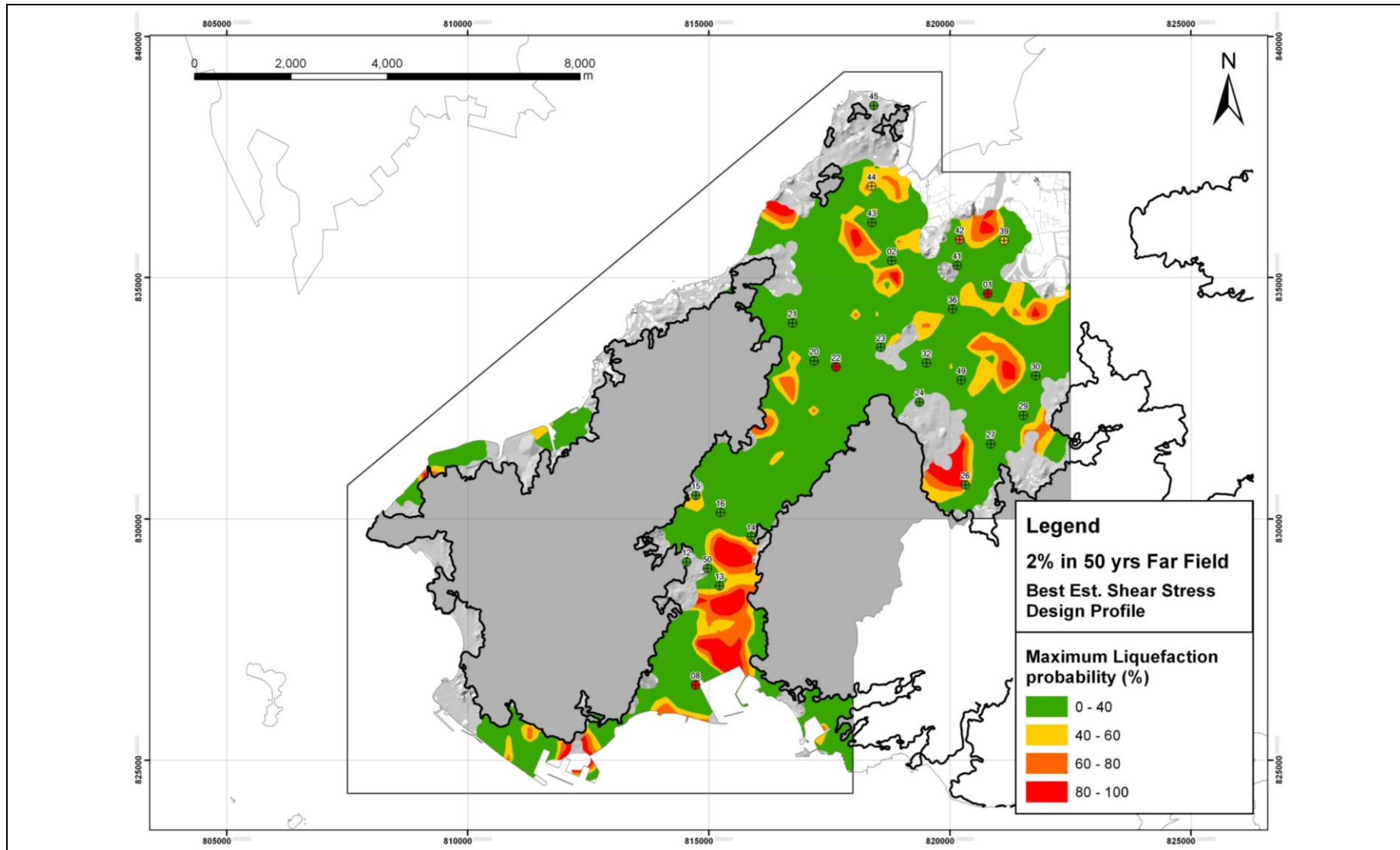


**Figure 8.53 Liquefaction Probability of Each Boreholes Based on Upper Estimate Design Lines for Far-field Earthquake for 2% in 50 Years Ground Motion**

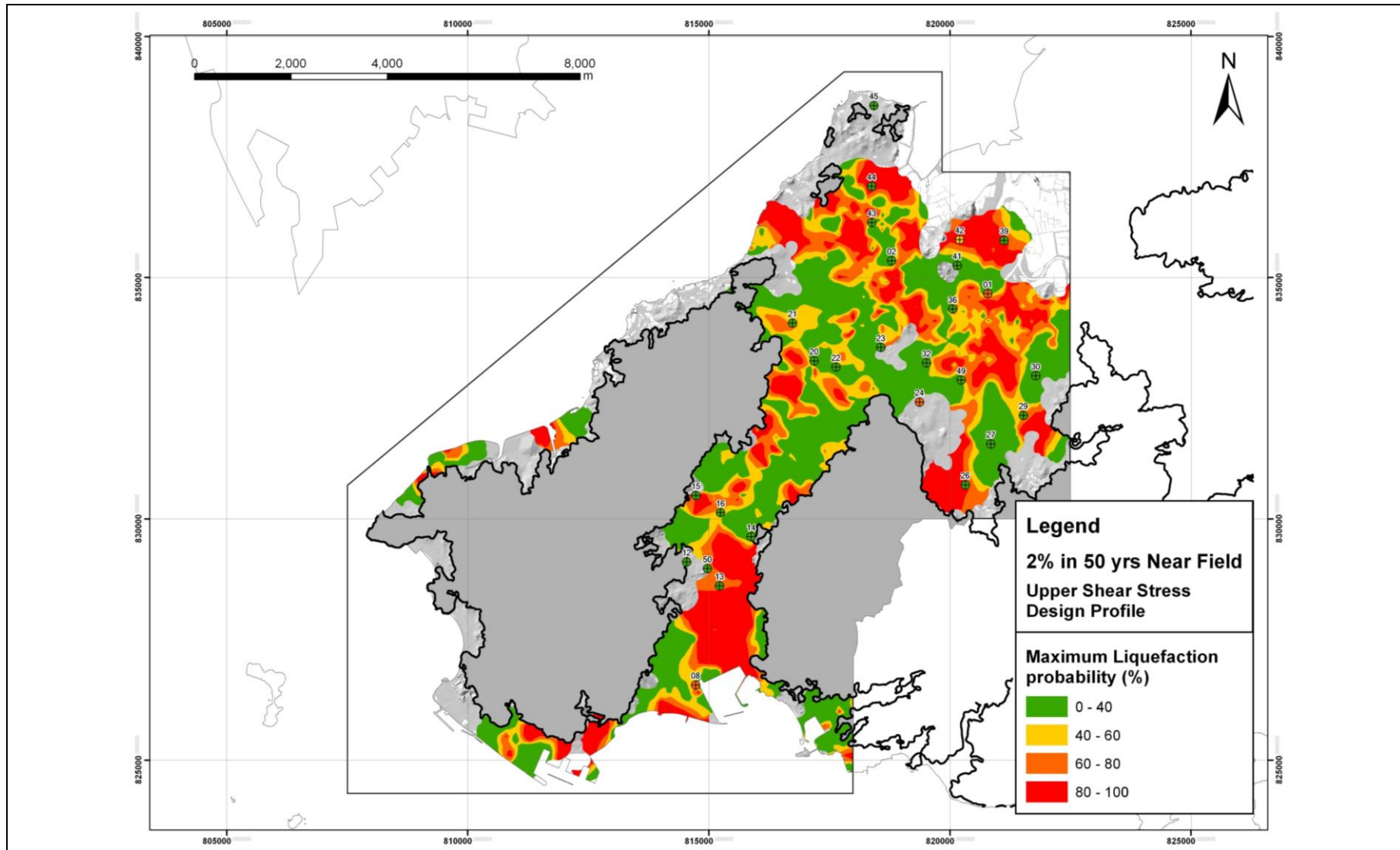




**Figure 8.54 Liquefaction Probability of Each Boreholes Based on Upper Estimate Design Lines for Near-field Earthquake for 2% in 50 Years Ground Motion**



**Figure 8.55 Contour of Liquefaction Probability Based on Best Estimate Design Lines for Far-field Earthquake for 2% in 50 Years Ground Motion**



**Figure 8.56 Contour of Liquefaction Probability Based on Upper Estimate Design Lines for Near-field Earthquake for 2% in 50 Years Ground Motion**

## 9 Topographic Effect

### 9.1 General

It is well understood that larger ground motions are observed where there are noticeable topographic features. Irregular surface features such as ridges, canyons or slopes can affect the amplitude of the surface ground motions. At ridgelines or cliff tops (convex features), the effect is an amplification of the ground motions, whereas in canyons, de-amplification occurs. The phenomenon is due to focussing (or defocusing) of the seismic waves (Faccioli et al, 2002).

In addition to amplifying the ground motions at the base of buildings located on slopes, the topographic effect during an earthquake may contribute to the reactivation of landslides and rockslides (Paolucci, 2002).

Topographic amplification of seismic ground motions is evident from historical incidences of concentrated damages to areas located on prominent topographic features (Faccioli et al, 2002). Additional research has been carried out (e.g. Geli et al, 1988; Bard, 1995) using both instrumental data and two-dimensional modelling. There is insufficient published data to draw any quantitative conclusions, but the general features identified by researchers are:

- (a) Significant amplification occurs when the wavelength is of a magnitude similar to the length of the feature (e.g. ridge length).
- (b) Steeper slope angles cause greater amplification at their crests whilst higher slopes are also more critical.
- (c) Amplification is sensitive to the angle of the incidence wave.
- (d) The response of irregular topographic features is too complex to represent.

Instrumental data generally shows significantly higher amplification than analytical modelling. However, it is generally very difficult to separate out topographic effects from other ground motion variability responses.

As indicated above, there are many variables that affect the prediction of topographic effects. Simplified approaches, using a range of amplification factors, are discussed below. Spectral amplifications from analytical models, as summarised by Stewart et al (2001), ranged between 1 and 2. For a ridge with a shape ratio (height / half-width)  $\approx 0.4$ , and a wavelength equal to the half-width of the ridge, Geli et al (1988) reported a factor of 1.6. The maximum amplification was found to occur at the top of a ridge or slope, decreasing towards the base. An instrumental study for a single slope during the  $M = 6.3$  Coalinga earthquake resulted in an amplification factor of 1.2 (Stewart et al, 2001).

In most seismic codes, topographic amplification is ignored (Paolucci, 2002). This may be because in many locations the site amplification due to local soil conditions is more significant. Some amplification factors are suggested in the published literature mentioned above. In particular, the French seismic design code (French Seismic Code, 1992) makes

particular recommendations for sites located near ridges or slopes. The French code has been superseded by Eurocode 8 (BSI, 2004b) with more appropriate and simplified rules.

## 9.2 Methodology

### 9.2.1 The French Seismic Design Code

The *Règles de construction parasismique* (French Seismic Code, 1992) makes specific recommendations for topographic amplification factors, which are to be applied to the spectral acceleration for sites situated on or adjacent to the edge of a slope. The parameters used to define the slope geometry are shown in Figure 9.1. The recommended topographic amplification factor,  $\tau$ , are defined as follows:

For a site at location C, if  $H \geq 10$  m, and  $i \leq I/3$ :

$$\begin{aligned} \tau &= 1 && \text{for } I - i \leq 0.4 \\ \tau &= 1 + 0.8(I - i - 0.4) && \text{for } 0.4 \leq I - i \leq 0.9 \\ \tau &= 1.4 && \text{for } I - i \geq 0.9 \end{aligned}$$

The distance,  $b$  (m), over which the above rules apply is defined by:

$$b = \min \left\{ \begin{array}{l} 20I \\ \frac{H+10}{4} \end{array} \right. \dots\dots\dots (9.1)$$

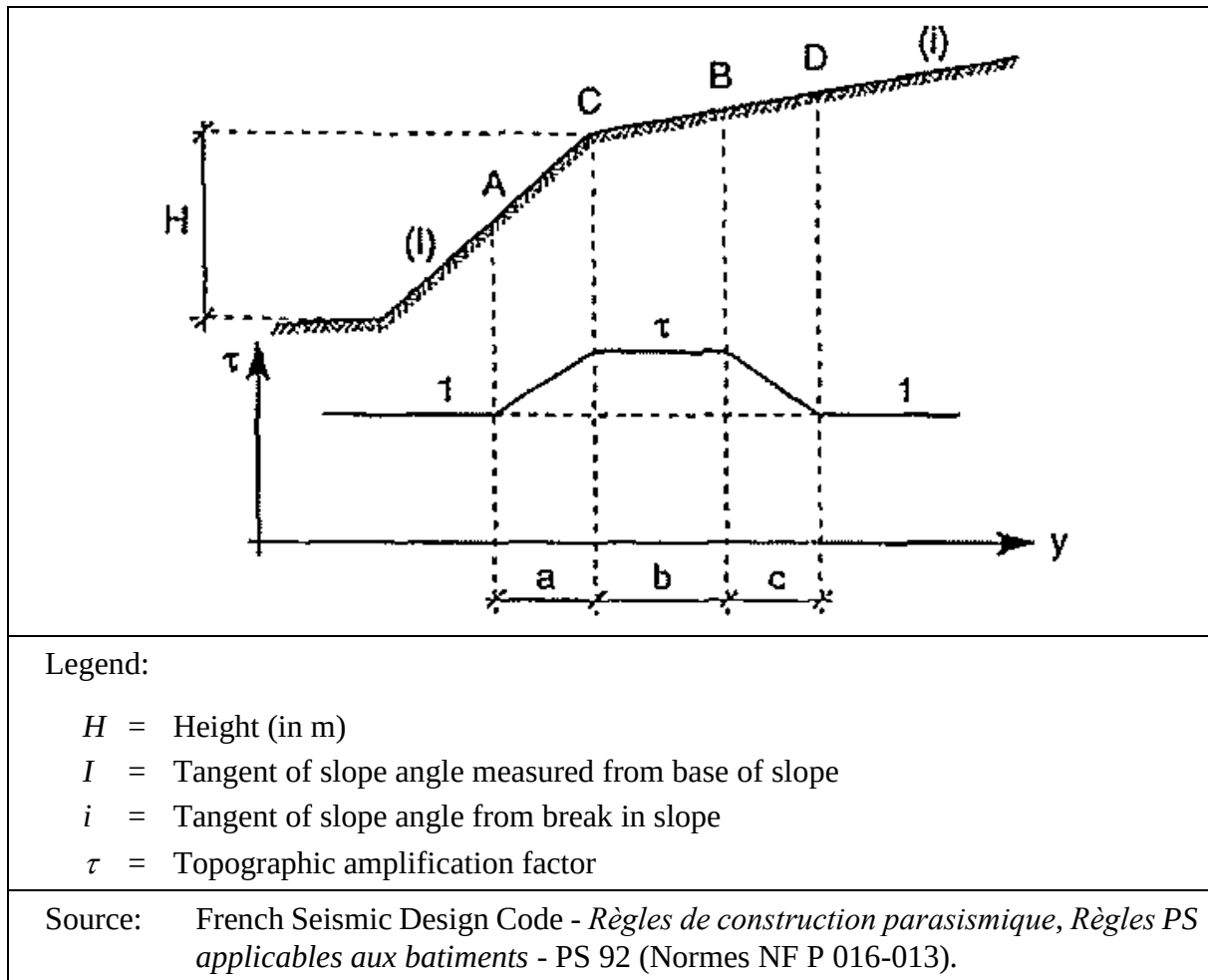
Within sections  $a$  and  $c$  (AC and BD in Figure 9.1),  $\tau$  varies linearly between its upper limit and 1, where:

$$a = H/3 \quad \text{and} \quad b = H/4.$$

Whitman (1992) provided some additional commentaries on this code:

“Empirical coefficients given...should be considered as design coefficient intended on reducing the mean risk and on deterring from choosing settlements of which it has been proven by experience that they might be liable to be dangerous. The whole article...should be considered to be provisional.”

The determination of the height  $H$  is subject to judgement. Whitman (1992) suggested that since slopes with  $I < 0.4$  are not considered, the base of the slope could be assumed to be the point where  $I$  becomes  $< 0.4$ . The commentary recommends consideration of both maximum slope and average slope with their corresponding heights, where there is a variable topography. Finally, for ridges, rather than slopes, the same rules should be applied, but  $(I + i)$  should be used in lieu of  $(I - i)$ .



**Figure 9.1 Definition of the Slope Geometry for Topographic Amplification Factor**

### 9.2.2 Eurocode 8

The Eurocode 8, Part 1 (BSI, 2004a) states that ‘For important structures in high seismicity zones it is necessary to consider topographic amplification effects’. The Eurocode 8, Part 2 (BSI, 2004b) states that ‘An increase in the design seismic action shall be considered in the ground stability verifications for important structures on or near slopes with significant inclination’. Key recommendations for topographic amplification factors are discussed in Annex A of BSI (2004b) and summarised as follows:

- (a) Slopes less than  $15^\circ$  can be ignored.
- (b) A site-specific study should be carried out for strongly irregular topography.
- (c) For sites near the edge of isolated cliffs and slopes, a factor  $\geq 1.2$  should be used.

- (d) Where the crest width of a ridge is significantly greater than the base width, if the slope angle  $> 30^\circ$ , a factor  $\geq 1.4$  should be used, or  $\geq 1.2$  otherwise.
- (e) A 20% increase to any factor should be applied where there is a thick loose surface layer.
- (f) The factor at the base of a ridge can be assumed to be unity, with a linear variation between the top and the base.

The factors are to be applied to spectral amplification at all structural periods.

### 9.2.3 Procedures Adopted for this Study

The following issues have been taken into consideration when developing the methodology for assessment of topographic effects for ridges in the Study Area. They are consistent with the recommendations in the Eurocode 8 (BSI, 2004b) discussed above.

- (a) A digital terrain model (DTM) for Hong Kong has been developed from the Lands Department 1:5,000 scale topographic maps using the software ArcGIS with 3D Analyst Extension.
- (b) Slopes inclined less than  $15^\circ$  are considered to have no topographic amplification.
- (c) Slopes inclined  $15^\circ$  to  $45^\circ$  are considered to have topographic amplification of 1.0 to 1.8 increasing linearly with the slope angle.
- (d) The factor at the base of a ridge is assumed to be unity, with a linear variation between the top and the base defined as being where the slope inclination became greater than  $15^\circ$ .

Topographic ridgelines have been defined in the DTM and a buffer has been established on either side of the ridgeline to define the location of the upper convex break in a slope. Intermediate convex and concave breaks in the slope have not been considered. There are 148 topographical sections produced in this study to analyse the topographic effects in the Study Area, which are presented in Appendix D. All the defined ridges and slope inclinations and calculated topographic amplification factors are also included in Appendix D.

Topographic amplification with a factor between 1.0 and 1.5 is applied to the crest region of the slope as shown in Figure 9.2. When the factor is less than 1.1, it is recommended to be ignored. The calculated amplification factors and the associated slope heights are plotted in Figure 9.3. It shows that the ridge height varies from 30 m to 300 m in the Study Area.

A preliminary study carried out using a non-linear two-dimensional dynamic analysis using FLAC dynamic (a non-linear finite-difference program similar to *Oasys*

SIREN) indicates that the topographic amplification factor is likely to be period-dependent. Figure 9.4 shows the smoothed results for the spectral ratios obtained from the FLAC analyses for 30 m, 100 m and 300 m high ridges with 30° side slopes. The spectral ratio is calculated using the crest response spectrum divided by the surface response spectrum at a distance from the toe. The natural period of the ridge is indicated to be about 2.0 to 2.5 times the ridge height divided by the shear wave velocity of the rock mass of the terrain (taken as about 1,000 m/s). It is noted that the calculation has only considered a rock slope with no soil cover. The preliminary results indicate that the ground motion amplification will be the greatest at the natural period of the ridge and will reduce to unity at longer structural periods. The period-dependence of the topographic amplification factors is evidenced.

The topographic amplification is restricted to ridge lines and will therefore not have a significant effect on the major building areas within the Study Area, which are concentrated in low-lying areas along the coast and in inland valleys. However, topographic amplification may affect the risk of earthquake-induced landslides at the ridge areas.



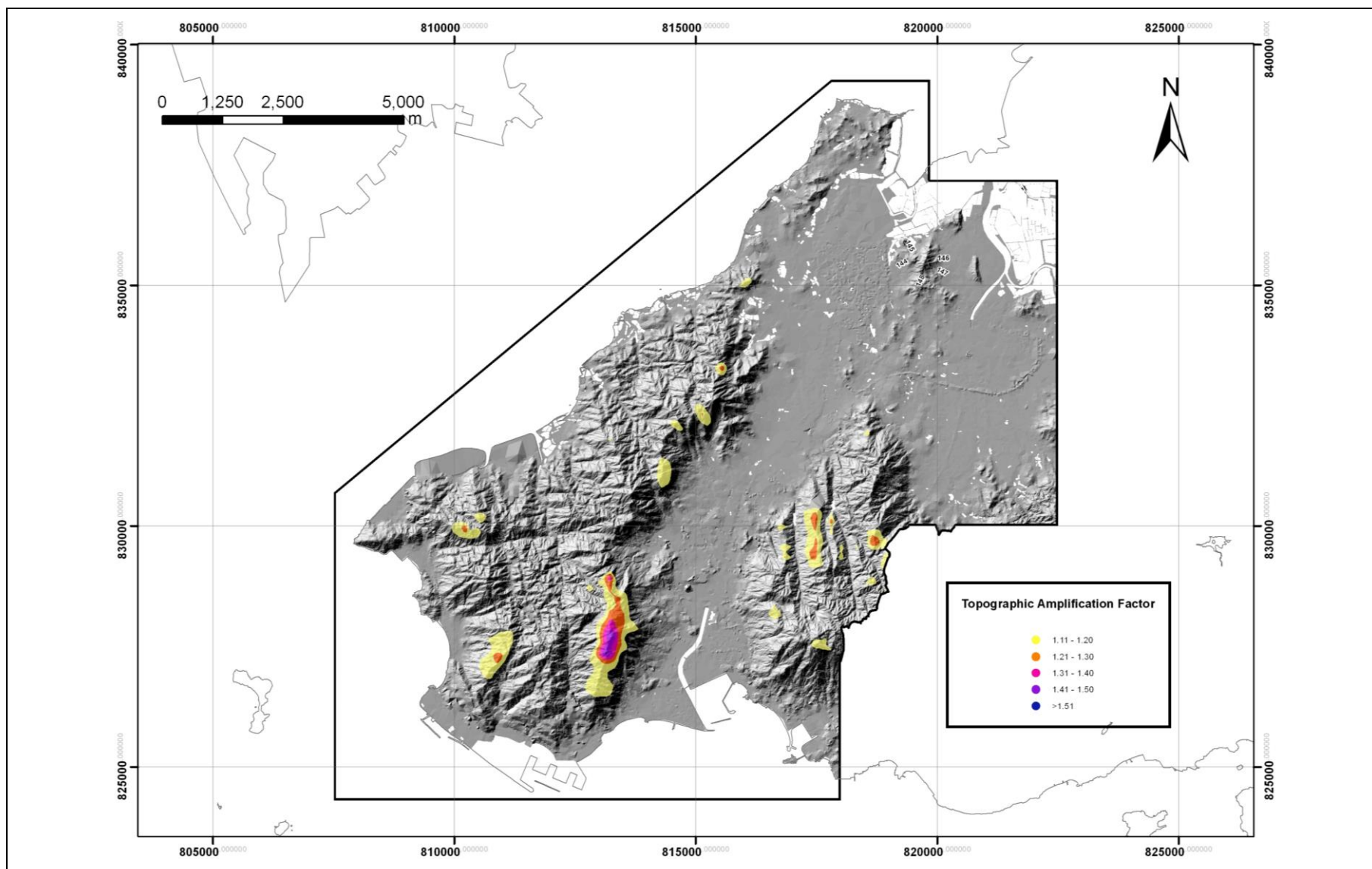
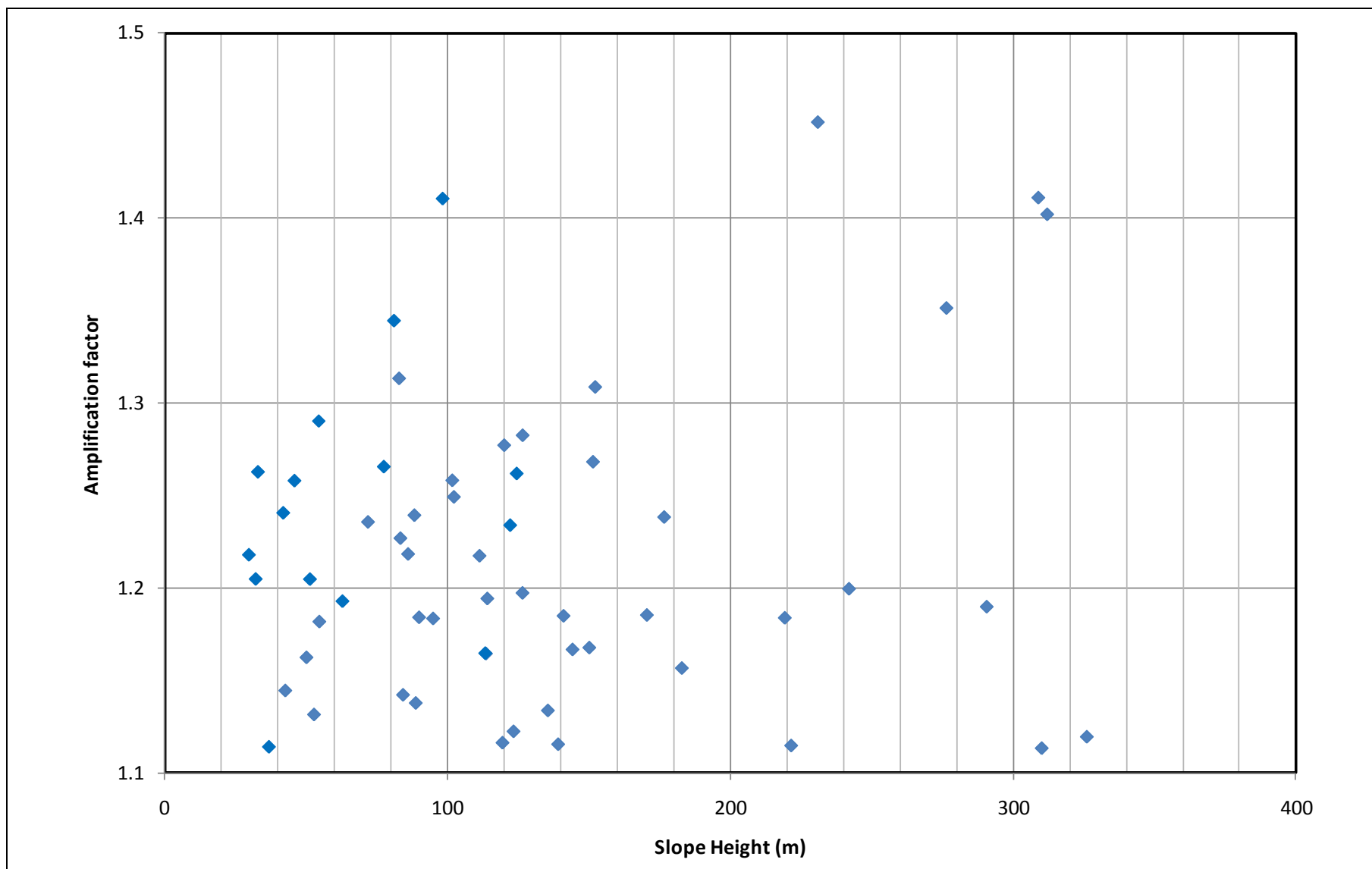
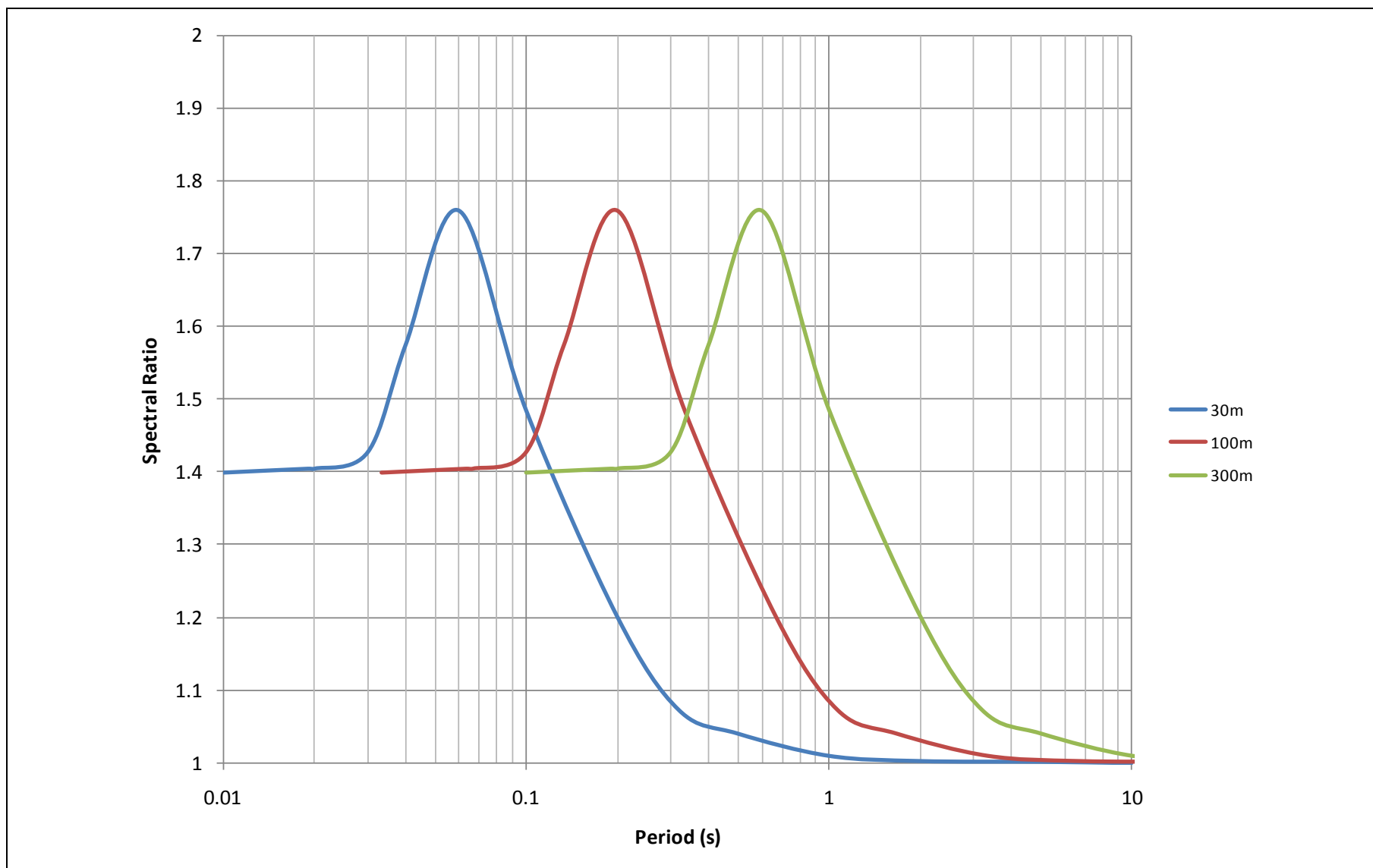


Figure 9.2 Topographic Amplification Factor Zoning Map



**Figure 9.3 Amplification Factor against Slope Height Distribution**



**Figure 9.4** Spectral Ratio for Ridges with Heights of 30 m, 100 m and 300 m

## 10 Conclusions

A seismic microzonation assessment for a Study Area in the North-west New Territories of Hong Kong has been carried out in this study. The following sections summarise the key findings of this study.

### 10.1 Soil Profiles

The soil profiles in the Study Area have been investigated with SPT and in-situ  $V_s$  measurements (downhole seismic, PS logging, crosshole seismic and MASW tests). The design profiles, defined in terms of soil types, shear wave velocity and small-strain shear modulus versus depth are presented.

The PS logging data appear to be of better overall quality than the downhole seismic processed data. However, similar trend is not observed for sites with a deeper rockhead. It is probably because of some significant collapses due to the removal of the borehole casing during the PS logging tests in deep rockhead site.

The MASW test results are considered to be reliable down to a depth of approximately 10 m from the existing ground level based on the quality of resolution of the dispersion curves.

Regarding the microtremor test, the calculated and measured site periods for sites with a shallower rockhead generally agree well. For sites with a deeper rockhead, the agreement is also generally quite good if the soil profile down to a depth where the SPT-N value exceeds 100 is considered. The measured site period determined from the microtremor test, therefore, appears to be dominated by the resonance of the relatively softer soils of the shallower strata. As the test is economical to be carried out and is non-invasive, it may be considered to be a useful method for determining the variation of site periods for a site with widely-spread boreholes.

### 10.2 Site Response Analyses

Although earthquake site response analyses have been carried out previously for a number of specific sites in Hong Kong, there are no existing recommendations for design site response spectra that can be applied throughout Hong Kong for regional site classification. In order to better understand the potential regional earthquake-induced soil amplification trends in the Study Area, a series of one-dimensional site response analyses have been undertaken for all 27 boreholes with in-situ shear wave velocity measurements. A non-linear program *Oasys SIREN* has been used by Arup to perform time-domain site response analyses. The results have been used to determine the ground motion amplitude and period-dependent factors for each of the Site Classes defined in the microzonation exercise. GEERRI have also carried out independent microzonation using their frequency-domain program.

A comparison of spectral ratios calculated by Arup and GEERRI has been carried out for the 10% in the next 50 years ground motion. It shows that the calculated spectral ratios as a function of the structural period by different methods used by Arup and GEERRI are similar.

### 10.3 Seismic Ground Motion Microzonation

The ground surface response spectra produced by site response analyses have been studied and classified such that a systematic seismic ground motion microzonation methodology can be applied to the whole Study Area. It also compares the recommendations with those of GEERRI based on the conventional practice in the Mainland China.

The boreholes have been divided into different groups on the basis of four different parameters ( $S_{\max}/S_1$ ,  $V_{S,30}$ ,  $V_{S,20}$  and  $T_{N100}$ ) to understand how they could be rationally classified. These parameters have been selected based on the recommendations by different seismic codes. It is found that the most consistent grouping is the one based on the  $S_{\max}/S_1$  ratios. Nevertheless, this parameter has to be determined from site response analyses and cannot be derived directly from borehole logs. Other parameters (i.e.  $V_{S,30}$ ,  $V_{S,20}$  and  $T_{N100}$ ), on the other hand, can be determined directly from borehole logs. They are, therefore, used to extrapolate the grouping to the AGS borehole data available within the Study Area. Of these parameters, it is found that the  $T_{N100}$  grouping gives the most consistent result. Microzonation maps, incorporating the AGS data, have been produced for these three classification methods. Another microzonation map, based on the correlation between the natural slope angle and the  $V_{S,30}$  values, has also been developed. An advantage of this map is that it is derived based on a relatively uniformly distributed dataset whereas other maps derived from AGS data are more variable in terms of its distribution. However, it is noted that man-made activities could exert an effect on the resulted zoning based on the natural slope angle –  $V_S$  correlation.

The microzonation maps produced above are, inevitably, very dependent on their underlying data distribution. For example, microzonation maps for flatter valleys containing deeper soils, of which soil properties and characteristics are highly variable, could not be considered as sufficiently precise for site-specific design purposes. In essence, the microzonation maps are not used directly in engineering design practice as overseas codes of practice generally demand site-specific site classification to be done using borehole data. Also, the codes allow for site-specific site response analyses which can be readily undertaken using computer programs that are freely available. However, the microzonation maps could be used for planning purpose as they provide useful information about the seismic effects on different types of buildings situated at different geological and topographic settings. For example, this study shows that low-rise buildings will be less affected by earthquakes on flatter soil areas, and that high-rise buildings will be less affected on steeper thin soil and rock areas. However, the final planning decision is still subject to a spectrum of factors.

### 10.4 Liquefaction

Liquefaction generally refers to the cyclic generation of large pore water pressure in saturated granular soils and the resulting reduction in effective stress leading to a rapid strength loss of the soils. Sandy soils are the most liquefiable under an earthquake event. Common engineering practice in the liquefaction potential assessment is to use empirical correlations, which have been derived based on field observations of liquefaction, or absence of liquefaction in past earthquakes, and in-situ soil properties measured from, for example, SPT, CPT and  $V_S$  tests. In this study, Arup have adopted the Seed's empirical method (Seed et al, 2001) to assess the probability of liquefaction potential whilst GEERRI carried out an independent liquefaction assessment based on Chinese Seismic Code (2010). The soil properties are derived from site-

specific field and laboratory tests for the Study Area. Microzonation maps have also been produced.

The maximum liquefaction probability calculated using the Seed method of any single soil layer and the liquefaction index calculated using the Chinese Code method have been compared. In general, the two methods have similar findings on the level of liquefaction potential for the boreholes. The different results are mainly attributed to the use of fines content in the Seed method and the use of clay content in the Chinese Code method.

GEERRI also produced a liquefaction index zoning map for Earthquake Intensities 7 and 8 (equivalent to the ground motions having 10% and 2% probabilities of being exceeded in the next 50 years respectively) using the Chinese Code method. It generally shows that the Chinese Code method gives a higher chance of liquefaction for the 10% in the next 50 years ground motion but is similar to the Seed method for the 2% in the next 50 years ground motion. As discussed above, the microzonation maps could be used for planning purpose but are not suitable for direct engineering design purpose.

## 10.5 Topographic Effects

It is well understood that larger ground motions are observed where there are noticeable topographic features. Irregular surface features such as ridges, canyons, or slopes can affect the amplitude of the surface ground motions. At ridgelines or cliff tops (convex features) the effect is amplification of the ground motion, whereas in canyons, de-amplification occurs. In most seismic codes, topographic amplification is ignored mainly because the site amplification due to local soil conditions is more significant in many locations. Eurocode 8 (BSI, 2004a; 2004b) make particular recommendations on topographic amplification for sites located near ridges or slopes. These recommendations have been used to estimate the topographic amplification factors for the Study Area. A microzonation map has also been produced.

Topographic amplification with a factor on peak ground acceleration of up to 1.5 is found at the crest regions in the Study Area. When the topographic amplification factor is less than 1.1, it is recommended to be ignored. Preliminary studies show that the amplification factors for ridge effects will be the largest at the natural period of the ridge and reduce to unity at longer structural periods.

The topographic amplification factors are restricted to ridge lines and will, therefore, not have a significant effect on the major building areas in the Study Area, which are concentrated in low-lying areas along the coast and in inland valleys. However, it may affect the risk of earthquake-induced landslides at those ridge areas.

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## Appendix A

### Bulk Density Detailed Summary

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**Table A1 Bulk Density Summary for Alluvial Soils**

| Borehole | Depth (m) | Soil Description | Bulk Density (t/m <sup>3</sup> ) | Average Bulk Density (t/m <sup>3</sup> ) |
|----------|-----------|------------------|----------------------------------|------------------------------------------|
| BH21     | 4.6       | Clay             | 1.96                             | 1.98                                     |
| BH29     | 4.6       |                  | 1.91                             |                                          |
| BH44     | 8.6       |                  | 1.97                             |                                          |
| BH30     | 3.5       |                  | 1.96                             |                                          |
| BH45     | 1.5       |                  | 2.01                             |                                          |
| BH49     | 3.5       |                  | 2.00                             |                                          |
| BH26     | 8.2       |                  | 2.05                             |                                          |
| BH30     | 9.5       | Sand & Silt      | 1.89                             | 1.96                                     |
| BH22     | 5.5       |                  | 2.06                             |                                          |
| BH20     | 6.0       |                  | 1.78                             |                                          |
| BH21     | 6.6       |                  | 1.93                             |                                          |
| BH14     | 6.6       |                  | 2.17                             |                                          |
| BH13     | 12.2      |                  | 2.01                             |                                          |
| BH29     | 10.6      |                  | 1.82                             |                                          |
| BH32     | 5.0       |                  | 1.92                             |                                          |
| BH23     | 14.6      |                  | 2.14                             |                                          |
| BH43     | 11.7      |                  | 1.75                             |                                          |
| BH43     | 16.8      |                  | 1.76                             |                                          |
| BH45     | 5.5       |                  | 2.20                             |                                          |
| BH49     | 11.7      |                  | 2.00                             |                                          |
| BH45     | 5.5       |                  | 2.20                             |                                          |
| BH24     | 11.1      |                  | 1.91                             |                                          |
| BH24     | 9.2       |                  | 1.99                             |                                          |
| BH22     | 1.5       |                  | 1.92                             |                                          |
| BH23     | 3.5       |                  | 1.79                             |                                          |
| BH43     | 18.8      |                  | 1.99                             |                                          |

**Table A2 Bulk Density Summary for Estuarine/Marine Deposits, Fill, Residual/Top Soil, Debris Flow Deposits and Colluvium**

| Borehole | Depth (m) | Soil Description             | Bulk Density (t/m <sup>3</sup> ) | Average Bulk Density (t/m <sup>3</sup> ) |
|----------|-----------|------------------------------|----------------------------------|------------------------------------------|
| BH39     | 5.5       | Estuarine/<br>Marine deposit | 1.75                             | 1.73                                     |
| BH39     | 3.5       |                              | 1.59                             |                                          |
| BH43     | 5.7       |                              | 1.65                             |                                          |
| BH44     | 3.5       |                              | 1.76                             |                                          |
| BH13     | 8.2       |                              | 1.91                             |                                          |
| BH43     | 2.6       | Fill                         | 1.91                             | 1.96                                     |
| BH44     | 1.5       |                              | 2.04                             |                                          |
| BH29     | 1.5       |                              | 1.95                             |                                          |
| BH08     | 8.2       |                              | 2.06                             |                                          |
| BH14     | 1.5       |                              | 2.02                             |                                          |
| BH13     | 2.0       |                              | 1.94                             |                                          |
| BH23     | 1.5       |                              | 1.96                             |                                          |
| BH36     | 1.5       |                              | 1.80                             |                                          |
| BH41     | 1.5       | Residual soil                | 1.92                             | 1.89                                     |
| BH16     | 1.5       |                              | 1.85                             |                                          |
| BH49     | 1.5       | Top soil                     | 2.12                             | 2.12                                     |
| BH23     | 18.6      | Debris flow                  | 2.18                             | 2.18                                     |
| UKS-TP5  | 2.8       | Colluvium                    | 2.42                             | 2.42                                     |

**Table A3 Bulk Density Summary for Completely Decomposed Rock**

| Borehole | Depth (m) | Soil Description                                                                          |                  | Bulk Density (t/m <sup>3</sup> ) | Average Bulk Density (t/m <sup>3</sup> ) |
|----------|-----------|-------------------------------------------------------------------------------------------|------------------|----------------------------------|------------------------------------------|
| BH22     | 11.7      | C<br>D<br><br>S<br>E<br>D<br>I<br>M<br>E<br>N<br>T<br>A<br>R<br>Y<br><br>R<br>O<br>C<br>K | Metasandstone    | 2.04                             | 2.05                                     |
| BH32     | 16.1      |                                                                                           |                  | 2.06                             |                                          |
| BH42     | 12.6      |                                                                                           | Metasiltstone    | 2.11                             | 2.09                                     |
| BH32     | 24.1      |                                                                                           |                  | 2.11                             |                                          |
| BH39     | 31.2      |                                                                                           |                  | 2.14                             |                                          |
| BH49     | 24.8      |                                                                                           |                  | 1.94                             |                                          |
| BH41     | 5.5       |                                                                                           |                  | 2.03                             |                                          |
| BH32     | 14.1      |                                                                                           |                  | 2.06                             |                                          |
| BH42     | 16.6      |                                                                                           |                  | 2.23                             |                                          |
| BH39     | 19.2      |                                                                                           |                  | 2.11                             |                                          |
| BH36     | 13.5      |                                                                                           | Metamudstone     | 2.07                             | 2.03                                     |
| BH43     | 21.9      |                                                                                           |                  | 1.90                             |                                          |
| BH26     | 23.5      |                                                                                           |                  | 2.07                             |                                          |
| BH43     | 39.0      |                                                                                           |                  | 2.07                             |                                          |
| BH21     | 13.7      |                                                                                           | Metaconglomerate | 1.69                             | 1.89                                     |
| BH21     | 24.8      |                                                                                           |                  | 1.98                             |                                          |
| BH21     | 29.9      |                                                                                           |                  | 1.99                             |                                          |
| BH14     | 21.9      | C<br>D<br><br>I<br>G<br>N<br>E<br>O<br>U<br>S<br><br>R<br>O<br>C<br>K                     | Metaandesite     | 1.77                             | 1.77                                     |
| BH15     | 5.7       |                                                                                           | Tuff (all types) | 2.24                             | 2.05                                     |
| BH29     | 16.6      |                                                                                           |                  | 1.86                             |                                          |
| BH29     | 33.7      |                                                                                           |                  | 1.93                             |                                          |
| BH30     | 36.6      |                                                                                           |                  | 2.12                             |                                          |
| BH27     | 12.6      |                                                                                           |                  | 1.77                             |                                          |
| BH30     | 12.6      |                                                                                           |                  | 2.17                             |                                          |
| BH30     | 80.6      |                                                                                           |                  | 2.02                             |                                          |
| BH13     | 18.1      |                                                                                           |                  | 2.25                             |                                          |
| BH45     | 17.5      |                                                                                           | Granite          | 2.09                             | 2.01                                     |
| BH24     | 13.1      |                                                                                           |                  | 1.83                             |                                          |
| BH24     | 17.1      |                                                                                           |                  | 2.10                             |                                          |
| BH49     | 28.8      |                                                                                           | Rhyolite         | 1.90                             | 1.82                                     |
| BH49     | 16.8      |                                                                                           |                  | 1.73                             |                                          |
| BH23     | 59.2      |                                                                                           | CD Fault Breccia | 1.67                             | 1.93                                     |
| BH23     | 64.3      |                                                                                           |                  | 2.08                             |                                          |
| BH23     | 21.7      |                                                                                           |                  | 2.05                             |                                          |

**Table A4 Bulk Density Summary for Rock**

| Borehole | Depth (m) | Rock Description                                    |                  | Bulk Density (t/m <sup>3</sup> ) | Average Bulk Density (t/m <sup>3</sup> ) |
|----------|-----------|-----------------------------------------------------|------------------|----------------------------------|------------------------------------------|
| BH50     | 5.0       | I<br>G<br>N<br>E<br>O<br>U<br>S                     | Tuff             | 2.74                             | 2.74                                     |
| BH12     | 6.5       |                                                     | Tuff Brecciate   | 2.81                             | 2.76                                     |
| BH13     | 26.4      |                                                     |                  | 2.71                             |                                          |
| BH16     | 12.2      |                                                     | Metatuff         | 2.89                             | 2.82                                     |
| BH08     | 24.0      |                                                     |                  | 2.78                             |                                          |
| BH15     | 15.8      |                                                     |                  | 2.78                             |                                          |
| BH27     | 63.3      |                                                     | Crystal Tuff     | 2.62                             | 2.66                                     |
| BH29     | 40.9      |                                                     |                  | 2.70                             |                                          |
| BH45A    | 40.9      |                                                     | Granite          | 2.49                             | 2.57                                     |
| BH24     | 23.9      |                                                     |                  | 2.65                             |                                          |
| BH02     | 44.3      | S<br>E<br>D<br>I<br>M<br>E<br>N<br>T<br>A<br>R<br>Y | Metasiltstone    | 2.65                             | 2.64                                     |
| BH02     | 46.0      |                                                     |                  | 2.66                             |                                          |
| BH21A    | 36.3      |                                                     |                  | 2.49                             |                                          |
| BH22A    | 46.3      |                                                     |                  | 2.75                             |                                          |
| BH43     | 50.7      |                                                     |                  | 2.69                             |                                          |
| BH44A    | 53.0      |                                                     |                  | 2.74                             |                                          |
| BH32     | 39.2      |                                                     |                  | 2.52                             |                                          |
| BH21A    | 36.8      |                                                     | Metaconglomerate | 2.52                             | 2.65                                     |
| BH43A    | 53.4      |                                                     |                  | 2.77                             |                                          |
| BH36A    | 41.5      |                                                     | Metamudstone     | 2.91                             | 2.78                                     |
| BH43A    | 50.4      |                                                     |                  | 2.68                             |                                          |
| BH44     | 50.9      |                                                     |                  | 2.76                             |                                          |
| BH23     | 102.1     |                                                     | Marble           | 2.80                             | 2.78                                     |
| BH49     | 45.0      |                                                     |                  | 2.82                             |                                          |
| BH49A    | 37.4      |                                                     |                  | 2.72                             |                                          |



## Appendix B

### Fines and Clay Content Detailed Summary

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**Table B1 Fines and Clay Content Summary for Alluvial Soils**

| Borehole               | Depth (m)         | Soil Description  | Fine Content (%)<br>P.S. < 0.074 mm | Clay Content (%)<br>P.S. < 0.005 mm | Average Fines Content (%)<br>P.S. < 0.074 mm | Average Clay Content (%)<br>P.S. < 0.005 mm |
|------------------------|-------------------|-------------------|-------------------------------------|-------------------------------------|----------------------------------------------|---------------------------------------------|
| BH21                   | 4.6               | Silty CLAY        | 46                                  | 28                                  | 76                                           | 51                                          |
| BH29                   | 4.6               |                   | 80                                  | 47                                  |                                              |                                             |
| BH44                   | 8.6               |                   | 96                                  | 72                                  |                                              |                                             |
| BH02                   | 5.1               |                   | 70                                  | 47                                  |                                              |                                             |
| BH08                   | 11.3              |                   | 68                                  | 43                                  |                                              |                                             |
| BH43                   | 9.7               |                   | 96                                  | 70                                  |                                              |                                             |
| BH30                   | 3.5               | Sandy CLAY        | 55                                  | 27                                  | 46                                           | 32                                          |
| BH45                   | 1.5               |                   | 49                                  | 32                                  |                                              |                                             |
| BH24                   | 7.1               |                   | 43                                  | 31.0                                |                                              |                                             |
| BH30                   | 7.5               |                   | 62                                  | 33.0                                |                                              |                                             |
| BH49                   | 3.5               |                   | 47                                  | 33                                  |                                              |                                             |
| BH26                   | 8.2               |                   | 20                                  | 37                                  |                                              |                                             |
| BH30                   | 9.5               | Clayey SILT       | 43                                  | 14                                  | 59                                           | 26                                          |
| BH42                   | 3.5               |                   | 81                                  | 47                                  |                                              |                                             |
| BH22                   | 5.5               |                   | 32                                  | 27                                  |                                              |                                             |
| BH27                   | 8.6               |                   | 78                                  | 16                                  |                                              |                                             |
| BH20                   | 6.0               | Sandy Clayey SILT | 17                                  | 8*                                  | 46                                           | 17                                          |
| BH21                   | 6.6               |                   | 22                                  | 17                                  |                                              |                                             |
| BH14                   | 6.6               |                   | 62                                  | 8*                                  |                                              |                                             |
| BH36                   | 3.5               |                   | 48                                  | 20                                  |                                              |                                             |
| BH13                   | 12.2              |                   | 82                                  | 30                                  |                                              |                                             |
| BH42                   | 5.5               | Sandy SILT        | 57                                  | 37                                  | 57                                           | 22                                          |
| BH29                   | 10.6              |                   | 79                                  | 20                                  |                                              |                                             |
| BH32                   | 5.0               |                   | 35                                  | 18                                  |                                              |                                             |
| BH23                   | 14.6              |                   | 25                                  | 9*                                  |                                              |                                             |
| BH43                   | 11.7              |                   | 60                                  | 22                                  |                                              |                                             |
| BH43                   | 16.8              |                   | 73                                  | 20                                  |                                              |                                             |
| BH36                   | 5.5               |                   | 52                                  | 12*                                 |                                              |                                             |
| BH2                    | 9.1               |                   | 76                                  | 35                                  |                                              |                                             |
| Total average for SILT |                   |                   |                                     |                                     | 54                                           | 21                                          |
| BH45                   | 5.5               | Clayey SAND       | 18                                  | 12*                                 | 18                                           | 13                                          |
| BH24                   | 3.1               |                   | 8                                   | 7*                                  |                                              |                                             |
| BH49                   | 12                |                   | 20.0                                | 17                                  |                                              |                                             |
| BH45                   | 8                 |                   | 18.0                                | 12*                                 |                                              |                                             |
| BH24                   | 11                |                   | 25.0                                | 17                                  |                                              |                                             |
| BH23                   | 11.5              | Silty SAND        | 66                                  | 8*                                  | 26                                           | 8                                           |
| BH24                   | 5.1               |                   | 13                                  | 8*                                  |                                              |                                             |
| BH45                   | 11.5              |                   | 16                                  | 8*                                  |                                              |                                             |
| BH24                   | 9.2               |                   | 10                                  | 6*                                  |                                              |                                             |
| BH23                   | 5.5               | SAND              | 24                                  | 14                                  | 28                                           | 11                                          |
| BH22                   | 1.5               |                   | 20                                  | 12*                                 |                                              |                                             |
| BH02                   | 13.1 <sup>#</sup> |                   | 86 <sup>#</sup>                     | 65 <sup>#</sup>                     |                                              |                                             |
| BH23                   | 3.5               |                   | 7                                   | 5*                                  |                                              |                                             |
| BH43                   | 18.8              |                   | 60                                  | 13*                                 |                                              |                                             |
| Total average for SAND |                   |                   |                                     |                                     | 23                                           | 11                                          |

Legend:

\* Clay Content &lt; 13%

# Ignored values for the following reasons:

<sup>1</sup> outlayer values compared to Alluvium Silt;<sup>2</sup> not representative of Sand for a conservative approach of liquefaction assessment

**Table B2 Fines and Clay Content Summary for Estuarine/Marine Deposits, Fill, Residual/Top Soil, Debris Flow Deposits and Colluvium**

| Borehole | Depth (m)        | Soil Description                 |                                 | Fine Content (%)<br>P.S. < 0.074 mm | Clay Content (%)<br>P.S. < 0.005 mm | Average Fines Content (%)<br>P.S. < 0.074 mm | Average Clay Content (%)<br>P.S. < 0.005 mm |
|----------|------------------|----------------------------------|---------------------------------|-------------------------------------|-------------------------------------|----------------------------------------------|---------------------------------------------|
| BH39     | 5.5              | Estuarine/<br>Marine<br>deposite | Sandy clayey SILT               | 73                                  | 38                                  | 63                                           | 25                                          |
| BH13     | 3.1              |                                  |                                 | 53                                  | 12                                  |                                              |                                             |
| BH39     | 3.5              |                                  | clayey SILT/<br>silty CLAY      | 97                                  | 77                                  | 76                                           | 47                                          |
| BH43     | 5.7              |                                  |                                 | 88                                  | 54                                  |                                              |                                             |
| BH44     | 3.5              |                                  |                                 | 52                                  | 28                                  |                                              |                                             |
| BH13     | 8.2              |                                  |                                 | 68                                  | 30                                  |                                              |                                             |
| BH43     | 3                | Fill                             | SAND                            | 19                                  | 12*                                 | 11                                           | 6                                           |
| BH44     | 1.5 <sup>#</sup> |                                  |                                 | 2                                   | 0                                   |                                              |                                             |
| BH29     | 1.5              |                                  |                                 | 73 <sup>#2</sup>                    | 37 <sup>#2</sup>                    |                                              |                                             |
| BH8      | 8.2              |                                  |                                 | 52 <sup>#2</sup>                    | 34 <sup>#2</sup>                    |                                              |                                             |
| BH14     | 1.5              |                                  | Sandy clayey SILT               | 59                                  | 28                                  | 59                                           | 28                                          |
| BH13     | 2.0 <sup>#</sup> |                                  |                                 | 97 <sup>#1</sup>                    | 28 <sup>#1</sup>                    |                                              |                                             |
| BH23     | 1.5              |                                  | Sandy SILT                      | 49                                  | 28                                  | 49                                           | 28                                          |
| BH36     | 1.5 <sup>#</sup> |                                  |                                 | 99 <sup>#1</sup>                    | 78 <sup>#1</sup>                    |                                              |                                             |
|          |                  |                                  | Total average for SILT          |                                     |                                     | 54                                           | 28                                          |
| BH41     | 1.5              | Residual<br>soil                 | clayey SILT                     | 72                                  | 32                                  | 72                                           | 32                                          |
| BH16     | 1.5              |                                  | Silty clayey SILT               | 27                                  | 18                                  | 27                                           | 18                                          |
| BH49     | 1.5              |                                  | Sandy SILT                      | 31                                  | 13*                                 | 31                                           | 13                                          |
|          |                  |                                  | Total average for Residual Soil |                                     |                                     | 43                                           | 21                                          |
| BH23     | 18.6             | Debris<br>Flow<br>Deposit        | Sandy SILT                      | 34                                  | 10*                                 | 34                                           | 10                                          |

Legend:

\* Clay Content < 13%

# Ignored values for the following reasons:

<sup>1</sup> outlayer values compared to Alluvium Silt;

<sup>2</sup> not representative of Sand for a conservative approach of liquefaction assessment

**Table B3 Fines and Clay Content Summary for Completely Decomposed Rocks**

| Borehole | Depth (m) | Type of Decomposed Rock                                                     |                                                         | Soil Description  | Fine Content (%)<br>P.S. < 0.074 mm | Clay Content (%)<br>P.S. < 0.005 mm | Average Fines Content (%)<br>P.S. < 0.074 mm | Average Clay Content (%)<br>P.S. < 0.005 mm |    |    |    |
|----------|-----------|-----------------------------------------------------------------------------|---------------------------------------------------------|-------------------|-------------------------------------|-------------------------------------|----------------------------------------------|---------------------------------------------|----|----|----|
| BH22     | 11.7      | S<br>E<br>D<br>I<br>M<br>E<br>N<br>T<br>A<br>R<br>Y<br><br>R<br>O<br>C<br>K | CD Metasandstone                                        | Clayey SILT       | 72                                  | 13                                  | 64                                           | 16                                          |    |    |    |
| BH22     | 23.7      |                                                                             |                                                         |                   | 77                                  | 17                                  |                                              |                                             |    |    |    |
| BH42     | 12.6      |                                                                             | CD Metasiltstone                                        |                   |                                     | 33                                  |                                              |                                             | 10 |    |    |
| BH02     | 24.3      |                                                                             |                                                         |                   |                                     | 42                                  |                                              |                                             | 16 |    |    |
| BH22     | 8.6       |                                                                             |                                                         |                   |                                     | 77                                  |                                              |                                             | 18 |    |    |
| BH26     | 95.5      |                                                                             |                                                         |                   |                                     | 85                                  |                                              |                                             | 12 |    |    |
| BH36     | 13.5      |                                                                             |                                                         |                   |                                     | 30                                  |                                              |                                             | 15 |    |    |
| BH43     | 21.9      |                                                                             | CD Metamudstone                                         |                   |                                     | 65                                  |                                              |                                             | 24 |    |    |
| BH26     | 23.5      |                                                                             |                                                         |                   |                                     | 97                                  |                                              |                                             | 22 |    |    |
| BH21     | 13.7      |                                                                             |                                                         | CD Metasandstone  | 56                                  | 25                                  | 58                                           | 18                                          |    |    |    |
| BH20     | 12.2      |                                                                             | CD Metasiltstone                                        | 47                | 15                                  |                                     |                                              |                                             |    |    |    |
| BH20     | 16.2      |                                                                             |                                                         | 71                | 15                                  |                                     |                                              |                                             |    |    |    |
| BH21     | 24.8      |                                                                             | CD Metaconglomerate                                     | Sandy SILT        | 65                                  | 14                                  | 56                                           | 18                                          |    |    |    |
| BH32     | 24.1      |                                                                             |                                                         |                   |                                     | 38                                  |                                              |                                             | 4  |    |    |
| BH39     | 31.2      |                                                                             |                                                         |                   |                                     | 69                                  |                                              |                                             | 34 |    |    |
| BH49     | 24.8      |                                                                             |                                                         |                   |                                     | 28                                  |                                              |                                             | 10 |    |    |
| BH41     | 5.5       |                                                                             |                                                         |                   |                                     | 81                                  |                                              |                                             | 47 |    |    |
| BH44     | 17.7      |                                                                             |                                                         |                   |                                     | 63                                  |                                              |                                             | 15 |    |    |
| BH36     | 23.5      |                                                                             |                                                         |                   | CD Metamudstone                     | 42                                  |                                              |                                             | 8  |    |    |
| BH43     | 39.0      |                                                                             |                                                         |                   |                                     | 59                                  |                                              |                                             | 10 |    |    |
|          |           |                                                                             | Total average for SILT                                  |                   |                                     |                                     |                                              | 60                                          | 17 |    |    |
| BH20     | 20.2      | I<br>G<br>N<br>E<br>O<br>U<br>S<br><br>R<br>O<br>C<br>K                     | CD Metasandstone                                        | Sandy SAND        | 48                                  | 10                                  | 39                                           | 11                                          |    |    |    |
| BH32     | 16.1      |                                                                             |                                                         |                   |                                     | 29                                  |                                              |                                             | 12 |    |    |
| BH21     | 29.9      |                                                                             | HD Metaconglomerate                                     | GRAVEL            | 32                                  | 6                                   | 48                                           | 11                                          |    |    |    |
| BH32     | 14.1      |                                                                             | HD Metasiltstone                                        |                   | 72                                  | 10                                  |                                              |                                             |    |    |    |
| BH42     | 16.6      |                                                                             |                                                         |                   | 23                                  | 9                                   |                                              |                                             |    |    |    |
| BH39     | 19.2      |                                                                             |                                                         |                   | 65                                  | 20                                  |                                              |                                             |    |    |    |
| BH14     | 21.9      |                                                                             | I<br>G<br>N<br>E<br>O<br>U<br>S<br><br>R<br>O<br>C<br>K | CD Metaandesite   | Clayey SILT                         | 93                                  | 17                                           | 73                                          | 18 |    |    |
| BH08     | 15.3      | CD Metatuff                                                                 |                                                         |                   |                                     | 96                                  | 27                                           |                                             |    |    |    |
| BH15     | 5.7       |                                                                             |                                                         |                   |                                     | 54                                  | 15                                           |                                             |    |    |    |
| BH29     | 16.6      |                                                                             |                                                         |                   |                                     | 78                                  | 20                                           |                                             |    |    |    |
| BH29     | 33.7      |                                                                             |                                                         |                   |                                     | 69                                  | 18                                           |                                             |    |    |    |
| BH30     | 36.6      |                                                                             |                                                         | CD Tuff           |                                     |                                     | 65                                           |                                             |    | 17 |    |
| BH30     | 56.6      |                                                                             |                                                         |                   |                                     | 65                                  | 20                                           |                                             |    |    |    |
| BH27     | 12.6      |                                                                             |                                                         |                   |                                     | 77                                  | 20                                           |                                             |    |    |    |
| BH13     | 18.1      | CD Tuff breccia                                                             |                                                         |                   |                                     | 58                                  | 11                                           |                                             |    |    |    |
| BH49     | 16.8      | CD Rhyolite                                                                 |                                                         | 81                | 24                                  | 36                                  | 21                                           |                                             |    |    |    |
| BH45     | 23.5      | CDG                                                                         |                                                         | Sandy clayey SILT | 36                                  |                                     |                                              | 21                                          |    |    |    |
| BH49     | 28.8      | CD Rhyolite                                                                 |                                                         | Sandy SILT        | 27                                  |                                     |                                              | 8                                           | 53 | 16 |    |
| BH45     | 17.5      |                                                                             |                                                         |                   |                                     |                                     |                                              | 40                                          |    |    | 27 |
| BH24     | 13.1      | CDG                                                                         |                                                         |                   |                                     |                                     |                                              | 39                                          |    |    | 18 |
| BH30     | 12.6      |                                                                             |                                                         |                   |                                     |                                     |                                              | 63                                          |    |    | 14 |
| BH30     | 80.6      |                                                                             |                                                         |                   |                                     |                                     |                                              | 69                                          |    |    | 17 |
| BH27     | 24.6      |                                                                             |                                                         |                   |                                     |                                     |                                              | 73                                          |    |    | 12 |
| BH27     | 48.6      |                                                                             |                                                         |                   |                                     | 58                                  | 17                                           |                                             |    |    |    |
|          |           | Total average for Sandy SILT/Sandy clayey SILT                              |                                                         |                   |                                     |                                     | 51                                           | 17                                          |    |    |    |
| BH24     | 17.1      | I<br>G<br>N<br>E<br>O<br>U<br>S<br><br>R<br>O<br>C<br>K                     | CDG                                                     | Sandy SAND        | 20                                  | 11                                  | 20                                           | 11                                          |    |    |    |
| BH12     | 1.5       |                                                                             | HD Tuff                                                 | GRAVEL            | 28                                  | 8                                   | 28                                           | 8                                           |    |    |    |
|          |           |                                                                             | Total average for SAND/GRAVEL                           |                   |                                     |                                     |                                              | 24                                          | 10 |    |    |
| BH23     | 59.2      |                                                                             |                                                         | CD Fault Breccia  | Sandy clayey                        | 59                                  | 30                                           | 59                                          | 30 |    |    |
| BH23     | 64.3      |                                                                             |                                                         |                   | Sandy SILT                          | 39                                  | 12                                           | 55                                          | 14 |    |    |
| BH23     | 21.7      | 70                                                                          |                                                         |                   |                                     | 15                                  |                                              |                                             |    |    |    |
|          |           | Total average for CD Fault Breccia                                          |                                                         |                   |                                     |                                     | 56                                           | 19                                          |    |    |    |

## Appendix C

### Plasticity Index Detailed Summary

**List of Tables**

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**Table C1 Plasticity Index Summary for Alluvial Soils**

| Borehole | Depth (m) | Soil Description | PI (%) | Average PI (%) |    |    |
|----------|-----------|------------------|--------|----------------|----|----|
| BH21     | 4.6       | Clay             | 21     | 26             | 21 | 21 |
| BH29     | 4.6       |                  | 40     |                |    |    |
| BH44     | 8.6       |                  | 35     |                |    |    |
| BH02     | 5.1       |                  | 20     |                |    |    |
| BH8      | 11.3      |                  | 27     |                |    |    |
| BH43     | 9.7       |                  | 34     |                |    |    |
| BH30     | 3.5       |                  | 16     |                |    |    |
| BH45     | 1.5       |                  | 21     |                |    |    |
| BH24     | 7.1       |                  | 30     |                |    |    |
| BH30     | 7.5       |                  | 19     |                |    |    |
| BH49     | 3.5       |                  | 24     |                |    |    |
| BH30     | 9.5       |                  | Silt   |                |    |    |
| BH42     | 3.5       | 18               |        |                |    |    |
| BH22     | 5.5       | 20               |        |                |    |    |
| BH21     | 6.6       | 24               |        |                |    |    |
| BH36     | 3.5       | 19               |        |                |    |    |
| BH13     | 12.2      | 12               |        |                |    |    |
| BH42     | 5.5       | 17               |        |                |    |    |
| BH29     | 10.6      | 19               |        |                |    |    |
| BH32     | 5.0       | 15               |        |                |    |    |
| BH43     | 11.7      | 13               |        |                |    |    |
| BH43     | 16.8      | 12               |        |                |    |    |
| BH23     | 11.5      | Sand             |        | 8              | 8  |    |
| UKS-TP5  | 2.8       | Colluvium (Silt) | 17     | 17             |    |    |

**Table C2 Plasticity Index Summary for Estuarine/Marine deposits, Fill and Residual Soil**

| Borehole | Depth (m) | Soil Description         | PI (%) | Average PI (%) |
|----------|-----------|--------------------------|--------|----------------|
| BH39     | 5.5       | Estuarine/Marine deposit | 19     | 20             |
| BH39     | 3.5       |                          | 31     |                |
| BH43     | 5.7       |                          | 13     |                |
| BH13     | 8.2       |                          | 17     |                |
| BH43     | 2.6       | Fill                     | 8      | 13             |
| BH23     | 1.5       |                          | 18     |                |
| BH41     | 1.5       | Residual soil            | 15     | 19             |
| BH16     | 1.5       |                          | 29     |                |
| BH49     | 1.5       |                          | 12     |                |



**Table C3 Plasticity Index Summary for In-situ Completely Decomposed Rocks**

| Borehole | Depth (m) | Soil Description                                    |                     | PI (%) | Average PI (%) |    |
|----------|-----------|-----------------------------------------------------|---------------------|--------|----------------|----|
| BH22     | 8.6       | S<br>E<br>D<br>I<br>M<br>E<br>N<br>T<br>A<br>R<br>Y | CD Metasiltstone    | 12     | 17             | 17 |
| BH39     | 31.2      |                                                     |                     | 13     |                |    |
| BH49     | 24.8      |                                                     |                     | 16     |                |    |
| BH41     | 5.5       |                                                     |                     | 30     |                |    |
| BH32     | 24.1      |                                                     |                     | 12     |                |    |
| BH20     | 10.2      |                                                     |                     | 26     |                |    |
| BH20     | 12.2      |                                                     |                     | 12     |                |    |
| BH43     | 21.9      |                                                     | CD Metamudstone     | 16     | 14             |    |
| BH43     | 39.0      |                                                     |                     | 11     |                |    |
| BH21     | 13.7      |                                                     | CD Metaconglomerate | 14     | 13             |    |
| BH21     | 24.8      |                                                     |                     | 14     |                |    |
| BH21     | 29.9      |                                                     |                     | 12     |                |    |
| BH22     | 11.7      |                                                     | CD Metasandstone    | 10     | 27             |    |
| BH22     | 23.7      |                                                     |                     | 43     |                |    |
| BH29     | 16.6      | I<br>G<br>N<br>E<br>O<br>U<br>S                     | CD Tuff             | 13     | 11             | 15 |
| BH29     | 33.7      |                                                     |                     | 10     |                |    |
| BH30     | 36.6      |                                                     |                     | 11     |                |    |
| BH27     | 10.8      |                                                     |                     | 14     |                |    |
| BH30     | 18.6      |                                                     |                     | 7      |                |    |
| BH30     | 12.6      |                                                     |                     | 10     |                |    |
| BH49     | 16.8      |                                                     | CD Rhyolite         | 20     | 14             |    |
| BH49     | 28.8      |                                                     |                     | 8      |                |    |
| BH45     | 23.5      |                                                     | CD Granite          | 14     | 21             |    |
| BH45     | 17.5      |                                                     |                     | 20     |                |    |
| BH24     | 13.1      |                                                     |                     | 22     |                |    |
| BH24     | 17.1      |                                                     |                     | 27     |                |    |
| BH23     | 59.2      |                                                     | CD Fault Breccia    | 26     | 17             |    |
| BH23     | 64.3      |                                                     |                     | 14     |                |    |
| BH23     | 21.7      |                                                     |                     | 11     |                |    |

## Appendix D

Topographical Sections  
(data in enclosed CD)

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## Appendix E

### GEERRI Seismic Microzonation Assessment Report

# 香港元朗—屯門地區滑坡與 地震影響小區劃

## 地震影響小區劃報告修改稿

(Final Report on the Seismic Microzonation Assessment)

廣東省工程防震研究院

**Ove Arup & Partners Hong Kong Limited**

2011 年 7 月

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根據工作區的地質、地貌特徵以及工作主要針對目標和工作條件，在場區內共進行了 27 個地震工程地質鑽孔的鑽探勘測（為進行跨孔測試及對比測試，額外進行了 9 個輔助鑽孔的鑽探），採用了三種不同測試方法進行的地震工程測試鑽孔的剪切波速測試工作，採取若干組岩土樣品進行土動三軸試驗、土常規試驗和岩石抗壓強度試驗。各地震工程鑽孔概況及分佈分別見表 5.1、5.2 和圖 5.2。

**表 5.1 地震工程地質鑽孔及輔助鑽孔概況表**

| Hole | HK Grid E<br>(m) | HK Grid N<br>(m) | Ground Level<br>(mPD) | Termination<br>Depth (mPD) |
|------|------------------|------------------|-----------------------|----------------------------|
| BH01 | 820 788.01       | 834 662.81       | 3.49                  | 49.05                      |
| BH02 | 818 797.50       | 835 346.62       | 6.10                  | 91.00                      |
| BH08 | 814 731.24       | 826 550.68       | 4.81                  | 28.86                      |
| BH12 | 814 545.68       | 829 101.75       | 22.83                 | 7.45                       |
| BH13 | 815 228.54       | 828 606.03       | 4.60                  | 31.89                      |
| BH14 | 815 878.90       | 829 623.70       | 9.76                  | 42.88                      |
| BH15 | 814 736.30       | 830 479.68       | 28.55                 | 16.97                      |
| BH16 | 815 248.43       | 830 122.68       | 15.89                 | 15.95                      |
| BH20 | 817 186.69       | 833 269.83       | 6.56                  | 29.02                      |
| BH21 | 816 742.75       | 834 053.95       | 11.50                 | 38.61                      |
| BH22 | 817 639.96       | 833 141.84       | 6.98                  | 55.28                      |
| BH23 | 818 574.03       | 833 547.56       | 6.03                  | 105.59                     |
| BH24 | 819 373.99       | 832 415.73       | 12.82                 | 28.41                      |
| BH26 | 820 329.16       | 830 697.38       | 16.01                 | 146.50                     |
| BH27 | 820 851.05       | 831 545.75       | 10.70                 | 70.58                      |
| BH29 | 821 526.55       | 832 139.46       | 10.28                 | 41.52                      |
| BH30 | 821 782.24       | 832 860.94       | 7.22                  | 150.00                     |
| BH32 | 819 518.02       | 833 226.85       | 8.94                  | 48.43                      |
| BH36 | 820 061.08       | 834 344.40       | 9.25                  | 44.43                      |
| BH39 | 821 126.41       | 835 767.88       | 4.56                  | 49.68                      |
| BH41 | 820 154.63       | 835 247.23       | 11.85                 | 24.90                      |
| BH42 | 820 208.96       | 835 782.70       | 4.08                  | 32.92                      |
| BH43 | 818 385.85       | 836 137.79       | 6.49                  | 51.00                      |
| BH44 | 818 381.82       | 836 888.04       | 4.77                  | 55.93                      |
| BH45 | 818 426.21       | 838 562.87       | 8.44                  | 68.13                      |
| BH49 | 820 239.20       | 832 872.00       | 5.81                  | 54.12                      |
| BH50 | 814 975.32       | 828 963.20       | 19.70                 | 7.39                       |

表 5.2 地震工程地質輔助鑽孔概況表

| Hole  | HK Grid E (m) | HK Grid N (m) | Ground Level (mPD) | Termination Depth (mPD) |
|-------|---------------|---------------|--------------------|-------------------------|
| BH20A | 817 186.72    | 833 264.73    | 6.57               | 35.75                   |
| BH21A | 816 743.61    | 834 055.50    | 11.55              | 43.90                   |
| BH22A | 817 648.10    | 833 140.55    | 6.86               | 50.16                   |
| BH26A | 820 327.71    | 830 702.62    | 15.88              | 30.00                   |
| BH36A | 820 056.39    | 834 349.23    | 9.34               | 44.9                    |
| BH43A | 818 379.00    | 836 139.15    | 6.17               | 57.30                   |
| BH44A | 818 379.26    | 836 885.51    | 4.75               | 54.70                   |
| BH45A | 818 423.83    | 838 563.74    | 8.35               | 49.26                   |
| BH49A | 820 241.08    | 832 873.62    | 5.68               | 43.97                   |

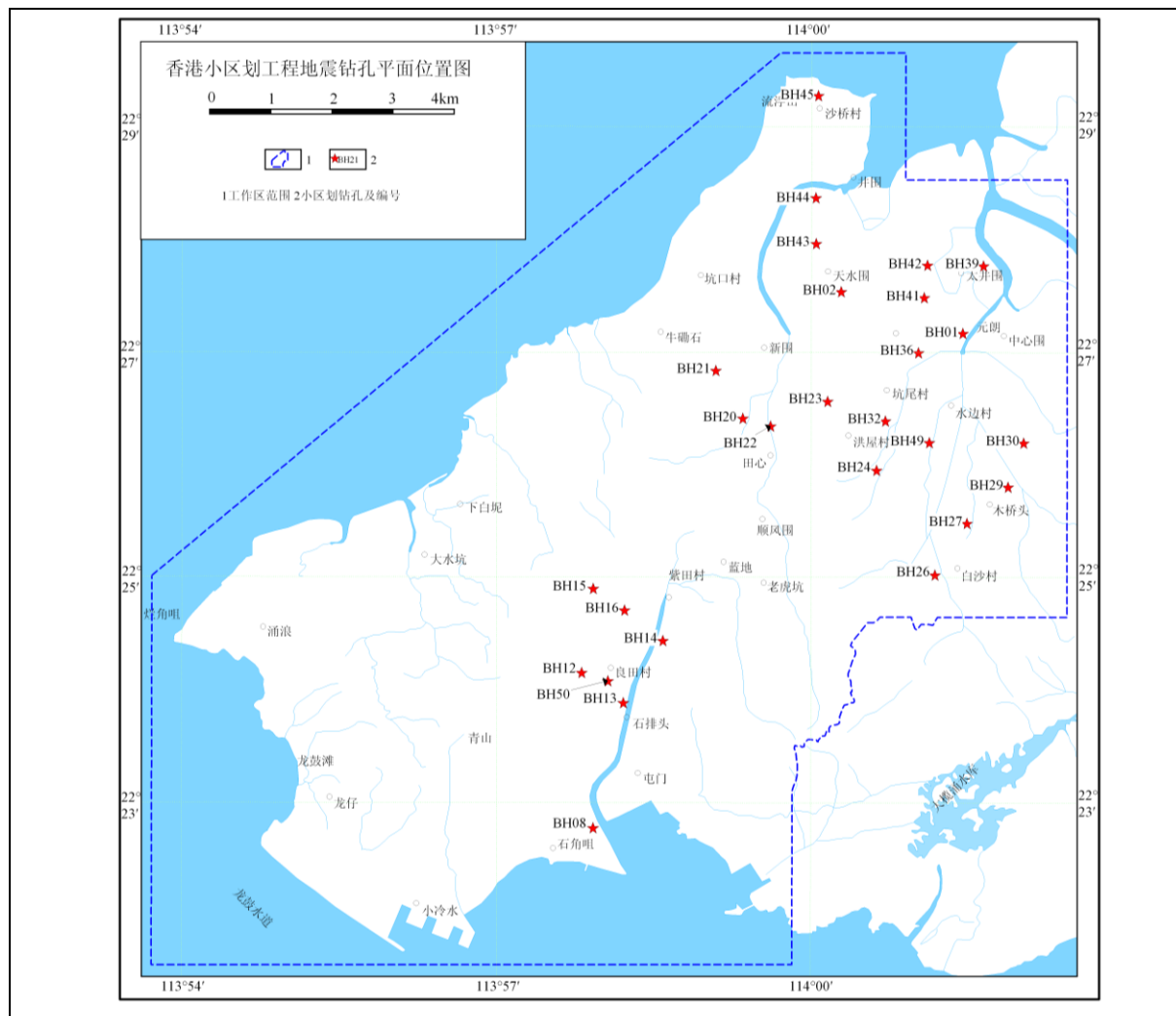


圖 5.2 工程場區地震工程鑽孔平面位置示意圖（藍色框為工程場區）

## 5.2 場地工程地質條件

### 5.2.1 地形地貌特徵

工程場區位於新界西北，西、南、北三面被海水包圍，區內水系發育，河網密佈。地貌主要為丘陵谷地（面積58.6平方公里）和沖、沉積小平原（包括山間坡麓堆積小平地，面積51.2平方公里，一些地段表面被人工填土所覆蓋）。地勢總體南高，北低。丘陵谷地主要分佈於場區南部的東西兩側，形成中間低窪，東西兩側高的鞍狀地形，場區南部地形起伏變化大，山勢陡峭，場區內最高峰位於南端西側的青山（海拔583米），東側最高為恒順園東面海拔約500米的山峰，中間窪地的最低海拔為0米，相對高差達500餘米；平原區主要位於北部，為平整廣闊的元朗平原，海拔多在20米以下，地形起伏小（圖 5.3 - 5.5）。

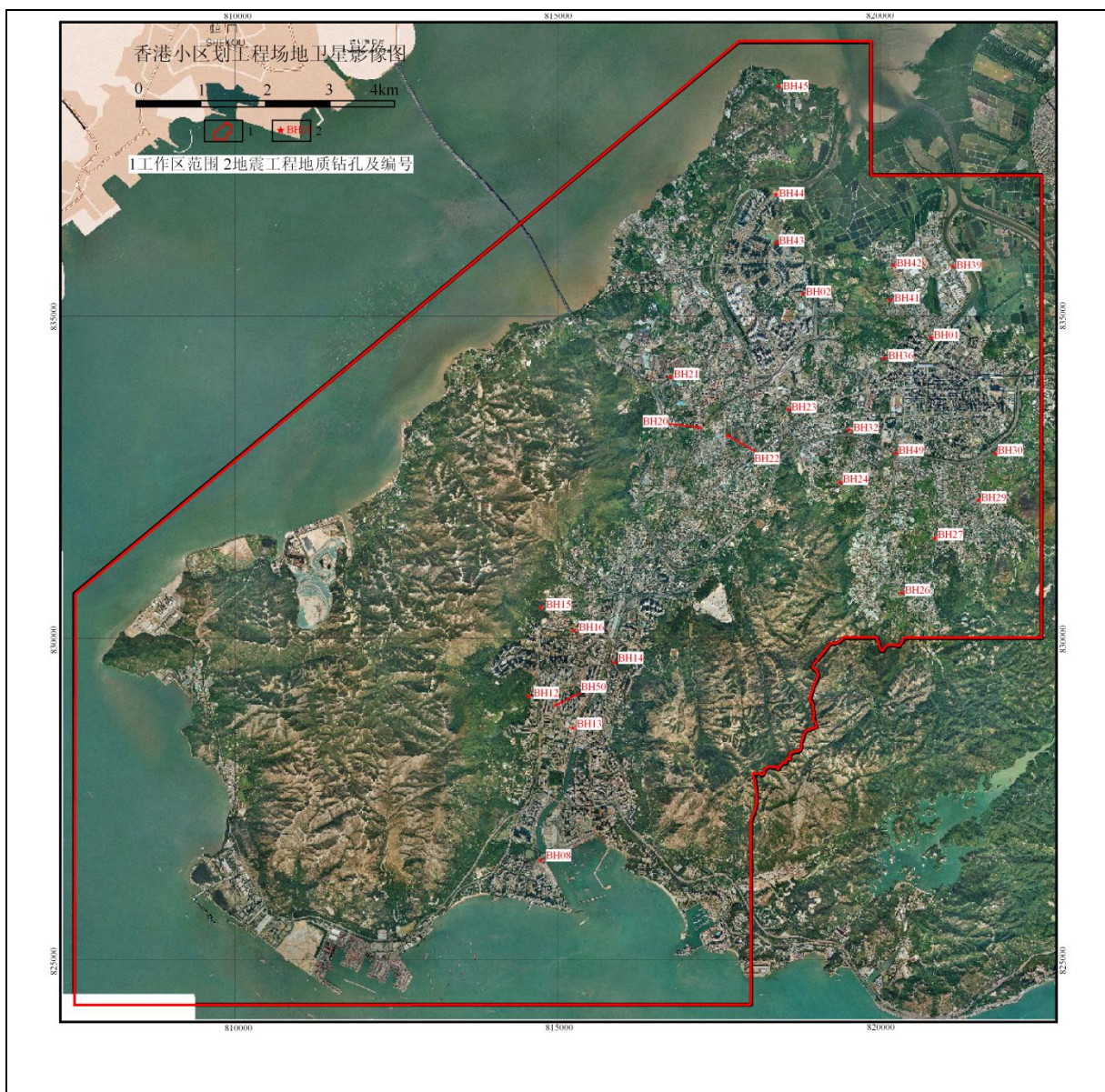


圖 5.3 工程場區地貌衛星影像及地震工程鑽孔位置圖



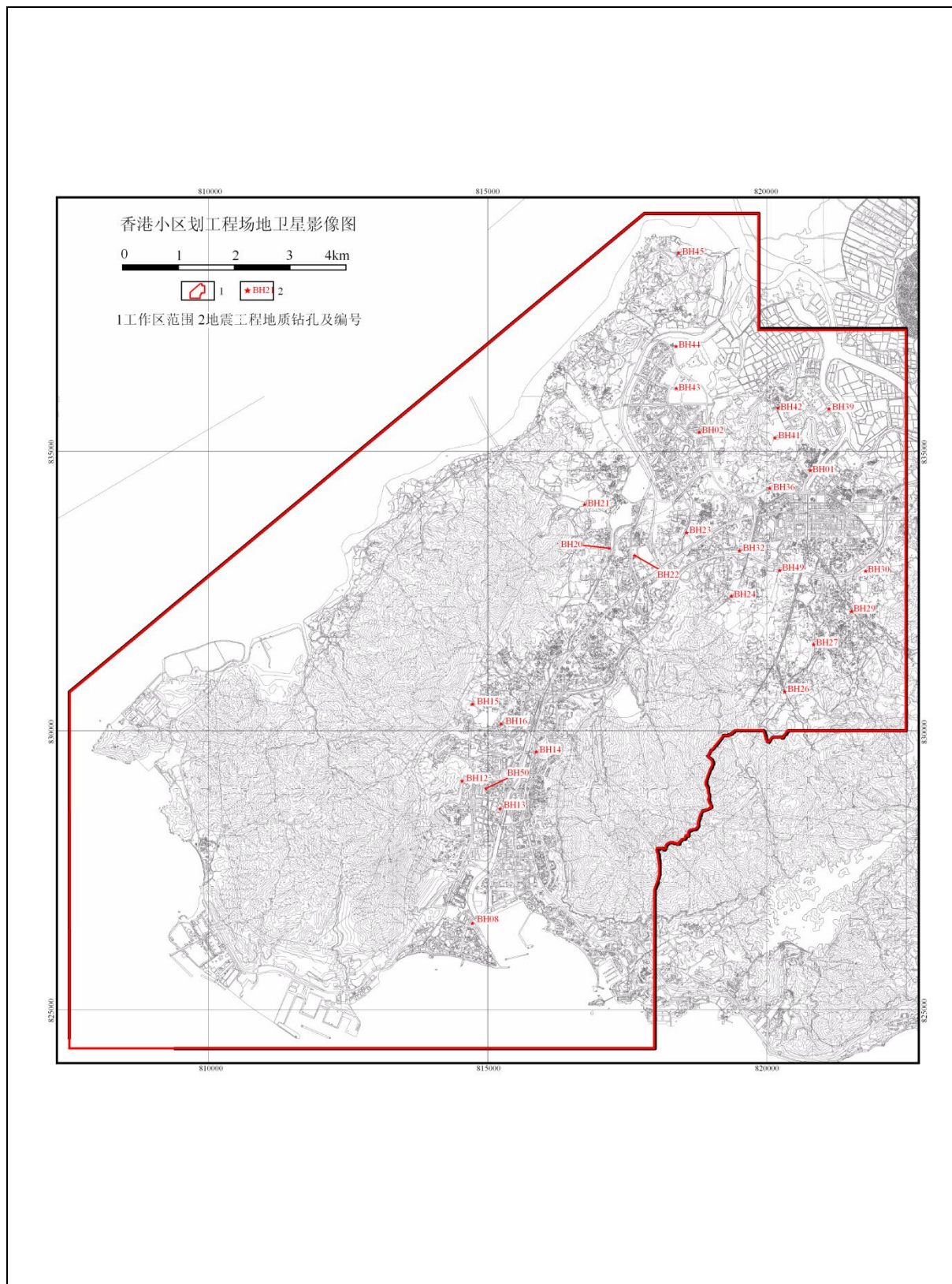


圖 5.4 工程場區地形圖

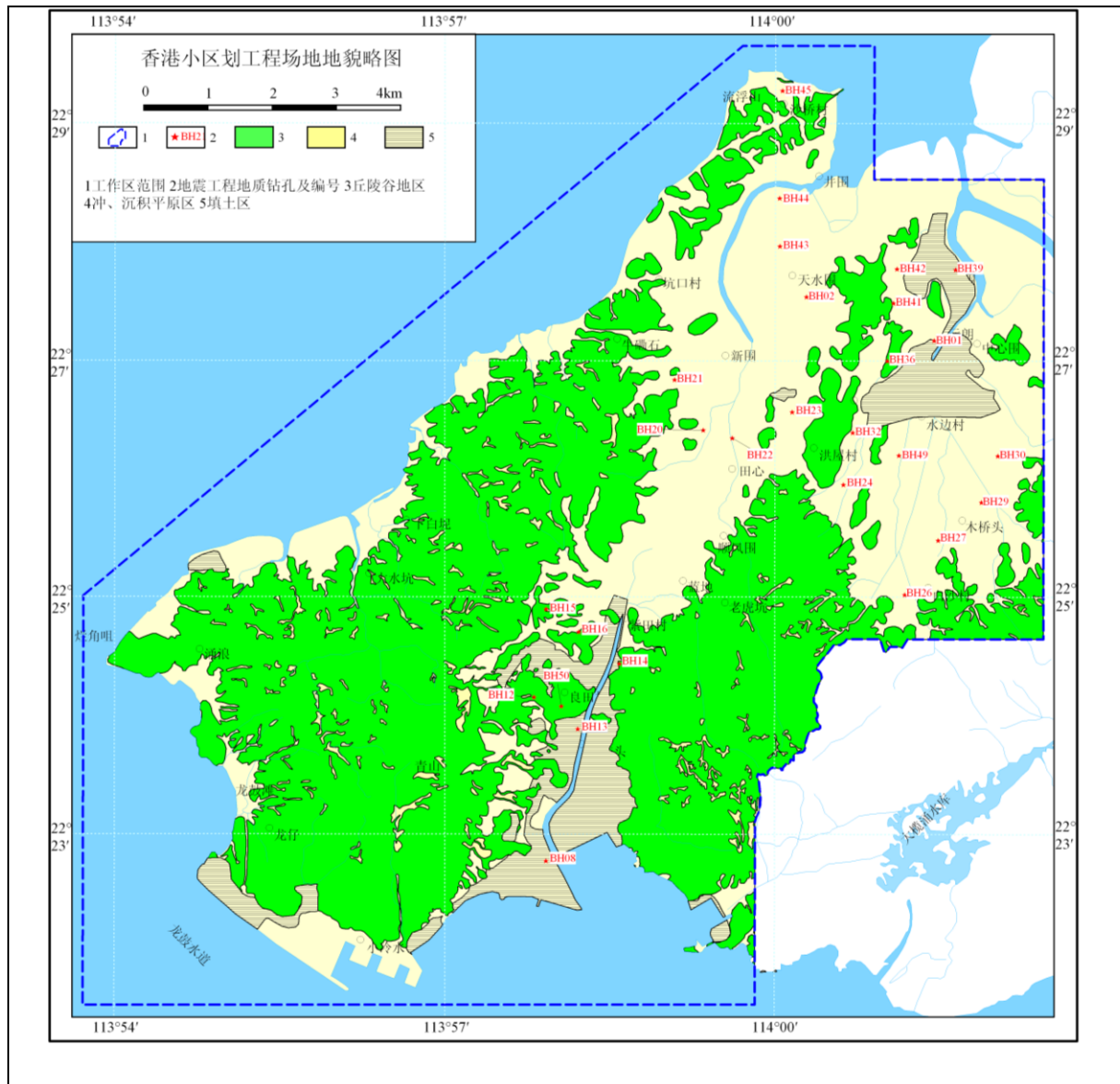


圖 5.5 工程場區地貌圖

### 5.2.2 岩土性狀概述

香港地區主要由火成岩、沉積岩及變質岩構成，火成岩的出露面積最廣泛，包括火山岩（50%）及侵入岩（35%）約佔據香港面積 85%，其中花崗岩更佔香港總面積約三分之一，主要分佈在香港島、九龍半島、青山和大嶼山北部；沉積岩及變質岩分佈局限，主要集中在新界北部地方及零星散佈在赤門海峽兩岸和大嶼山島的西端。根據各岩層的岩石特徵和它們形成的時代，香港的地質工作者把香港地區的地層柱劃分為 17 個地層組和 4 個火山岩群，見表 5.3<sup>1</sup>。

<sup>1</sup> 資料來源：何耀生（2005 年）：《集體回憶之維多利亞港》，香港：明報出版社。ISBN 962-8872-68-0；香港歷史博物館：“香港故事”常設展資料（PDF），展區一：自然生態環境，第 3 至 12 頁；杜德俊、高力行著，陳慧聰譯（2004 年）：《香港生態情報》第 24~30 頁，香港：三聯書店。ISBN 962-04-2386-0。

表 5.3 香港地區地層劃分序列表 (據李曉池《香港的地理與地質歷史》)

| 代<br>Era                | 統 / 系<br>Series/System        | 群 / 組<br>Group/Formation                       | 厚度(米)<br>Thickness (meters) | 分佈/形成環境<br>Distributions/Environment | 年齡(百萬元)<br>Ages(Ma) |
|-------------------------|-------------------------------|------------------------------------------------|-----------------------------|--------------------------------------|---------------------|
| 新生代<br>Cenozoic         | 全新統<br>(Holocene)             | 沖積層(未分組)<br>alluvium                           | 21                          | 新界北部沖積平原                             | 0.6-0               |
|                         |                               | 坡積/洪積層(未分組)<br>colluvium/proluvium             | 0-15                        | 全港各處山坡及山間盆地/山坡堆積及洪積                  |                     |
|                         |                               | 坑口組<br>Hang Hau Form.                          | 31                          | 香港海域/海相砂泥                            |                     |
|                         | 上更新統<br>(Upper Pleistocene)   | 山下村組(陸上)<br>Shan Ha Tsuen Form.                | 10-36                       | 新界北部/河流階地；山坡及山間盆地坡積和洪積               | 1.40-0.6            |
|                         |                               | 赤蠟角組上部(海區)<br>Upper Chek Lap Kok Form.         | 60                          | 香港海域/海相砂泥                            |                     |
|                         | 中更新統<br>(Middle Pleistocene)  | 黃崗山組(陸上)<br>Wong Kong Shan Form.               | 17-30                       | 新界北部/河流階地；山坡及山間盆地坡積和洪積               |                     |
|                         |                               | 赤蠟角組下部(海區)<br>Lower Chek Lap Kok Form.         | 30                          | 香港海域/海相砂泥                            |                     |
|                         | 下第三系<br>(Eocene)              | 平洲組<br>Ping Chau Form.                         | 450                         | 平洲島一帶/淡水湖泊沉積                         | 53-33.7             |
| 中生代<br>Mesozoic         | 上白堊統<br>(Upper Cretaceous)    | 吉澳組<br>Kat O Form.                             | >100                        | 吉澳、鴨洲、長排頭和流浮山                        | 96-65               |
|                         |                               | 赤洲組<br>Port Island Form.                       | >1200                       | 赤洲、石牛洲及大鵬灣海底                         |                     |
|                         | 下白堊統<br>(Lower Cretaceous)    | 八仙嶺組<br>Pat Sin Leng Form.                     | >500                        | 八仙嶺等地                                | 135-96              |
|                         |                               | 潛西洲火山岩群<br>Kau Sai Chau Volcanic Group         | >1000                       | 新界東西貢，清水灣，牛尾海一帶                      |                     |
|                         |                               | 淺水灣火山岩群<br>Repules Bay Volcanic Group          | >2000                       | 大嶼山島、嶂上、西貢和香港島                       |                     |
|                         | 下白堊統<br>(L. Cretaceous)       | 大嶼山火山岩群<br>Lantau Volcanic Group               | 1500                        | 大嶼山島                                 | 154-96              |
|                         | 上侏羅統<br>(U. Jurassic)         | 荃灣火山岩群<br>Tsueng Wan Volcanic Group            | >500                        | 元朗、上水、沙田和大埔                          |                     |
|                         | 中下侏羅統<br>(L. & M. Jurassic)   | 大澳組<br>Tai O Form.                             | 800                         | 大澳                                   | 203-160             |
|                         | 下侏羅統<br>(Lower Jurassic)      | 屯門組<br>Tuen Mun Form.                          | 400                         | 屯門至天水圍一帶                             |                     |
|                         |                               | 赤門海峽組<br>Tolo Channel Form.                    | 120                         | 鳳凰笏、白角山南岸、泥涌、深涌和元朗                   |                     |
| 上古生代<br>Upper Paleozoic | 中下二疊統<br>(L. & M. Permian)    | 丫洲組<br>Centre Island Form.                     | >100                        | 大埔海丫洲島                               | 290-260             |
|                         | 下二疊統<br>(Lower Permian)       | 大埔海組<br>Tolo Harbour Form.                     | 500                         | 馬屎洲和中文大學                             |                     |
|                         | 下石炭統<br>(Lower Carboniferous) | 落馬洲組(新田群)<br>Lok Ma Chau Form. (San Tin Group) | 300-400                     | 羅湖、大石磨和落馬洲，老鼠嶺、米埔、橫洲和虎地上村            | 355-325             |
|                         |                               | 元朗組(新田群)<br>Yuen Long Form. (San Tin Group)    | 350                         | 馬田、元朗和朗屏                             |                     |
|                         | 泥盆系<br>(Devonian)             | 馬鞍山組<br>Ma On Shan Form.                       | >500                        | 馬鞍山                                  | 400                 |
|                         |                               | 黃竹角咀組<br>Bluff Head Form.                      | 300-600                     | 馬鞍山，白沙頭洲至黃竹角咀，泥涌和大洞等地                |                     |

同樣，根據地質資料和鑽探結果，場區火山岩和變質岩相當發育，火山岩主要為侏羅紀噴出岩和侵入岩，場區廣泛分佈，噴出岩岩性主要為凝灰岩類（含角閃石凝灰岩、沉凝灰岩及凝灰質碎屑岩等）及少量安山岩和流紋岩，侵入岩岩性主要為花崗岩類（花崗岩、花崗閃長岩等）；變質岩主要為變質砂岩類和片岩，場區內分佈也較廣泛；此外在場區的北部、中部及南部零星分佈有侏羅紀的砂岩、粉砂岩、礫岩等和石炭紀的大理岩、石灰岩等（圖 5.6）。

第四系在場區分佈廣泛，約佔陸地面積的 47%，主要呈條帶狀分佈於場區中部及北部，其成因為河流相、海相及洪積相三種，其形成時代見表 5.3，其土性主要為粘土類（淤泥、粘土、粉質粘土等）和砂土類（各種粒徑的砂及含粘土類砂、粉土等）。

### 5.3 場地岩土力學性能測定

場地岩土力學性能測定是確定場地力學模型的關鍵，模型力學參數是用場地土靜力與動力參數測定結果確定的。

#### 5.3.1 場地岩土物理力學性能

本次研究為取得場區內各岩土層的物理力學性質指標，現場對土層、全、強風化岩層進行標準貫入試驗，並採取土樣和岩石試樣。實驗室對所採取的土樣做常規試驗，岩樣做天然單軸抗壓強度試驗，對水樣做簡分析試驗。

#### 5.3.2 土層剪切波速及地面脈動卓越週期測定

##### 5.3.2.1 測試方法及概況

土層的波速不僅是進行土層地震反應分析的重要基本參數，同時也是場地分類法中劃分場地土類別的重要依據。在開展場地工程地質條件勘測鑽孔的同時，應進行鑽孔分層岩土剪切波速的原位測量和樣品密度測定，給出場地鑽孔剖面岩土分層剪切波速和密度隨深度的變化值。波速測量可採用單孔檢層法或跨孔法，但測量間距不得大於 2 米，在地層分界面附近應加密測點，以便得到較合理的波速剖面。

本次地震工程地質鑽孔的剪切波速測試，採用單孔法（PS Logging、Downhole Seismic）和跨孔法（Crosshole Seismic）進行測試，並進行了 22 個孔的面波輔助測試（MASW Tests）和 61 點的地面脈動測試（Microtremor Tests）工作，測試概況見表 5.4 - 5.7。



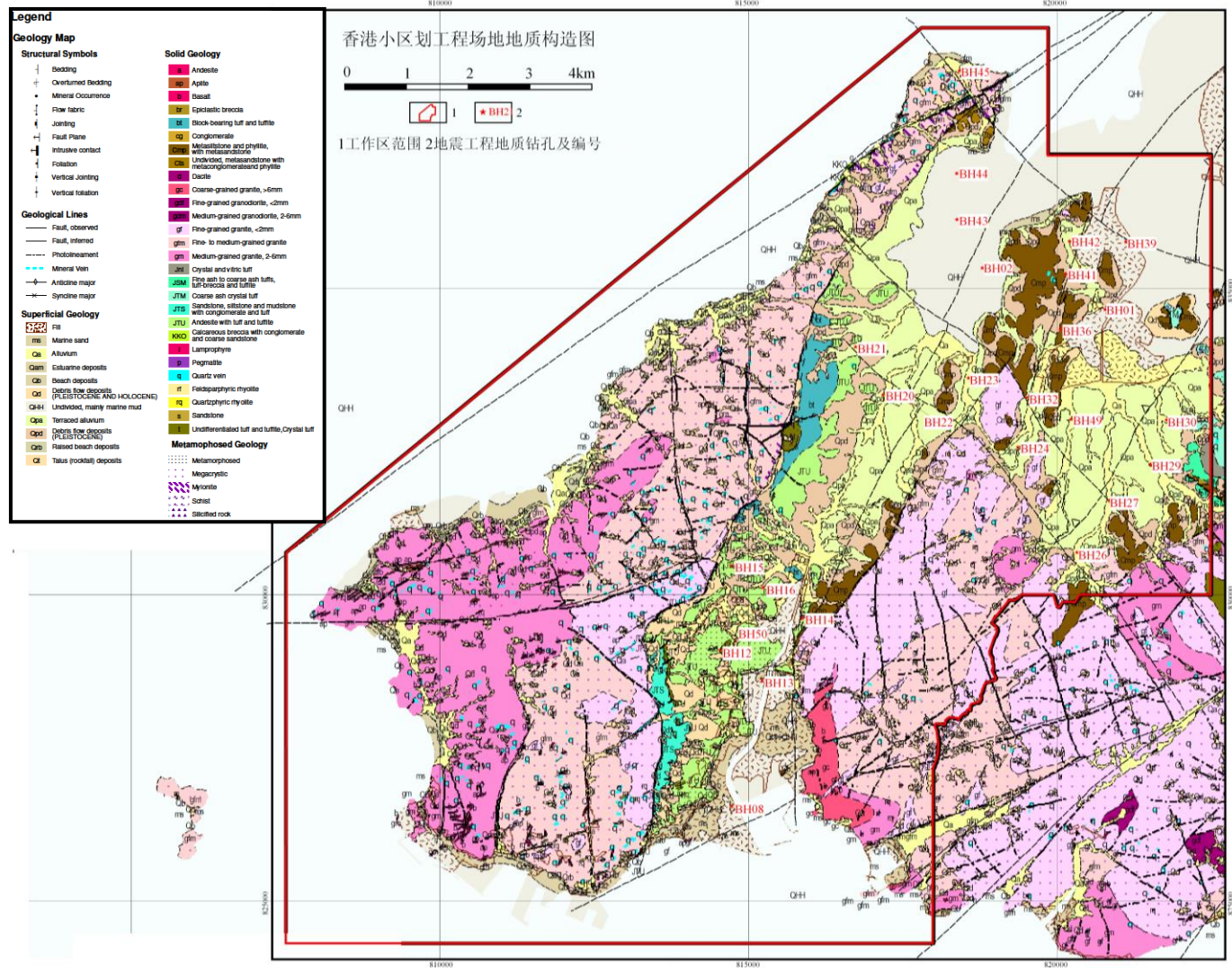


圖 5.6 工程場地地質構造圖



表 5.4 剪切波速測試概況表

| BH  | Type | Deepest Data (m) | Shallowest Data (m) | Date Logged |
|-----|------|------------------|---------------------|-------------|
| 1   | PS   | 45.7             | 3                   | 14/12/2010  |
| 2   | PS   | 88.11            | 7.64                | 08/11/2010  |
| 8   | DH   | 28.5             | 1                   | 05/11/2010  |
| 12  | DH   | 6.8              | 1                   | 25/08/2010  |
| 13  | PS   | 28.42            | 3.91                | 09/11/2010  |
| 14  | DH   | 6.5              | 1                   | 29/09/2010  |
| 15  | DH   | 16               | 1                   | 08/08/2010  |
| 16  | DH   | 15               | 1                   | 19/08/2010  |
| 20  | DH   | 28.8             | 0.8                 | 29/07/2010  |
| 20A | PS   | 33.3             | 3                   | 09/12/2010  |
| 21  | DH   | 38               | 1                   | 23/08/2010  |
| 21A | PS   | 44.1             | 3                   | 12/07/2010  |
| 22  | DH   | 55.3             | 0.3                 | 29/07/2010  |
| 22A | PS   | 30               | 3.7                 | 16/11/2010  |
| 23  | PS   | 101.5            | 4.5                 | 11/09/2010  |
| 24  | DH   | 28               | 1                   | 23/08/2010  |
| 26  | PS   | 89.4             | 3.9                 | 28/08/2010  |
| 26A | DH   | 30               | 1                   | 03/12/2010  |
| 27  | PS   | 66.8             | 3.5                 | 21/07/2010  |
| 29  | DH   | 41               | 1                   | 24/08/2010  |
| 30  | PS   | 145.6            | 2.5                 | 17/07/2010  |
| 32  | PS   | 44.7             | 3.7                 | 22/07/2010  |
| 36  | PS   | 40.5             | 2.97                | 29/09/2010  |
| 36  | DH   | 40               | 1                   | 04/11/2010  |
| 36  | XH   | 40               | 1                   | 04/11/2010  |
| 36A | DH   | 44.5             | 1                   | 10/10/2010  |
| 36A | XH   | 44.5             | 1                   | 04/11/2010  |
| 39  | DH   | 49               | 1                   | 22/09/2010  |
| 41  | DH   | 24               | 1                   | 19/08/2010  |
| 42  | PS   | 29.4             | 6.3                 | 12/07/2010  |
| 43  | DH   | 50               | 1                   | 21/08/2010  |
| 43A | PS   | 47               | 3                   | 10/12/2010  |
| 44  | PS   | 51               | 2.5                 | 12/08/2010  |
| 44A | DH   | 54               | 1                   | 03/12/2010  |
| 45  | DH   | 57.5             | 0.5                 | 24/07/2010  |
| 45A | PS   | 49.8             | 3                   | 15/12/2010  |
| 49  | OYO  | 48.7             | 2.5                 | 05/08/2010  |
| 49A | DH   | 44               | 1                   | 02/12/2010  |
| 50  | DH   | 6.5              | 1                   | 28/09/2010  |

表 5.5 地區滑坡與地震影響小區劃

| BHID     | Seismic Source                       |
|----------|--------------------------------------|
| 14       | Accelerated Weight Drop              |
| 15       | Accelerated Weight Drop/Sledgehammer |
| 16       | Sledgehammer                         |
| 8        | Accelerated Weight Drop              |
| 21       | Sledgehammer                         |
| 32       | Accelerated Weight Drop              |
| 44       | Accelerated Weight Drop/Sledgehammer |
| 45       | Accelerated Weight Drop              |
| 49       | Accelerated Weight Drop/Sledgehammer |
| 50       | Accelerated Weight Drop              |
| 20       | Accelerated Weight Drop              |
| 22       | Accelerated Weight Drop              |
| 23       | Accelerated Weight Drop              |
| 24       | Accelerated Weight Drop              |
| 27       | Accelerated Weight Drop              |
| 29       | Sledgehammer                         |
| 30       | Sledgehammer                         |
| 36       | Accelerated Weight Drop/Sledgehammer |
| 39       | Sledgehammer                         |
| CP2(M55) | Sledgehammer                         |
| CP1(M60) | Sledgehammer                         |
| 43A      | Sledgehammer                         |

### 5.3.2.2 測試結果

根據幾種不同測試方法的現場測試資料，進行綜合分析、計算、判定，其結果見表 5.6 和 5.7，圖 5.7 - 5.33 為反映所測各孔位土層剪切波速隨深度的分佈及工程地質特性的工程地震綜合柱狀圖。圖 5.34 為工程場區地面脈動測試點位置及其卓越週期圖。

等效剪切波速即地面以下 20 米且埋深不大於場地覆蓋層厚度範圍內各土層剪切波速的等效值。

等效剪切波速的計算公式為：

$$V_{se} = d_0 / t \dots\dots\dots (5.1)$$

$$t = \sum_{i=1}^n (d_i / V_{si}) \dots\dots\dots (5.2)$$

其中：

- $V_{se}$  = 土層等效剪切波速 (m/s)；
- $d_0$  = 計算深度 (m)，取覆蓋層厚度和 20 米兩者較小值；
- $t$  = 剪切波速在地面至計算深度之間的傳播時間；
- $d_i$  = 計算深度範圍內第  $i$  土層的厚度 (m)；
- $V_{si}$  = 計算深度範圍內第  $i$  土層的剪切波速 (m/s)；
- $n$  = 計算深度範圍內土層的分層數。

覆蓋層厚度一般情況下應按地面至剪切波速大於 500 m/s 且其下臥各層岩土の剪切波速均不小於 500 m/s 的土層頂面的距離確定；當地面 5 米以下存在剪切波速大於其上部各土層剪切波速 2.5 倍的土層，且該土層及其下臥各層岩土の剪切波速均不小於 400 m/s 時，可按地面至該土層的頂面距離確定；剪切波速大於 500 m/s 的孤石、透鏡體，應視同周圍土層；土層中的火山岩硬夾層，應視為剛體，其厚度應從覆蓋土層中扣除。

根據工程場地覆蓋層厚度、等效波速等資料，依據 GB50011-2010《建築抗震設計規範》の有關規定，進行場地土類型和場地類別の判定，其結果見表 5.6。由表知：場區場地土類型屬於中軟~中硬場地土，建築場地類別為 I~III 類。

表 5.6 剪切波速測試概況表

| 孔位   | 覆蓋層厚度 $d_0$ (m) | 等效波速 $V_{se}$ (m/s) | 場地土類型 | 建築地土類別 |
|------|-----------------|---------------------|-------|--------|
| BH01 | 28.99           | 222                 | 中軟    | II     |
| BH02 | 33.40           | 248                 | 中軟    | II     |
| BH08 | 22.60           | 201                 | 中軟    | II     |
| BH12 | 2.50            | 200                 | 中軟    | II     |
| BH13 | 23.10           | 166                 | 中軟    | I      |
| BH14 | 35.00           | 333                 | 中硬    | II     |
| BH15 | 11.90           | 256                 | 中硬    | II     |
| BH16 | 7.19            | 350                 | 中硬    | II     |
| BH20 | 20.20           | 208                 | 中軟    | II     |
| BH21 | 28.80           | 280                 | 中硬    | II     |
| BH22 | 39.90           | 203                 | 中軟    | II     |
| BH23 | 21.70           | 309                 | 中硬    | II     |
| BH24 | 19.85           | 301                 | 中硬    | II     |
| BH26 | 60.60           | 270                 | 中硬    | II     |
| BH27 | 53.50           | 173                 | 中軟    | III    |
| BH29 | 36.47           | 195                 | 中軟    | II     |
| BH30 | > 150           | 238                 | 中軟    | III    |
| BH32 | 18.10           | 245                 | 中軟    | II     |
| BH36 | 33.25           | 241                 | 中軟    | II     |
| BH39 | 17.20           | 206                 | 中軟    | II     |
| BH41 | 9.17            | 304                 | 中硬    | II     |
| BH42 | 15.20           | 255                 | 中硬    | II     |
| BH43 | 45.80           | 184                 | 中軟    | II     |
| BH44 | 47.10           | 219                 | 中軟    | II     |
| BH45 | 26.44           | 292                 | 中硬    | II     |
| BH49 | 34.50           | 252                 | 中硬    | II     |
| BH50 | 4.00            | 350                 | 中硬    | I      |

表 5.7 場區地面脈動卓越週期測試結果表

| No. | Freq.<br>(Hz)  | Period<br>(Hz) |      | No.          | Freq.<br>(Hz) | Period<br>(Hz) |
|-----|----------------|----------------|------|--------------|---------------|----------------|
| M01 | 3.00           | 0.33           |      | M26          | 2.50          | 0.40           |
| M02 | 3.10           | 0.32           |      | M27          | 2.20          | 0.46           |
| M03 | 4.20           | 0.24           |      | M28          | 2.90          | 0.35           |
| M04 | 11.09          | 0.09           |      | M29          | 2.50          | 0.40           |
| M05 | 2.20           | 0.46           |      | M30          | 2.50          | 0.40           |
| M06 | 2.90           | 0.35           |      | M31          | 1.80          | 0.56           |
| M07 | 6.89           | 0.15           |      | M32          | 2.80          | 0.36           |
| M08 | 2.40           | 0.42           |      | M33          | 2.90          | 0.35           |
| M09 | 6.29           | 0.16           |      | M34          | 2.40          | 0.42           |
| M10 | 2.00           | 0.50           |      | M35          | 2.90          | 0.35           |
| M11 | 5.99           | 0.17           |      | M36          | 2.60          | 0.39           |
| M12 | 28.27          | 0.04           |      | M37          | 2.40          | 0.42           |
| M13 | 2.30           | 0.44           |      | M38          | 2.50          | 0.40           |
| M14 | 3.90           | 0.26           |      | M39          | 2.70          | 0.37           |
| M15 | 6.69           | 0.15           |      | M40          | 4.20          | 0.24           |
| M16 | 4.20           | 0.24           |      | M41          | 5.89          | 0.17           |
| M17 | 2.40           | 0.42           |      | M42          | 4.70          | 0.21           |
| M18 | 2.50           | 0.40           |      | M43          | 1.90          | 0.53           |
| M19 | 3.60           | 0.28           |      | M44          | 1.90          | 0.53           |
| M20 | 2.30           | 0.44           |      | M45          | 3.10          | 0.32           |
| M21 | 2.20           | 0.46           |      | M46          | 3.00          | 0.33           |
| M22 | 2.30           | 0.44           |      | M47          | 3.10          | 0.32           |
| M23 | 3.30           | 0.30           |      | M48          | 2.70          | 0.37           |
| M24 | 3.20           | 0.31           |      | M49          | 2.20          | 0.46           |
| M25 | 2.30           | 0.44           |      | M50          | 45.25         | 0.02           |
| No. | Frequency (Hz) |                |      | Period (sec) |               |                |
|     | X/Y            | Y/Z            | H/Z  | X/Y          | Y/Z           | H/Z            |
| M51 | 5.1            | 5.2            | 5.1  | 0.20         | 0.19          | 0.20           |
| M52 | 5.1            | 5.1            | 5.1  | 0.20         | 0.20          | 0.20           |
| M53 | 3.5            | 3.2            | 3.5  | 0.29         | 0.31          | 0.29           |
| M54 | 4.6            | 4.8            | 4.6  | 0.22         | 0.21          | 0.22           |
| M55 | 5.0            | 5.0            | 5.0  | 0.20         | 0.20          | 0.20           |
| M56 | 7.6            | 6.4            | 6.4  | 0.13         | 0.16          | 0.16           |
| M57 | 18.1           | 13.4           | 13.4 | 0.06         | 0.07          | 0.70           |
| M58 | -              | -              | -    | -            | -             | -              |
| M59 | 4.9            | 4.7            | 4.9  | 0.20         | 0.21          | 0.20           |
| M60 | 5.3            | 6.8            | 5.3  | 0.19         | 0.15          | 0.19           |

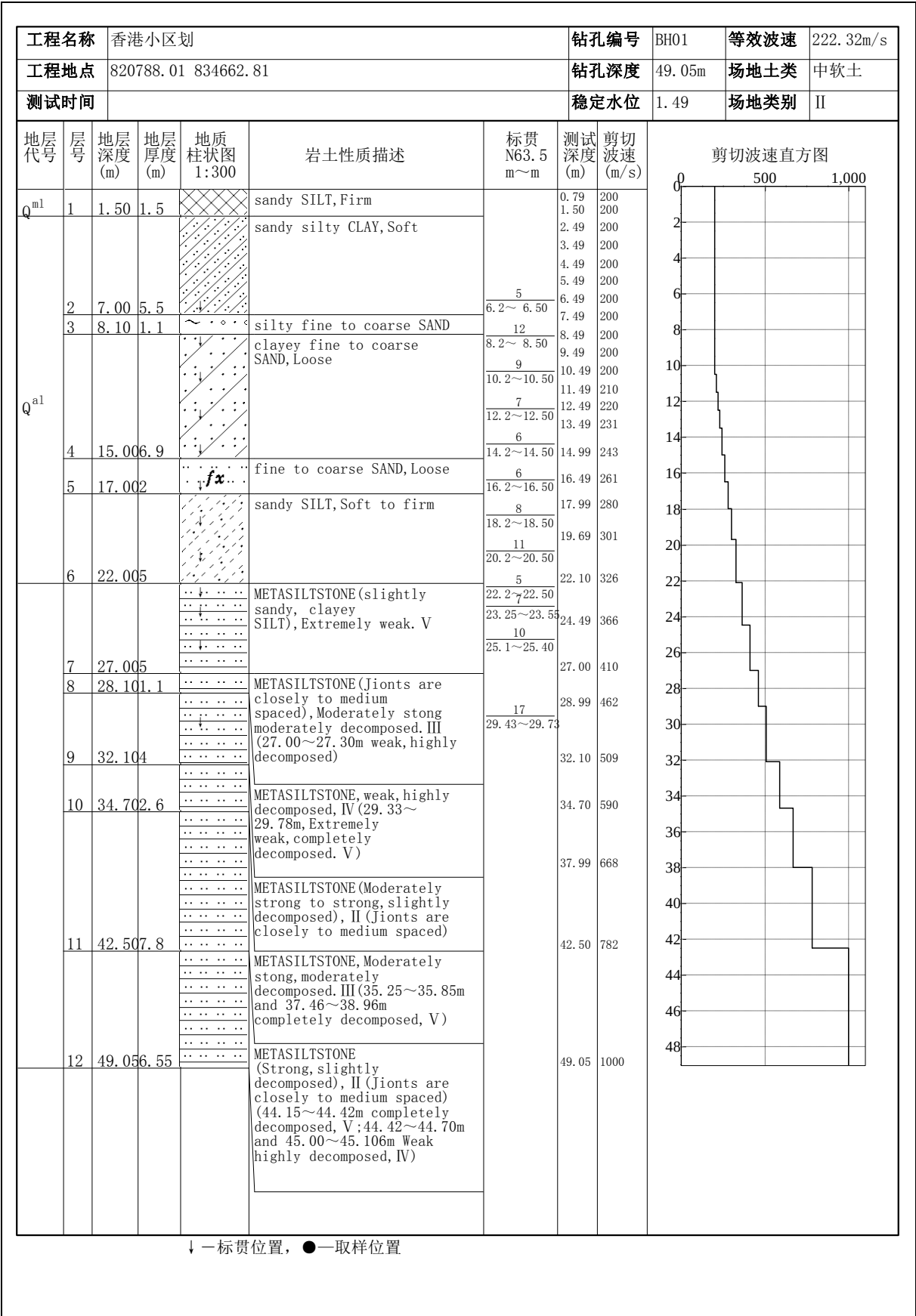


圖5.7 BH01孔地震工程綜合柱狀圖

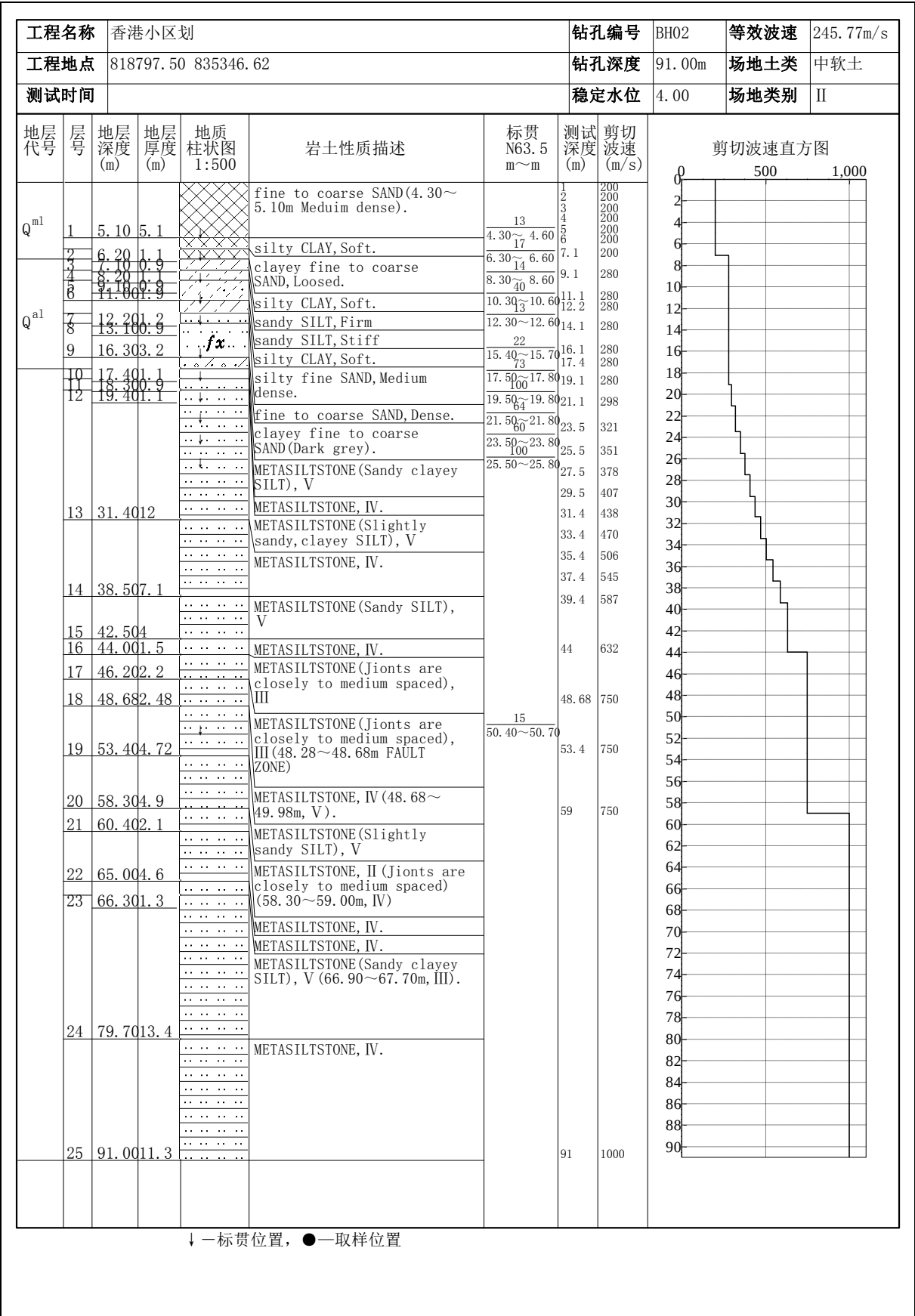


圖5.8 BH02孔地震工程綜合柱狀圖

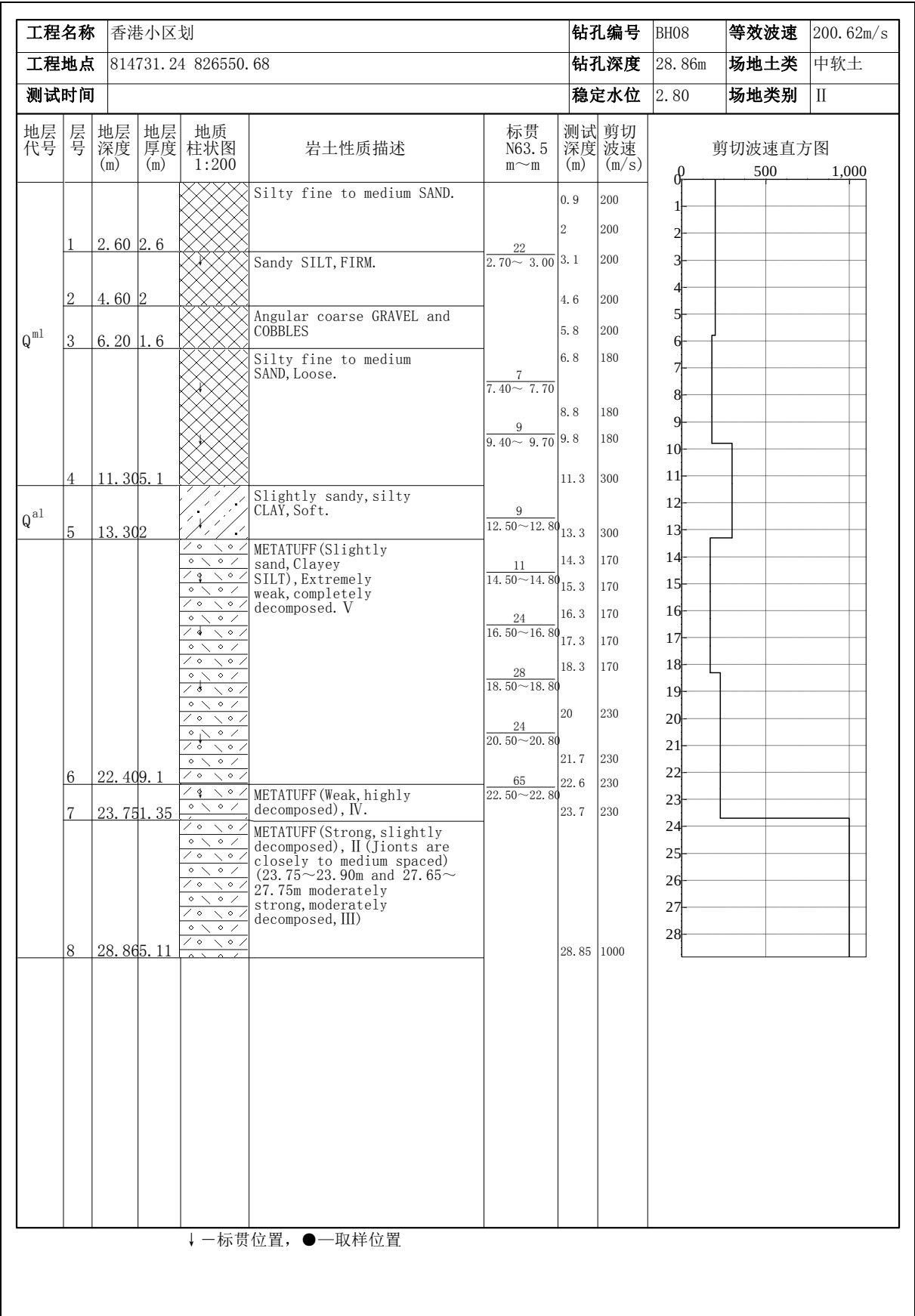


圖5.9 BH08孔地震工程綜合柱狀圖

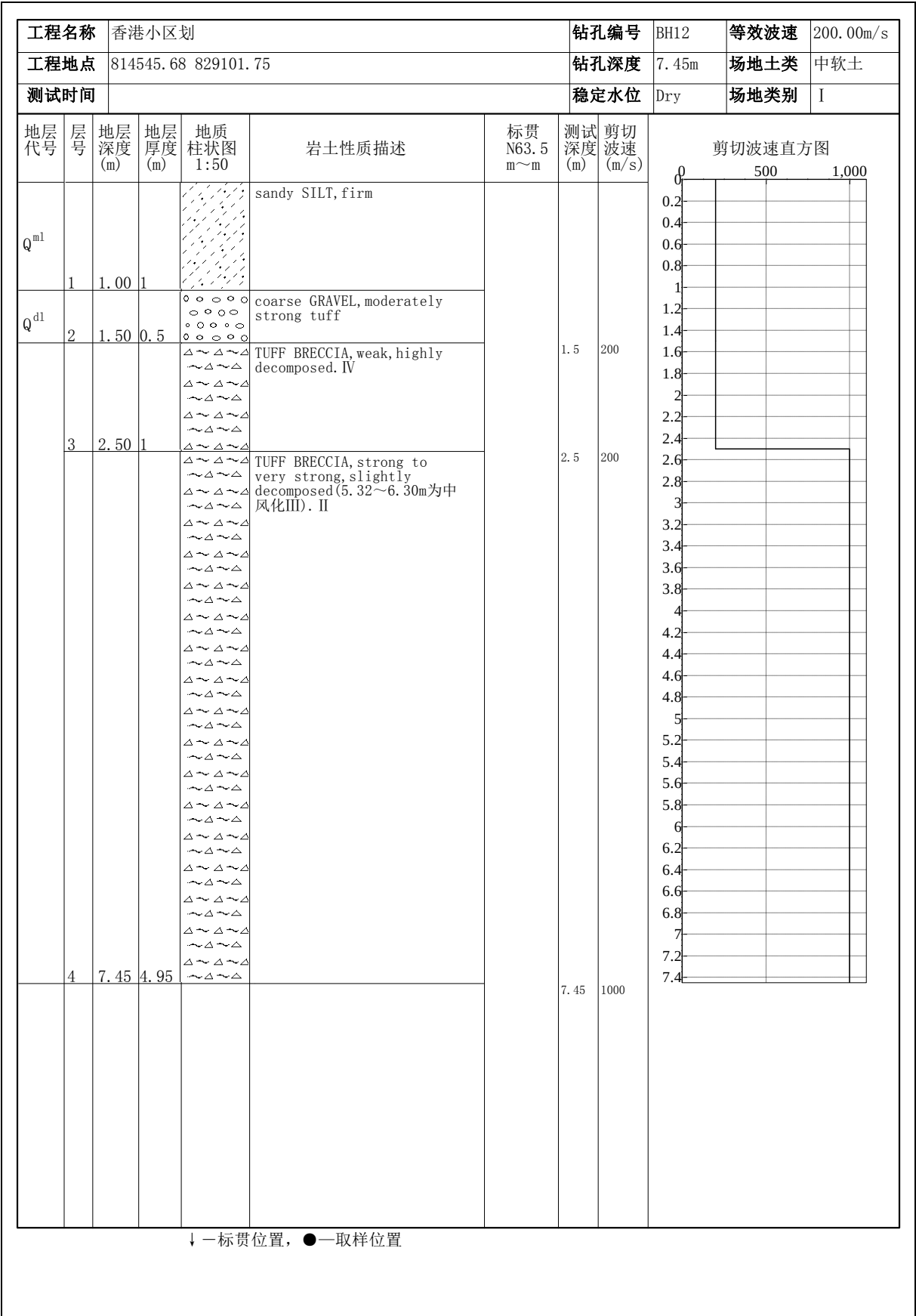


圖5.10 BH12孔地震工程綜合柱狀圖



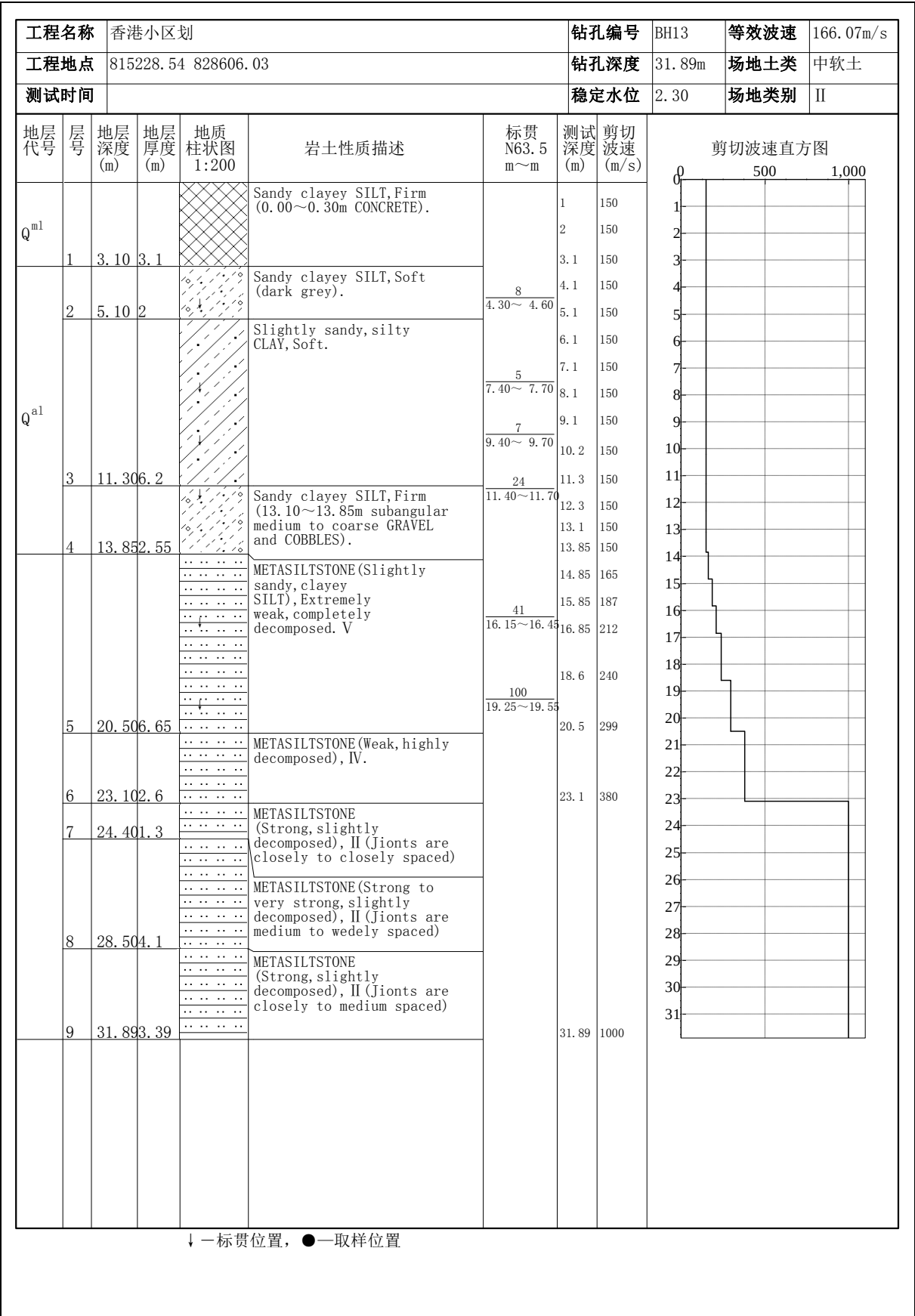


圖5.11 BH13孔地震工程綜合柱狀圖

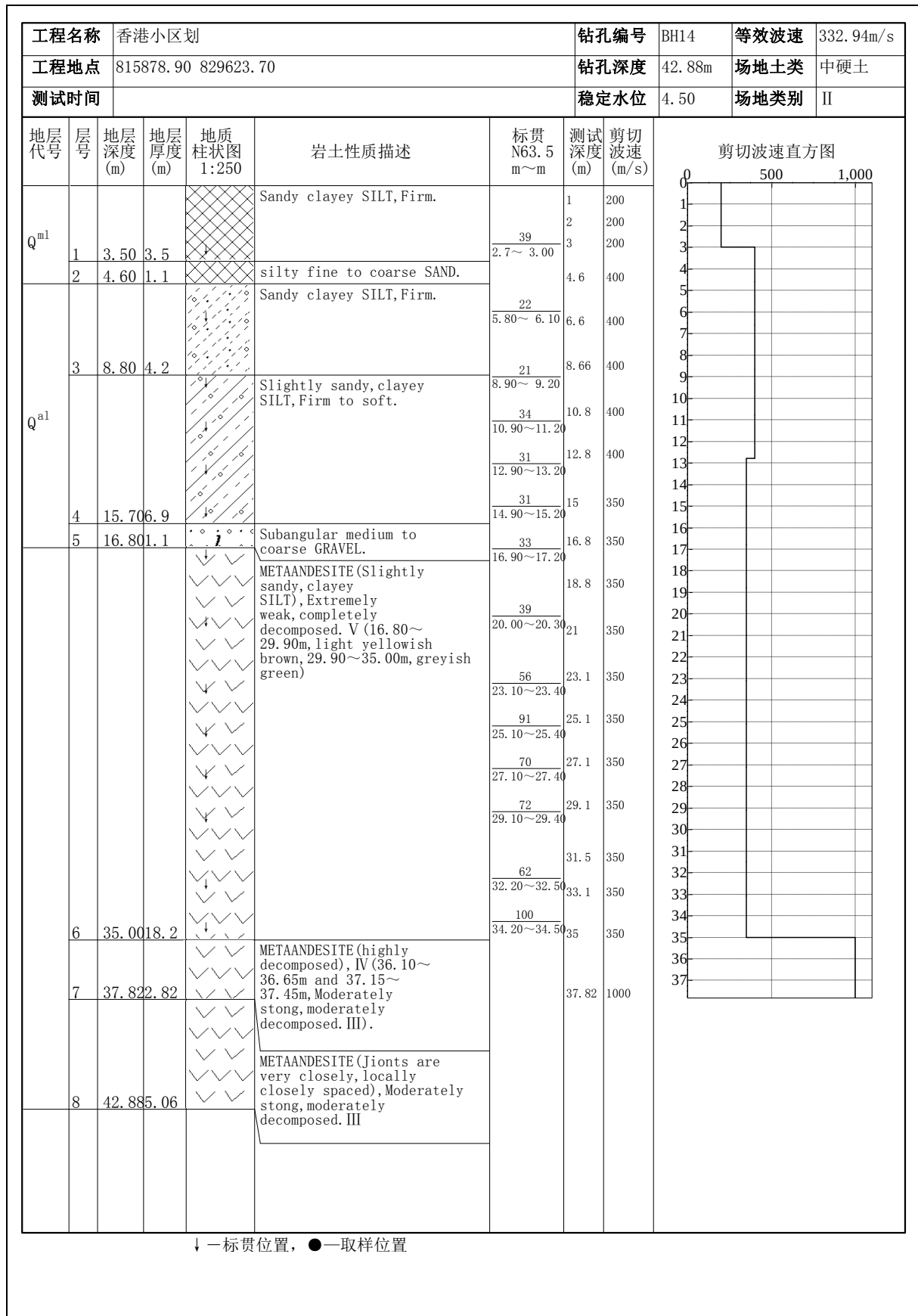


圖5.12 BH14孔地震工程綜合柱狀圖

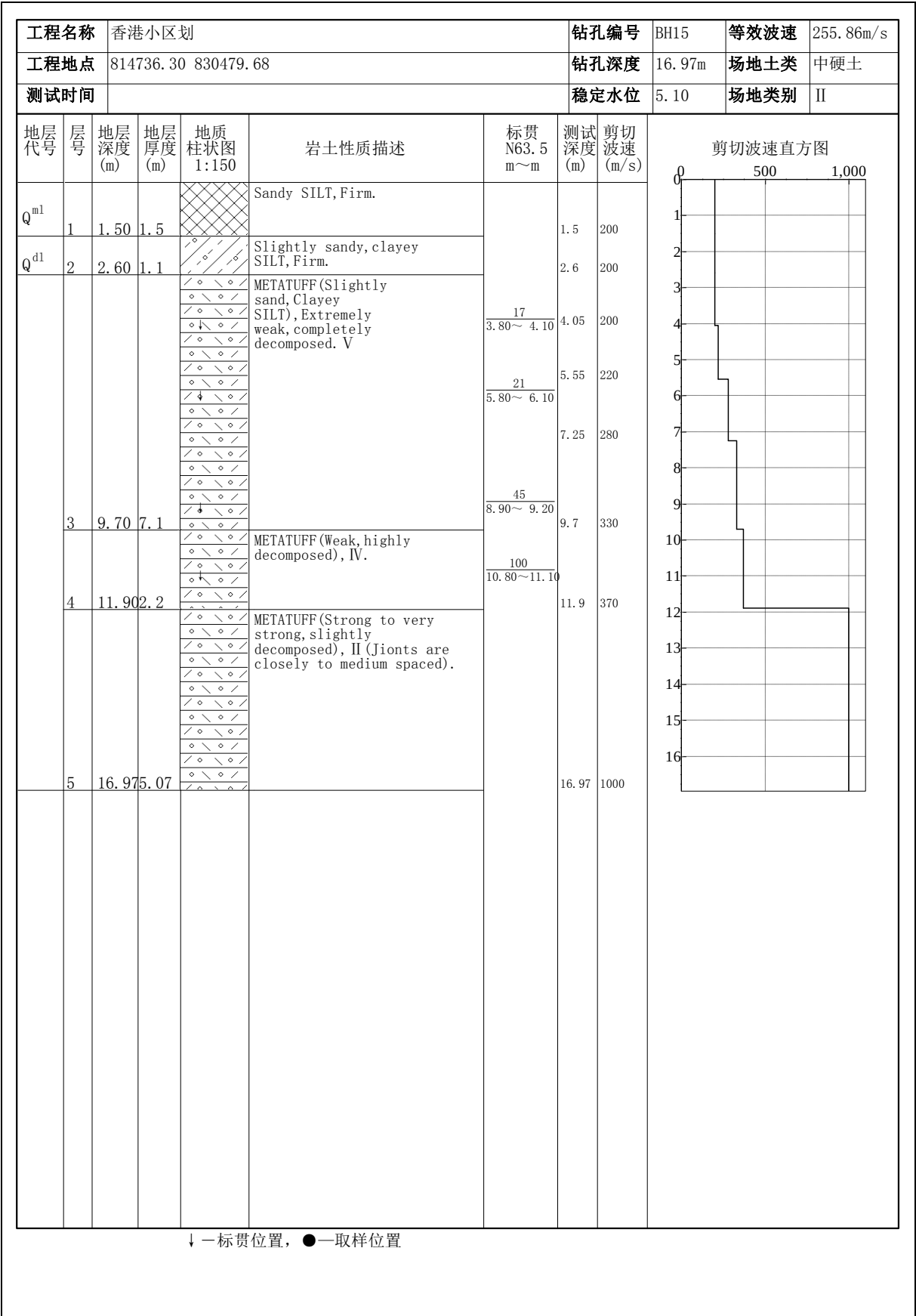


圖5.13 BH15孔地震工程綜合柱狀圖

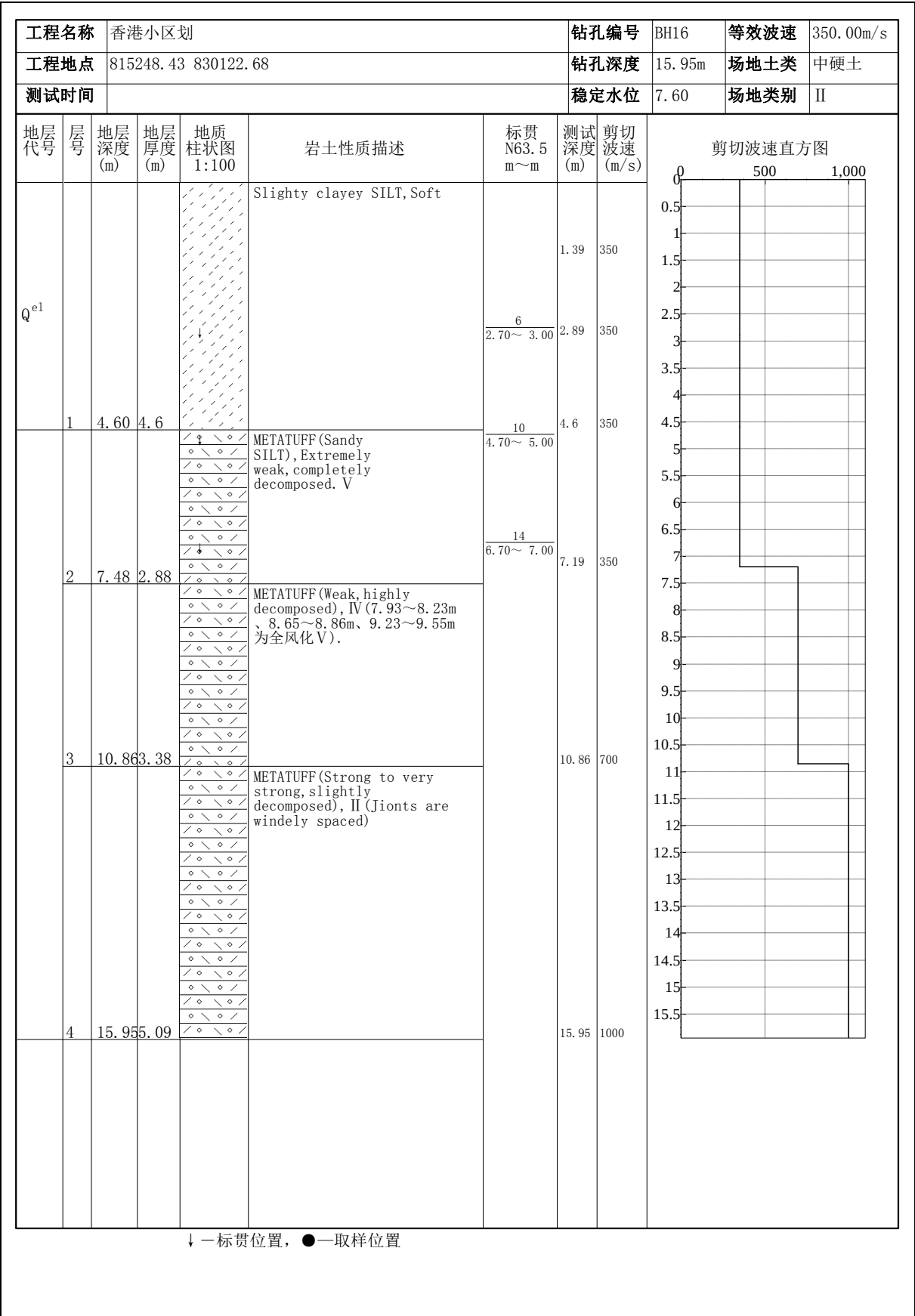


圖5.14 BH16孔地震工程綜合柱狀圖

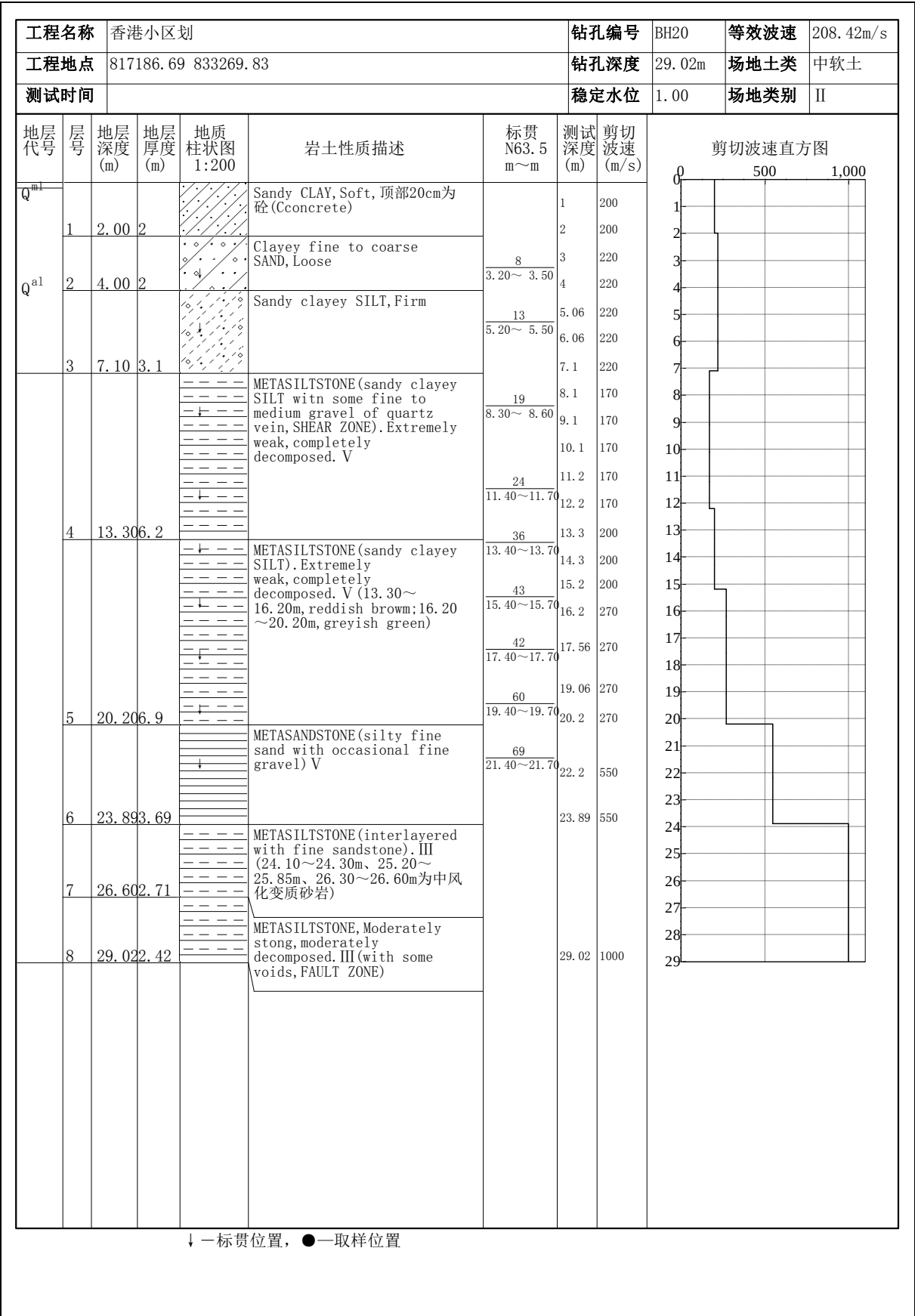


圖5.15 BH20孔地震工程綜合柱狀圖

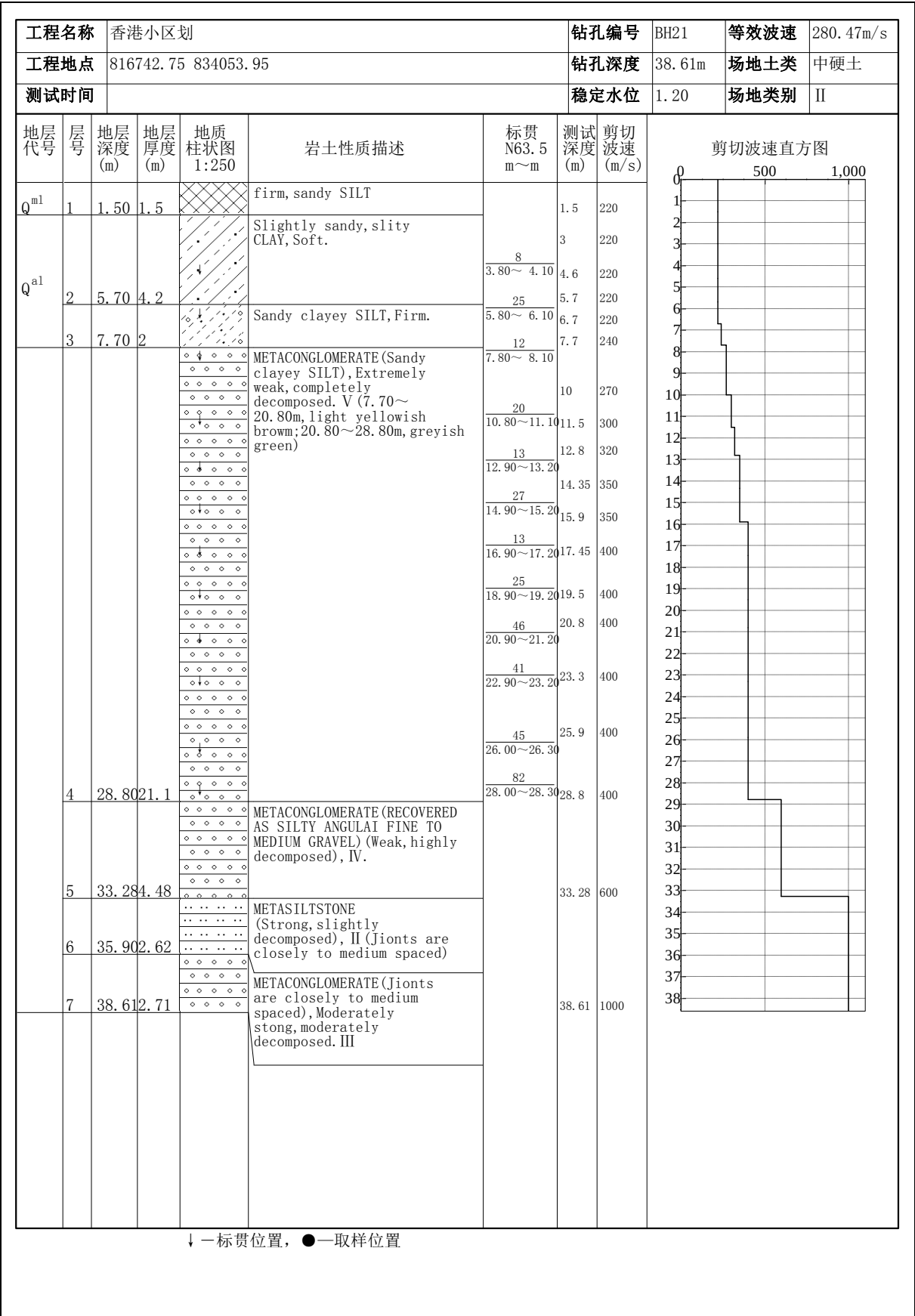


圖5.16 BH21孔地震工程綜合柱狀圖

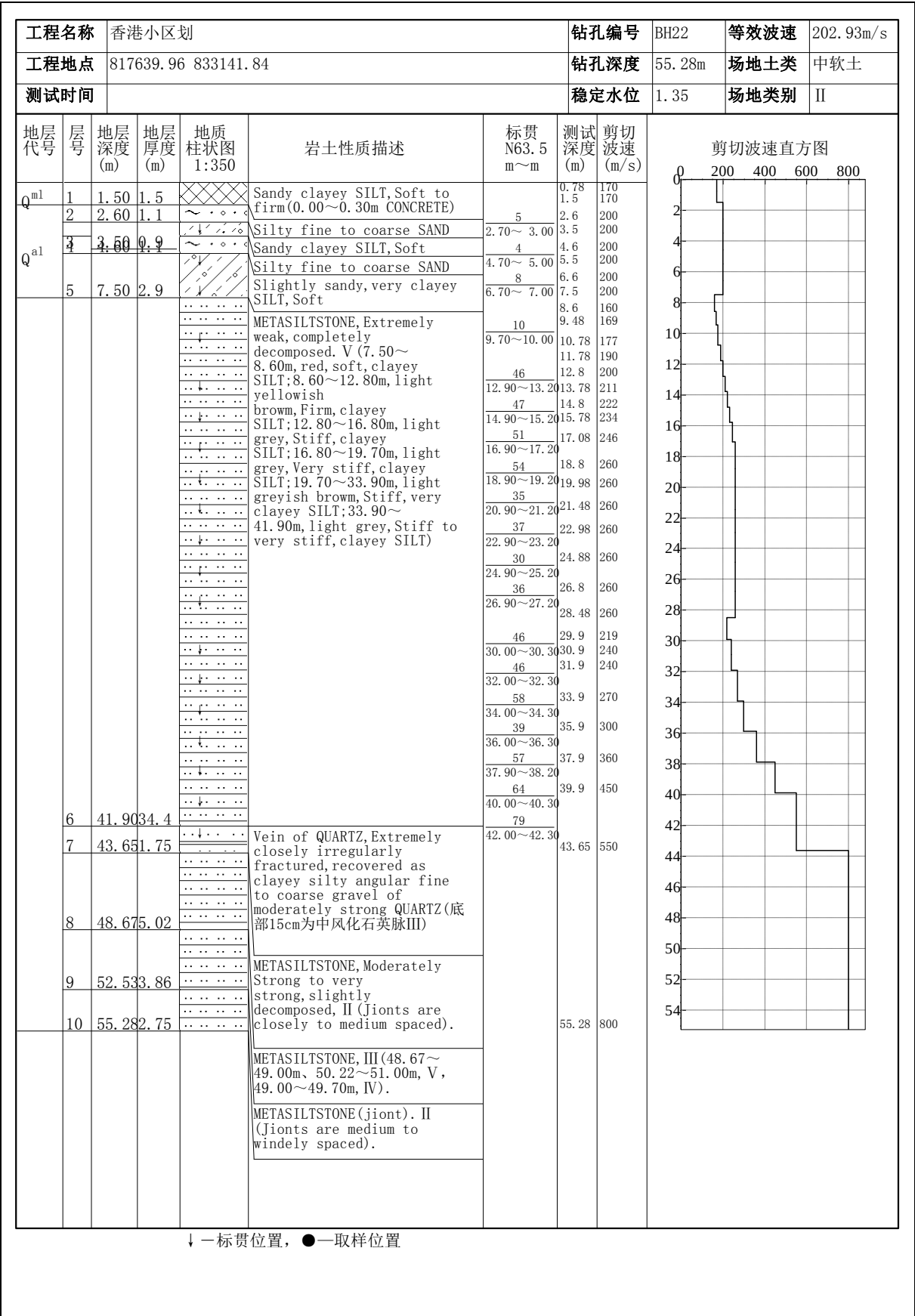


圖5.17 BH22孔地震工程綜合柱狀圖

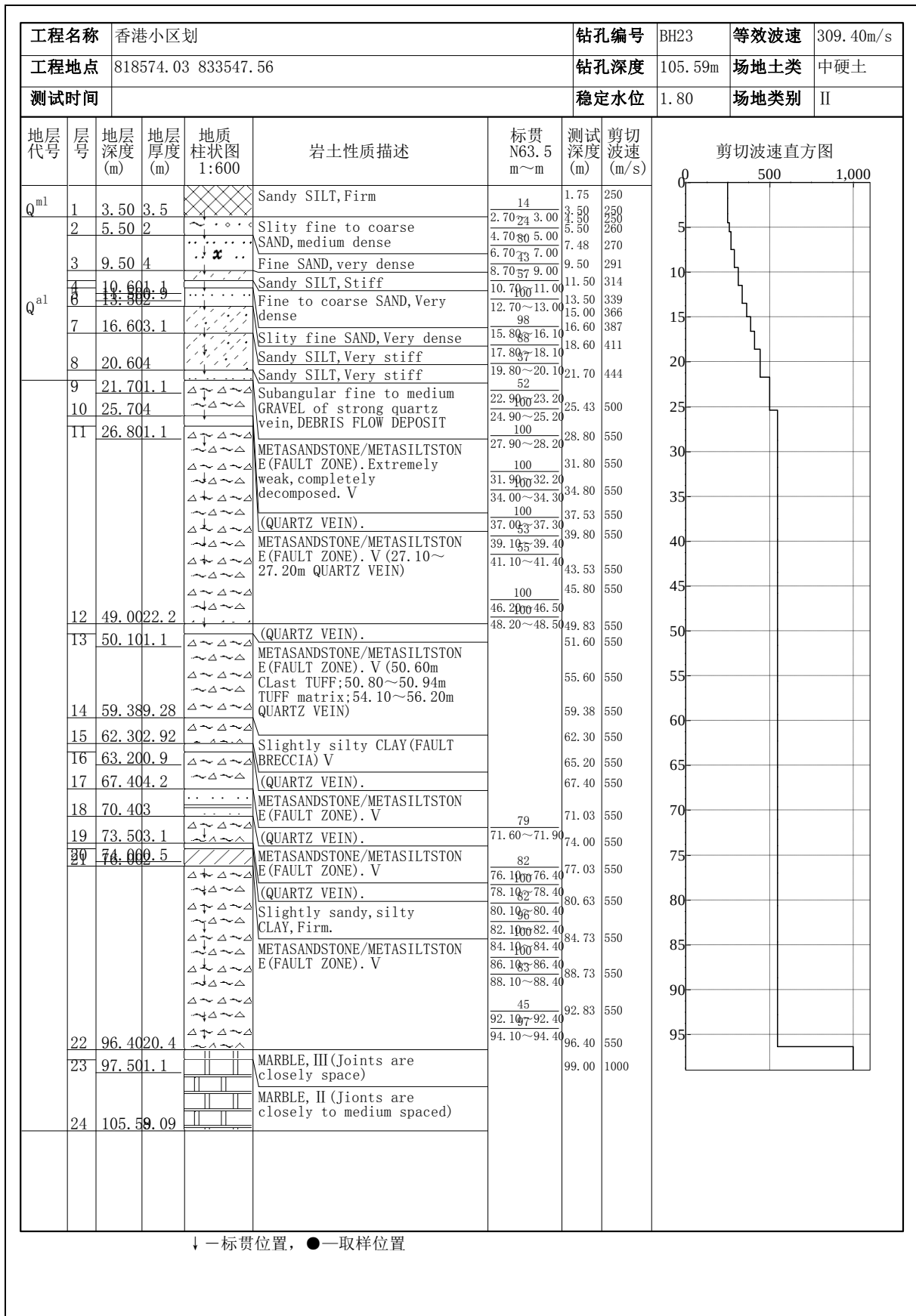


圖5.18 BH23孔地震工程綜合柱狀圖



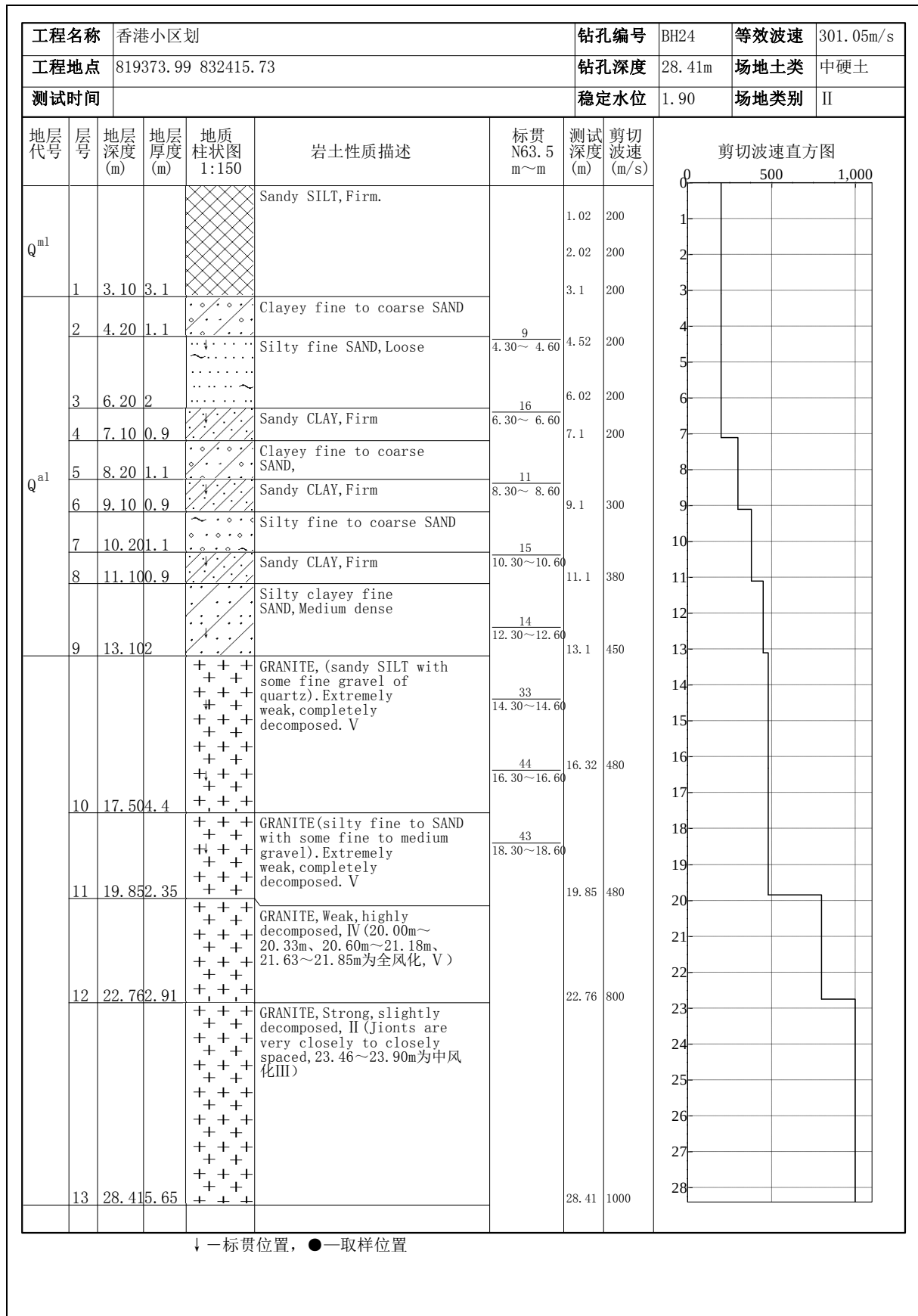


圖5.19 BH24孔地震工程綜合柱狀圖

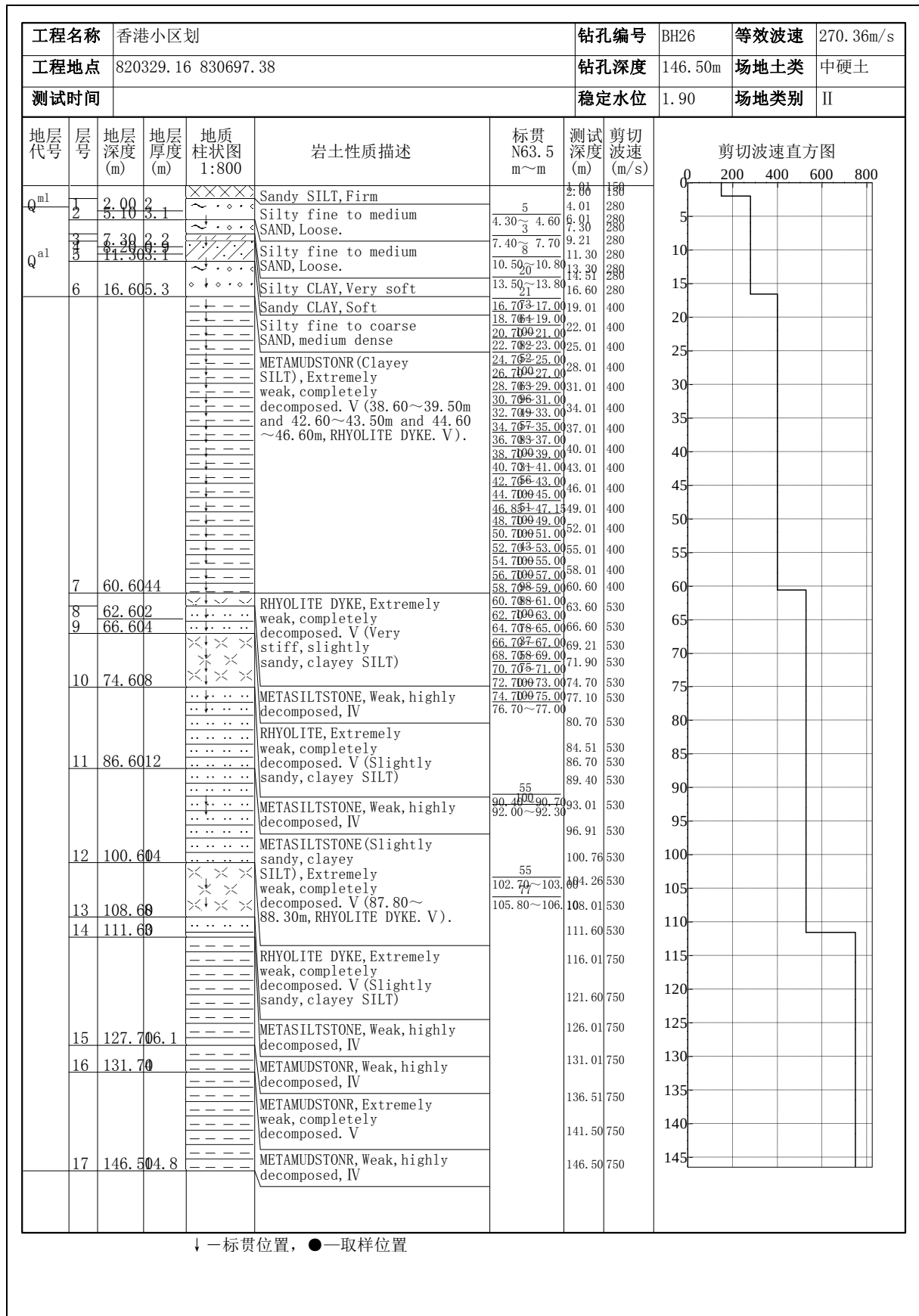


圖5.20 BH26孔地震工程綜合柱狀圖

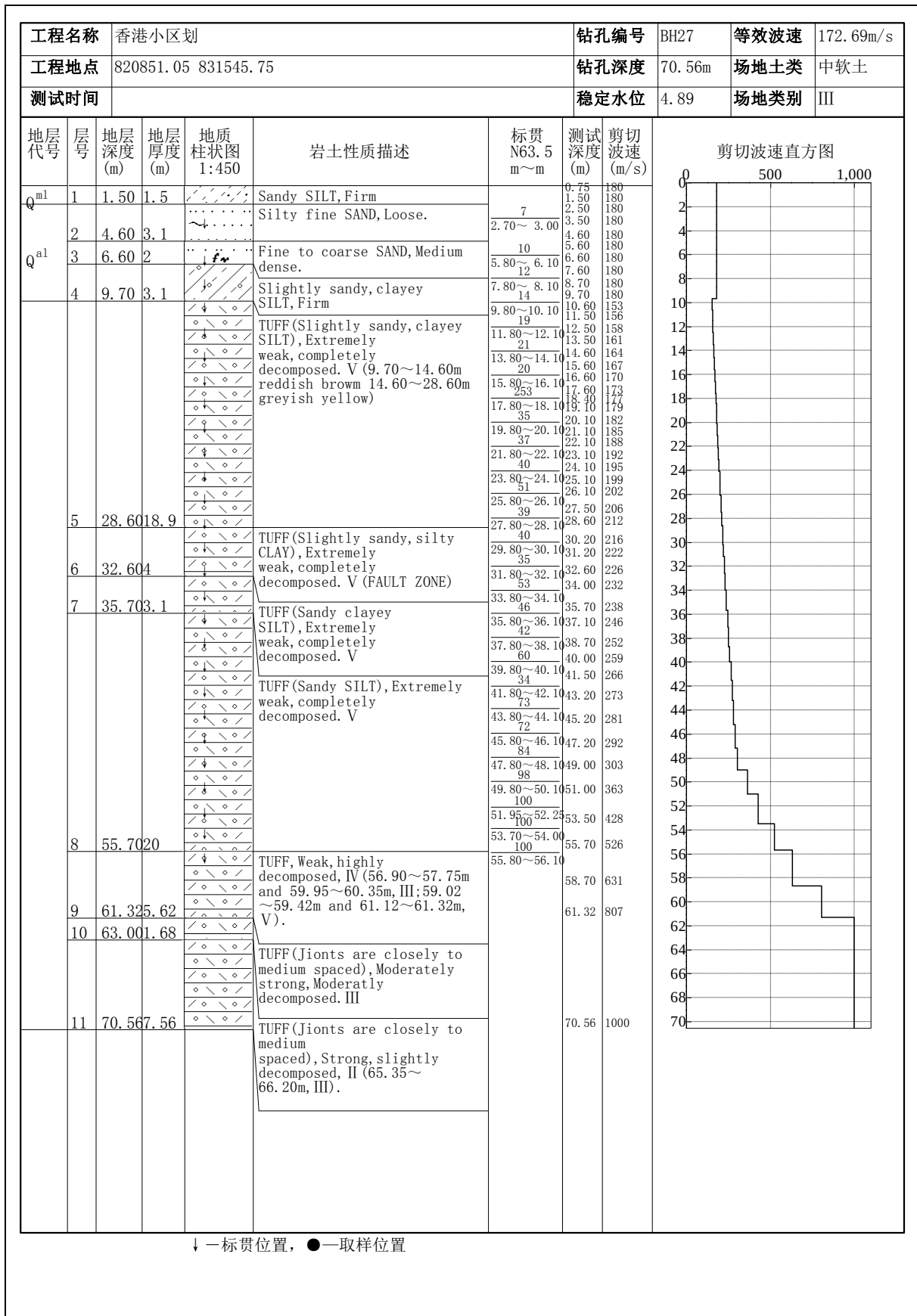


圖5.21 BH27孔地震工程綜合柱狀圖

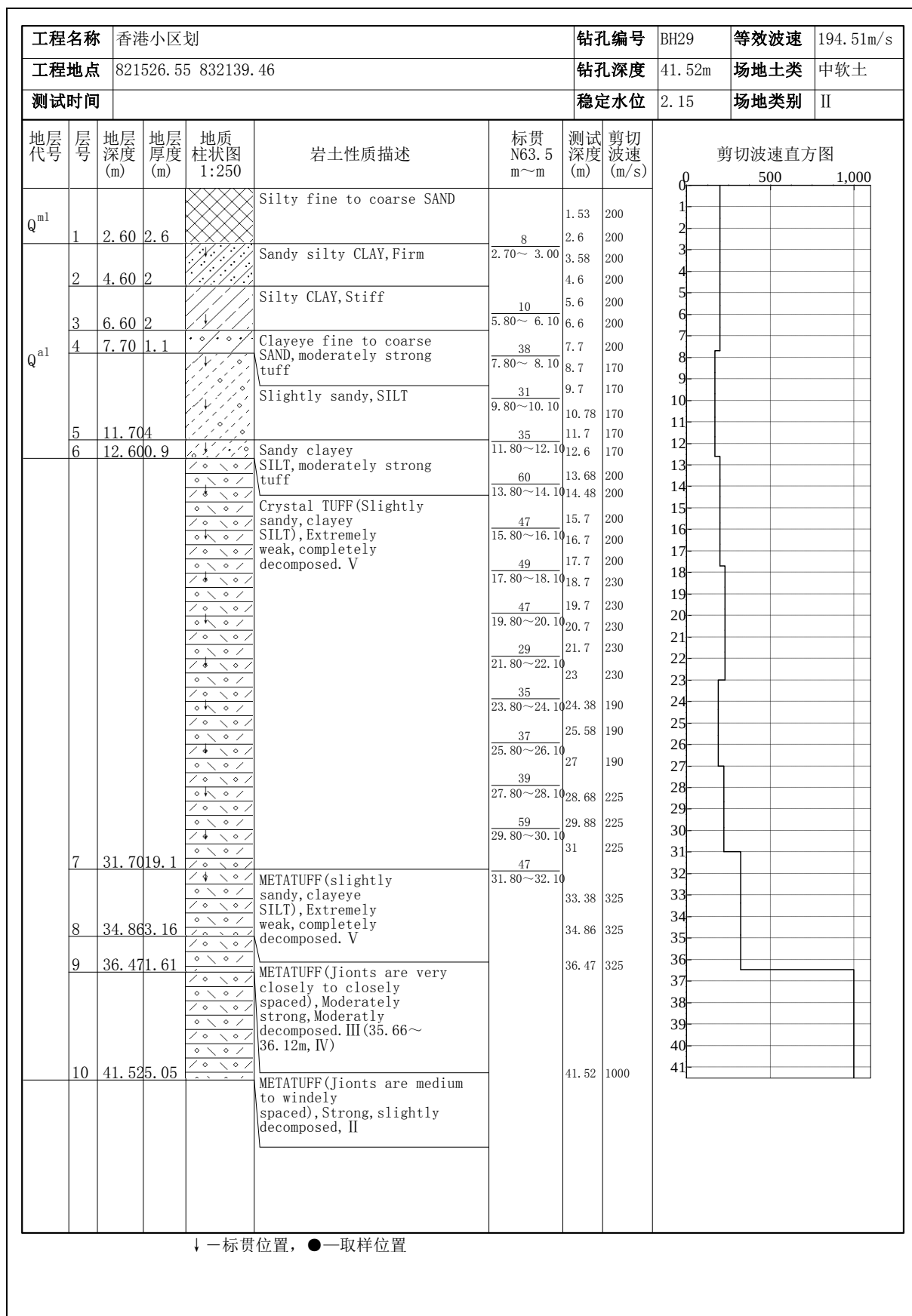


圖5.22 BH29孔地震工程綜合柱狀圖

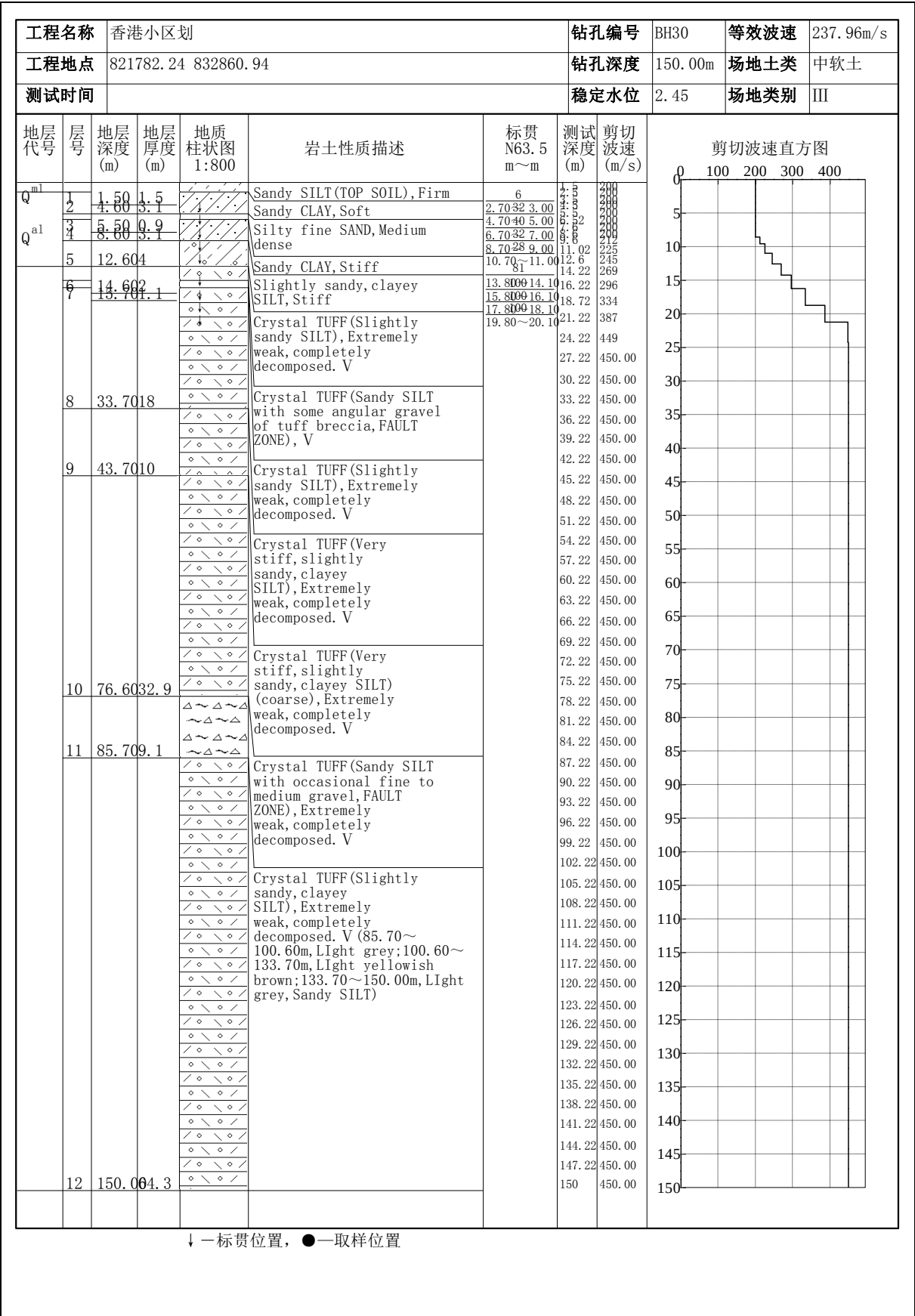


圖5.23 BH30孔地震工程綜合柱狀圖

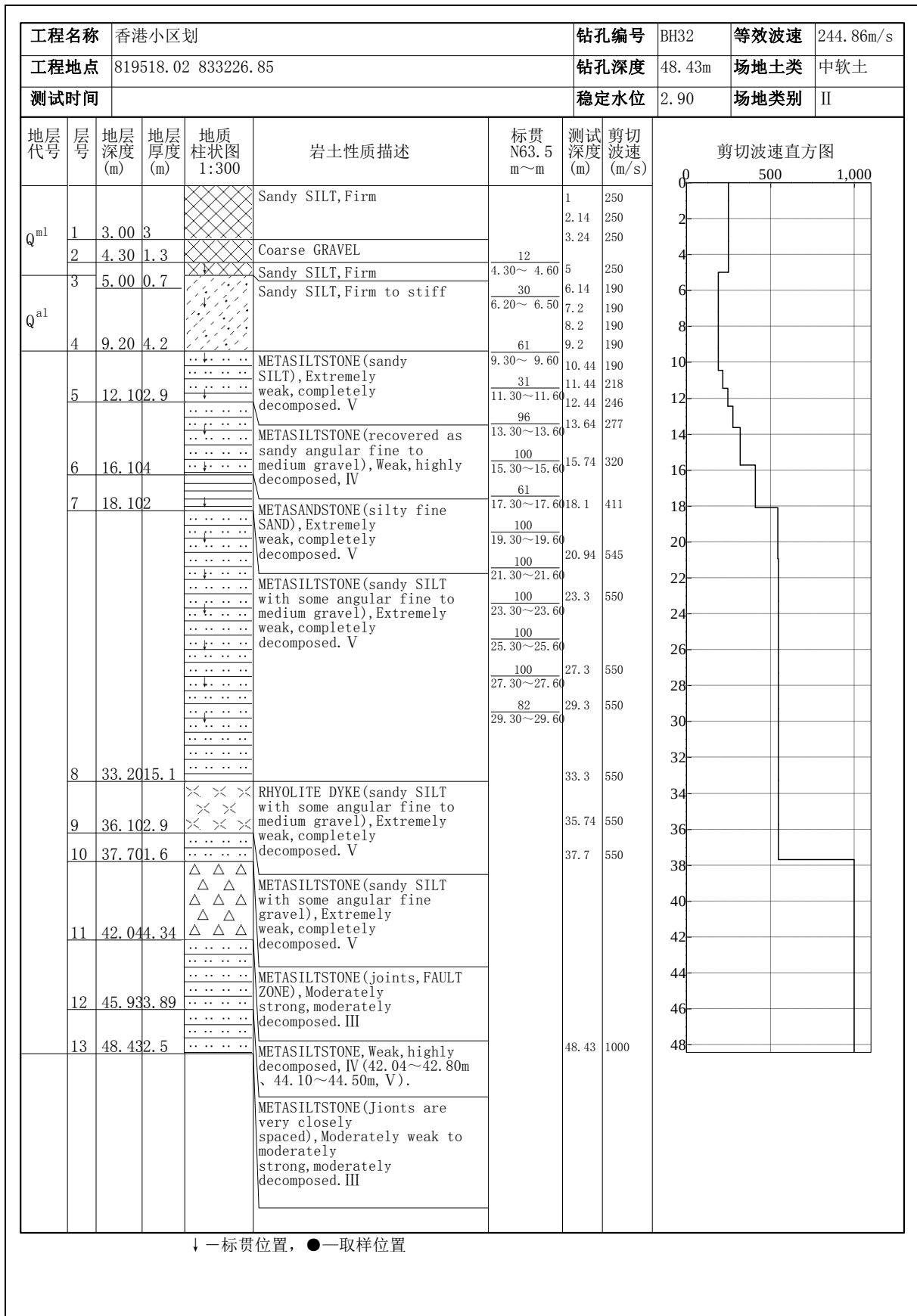


圖5.24 BH32孔地震工程綜合柱狀圖

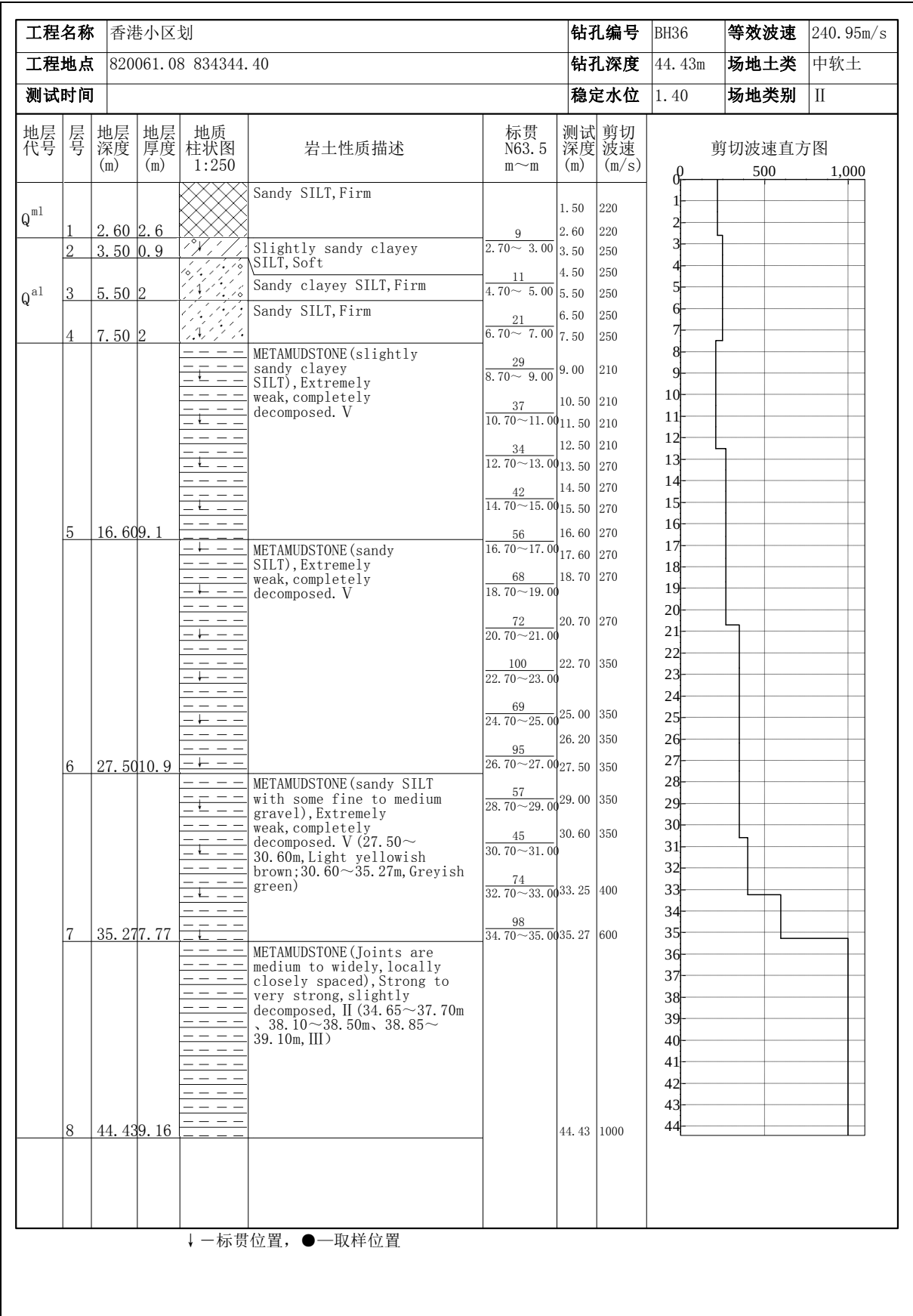


圖5.25 BH36孔地震工程綜合柱狀圖

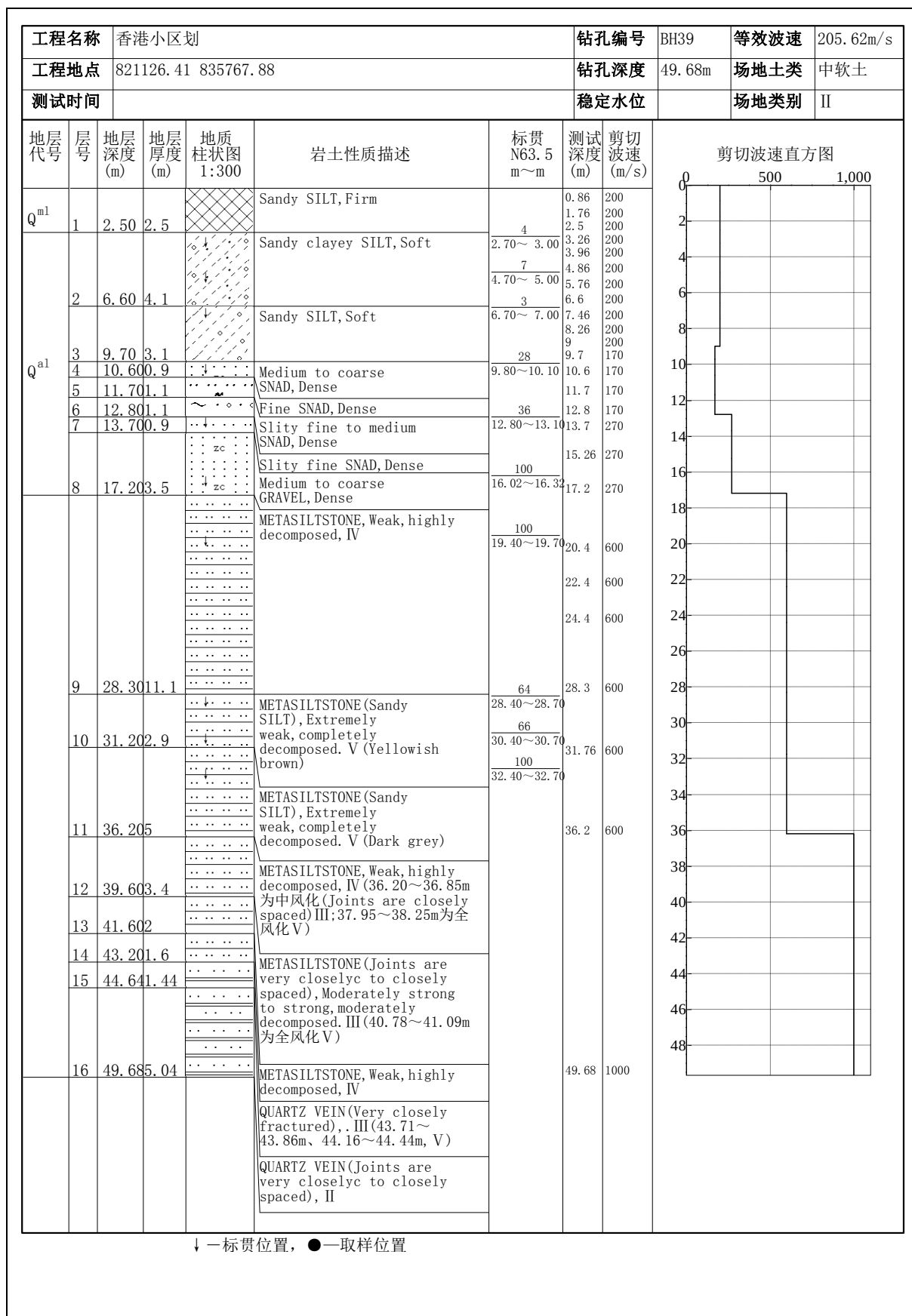


圖5.26 BH39孔地震工程綜合柱狀圖



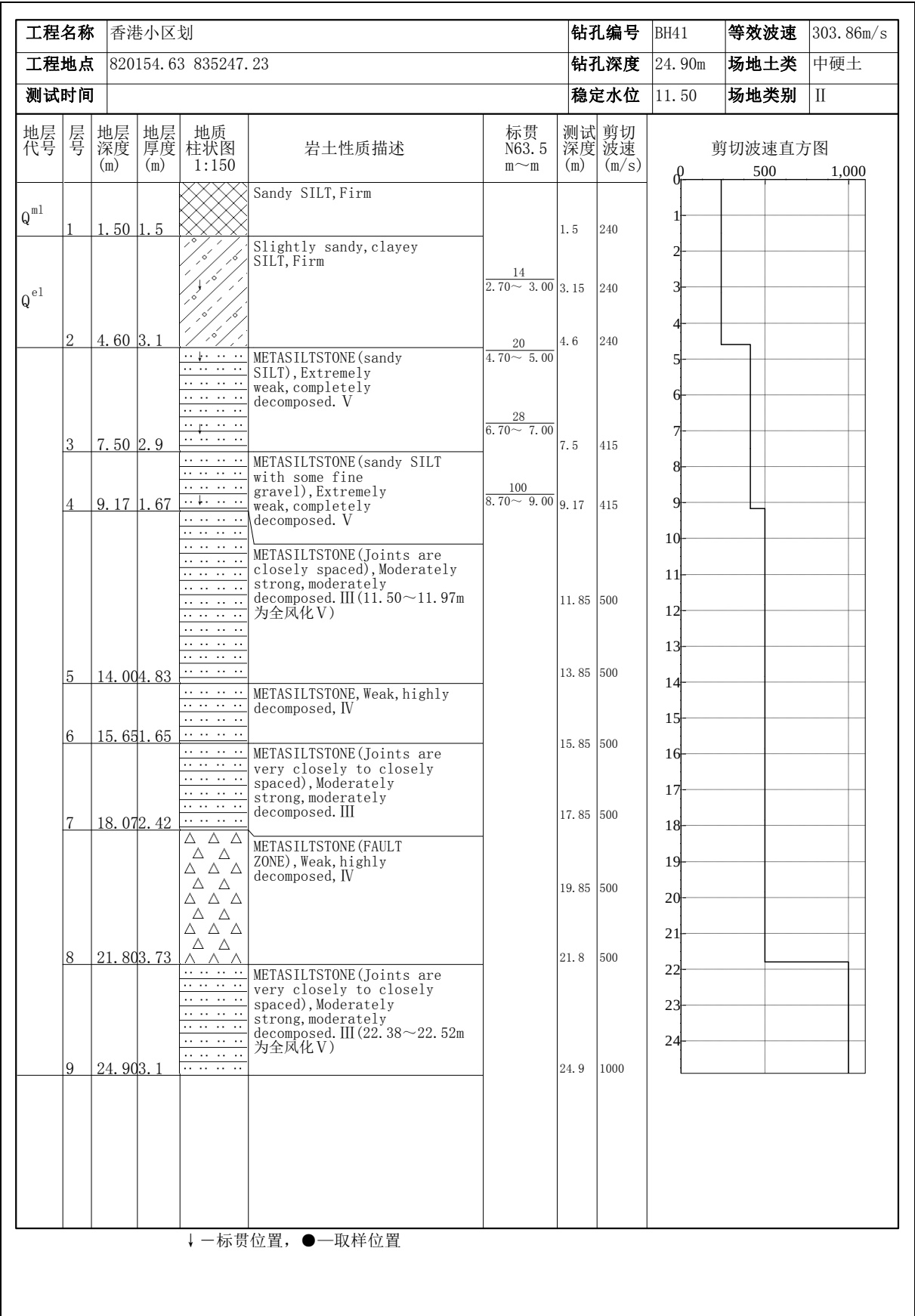


圖5.27 BH41地震工程綜合柱狀圖

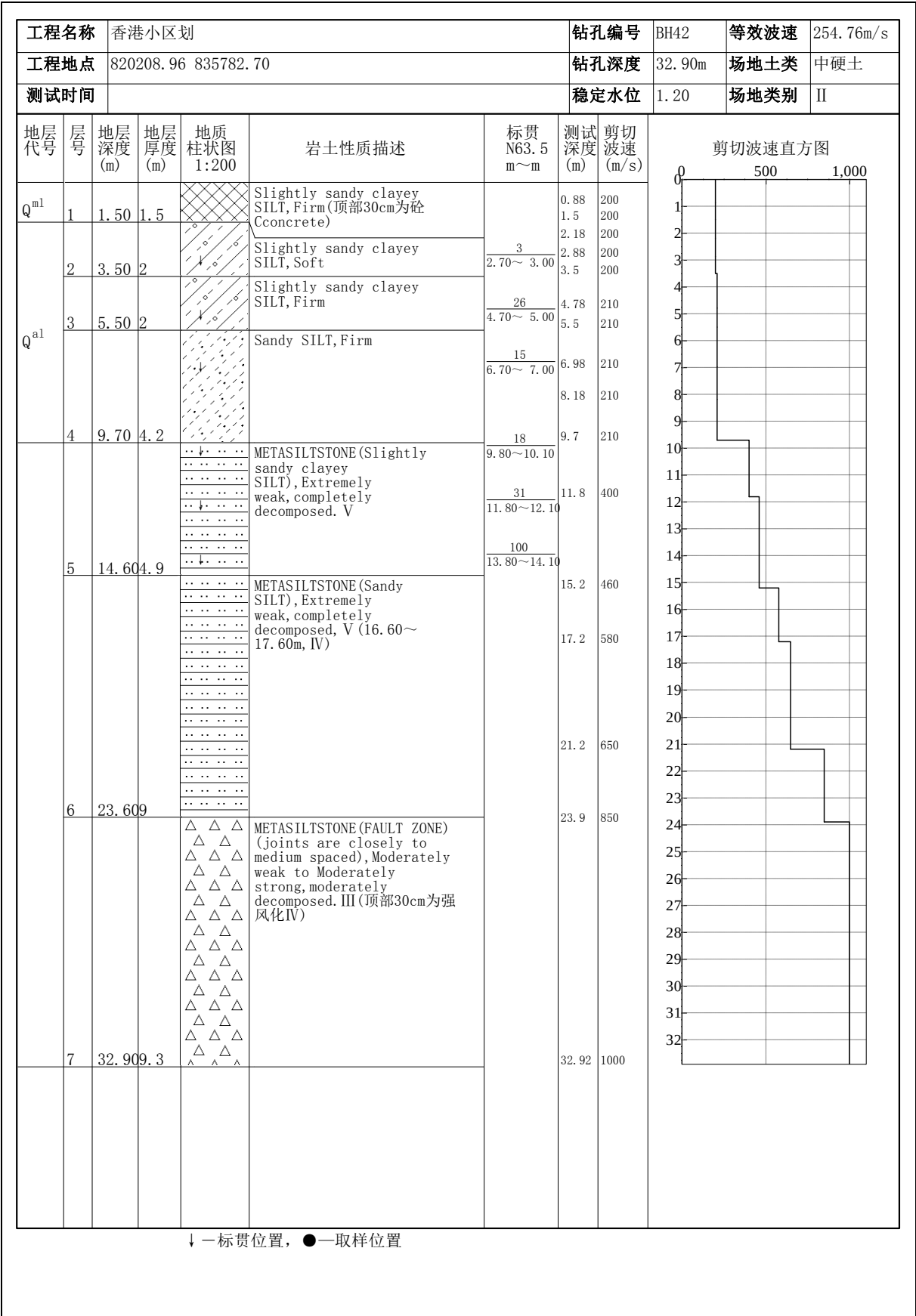


圖5.28 BH42地震工程綜合柱狀圖

|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    |                     |                 |                   |             |      |           |     |
|-----------------|--------|-----------------|-----------------|------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|---------------------|-----------------|-------------------|-------------|------|-----------|-----|
| 工程名称            |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 香港小区划               |                 | 钻孔编号              | BH43        | 等效波速 | 184.07m/s |     |
| 工程地点            |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 818385.85 836137.79 |                 | 钻孔深度              | 51.00m      | 场地土类 | 中软土       |     |
| 测试时间            |        |                 |                 |                                                                                                                                    |                                                                                                                                    |                     |                 | 稳定水位              | 1.10        | 场地类别 | II        |     |
| 地层<br>代号        | 层<br>号 | 地层<br>深度<br>(m) | 地层<br>厚度<br>(m) | 地质<br>柱状图<br>1:300                                                                                                                 | 岩土性质描述                                                                                                                             | 标贯<br>N63.5<br>m~m  | 测试<br>深度<br>(m) | 剪切<br>波速<br>(m/s) | 剪切波速直方图<br> |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    |                     |                 |                   |             |      |           |     |
| Q <sup>ml</sup> | 1      | 2.60            | 2.6             |                                                                                                                                    | Fine to coarse SAND(0.00~1.50m Light yellow;1.50~2.60m Light yellow brown)                                                         |                     | 0.75            | 130               |             |      |           |     |
|                 | 2      | 3.70            | 1.1             |                                                                                                                                    |                                                                                                                                    | 10                  | 1.5             | 130               |             |      |           |     |
|                 | 3      | 4.60            | 0.9             |                                                                                                                                    | Silty CLAY,Soft                                                                                                                    | 3.80~4.10           | 2.1             | 130               |             |      |           |     |
|                 | 4      | 5.70            | 1.1             |                                                                                                                                    | Fine to medium SAND,Medium dense                                                                                                   |                     | 2.6             | 130               |             |      |           |     |
| Q <sup>m</sup>  |        |                 |                 |                                                                                                                                    | Medium to coarse SAND                                                                                                              | 9                   | 3.2             | 130               |             |      |           |     |
|                 | 5      | 7.70            | 2               |                                                                                                                                    | Silty CLAY,Soft                                                                                                                    | 6.90~7.20           | 3.99            | 130               |             |      |           |     |
| Q <sup>al</sup> |        |                 |                 |                                                                                                                                    | Silty CLAY,Firm(7.70~9.70m Greyish whiteLight;9.70~11.70m Light yellow)                                                            | 13                  | 4.74            | 130               |             |      |           |     |
|                 | 6      | 11.70           | 4               |                                                                                                                                    |                                                                                                                                    |                     | 5.7             | 130               |             |      |           |     |
|                 | 7      | 12.80           | 1.1             |                                                                                                                                    | Slightly sandy SILT,Firm                                                                                                           | 43                  | 6.7             | 175               |             |      |           |     |
|                 | 8      | 14.80           | 2               |                                                                                                                                    | Silty clayey fine to coarse SAND,Dense                                                                                             | 12.90~13.20         | 7.7             | 175               |             |      |           |     |
|                 | 9      | 15.90           | 1.1             |                                                                                                                                    | Sandy fine to coarse GRAVEL,Dense                                                                                                  | 16.00~16.30         | 8.7             | 230               |             |      |           |     |
|                 | 10     | 18.80           | 2.9             |                                                                                                                                    | Sandy SILT,Very dense                                                                                                              | 67                  | 9.7             | 230               |             |      |           |     |
|                 | 11     | 19.90           | 1.1             |                                                                                                                                    | Silty fine to medium SAND                                                                                                          | 18.00~18.30         | 9.7             | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    |                     | 10.7            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    | METAMUDSTONE(Slightly sandy clayey SILT,23.00~25.00m With gravei of QUARTZ VEIN fragments),Extremely weak,completely decomposed. V | 56                  | 10.90~11.20     | 11.7              |             |      |           | 230 |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 21.10~21.40         | 12.8            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 23.10~23.40         | 13.8            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 25.10~25.40         | 14.8            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 27.10~27.40         | 15.9            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 29.10~29.40         | 17.5            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 31.10~31.40         | 18.8            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 33.10~33.40         | 19.9            | 230               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 35.10~35.40         | 21.99           | 300               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 37.10~37.40         | 23.99           | 300               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 39.99               | 25.99           | 300               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 41.99               | 27.99           | 300               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 43.99               | 29.99           | 300               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 45.8                | 31.99           | 300               |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 47.99               | 33.99           | 300               |             |      |           |     |
|                 |        |                 |                 | METAMUDSTONE (sandy SILT),Extremely weak,completely decomposed. V                                                                  | 100                                                                                                                                | 35.99               | 300             |                   |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    | 37.10~37.40                                                                                                                        | 37.99               | 300             |                   |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 39.99               | 300             |                   |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 41.99               | 300             |                   |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 43.99               | 400             |                   |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    | 45.8                | 400             |                   |             |      |           |     |
|                 |        |                 |                 | METAMUDSTONE (Jionts are very closely to closely spaced), III(46.30~46.70m and 47.70~48.00m CONGLOMERATE;47.00~47.20m QUARTZ VEIN) |                                                                                                                                    | 51.00               | 1000            |                   |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    |                     |                 |                   |             |      |           |     |
|                 |        |                 |                 | METASILTSTONE(Jionts are medium spaced). II(49.85~50.15m CONGLOMERATE)                                                             |                                                                                                                                    |                     |                 |                   |             |      |           |     |
|                 |        |                 |                 |                                                                                                                                    |                                                                                                                                    |                     |                 |                   |             |      |           |     |

↓—标贯位置, ●—取样位置

圖5.29 BH43地震工程綜合柱狀圖



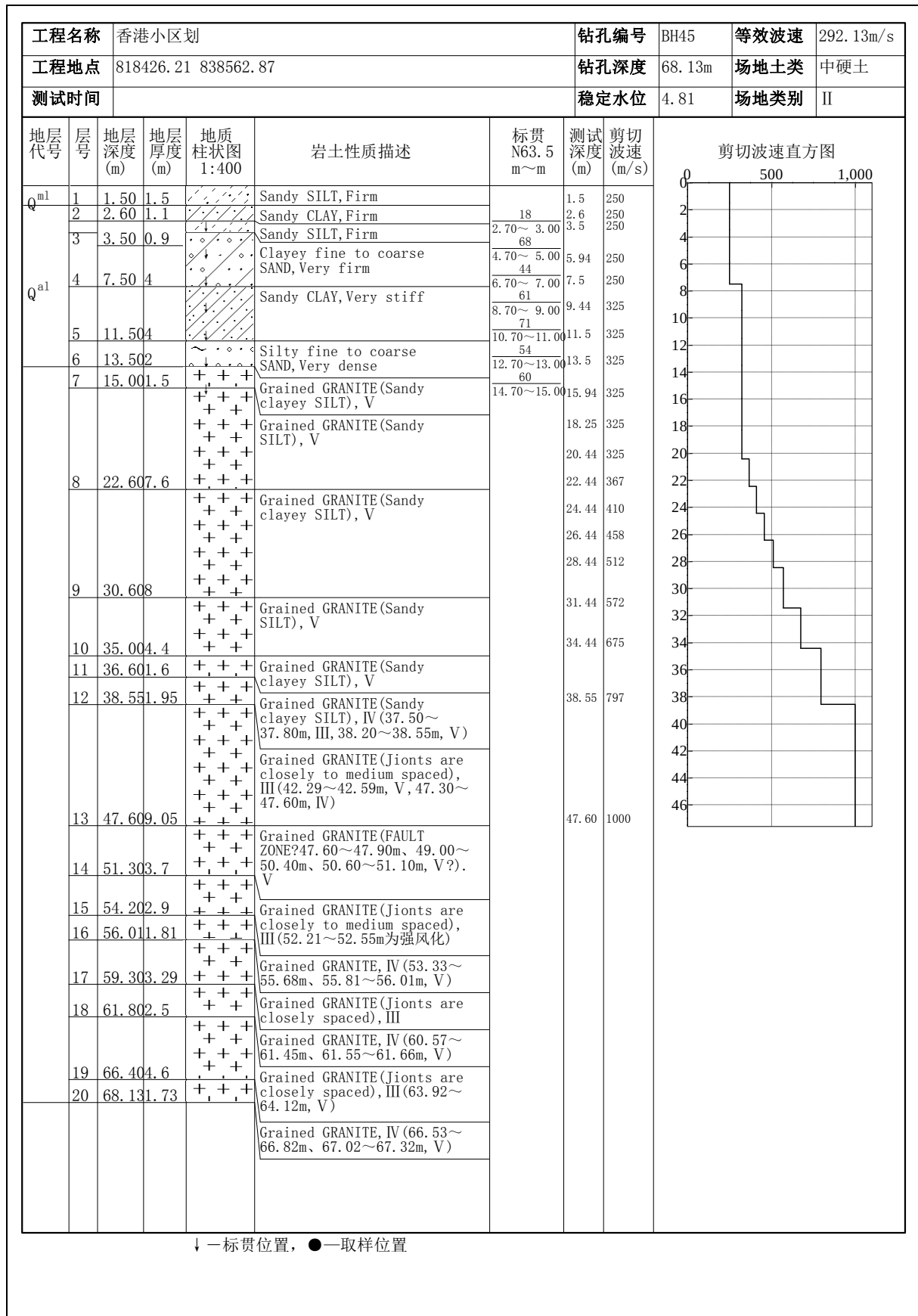


圖5.31 BH45地震工程綜合柱狀圖

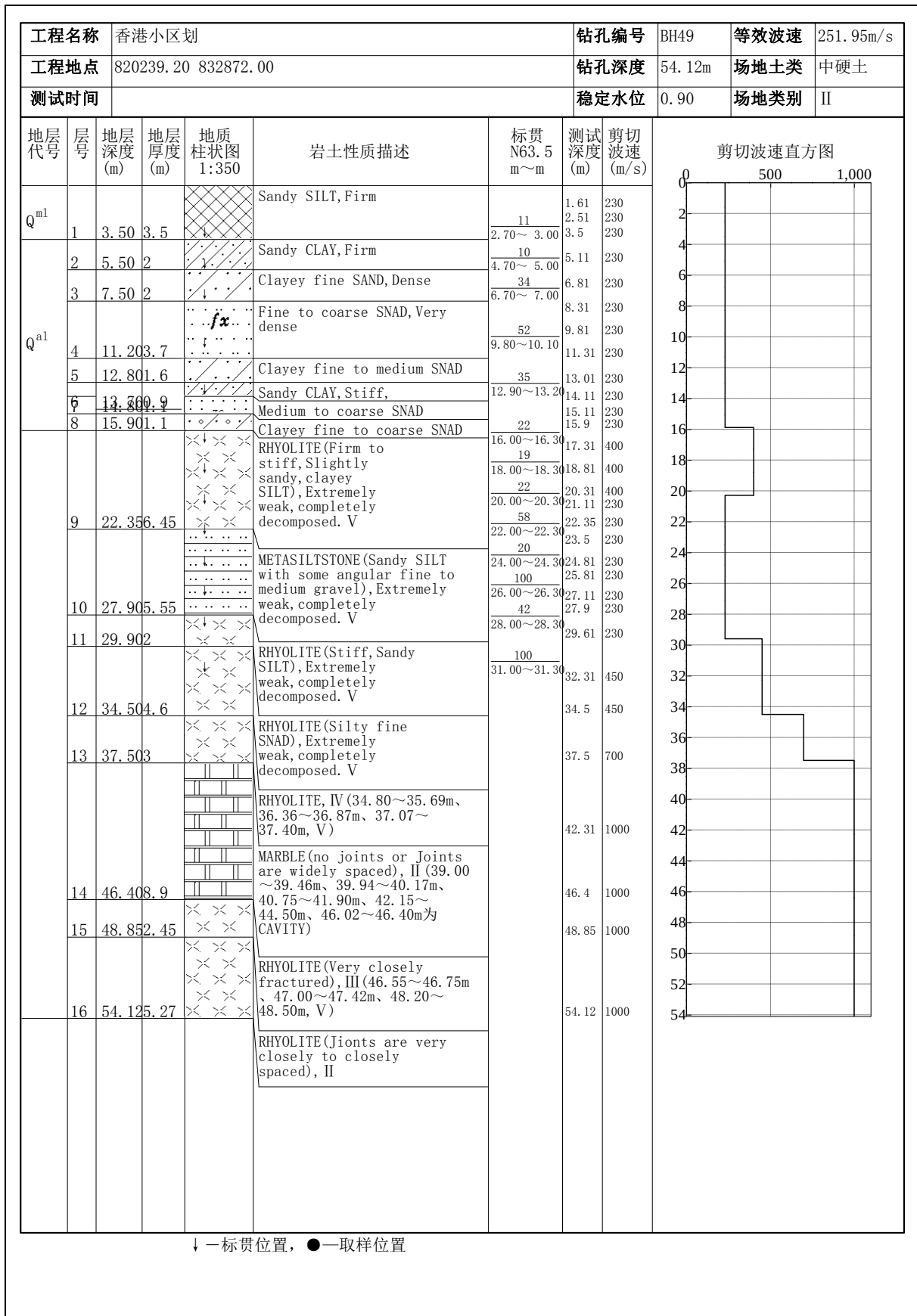


圖5.32 BH49地震工程綜合柱狀圖

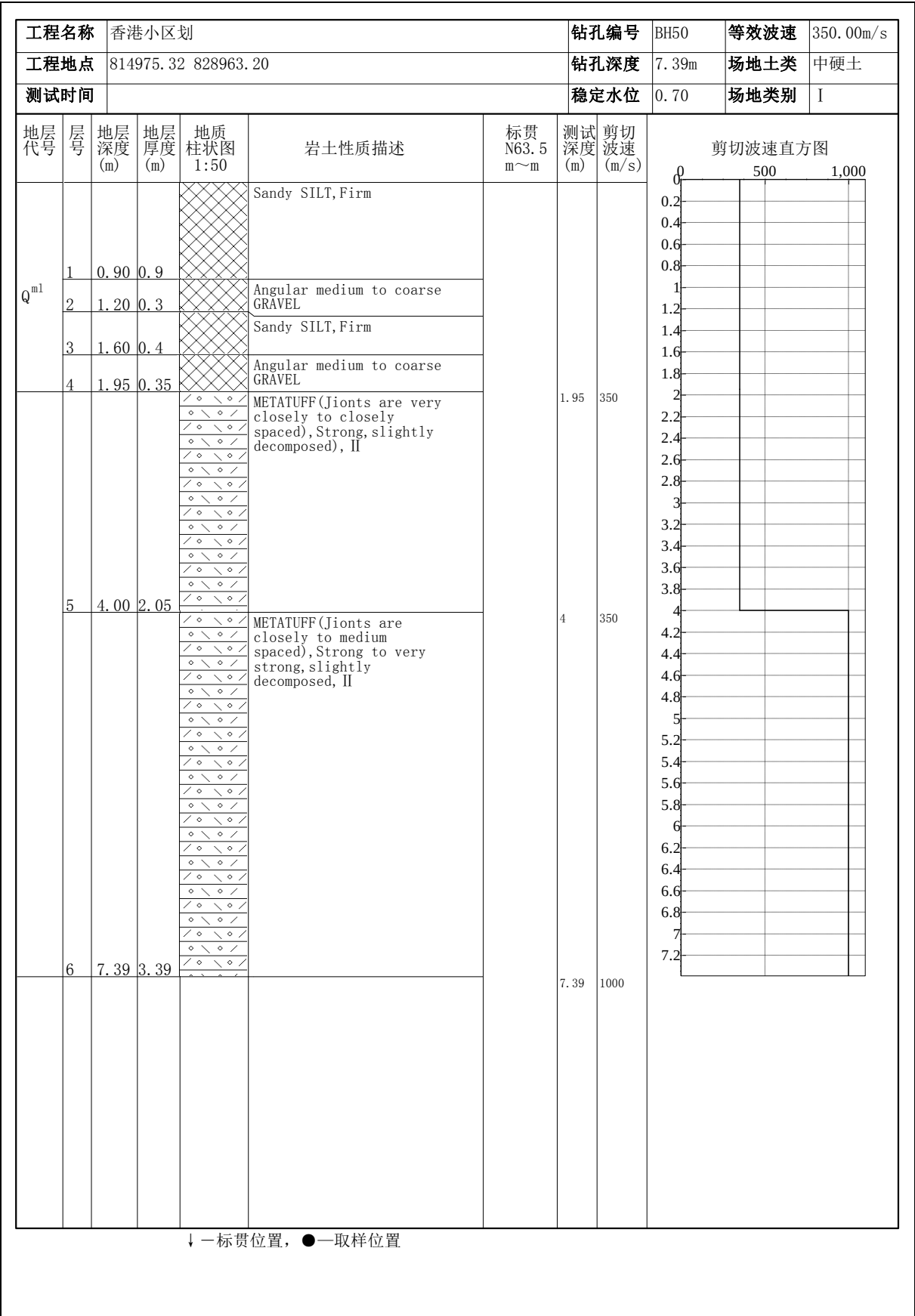


圖5.33 BH50地震工程綜合柱狀圖



由於強烈地震波在土層中傳播時，土處於大應變狀態，其本構關係是非線性的。為了準確進行土層地震反應計算，應確定土的本構關係。一般在現場採集多組原樣土，對有代表性的土樣進行室內動力三軸實驗，或者利用本區已有資料，得到剪應變模量比與剪應變關係曲線、阻尼比與剪應變關係曲線，以便在場地土層地震反應計算中合理考慮場地土體的非線性特性影響。



## 5.5 場地工程地質分區

大量震害調查資料顯示：場地條件對建築物的安全影響非常顯著。因此，為計算局部場地條件對工程的影響，需要對場地範圍內的工程地質條件進行詳細分析，利用收集到的工程地質資料，對場區進行工程地質單元的劃分，也就是將場地地震效應相同或相近的地質單元進行歸類合併，保證地震小區劃結果科學合理。

### 5.5.1 工程場區的建築場地類別分區

從本質上看，場地分類的目的是為了考慮場地條件對設計反應譜的影響，以利於採取合理的設計參數和抗震構造措施。分類標準主要考慮土層的動力放大作用和濾波特性的。經驗表明，這些特性與許多複雜的地質因素有關。

根據中外震害和層狀土理論分析的結果，場地類別的劃分可主要依據覆蓋層厚度和表層剛度。中國建築抗震設計規範也主要考慮這兩個因素按地震效應進行場地類別劃分。根據《建築抗震設計規範（GB50011-2010）》規定，建築場地類別根據土層等效剪切波速和場地覆蓋層厚度確定，見表 5.8；場地覆蓋層厚度，一般情況下應按地面至剪切波速  $V_s > 500 \text{ m/s}$  的土層或堅硬土頂面的距離確定。鑒於場地全風化岩、強風化岩剪切波速多小於  $500 \text{ m/s}$ ，中微風化岩剪切波速均大於  $500 \text{ m/s}$ ，根據野外踏勘及收集的鑽孔資料顯示，丘陵谷地地區大部分覆蓋層較薄，尤其是坡角大於  $15^\circ$  的地區，其上覆蓋土層較薄，因此根據實測的地震工程地質鑽孔資料，結合工程場區的坡角（坡度）資料，將工程場區覆蓋層的厚度進行分區（圖 5.35）：

- (i) 在無鑽孔的地區，根據坡角資料，坡角大於  $15^\circ$  的地區劃分為覆蓋層厚度  $0 - 10$  米區；
- (ii) 將坡角為  $2 - 15^\circ$  的地區劃分為覆蓋層厚度  $10 - 20$  米區（在一些地段如龍鼓水道東側等，其坡角小於  $2^\circ$ ，為人類工程活動改變原始地形和坡角，因此將該類地段劃進覆蓋層厚度  $10 - 20$  米區）；
- (iii) 將坡角小於  $2^\circ$  的地區劃分為覆蓋層厚度大於  $20$  米區，再根據已有的數據，在大於  $20$  米地區內劃分出大於  $40$  米的地區（該區為在現有鑽孔資料的基礎上劃分的，無數據的地段就沒有進行大於  $40$  米區的劃分（如太井圍東部和北部地方等））。

在覆蓋層厚度分區的基礎上，根據分區結果結合剪切波速測試結果，對工程場區的建築場地類別進行了分區（無剪切波速測試的地段根據收集的地質鑽孔資料和地質條件類比，相似的地質情況為相同的建築場地類別），其結果見圖 5.36。由圖 5.35 和 5.36 可看出，場地大部分地區覆蓋層厚度小於  $20$  米（約佔陸地面積的  $79\%$ ），極少數地區（井圍西南、天水圍西北和木橋頭—白沙村一帶）覆蓋層厚度大於  $40$  米（約佔陸地面積的  $79\%$ ）；場地主要為 I 類和 II 類建築場地，其中 I 類建築場地主要分佈於屯門的東





## 5.5.2 工程場區的工程地質分區

### 5.5.2.1 概述

依據地質資料和場區工程地質勘測資料及實地勘測，場地地質條件複雜，地形起伏很大，水系發育，地貌以丘陵谷地和沖、沉積平原（間夾孤立的緩坡殘丘）為主，根據第四系沉積物及坡積物並結合基岩埋藏深度等特徵，確定場地工程地質區劃分原則如下：主要綜合場區的地貌形態、物質成因及地基岩土力學性能等，結合建築場地類別、覆蓋層厚度等因素進行工程地質區段劃分。

根據上述原則，將工程場地劃分為：（1）丘陵谷地淺基岩工程地質區（A）；（2）坡麓堆積工程地質區（B）；（3）山前濱海平原工程地質區（C）；及（4）濱岸填海工程地質區（D）四個工程地質區（見圖 5.37 和表 5.9）。

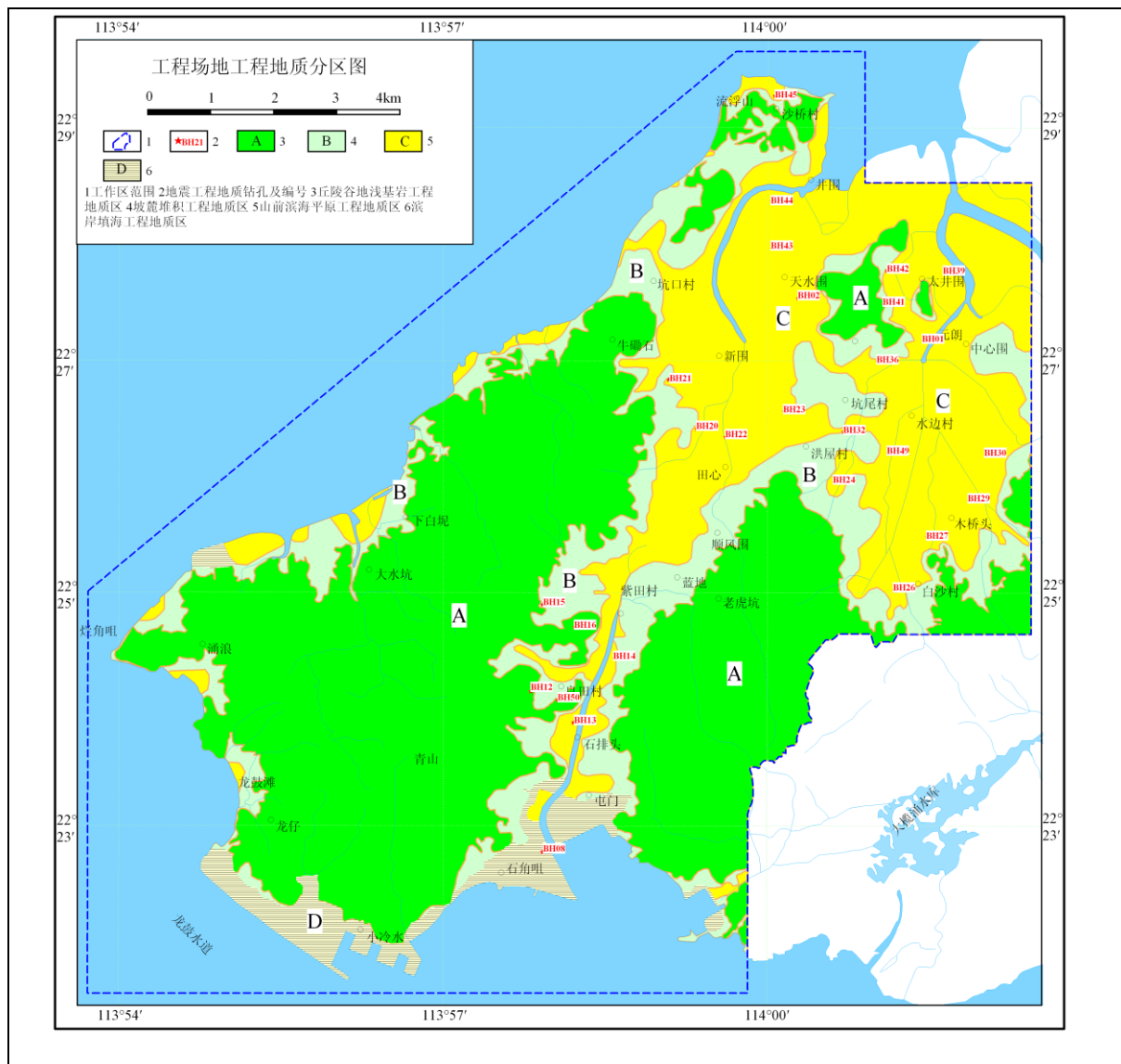


圖 5.37 工程場區工程地質單元劃分圖

表 5.9 工程場區工程地質單元特徵簡表

| 序號 | 工程地質分區名稱  | 地貌類型               | 岩土特徵                                                                                  | 不良地質作用與地震效應                                                                      | 地基條件與施工條件                                                       | 覆蓋層 ( $V_s \geq 500$ m/s) 深度 (米)   | 場地土類型    | 建築場地類別   |
|----|-----------|--------------------|---------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|-----------------------------------------------------------------|------------------------------------|----------|----------|
| A  | 丘陵谷地淺基岩區  | 丘陵谷地貌              | 埋藏基岩為玄武岩、花崗岩、粉沙岩及其變質岩類，其上覆蓋較薄坡砂積、殘積層，或基岩直接出露。                                         | 無軟土及可液化砂土分佈，但由於該區大部分地段地形起伏變化大，邊坡效明顯，屬對建築抗震不利地段。該區大部分地區坡度大於 15 度，易出現崩塌、滑坡等地震地質災害。 | 基岩面（中風化面）埋藏淺，為良好天然持力層，該區坡度大於 15 度，施工條件較差。                       | 基岩面（中風化面）埋藏淺（大部分埋深小於 5 米）          | 中硬～堅硬場地土 | I~II 類   |
| B  | 坡麓堆積區     | 丘陵向平原過渡地帶的山麓斜坡堆積地貌 | 埋藏基岩為玄武岩、花崗岩、粉沙岩及其變質岩類，其上覆蓋坡積、殘積層第四系沖積層，局部地段為人工填土層。                                   | 該區地勢相對較低，地形起伏較平緩，坡度在 2 - 10 度之間，一些地段存在軟土及可液化砂土，屬對建築抗震不利地段。局部地段位元於谷口，易受泥石流的威脅。    | 但基岩面埋稍深，岩面（中風化面）稍起伏，地形起伏較平緩，施工條件較好。                             | 基岩面（中風化面）埋稍深（大部分埋深 10 - 20 米）      | 中硬～中軟場地土 | II 類     |
| C  | 山前濱海平原區   | 山前平原及濱海平原地貌        | 基岩為侏羅紀火成岩、火成碎屑岩和羅系砂岩、粉砂岩及石灰岩等，其上覆蓋殘積層和第四系沖積、沈積層，一些地段表面覆蓋人工填土層，殘積層厚度變化大，岩面（風中化岩面）起伏很大。 | 該區地勢低，平坦，地形起伏小，存在軟土及可液化砂土，屬對建築抗震不利地段，存在石灰岩，在外界誘因下，易發生岩溶塌陷。                       | 該區基岩面（中風化面）埋藏較深，局部超過 150 米，坡度多小於 2 度，局部 2 - 5 度，海拔在 0 - 10 米之間。 | 基岩面（中風化岩面）埋藏較深，局部超過 150 米          | 中軟～中硬場地土 | II~III 類 |
| D  | 濱岸填海工程地質區 | 地勢低平，人工堆填          | 基岩為侏羅紀火成岩、火成碎屑岩等，其上覆蓋第四系沖積、沈積層和人工填土層，填土層厚度較大（離岸越大），較鬆散。                               | 一些地段存在可液化砂土，屬對建築抗震不利地段。                                                          | 該區地勢低，地形起伏小，坡度多小於 2 度，海拔低，填土層厚度大，施工條件較好。                        | 基岩面（中風化岩面）埋藏稍深（BH08 孔揭露埋深 23.75 米） | 中軟場地土    | II 類     |

### 5.5.2.2 工程地質分區特徵

#### (1) 丘陵谷地淺基岩工程地質區 (A)

分佈於流浮山－青山和場區東南部的九徑山一帶，總面積約 56.5 平方公里，佔場區陸地面積的 51.5%。BH12、BH16、BH41、BH50 共四個地震工程地質鑽孔位於該區內。

該區地勢高，大部分海拔大於 40 米，地形起伏變化大，坡度多大於 15 度，局部 10 - 15 度，基岩面埋藏淺（大部分埋深小於 5 米），埋藏基岩為玄武岩、花崗岩、粉砂岩及其變質岩類，其上多覆蓋較薄坡積、殘積層。

該區場地土類型多屬中硬～堅硬場地土，建築場地類別多為 I 類，局部為 II 類，無軟土及可液化砂土分佈，但由於該區大部分地段地形起伏變化大，邊坡效應明顯，屬對建築抗震不利地段。該區大部分地區坡度大於 15 度，可能出現崩塌、滑坡等地震地質災害。

#### (2) 坡麓堆積工程地質區 (B)

分佈於流浮山－青山和場區東南部的九徑山的坡麓不規則狹長地帶，總面積約 20.1 平方公里，佔場區陸地面積的 18.3%。僅 1 個地震工程地質鑽孔 (BH15) 位於該區內。

該區地勢相對較低，大部分位於海拔 10 - 30 米之間，地形起伏較平緩，坡度在 2 - 10 度之間，基岩面埋稍深（大部分埋深 10 - 20 米），埋藏基岩為玄武岩、花崗岩、粉砂岩及其變質岩類，其上覆蓋崩坡積、殘積層或薄層第四系沖積、洪積層，局部地段為人工填土層。

該區場地土類型多屬中硬場地土，局部為中軟場地土，建築場地類別為 II 類，一些地段存在軟土及可液化砂土，屬對建築抗震不利地段。該區地勢總體背山傾斜，大部分地區坡度在 2 - 5 度之間，施工條件較好，但局部地段位於谷口，可能會遭受泥石流的威脅。

#### (3) 山前濱海平原工程地質區 (C)

該區主要分佈於元朗平原至屯門一帶，此外在場區的西、西北、西南近岸局部有零星分佈，總面積約 29.0 平方公里，佔場區陸地面積的 26.4%。BH01、BH02、BH13、BH14、BH20、BH21、BH22、BH23、BH24、BH26、BH27、BH29、BH30、BH32、BH36、BH39、BH42、BH43、BH44、BH45、BH49 共 22 個地震工程地質鑽孔位於該區內。

該區地勢低，平坦，地形起伏小，坡度多小於 2 度，局部 2 - 5 度，海拔在 0 - 10 米之間，該區基岩為侏羅紀火成岩、火成碎屑岩和侏羅系砂岩、粉砂岩及石灰岩等。該區基岩面（中風化岩面）埋藏較深，局部超過 150 米，其上覆蓋殘積層和第四系沖積、沉積層，一些地段表面覆蓋人工填土層，殘積層厚度變化大，岩面（中風化岩面）起伏很大。

該區場地土類型屬中軟場地土，建築場地類別為 II~III 類，一些地段存在軟土及可液化砂土，屬對建築抗震不利地段。

#### (4) 濱岸填海工程地質區 (D)

該區主要分佈於屯門至石角咀、龍鼓水道東側一帶，此外在場區的西北近岸局部有零星分佈，總面積約 4.2 平方公里，佔場區陸地面積的 3.8%。僅 BH08 地震工程地質鑽孔位於該區內。

該區地勢低，平坦，地形起伏小，坡度多小於 2 度，極少數地段大於 2 度，該區基岩為侏羅紀火成岩、火成碎屑岩等。該區基岩面（中風化岩面）埋藏稍深（BH08 孔揭露埋深 23.75 米），其上覆蓋第四系沖積、沉積層和人工填土層，填土層厚度較大（離岸越遠厚度越大），較鬆散。

該區場地土類型屬中軟場地土，建築場地類別為 II 類，一些地段存在可液化砂土，屬對建築抗震不利地段。

### 第六章 場地土層地震反應分析

本章將進一步考慮局部場地條件的影響，以便為工程場地提供合理的抗震設計依據。

#### 6.1 場地基岩的人造地震動時程

以基岩加速度反應譜和峰值為目標，用數值類比的方法合成地震動時程，作為場地土層地震動力反應分析的地震動輸入值。每個基岩加速度反應譜擬合 3 組地震動輸入，嚴格滿足規範要求，並保證波形美觀合理。

##### 6.1.1 方法簡介

本專案採用《工程場地地震安全性評價技術規範》（GB 17741-2005）宣貫教材所推薦的方法，該地震動合成方法的主要思路為：

- (1) 用反應譜與功率譜的近似轉換關係，將目標反應譜轉換成相應的功率譜，轉換關係為：

$$S(\omega) = \frac{\varepsilon}{\pi\omega} S_a^2(\omega) / \left\{ -\ln \left[ -\frac{\pi}{\omega T} \ln(1-r) \right] \right\} \dots\dots\dots (6.1)$$

其中：

|               |   |              |
|---------------|---|--------------|
| $S(\omega)$   | = | 功率譜；         |
| $\varepsilon$ | = | 阻尼比；         |
| $S_a(\omega)$ | = | 目標反應譜；       |
| $T$           | = | 持續時間；        |
| $r$           | = | 超過目標反應譜值的概率。 |

(2) 用三角級數疊加法，生成零均值的平穩高斯過程：

$$X(t) = \sum_{i=0}^n A_i \cos(\omega_i t + \phi_i) \dots\dots\dots (6.2)$$

其中： $A_i = [4S(\omega_i)\Delta\omega]^{0.5}$ ，初相位 $\phi$ 為 $[0-2\pi]$ 均勻分佈的隨機變量。

(3) 將平穩時程乘以非平穩強度包線，得到非平穩的加速度時程：

$$a(t) = \psi(t) \times X(t) \dots\dots\dots (6.3)$$

非平穩包線函數為如下形式：

$$\psi(t) = \begin{cases} \left(\frac{t}{t_1}\right)^2 & 0 < t \leq t_1 \\ 1 & t_1 < t \leq t_2 \\ e^{-c(t-t_2)} & t_2 < t \leq T_d \end{cases} \dots\dots\dots (6.4)$$

其中：  
 $t_1$  = 峰值的上升段；  
 $t_2 - t_1$  = 峰值的平穩段；  
 $T_d$  = 持續時間；  
 $c$  = 峰值的衰減係數。

表 6.1 合成地震動地震動包線函數參數

| 超越概率     | $t_1$ | $t_2$ | $c$  | 離散點數 |
|----------|-------|-------|------|------|
| 50 年 63% | 2.0   | 15.0  | 0.20 | 8192 |
| 50 年 50% | 3.0   | 17.0  | 0.20 | 8192 |
| 50 年 10% | 5.0   | 23.0  | 0.21 | 8192 |
| 50 年 2%  | 6.0   | 25.0  | 0.22 | 8192 |

由於式 6.1 表示的反應譜與功率譜的關係是近似關係，所以按初始時程  $a(t)$  計算出來的反應譜一般只近似於目標譜，符合的程度也是概率平均的。為了提高擬合精度，還需要進行反覆運算調整。通用的方法是按下式調整式 6.2 中的傅氏幅值譜：

$$A^{i+1}(\omega_k) = \frac{S_a^T(\omega_j)}{S_a(\omega_j)} A^i(\omega_k) \quad N_{1j} < k \leq N_{2j} \dots\dots\dots (6.5)$$



式中  $A^i(\omega_k)$  和  $A^{i+1}(\omega_k)$  分別為第  $i$  和  $i+1$  次反覆運算的結果， $S_a^T(\omega_j)$  和  $S_a(\omega_j)$  為第  $j$  個控制點的目標譜和計算反應譜。採用上述方式對幅值譜調整僅局限在控制頻率  $\omega_j$  附近的  $N_{1j}-N_{2j}$  個傅裡葉分量。通常  $\omega_{1j}$  和  $\omega_{2j}$  按下述方法選取：

$$\omega_{1j} = \frac{1}{2}(\omega_{j-1} + \omega_j) \quad \omega_{2j} = \frac{1}{2}(\omega_j + \omega_{j+1}) \dots\dots\dots (6.6)$$

頻段  $\omega_{1j}-\omega_{2j}$  被稱為  $\omega_j$  的主控頻段。對於目標譜控制點  $\omega_j$ ，反覆運算運算時只改變主控頻段的幅值譜，這是因為在整個頻段中，由於共振原理主控頻段頻率分量的改變對  $\omega_j$  反應譜的變化最為敏感，另一方面調整幅值譜時，應儘量將幅值譜變化的影響局限在特定的控制頻率  $\omega_j$  附近，以避免在擬合  $\omega_j$  頻率處目標反應譜時對其鄰近控制頻率處的反應譜帶來過大的影響，對幅值譜進行多次反覆運算修正，即可使其反應譜向目標譜逼近。在對幅值譜進行反覆運算修正的同時，還對相位譜進行反覆運算修正。

### 6.1.2 持時參數的確定

本文的地震動持續時間參數的確定見下式（具體值參閱霍俊榮等（1988）的研究結果）。

$$1gT_d = -a_1 + a_2M + a_31g(R + R_0) \dots\dots\dots (6.7)$$

其中：  
 $T_d$  = 持時參數，代表  $t_1$ ， $T_s$  和  $c$ ；  
 $T_s$  = 峰值平穩段的持時，即  $t_2-t_1$ ；  
 $M$  = 等效震級；  
 $R$  = 等效震中距。

參照地震危險性分析所得等效震級、等效震中距，得到了本專案工程區工程場地基岩地震動持時參數。

### 6.1.3 目標譜及基岩地震動時程的合成

在合成本工程場點基岩地震動時程時，50 年超越概率 63%、10% 及 2% 所對應的目標峰值加速度和反應譜取前面危險性分析得到的結果。根據所給參數分別合成各個概率水準的地震動時程。為了考慮相位隨機性的影響，對於每一概率水準情況都分別合成三個不同隨機相位的地震動時程樣本。

目標反應譜在 0.04 - 10 s 內取 55 個控制點，以保證合成地震動時擬合目標反應譜的精度。在合成過程中，利用逐步逼近目標譜的方法，使合成的加速度時程精確滿足目標峰值加速度，並近似滿足目標加速度反應譜。擬合目標加速度反應譜時其擬合相對誤差小於 5%。

圖 6.1a - 6.1d 所示的例子為工程場地基岩地震動時程樣本和相應樣本時程反應譜在控制點上對目標譜的擬合情況及方差，圖中實線為目標譜，加點綴實線為擬合譜。

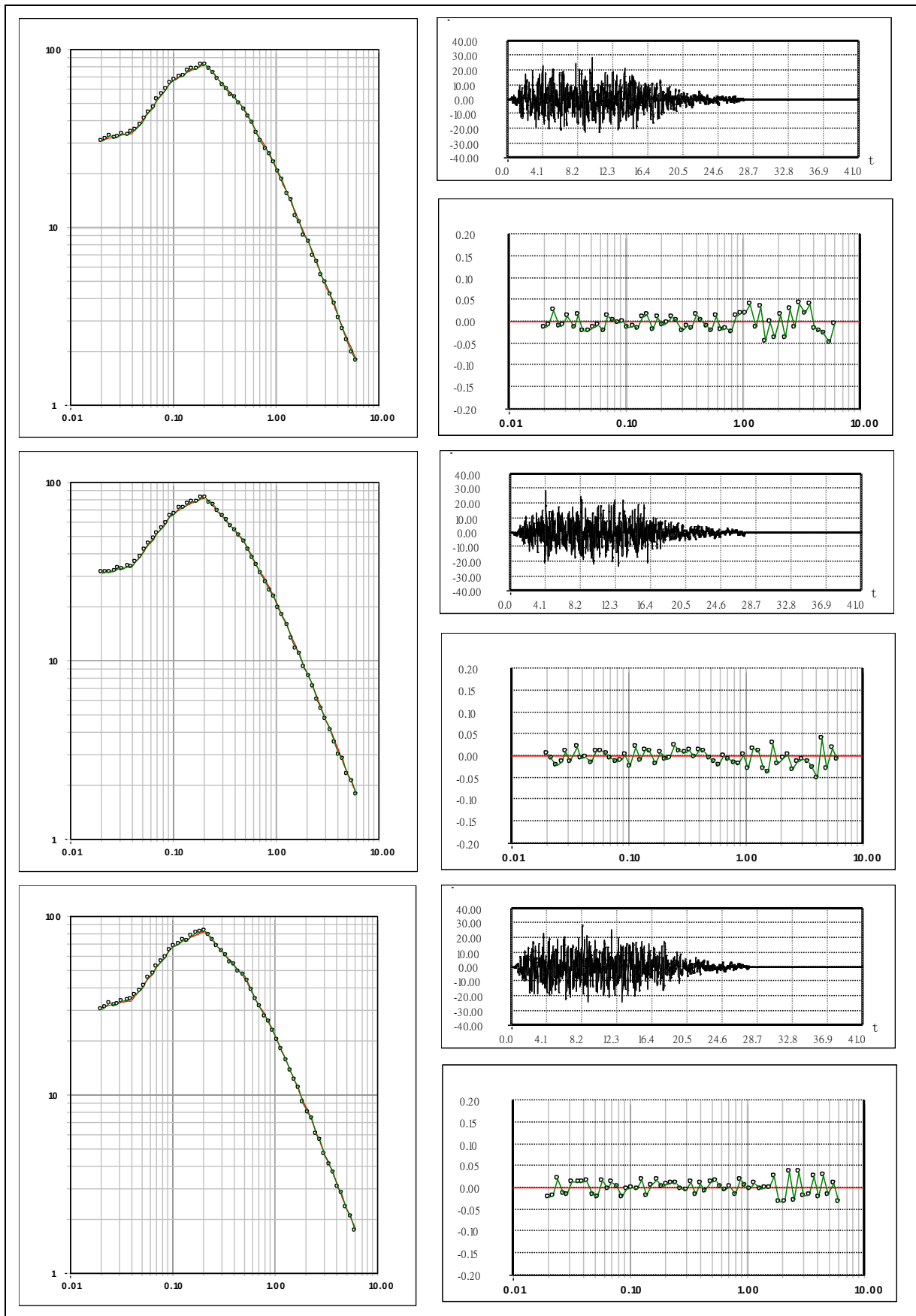


圖 6.1a 對應於 50 年超越概率 63% 情況下的場地基岩地震動時程及其反應譜擬合情況

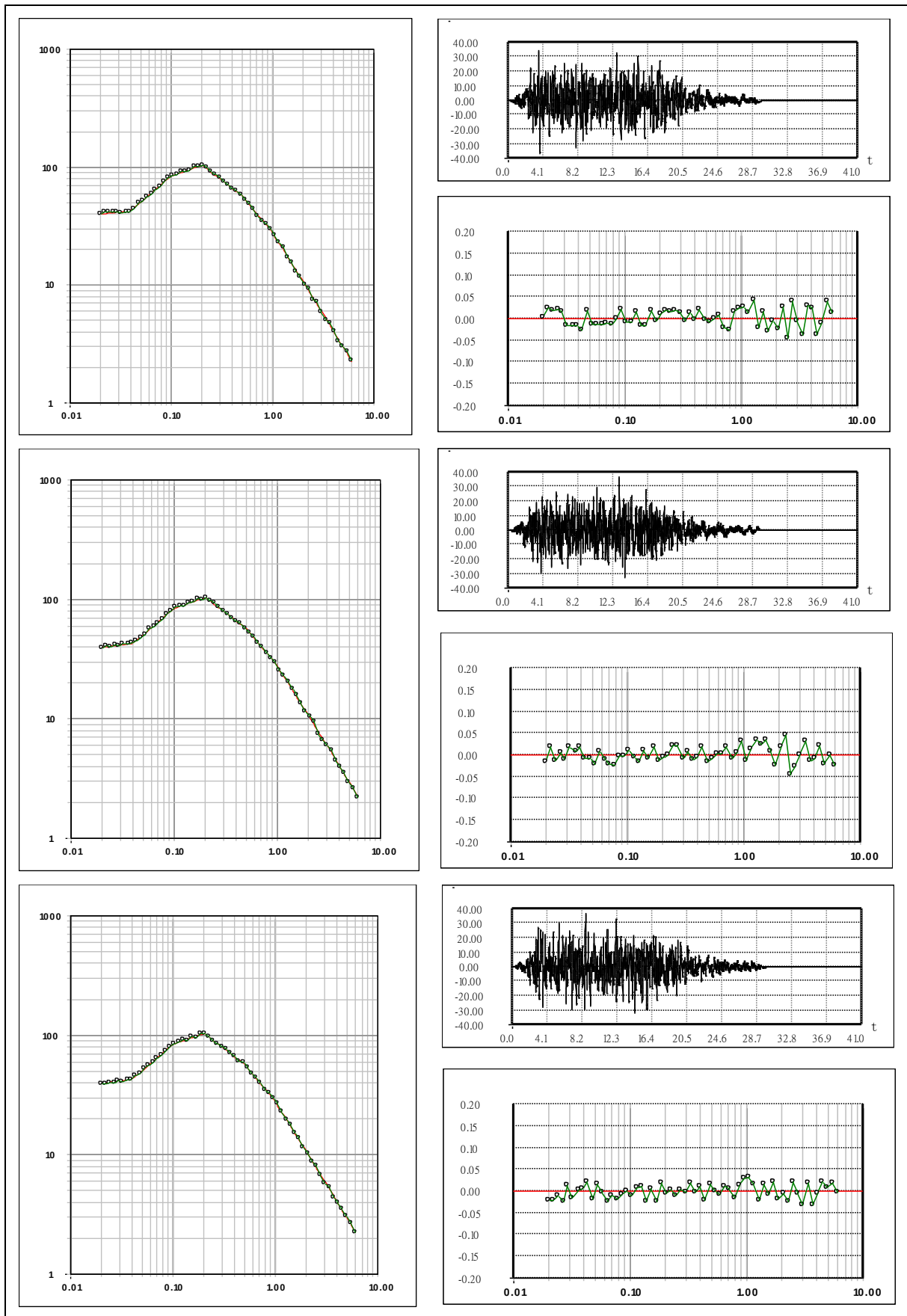


圖 6.1b 對應於 50 年超越概率 50%情況下的場地基岩地震動時程及其反應譜擬合情況

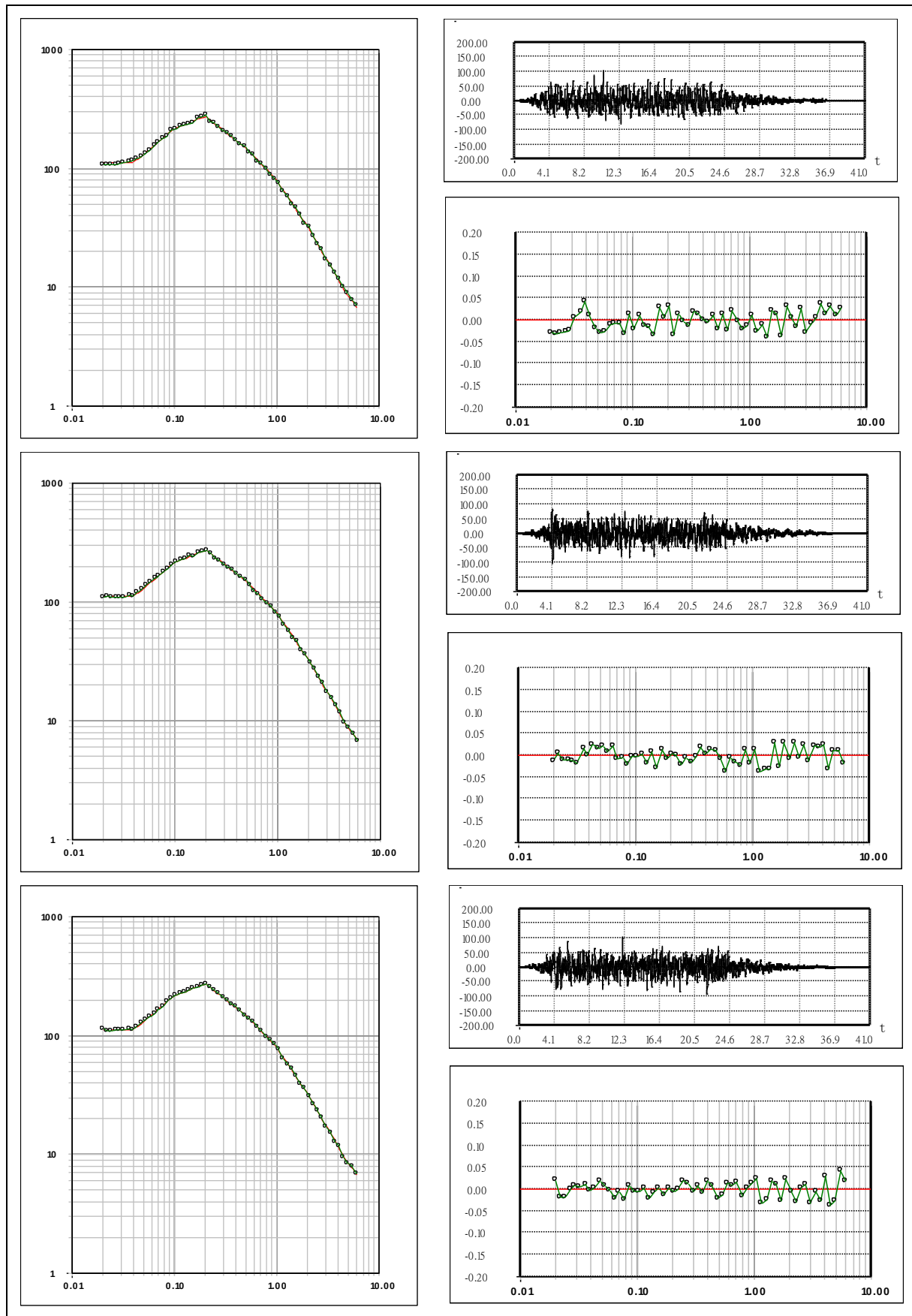


圖 6.1c 對應於 50 年超越概率 10% 情況下的場地基岩地震動時程及其反應譜擬合情況

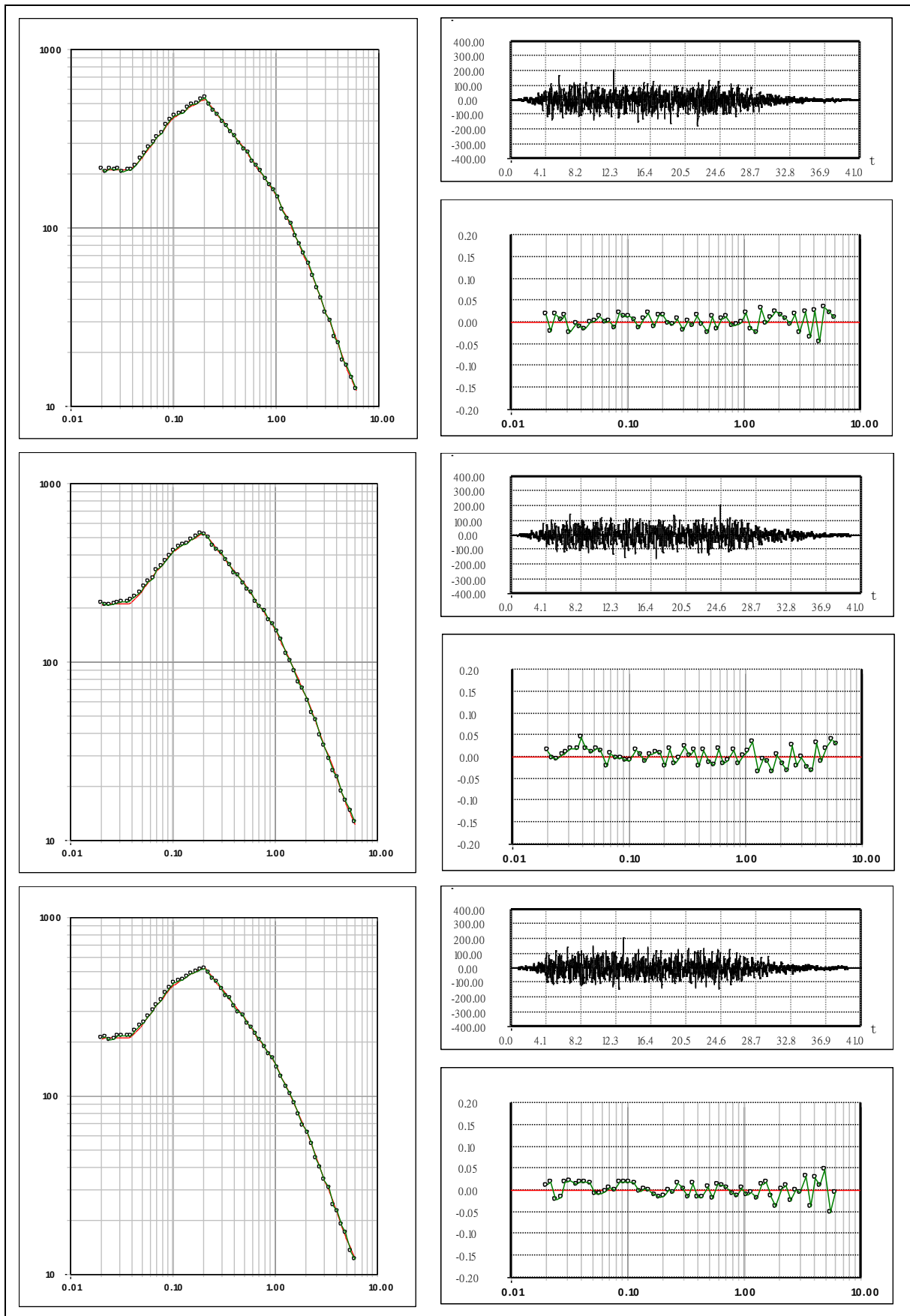


圖 6.1d 對應於 50 年超越概率 2% 情況下的場地基岩地震動時程及其反應譜擬合情況

## 6.2 場地土層地震反應計算

### 6.2.1 計算模型及方法簡介

在工作區域範圍基於一維場地模型，採用《工程場地地震安全性評價技術規範》(GB 17744-2005) 所推薦的一維土層剪切動力反應分析的等效線性化方法，來考慮場地條件對地震地面運動的影響，其基本原理如下：

假設剪切波從粘彈性半無限基岩空間垂直入射到水準成層( $N$  層)非線性土體中，並向上傳播。對於這一計算模型，根據波傳播理論，利用時頻變換技術(即傅氏變換法)結合土體非線性特性的複阻尼類比及等效線性化處理方法可以計算出場地介質動力反應值。

設有一剪切諧波自計算基底垂直向上入射並在土層中傳播，則根據波動理論及複阻尼理論可知，每一土層中介質運動必須滿足波動方程：

$$\rho_j \frac{\partial^2 U_j(x,t)}{\partial t^2} = G_j^c \frac{\partial^2 U_j(x,t)}{\partial x^2} \dots\dots\dots (6.8)$$

其中：  $U_j(x,t)$  = 第  $j$  土層中介質反應的位移值；  
 $\rho_j$  = 第  $j$  土層中介質的密度；  
 $G_j^c$  = 第  $j$  土層中介質的動力複剪切模量；

$G_j^c$  由下式給出：

$$G_j^c = [1 + 2\lambda_j(\gamma_{je})i] G_{jd}(\gamma_{je}) G_{jo} \dots\dots\dots (6.9)$$

其中：  $i$  =  $(-1)^{0.5}$ ；  
 $G_{jo}$  = 第  $j$  土層中介質的最大動力剪切模量；  
 $G_{jd}(\gamma_{je}), \lambda_j(\gamma_{je})$  = 第  $j$  土層中介質的等效動力剪切模量無量綱係數及滯回阻尼比；  
 $\gamma_{je}$  = 第  $j$  土層中層中點介質的等效動力剪切應變值。

各土層之間介質運動滿足位移連續條件和應力連續條件：

$$U_j(x, t) \big|_{x=H_j} = U_{j+1}(x, t) \big|_{x=0} \dots\dots\dots (6.10)$$

$$\tau_j(x, t) \big|_{x=H_j} = \tau_{j+1}(x, t) \big|_{x=0} \dots\dots\dots (6.11)$$

$$\tau_1(x, t) \big|_{x=0} = 0 \dots\dots\dots (6.12)$$

這裡， $H_j$  為第  $j$  土層的層厚，且規定  $x$  座標以垂直向下方向為正方向，座標原點置於每一土層層頂面位置。求解方程式 6.8，並利用已知的計算基底入射波值可得到土層中介質反應量的頻域值，再利用傅氏變換方法可以得到土層中介質反應量的時域值。具體的求解過程及求解公式可以參見胡聿賢主編的《地震安全性評價技術教程》一書中第 358 頁至 363 頁的內容。

考慮到土體的非線性特性，各土層的等效動力剪切模量的無量綱係數和滯回阻尼比都是等效剪應變的函數。因此，實際計算時，先假定每一土層層內介質反應的初始等

效動力剪切應變，利用上述方法進行反應計算，並計算出相應的各土層內中點處介質的剪應變反應的最大值，而後取每一土層內層中點處介質反應的最大剪應變值乘以折減係數（這裡取 0.65）的值作為該土層中介質的等效剪應變的計算值。比較計算所用等效剪應變及計算所得等效剪應變相對應的等效動力剪切模量和滯回阻尼比值，如果它們的相對誤差都小於給定的允許誤差（這裡取 0.05），則認為土體的非線性特性的考慮滿足了要求，否則，以最新計算所得等效剪應變值取代初始等效剪應變值，並重複上述計算過程，直到相對誤差都小於允許誤差為止。

## 6.2.2 場地計算土層模型動力參數的確定

進行場地土層地震動力反應分析，需要土層剖面的土層分層厚度及土層土體性狀描述資料，同時也需要土層中土體的力學特性資料。它們包括土體的波速值（剪切波及縱波波速值）、土體的密度值及土體動力非線性特性參數值。在進行場地土層地震動力反應分析時，必須先根據場地工程地震條件勘查資料確定計算場地模型的這些動力參數。

工程地質鑽孔資料包括土層分層厚度、土層土體性狀描述等。對鑽孔進行現場土層土體剪切波及縱波波速測量。從鑽孔中取得部分土體的動力實驗用原狀土樣，並利用原狀土樣進行了室內土體的密度值與土體動力非線性特性實驗，詳細結果見本報告的前述有關章節。表 6.2a 及表 6.2 為某鑽孔計算場地模型的剖面與力學特性參數。

表 6.2a 某鑽孔計算場地模型資料示意

| 土層序號 | 土性描述 | 土類編號 | 厚度 (m) | 土層深度<br>範圍 (m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|------|--------|----------------|---------------|-----------------------------|
| 1    | 回填土  | 1    | 0.8    | 0 - 0.8        | 320           | 1.80                        |
| 2    | 卵礫石  | 3    | 1.7    | 0.8 - 2.5      | 398           | 2.00                        |
| 3    | 卵礫石  | 3    | 1.5    | 2.5 - 4.0      | 431           | 2.01                        |
| 4    | 卵礫石  | 3    | 2.0    | 4.0 - 6.0      | 437           | 2.03                        |
| 5    | 卵礫石  | 3    | 2.0    | 6.0 - 8.0      | 450           | 2.04                        |
| 6    | 卵礫石  | 3    | 2.0    | 8.0 - 10.0     | 457           | 2.05                        |
| 7    | 卵礫石  | 3    | 2.6    | 10.0 - 12.6    | 460           | 2.06                        |
| 8    | 砂礫石  | 3    | 1.4    | 12.6 - 14.0    | 461           | 2.07                        |
| 9    | 卵礫石  | 3    | 1.2    | 14.0 - 15.2    | 469           | 2.08                        |
| 10   | 基石   | 5    | 2.4    | 15.2 - 17.6    | 613           | 2.10                        |
| 11   | 卵礫石  | 3    | 1.4    | 17.6 - 19.0    | 462           | 2.08                        |
| 12   | 卵礫石  | 3    | 2.0    | 19.0 - 21.0    | 467           | 2.10                        |
| 13   | 基石   | 5    | 1.4    | 21.0 - 22.4    | 599           | 2.10                        |
| 14   | 基石   | 5    | -      | > 22.4         | 599           | 2.00                        |

表 6.2 BH01 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|---------------|------------|--------------------------|
| 1    | 1    | 0.8    | 0 - 0.79      | 200        | 2.0                      |
| 2    | 1    | 0.7    | 0.79 - 1.50   | 200        | 2.0                      |
| 3    | 2    | 0.8    | 1.50 - 2.49   | 200        | 2.0                      |
| 4    | 2    | 1.0    | 2.49 - 3.49   | 200        | 2.0                      |
| 5    | 2    | 1.0    | 3.49 - 4.49   | 200        | 2.0                      |
| 6    | 2    | 1.0    | 4.49 - 5.49   | 200        | 2.0                      |
| 7    | 2    | 1.0    | 5.49 - 6.49   | 200        | 2.0                      |
| 8    | 2    | 1.0    | 6.49 - 7.49   | 200        | 1.9                      |
| 9    | 2    | 1.0    | 7.49 - 8.49   | 200        | 1.9                      |
| 10   | 2    | 1.0    | 8.49 - 9.49   | 200        | 1.9                      |
| 11   | 2    | 1.0    | 9.49 - 10.49  | 200        | 1.9                      |
| 12   | 2    | 1.0    | 10.49 - 11.49 | 210        | 1.9                      |
| 13   | 2    | 1.0    | 11.49 - 12.49 | 220        | 1.9                      |
| 14   | 2    | 1.0    | 12.49 - 13.49 | 231        | 1.9                      |
| 15   | 2    | 1.5    | 13.49 - 14.99 | 243        | 1.9                      |
| 16   | 2    | 1.5    | 14.99 - 16.49 | 261        | 1.9                      |
| 17   | 2    | 1.5    | 16.49 - 17.99 | 280        | 1.9                      |
| 18   | 2    | 1.7    | 17.99 - 19.69 | 301        | 1.9                      |
| 19   | 2    | 2.4    | 19.69 - 22.10 | 326        | 1.9                      |
| 20   | 5    | 2.4    | 22.10 - 24.49 | 366        | 2.0                      |
| 21   | 5    | 2.5    | 24.49 - 27.00 | 410        | 2.0                      |
| 22   | 5    | 2.0    | 27.00 - 28.99 | 462        | 2.1                      |
| 23   | 5    | 3.1    | 28.99 - 32.10 | 509        | 2.1                      |
| 24   | 5    | 2.6    | 32.10 - 34.70 | 590        | 2.4                      |
| 25   | 5    | 3.3    | 34.70 - 37.99 | 668        | 2.1                      |
| 26   | 5    | 4.5    | 37.99 - 42.50 | 782        | 2.1                      |
| 27   | 7    | N/A    | > 42.50       | 1,000      | 2.4                      |



表 6.3 BH02 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)   | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|--------------|------------|--------------------------|
| 1    | 1    | 1.0    | 0 - 1.0      | 200        | 2.0                      |
| 2    | 1    | 1.0    | 1.0 - 2.0    | 200        | 2.0                      |
| 3    | 1    | 1.0    | 2.0 - 3.0    | 200        | 2.0                      |
| 4    | 1    | 1.0    | 3.0 - 4.0    | 200        | 2.0                      |
| 5    | 1    | 1.0    | 4.0 - 5.0    | 200        | 2.0                      |
| 6    | 1    | 1.0    | 5.0 - 6.0    | 200        | 2.0                      |
| 7    | 1    | 1.1    | 6.0 - 7.1    | 200        | 2.0                      |
| 8    | 2    | 2.0    | 7.1 - 9.1    | 280        | 1.9                      |
| 9    | 2    | 2.0    | 9.1 - 11.1   | 280        | 1.9                      |
| 10   | 2    | 1.1    | 11.1 - 12.2  | 280        | 1.9                      |
| 11   | 2    | 1.9    | 12.2 - 14.1  | 280        | 1.9                      |
| 12   | 2    | 2.0    | 14.1 - 16.1  | 280        | 1.9                      |
| 13   | 2    | 1.3    | 16.1 - 17.4  | 280        | 1.9                      |
| 14   | 5    | 1.7    | 17.4 - 19.1  | 280        | 2.0                      |
| 15   | 5    | 2.0    | 19.1 - 21.1  | 298        | 2.0                      |
| 16   | 5    | 2.4    | 21.1 - 23.5  | 321        | 2.0                      |
| 17   | 5    | 2.0    | 23.5 - 25.5  | 351        | 2.0                      |
| 18   | 5    | 2.0    | 25.5 - 27.5  | 378        | 2.0                      |
| 19   | 5    | 2.0    | 27.5 - 29.5  | 407        | 2.0                      |
| 20   | 5    | 1.9    | 29.5 - 31.4  | 438        | 2.0                      |
| 21   | 5    | 2.0    | 31.4 - 33.4  | 470        | 2.0                      |
| 22   | 5    | 2.0    | 33.4 - 35.4  | 506        | 2.0                      |
| 23   | 5    | 2.0    | 35.4 - 37.4  | 545        | 2.0                      |
| 24   | 5    | 2.0    | 37.4 - 39.4  | 587        | 2.0                      |
| 25   | 5    | 4.6    | 39.4 - 44.0  | 632        | 2.0                      |
| 26   | 5    | 4.7    | 44.0 - 48.68 | 750        | 2.1                      |
| 27   | 5    | 4.7    | 48.68 - 53.4 | 750        | 2.0                      |
| 28   | 5    | 5.6    | 53.4 - 59.0  | 750        | 2.0                      |
| 29   | 7    | N/A    | > 59.0       | 1,000      | 2.5                      |

表 6.4 BH08 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)  | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|-------------|------------|--------------------------|
| 1    | 1    | 0.9    | 0 - 0.9     | 200        | 2.0                      |
| 2    | 1    | 1.1    | 0.9 - 2.0   | 200        | 2.0                      |
| 3    | 1    | 1.1    | 2.0 - 3.1   | 200        | 2.0                      |
| 4    | 1    | 1.5    | 3.1 - 4.6   | 200        | 2.0                      |
| 5    | 1    | 1.2    | 4.6 - 5.8   | 200        | 2.0                      |
| 6    | 1    | 1.0    | 5.8 - 6.8   | 180        | 2.0                      |
| 7    | 1    | 2.0    | 6.8 - 8.8   | 180        | 2.0                      |
| 8    | 1    | 1.0    | 8.8 - 9.8   | 180        | 2.0                      |
| 9    | 1    | 1.5    | 9.8 - 11.3  | 280        | 2.0                      |
| 10   | 2    | 2.0    | 11.3 - 13.3 | 300        | 2.0                      |
| 11   | 6    | 1.0    | 13.3 - 14.3 | 300        | 2.0                      |
| 12   | 6    | 1.0    | 14.3 - 15.3 | 170        | 2.0                      |
| 13   | 6    | 1.0    | 15.3 - 16.3 | 170        | 2.0                      |
| 14   | 6    | 1.0    | 16.3 - 17.3 | 170        | 2.0                      |
| 15   | 6    | 1.0    | 17.3 - 18.3 | 170        | 2.0                      |
| 16   | 6    | 1.7    | 18.3 - 20.0 | 230        | 2.0                      |
| 17   | 6    | 1.7    | 20.0 - 21.7 | 230        | 2.0                      |
| 18   | 6    | 0.9    | 21.7 - 22.6 | 230        | 2.0                      |
| 19   | 6    | 1.1    | 22.6 - 23.7 | 230        | 2.0                      |
| 20   | 7    | N/A    | > 23.7      | 1,000      | 2.8                      |

表 6.5 BH12 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m) | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|------------|------------|--------------------------|
| 1    | 2    | 1.5    | 0 - 1.5    | 200        | 2.1                      |
| 2    | 6    | 1.0    | 1.5 - 2.5  | 200        | 2.0                      |
| 3    | 7    | N/A    | > 2.5      | 1,000      | 2.8                      |

表 6.6 BH13 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)  | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|-------------|------------|--------------------------|
| 1    | 1    | 1.0    | 0 – 1.0     | 150        | 2.0                      |
| 2    | 1    | 1.0    | 1.0 - 2.0   | 150        | 2.0                      |
| 3    | 1    | 1.1    | 2.0 - 3.1   | 150        | 2.0                      |
| 4    | 3    | 1.0    | 3.1 - 4.1   | 150        | 1.7                      |
| 5    | 3    | 1.0    | 4.1 - 5.1   | 150        | 1.7                      |
| 6    | 3    | 1.0    | 5.1 - 6.1   | 150        | 1.7                      |
| 7    | 3    | 1.0    | 6.1 - 7.1   | 150        | 1.7                      |
| 8    | 3    | 1.0    | 7.1 - 8.1   | 150        | 1.7                      |
| 9    | 3    | 1.0    | 8.1 - 9.1   | 150        | 1.7                      |
| 10   | 3    | 1.1    | 9.1 - 10.2  | 150        | 1.7                      |
| 11   | 3    | 1.1    | 10.2 - 11.3 | 150        | 1.7                      |
| 12   | 2    | 1.0    | 11.3 - 12.3 | 150        | 1.9                      |
| 13   | 2    | 0.8    | 12.3 - 13.1 | 150        | 1.9                      |
| 14   | 2    | 0.8    | 13.1 - 13.9 | 150        | 1.9                      |
| 15   | 6    | 1.0    | 13.9 - 14.9 | 165        | 2.0                      |
| 16   | 6    | 1.0    | 14.9 - 15.9 | 187        | 2.0                      |
| 17   | 6    | 1.0    | 15.9 - 16.9 | 212        | 2.0                      |
| 18   | 6    | 1.8    | 16.9 - 18.6 | 240        | 2.0                      |
| 19   | 6    | 1.9    | 18.6 - 20.5 | 299        | 2.0                      |
| 20   | 6    | 2.6    | 20.5 - 23.1 | 380        | 2.0                      |
| 21   | 7    | N/A    | > 23.1      | 1,000      | 2.8                      |

表 6.7 BH14 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)  | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|-------------|------------|--------------------------|
| 1    | 1    | 1.0    | 0 - 1.0     | 200        | 2.0                      |
| 2    | 1    | 1.0    | 1.0 - 2.0   | 200        | 2.0                      |
| 3    | 1    | 1.0    | 2.0 - 3.0   | 200        | 2.0                      |
| 4    | 1    | 1.6    | 3.0 - 4.6   | 400        | 2.0                      |
| 5    | 2    | 2.0    | 4.6 - 6.6   | 400        | 1.9                      |
| 6    | 2    | 2.1    | 6.6 - 8.7   | 400        | 1.9                      |
| 7    | 2    | 2.1    | 8.7 - 10.8  | 400        | 1.9                      |
| 8    | 2    | 2.0    | 10.8 - 12.8 | 400        | 1.9                      |
| 9    | 2    | 2.2    | 12.8 - 15.0 | 350        | 1.9                      |
| 10   | 2    | 1.8    | 15.0 - 16.8 | 350        | 1.9                      |
| 11   | 6    | 2.0    | 16.8 - 18.8 | 350        | 2.0                      |
| 12   | 6    | 2.2    | 18.8 - 21.0 | 350        | 2.0                      |
| 13   | 6    | 2.1    | 21.0 - 23.1 | 350        | 2.0                      |
| 14   | 2    | 2.0    | 23.1 - 25.1 | 350        | 2.0                      |
| 15   | 6    | 2.0    | 25.1 - 27.1 | 350        | 2.0                      |
| 16   | 6    | 2.0    | 27.1 - 29.1 | 350        | 2.0                      |
| 17   | 6    | 2.4    | 29.1 - 31.5 | 350        | 2.0                      |
| 18   | 6    | 1.6    | 31.5 - 33.1 | 350        | 2.0                      |
| 19   | 6    | 1.9    | 33.1 - 35.0 | 350        | 2.0                      |
| 20   | 6    | 2.8    | 35.0 - 37.8 | 1,000      | 2.3                      |
| 21   | 7    | N/A    | > 37.8      | 1,000      | 2.5                      |

表 6.8 BH15 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)   | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|--------------|------------|--------------------------|
| 1    | 1    | 1.5    | 0 - 1.50     | 200        | 2.0                      |
| 2    | 2    | 1.1    | 1.50 - 2.60  | 200        | 2.0                      |
| 3    | 6    | 1.5    | 2.60 - 4.05  | 200        | 2.0                      |
| 4    | 6    | 1.5    | 4.05 - 5.55  | 220        | 2.0                      |
| 5    | 6    | 1.7    | 5.55 - 7.25  | 280        | 2.0                      |
| 6    | 6    | 2.5    | 7.25 - 9.70  | 330        | 2.0                      |
| 7    | 6    | 2.2    | 9.70 - 11.90 | 370        | 2.5                      |
| 8    | 7    | N/A    | > 11.90      | 1,000      | 2.8                      |

表 6.9 BH16 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)   | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|--------------|------------|--------------------------|
| 1    | 6    | 1.39   | 0 - 1.39     | 350        | 1.9                      |
| 2    | 6    | 1.50   | 1.39 - 2.89  | 350        | 1.9                      |
| 3    | 6    | 1.71   | 2.89 - 4.60  | 350        | 1.9                      |
| 4    | 6    | 2.59   | 4.60 - 7.19  | 350        | 2.0                      |
| 5    | 6    | 3.67   | 7.19 - 10.86 | 700        | 2.3                      |
| 6    | 7    | N/A    | > 10.86      | 1,000      | 2.8                      |

表 6.10 BH20 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|---------------|------------|--------------------------|
| 1    | 1    | 1.00   | 0 - 1.00      | 200        | 2.0                      |
| 2    | 1    | 1.00   | 1.00 - 2.00   | 200        | 2.0                      |
| 3    | 2    | 1.00   | 2.00 - 3.00   | 220        | 1.9                      |
| 4    | 2    | 1.00   | 3.00 - 4.00   | 220        | 1.9                      |
| 5    | 2    | 1.06   | 4.00 - 5.06   | 220        | 1.9                      |
| 6    | 2    | 1.00   | 5.06 - 6.06   | 220        | 1.9                      |
| 7    | 2    | 1.04   | 6.06 - 7.10   | 220        | 1.9                      |
| 8    | 5    | 1.00   | 7.10 - 8.10   | 170        | 2.0                      |
| 9    | 5    | 1.00   | 8.10 - 9.10   | 170        | 2.0                      |
| 10   | 5    | 1.00   | 9.10 - 10.10  | 170        | 2.0                      |
| 11   | 5    | 1.10   | 10.10 - 11.20 | 170        | 2.0                      |
| 12   | 5    | 1.00   | 11.20 - 12.20 | 170        | 2.0                      |
| 13   | 5    | 1.10   | 12.20 - 13.30 | 200        | 2.0                      |
| 14   | 5    | 1.00   | 13.30 - 14.30 | 200        | 2.0                      |
| 15   | 5    | 0.90   | 14.30 - 15.20 | 200        | 2.0                      |
| 16   | 5    | 1.00   | 15.20 - 16.20 | 270        | 2.0                      |
| 17   | 5    | 1.36   | 16.20 - 17.56 | 270        | 2.0                      |
| 18   | 5    | 1.50   | 17.56 - 19.06 | 270        | 2.0                      |
| 19   | 5    | 1.14   | 19.06 - 20.20 | 270        | 2.0                      |
| 20   | 5    | 2.00   | 20.20 - 22.20 | 550        | 2.0                      |
| 21   | 5    | 1.69   | 22.22 - 23.89 | 550        | 2.0                      |
| 22   | 7    | N/A    | > 23.89       | 1,000      | 2.2                      |

表 6.11 BH21 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)  | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|-------------|------------|--------------------------|
| 1    | 1    | 1.5    | 0 - 1.5     | 200        | 2.0                      |
| 2    | 2    | 1.5    | 1.5 - 3.0   | 200        | 1.9                      |
| 3    | 2    | 1.6    | 3.0 - 4.6   | 220        | 1.9                      |
| 4    | 2    | 1.1    | 4.6 - 5.7   | 220        | 1.9                      |
| 5    | 2    | 1.0    | 5.7 - 6.7   | 220        | 1.9                      |
| 6    | 2    | 1.0    | 6.7 - 7.7   | 240        | 1.9                      |
| 7    | 5    | 2.3    | 7.7 - 10.0  | 270        | 2.0                      |
| 8    | 5    | 1.5    | 10.0 - 11.5 | 300        | 2.0                      |
| 9    | 5    | 1.3    | 11.5 - 12.8 | 320        | 2.0                      |
| 10   | 5    | 1.6    | 12.8 - 14.4 | 350        | 2.0                      |
| 11   | 5    | 1.6    | 14.4 - 15.9 | 350        | 2.0                      |
| 12   | 5    | 1.6    | 15.9 - 17.5 | 400        | 2.0                      |
| 13   | 5    | 2.1    | 17.5 - 19.5 | 400        | 2.0                      |
| 14   | 5    | 1.3    | 19.5 - 20.8 | 400        | 2.0                      |
| 15   | 5    | 2.5    | 20.8 - 23.3 | 400        | 2.0                      |
| 16   | 5    | 2.6    | 23.3 - 25.9 | 400        | 2.0                      |
| 17   | 5    | 2.9    | 25.9 - 28.8 | 400        | 2.0                      |
| 18   | 5    | 4.5    | 28.8 - 33.3 | 600        | 2.1                      |
| 19   | 7    | N/A    | > 33.3      | 1,000      | 2.2                      |

表 6.12 BH22 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|---------------|------------|--------------------------|
| 1    | 1    | 0.78   | 0 - 0.78      | 170        | 2.0                      |
| 2    | 1    | 0.72   | 0.78 - 1.50   | 170        | 2.0                      |
| 3    | 1    | 1.10   | 1.50 - 2.60   | 200        | 2.0                      |
| 4    | 1    | 0.90   | 2.60 - 3.50   | 200        | 2.0                      |
| 5    | 1    | 1.10   | 3.50 - 4.60   | 200        | 2.0                      |
| 6    | 1    | 0.90   | 4.60 - 5.50   | 200        | 2.0                      |
| 7    | 2    | 1.10   | 5.50 - 6.60   | 200        | 1.9                      |
| 8    | 2    | 0.90   | 6.60 - 7.50   | 200        | 1.9                      |
| 9    | 4    | 1.10   | 7.50 - 8.60   | 160        | 2.0                      |
| 10   | 4    | 0.88   | 8.60 - 9.48   | 169        | 2.0                      |
| 11   | 4    | 1.30   | 9.48 - 10.78  | 177        | 2.0                      |
| 12   | 4    | 1.00   | 10.78 - 11.78 | 190        | 2.0                      |
| 13   | 4    | 1.02   | 11.78 - 12.80 | 200        | 2.0                      |
| 14   | 4    | 0.98   | 12.80 - 13.78 | 211        | 2.0                      |
| 15   | 4    | 1.02   | 13.78 - 14.80 | 222        | 2.0                      |
| 16   | 4    | 0.98   | 14.80 - 15.78 | 234        | 2.0                      |
| 17   | 4    | 1.30   | 15.78 - 17.08 | 246        | 2.0                      |
| 18   | 4    | 1.72   | 17.08 - 18.80 | 260        | 2.0                      |
| 19   | 4    | 1.18   | 18.80 - 19.98 | 260        | 2.0                      |
| 20   | 4    | 1.50   | 19.98 - 21.48 | 260        | 2.0                      |
| 21   | 4    | 1.50   | 21.48 - 22.98 | 260        | 2.0                      |
| 22   | 4    | 1.90   | 22.98 - 24.88 | 260        | 2.0                      |
| 23   | 4    | 1.92   | 24.88 - 26.80 | 260        | 2.0                      |
| 24   | 4    | 1.68   | 26.80 - 28.48 | 260        | 2.0                      |
| 25   | 4    | 1.42   | 28.48 - 29.90 | 219        | 2.0                      |
| 26   | 4    | 1.00   | 29.90 - 30.90 | 240        | 2.0                      |
| 27   | 4    | 1.00   | 30.90 - 31.90 | 240        | 2.0                      |
| 28   | 4    | 2.00   | 31.90 - 33.90 | 270        | 2.0                      |
| 29   | 4    | 2.00   | 33.90 - 35.90 | 300        | 2.0                      |
| 30   | 4    | 2.00   | 35.90 - 37.90 | 360        | 2.0                      |
| 31   | 4    | 2.00   | 37.90 - 39.90 | 450        | 2.0                      |
| 32   | 4    | 3.75   | 39.90 - 43.56 | 550        | 2.0                      |
| 33   | 7    | N/A    | > 43.65       | 800        | 2.3                      |

表 6.13 BH23 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|---------------|------------|--------------------------|
| 1    | 1    | 1.75   | 0 - 0.75      | 250        | 2.0                      |
| 2    | 1    | 1.75   | 1.75 - 3.50   | 250        | 2.0                      |
| 3    | 2    | 1.00   | 3.50 - 4.50   | 250        | 1.9                      |
| 4    | 2    | 1.00   | 4.50 - 5.50   | 260        | 1.9                      |
| 5    | 2    | 1.98   | 5.50 - 7.48   | 270        | 1.9                      |
| 6    | 2    | 2.02   | 7.48 - 9.50   | 291        | 1.9                      |
| 7    | 2    | 2.00   | 9.50 - 11.50  | 314        | 1.9                      |
| 8    | 2    | 2.00   | 11.50 - 13.50 | 339        | 1.9                      |
| 9    | 2    | 1.50   | 13.50 - 15.00 | 366        | 1.9                      |
| 10   | 2    | 1.60   | 15.00 - 16.60 | 387        | 1.9                      |
| 11   | 2    | 2.00   | 16.60 - 18.60 | 411        | 2.2                      |
| 12   | 2    | 3.10   | 18.60 - 21.70 | 444        | 2.2                      |
| 13   | 5    | 3.73   | 21.70 - 25.43 | 500        | 2.0                      |
| 14   | 5    | 3.37   | 25.43 - 28.80 | 550        | 2.0                      |
| 15   | 5    | 3.00   | 28.80 - 31.80 | 550        | 2.0                      |
| 16   | 5    | 3.00   | 31.80 - 34.80 | 550        | 2.0                      |
| 17   | 5    | 2.73   | 34.80 - 37.53 | 550        | 2.0                      |
| 18   | 5    | 2.27   | 37.53 - 39.80 | 550        | 2.0                      |
| 19   | 5    | 3.73   | 39.80 - 43.53 | 550        | 2.0                      |
| 20   | 5    | 2.27   | 43.53 - 45.80 | 550        | 2.0                      |
| 21   | 5    | 4.03   | 45.80 - 49.83 | 550        | 2.0                      |
| 22   | 5    | 1.77   | 49.83 - 51.60 | 550        | 2.0                      |
| 23   | 5    | 4.00   | 51.60 - 55.60 | 550        | 2.0                      |
| 24   | 5    | 3.78   | 55.60 - 59.38 | 550        | 2.0                      |
| 25   | 5    | 2.92   | 59.38 - 62.30 | 550        | 2.0                      |
| 26   | 5    | 2.90   | 62.30 - 65.20 | 550        | 2.0                      |
| 27   | 5    | 2.20   | 65.20 - 67.40 | 550        | 2.0                      |
| 28   | 5    | 3.63   | 67.40 - 71.03 | 550        | 2.0                      |
| 29   | 5    | 2.79   | 71.03 - 74.00 | 550        | 2.0                      |
| 30   | 5    | 3.03   | 74.00 - 77.03 | 550        | 2.0                      |
| 31   | 5    | 3.60   | 77.03 - 80.63 | 550        | 2.0                      |
| 32   | 5    | 4.10   | 80.63 - 84.73 | 550        | 2.0                      |
| 33   | 5    | 4.00   | 84.73 - 88.73 | 550        | 2.0                      |
| 34   | 5    | 4.10   | 88.73 - 92.83 | 550        | 2.0                      |
| 35   | 5    | 3.57   | 92.83 - 96.40 | 550        | 2.0                      |
| 36   | 7    | N/A    | > 96.4        | 1,000      | 2.6                      |



表 6.14 BH24 鑽孔剖面場地土層模型數據列表

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|---------------|------------|--------------------------|
| 1    | 1    | 1.02   | 0 - 1.02      | 200        | 2.0                      |
| 2    | 1    | 1.00   | 1.02 - 2.02   | 200        | 2.0                      |
| 3    | 1    | 1.08   | 2.02 - 3.10   | 200        | 2.0                      |
| 4    | 2    | 1.42   | 3.10 - 4.52   | 200        | 1.9                      |
| 5    | 2    | 1.50   | 4.52 - 6.02   | 200        | 1.9                      |
| 6    | 2    | 1.08   | 6.02 - 7.10   | 200        | 1.9                      |
| 7    | 2    | 2.00   | 7.10 - 9.10   | 300        | 1.9                      |
| 8    | 2    | 2.00   | 9.10 - 11.10  | 380        | 1.9                      |
| 9    | 2    | 2.00   | 11.10 - 13.10 | 450        | 1.9                      |
| 10   | 6    | 3.22   | 13.10 - 16.32 | 480        | 2.0                      |
| 11   | 6    | 3.53   | 16.32 - 19.85 | 480        | 2.0                      |
| 12   | 6    | 2.91   | 19.85 - 22.76 | 800        | 2.0                      |
| 13   | 7    | N/A    | > 22.76       | 1,000      | 2.6                      |

表 6.15 BH26 鑽孔剖面場地土層模型數據列表（第 1 頁共 2 頁）

| 土層序號 | 土類編號 | 厚度(m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|-------|---------------|------------|--------------------------|
| 1    | 1    | 1.01  | 0 - 1.01      | 150        | 2.0                      |
| 2    | 1    | 0.99  | 1.01 - 2.00   | 150        | 2.0                      |
| 3    | 2    | 2.01  | 2.00 - 4.01   | 280        | 1.9                      |
| 4    | 2    | 2.00  | 4.01 - 6.01   | 280        | 1.9                      |
| 5    | 2    | 1.29  | 6.01 - 7.30   | 280        | 1.9                      |
| 6    | 2    | 1.91  | 7.30 - 9.21   | 280        | 1.9                      |
| 7    | 2    | 2.09  | 9.21 - 11.30  | 280        | 1.9                      |
| 8    | 2    | 2.00  | 11.30 - 13.30 | 280        | 1.9                      |
| 9    | 2    | 1.21  | 13.30 - 14.51 | 280        | 1.9                      |
| 10   | 2    | 2.09  | 14.51 - 16.60 | 280        | 1.9                      |
| 11   | 4    | 2.41  | 16.60 - 19.01 | 400        | 2.0                      |
| 12   | 4    | 3.00  | 19.01 - 22.01 | 400        | 2.0                      |
| 13   | 4    | 3.00  | 22.01 - 25.01 | 400        | 2.0                      |
| 14   | 4    | 3.00  | 25.01 - 28.01 | 400        | 2.0                      |
| 15   | 4    | 3.00  | 28.01 - 31.01 | 400        | 2.0                      |

表 6.15 BH26 鑽孔剖面場地土層模型數據列表（第 2 頁共 2 頁）

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)      | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|-----------------|------------|--------------------------|
| 16   | 4    | 3.00   | 31.01 - 34.01   | 400        | 2.0                      |
| 17   | 4    | 3.00   | 34.01 - 37.01   | 400        | 2.0                      |
| 18   | 4    | 3.00   | 37.01 - 40.01   | 400        | 2.0                      |
| 19   | 4    | 3.00   | 40.01 - 43.01   | 400        | 2.0                      |
| 20   | 4    | 3.00   | 43.01 - 46.01   | 400        | 2.0                      |
| 21   | 4    | 3.00   | 46.01 - 49.01   | 400        | 2.0                      |
| 22   | 4    | 3.00   | 49.01 - 52.01   | 400        | 2.0                      |
| 23   | 4    | 3.00   | 52.01 - 55.01   | 400        | 2.0                      |
| 24   | 4    | 3.00   | 55.01 - 58.01   | 400        | 2.0                      |
| 25   | 4    | 2.59   | 58.01 - 60.60   | 400        | 2.0                      |
| 26   | 4    | 3.00   | 60.60 - 63.60   | 530        | 2.1                      |
| 27   | 4    | 3.00   | 63.60 - 66.60   | 530        | 2.1                      |
| 28   | 4    | 2.61   | 66.60 - 69.21   | 530        | 2.1                      |
| 29   | 4    | 2.69   | 69.21 - 71.90   | 530        | 2.1                      |
| 30   | 4    | 2.80   | 71.90 - 74.70   | 530        | 2.1                      |
| 31   | 4    | 2.40   | 74.70 - 77.10   | 530        | 2.1                      |
| 32   | 4    | 3.60   | 77.10 - 80.70   | 530        | 2.1                      |
| 33   | 4    | 3.81   | 80.70 - 84.51   | 530        | 2.1                      |
| 34   | 4    | 2.19   | 84.51 - 86.70   | 530        | 2.1                      |
| 35   | 4    | 2.70   | 86.70 - 89.40   | 530        | 2.1                      |
| 36   | 4    | 3.61   | 89.40 - 93.01   | 530        | 2.1                      |
| 37   | 4    | 3.90   | 93.01 - 96.91   | 530        | 2.1                      |
| 38   | 4    | 3.85   | 96.91 - 100.76  | 530        | 2.1                      |
| 39   | 4    | 3.50   | 100.76 - 104.26 | 530        | 2.1                      |
| 40   | 4    | 3.75   | 104.26 - 108.01 | 530        | 2.1                      |
| 41   | 4    | 3.59   | 108.01 - 111.60 | 530        | 2.1                      |
| 42   | 4    | 4.41   | 111.60 - 116.01 | 750        | 2.1                      |
| 43   | 4    | 5.59   | 116.01 - 121.60 | 750        | 2.1                      |
| 44   | 4    | 4.41   | 121.60 - 126.01 | 750        | 2.1                      |
| 45   | 4    | 5.00   | 126.01 - 131.01 | 750        | 2.1                      |
| 46   | 4    | 5.50   | 131.01 - 136.51 | 750        | 2.1                      |
| 47   | 4    | 4.99   | 136.51 - 141.50 | 750        | 2.1                      |
| 48   | 4    | 5.00   | 141.50 - 146.50 | 750        | 2.1                      |
| 49   | 7    | N/A    | > 146.50        | 750        | 2.1                      |

表 6.16 BH27 鑽孔剖面場地土層模型資料清單（第 1 頁共 2 頁）

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 2    | 0.8       | 0 - 0.8       | 180           | 2.1                         |
| 2    | 2    | 0.8       | 0.8 - 1.5     | 180           | 2.1                         |
| 3    | 2    | 1.0       | 1.5 - 2.5     | 180           | 1.9                         |
| 4    | 2    | 1.0       | 2.5 - 3.5     | 180           | 1.9                         |
| 5    | 2    | 1.1       | 3.5 - 4.6     | 180           | 1.9                         |
| 6    | 2    | 1.0       | 4.6 - 5.6     | 180           | 1.9                         |
| 7    | 2    | 1.0       | 5.6 - 6.6     | 180           | 1.9                         |
| 8    | 2    | 1.0       | 6.6 - 7.6     | 180           | 1.9                         |
| 9    | 2    | 1.1       | 7.6 - 8.7     | 180           | 1.9                         |
| 10   | 2    | 1.0       | 8.7 - 9.7     | 180           | 1.9                         |
| 11   | 6    | 0.9       | 9.7 - 10.6    | 153           | 2.0                         |
| 12   | 6    | 0.9       | 10.6 - 11.5   | 156           | 2.0                         |
| 13   | 6    | 1.0       | 11.5 - 12.5   | 158           | 2.0                         |
| 14   | 6    | 1.0       | 12.5 - 13.5   | 161           | 2.0                         |
| 15   | 6    | 1.1       | 13.5 - 14.6   | 164           | 2.0                         |
| 16   | 6    | 1.0       | 14.6 - 15.6   | 167           | 2.0                         |
| 17   | 6    | 1.0       | 15.6 - 16.6   | 170           | 2.0                         |
| 18   | 6    | 1.0       | 16.6 - 17.6   | 173           | 2.0                         |
| 19   | 6    | 0.8       | 17.6 - 18.4   | 177           | 2.0                         |
| 20   | 6    | 0.7       | 18.4 - 19.1   | 179           | 2.0                         |
| 21   | 6    | 1.0       | 19.1 - 20.1   | 182           | 2.0                         |
| 22   | 6    | 1.0       | 20.1 - 21.1   | 185           | 2.0                         |
| 23   | 6    | 1.0       | 21.1 - 22.1   | 188           | 2.0                         |
| 24   | 6    | 1.0       | 22.1 - 23.1   | 192           | 2.0                         |
| 25   | 6    | 1.0       | 23.1 - 24.1   | 195           | 2.0                         |
| 26   | 6    | 1.0       | 24.1 - 25.1   | 199           | 2.0                         |
| 27   | 6    | 1.0       | 25.1 - 26.1   | 202           | 2.0                         |
| 28   | 6    | 1.4       | 26.1 - 27.5   | 206           | 2.0                         |
| 29   | 6    | 1.1       | 27.5 - 28.6   | 212           | 2.0                         |
| 30   | 6    | 1.6       | 28.6 - 30.2   | 216           | 2.0                         |
| 31   | 6    | 1.0       | 30.2 - 31.2   | 222           | 2.0                         |
| 32   | 6    | 1.4       | 31.2 - 32.6   | 226           | 2.0                         |
| 33   | 6    | 1.4       | 32.6 - 34.0   | 232           | 2.0                         |

表 6.16 BH27 鑽孔剖面場地土層模型資料清單（第 2 頁共 2 頁）

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)  | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|-------------|------------|--------------------------|
| 34   | 6    | 1.7    | 34.0 - 35.7 | 238        | 2.0                      |
| 35   | 6    | 1.4    | 35.7 - 37.1 | 246        | 2.0                      |
| 36   | 6    | 1.6    | 37.1 - 38.7 | 252        | 2.0                      |
| 37   | 6    | 1.3    | 38.7 - 40.0 | 259        | 2.0                      |
| 38   | 6    | 1.5    | 40.0 - 41.5 | 266        | 2.0                      |
| 39   | 6    | 1.7    | 41.5 - 43.2 | 273        | 2.0                      |
| 40   | 6    | 2.0    | 43.2 - 45.2 | 281        | 2.0                      |
| 41   | 6    | 2.0    | 45.2 - 47.2 | 292        | 2.0                      |
| 42   | 6    | 1.8    | 47.2 - 49.0 | 303        | 2.0                      |
| 43   | 6    | 2.0    | 49.0 - 51.0 | 363        | 2.0                      |
| 44   | 6    | 2.5    | 51.0 - 53.5 | 428        | 2.0                      |
| 45   | 6    | 2.2    | 53.5 - 55.7 | 526        | 2.0                      |
| 46   | 6    | 3.0    | 55.7 - 58.7 | 631        | 2.3                      |
| 47   | 6    | 2.6    | 58.7 - 61.3 | 807        | 2.3                      |
| 48   | 7    | N/A    | > 61.32     | 1,000      | 2.6                      |

表 6.17 BH29 鑽孔剖面場地土層模型資料清單（第 1 頁共 2 頁）

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|---------------|------------|--------------------------|
| 1    | 1    | 1.53   | 0 - 1.53      | 200        | 2.0                      |
| 2    | 1    | 1.07   | 1.53 - 2.60   | 200        | 2.0                      |
| 3    | 2    | 0.98   | 2.60 - 3.58   | 200        | 2.0                      |
| 4    | 2    | 1.02   | 3.58 - 4.60   | 200        | 2.0                      |
| 5    | 2    | 1.00   | 4.60 - 5.60   | 200        | 2.0                      |
| 6    | 2    | 1.00   | 5.60 - 6.60   | 200        | 2.0                      |
| 7    | 2    | 1.10   | 6.60 - 7.70   | 200        | 1.9                      |
| 8    | 2    | 1.00   | 7.70 - 8.70   | 170        | 1.9                      |
| 9    | 2    | 1.00   | 8.70 - 9.70   | 170        | 1.9                      |
| 10   | 2    | 1.08   | 9.70 - 10.78  | 170        | 1.9                      |
| 11   | 2    | 0.92   | 10.78 - 11.70 | 170        | 1.9                      |
| 12   | 2    | 0.90   | 11.70 - 12.60 | 170        | 1.9                      |
| 13   | 6    | 1.08   | 12.60 - 13.68 | 200        | 2.0                      |

表 6.17 BH29 鑽孔剖面場地土層模型資料清單 (第 2 頁共 2 頁)

| 土層序號 | 土類編號 | 厚度 (m) | 土層深度範圍 (m)    | 剪切波速 (m/s) | 土密度 (g/cm <sup>3</sup> ) |
|------|------|--------|---------------|------------|--------------------------|
| 14   | 6    | 0.80   | 13.68 - 14.48 | 200        | 2.0                      |
| 15   | 6    | 1.22   | 14.48 - 15.70 | 200        | 2.0                      |
| 16   | 6    | 1.00   | 15.70 - 16.70 | 200        | 2.0                      |
| 17   | 6    | 1.00   | 16.70 - 17.70 | 200        | 2.0                      |
| 18   | 6    | 1.00   | 17.70 - 18.70 | 230        | 2.0                      |
| 19   | 6    | 1.00   | 18.70 - 19.70 | 230        | 2.0                      |
| 20   | 6    | 1.00   | 19.70 - 20.70 | 230        | 2.0                      |
| 21   | 6    | 1.00   | 20.70 - 21.70 | 230        | 2.0                      |
| 22   | 6    | 1.30   | 21.70 - 23.00 | 230        | 2.0                      |
| 23   | 6    | 1.38   | 23.00 - 24.38 | 190        | 2.0                      |
| 24   | 6    | 1.20   | 24.38 - 25.58 | 190        | 2.0                      |
| 25   | 6    | 1.42   | 25.58 - 27.00 | 190        | 2.0                      |
| 26   | 6    | 1.68   | 27.00 - 28.68 | 225        | 2.0                      |
| 27   | 6    | 1.20   | 28.68 - 29.88 | 225        | 2.0                      |
| 28   | 6    | 1.12   | 29.88 - 31.00 | 225        | 2.0                      |
| 29   | 6    | 2.38   | 31.00 - 33.38 | 325        | 2.0                      |
| 30   | 6    | 1.48   | 33.38 - 34.86 | 325        | 2.0                      |
| 31   | 6    | 1.61   | 34.86 - 36.47 | 325        | 2.3                      |
| 32   | 7    | N/A    | > 36.47       | 1,000      | 2.6                      |

表 6.18 BH30 鑽孔剖面場地土層模型資料清單（第 1 頁共 2 頁）

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍(m)     | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 2    | 1.5       | 0 - 1.50      | 200           | 2.1                         |
| 2    | 2    | 1.0       | 1.50 - 2.50   | 200           | 1.9                         |
| 3    | 2    | 1.0       | 2.50 - 3.50   | 200           | 1.9                         |
| 4    | 2    | 1.0       | 3.50 - 4.50   | 200           | 1.9                         |
| 5    | 2    | 1.0       | 4.50 - 5.50   | 200           | 1.9                         |
| 6    | 2    | 1.0       | 5.50 - 6.52   | 200           | 1.9                         |
| 7    | 2    | 1.1       | 6.52 - 7.6    | 200           | 1.9                         |
| 8    | 2    | 1.0       | 7.60 - 8.60   | 200           | 1.9                         |
| 9    | 2    | 1.0       | 8.60 - 9.60   | 212           | 1.9                         |
| 10   | 2    | 1.4       | 9.60 - 11.02  | 225           | 1.9                         |
| 11   | 2    | 1.6       | 11.02 - 12.60 | 245           | 1.9                         |
| 12   | 6    | 1.6       | 12.60 - 14.22 | 269           | 2.0                         |
| 13   | 6    | 2.0       | 14.22 - 16.22 | 296           | 2.0                         |
| 14   | 6    | 2.5       | 16.22 - 18.72 | 334           | 2.0                         |
| 15   | 6    | 2.5       | 18.72 - 21.22 | 387           | 2.0                         |
| 16   | 6    | 3.0       | 21.22 - 24.22 | 449           | 2.0                         |
| 17   | 6    | 3.0       | 24.22 - 27.22 | 450           | 2.0                         |
| 18   | 6    | 3.0       | 27.22 - 30.22 | 450           | 2.0                         |
| 19   | 6    | 3.0       | 30.22 - 33.22 | 450           | 2.0                         |
| 20   | 6    | 3.0       | 33.22 - 36.22 | 450           | 2.0                         |
| 21   | 6    | 3.0       | 36.22 - 39.22 | 450           | 2.0                         |
| 22   | 6    | 3.0       | 39.22 - 42.22 | 450           | 2.0                         |
| 23   | 6    | 3.0       | 42.22 - 45.22 | 450           | 2.0                         |
| 24   | 6    | 3.0       | 45.22 - 48.22 | 450           | 2.0                         |
| 25   | 6    | 3.0       | 48.22 - 51.22 | 450           | 2.0                         |
| 26   | 6    | 3.0       | 51.22 - 54.22 | 450           | 2.0                         |
| 27   | 6    | 3.0       | 54.22 - 57.22 | 450           | 2.0                         |
| 28   | 6    | 3.0       | 57.22 - 60.22 | 450           | 2.0                         |
| 29   | 6    | 3.0       | 60.22 - 63.22 | 450           | 2.0                         |
| 30   | 6    | 3.0       | 63.22 - 66.22 | 450           | 2.0                         |
| 31   | 6    | 3.0       | 66.22 - 69.22 | 450           | 2.0                         |
| 32   | 6    | 3.0       | 69.22 - 72.22 | 450           | 2.0                         |
| 33   | 6    | 3.0       | 72.22 - 75.22 | 450           | 2.0                         |

表 6.18 BH30 鑽孔剖面場地土層模型資料清單 (第 2 頁共 2 頁)

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍(m)       | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|-----------------|---------------|-----------------------------|
| 34   | 6    | 3.00      | 75.22 - 78.22   | 450           | 2.0                         |
| 35   | 6    | 3.00      | 78.22 - 81.22   | 450           | 2.0                         |
| 36   | 6    | 3.00      | 81.22 - 84.22   | 450           | 2.0                         |
| 37   | 6    | 3.00      | 84.22 - 87.22   | 450           | 2.0                         |
| 38   | 6    | 3.00      | 87.22 - 90.22   | 450           | 2.0                         |
| 39   | 6    | 3.00      | 90.22 - 93.22   | 450           | 2.0                         |
| 40   | 6    | 3.00      | 93.22 - 96.22   | 450           | 2.0                         |
| 41   | 6    | 3.00      | 96.22 - 99.22   | 450           | 2.0                         |
| 42   | 6    | 3.00      | 99.22 - 102.22  | 450           | 2.0                         |
| 43   | 6    | 3.00      | 102.22 - 105.22 | 450           | 2.0                         |
| 44   | 6    | 3.00      | 105.22 - 108.22 | 450           | 2.0                         |
| 45   | 6    | 3.00      | 108.22 - 111.22 | 450           | 2.0                         |
| 46   | 6    | 3.00      | 111.22 - 114.22 | 450           | 2.0                         |
| 47   | 6    | 3.00      | 114.22 - 117.22 | 450           | 2.0                         |
| 48   | 6    | 3.00      | 117.22 - 120.22 | 450           | 2.0                         |
| 49   | 6    | 3.00      | 120.22 - 123.22 | 450           | 2.0                         |
| 50   | 6    | 3.00      | 123.22 - 126.22 | 450           | 2.0                         |
| 51   | 6    | 3.00      | 126.22 - 129.22 | 450           | 2.0                         |
| 52   | 6    | 3.00      | 129.22 - 132.22 | 450           | 2.0                         |
| 53   | 6    | 3.00      | 132.22 - 135.22 | 450           | 2.0                         |
| 54   | 6    | 3.00      | 135.22 - 138.22 | 450           | 2.0                         |
| 55   | 6    | 3.00      | 138.22 - 141.22 | 450           | 2.0                         |
| 56   | 6    | 3.00      | 141.22 - 144.22 | 450           | 2.0                         |
| 57   | 6    | 3.00      | 144.22 - 147.22 | 450           | 2.0                         |
| 58   | 6    | 2.78      | 147.22 - 150.00 | 450           | 2.0                         |
| 59   | 7    | N/A       | > 150.00        | 750           | 2.2                         |

表 6.19 BH32 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 1.00      | 0 - 1.00      | 250           | 2.0                         |
| 2    | 1    | 1.14      | 1.00 - 2.14   | 250           | 2.0                         |
| 3    | 1    | 1.10      | 2.14 - 3.24   | 250           | 2.0                         |
| 4    | 1    | 1.76      | 3.24 - 5.00   | 250           | 2.0                         |
| 5    | 2    | 1.14      | 5.00 - 6.14   | 190           | 1.9                         |
| 6    | 2    | 1.06      | 6.14 - 7.20   | 190           | 1.9                         |
| 7    | 2    | 1.00      | 7.20 - 8.20   | 190           | 1.9                         |
| 8    | 2    | 1.00      | 8.20 - 9.20   | 190           | 1.9                         |
| 9    | 5    | 1.24      | 9.20 - 10.44  | 190           | 2.1                         |
| 10   | 5    | 1.00      | 10.44 - 11.44 | 218           | 2.1                         |
| 11   | 5    | 1.00      | 11.44 - 12.44 | 246           | 2.1                         |
| 12   | 5    | 1.20      | 12.44 - 13.64 | 277           | 2.1                         |
| 13   | 5    | 2.10      | 13.64 - 15.74 | 320           | 2.1                         |
| 14   | 5    | 2.36      | 15.74 - 18.10 | 411           | 2.1                         |
| 15   | 5    | 2.84      | 18.10 - 20.94 | 545           | 2.1                         |
| 16   | 5    | 2.36      | 20.94 - 23.30 | 550           | 2.1                         |
| 17   | 5    | 4.00      | 23.30 - 27.30 | 550           | 2.1                         |
| 18   | 5    | 2.00      | 27.30 - 29.30 | 550           | 2.1                         |
| 19   | 5    | 4.00      | 29.30 - 33.30 | 550           | 2.1                         |
| 20   | 5    | 2.44      | 33.30 - 35.74 | 550           | 2.1                         |
| 21   | 5    | 1.96      | 35.74 - 37.70 | 550           | 2.1                         |
| 22   | 7    | N/A       | > 37.70       | 1,000         | 2.3                         |



表 6.20 BH36 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 1.5       | 0 - 1.5       | 220           | 2.0                         |
| 2    | 1    | 1.1       | 1.5 - 2.6     | 220           | 2.0                         |
| 3    | 2    | 0.9       | 2.6 - 3.5     | 250           | 1.9                         |
| 4    | 2    | 1.0       | 3.5 - 4.5     | 250           | 1.9                         |
| 5    | 2    | 1.0       | 4.5 - 5.5     | 250           | 1.9                         |
| 6    | 2    | 1.0       | 5.5 - 6.5     | 250           | 1.9                         |
| 7    | 2    | 1.0       | 6.5 - 7.5     | 250           | 1.9                         |
| 8    | 5    | 1.5       | 7.5 - 9.0     | 210           | 2.0                         |
| 9    | 5    | 1.5       | 9.0 - 10.5    | 210           | 2.0                         |
| 10   | 5    | 1.0       | 10.5 - 11.5   | 210           | 2.0                         |
| 11   | 5    | 1.0       | 11.5 - 12.5   | 210           | 2.0                         |
| 12   | 5    | 1.0       | 12.5 - 13.5   | 270           | 2.0                         |
| 13   | 5    | 1.0       | 13.5 - 14.5   | 270           | 2.0                         |
| 14   | 5    | 1.0       | 14.5 - 15.5   | 270           | 2.0                         |
| 15   | 5    | 1.1       | 15.5 - 16.6   | 270           | 2.0                         |
| 16   | 5    | 1.0       | 16.6 - 17.6   | 270           | 2.0                         |
| 17   | 5    | 1.1       | 17.6 - 18.7   | 270           | 2.0                         |
| 18   | 5    | 2.0       | 18.7 - 20.7   | 270           | 2.0                         |
| 19   | 5    | 2.0       | 20.7 - 22.7   | 350           | 2.0                         |
| 20   | 5    | 2.3       | 22.7 - 25.0   | 350           | 2.0                         |
| 21   | 5    | 1.2       | 25.0 - 26.2   | 350           | 2.0                         |
| 22   | 5    | 1.3       | 26.2 - 27.5   | 350           | 2.0                         |
| 23   | 5    | 1.5       | 27.5 - 29.0   | 350           | 2.0                         |
| 24   | 5    | 1.6       | 29.0 - 30.6   | 350           | 2.0                         |
| 25   | 5    | 2.7       | 30.6 - 33.3   | 400           | 2.0                         |
| 26   | 5    | 2.0       | 33.3 - 35.3   | 600           | 2.0                         |
| 27   | 7    | N/A       | > 35.3        | 1,000         | 2.3                         |

表 6.21 BH39 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 0.86      | 0 - 0.86      | 200           | 2.0                         |
| 2    | 1    | 0.90      | 0.86 - 1.76   | 200           | 2.0                         |
| 3    | 1    | 0.74      | 1.76 - 2.50   | 200           | 2.0                         |
| 4    | 3    | 0.76      | 2.50 - 3.26   | 200           | 1.7                         |
| 5    | 3    | 0.70      | 3.26 - 3.96   | 200           | 1.7                         |
| 6    | 3    | 0.90      | 3.96 - 4.86   | 200           | 1.7                         |
| 7    | 3    | 0.90      | 4.86 - 5.76   | 200           | 1.7                         |
| 8    | 3    | 0.84      | 5.76 - 6.60   | 200           | 1.7                         |
| 9    | 2    | 0.86      | 6.60 - 7.46   | 200           | 1.9                         |
| 10   | 2    | 0.80      | 7.46 - 8.26   | 200           | 1.9                         |
| 11   | 2    | 0.74      | 8.26 - 9.00   | 200           | 1.9                         |
| 12   | 2    | 0.70      | 9.00 - 9.70   | 170           | 1.9                         |
| 13   | 2    | 0.90      | 9.70 - 10.60  | 170           | 1.9                         |
| 14   | 2    | 1.10      | 10.60 - 11.70 | 170           | 1.9                         |
| 15   | 2    | 1.10      | 11.70 - 12.80 | 170           | 1.9                         |
| 16   | 2    | 0.90      | 12.80 - 13.70 | 270           | 1.9                         |
| 17   | 2    | 1.56      | 13.70 - 15.26 | 270           | 1.9                         |
| 18   | 2    | 1.94      | 15.26 - 17.20 | 270           | 1.9                         |
| 19   | 5    | 3.20      | 17.20 - 20.40 | 600           | 2.1                         |
| 20   | 5    | 2.00      | 20.40 - 22.40 | 600           | 2.1                         |
| 21   | 5    | 2.00      | 22.40 - 24.40 | 600           | 2.1                         |
| 22   | 5    | 3.90      | 24.40 - 28.30 | 600           | 2.1                         |
| 23   | 5    | 3.46      | 28.30 - 31.76 | 600           | 2.0                         |
| 24   | 5    | 4.44      | 31.76 - 36.20 | 600           | 2.0                         |
| 25   | 7    | N/A       | > 36.20       | 1,000         | 2.3                         |

表 6.22 BH41 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 1.50      | 0 - 1.50      | 240           | 2.0                         |
| 2    | 5    | 1.65      | 1.50 - 3.15   | 240           | 1.9                         |
| 3    | 5    | 1.45      | 3.15 - 4.60   | 240           | 1.9                         |
| 4    | 5    | 2.90      | 4.60 - 7.50   | 415           | 2.0                         |
| 5    | 5    | 1.67      | 7.50 - 9.17   | 415           | 2.0                         |
| 6    | 5    | 2.68      | 9.17 - 11.85  | 500           | 2.1                         |
| 7    | 5    | 2.00      | 11.85 - 13.85 | 500           | 2.1                         |
| 8    | 5    | 2.00      | 13.85 - 15.85 | 500           | 2.1                         |
| 9    | 5    | 2.00      | 15.85 - 17.85 | 500           | 2.1                         |
| 10   | 5    | 2.00      | 17.85 - 19.85 | 500           | 2.1                         |
| 11   | 5    | 1.95      | 19.85 - 21.80 | 500           | 2.1                         |
| 12   | 7    | N/A       | > 21.80       | 1000          | 2.3                         |

表 6.23 BH42 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 0.88      | 0 - 0.88      | 200           | 2.0                         |
| 2    | 1    | 0.62      | 0.88 - 1.50   | 200           | 2.0                         |
| 3    | 3    | 0.68      | 1.50 - 2.18   | 200           | 1.7                         |
| 4    | 3    | 0.70      | 2.18 - 2.88   | 200           | 1.7                         |
| 5    | 3    | 0.62      | 2.88 - 3.50   | 200           | 1.7                         |
| 6    | 2    | 1.28      | 3.50 - 4.78   | 210           | 1.9                         |
| 7    | 2    | 0.72      | 4.78 - 5.50   | 210           | 1.9                         |
| 8    | 2    | 1.48      | 5.50 - 6.98   | 210           | 1.9                         |
| 9    | 2    | 1.20      | 6.98 - 8.18   | 210           | 1.9                         |
| 10   | 2    | 1.52      | 8.18 - 9.70   | 210           | 1.9                         |
| 11   | 5    | 2.10      | 9.70 - 11.80  | 400           | 2.0                         |
| 12   | 5    | 3.40      | 11.80 - 15.20 | 460           | 2.0                         |
| 13   | 5    | 2.00      | 15.20 - 17.20 | 580           | 2.0                         |
| 14   | 5    | 4.00      | 17.20 - 21.20 | 650           | 2.0                         |
| 15   | 5    | 2.70      | 21.20 - 23.90 | 850           | 2.0                         |
| 16   | 7    | N/A       | > 23.90       | 1,000         | 2.3                         |

表 6.24 BH43 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 0.75      | 0 - 0.75      | 130           | 2.0                         |
| 2    | 1    | 0.75      | 0.75 - 1.50   | 130           | 2.0                         |
| 3    | 1    | 0.60      | 1.50 - 2.10   | 130           | 2.0                         |
| 4    | 1    | 0.50      | 2.10 - 2.60   | 130           | 2.0                         |
| 5    | 1    | 0.60      | 2.60 - 3.20   | 130           | 2.0                         |
| 6    | 1    | 0.79      | 3.20 - 3.99   | 130           | 2.0                         |
| 7    | 1    | 0.75      | 3.99 - 4.74   | 130           | 2.0                         |
| 8    | 1    | 0.96      | 4.74 - 5.70   | 130           | 2.0                         |
| 9    | 3    | 1.00      | 5.70 - 6.70   | 175           | 1.7                         |
| 10   | 3    | 1.00      | 6.70 - 7.70   | 175           | 1.7                         |
| 11   | 2    | 1.00      | 7.70 - 8.70   | 230           | 1.9                         |
| 12   | 2    | 1.00      | 8.70 - 9.70   | 230           | 1.9                         |
| 13   | 2    | 1.00      | 9.70 - 10.70  | 230           | 1.9                         |
| 14   | 2    | 1.00      | 10.70 - 11.70 | 230           | 1.9                         |
| 15   | 2    | 1.10      | 11.70 - 12.80 | 230           | 1.9                         |
| 16   | 2    | 1.00      | 12.80 - 13.80 | 230           | 1.9                         |
| 17   | 2    | 1.00      | 13.80 - 14.80 | 230           | 1.9                         |
| 18   | 2    | 1.10      | 14.80 - 15.90 | 230           | 1.9                         |
| 19   | 2    | 1.60      | 15.90 - 17.50 | 230           | 1.9                         |
| 20   | 2    | 1.30      | 17.50 - 18.80 | 230           | 1.9                         |
| 21   | 2    | 1.10      | 18.80 - 19.90 | 230           | 1.9                         |
| 22   | 5    | 2.09      | 19.90 - 21.99 | 300           | 2.0                         |
| 23   | 5    | 2.00      | 21.99 - 23.99 | 300           | 2.0                         |
| 24   | 5    | 2.00      | 23.99 - 25.99 | 300           | 2.0                         |
| 25   | 5    | 2.00      | 25.99 - 27.99 | 300           | 2.0                         |
| 26   | 5    | 2.00      | 27.99 - 29.99 | 300           | 2.0                         |
| 27   | 5    | 2.00      | 29.99 - 31.99 | 300           | 2.0                         |
| 28   | 5    | 2.00      | 31.99 - 33.99 | 300           | 2.0                         |
| 29   | 5    | 2.00      | 33.99 - 35.99 | 300           | 2.0                         |
| 30   | 5    | 2.00      | 35.99 - 37.99 | 300           | 2.0                         |
| 31   | 5    | 2.00      | 37.99 - 39.99 | 300           | 2.0                         |
| 32   | 5    | 2.00      | 39.99 - 41.99 | 300           | 2.0                         |
| 33   | 5    | 2.00      | 41.99 - 43.99 | 400           | 2.0                         |
| 34   | 5    | 1.81      | 43.99 - 45.80 | 400           | 2.0                         |
| 35   | 7    | N/A       | > 45.80       | 1,000         | 2.3                         |

表 6.25 BH44 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 0.77      | 0 - 0.8       | 160           | 2.0                         |
| 2    | 1    | 0.73      | 0.8 - 1.5     | 160           | 2.0                         |
| 3    | 1    | 1.00      | 1.5 - 2.5     | 160           | 2.0                         |
| 4    | 1    | 1.00      | 2.5 - 3.5     | 160           | 2.0                         |
| 5    | 3    | 1.00      | 3.5 - 4.5     | 160           | 1.7                         |
| 6    | 3    | 1.00      | 4.5 - 5.5     | 160           | 1.7                         |
| 7    | 3    | 1.10      | 5.5 - 6.6     | 160           | 1.7                         |
| 8    | 3    | 1.10      | 6.6 - 7.7     | 180           | 1.7                         |
| 9    | 2    | 1.00      | 7.7 - 8.7     | 180           | 1.9                         |
| 10   | 2    | 1.00      | 8.7 - 9.7     | 200           | 1.9                         |
| 11   | 2    | 1.00      | 9.7 - 10.7    | 280           | 1.9                         |
| 12   | 2    | 1.90      | 10.7 - 12.6   | 280           | 1.9                         |
| 13   | 2    | 2.00      | 12.6 - 14.6   | 280           | 1.9                         |
| 14   | 2    | 1.10      | 14.6 - 15.7   | 280           | 1.9                         |
| 15   | 5    | 1.70      | 15.7 - 17.4   | 360           | 2.1                         |
| 16   | 5    | 1.50      | 17.4 - 18.9   | 360           | 2.1                         |
| 17   | 5    | 1.50      | 18.9 - 20.4   | 360           | 2.1                         |
| 18   | 5    | 2.17      | 20.4 - 22.6   | 360           | 2.1                         |
| 19   | 5    | 2.23      | 22.6 - 24.8   | 360           | 2.1                         |
| 20   | 5    | 1.50      | 24.8 - 26.3   | 360           | 2.1                         |
| 21   | 5    | 2.50      | 26.3 - 28.8   | 360           | 2.1                         |
| 22   | 5    | 2.10      | 28.8 - 30.9   | 360           | 2.1                         |
| 23   | 5    | 2.00      | 30.9 - 32.9   | 360           | 2.1                         |
| 24   | 5    | 2.00      | 32.9 - 34.9   | 360           | 2.1                         |
| 25   | 5    | 2.00      | 34.9 - 36.9   | 360           | 2.1                         |
| 26   | 5    | 2.00      | 36.9 - 38.9   | 360           | 2.1                         |
| 27   | 5    | 2.00      | 38.9 - 40.9   | 360           | 2.1                         |
| 28   | 5    | 2.00      | 40.9 - 42.9   | 360           | 2.1                         |
| 29   | 5    | 2.00      | 42.9 - 44.9   | 360           | 2.1                         |
| 30   | 5    | 2.20      | 44.9 - 47.1   | 360           | 2.1                         |
| 31   | 7    | N/A       | > 47.1        | 1,000         | 2.3                         |

表 6.26 BH45 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 1.50      | 0 - 1.50      | 250           | 2.0                         |
| 2    | 2    | 1.10      | 1.50 - 2.60   | 250           | 1.9                         |
| 3    | 2    | 0.90      | 2.60 - 3.50   | 250           | 1.9                         |
| 4    | 2    | 2.44      | 3.50 - 5.94   | 250           | 1.9                         |
| 5    | 2    | 1.56      | 5.94 - 7.50   | 250           | 1.9                         |
| 6    | 2    | 1.94      | 7.50 - 9.44   | 325           | 1.9                         |
| 7    | 2    | 2.06      | 9.44 - 11.50  | 325           | 1.9                         |
| 8    | 2    | 2.00      | 11.50 - 13.50 | 325           | 1.9                         |
| 9    | 6    | 2.44      | 13.50 - 15.94 | 325           | 2.0                         |
| 10   | 6    | 2.31      | 15.94 - 18.25 | 325           | 2.0                         |
| 11   | 6    | 2.19      | 18.25 - 20.44 | 325           | 2.0                         |
| 12   | 6    | 2.00      | 20.44 - 22.44 | 367           | 2.0                         |
| 13   | 6    | 2.00      | 22.44 - 24.44 | 410           | 2.0                         |
| 14   | 6    | 2.00      | 24.44 - 26.44 | 458           | 2.0                         |
| 15   | 6    | 2.00      | 26.44 - 28.44 | 512           | 2.0                         |
| 16   | 6    | 3.00      | 28.44 - 31.44 | 572           | 2.0                         |
| 17   | 6    | 3.00      | 31.44 - 34.44 | 675           | 2.0                         |
| 18   | 6    | 4.11      | 34.44 - 38.55 | 797           | 2.0                         |
| 19   | 7    | N/A       | > 38.55       | 1,000         | 2.3                         |

表 6.27 BH49 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 1.61      | 0 - 1.61      | 230           | 2.0                         |
| 2    | 1    | 0.90      | 1.61 - 2.51   | 230           | 2.0                         |
| 3    | 1    | 0.99      | 2.51 - 3.50   | 230           | 2.0                         |
| 4    | 2    | 1.61      | 3.50 - 5.11   | 230           | 1.9                         |
| 5    | 2    | 1.70      | 5.11 - 6.81   | 230           | 1.9                         |
| 6    | 2    | 1.50      | 6.81 - 8.31   | 230           | 1.9                         |
| 7    | 2    | 1.50      | 8.31 - 9.81   | 230           | 1.9                         |
| 8    | 2    | 1.50      | 9.81 - 11.31  | 230           | 1.9                         |
| 9    | 2    | 1.70      | 11.31 - 13.01 | 230           | 1.9                         |
| 10   | 2    | 1.10      | 13.01 - 14.11 | 230           | 1.9                         |
| 11   | 2    | 1.00      | 14.11 - 15.11 | 230           | 1.9                         |
| 12   | 2    | 0.79      | 15.11 - 15.90 | 230           | 1.9                         |
| 13   | 6    | 1.41      | 15.90 - 17.31 | 400           | 2.0                         |
| 14   | 6    | 1.50      | 17.31 - 18.81 | 400           | 2.0                         |
| 15   | 6    | 1.50      | 18.81 - 20.31 | 400           | 2.0                         |
| 16   | 6    | 0.80      | 20.31 - 21.11 | 230           | 2.0                         |
| 17   | 6    | 1.24      | 21.11 - 22.35 | 230           | 2.0                         |
| 18   | 5    | 1.15      | 22.35 - 23.50 | 230           | 2.0                         |
| 19   | 5    | 1.31      | 23.50 - 24.81 | 230           | 2.0                         |
| 20   | 5    | 1.00      | 24.81 - 25.81 | 230           | 2.0                         |
| 21   | 5    | 1.30      | 25.81 - 27.11 | 230           | 2.0                         |
| 22   | 5    | 0.79      | 27.11 - 27.90 | 230           | 2.0                         |
| 23   | 6    | 1.71      | 27.90 - 29.61 | 230           | 2.0                         |
| 24   | 6    | 2.70      | 29.61 - 32.31 | 450           | 2.0                         |
| 25   | 6    | 2.19      | 32.31 - 34.50 | 450           | 2.0                         |
| 26   | 6    | 3.00      | 34.50 - 37.50 | 700           | 2.1                         |
| 27   | 6    | 4.81      | 37.50 - 42.31 | 1,000         | 2.3                         |
| 28   | 6    | 4.09      | 42.31 - 46.40 | 1,000         | 2.3                         |
| 29   | 6    | 2.45      | 46.40 - 48.85 | 1,000         | 2.1                         |
| 30   | 7    | N/A       | > 48.85       | 1,000         | 2.6                         |

表 6.28 BH50 鑽孔剖面場地土層模型資料清單

| 土層序號 | 土類編號 | 厚度<br>(m) | 土層深度範圍<br>(m) | 剪切波速<br>(m/s) | 土密度<br>(g/cm <sup>3</sup> ) |
|------|------|-----------|---------------|---------------|-----------------------------|
| 1    | 1    | 1.95      | 0 - 1.95      | 350           | 2.0                         |
| 2    | 6    | 2.05      | 1.95 - 4.00   | 350           | 2.6                         |
| 3    | 7    | N/A       | > 4.00        | 1,000         | 2.6                         |

計算場地模型中的土類參數由動三軸試驗獲得，6 種典型土的推薦值如表 6.29 和場地土層反應分析中土體動力非線性特性曲線圖（圖 6.2）所示。

表 6.29 場地土層反應分析中土體動力非線性特性曲線參數

[illegible]



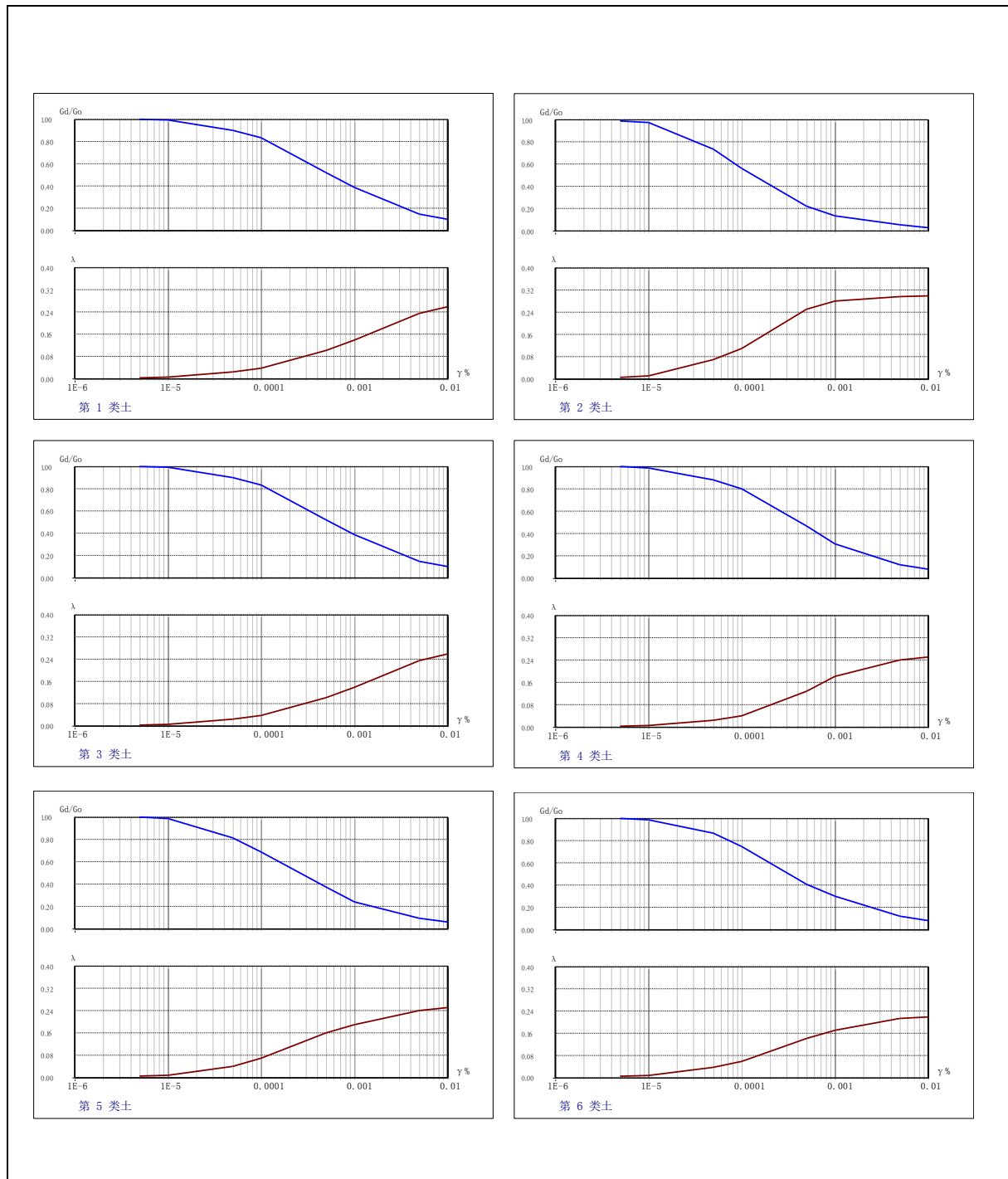


圖 6.2 場地土層反應分析中土體動力非線性特性曲線圖

### 6.2.3 計算結果

根據工程結構抗震設計的要求，對工程場地進行場地地震反應計算時，分別以工程場地 50 年超越概率為 63%、10% 及 2% 基岩地震動加速度時程（各 3 條樣本），按幅值縮小一半確定一維土層反應分析模型的計算基底入射波輸入量。對每一種情況分別計算出地表面處地震動反應的加速度時程和反應譜值，表 6.30 為工程場地各鑽孔 50 年

超越概率 63%、50%、10%、2% 的水準向加速度峰值及其平均值圖，圖 6.3 - 6.29 為場地各鑽孔 50 年 3 個超越概率水準的場地加速度時程和場地相關加速度反應譜。

**表 6.30 工程場地各鑽孔 50 年超越概率 63%、50%、10%、2% 的水平向加速度峰值及其平均值 (gal) (第 1 頁共 4 頁)**

| 超越概率 | 鑽孔號  | 輸入 1 | 輸入 2 | 輸入 3 | 單孔<br>平均值 | 總<br>平均值 |
|------|------|------|------|------|-----------|----------|
| 63%  | BH01 | 42.2 | 49.8 | 40.3 | 44.1      | 48.6     |
|      | BH02 | 50.8 | 55.7 | 48.6 | 51.7      |          |
|      | BH08 | 43.9 | 53.7 | 47.4 | 48.3      |          |
|      | BH12 | 39.8 | 37.1 | 37.5 | 38.1      |          |
|      | BH13 | 43.3 | 51.5 | 43.9 | 46.2      |          |
|      | BH14 | 48.7 | 52.7 | 46.1 | 49.1      |          |
|      | BH15 | 70.9 | 58.2 | 73.1 | 67.4      |          |
|      | BH16 | 44.1 | 42.9 | 45.1 | 44.0      |          |
|      | BH20 | 46.3 | 48.7 | 39.2 | 44.7      |          |
|      | BH21 | 50.0 | 62.4 | 61.6 | 58.0      |          |
|      | BH22 | 43.1 | 46.0 | 43.7 | 44.3      |          |
|      | BH23 | 53.4 | 51.6 | 51.9 | 52.3      |          |
|      | BH24 | 66.3 | 66.6 | 61.2 | 64.7      |          |
|      | BH26 | 44.0 | 46.8 | 43.6 | 44.8      |          |
|      | BH27 | 38.5 | 38.0 | 44.9 | 40.5      |          |
|      | BH29 | 39.4 | 35.6 | 37.3 | 37.4      |          |
|      | BH30 | 35.8 | 46.2 | 44.1 | 42.0      |          |
|      | BH32 | 43.3 | 64.0 | 54.5 | 53.9      |          |
|      | BH36 | 42.7 | 54.7 | 44.1 | 47.2      |          |
|      | BH39 | 39.2 | 44.3 | 37.6 | 40.3      |          |
|      | BH41 | 63.0 | 54.2 | 63.9 | 60.4      |          |
|      | BH42 | 56.8 | 63.9 | 57.1 | 59.3      |          |
|      | BH43 | 44.6 | 51.7 | 47.4 | 47.9      |          |
|      | BH44 | 50.9 | 60.8 | 52.7 | 54.8      |          |
|      | BH45 | 56.2 | 58.1 | 62.5 | 58.9      |          |
|      | BH49 | 37.4 | 41.4 | 36.6 | 38.5      |          |
|      | BH50 | 32.0 | 32.8 | 33.7 | 32.8      |          |

**表 6.30 工程場地各鑽孔 50 年超越概率 63%、50%、10%、2% 的水平向加速度峰值及其平均值 (gal) (第 2 頁共 4 頁)**

| 超越概率 | 鑽孔號  | 輸入 1 | 輸入 2 | 輸入 3 | 單孔<br>平均值 | 總<br>平均值 |
|------|------|------|------|------|-----------|----------|
| 50%  | BH01 | 60.5 | 56.7 | 60.2 | 59.1      | 60.7     |
|      | BH02 | 72.8 | 67.3 | 73.3 | 71.1      |          |
|      | BH08 | 62.2 | 58.4 | 61.7 | 60.8      |          |
|      | BH12 | 51.6 | 46.0 | 48.3 | 48.6      |          |
|      | BH13 | 61.7 | 57.5 | 61.0 | 60.1      |          |
|      | BH14 | 58.9 | 60.2 | 63.4 | 60.8      |          |
|      | BH15 | 92.5 | 86.8 | 86.6 | 88.7      |          |
|      | BH16 | 55.7 | 51.6 | 55.2 | 54.2      |          |
|      | BH20 | 58.9 | 58.2 | 62.7 | 59.9      |          |
|      | BH21 | 66.1 | 69.4 | 73.3 | 69.6      |          |
|      | BH22 | 66.3 | 51.5 | 58.0 | 58.6      |          |
|      | BH23 | 66.7 | 63.7 | 67.9 | 66.1      |          |
|      | BH24 | 78.7 | 68.6 | 78.5 | 75.3      |          |
|      | BH26 | 58.1 | 47.0 | 54.7 | 53.3      |          |
|      | BH27 | 48.0 | 43.5 | 42.6 | 44.7      |          |
|      | BH29 | 42.1 | 39.8 | 41.7 | 41.2      |          |
|      | BH30 | 57.1 | 46.2 | 50.9 | 51.4      |          |
|      | BH32 | 72.8 | 56.4 | 67.4 | 65.5      |          |
|      | BH36 | 67.0 | 59.8 | 69.8 | 65.5      |          |
|      | BH39 | 53.8 | 48.7 | 53.5 | 52.0      |          |
|      | BH41 | 75.1 | 64.8 | 71.7 | 70.5      |          |
|      | BH42 | 74.1 | 60.6 | 76.2 | 70.3      |          |
|      | BH43 | 58.9 | 61.7 | 60.1 | 60.2      |          |
|      | BH44 | 72.4 | 67.9 | 66.8 | 69.0      |          |
|      | BH45 | 74.5 | 67.6 | 65.0 | 69.1      |          |
|      | BH49 | 53.3 | 53.1 | 46.7 | 51.0      |          |
|      | BH50 | 42.6 | 41.0 | 42.9 | 42.2      |          |

**表 6.30 工程場地各鑽孔 50 年超越概率 63%、50%、10%、2% 的水準向加速度峰值及其平均值 (gal) (第 3 頁共 4 頁)**

| 超越概率 | 鑽孔號  | 輸入 1  | 輸入 2  | 輸入 3  | 單孔<br>平均值 | 總<br>平均值 |
|------|------|-------|-------|-------|-----------|----------|
| 10%  | BH01 | 94.5  | 77.5  | 88.3  | 86.8      | 119.3    |
|      | BH02 | 128.5 | 107.7 | 132.8 | 123.0     |          |
|      | BH08 | 122.1 | 96.2  | 101.0 | 106.4     |          |
|      | BH12 | 137.6 | 140.1 | 132.3 | 136.7     |          |
|      | BH13 | 106.6 | 76.8  | 92.7  | 92.0      |          |
|      | BH14 | 144.8 | 126.9 | 150.8 | 140.9     |          |
|      | BH15 | 239.1 | 246.5 | 197.4 | 227.6     |          |
|      | BH16 | 165.7 | 137.3 | 152.7 | 151.9     |          |
|      | BH20 | 124.7 | 106.7 | 122.7 | 118.0     |          |
|      | BH21 | 127.5 | 173.0 | 160.1 | 153.6     |          |
|      | BH22 | 110.3 | 101.7 | 106.2 | 106.1     |          |
|      | BH23 | 113.8 | 126.0 | 120.2 | 120.0     |          |
|      | BH24 | 124.3 | 163.3 | 150.2 | 145.9     |          |
|      | BH26 | 100.0 | 91.0  | 112.3 | 101.1     |          |
|      | BH27 | 79.2  | 85.5  | 89.1  | 84.6      |          |
|      | BH29 | 72.0  | 63.4  | 69.8  | 68.4      |          |
|      | BH30 | 75.6  | 77.3  | 99.1  | 84.0      |          |
|      | BH32 | 102.2 | 88.9  | 112.7 | 101.3     |          |
|      | BH36 | 129.3 | 110.9 | 128.0 | 122.7     |          |
|      | BH39 | 87.9  | 68.5  | 78.8  | 78.4      |          |
|      | BH41 | 206.5 | 202.0 | 179.0 | 195.8     |          |
|      | BH42 | 115.0 | 122.9 | 133.2 | 123.7     |          |
|      | BH43 | 87.3  | 84.7  | 90.0  | 87.3      |          |
|      | BH44 | 108.5 | 97.1  | 114.9 | 106.8     |          |
|      | BH45 | 138.3 | 163.1 | 173.9 | 158.4     |          |
|      | BH49 | 77.9  | 81.4  | 81.0  | 80.1      |          |
|      | BH50 | 119.7 | 117.5 | 117.8 | 118.3     |          |

**表 6.30 工程場地各鑽孔 50 年超越概率 63%、50%、10%、2% 的水準向加速度峰值及其平均值 (gal) (第 4 頁共 4 頁)**

| 超越概率 | 鑽孔號  | 輸入 1  | 輸入 2  | 輸入 3  | 單孔<br>平均值 | 總<br>平均值 |
|------|------|-------|-------|-------|-----------|----------|
| 2%   | BH01 | 118.5 | 118.5 | 157.0 | 131.3     | 180.8    |
|      | BH02 | 157.2 | 152.8 | 196.1 | 168.7     |          |
|      | BH08 | 144.1 | 127.6 | 209.1 | 160.3     |          |
|      | BH12 | 252.7 | 279.1 | 229.8 | 253.8     |          |
|      | BH13 | 129.7 | 105.0 | 157.4 | 130.7     |          |
|      | BH14 | 178.1 | 177.6 | 167.2 | 174.3     |          |
|      | BH15 | 335.6 | 342.5 | 395.4 | 357.8     |          |
|      | BH16 | 293.7 | 346.3 | 312.4 | 317.5     |          |
|      | BH20 | 150.7 | 142.8 | 179.3 | 157.6     |          |
|      | BH21 | 234.7 | 225.5 | 189.6 | 216.6     |          |
|      | BH22 | 142.5 | 141.4 | 172.5 | 152.1     |          |
|      | BH23 | 176.4 | 167.7 | 195.0 | 179.7     |          |
|      | BH24 | 238.2 | 204.3 | 201.3 | 214.6     |          |
|      | BH26 | 145.9 | 136.1 | 149.2 | 143.7     |          |
|      | BH27 | 125.6 | 111.8 | 119.9 | 119.1     |          |
|      | BH29 | 103.4 | 95.1  | 107.8 | 102.1     |          |
|      | BH30 | 119.0 | 109.6 | 105.6 | 111.4     |          |
|      | BH32 | 147.3 | 151.8 | 158.4 | 152.5     |          |
|      | BH36 | 166.1 | 173.9 | 185.3 | 175.1     |          |
|      | BH39 | 109.4 | 91.8  | 148.8 | 116.7     |          |
|      | BH41 | 317.7 | 338.1 | 375.4 | 343.7     |          |
|      | BH42 | 195.5 | 170.3 | 154.5 | 173.4     |          |
|      | BH43 | 124.0 | 101.6 | 128.2 | 117.9     |          |
|      | BH44 | 136.4 | 143.7 | 154.4 | 144.8     |          |
|      | BH45 | 234.8 | 220.1 | 204.9 | 219.9     |          |
|      | BH49 | 115.8 | 106.3 | 131.6 | 117.9     |          |
|      | BH50 | 223.5 | 234.8 | 224.9 | 227.7     |          |

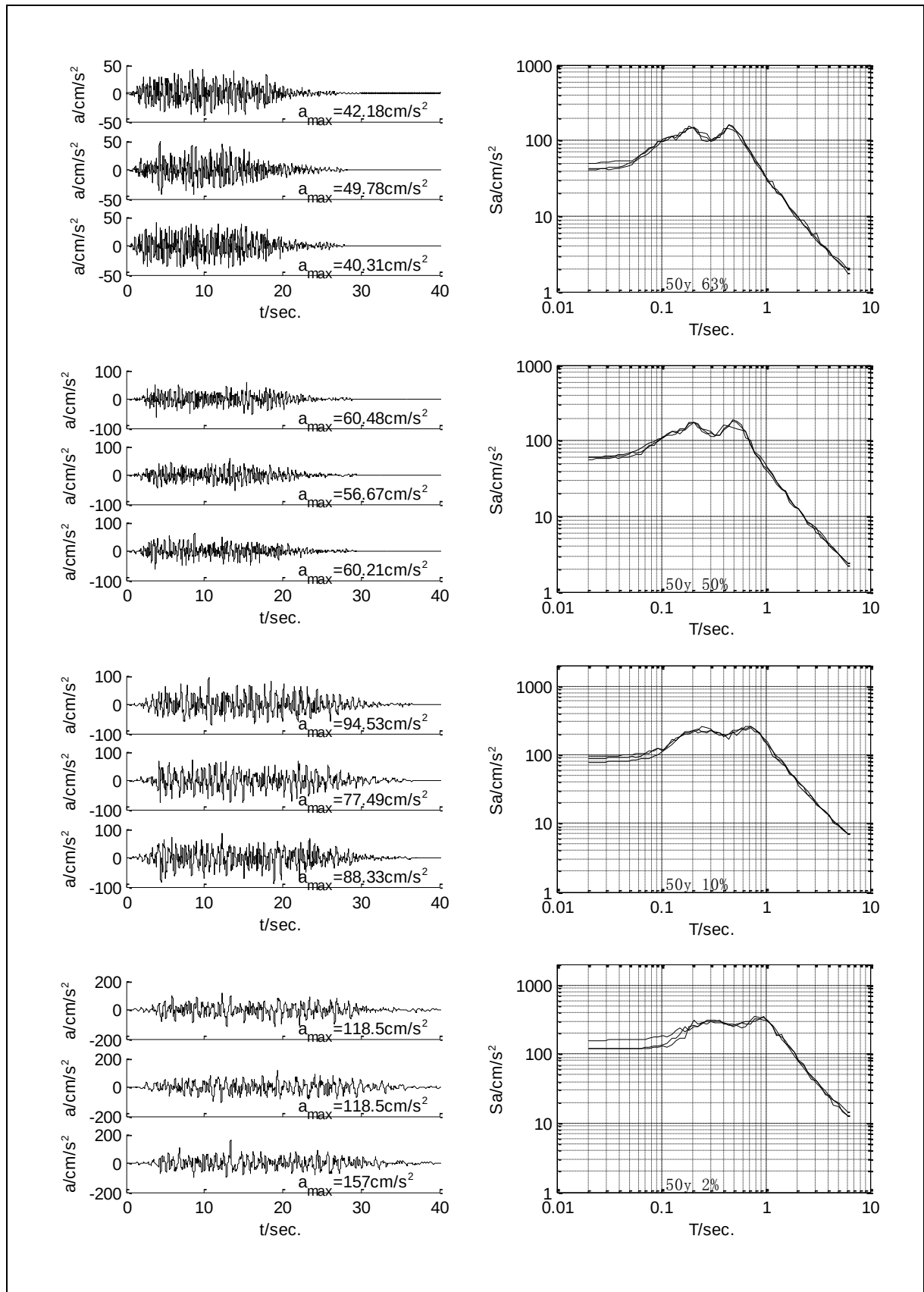


圖 6.3 BH01 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

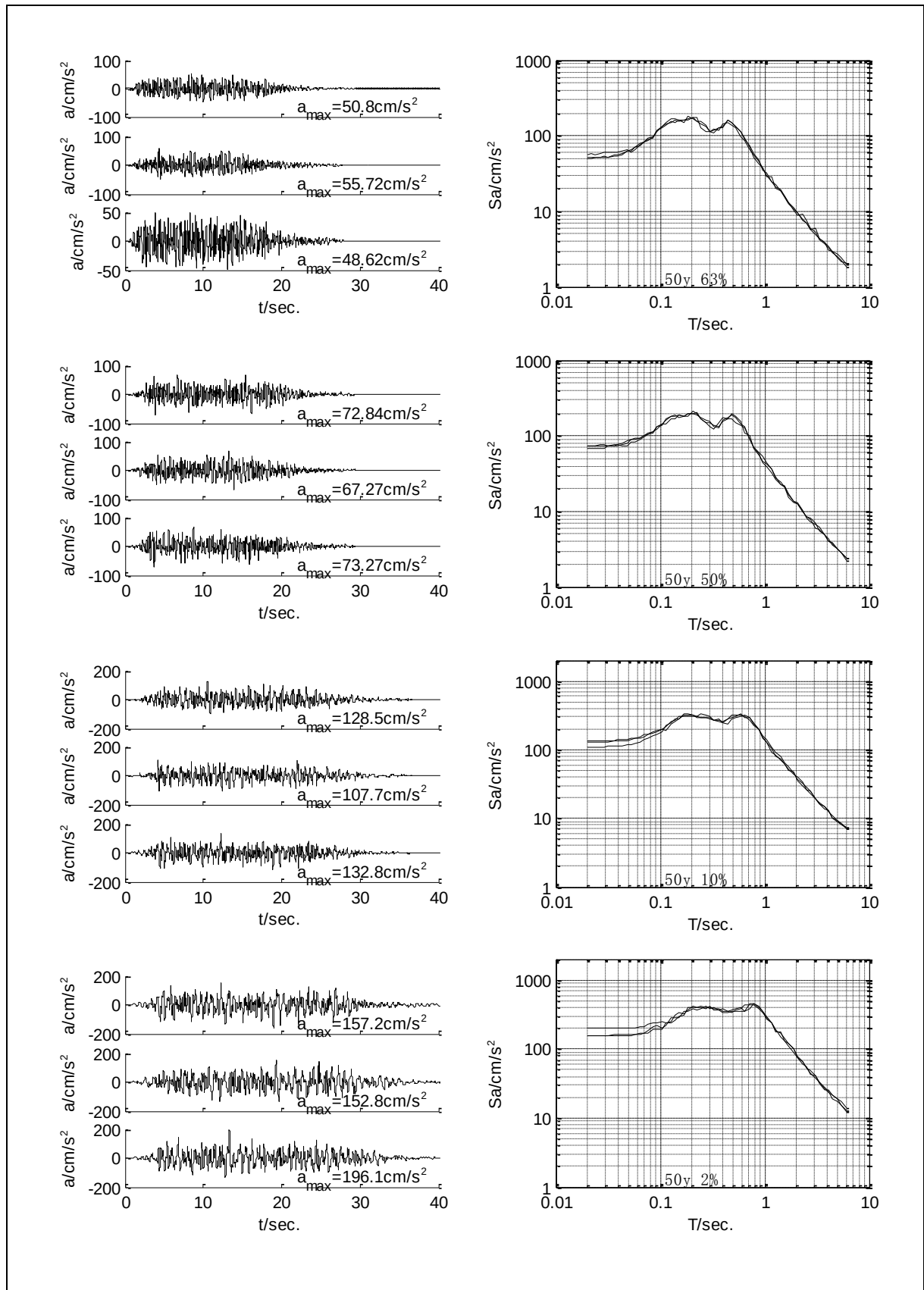


圖 6.4 BH02 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

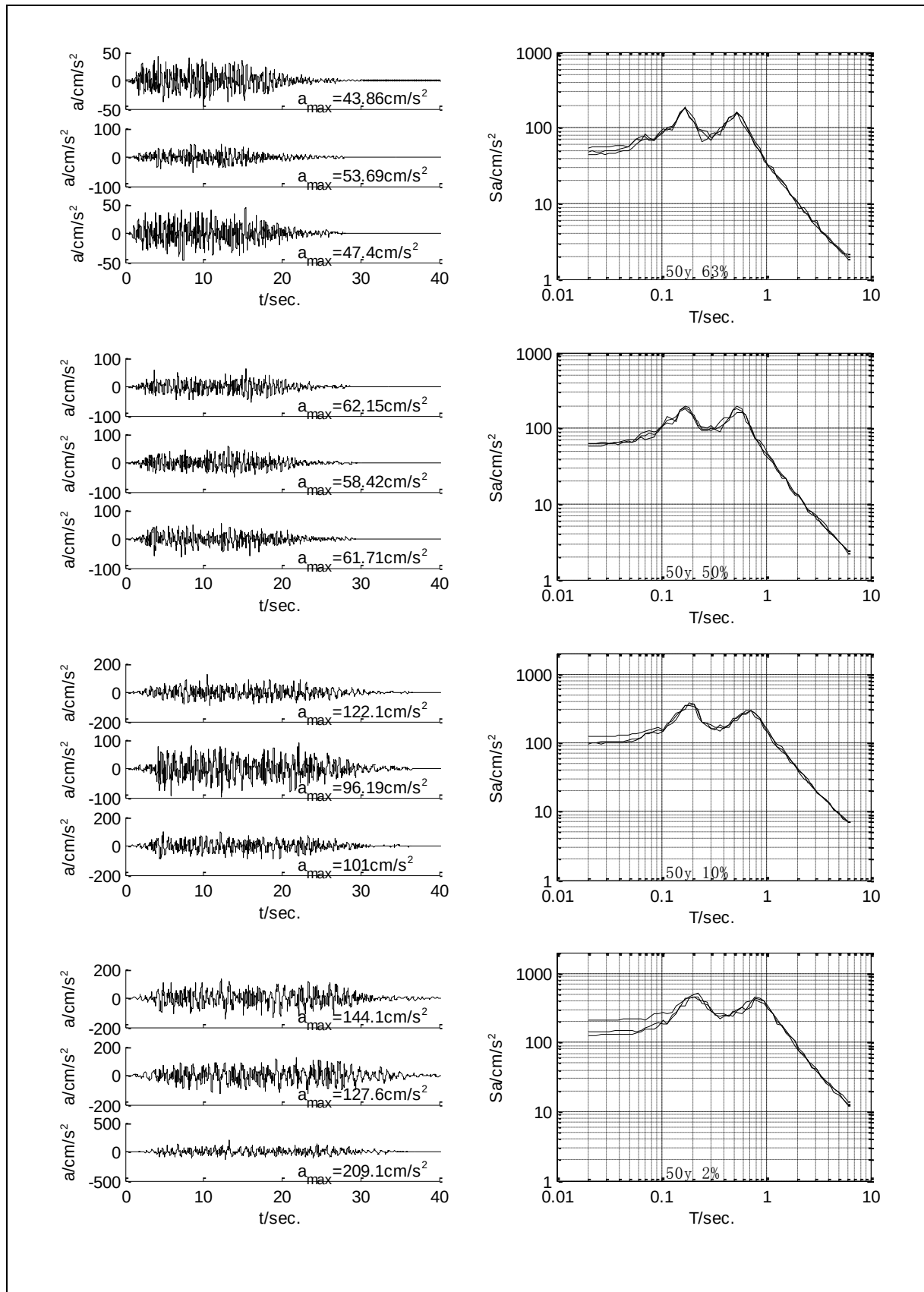


圖 6.5 BH08 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜



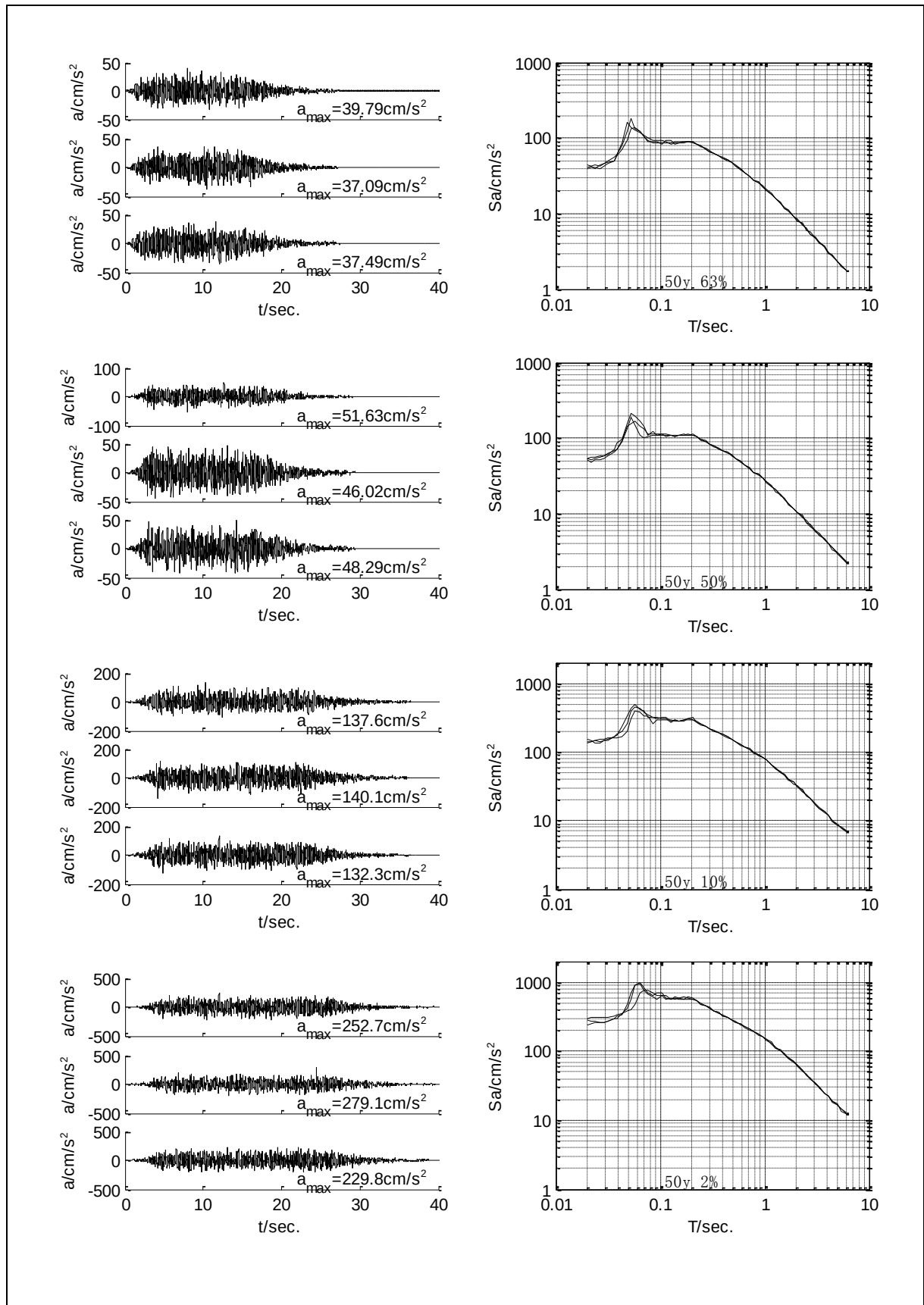


圖 6.6 BH12 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

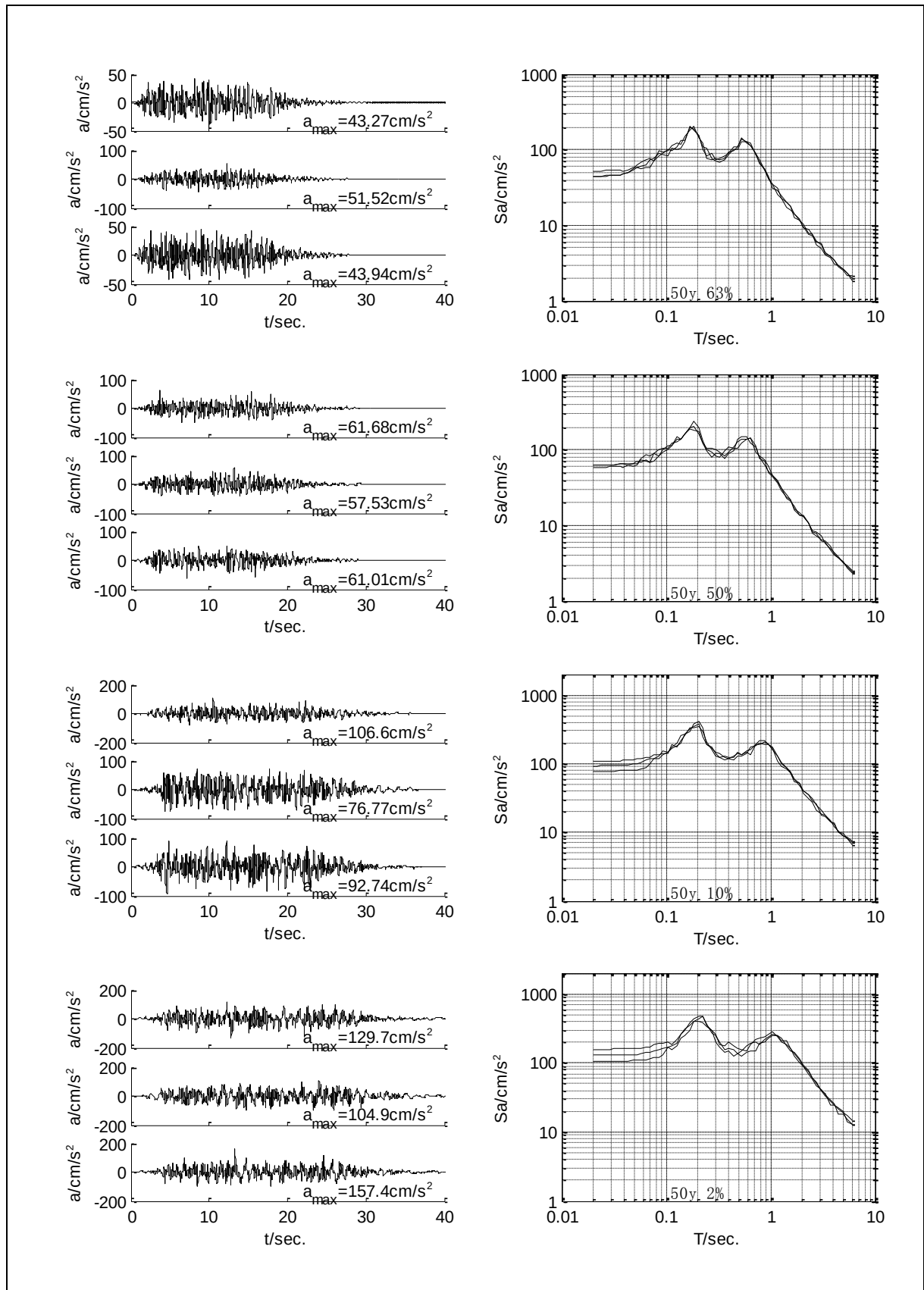


圖 6.7 BH13 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

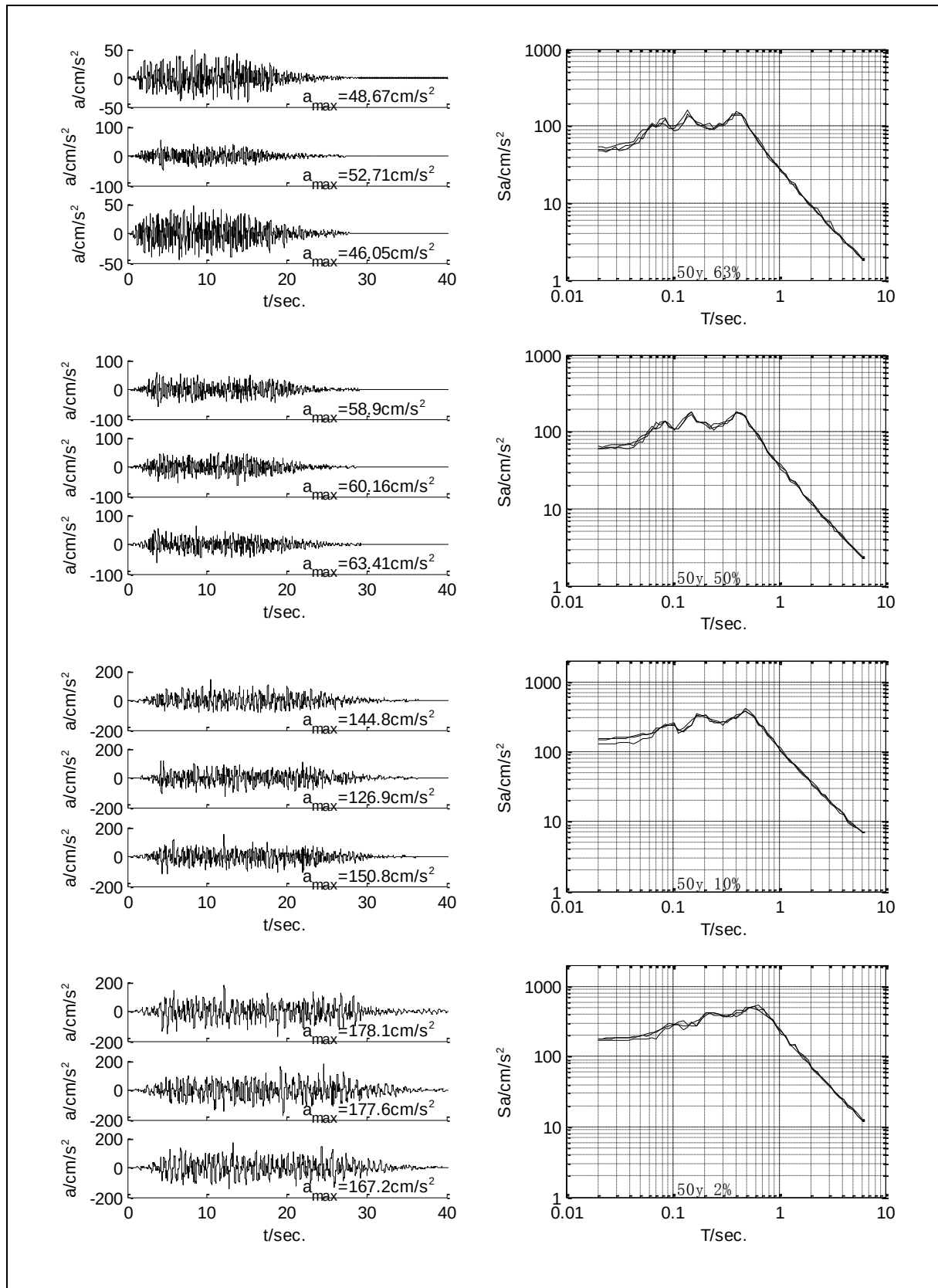


圖 6.8 BH14 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

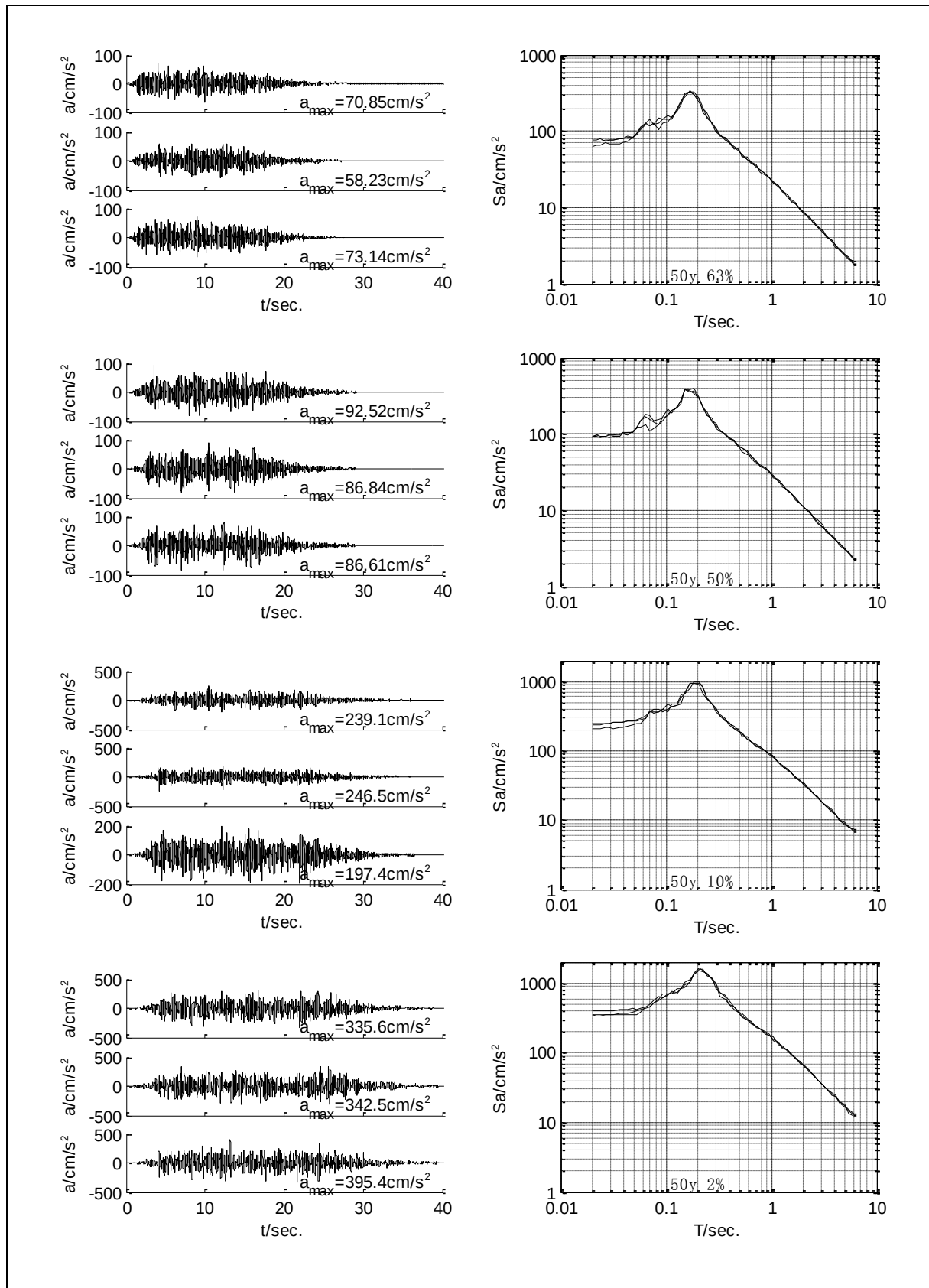


圖 6.9 BH15 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

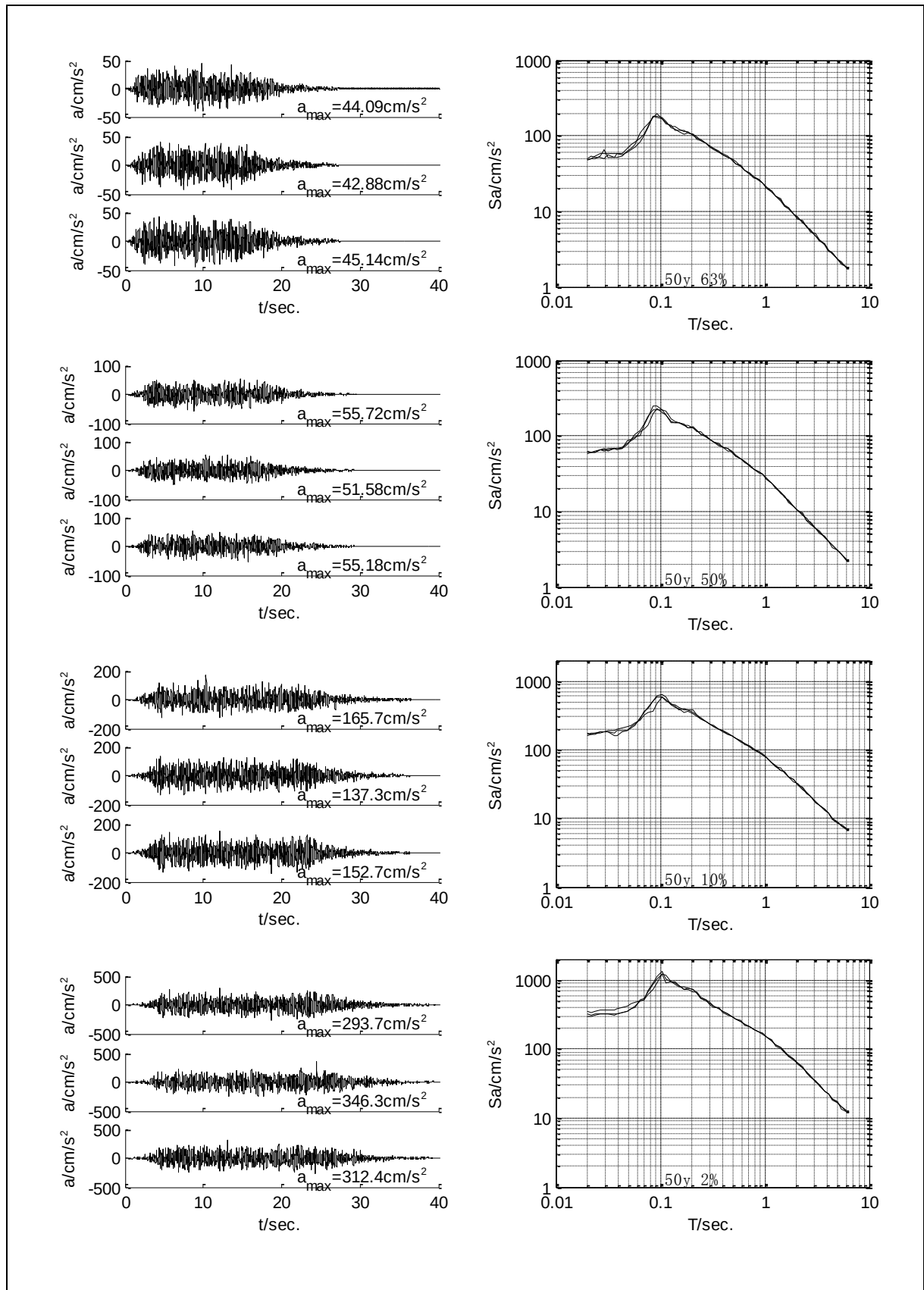


圖 6.10 BH16 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

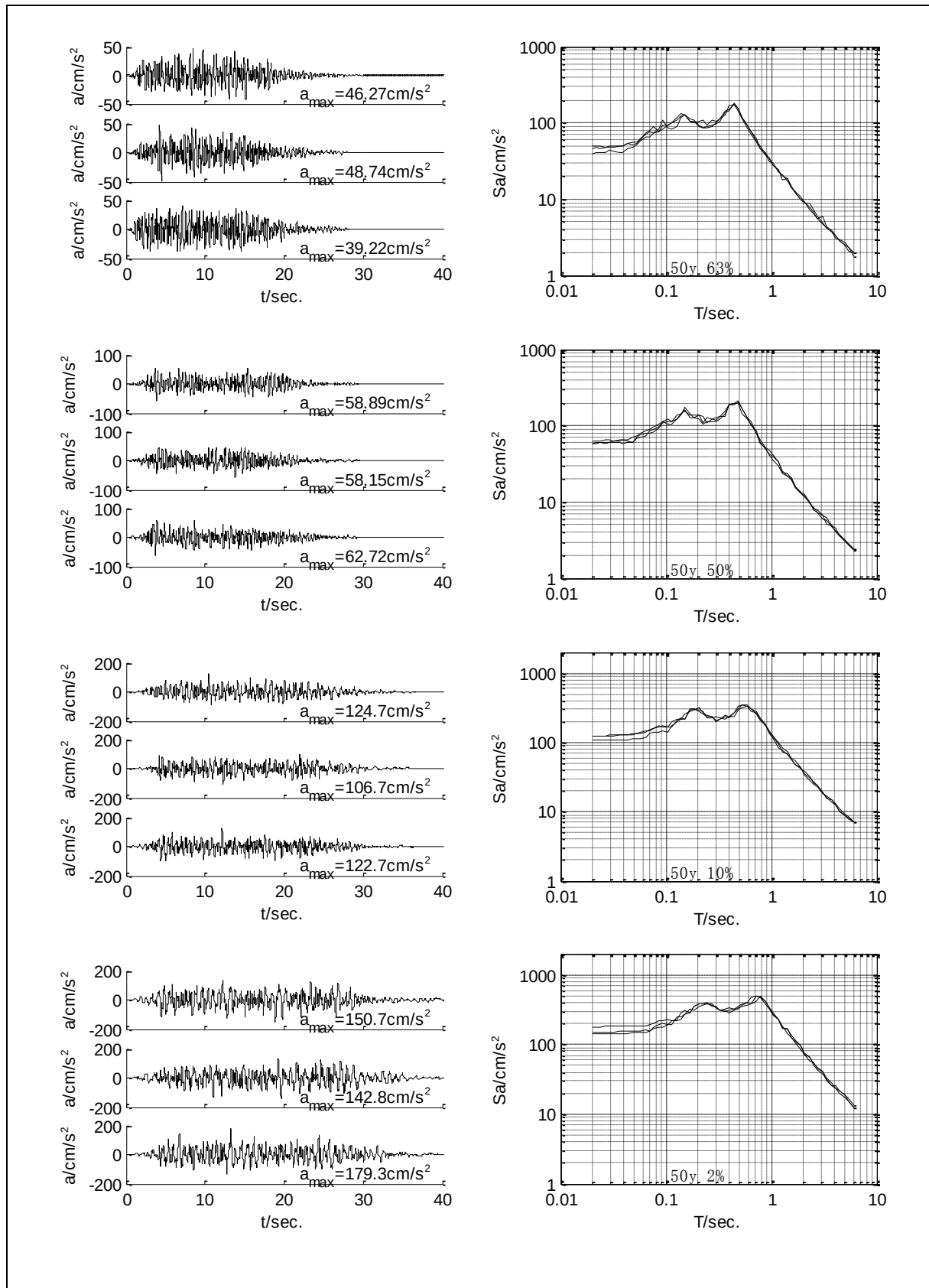


圖 6.11 BH20 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

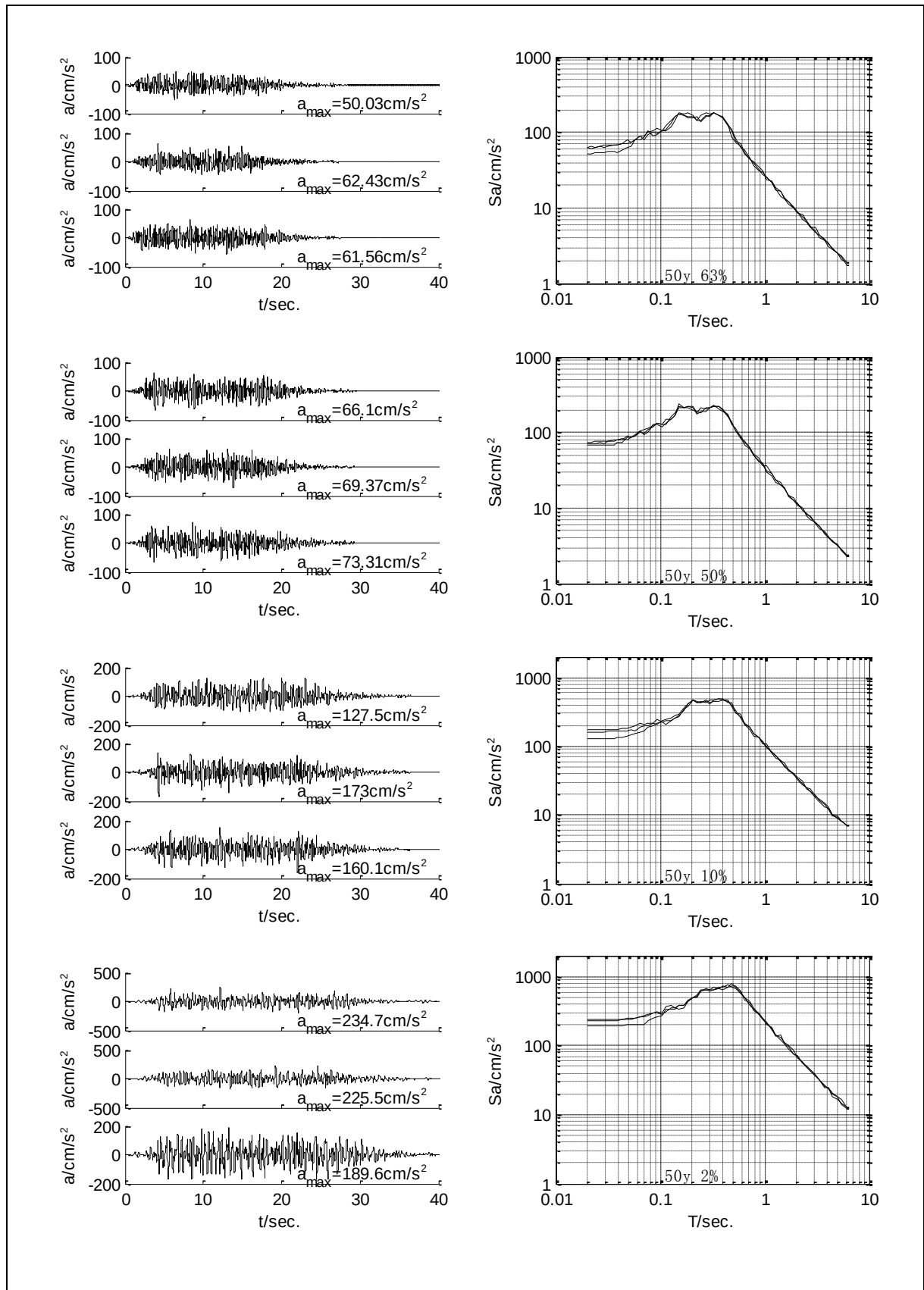


圖 6.12 BH21 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

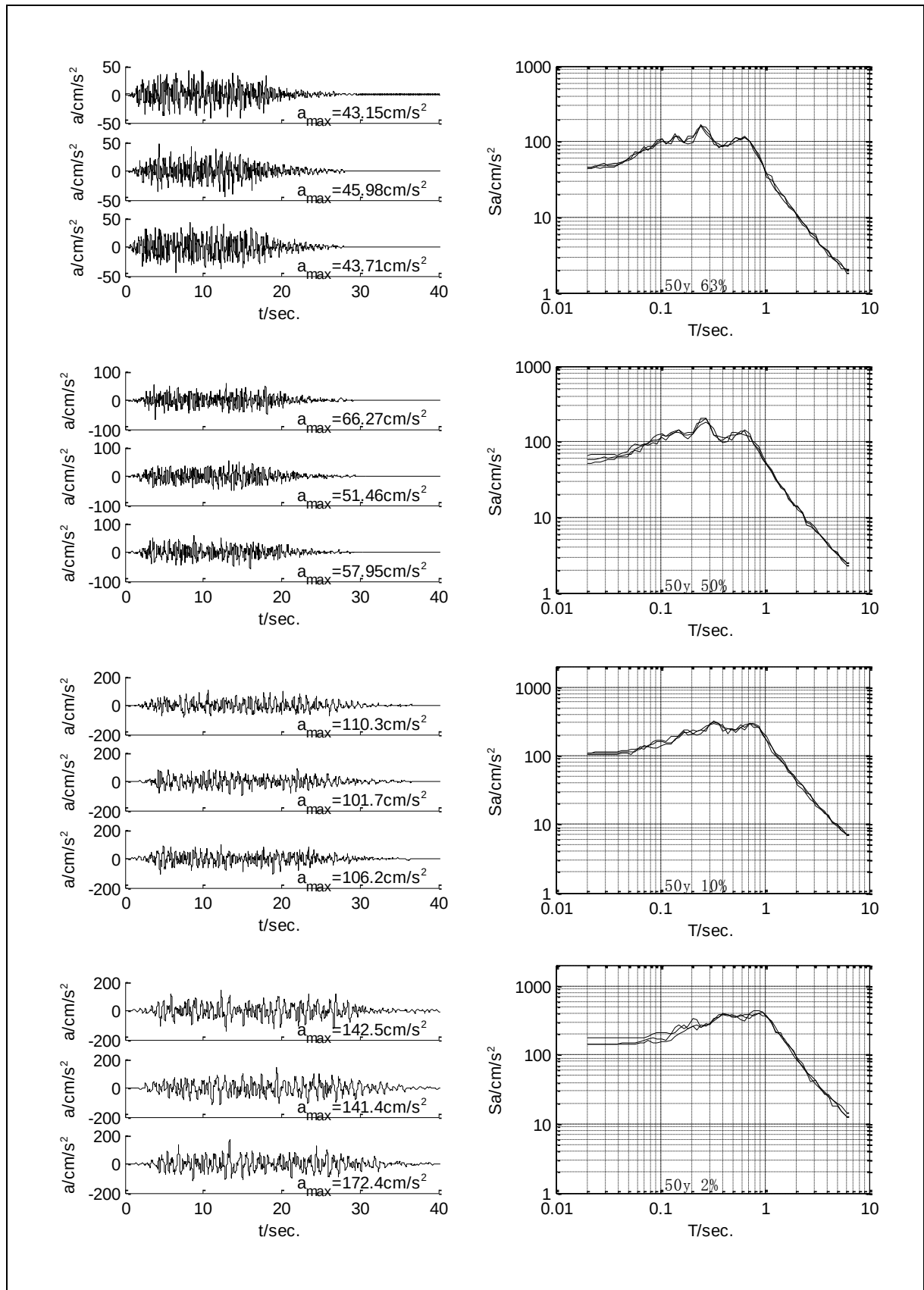


圖 6.13 BH22 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜



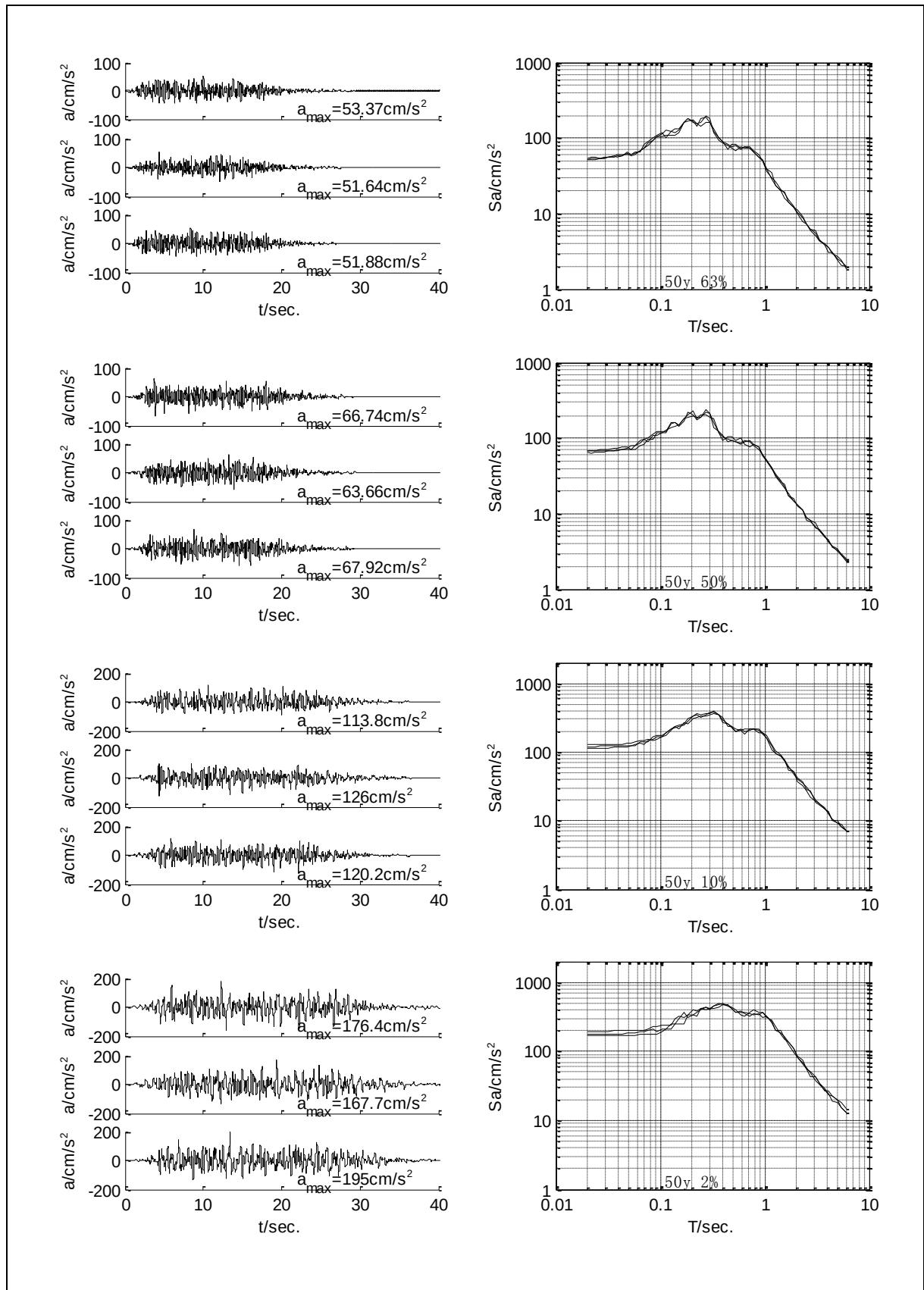


圖 6.14 BH23 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

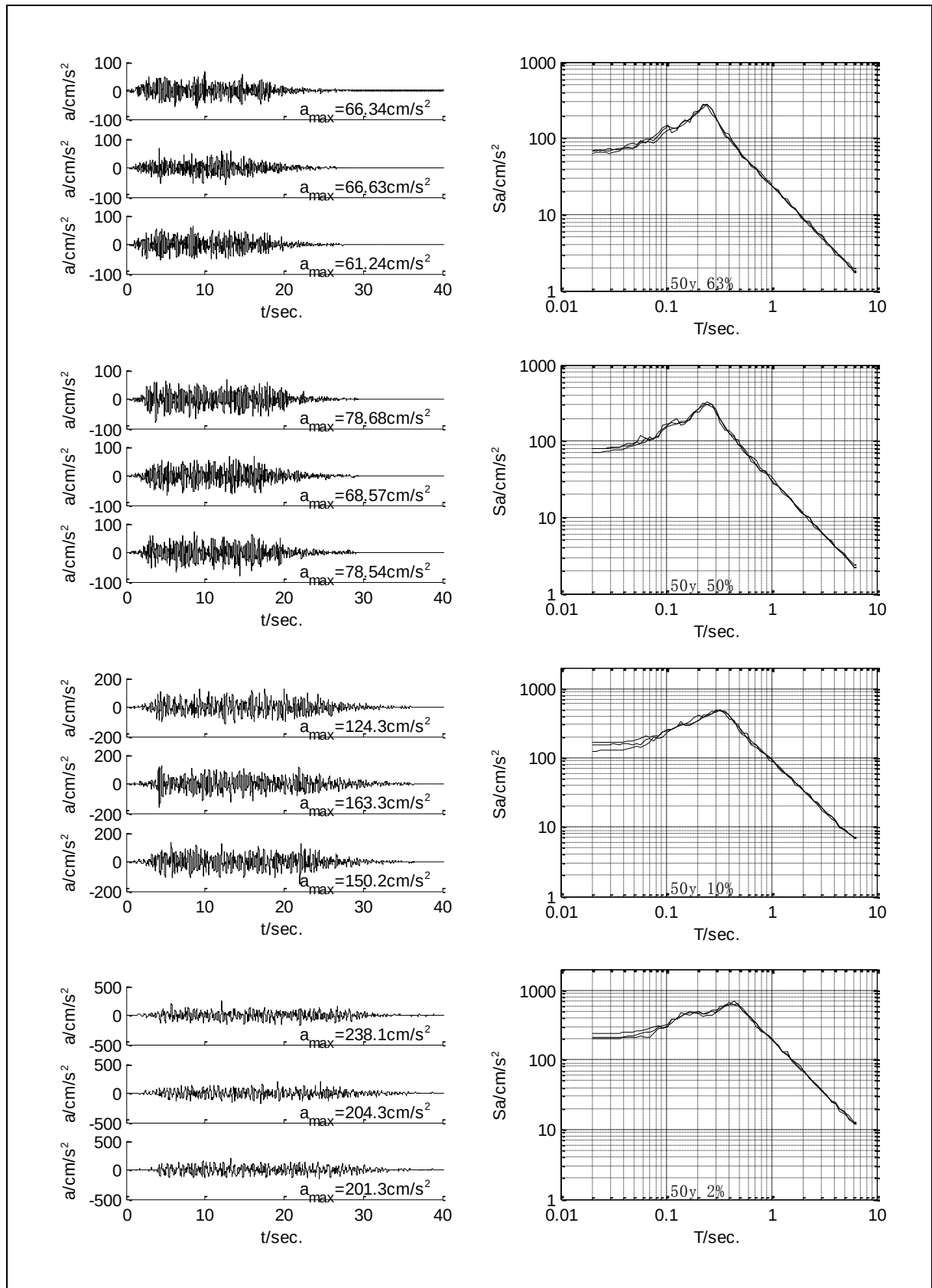


圖 6.15 BH24 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

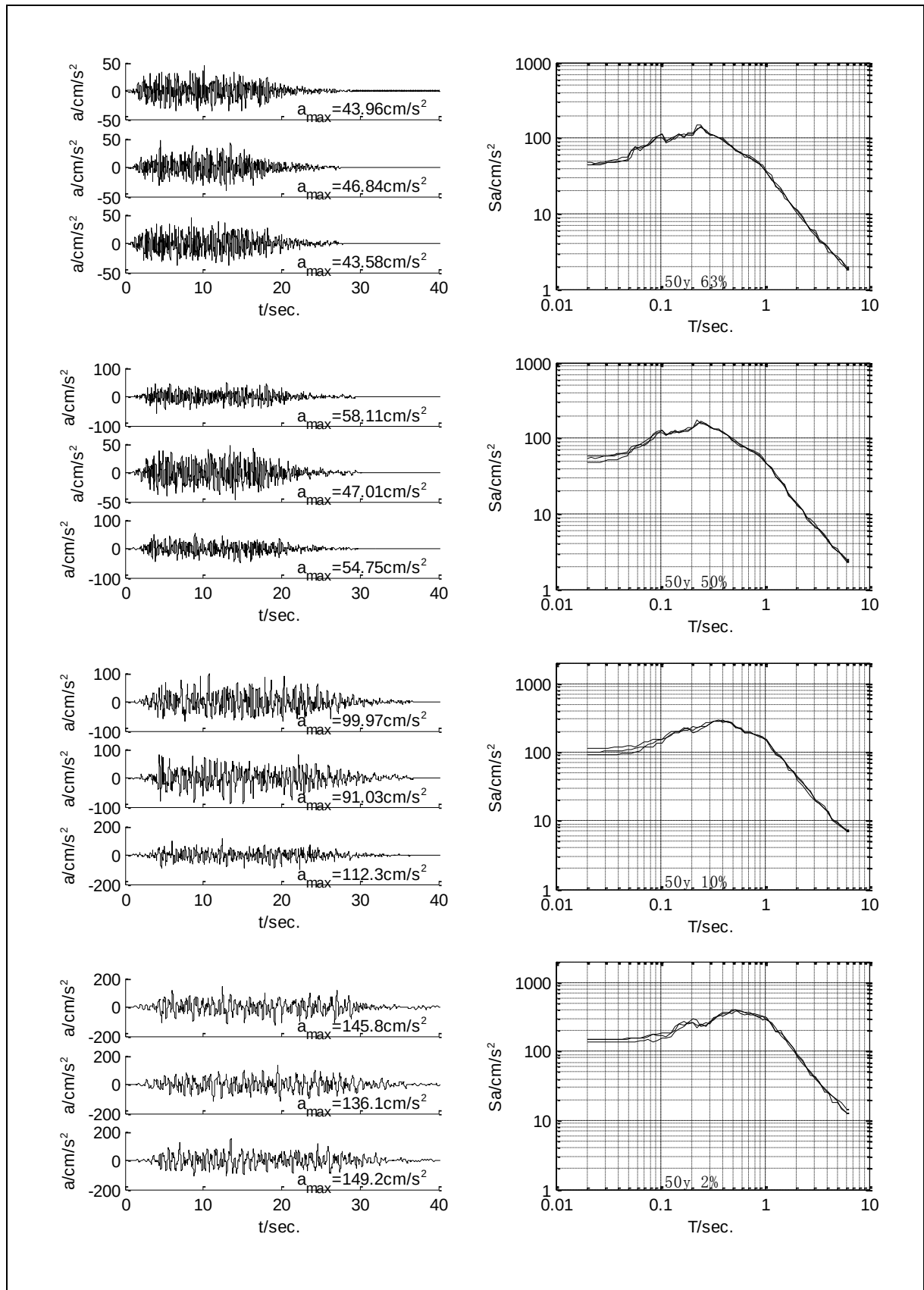


圖 6.16 BH26 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

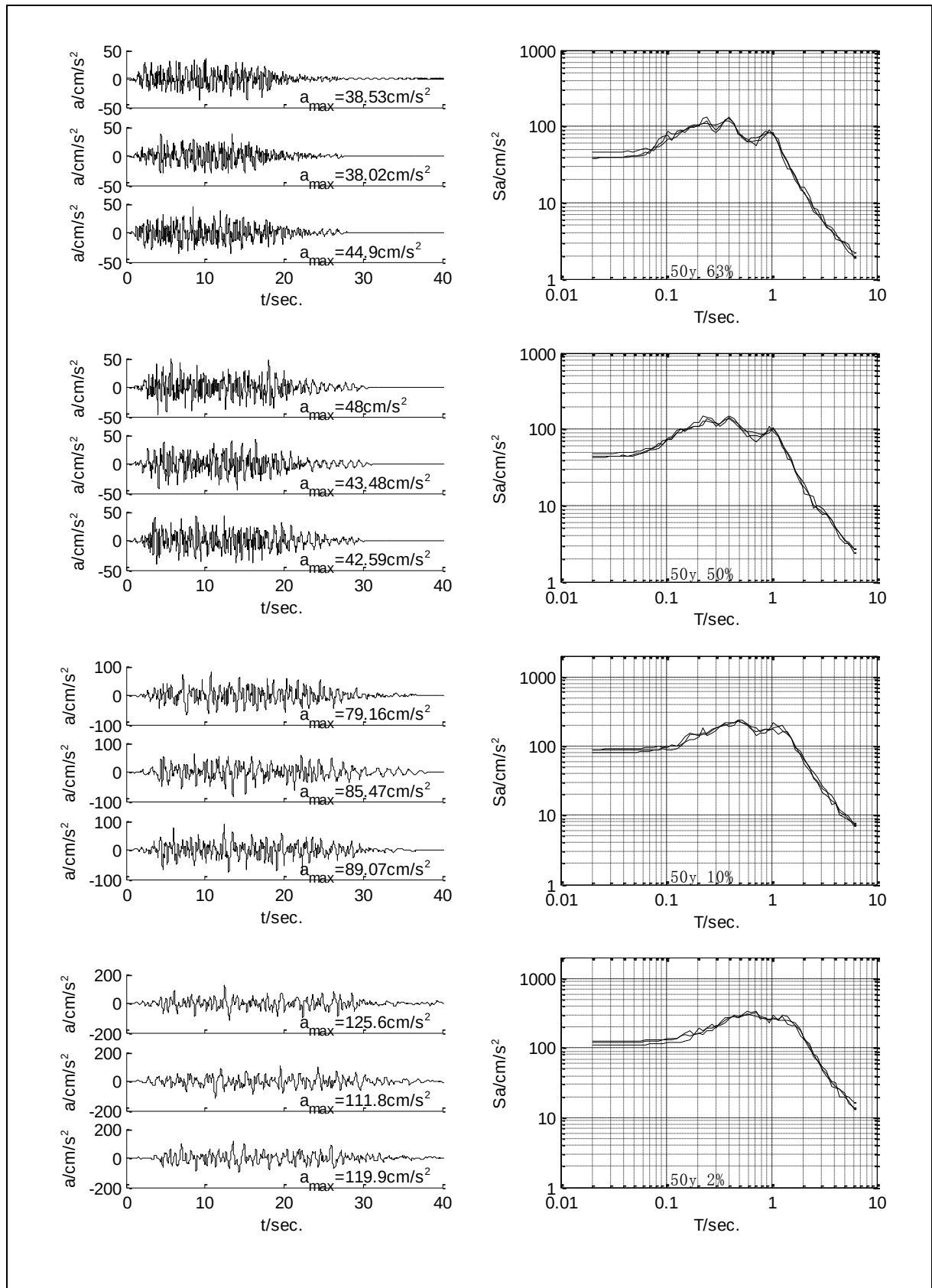


圖 6.17 BH27 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

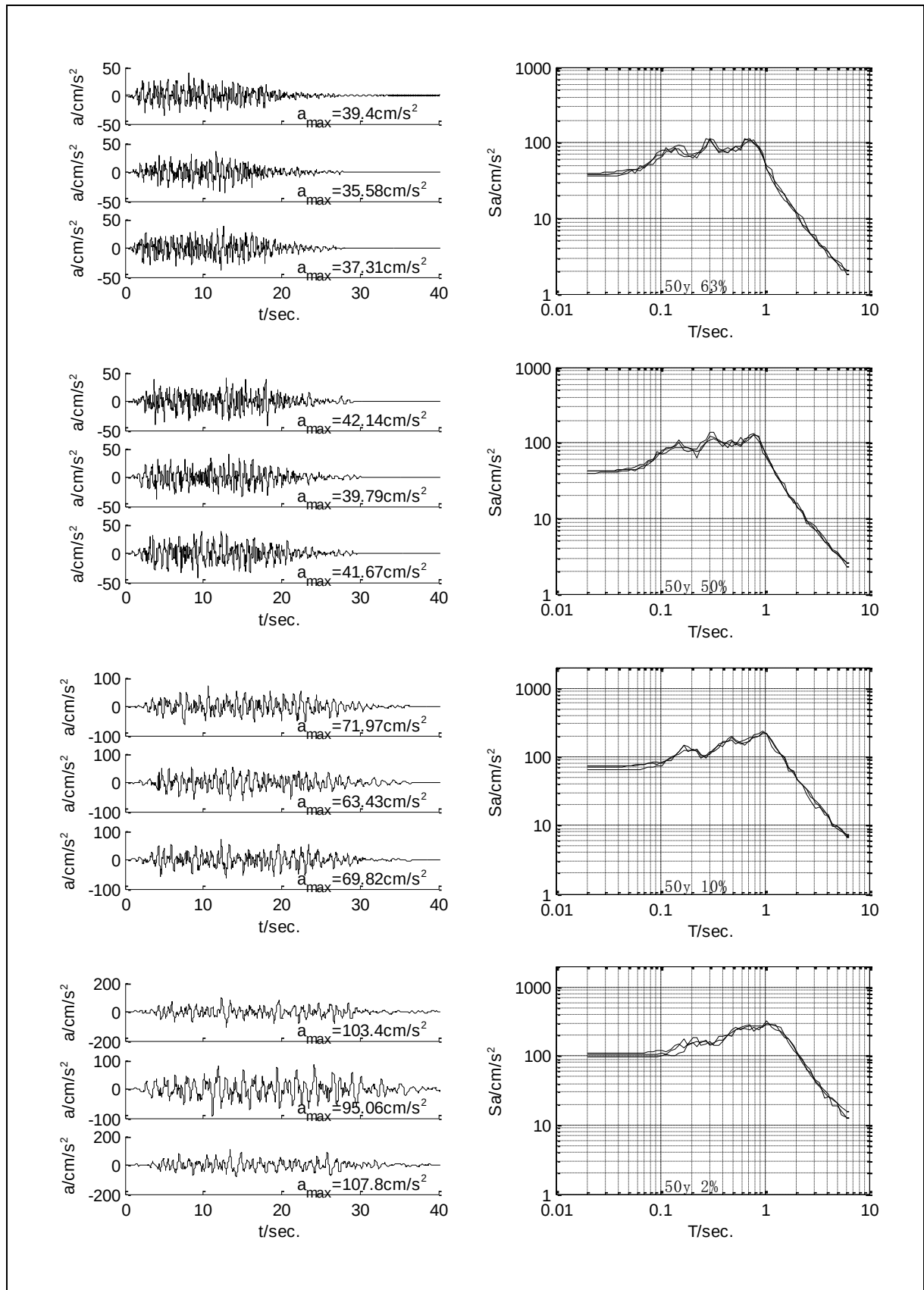


圖 6.18 BH29 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

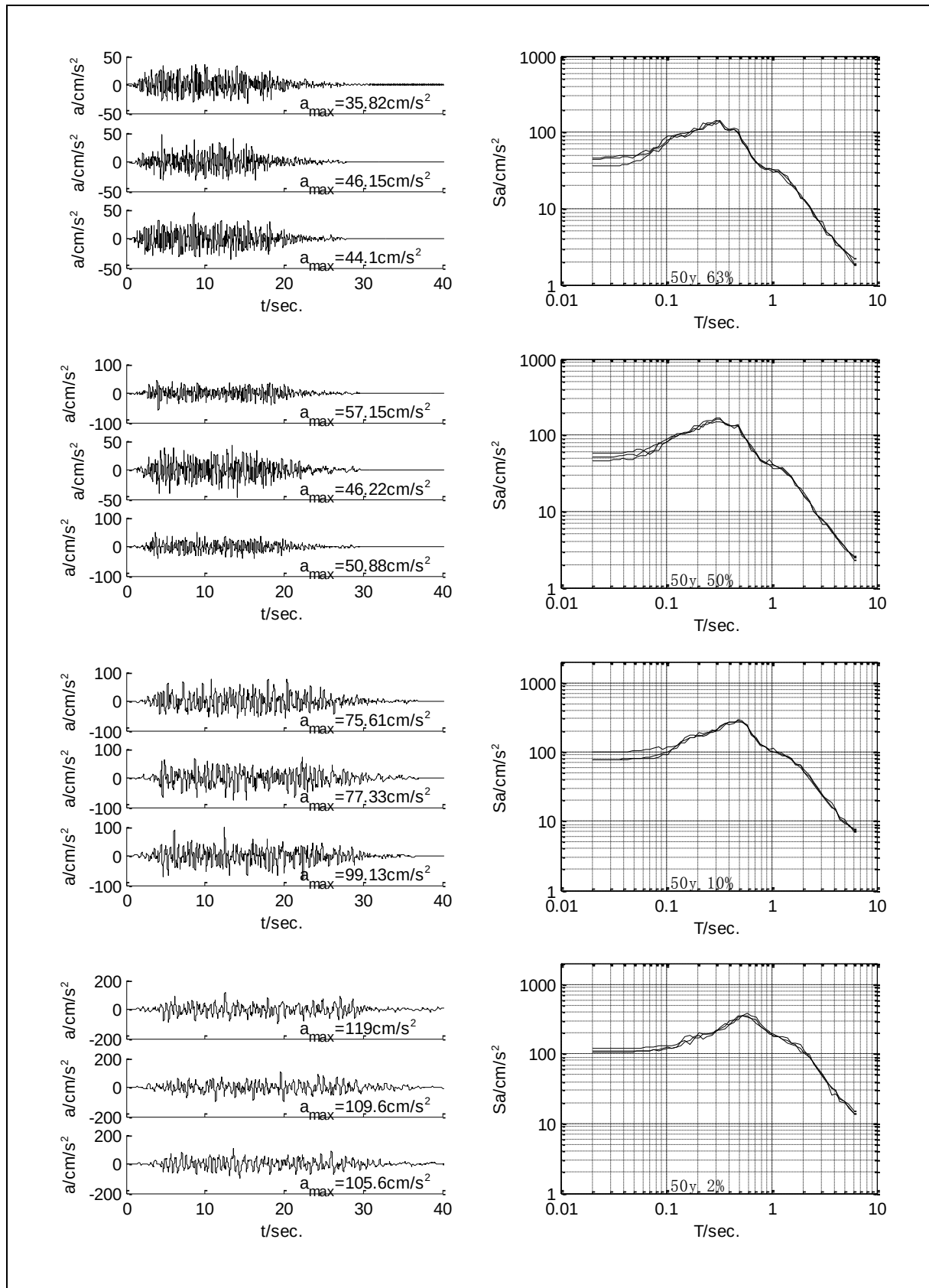


圖 6.19 BH30 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

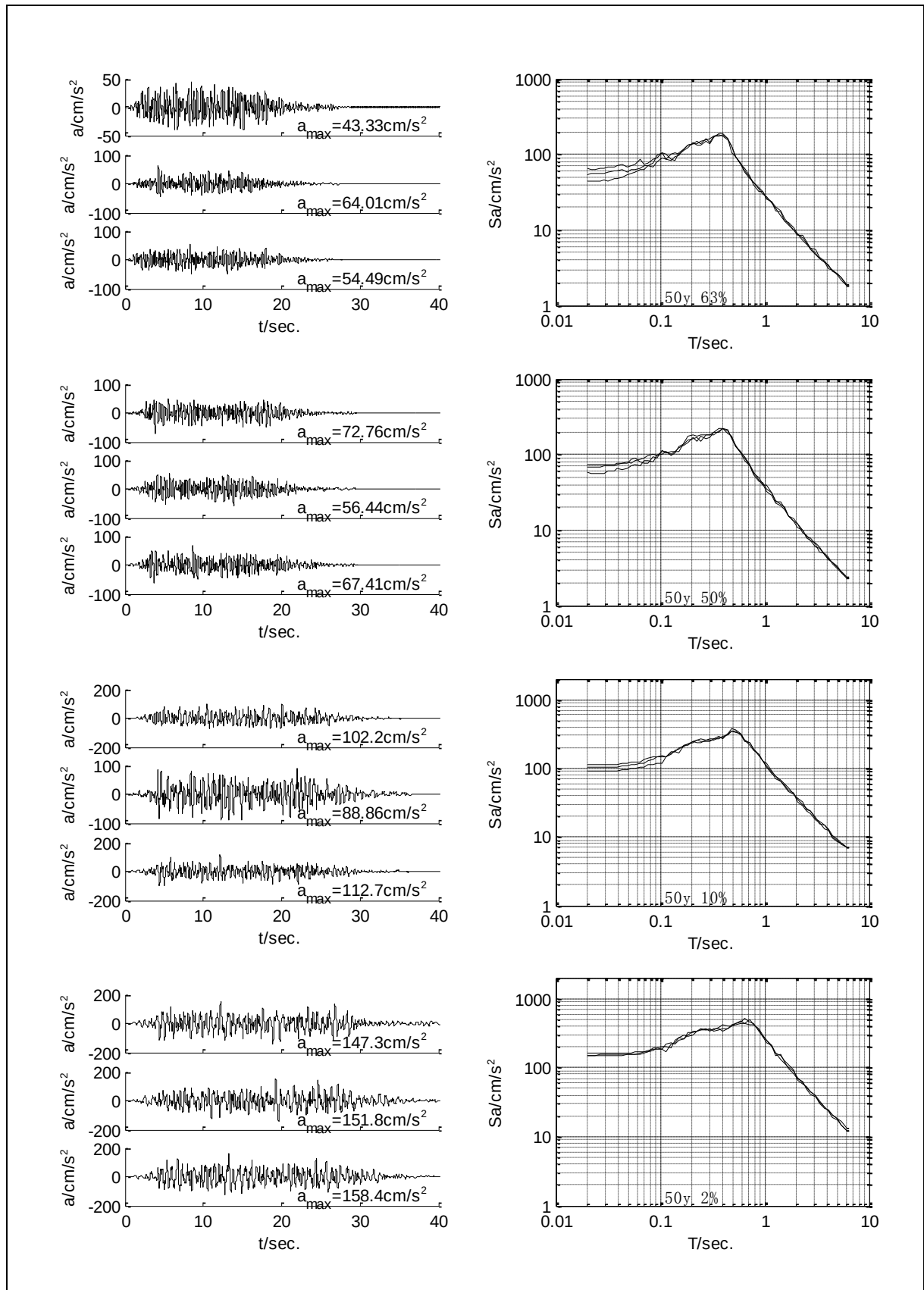


圖 6.20 BH32 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

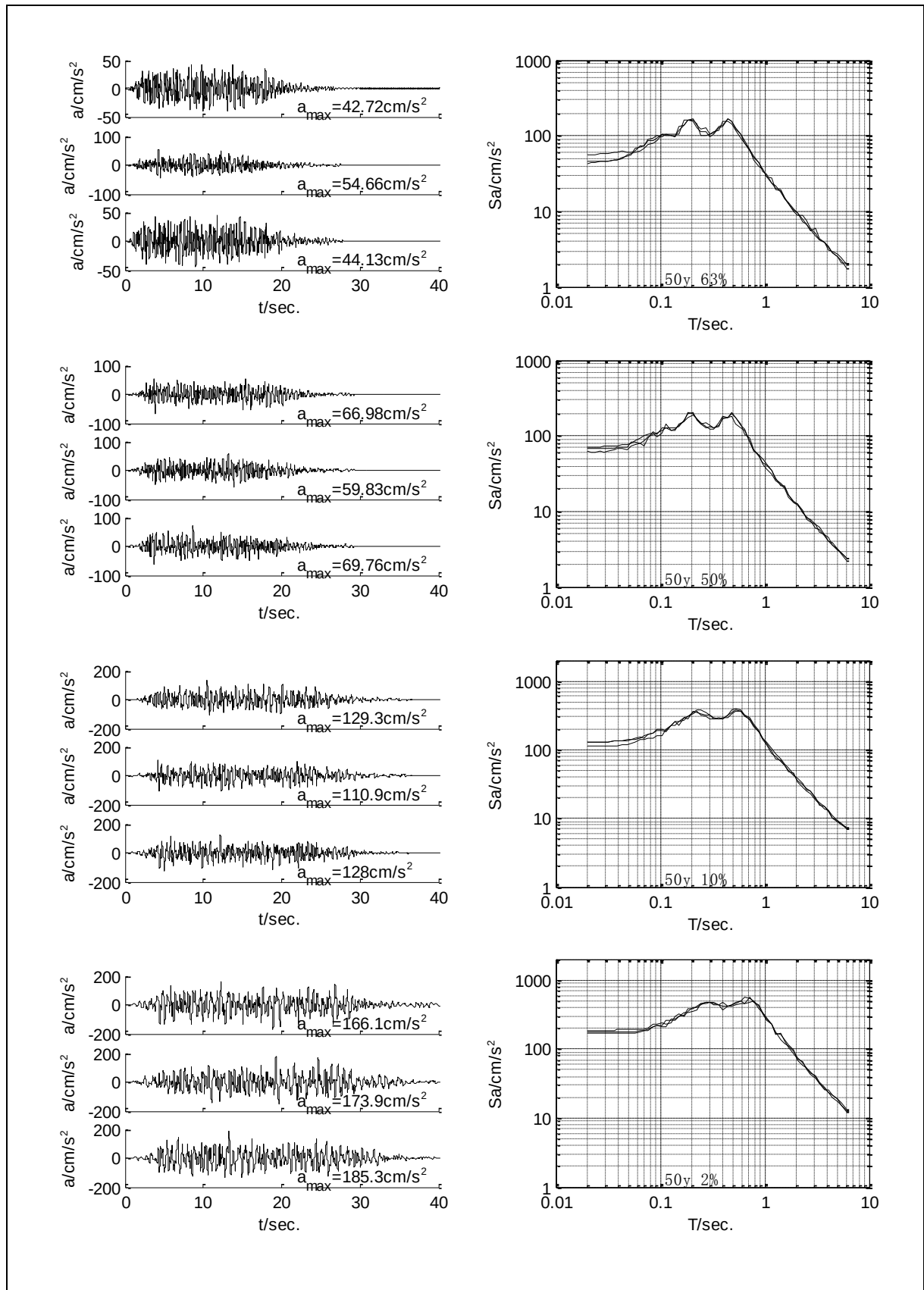


圖 6.21 BH36 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜



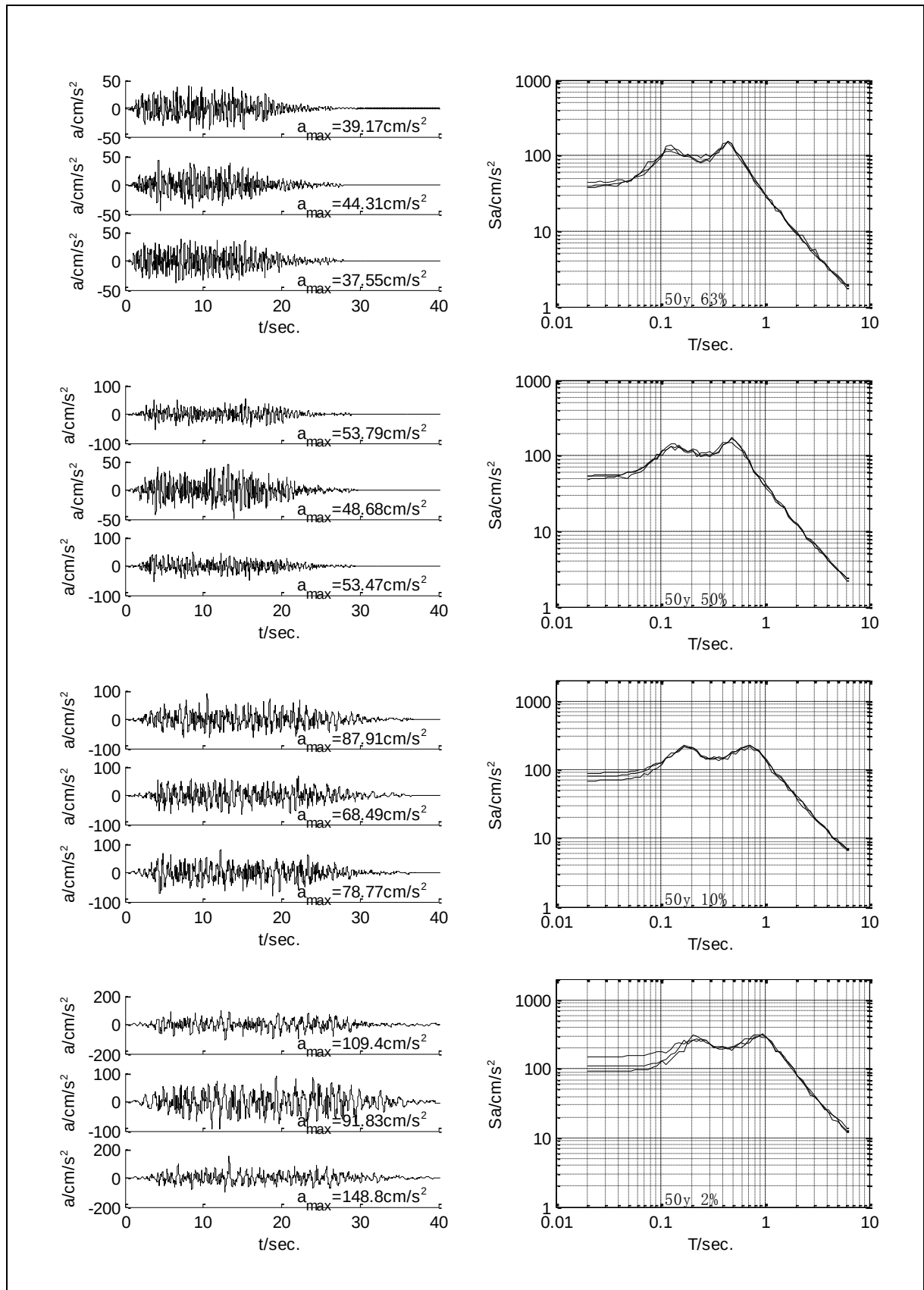


圖 6.22 BH39 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

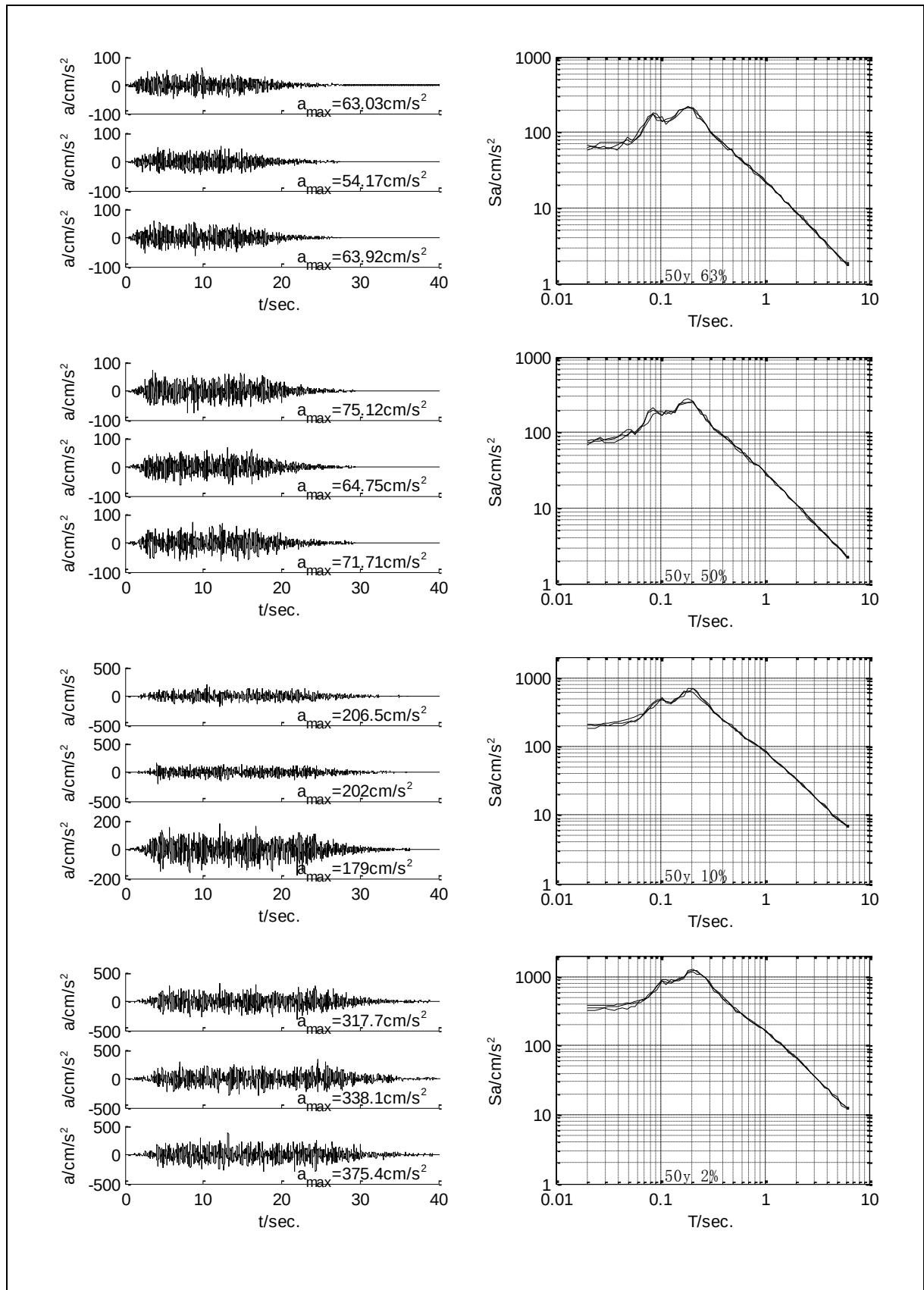


圖 6.23 BH41 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

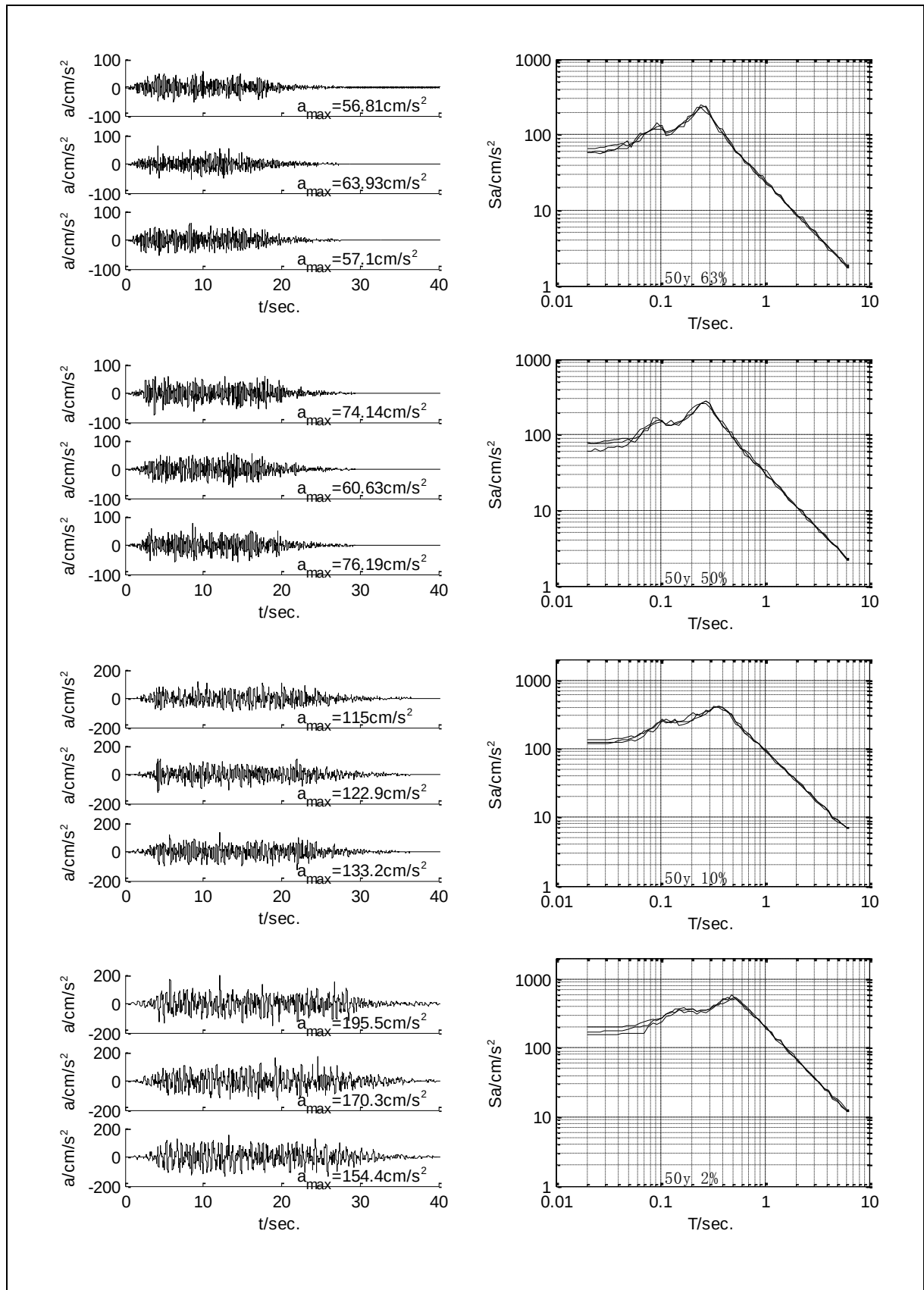


圖 6.24 BH42 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

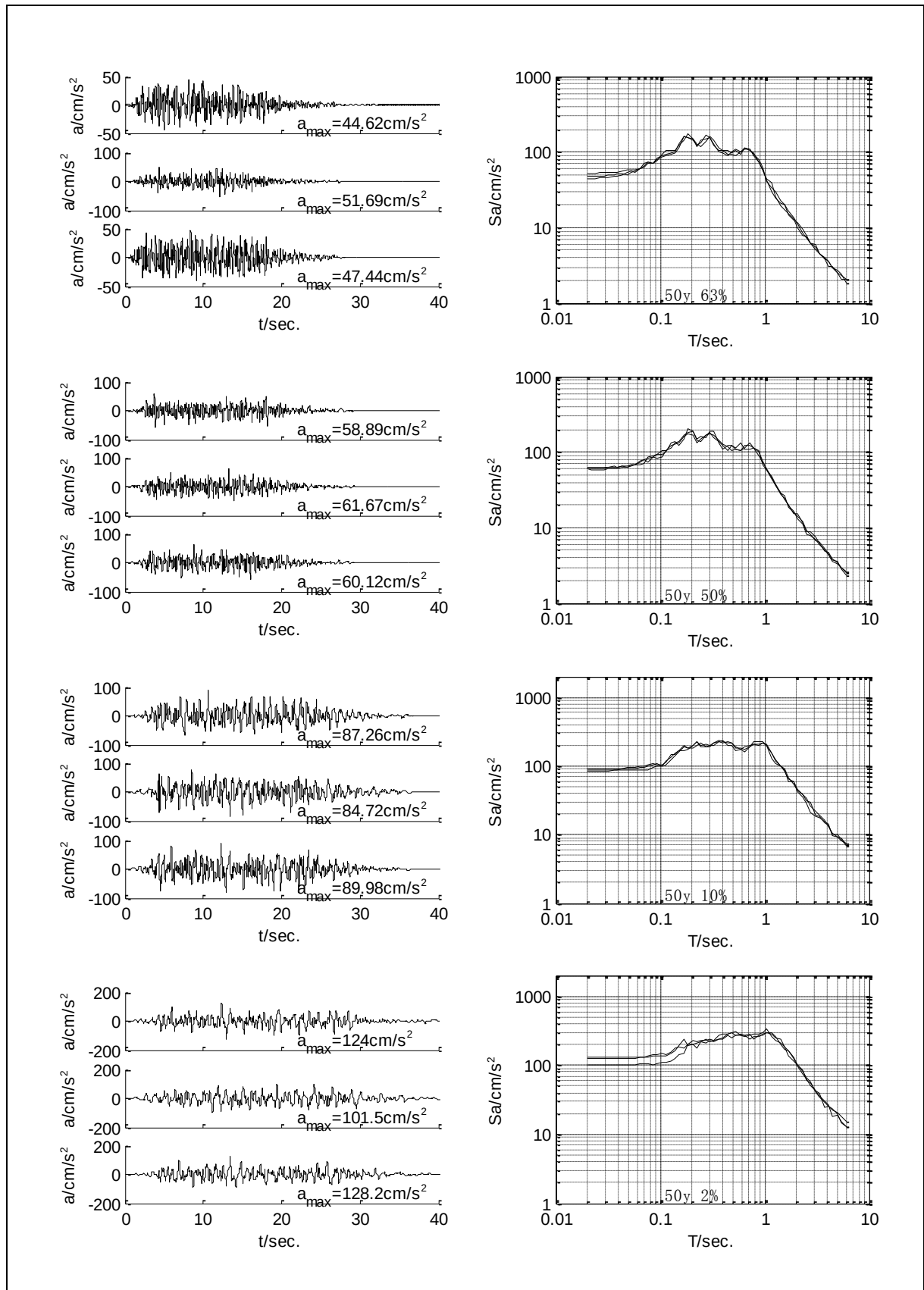


圖 6.25 BH43 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

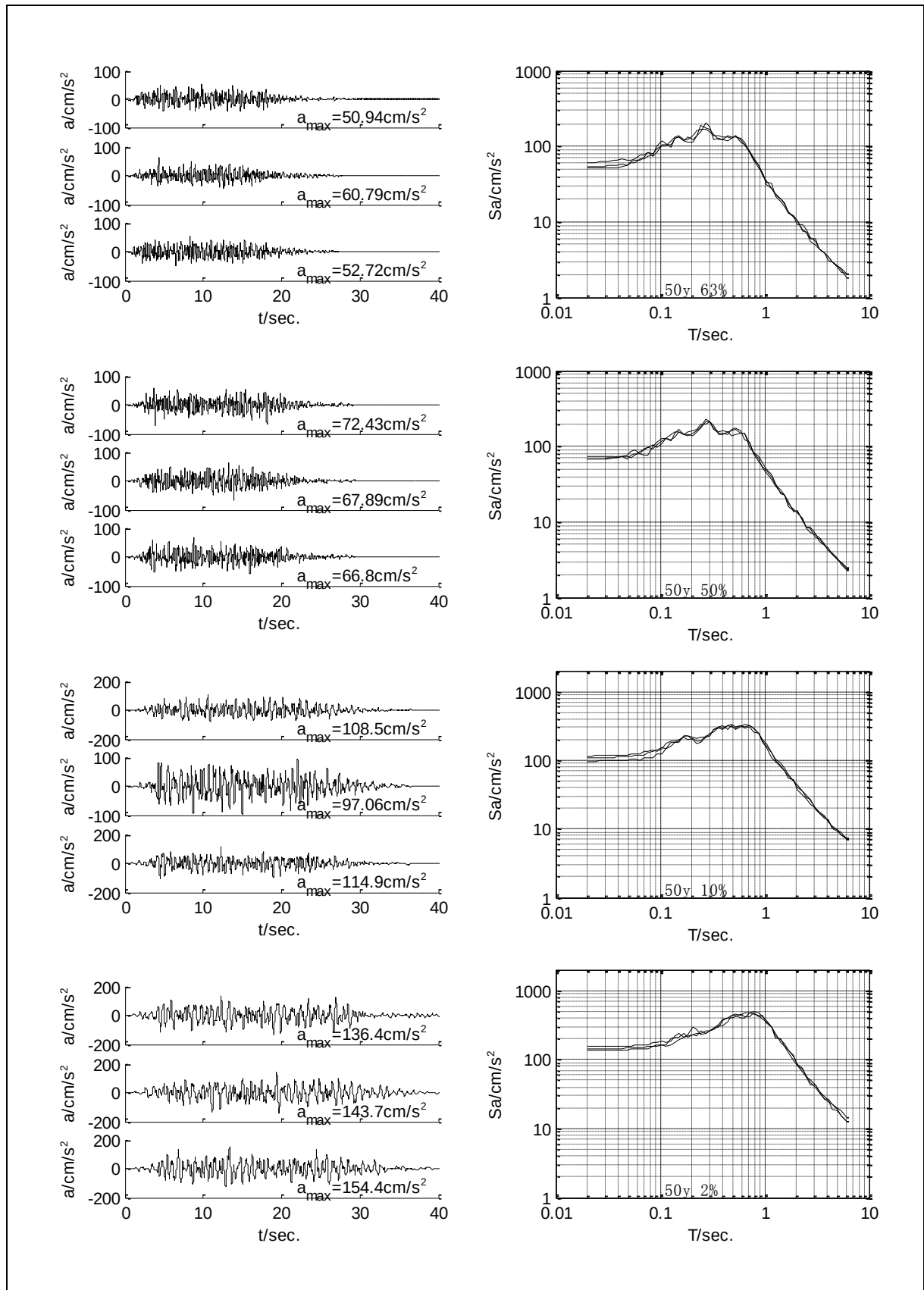


圖 6.26 BH44 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

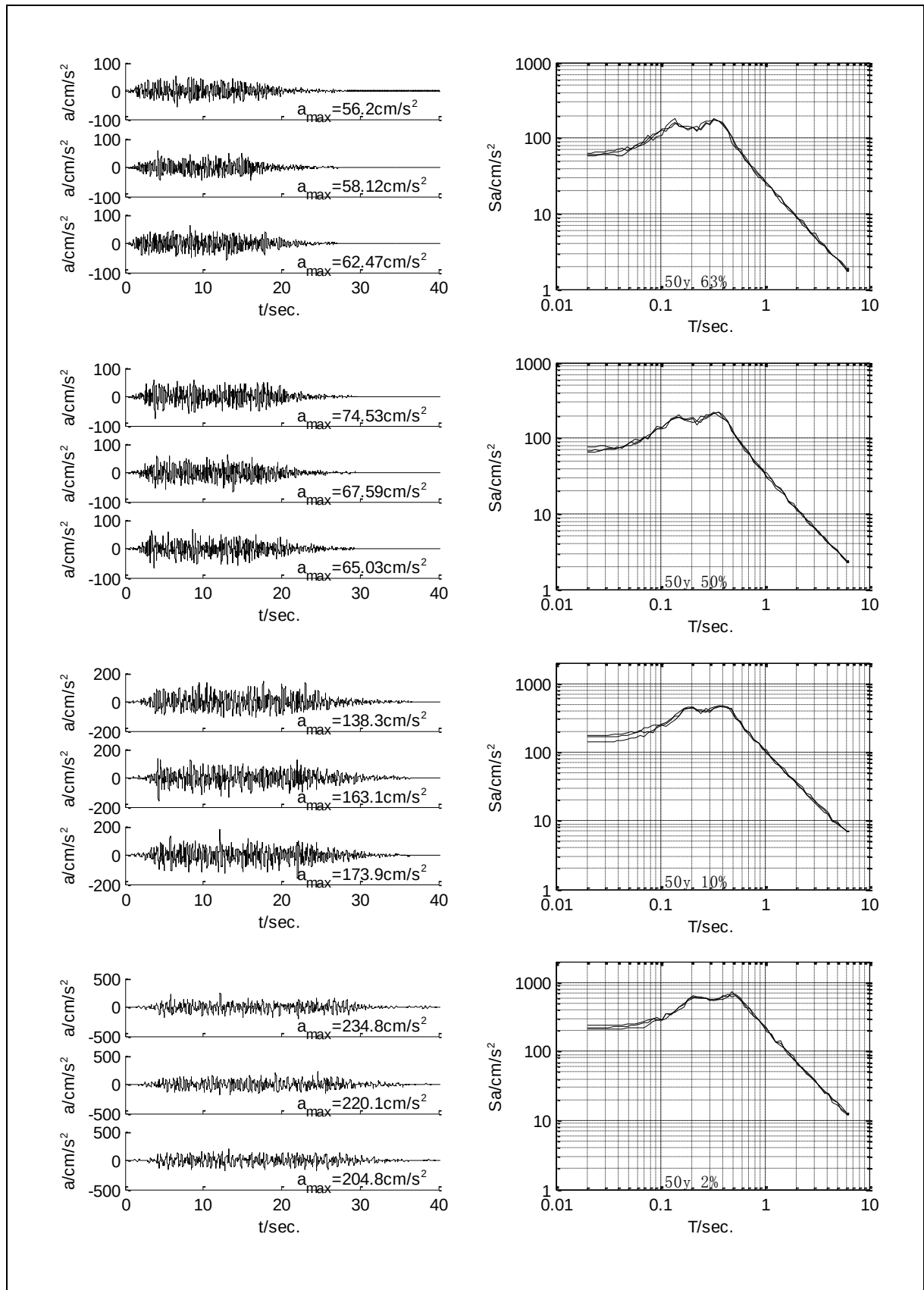


圖 6.27 BH45 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

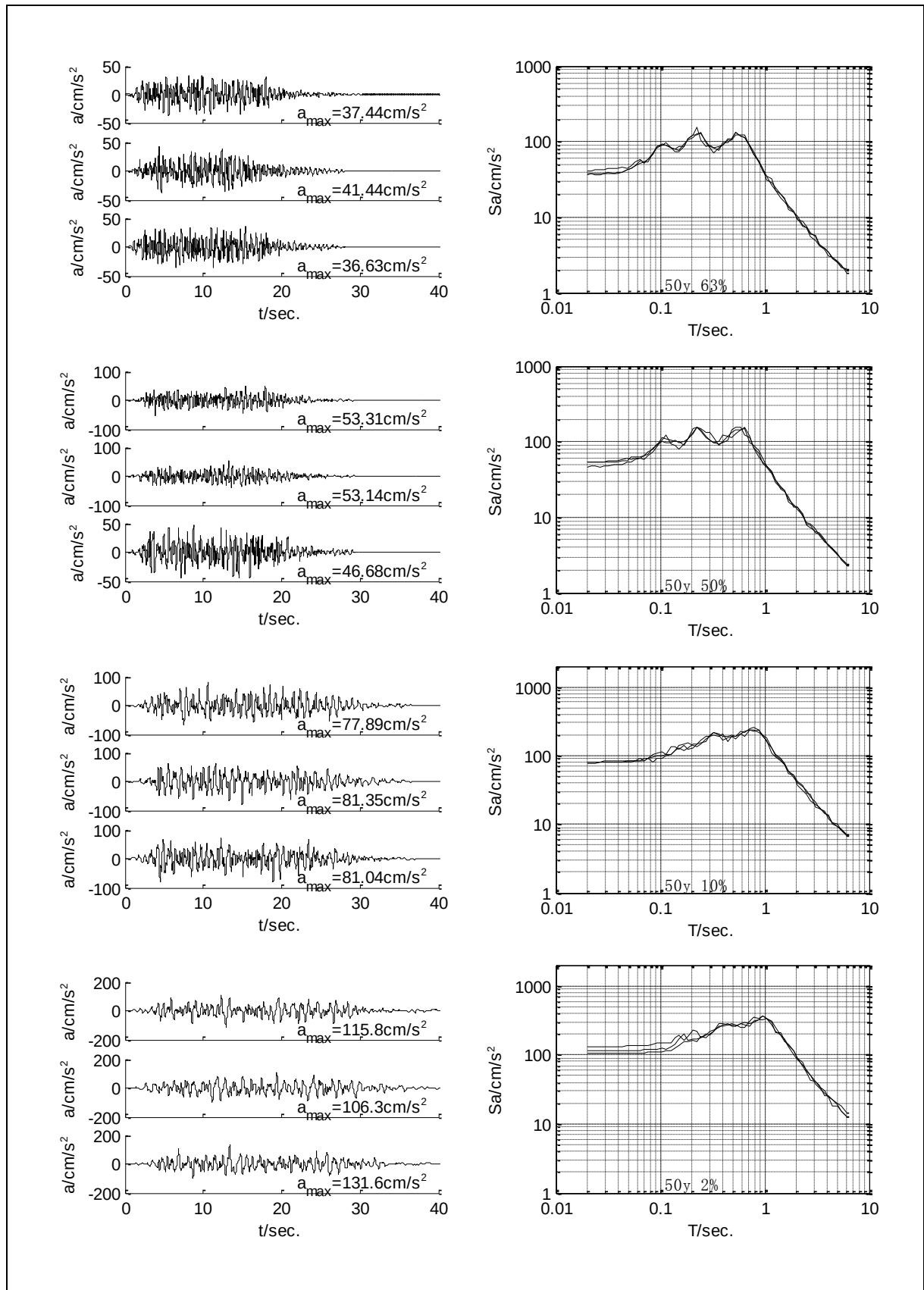


圖 6.28 BH49 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜

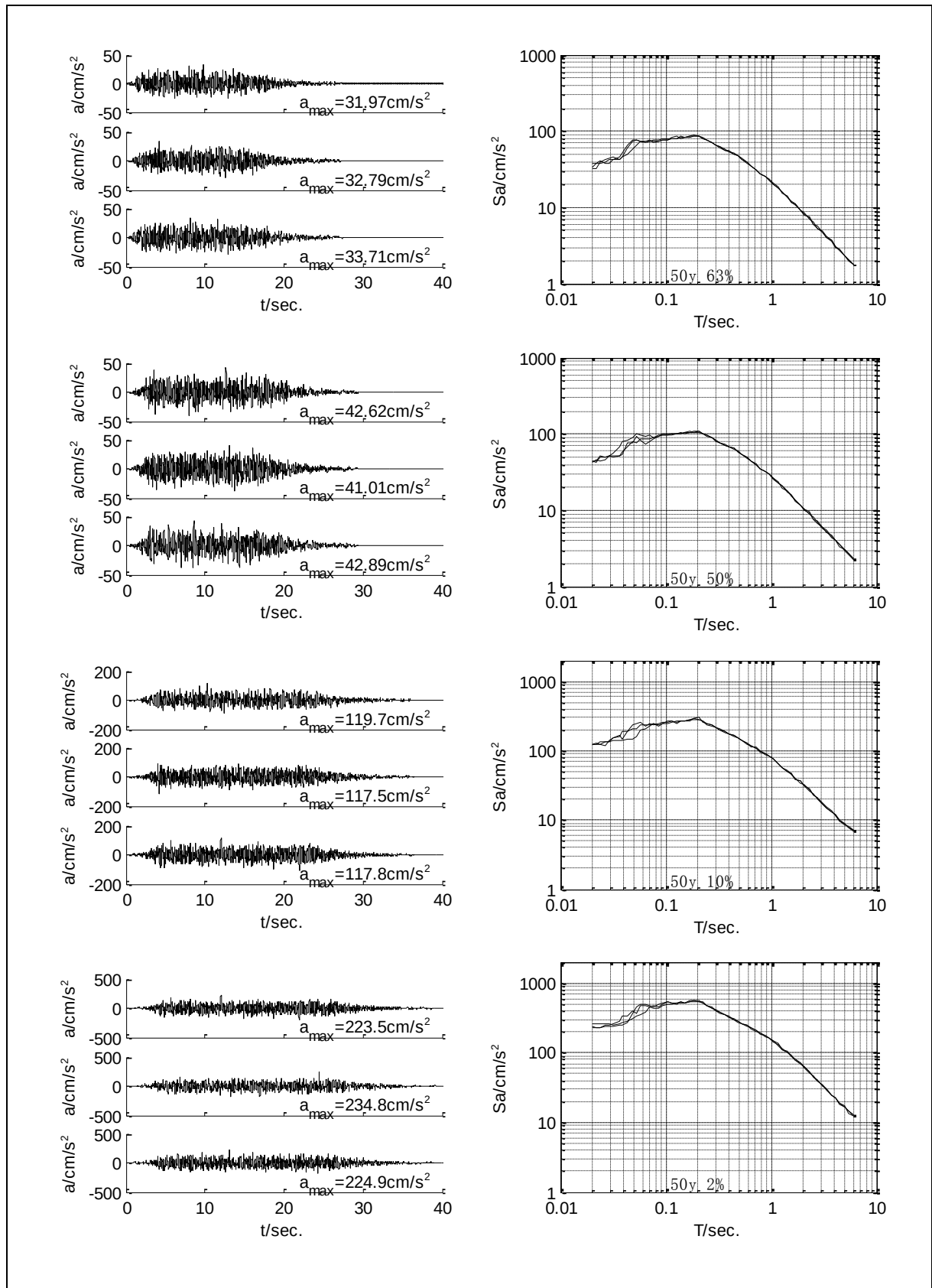


圖 6.29 BH50 鑽孔 50 年 4 個超越概率水準的場地加速度時程和場地相關加速度反應譜



## 第七章 地震動參數小區劃

在場地土層地震反應分析計算結果的基礎上，本章將給出場地地震小區劃的設計地震動分區及各分區的設計地震動參數，設計地震動參數包括設計地震動峰值加速度和加速度反應譜。

### 7.1 地震動參數標定和初步分區

為了獲得地面水平向地震動加速度反應譜（5% 阻尼比）參數，對每個鑽孔剖面進行了地震動參數單孔標定。根據工程場地地表 50 年超越概率 63%、10%、5%和 2% 的計算水準向地震動加速度反應譜結果，可得到各鑽孔處地表水準向地震動加速度反應譜相應的擬合曲線，對應的反應譜標定曲線如圖 7.1a - 7.1d 中的分段直線所示。表 7.1 為各鑽孔水準向加速度反應譜標定參數，為初步分區的主要依據。

表 7.1 水平向加速度反應譜標定參數表（第 1 頁共 3 頁）

| 鑽孔編號 | 63%        |       |       |       |          | 50%        |       |       |       |          |
|------|------------|-------|-------|-------|----------|------------|-------|-------|-------|----------|
|      | $A_{\max}$ | $T_g$ | $B_m$ | $T_1$ | $\gamma$ | $A_{\max}$ | $T_g$ | $B_m$ | $T_1$ | $\gamma$ |
| BH01 | 45         | 0.55  | 2.5   | 0.1   | 1.0      | 57         | 0.6   | 2.5   | 0.1   | 1.0      |
| BH02 | 50         | 0.55  | 2.5   | 0.1   | 1.0      | 65         | 0.6   | 2.5   | 0.1   | 1.0      |
| BH08 | 47         | 0.60  | 2.5   | 0.05  | 1.0      | 56         | 0.62  | 2.5   | 0.05  | 1.0      |
| BH12 | 45         | 0.22  | 2.5   | 0.1   | 1.0      | 55         | 0.24  | 2.5   | 0.1   | 1.0      |
| BH13 | 45         | 0.65  | 2.5   | 0.1   | 1.0      | 50         | 0.7   | 2.5   | 0.1   | 1.0      |
| BH14 | 50         | 0.40  | 2.5   | 0.1   | 1.0      | 57         | 0.5   | 2.5   | 0.1   | 1.0      |
| BH15 | 70         | 0.25  | 2.5   | 0.1   | 1.0      | 85         | 0.25  | 2.5   | 0.1   | 1.0      |
| BH16 | 55         | 0.20  | 2.5   | 0.08  | 1.0      | 60         | 0.22  | 2.5   | 0.08  | 1.0      |
| BH20 | 45         | 0.55  | 2.5   | 0.1   | 1.0      | 55         | 0.6   | 2.5   | 0.1   | 1.0      |
| BH21 | 60         | 0.40  | 2.5   | 0.1   | 1.0      | 68         | 0.45  | 2.5   | 0.1   | 1.0      |
| BH22 | 45         | 0.65  | 2.5   | 0.1   | 1.0      | 55         | 0.68  | 2.5   | 0.1   | 1.0      |
| BH23 | 50         | 0.40  | 2.5   | 0.1   | 1.0      | 60         | 0.45  | 2.5   | 0.1   | 1.0      |
| BH24 | 65         | 0.33  | 2.5   | 0.1   | 1.0      | 70         | 0.35  | 2.5   | 0.1   | 1.0      |
| BH26 | 45         | 0.35  | 2.5   | 0.1   | 1.0      | 55         | 0.4   | 2.5   | 0.1   | 1.0      |
| BH27 | 40         | 0.80  | 2.5   | 0.1   | 1.0      | 43         | 0.9   | 2.5   | 0.1   | 1.0      |
| BH29 | 37         | 0.80  | 2.5   | 0.1   | 1.0      | 40         | 0.9   | 2.5   | 0.1   | 1.0      |
| BH30 | 42         | 0.50  | 2.5   | 0.1   | 1.0      | 47         | 0.53  | 2.5   | 0.1   | 1.0      |
| BH32 | 55         | 0.50  | 2.5   | 0.1   | 1.0      | 65         | 0.5   | 2.5   | 0.1   | 1.0      |
| BH36 | 47         | 0.55  | 2.5   | 0.1   | 1.0      | 62         | 0.55  | 2.5   | 0.1   | 1.0      |
| BH39 | 42         | 0.55  | 2.5   | 0.1   | 1.0      | 50         | 0.58  | 2.5   | 0.1   | 1.0      |
| BH41 | 60         | 0.25  | 2.5   | 0.08  | 1.0      | 73         | 0.26  | 2.5   | 0.08  | 1.0      |
| BH42 | 55         | 0.35  | 2.5   | 0.1   | 1.0      | 65         | 0.38  | 2.5   | 0.1   | 1.0      |

表 7.1 水平向加速度反應譜標定參數表（第 2 頁共 3 頁）

| 鑽孔編號 | 63%        |       |       |       |          | 50%        |       |       |       |          |
|------|------------|-------|-------|-------|----------|------------|-------|-------|-------|----------|
|      | $A_{\max}$ | $T_g$ | $B_m$ | $T_1$ | $\gamma$ | $A_{\max}$ | $T_g$ | $B_m$ | $T_1$ | $\gamma$ |
| BH43 | 50         | 0.60  | 2.5   | 0.1   | 1.0      | 55         | 0.65  | 2.5   | 0.1   | 1.0      |
| BH44 | 52         | 0.60  | 2.5   | 0.1   | 1.0      | 65         | 0.63  | 2.5   | 0.1   | 1.0      |
| BH45 | 57         | 0.40  | 2.5   | 0.1   | 1.0      | 70         | 0.43  | 2.5   | 0.1   | 1.0      |
| BH49 | 40         | 0.70  | 2.5   | 0.1   | 1.0      | 45         | 0.7   | 2.5   | 0.1   | 1.0      |
| BH50 | 33         | 0.28  | 2.5   | 0.06  | 1.0      | 42         | 0.29  | 2.5   | 0.06  | 1.0      |

表 7.1 水平向加速度反應譜標定參數表（第 3 頁共 3 頁）

| 鑽孔編號 | 10%        |       |       |       |          | 2%         |       |       |       |          |
|------|------------|-------|-------|-------|----------|------------|-------|-------|-------|----------|
|      | $A_{\max}$ | $T_g$ | $B_m$ | $T_1$ | $\gamma$ | $A_{\max}$ | $T_g$ | $B_m$ | $T_1$ | $\gamma$ |
| BH01 | 85         | 0.8   | 2.5   | 0.1   | 1.0      | 120        | 1.1   | 2.5   | 0.1   | 1.0      |
| BH02 | 115        | 0.7   | 2.5   | 0.1   | 1.0      | 155        | 0.9   | 2.5   | 0.1   | 1.0      |
| BH08 | 100        | 0.8   | 2.5   | 0.05  | 1.0      | 145        | 1     | 2.5   | 0.05  | 1.0      |
| BH12 | 135        | 0.25  | 2.5   | 0.1   | 1.0      | 235        | 0.28  | 2.5   | 0.1   | 1.0      |
| BH13 | 85         | 0.85  | 2.5   | 0.1   | 1.0      | 105        | 1.1   | 2.5   | 0.1   | 1.0      |
| BH14 | 125        | 0.6   | 2.5   | 0.1   | 1.0      | 165        | 0.75  | 2.5   | 0.1   | 1.0      |
| BH15 | 210        | 0.27  | 2.5   | 0.1   | 1.0      | 300        | 0.35  | 2.5   | 0.1   | 1.0      |
| BH16 | 155        | 0.23  | 2.5   | 0.08  | 1.0      | 300        | 0.25  | 2.5   | 0.08  | 1.0      |
| BH20 | 105        | 0.72  | 2.5   | 0.1   | 1.0      | 150        | 0.9   | 2.5   | 0.1   | 1.0      |
| BH21 | 150        | 0.5   | 2.5   | 0.1   | 1.0      | 200        | 0.65  | 2.5   | 0.1   | 1.0      |
| BH22 | 100        | 0.85  | 2.5   | 0.1   | 1.0      | 150        | 1.1   | 2.5   | 0.1   | 1.0      |
| BH23 | 110        | 0.65  | 2.5   | 0.1   | 1.0      | 160        | 0.85  | 2.5   | 0.1   | 1.0      |
| BH24 | 140        | 0.43  | 2.5   | 0.1   | 1.0      | 200        | 0.55  | 2.5   | 0.1   | 1.0      |
| BH26 | 100        | 0.6   | 2.5   | 0.1   | 1.0      | 140        | 0.85  | 2.5   | 0.1   | 1.0      |
| BH27 | 80         | 1.1   | 2.5   | 0.1   | 1.0      | 110        | 1.3   | 2.5   | 0.1   | 1.0      |
| BH29 | 70         | 0.8   | 2.5   | 0.1   | 1.0      | 100        | 1.3   | 2.5   | 0.1   | 1.0      |
| BH30 | 80         | 0.63  | 2.5   | 0.1   | 1.0      | 110        | 0.65  | 2.5   | 0.1   | 1.0      |
| BH32 | 100        | 0.67  | 2.5   | 0.1   | 1.0      | 145        | 0.85  | 2.5   | 0.1   | 1.0      |
| BH36 | 120        | 0.68  | 2.5   | 0.1   | 1.0      | 175        | 0.85  | 2.5   | 0.1   | 1.0      |
| BH39 | 75         | 0.85  | 2.5   | 0.1   | 1.0      | 105        | 1.1   | 2.5   | 0.1   | 1.0      |
| BH41 | 795        | 0.28  | 2.5   | 0.08  | 1.0      | 330        | 0.3   | 2.5   | 0.08  | 1.0      |
| BH42 | 120        | 0.5   | 2.5   | 0.1   | 1.0      | 160        | 0.65  | 2.5   | 0.1   | 1.0      |
| BH43 | 85         | 0.95  | 2.5   | 0.1   | 1.0      | 110        | 1.2   | 2.5   | 0.1   | 1.0      |
| BH44 | 100        | 0.85  | 2.5   | 0.1   | 1.0      | 140        | 1.05  | 2.5   | 0.1   | 1.0      |
| BH45 | 160        | 0.5   | 2.5   | 0.1   | 1.0      | 230        | 0.6   | 2.5   | 0.1   | 1.0      |
| BH49 | 80         | 0.95  | 2.5   | 0.1   | 1.0      | 110        | 1.2   | 2.5   | 0.1   | 1.0      |
| BH50 | 110        | 0.30  | 2.5   | 0.06  | 1.0      | 210        | 0.32  | 2.5   | 0.06  | 1.0      |

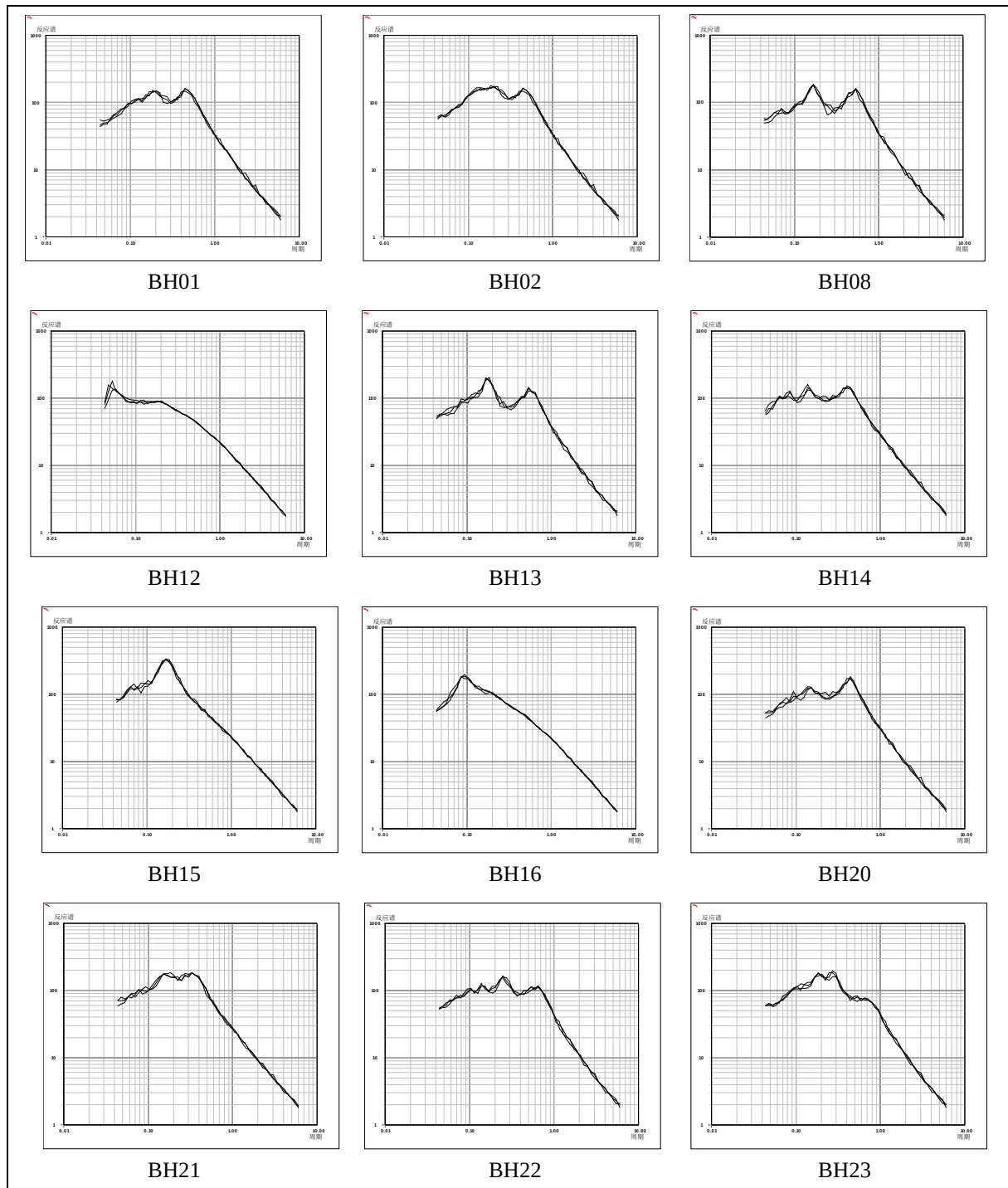


圖 7.1a 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜（50 年 63%）  
（第 1 頁共 2 頁）

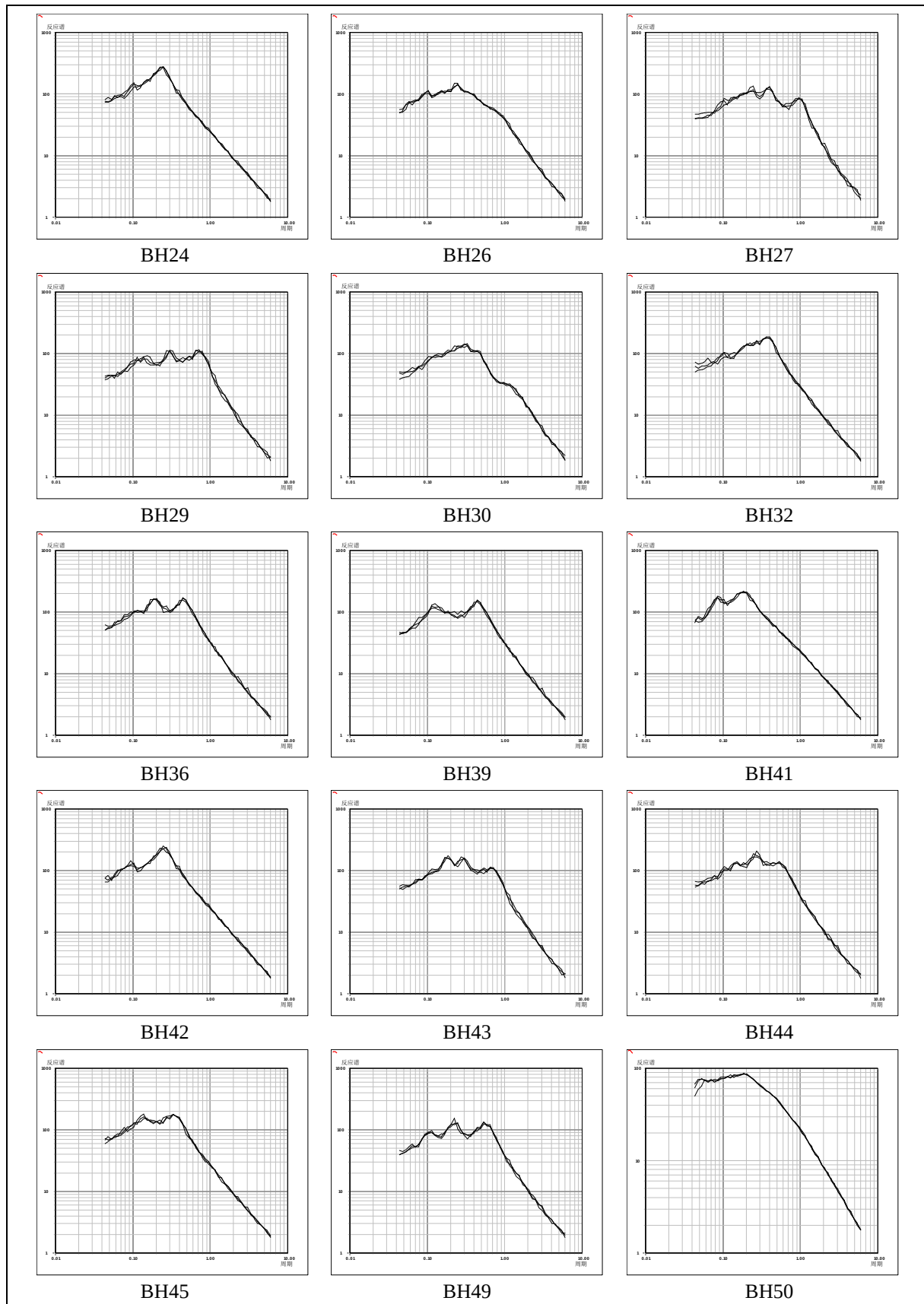


圖 7.1a 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜（50 年 63%）  
（第 2 頁共 2 頁）

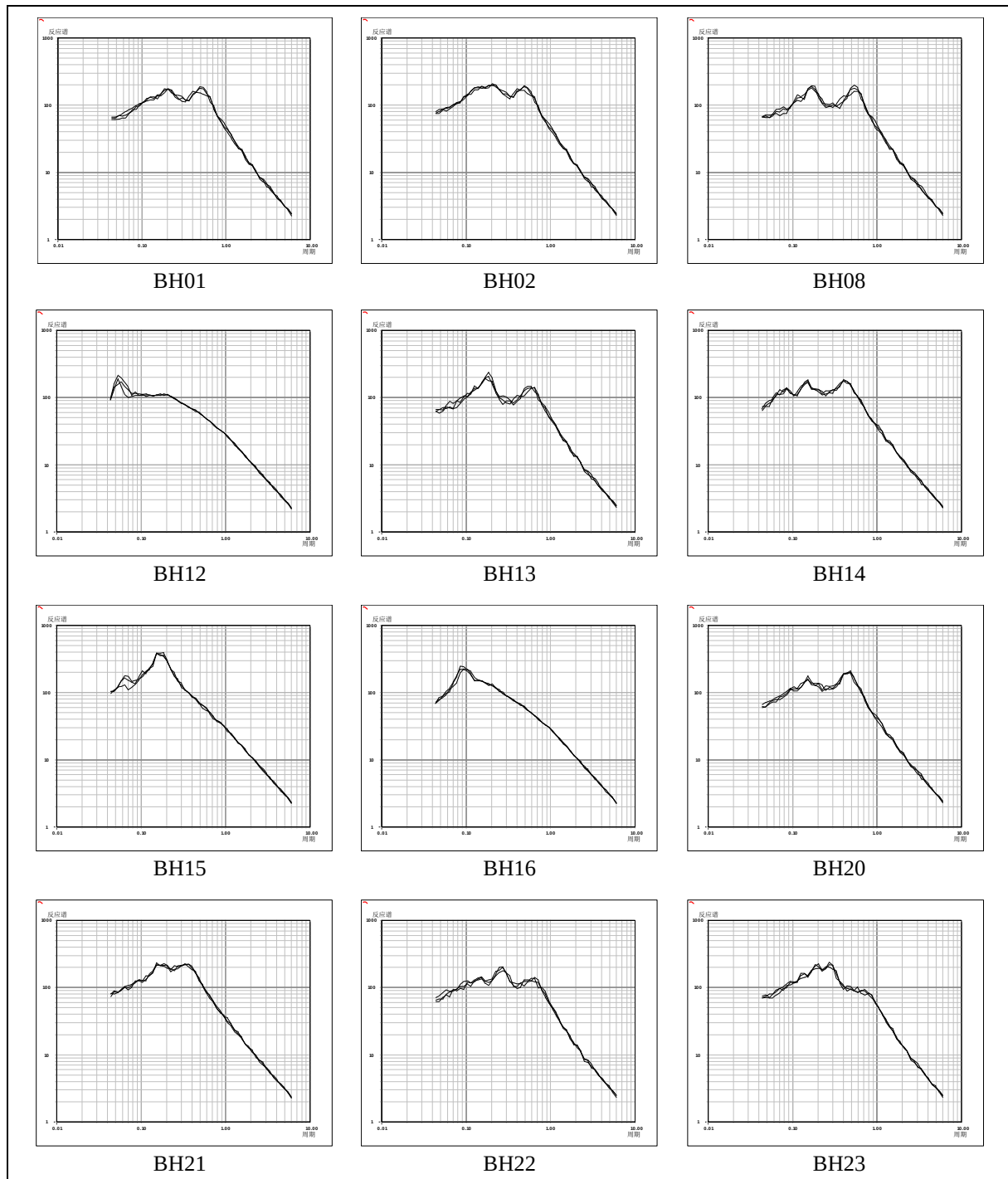


圖 7.1b 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜（50 年 50%）  
（第 1 頁共 2 頁）

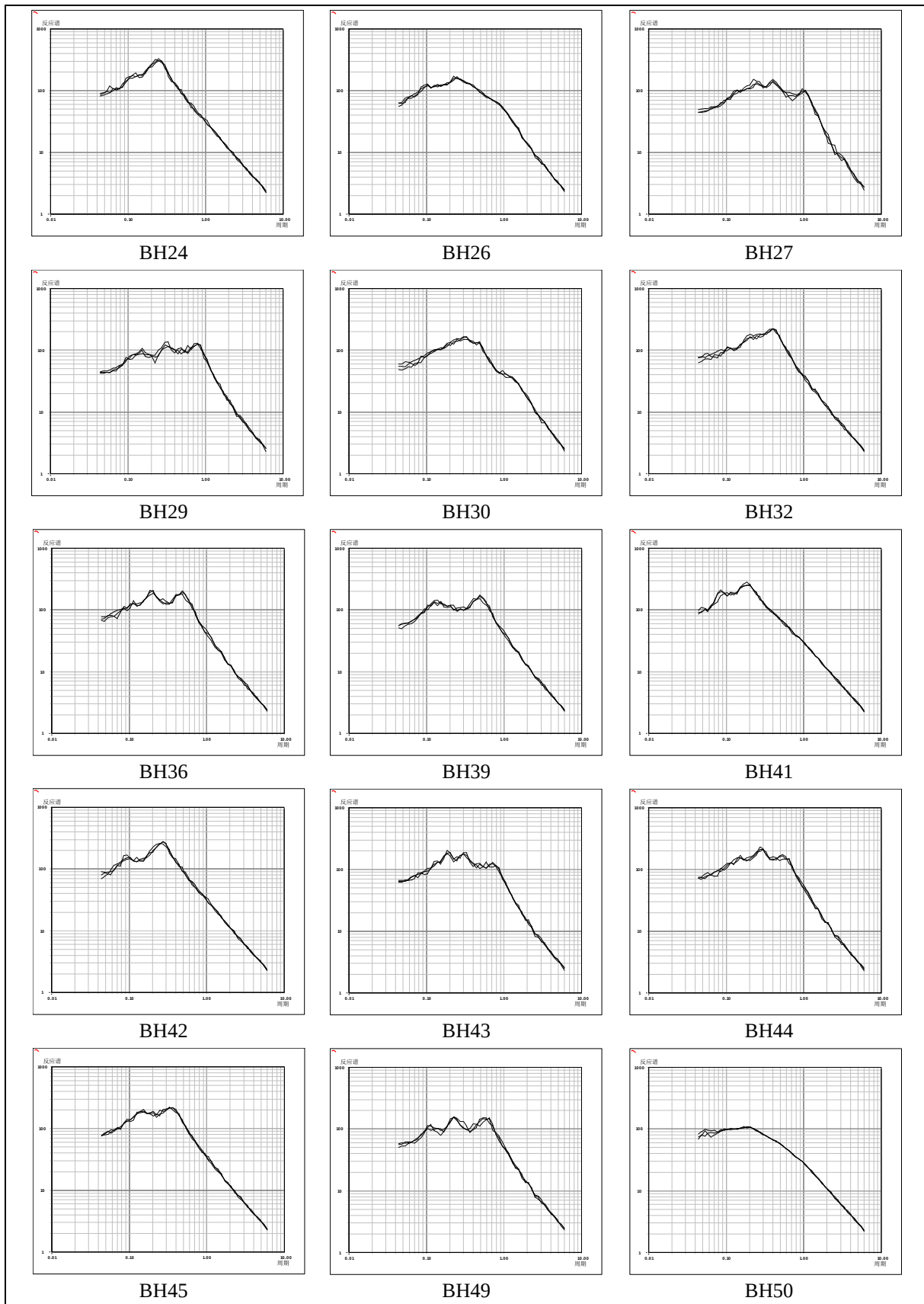


圖 7.1b 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜 (50 年 50%)  
(第 2 頁共 2 頁)



圖 7.1c 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜 (50 年 10%)  
(第 1 頁共 2 頁)

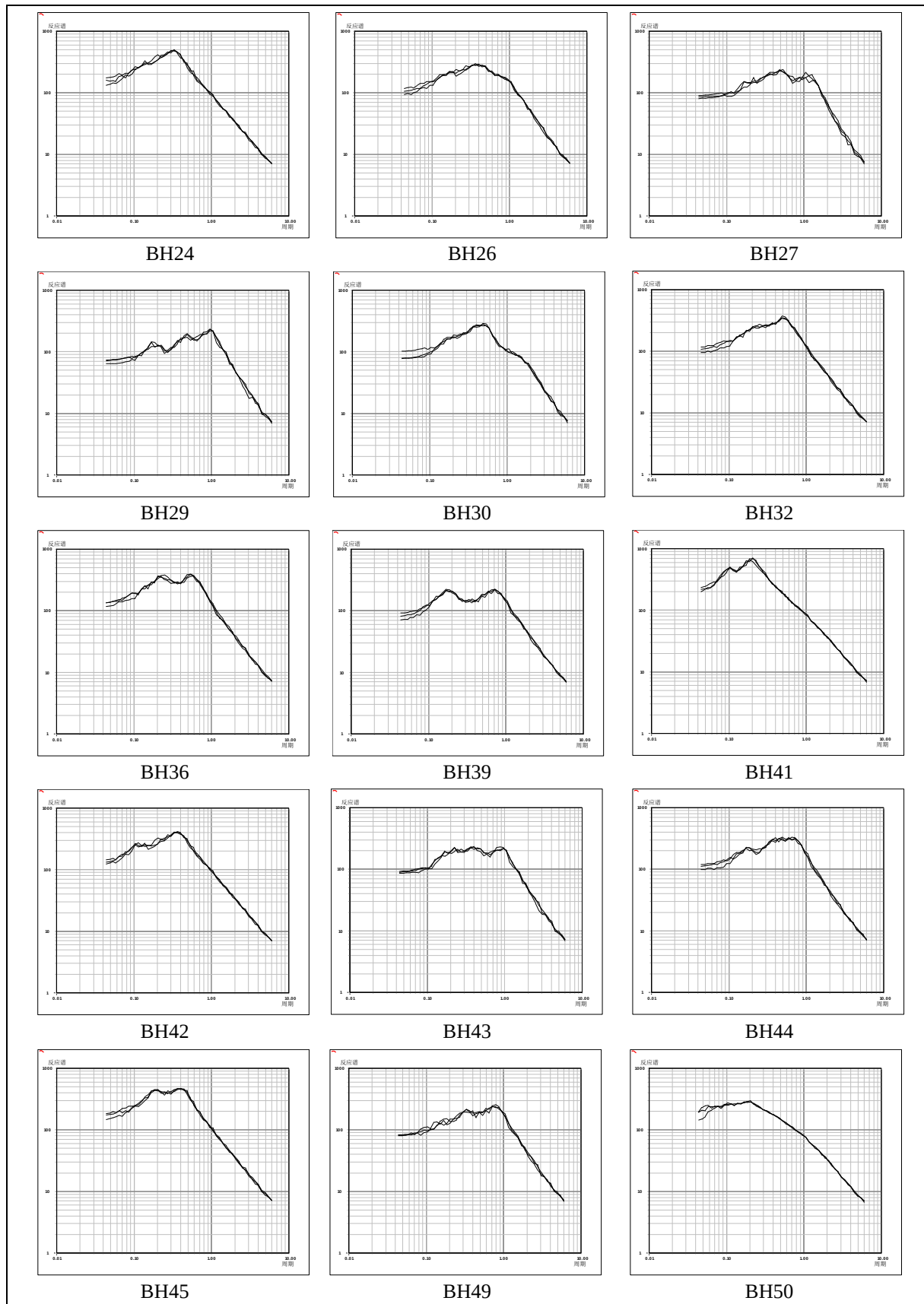


圖 7.1c 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜 (50 年 10%)  
(第 2 頁共 2 頁)



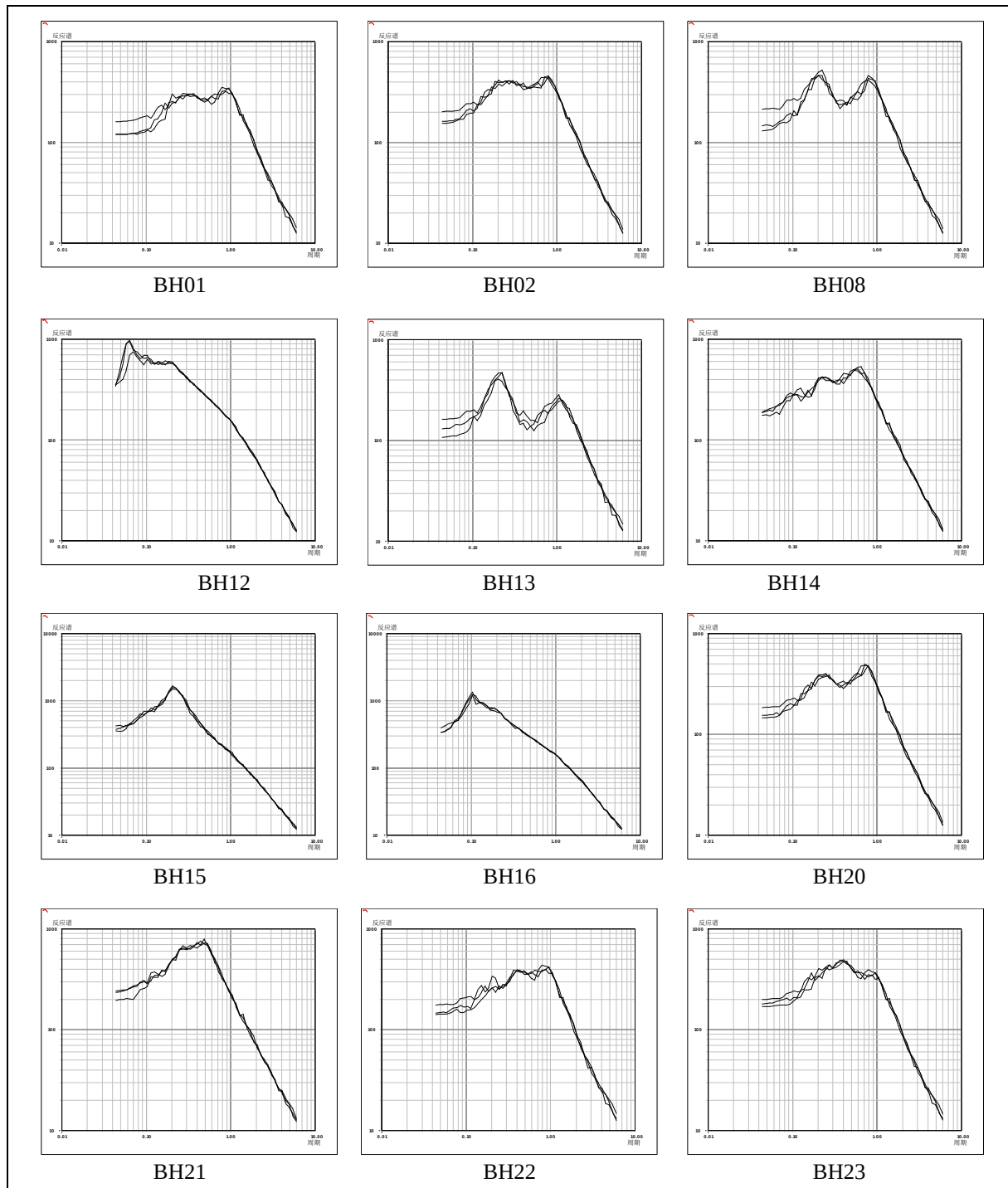


圖 7.1d 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜（50 年 2%）  
（第 1 頁共 2 頁）

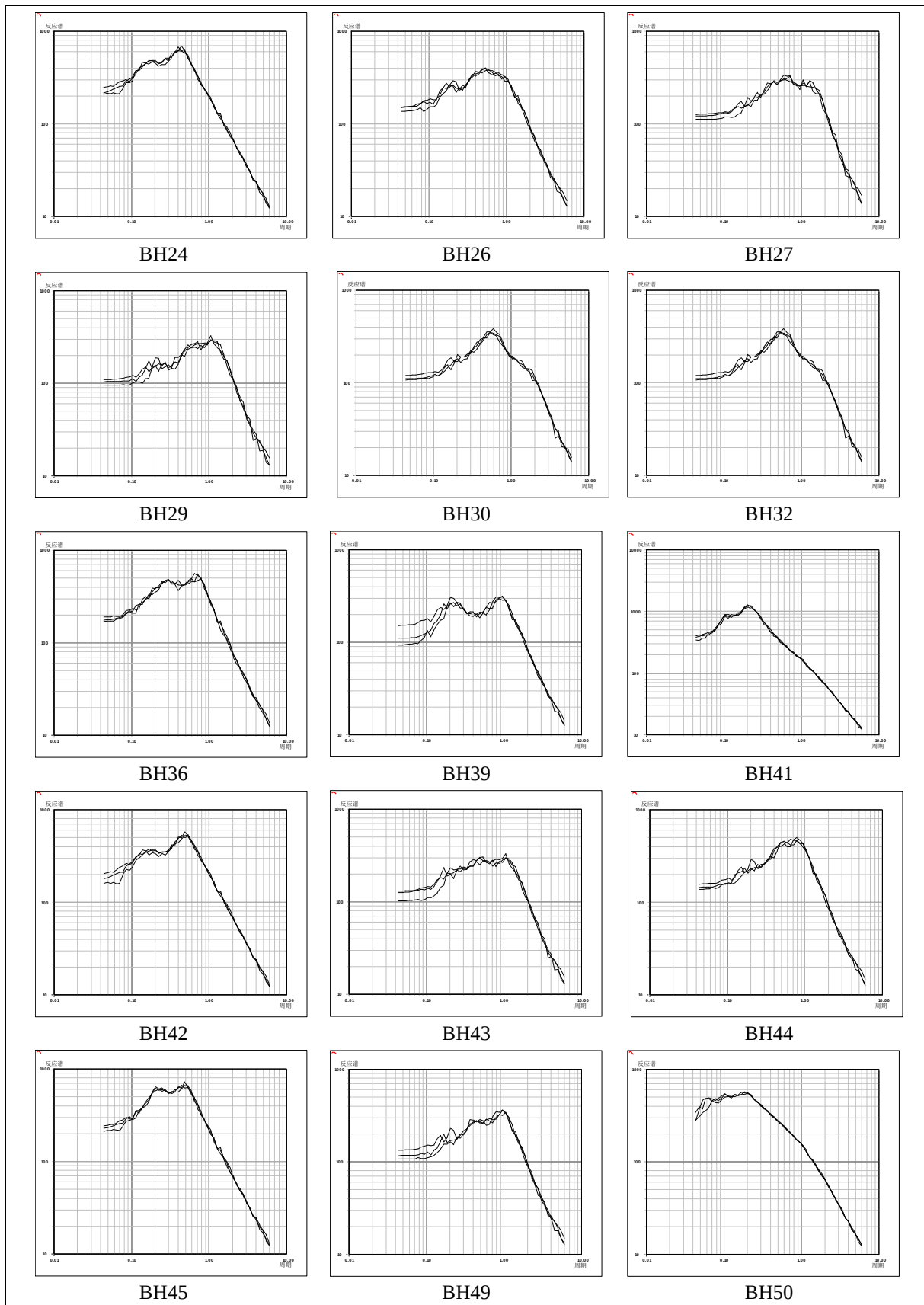


圖 7.1d 各鑽孔地表水平向地震動加速度反應譜及標定地震動反應譜 (50 年 2%)  
(第 2 頁共 2 頁)

以各鑽孔場點的場地地表水平向地震動峰值加速度計算結果和反應譜的參數值為基礎，參考工程地質單元分區，重點考慮工程場地地表 50 年超越概率 10% 計算水準向地震動加速度反應譜結果。對場地的地震動參數進行初步分區，香港元朗—屯門地區初步可分為 3 個地震動參數區。

I 區為 50 年超越概率 10% 的地震動加速度反應譜特徵週期  $T_g \leq 0.30$  s 的區域，包含 BH12、BH15、BH16、BH41、BH50 等鑽孔，其地震動加速度反應譜譜族曲線見圖 7.2；II 區為 50 年超越概率 10% 的地震動加速度反應譜特徵週期值  $0.30 \text{ s} < T_g < 0.55 \text{ s}$  的區域，包含 BH21、BH24、BH42、BH45 等鑽孔，其地震動加速度反應譜譜族曲線見圖 7.3；III 區為 50 年超越概率 10% 的地震動加速度反應譜特徵週期值  $0.55 \text{ s} \leq T_g$  的區域，包括 BH01、BH02、BH08、BH13、BH14、BH20、BH22、BH23、BH26、BH27、BH29、BH30、BH32、BH36、BH39、BH43、BH44、BH49 等鑽孔，其地震動加速度反應譜譜族曲線見圖 7.4。

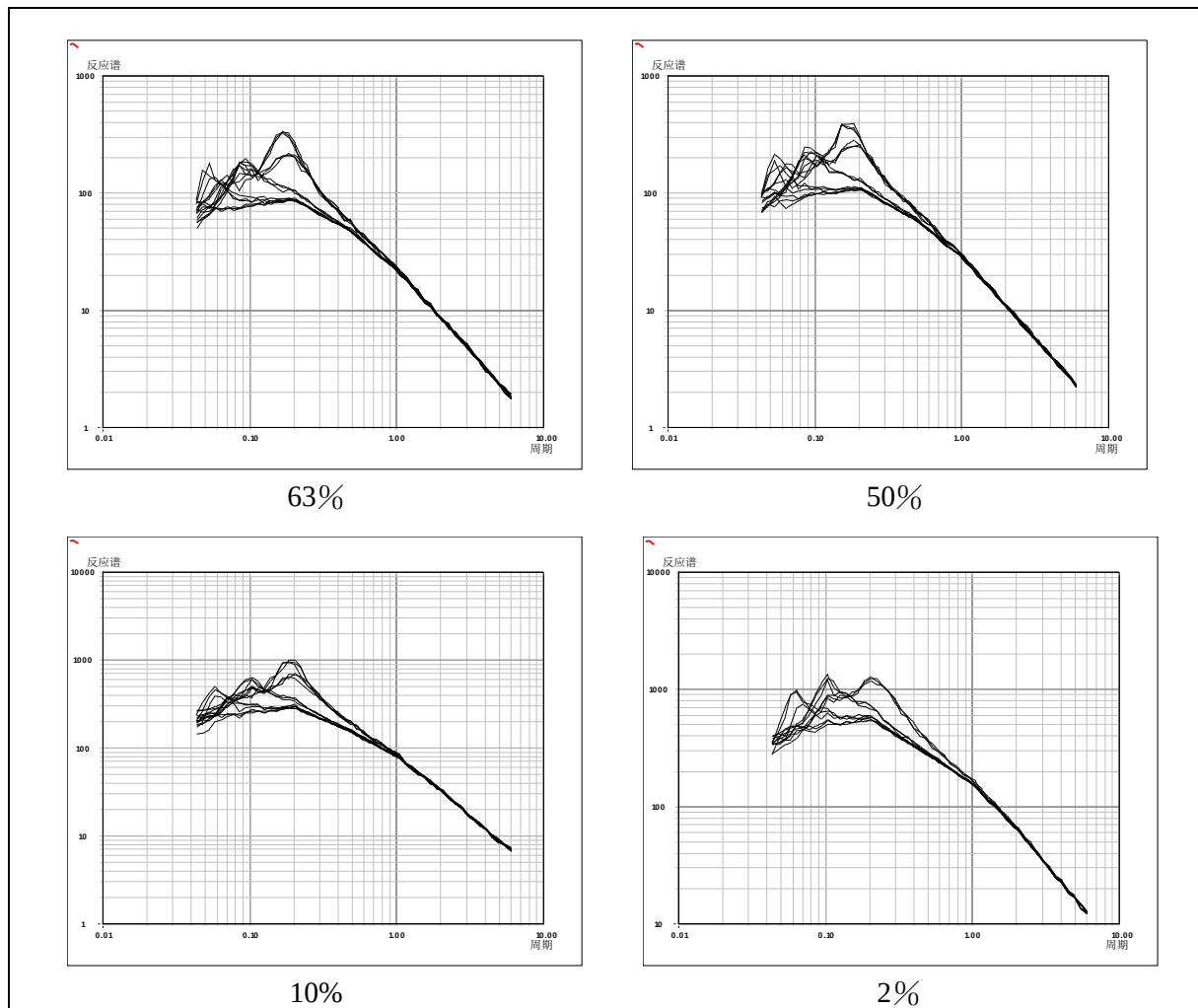


圖 7.2 香港元朗—屯門地區 I 分區的地震動加速度反應譜譜族及擬合曲線

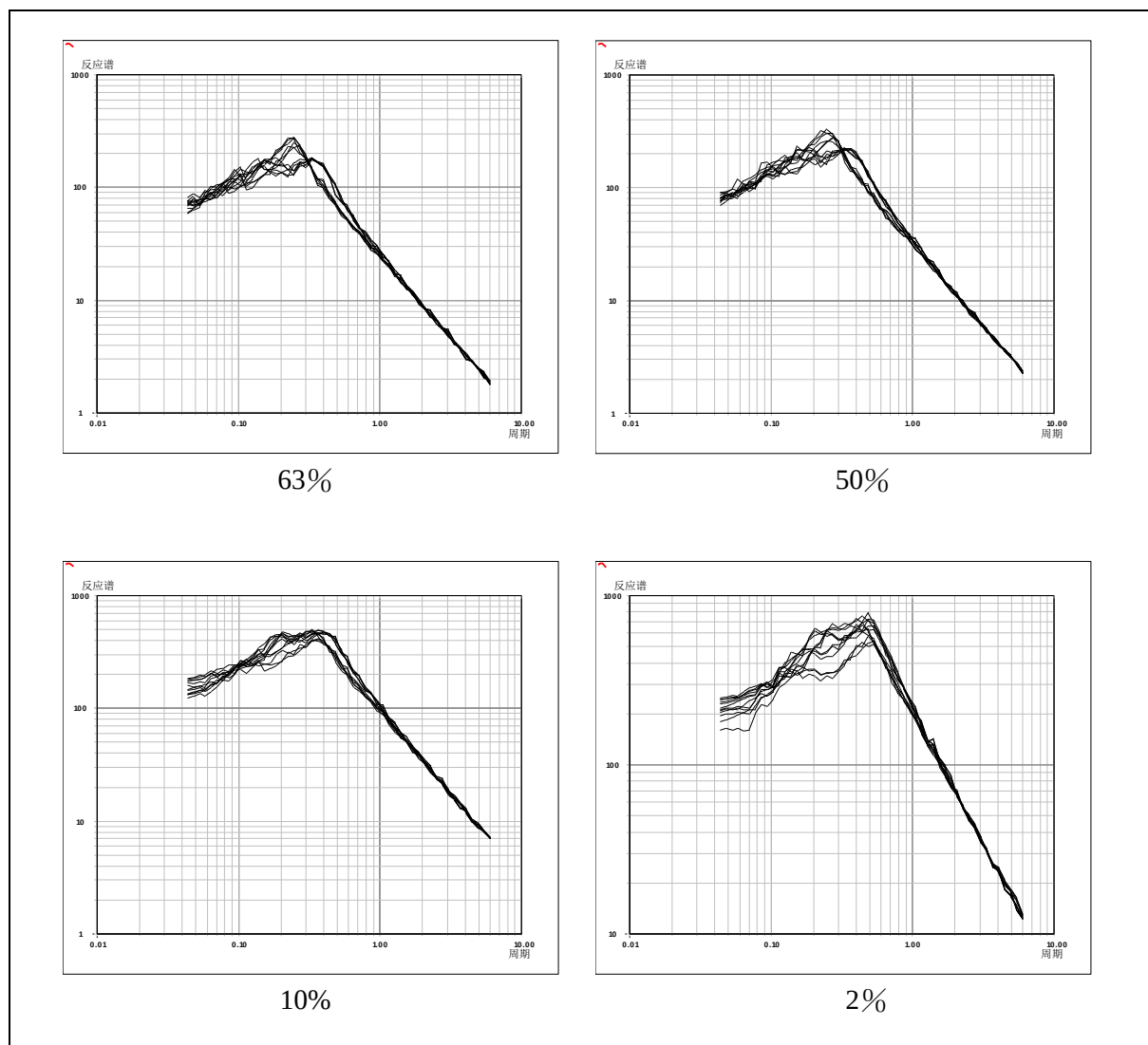


圖 7.3 香港元朗—屯門地區Ⅱ分區的地震動加速度反應譜譜族及擬合曲線

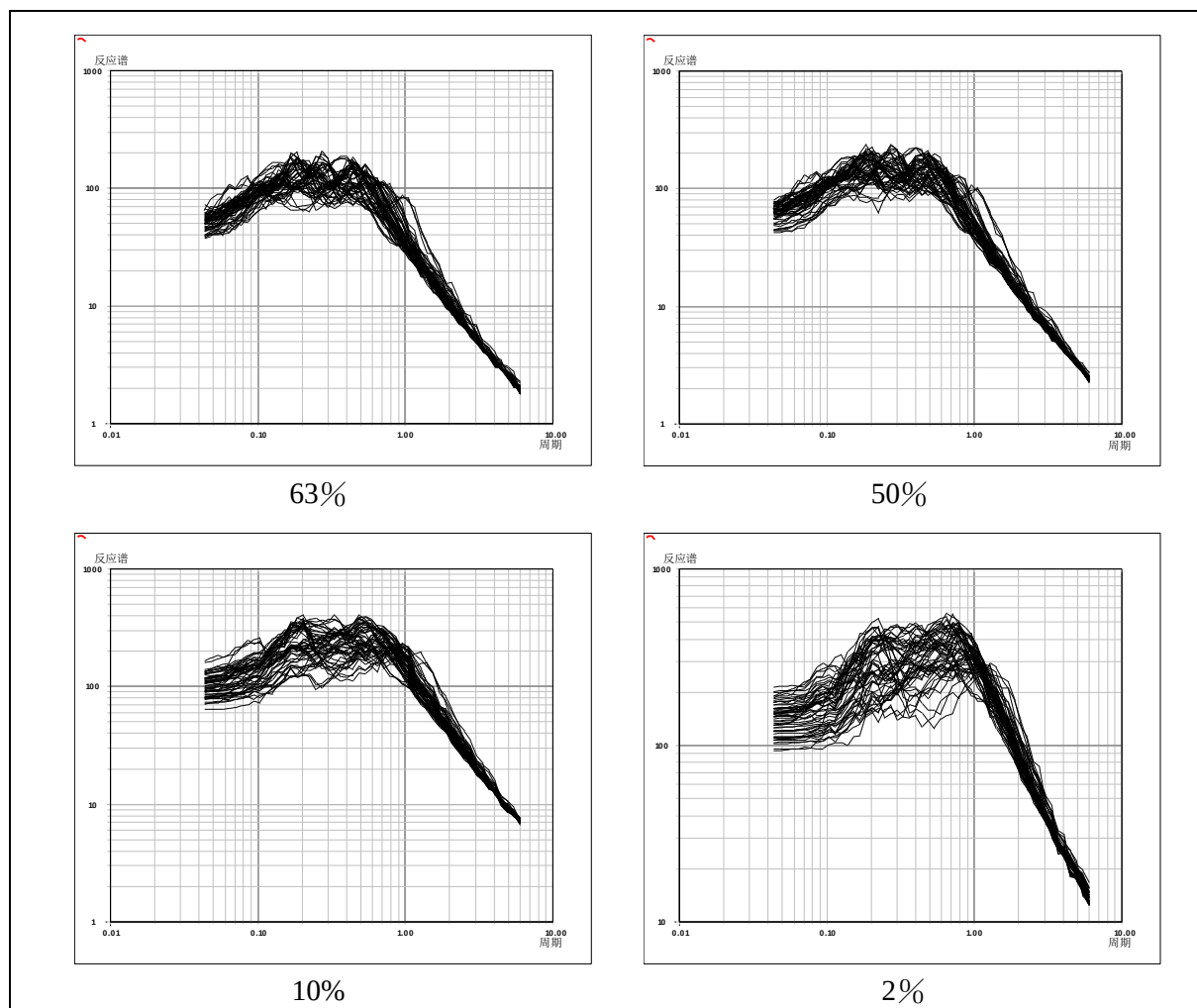


圖 7.4 香港元朗—屯門地區Ⅲ分區的地震動加速度反應譜譜族及擬合曲線

## 7.2 地震動參數小區劃及設計地震動參數

根據地震動加速度反應譜譜族的擬合曲線（圖 7.2 - 7.4 中的紅色折線），可得到各分區擬合地震動參數（見表 7.2）。其中，I 區的  $T_1$  值為 0.06 s，II 區和 III 區的  $T_1$  值取 0.1 s。

工程場地設計地震動影響係數為：

$$\alpha(T) = A_{\max} \beta(T) / g \quad \dots\dots\dots (7.1)$$

其中， $A_{\max}$  為設計地震動峰值加速度， $\beta(T)$  為設計地震動加速度放大係數反應譜，其運算式為：

$$\beta(T) = \begin{cases} 1 & T \leq 0.04s \\ 1 + (\beta_m - 1) \frac{T - 0.04}{T_1 - 0.04} & 0.04s < T \leq T_1 \\ \beta_m & T_1 < T \leq T_g \\ \beta_m \left( \frac{T_g}{T} \right)^\gamma & T_g < T \leq 6s \end{cases} \quad \dots\dots\dots (7.2)$$

由式 7.1 和 7.2 可得：

$$\alpha(T) = \begin{cases} K & T \leq 0.04s \\ K + (\alpha_m - K) \frac{T - 0.04}{T_1 - 0.04} & 0.04s < T \leq T_1 \\ \alpha_m & T_1 < T \leq T_g \\ \alpha_m \left( \frac{T_g}{T} \right)^\gamma & T_g < T \leq 6s \end{cases} \quad \dots\dots\dots (7.3)$$

其中  $K = A_{\max}/g$ ，為設計地震係數， $A_{\max}$  按表 7.2 取值； $\alpha_{\max} = A_{\max} \beta_m / g$ ，為地震影響係數最大值； $S_a(0.2)$  和  $S_a(1.0)$  分別週期為 0.2 s 和 1.0 s 地震動加速度反應譜的取值。表 7.3 為與式 7.3 對應的各分區設計地震動參數表。

香港元朗—屯門地區場地基岩面埋深和軟土埋深和厚度對地震動參數影響顯著，一般基岩面埋深越深，軟土厚度越大，其地震動反應譜特徵週期  $T_g$  越大，大震的加速度峰值越小。所以，香港元朗—屯門地區地震動參數小區劃邊界確定原則為：I 分區的邊界主要根據地形的坡角或山地的邊界，II、III 分區的邊界重點考慮場地基岩面埋深、軟土厚度和分佈、及 50 年 3 個超越概率 10% 的地震動反應譜  $T_g$  值三個要素，綜合考慮工程地質單元分區和建築場地類別區域圖的邊界，勾畫出香港元朗—屯門地區工程場地 3 個設計地震動參數分區的邊界，地震動參數小區劃圖見圖 7.5，各分區的設計地震動參數見表 7.3。

表 7.2 擬合地震動分區參數表（5% 阻尼比）

| 分區                                | I 區        |       |          |           |          | II 區       |       |          |           |          | III 區      |       |          |           |          |
|-----------------------------------|------------|-------|----------|-----------|----------|------------|-------|----------|-----------|----------|------------|-------|----------|-----------|----------|
|                                   | $A_{\max}$ | $T_g$ | $\gamma$ | $\beta_m$ | $S_a(1)$ | $A_{\max}$ | $T_g$ | $\gamma$ | $\beta_m$ | $S_a(1)$ | $A_{\max}$ | $T_g$ | $\gamma$ | $\beta_m$ | $S_a(1)$ |
| 63%                               | 50         | 0.28  | 1.0      | 2.5       | 36       | 60         | 0.40  | 1.0      | 2.5       | 60       | 45         | 0.60  | 1.0      | 2.5       | 67       |
| 50%                               | 60         | 0.29  | 1.0      | 2.5       | 43       | 75         | 0.43  | 1.0      | 2.5       | 80       | 50         | 0.65  | 1.0      | 2.5       | 80       |
| 10%                               | 155        | 0.30  | 1.0      | 2.5       | 120      | 150        | 0.50  | 1.0      | 2.5       | 190      | 100        | 0.75  | 1.0      | 2.5       | 185      |
| 2%                                | 265        | 0.35  | 1.0      | 2.5       | 228      | 210        | 0.65  | 1.0      | 2.5       | 343      | 140        | 1.00  | 1.0      | 2.5       | 350      |
| 註： $S_a(0.2)$ 的取值與 $A_{\max}$ 相同。 |            |       |          |           |          |            |       |          |           |          |            |       |          |           |          |

表 7.3 設計地震動分區參數表（5% 阻尼比）

| 分區<br>參數 | I 區      |            |       |            | II 區     |            |       |            | III 區    |            |       |            |
|----------|----------|------------|-------|------------|----------|------------|-------|------------|----------|------------|-------|------------|
|          | $T_1$    | $T_g$      | $K$   | $\alpha_m$ | $T_1$    | $T_g$      | $K$   | $\alpha_m$ | $T_1$    | $T_g$      | $K$   | $\alpha_m$ |
| 63%      | 0.06     | 0.28       | 0.051 | 0.127      | 0.1      | 0.40       | 0.061 | 0.153      | 0.1      | 0.60       | 0.046 | 0.115      |
| 50%      | 0.06     | 0.30       | 0.061 | 0.153      | 0.1      | 0.43       | 0.076 | 0.191      | 0.1      | 0.65       | 0.051 | 0.127      |
| 10%      | 0.06     | 0.32       | 0.158 | 0.395      | 0.1      | 0.50       | 0.153 | 0.382      | 0.1      | 0.75       | 0.102 | 0.255      |
| 2%       | 0.06     | 0.35       | 0.270 | 0.675      | 0.1      | 0.65       | 0.214 | 0.535      | 0.1      | 1.00       | 0.143 | 0.357      |
| 參數       | $\gamma$ | $S_a(0.2)$ |       | $S_a(1.0)$ | $\gamma$ | $S_a(0.2)$ |       | $S_a(1.0)$ | $\gamma$ | $S_a(0.2)$ |       | $S_a(1.0)$ |
| 63%      | 1.0      | 120        |       | 34         | 1.0      | 150.0      |       | 60         | 1.0      | 112.5      |       | 67         |
| 50%      | 1.0      | 145        |       | 43         | 1.0      | 187.5      |       | 80         | 1.0      | 125.0      |       | 80         |
| 10%      | 1.0      | 375        |       | 120        | 1.0      | 375.0      |       | 190        | 1.0      | 250.0      |       | 185        |
| 2%       | 1.0      | 650        |       | 228        | 1.0      | 525.0      |       | 343        | 1.0      | 350.0      |       | 350        |

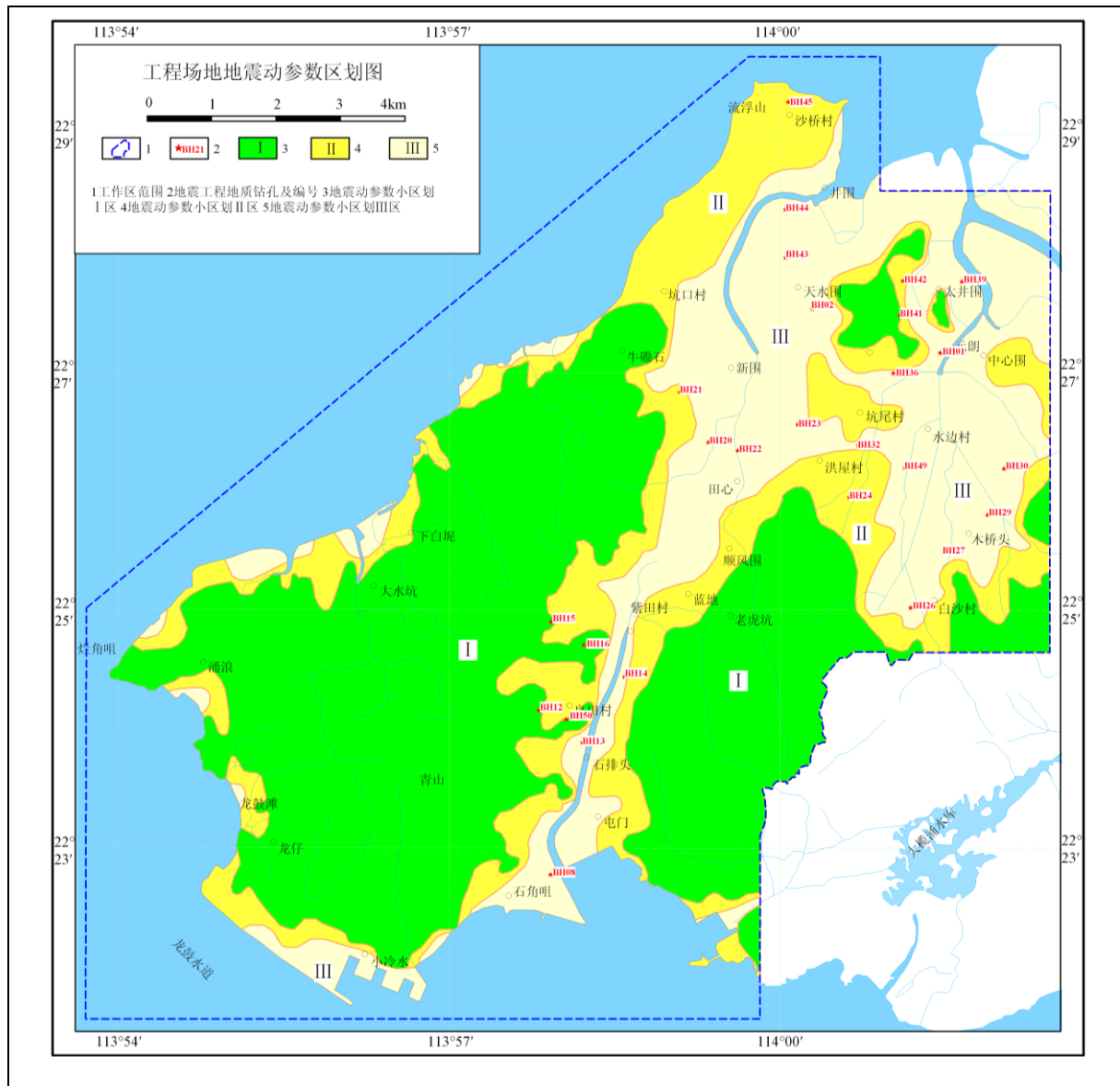


圖 7.5 香港元朗—屯門地區地震動參數小區劃圖

## 第八章 地震地質災害小區劃

地震地質災害小區劃的原則是：在一定的地震作用下，震害類型和程度可能重複；地震工程地質條件類同的地段災害相同。“一定的地震作用”是指場地地震危險性分析所得到的，50 年超越概率 10%所對應的地震動峰值加速度（或地震基本烈度）相當的地震作用。“震害類型”包括地基土液化、軟土震陷、地表斷層、崩塌、滑坡、地裂縫和泥石流、海嘯與湖湧等地震地質災害。

在香港地區重點評價山體滑坡的地震地質災害。

在廣泛收集資料的基礎上，結合當地的地形地貌、岩土性、地下水、地質構造等特徵，進行地震地質災害評價和小區劃。



## 8.1 地震地質災害評價

### 8.1.1 地基土液化

《建築抗震設計規範》（GB50011-2010）規定，存在飽和砂土和飽和粉土（不含黃土）的地基，除 6 度設防外，應進行液化判別；存在液化土層的地基，應根據建築的抗震設防類別、地基的液化等級，結合具體情況採取相應的措施。

當初步判別認為需進一步進行液化判別時，應採用標準貫入試驗判別法判別地面下 20 米深度範圍內的液化。

在地面下 20 米深度範圍內，液化判別標準貫入錘擊數臨界值可按式計算：

$$N_{cr} = N_0 \beta [\ln(0.6d_s + 1.5) - 0.1d_w] \sqrt{3/\rho_c} \dots\dots\dots (8.1)$$

其中  $N_{cr}$  = 液化判別標準貫入錘擊數臨界值；  
 $N_0$  = 液化判別標準貫入錘擊數基準值，可按表 8.1 採用；  
 $d_s$  = 飽和土標準貫入點深度（米）；  
 $d_w$  = 地下水位（米）；  
 $\rho_c$  = 粘粒含量百分率（%）；當  $\rho_c$ （%）< 3 或為砂土時取 3；  
 $\beta$  = 調整係數，設計地震第一組取 0.80，第二組取 0.95，第三組取 1.05。

表 8.1 液化判別標準貫入錘擊數基準值  $N_0$

| 設計基本地震加速度（g）   | 0.10 | 0.15 | 0.20 | 0.30 | 0.40 |
|----------------|------|------|------|------|------|
| 液化判別標準貫入錘擊數基準值 | 7    | 10   | 12   | 16   | 19   |

將臨界錘擊數  $N_{cr}$  與實測標準貫入錘擊數  $N$  進行比較，當  $N_{cr} \geq N$  為液化，否則為不液化。

對存在液化砂土層、粉土層的地基，按下式計算每個鑽孔的液化指數，並按表 8.2 綜合劃分地基的液化等級：

$$I_{LE} = \sum_{i=1}^n \left[ 1 - \frac{N_i}{N_{cri}} \right] d_i W_i \dots\dots\dots (8.2)$$

其中  $I_{LE}$  = 液化指數；  
 $n$  = 在判別深度範圍內每一個鑽孔標準貫入試驗點的總數；  
 $N_i$ 、 $N_{cri}$  = 分別為標準貫入錘擊數的實測值和臨界值，當實測值大於臨界值時應取臨界值；  
 $d_i$  =  $i$  點所代表的土層厚度；  
 $W_w$  =  $i$  土層單位如層厚度的層位元影響權函數值（單位為  $m^{-1}$ ）。

表 8.2 液化等級與液化指數的對應關係

| 液化等級              | 輕微                  | 中等                   | 嚴重            |
|-------------------|---------------------|----------------------|---------------|
| 液化指數 ( $I_{LE}$ ) | $0 < I_{LE} \leq 6$ | $6 < I_{LE} \leq 18$ | $I_{LE} > 18$ |

根據工程場區 27 個工程地震鑽孔和收集的 5 千多鑽孔資料，工程場區多個地段含有飽和砂土層，根據《建築抗震設計規範》(GB50011-2010) 規定和委託方要求，對工程場區鑽孔的砂土層分別按設計基本地震加速度 0.10 g 和 0.20 g 進行砂土液化的判別，27 個工程地震鑽孔判別結果如表 8.3，由表知，工程場區的飽和砂土層在遭受 VII 或 VIII 度地震作用下，局部可能發生液化，液化等級為“輕微”至“嚴重”。同時為了對場區的砂土液化地段進行詳細的分區，對 5 千多鑽孔資料的飽和砂土層也分別按設計基本地震加速度 0.10 g 和 0.20 g 進行了砂土液化的判別（沒有粘粒含量百分率的試驗資料時，從安全的角度，都把粘粒含量百分率取為 3%），根據上述的判別結果，對工程場區內的砂土液化情況進行小區劃，為場區內建築的規劃設計提供參考和依據，其結果見圖 8.1、8.2。

表 8.3 工程場區砂土層液化判別表

| 孔號   | 座標        |           | 液化判別結果(0.10 g) |          |          | 液化判別結果(0.20 g) |          |          |
|------|-----------|-----------|----------------|----------|----------|----------------|----------|----------|
|      | E         | N         | 是否<br>液化       | 液化<br>指數 | 液化<br>等級 | 是否<br>液化       | 液化<br>指數 | 液化<br>等級 |
| BH01 | 820788.01 | 834662.81 | 是              | 2.14     | 輕微       | 是              | 11.51    | 中等       |
| BH02 | 818797.50 | 835346.62 | 否              |          |          | 否              |          |          |
| BH08 | 814731.24 | 826550.68 | 否              |          |          | 是              | 10.03    | 中等       |
| BH12 | 814545.68 | 829101.75 | 無沖積、沉積砂土層      |          |          |                |          |          |
| BH13 | 815228.54 | 828606.03 | 否              |          |          | 否              |          |          |
| BH14 | 815878.90 | 829623.70 | 否              |          |          | 否              |          |          |
| BH15 | 814736.30 | 830479.68 | 無沖積、沉積砂土層      |          |          |                |          |          |
| BH16 | 815248.43 | 830122.68 | 無沖積、沉積砂土層      |          |          |                |          |          |
| BH20 | 817186.69 | 833269.83 | 否              |          |          | 否              |          | 輕微       |
| BH21 | 816742.75 | 834053.95 | 否              |          |          | 否              |          |          |
| BH22 | 817639.96 | 833141.84 | 是              | 2.61     | 輕微       | 是              | 6.06     | 中等       |
| BH23 | 818574.03 | 833547.56 | 否              |          |          | 否              |          |          |
| BH24 | 819373.99 | 832415.73 | 否              |          |          | 否              |          |          |
| BH26 | 820329.16 | 830697.38 | 否              |          |          | 是              | 5.58     | 輕微       |
| BH27 | 820851.05 | 831545.75 | 否              |          |          | 否              |          |          |
| BH29 | 821526.55 | 832139.46 | 否              |          |          | 否              |          |          |
| BH30 | 821782.24 | 832860.94 | 否              |          |          | 否              |          |          |
| BH32 | 819518.02 | 833226.85 | 否              |          |          | 否              |          |          |
| BH36 | 820061.08 | 834344.40 | 否              |          |          | 否              |          |          |
| BH39 | 821126.41 | 835767.88 | 否              |          |          | 否              |          |          |
| BH41 | 820154.63 | 835247.23 | 無沖積、沉積砂土層      |          |          |                |          |          |
| BH42 | 820208.96 | 835782.70 | 否              |          |          | 否              |          |          |
| BH43 | 818385.85 | 836137.79 | 否              |          |          | 否              |          |          |
| BH44 | 818381.82 | 836888.04 | 是              | 8.43     | 中等       | 是              | 19.50    | 嚴重       |
| BH45 | 818426.21 | 838562.87 | 否              |          |          | 否              |          |          |
| BH49 | 820239.20 | 832872.00 | 否              |          |          | 否              |          |          |
| BH50 | 814975.32 | 828963.20 | 無沖積、沉積砂土層      |          |          |                |          |          |

圖 8.1 工程場區砂土液化區域圖 (0.10 g)

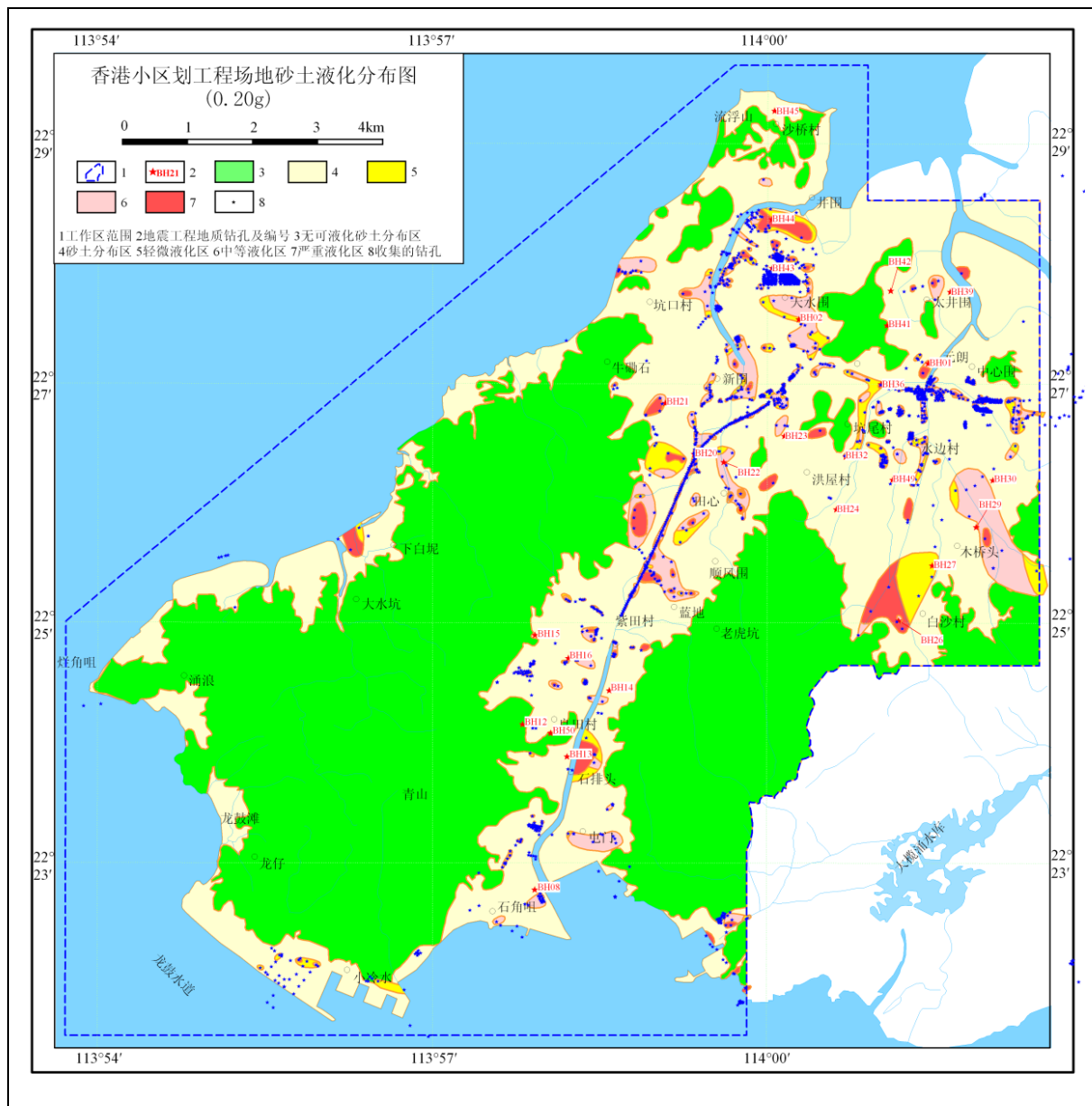


圖 8.2 工程場區砂土液化區域圖 (0.20 g)

### 8.1.2 軟土震陷

根據《軟土地區工程地質勘察規範》(JGJ 83-91)軟土最基本的特徵：

- (1) 外觀以灰色為主的細粒土；
- (2) 天然含水量大於或等於液限；及
- (3) 天然孔隙比大於或等於 1.0。

根據《工程地質手冊》，其液性指數  $I_L$  大於 0.75（軟塑），根據標準貫入試驗錘擊數與液性指數的關係，軟土的  $N_{63.5}$  的值  $\leq 3$  擊（ $f_k = 105 \text{ kPa}$ ）。根據地震工程地質鑽孔和收集的 5 千餘孔鑽探資料，工程場區局部地段  $N_{63.5}$  值  $\leq 3$  擊，也即工程場區局部地段分佈有軟土。

27 個地震工程地質鑽孔中，只有 BH26、BH39、BH42 共三個孔含有軟土，根據進行的標準貫入試驗結果，收集的 5,000 餘孔中也有僅有 432 孔存在軟土，根據這些鑽孔的分佈位置，對場區存在軟土的地段進行劃分，其結果見圖 8.3。由圖可知，工程場區潛在軟土震陷發育的地區主要分佈在場區的天水圍北部、太井圍北部、水邊村北部、白沙村西部、木橋頭東側、新圍東南、田心西北、石排頭及屯門附近等地的局部地段（總面積約 5.6 平方公里，佔場區陸地面積的 5.1%）；軟土具高壓縮性，承載力低，在強烈地震作用下，可能會出現軟土震陷現象，對工程抗震不利，因此，存在軟土的這些地段，為建築抗震的不利地段，該地段內的建築應根據具體情況進行地震震陷的分析計算。

### 8.1.3 地表斷層

國內外的大量震害資料表明，活動斷裂在地震時的地面破壞效應主要表現在斷裂的錯動引起建築物和構築物的破壞。對於活斷層的定義，本報告採用 GB17741-1999 規範的活動斷裂的定義，即“晚第四紀以來有活動的斷裂”，而可能引起地表或近地表明顯錯動的斷層定義為能動斷層。

前面章節對工程場區的斷裂及活動性進行了分析和綜合研究，場區內的斷裂最新活動時代在中更新世，為早第四紀斷裂，故可不考慮地表斷層及地裂縫的影響。

### 8.1.4 崩塌、滑坡

崩塌、滑坡等地質災害為另一專題研究。

## 8.2 地震地質災害小區劃

根據以上對工程場地地震地質災害的評價結果，本章節主要分別針對工程場區遭受 0.10 g 和 0.20 g 地震加速度影響時的砂土液化和軟土震陷地震地質災害進行社區劃分，其結果詳見圖 8.4 和 8.5。

從圖可看出，場區在遭受 0.10 g 和 0.20 g 地震加速度影響時，地震地質災害（砂土液化和軟土震陷）主要集中發生在天水圍北部、太井圍北部、水邊村北部、白沙村西部、木橋頭東側、新圍東南、田心西北、石排頭及屯門附近，多數地帶為單一的砂土液化或軟土震陷，局部地區同時存在兩種地震地質災害（砂土液化也有軟土震陷）的可能，未來分別遭受 0.10 g 和 0.20 g 地震加速度影響時，場地地震地質災害分佈區域大體接近，不同之處在於其液化程度及範圍的不同：遭受 0.20 g 的影響比遭受 0.10 g 影響時液化範圍大，在遭受 0.10 g 地震加速度的影響時，場地發生地震地質災害地區的總面積約 8.2 平方公里，佔場區陸地面積的 7.5%，在遭受 0.20 g 地震加速度的影響時，其液化等級在多處地帶相應增加，紫田村和洪屋村、坑尾村一帶附近有新的液化地段出現，發生地震地質災害地區的總面積約 11.6 平方公里，佔場區陸地面積的 10.6%。



圖 8.3 工程場區軟土分佈圖

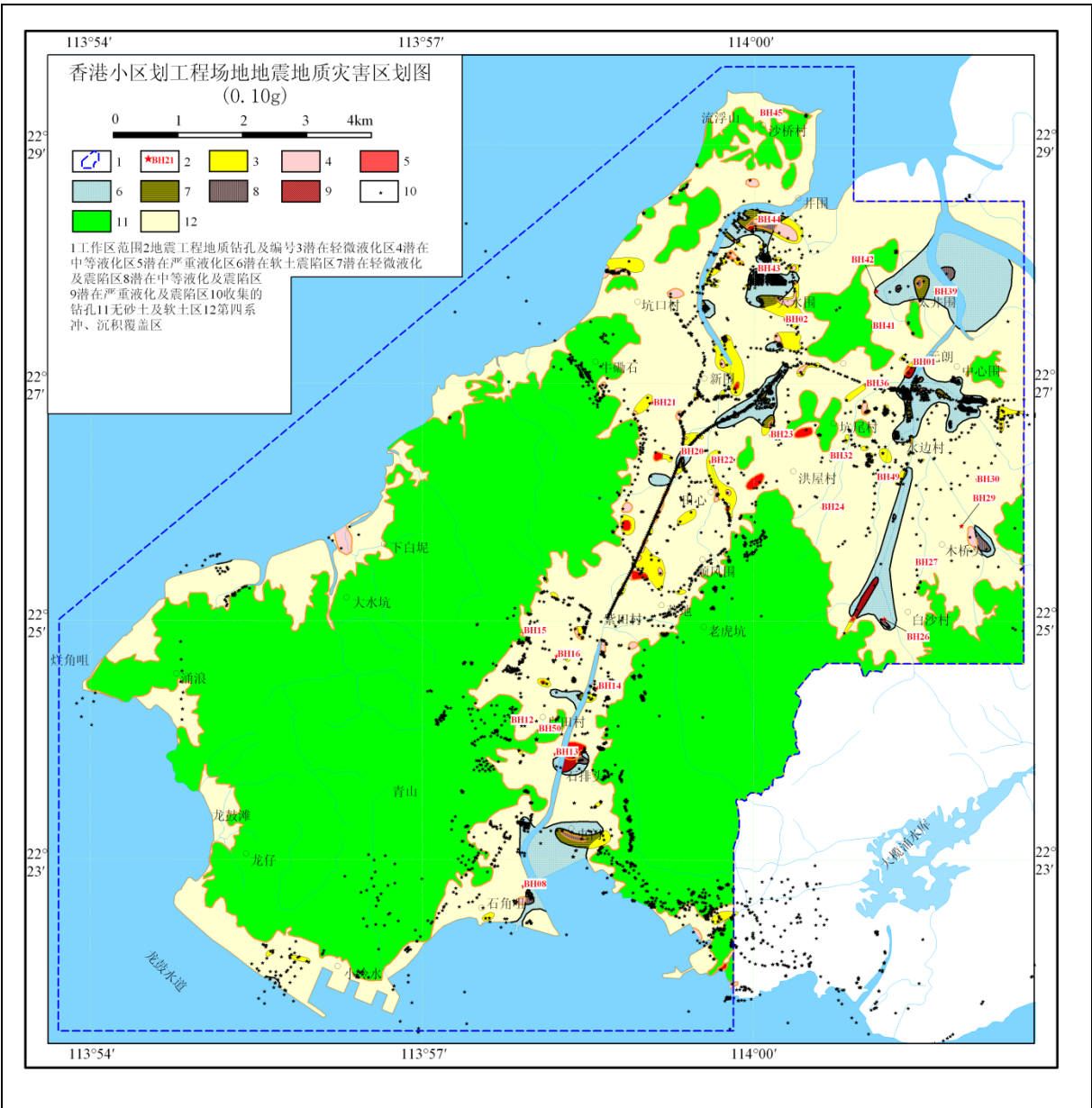


圖 8.4 工程場區地震地質災害小區劃圖（遭受 0.10 g 地震加速度）



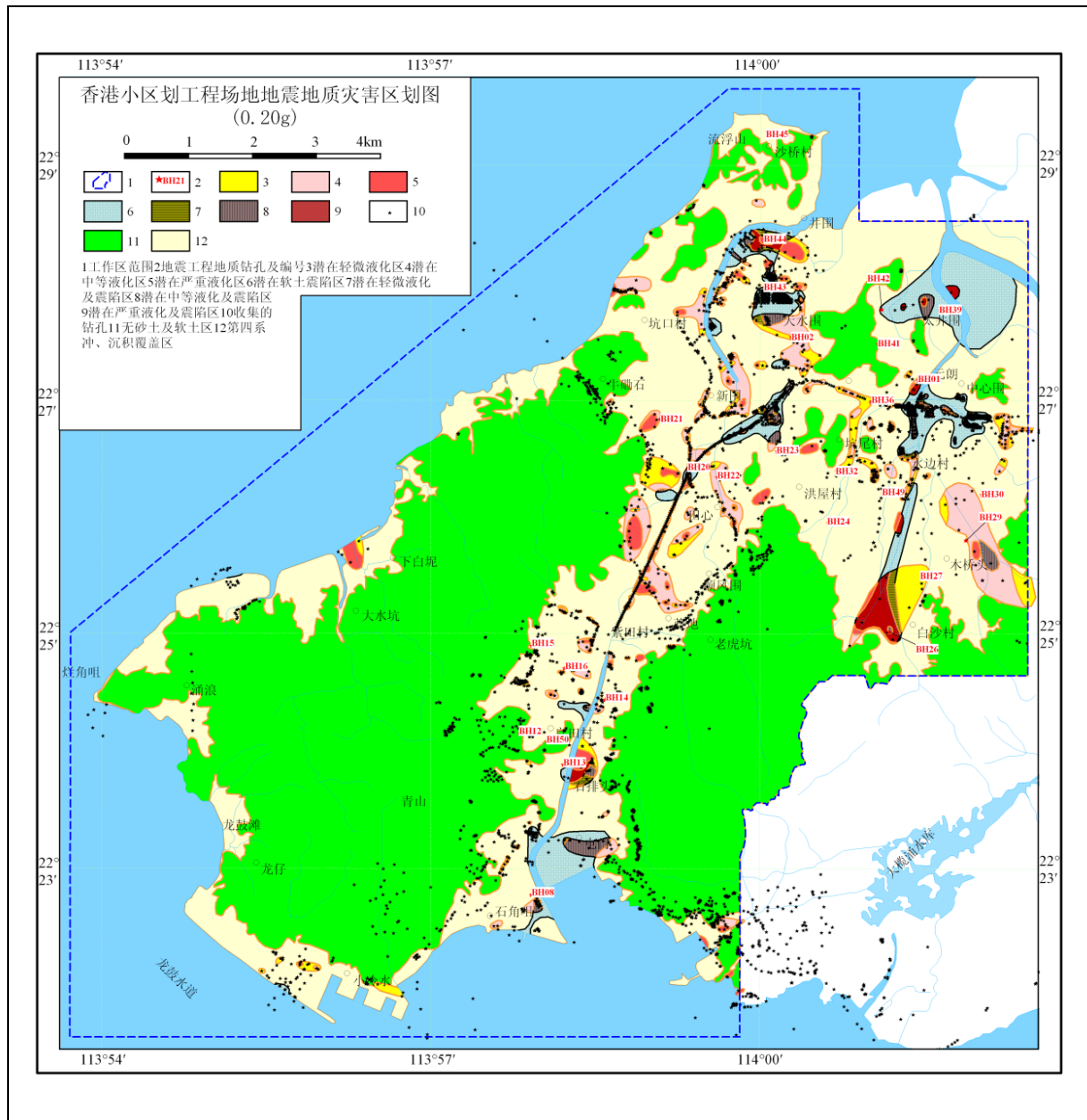


圖 8.5 工程場區地震地質災害小區劃圖（遭受 0.20 g 地震加速度）

## 第九章 結論

### 9.1 地震工程地質條件評價

#### (1) 地貌特徵

工程場區地貌主要為丘陵谷地和沖、沉積小平原，分別約佔場區陸地面積的 53.4% 和 46.6%。地勢總體南高，北低，丘陵谷地地形起伏變化大；沖、沉積小平原開闊平坦，地形起伏小。

#### (2) 岩土力學性能和場地類別

場區火山岩和變質岩相當發育，火山岩岩性主要為凝灰岩類（含角閃石凝灰岩、沉凝灰岩及凝灰質碎屑岩等）及少量安山岩和流紋岩及為花崗岩類（花崗岩、花崗閃長岩等）；變質岩主要為變質砂岩類和片岩；在場區的北部、中部及南部零星分佈有侏羅紀的砂岩、粉砂岩、礫岩等和石炭紀的大理岩、石灰岩等。

第四系在場區分佈廣泛，約佔陸地面積的 47%，主要呈條帶狀分佈於場區中部及北部，其成因為河流相、海相及洪積相三種，其土性主要為粘土類（淤泥、粘土、粉質粘土等）和砂土類（各種粒徑的砂及含粘土類砂、粉土等）。

場區場地土類型屬於中軟～中硬場地土，建築場地類別為 I ～ III 類，各地震工程地質測試鑽孔的覆蓋層、等效剪切波速等見下表 9.1。

#### (3) 場地工程地質分區

綜合場區的地貌形態、物質成因及地基岩土力學性能等，結合建築場地類別等因素將工程場地劃分為：

- (i) 丘陵谷地淺基岩工程地質區；
- (ii) 坡麓堆積工程地質區；
- (iii) 山前濱海平原工程地質區；及
- (iv) 濱岸填海工程地質區等，四個工程地質區。

丘陵谷地淺基岩工程地質區，分佈於流浮山—青山和場區東南部的九徑山一帶，總面積約 56.5 平方公里。該區地勢高，地形起伏變化大，坡度多大於 15 度，基岩面埋藏淺，埋藏基岩為玄武岩、花崗岩、粉砂岩及其變質岩類，其上多覆蓋較薄坡積、殘積層；場地土類型多屬中硬～堅硬場地土，建築場地類別多為 I 類，局部為 II 類，無軟土及可液化砂土分佈；該區大部分地段地形起伏變化大，邊坡效應明顯，屬對建築抗震不利地段；可能出現崩塌、滑坡等地震地質災害。

坡麓堆積工程地質區，分佈於流浮山—青山和場區東南部的九徑山的坡麓不規則狹長地帶，總面積約 20.1 平方公里；該區地勢相對較低，地形起伏較平緩，坡度在 2 - 10 度之間，基岩面埋稍深，埋藏基岩為玄武岩、花崗岩、粉砂岩及其變質岩類，其上

表 9.1 剪切波速測試綜合結果表

| 孔 位  | 覆蓋層<br>厚度 $d_0$ (m) | 等效波速<br>$V_{se}$ (m/s) | 場地土<br>類 型 | 建築場地<br>類 別 |
|------|---------------------|------------------------|------------|-------------|
| BH01 | 28.99               | 222                    | 中軟         | II          |
| BH02 | 33.40               | 248                    | 中軟         | II          |
| BH08 | 22.60               | 201                    | 中軟         | II          |
| BH12 | 2.50                | 200                    | 中軟         | I           |
| BH13 | 23.10               | 166                    | 中軟         | II          |
| BH14 | 35.00               | 333                    | 中硬         | II          |
| BH15 | 11.90               | 256                    | 中硬         | II          |
| BH16 | 7.19                | 350                    | 中硬         | II          |
| BH20 | 20.20               | 208                    | 中軟         | II          |
| BH21 | 28.80               | 280                    | 中硬         | II          |
| BH22 | 39.90               | 203                    | 中軟         | II          |
| BH23 | 21.70               | 309                    | 中硬         | II          |
| BH24 | 19.85               | 301                    | 中硬         | II          |
| BH26 | 60.60               | 270                    | 中硬         | II          |
| BH27 | 53.50               | 173                    | 中軟         | III         |
| BH29 | 36.47               | 195                    | 中軟         | II          |
| BH30 | > 150               | 238                    | 中軟         | III         |
| BH32 | 18.10               | 245                    | 中軟         | II          |
| BH36 | 33.25               | 241                    | 中軟         | II          |
| BH39 | 17.20               | 206                    | 中軟         | II          |
| BH41 | 9.17                | 304                    | 中硬         | II          |
| BH42 | 15.20               | 255                    | 中硬         | II          |
| BH43 | 45.80               | 184                    | 中軟         | II          |
| BH44 | 47.10               | 219                    | 中軟         | II          |
| BH45 | 26.44               | 292                    | 中硬         | II          |
| BH49 | 34.50               | 252                    | 中硬         | II          |
| BH50 | 4.00                | 350                    | 中硬         | I           |

覆蓋崩坡積、殘積層或薄層第四系沖積、洪積層；場地土類型多屬中硬場地土，局部為中軟場地土，建築場地類別為Ⅱ類，一些地段存在軟土及可液化砂土，屬對建築抗震不利地段；施工條件較好，但可能遭受泥石流的威脅。

山前濱海平原工程地質區，主要分佈於元朗平原至屯門一帶，總面積約 29.0 平方公里，該區地勢低，平坦，地形起伏小，坡度多小於 2 度；該區基岩為侏羅紀火成岩、火成碎屑岩和侏羅系砂岩、粉砂岩及石灰岩等；基岩面（中風化岩面）埋藏較深，局部超過 150 米，其上覆蓋殘積層和第四系沖積、沉積層，殘積層厚度變化大，岩面（中風化岩面）起伏很大；該區場地土類型屬中軟場地土，建築場地類別為Ⅱ～Ⅲ類，一些地段存在軟土及可液化砂土，屬對建築抗震不利地段。

濱岸填海工程地質區，主要分佈於屯門至石角咀、龍鼓水道東側一帶，總面積約 4.2 平方公里，該區地勢低，平坦，地形起伏小，海拔低，坡度多小於 2 度，基岩為侏羅紀火成岩、火成碎屑岩等；基岩面（中風化岩面）埋藏稍深（BH08 孔揭露埋深 23.75 米），其上覆蓋第四系沖積、沉積層和人工填土層，填土層厚度較大（離岸越遠厚度越大），較鬆散；該區場地土類型屬中軟場地土，建築場地類別為Ⅱ類，一些地段存在可液化砂土，屬對建築抗震不利地段。

## 9.2 設計地震動小區劃分區參數

工程場地設計地震動影響係數的運算式為：

$$\alpha(T) = \begin{cases} K & T \leq 0.04s \\ K + (\alpha_m - K) \frac{T - 0.04}{T_1 - 0.04} & 0.04s < T \leq T_1 \\ \alpha_m & T_1 < T \leq T_g \\ \alpha_m \left( \frac{T_g}{T} \right)^\gamma & T_g < T \leq 6s \end{cases} \quad (9.1)$$

其中  $K$  為設計地震係數，即單位為  $g$  的地面加速度峰值， $K = A_{\max}/g$  或  $K = S_a(0.2)/2.5$ ，為結構剪力驗算的重要參數； $\alpha_{\max}$  為地震影響係數最大值； $S_a(0.2)$  和  $S_a(1.0)$  分別週期為 0.2 s 和 1.0 s 地震動加速度反應譜的取值。下表 9.2 為香港元朗 — 屯門地區各分區設計地震動參數表。

表 9.2 設計地震動分區參數表（5%阻尼比）

| 分區<br>參數 | I 區      |               |               |            |
|----------|----------|---------------|---------------|------------|
|          | $T_1$    | $T_g$         | $K$           | $\alpha_m$ |
| 63%      | 0.06     | 0.28          | 0.051         | 0.127      |
| 50%      | 0.06     | 0.30          | 0.061         | 0.153      |
| 10%      | 0.06     | 0.32          | 0.158         | 0.395      |
| 2%       | 0.06     | 0.35          | 0.270         | 0.675      |
| 參數       | $\gamma$ | $S_a$ ( 0.2 ) | $S_a$ ( 1.0 ) |            |
| 63%      | 1.0      | 120           | 36            |            |
| 50%      | 1.0      | 145           | 43            |            |
| 10%      | 1.0      | 375           | 120           |            |
| 2%       | 1.0      | 650           | 228           |            |
| 分區<br>參數 | II 區     |               |               |            |
|          | $T_1$    | $T_g$         | $K$           | $\alpha_m$ |
| 63%      | 0.1      | 0.40          | 0.061         | 0.153      |
| 50%      | 0.1      | 0.43          | 0.076         | 0.191      |
| 10%      | 0.1      | 0.50          | 0.153         | 0.382      |
| 2%       | 0.1      | 0.65          | 0.214         | 0.535      |
| 參數       | $\gamma$ | $S_a$ ( 0.2 ) | $S_a$ ( 1.0 ) |            |
| 63%      | 1.0      | 150.0         | 60            |            |
| 50%      | 1.0      | 187.5         | 80            |            |
| 10%      | 1.0      | 375.0         | 190           |            |
| 2%       | 1.0      | 525.0         | 343           |            |
| 分區<br>參數 | III 區    |               |               |            |
|          | $T_1$    | $T_g$         | $K$           | $\alpha_m$ |
| 63%      | 0.1      | 0.60          | 0.046         | 0.115      |
| 50%      | 0.1      | 0.65          | 0.051         | 0.127      |
| 10%      | 0.1      | 0.75          | 0.102         | 0.255      |
| 2%       | 0.1      | 1.00          | 0.143         | 0.357      |
| 參數       | $\gamma$ | $S_a$ ( 0.2 ) | $S_a$ ( 1.0 ) |            |
| 63%      | 1.0      | 112.5         | 67            |            |
| 50%      | 1.0      | 125.0         | 80            |            |
| 10%      | 1.0      | 250.0         | 185           |            |
| 2%       | 1.0      | 350.0         | 350           |            |

### 9.3 地震地質災害小區劃結果

#### (1) 地基土液化

根據工程場區 27 個工程地震鑽孔和收集的 5 千多鑽孔資料，工程場區在遭受 0.10 g 的地震加速度影響時，場區的天水圍北部、太井圍北部、水邊村北部、白沙村西部、木橋頭東側、新圍東南、田心西北、石排頭及屯門附近等地的局部地段飽和砂土層將會發生砂土液化現象（總面積約 3.4 平方公里，佔場區陸地面積的 3.1%），液化等級為“輕微”至“嚴重”；在遭受 0.20 g 的地震加速度影響時，場區除以上地帶外，在紫田村和洪屋村、坑尾村等地附近局部地段有新的液化地段出現，且各地帶的液化範圍相對擴大（總面積約 7.5 平方公里，佔場區 陸地面積的 6.8%），液化等級（液化指數）也有不同程度的增加。

#### (2) 軟土震陷

根據《軟土地區工程地質勘察規範》（JGJ 83-91）和 27 個工程地震鑽孔和收集的 5,000 多鑽孔資料，工程場區潛在軟土震陷發育的地區主要分佈在場區天水圍北部、太井圍北部、水邊村北部、白沙村西部、木橋頭東側、新圍東南、田心西北、石排頭及屯門附近等地的局部地段（總面積約 5.6 平方公里，佔場區陸地面積的 5.1%）。

#### (3) 地表斷層

場區內的斷裂最新活動時代在中更新世，為早第四紀斷裂，可不考慮地表斷層及地裂縫的影響。

#### (4) 地震地質災害小區劃

針對工程場區遭受 0.10 g 和 0.20 g 地震加速度影響時的砂土液化和軟土震陷地震地質災害進行的社區劃分，其結果為：場區在遭受 0.10 g 和 0.20 g 地震加速度影響時，地震地質災害（砂土液化和軟土震陷）主要集中發生在天水圍北部、太井圍北部、水邊村北部、白沙村西部、木橋頭東側、新圍東南、田心西北、石排頭及屯門附近，場地發生地震地質災害地區的總面積約 8.2 平方公里，佔場區陸地面積的 7.5%，多數地帶為單一的砂土液化或軟土震陷，局部地區既有砂土液化也有軟土震陷兩種地震地質災害同時發生；遭受 0.20 g 的影響時比遭受 0.10 g 影響時液化範圍擴大，其液化等級在多處地帶相應增加，紫田村和洪屋村、坑尾村一帶等地有新的液化地段出現（總面積約 11.6 平方公里，佔場區陸地面積的 10.6%）。

### 9.4 地震小區劃圖使用說明

- (1) 可作為研究區防震減災規劃和城市發展規劃的依據。
- (2) 地震動參數小區劃 50 年超越概率 10% 地震動參數小區劃結果適用於研究區範圍內新建（重建）、擴建、改建的一般建設工程的抗震設防。

- (3) 地震動參數小區劃 50 年超越概率 63%或 50%適用於研究區一般建設工程進行強度驗算，50 年超越概率 2%地震動參數小區劃結果適用於研究區一般建設工程進行變形驗算。
- (4) 設計地震影響係數最大值  $\alpha_{\max}$  和地震係數  $K$  值與地面地震動峰值加速度  $A_{\max}$ （單位為 gal 或  $\text{cm/s}^2$ ）的關係為：

$$K = A_{\max} / g \dots\dots\dots (9.1)$$

$$\alpha_{\max} = A_{\max} \beta_m / g = S_a(0.2) / g \dots\dots\dots (9.2)$$

$A_{\max}$  或  $S_a(0.2)$  決定設計地震動反應譜的幅值，特徵週期  $T_g$  決定反應譜平臺的寬度。設計地震動參數見設計地震動分區參數表。

- (5) 對崩塌、滑坡和泥石流影響較大的地區，應採取防護措施。
- (6) 重大建設工程應進行其抗震設計參數的專門研究，香港元朗一屯門地震小區劃研究報告應作參考之用。

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