TRIAL APPLICATION OF THERMAL INFRA-RED IMAGE AND SEISMIC SYMPATHETIC VIBRATION TECHNIQUES FOR SLOPE INVESTIGATION

GEO REPORT No. 199

T.H.H. Hui & H.W. Sun

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT
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SPECIAL ADMINISTRATIVE REGION

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents
Table of Contents
Table of Contents
Table of Contents

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. Printed copies are also available for some GEO Reports. For printed copies, a charge is made to cover the cost of printing.

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R.K.S. Chan
Head, Geotechnical Engineering Office
February 2007

FOREWORD

This report documents the details and findings of some pilot field trials of two non-invasive techniques, namely, Thermal Infra-red Image Analysis (TIIA) and Seismic Sympathetic Vibration Analysis (SSVA), for the detection of voids between a hard surface cover and the underlying slope-forming material. The trials were carried out at three separate slopes in Hong Kong. The principal objective of the field trails was to assess the applicability of TIIA and SSVA to landslide investigation or slope investigation work.

This report was prepared by Mr T.H.H. Hui, and Dr H.W. Sun of the Landslip Preventive Measures Division 1 under my supervision. Halcrow China Limited, the 2002 landslide investigation consultant, provided support by assisting to coordinate the field work. The field trials of TIIA and SSVA were carried out and interpreted by the Hong Kong Construction (Civil Engineering) Limited, with technical support by Nittoc Construction Limited from Japan, at their own costs. All contributions are gratefully acknowledged.

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Table of Contents
Table of Contents
Table of Contents
Table of Contents

ABSTRACT

Thermal Infra red Image Analysis (TIIA) and Seismic Sympathetic Vibration Analysis (SSVA) have been developed and used in Japan in recent years for the detection of air voids beneath a hard slope surface cover (or loss of contact between the hard surface cover and the underlying ground mass). To assess the potential applicability of such techniques for landslide study or slope investigation works in Hong Kong, a series of field trials has been carried out on selected cut slopes. Ground investigations, including coreholes and slope surface stripping, were subsequently carried out to verify the interpreted results of TIIA and SSVA.

Through this series of field trials, some useful experience was gained in the practicality and application of the techniques. More systematic studies are required to establish the general applicability and resolution of the techniques for different site conditions in Hong Kong.

It would appear from the trials that TIIA shows some promise as being able to identify the approximate locations of possible voided areas beneath a hard slope surface cover in a rapid manner. However, TIIA technique appears to be affected by some factors, such as slope surface profile, seepage, presence of cracks, shotcrete cover with variable mix and thickness and experience of operators.

SSVA test is generally capable of identifying areas with very minor loss of contact, although the reliability is not fully proven because of some inconsistent results in local areas. The resolution of the test is found to be a function of various factors, including the material density and thickness of the hard cover, continuity of the contact between the hard cover and the underlying ground and the characteristics of the near surface slope forming material. Some discrepancies for local areas are also noted between SSVA and hammer tapping and between SSVA/hammer tapping and coring.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

CONTENTS

Table of Contents
Table of Contents
Table of Contents

1. INTRODUCTION

New techniques have been developed and used in Japan in recent years for the detection of air voids beneath a hard slope surface cover (or loss of contact between the hard surface cover and the underlying ground mass), namely, Thermal Infra-red Image Analysis (TIIA) and Seismic Sympathetic Vibration Analysis (SSVA).

To explore the effectiveness of the use of the above two non-invasive techniques in detecting air voids beneath hard slope surface covers, four pilot field trials, three of which involving the TIIA technique and one involving the SSVA technique, were carried out in Hong Kong. Ground investigations, including coreholes and slope surface stripping, were subsequently carried out to verify the interpreted results of TIIA and SSVA. The objectives of the field trials are to assess the potential applicability of such techniques for landslide study or slope investigation works.

This report documents the findings of the pilot field trials using TIIA and SSVA techniques that were carried out in Hong Kong in 2002.

2. PRINCIPLES OF THERMAL INFRA-RED IMAGE ANALYSIS

The development, principles and applications of the infra-red thermography in Japan were described by Nakamura (2004). According to Nakamura (op cit), the Public Work Research Institute in Japan conducted research in the use of thermal infra-red remote sensing to diagnose possible deterioration of shotcreted surfaces of slopes. This technique involves remote inspections through the detection of the thermal radiation emitted from an object to provide an image of the temperature distribution over the object.

The TIIA technique adopted by (Nittoc Construction Limited) NCL was developed on the basis that the thermal conductivity between hard surface cover and the underlying soil material is a function of the continuity of their contact. During the day-time, the hard surface cover (e.g. shotcrete or chunam) is heated up by sunlight and the heat energy will be transmitted to the ground below. Conversely at night-time, the external air temperature will likely be lower in comparison with the ground mass within the slope, therefore heat energy would be transmitted out of the slope.

Transmission of heat energy (viz. cooling effect) will be retarded if voids are present beneath the hard surface cover, because air voids would act as an insulator in reducing the thermal conductivity between the surface cover and the ground below. Hence, during day-time, the areas of surface cover with voids underneath would have a comparatively higher temperature than other areas with good contact between the hard surface cover and the underlying ground. Conversely, at night-time the temperature of the surface cover with voids beneath would be comparatively lower than other areas with good contact.

The temperature of the hard surface can be determined by taking infra-red photographic images of the hard surface cover. The TIIA technique involves the use of sensors comprising light quantum detectors and thermal detectors (Nakamura, 2004) to provide good-quality infra-red images. The values of the thermal differential at various

Table of Contents
Table of Contents
Table of Contents
Table of Contents

locations of the slope cover may be evaluated by comparing infra-red images taken during day-time and during night-time respectively.

Infra-red images are taken (see Plates 1 and 2) when the slope surface under review is of the highest temperature (generally in the early afternoon when the sunlight intensity is at its maximum) and the lowest temperature (generally around mid-night or early morning before sunrise) respectively. The temperature distribution at various locations of a slope (as recorded in the infra-red photographic images) can be analysed using a computer program developed by NCL to produce a plot showing the thermal differential of the hard surface cover between the day-time and night-time. For a given slope, a hard slope cover with voids beneath will tend to have a greater thermal differential between the day-time and the night-time as compared with other areas of hard surface cover without voids beneath.

According to Nakamura (2004), the thermal infra-red remote sensing tool can also be used to investigate seepage behind the shotcreted surface through the detection of low temperature zones as well as to help assess the type of material behind the shotcrete, e.g. rock or regolith.

3. PRINCIPLES OF SEISMIC SYMPATHETIC VIBRATION ANALYSIS

According to NCL, the TIIA technique is used in Japan for the preliminary identification of potential voided areas beneath a hard surface cover. The SSVA system, which comprises one transmitter and one receiver, is used for a more detailed assessment of the extent and significance of the voided areas. The SSVA technique is based on the measurement of the intensity of a sympathetic vibration signal on hard surface cover.

Sympathetic vibration, or resonance, occurs when the frequency of the transmitter is same as the natural frequency of the surface cover material. Based on NCL's experience in Japan, the natural frequency of shotcrete is generally in the range of about 600 Hz to 800 Hz.

Where air void, or gaps, is present beneath a hard surface cover, it will act as a separator that will minimise the loss of resonance signal into the ground and hence a relatively higher intensity of the signal will be received. On the other hand, the intensity of the resonance signal received will be lower if the hard surface cover is in good contact with the underlying soil or rock material. Hence, possible voided areas are indicated at locations where a high-intensity of resonance signal is recorded. The signals received can be viewed on an oscilloscope.

According to NCL, SSVA is generally carried out on a grid pattern, typically at 1.0 m spacing. A contour plot of the signal strength can be produced using a computer program developed by NCL.

It is noteworthy that the SSVA technique can only delineate the two-dimensional extent (but not the depth) of a void across the plane of the slope surface. To determine the depth of a void, intrusive methods such as coring or probing are needed.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4. FIELD TRIALS

4.1 General

The field trials were carried out by Hong Kong Construction (Civil Engineering) Limited (HKCL), with technical support provided by their Japanese specialist sub-contractor, NCL. According to NCL, they have more than 7 years of experience in Japan in using the above two technologies in Japan as investigation tools to detect the presence of gaps beneath hard slope surface covers, reportedly with considerable success, which had proved helpful in identifying appropriate follow-up actions before the situation deteriorates to become a problem. A presentation on the application of these techniques in Japan was given by NCL and the presentation material is in Appendix A.

The field trials and the interpretation of the results were carried out at the own cost of HKCL and NCL.

Field trials using the TIIA technique were carried out on three selected slopes, namely slope No. 11NW-A/C58 at Castle Peak Road, slope No. 11NW-D/C131 at Homantin and slope No. 3SE-D/C82 at Tai Po. Of the three slopes, slope No. 3SE-D/C82 was subsequently selected for the SSVA trial for a more detailed assessment of the pattern of potential voids below the hard surface cover.

4.2 Slope Locations and Background

4.2.1 Slope No. 11NW-A/C58 at Castle Peak Road

Slope No. 11NW-A/C58 is a southwest-facing soil/rock cut slope, adjacent to Castle Peak Road near Kwai Chung (see Figure 1). The slope is about 210 m long, up to 32 m high and inclined at an angle of about 60°.

The slope was formed prior to 1949 in association with the construction of Castle Peak Road. In June 1997, a minor landslide of about 7 m^3 in volume (GEO Incident No. MW97/6/35) occurred within the central portion of the slope. After the incident, the entire soil portion of the slope was covered with shotcrete. The thickness of the shotcrete cover was not known before the TIIA trial. The slope was subjected to a landslide study by the landslide investigation consultant following a rockfall incident in June 2001 (GEO Incident No. MW2001/06/007).

4.2.2 Slope No. 11NW-D/C131 at Homantin

Slope No. 11NW-D/C131 is an east-facing soil/rock cut slope above Chung Hau Street, Homantin. The slope is about 150 m long, up to 32 m high and inclined at an angle of about 60° (see Figure 2). The shotcreted slope comprises four batters.

The slope was upgraded in 1998 under the LPM Programme. Upgrading works comprised the installation of soil nails at 2 m centres and the provision of an additional layer of shotcrete cover of about 75 mm thick to the lower two slope batters (the existing shotcrete cover was left in place). The thickness of the pre-existing shotcrete cover on the slope before the upgrading works was not known.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

4.2.3 Slope No. 3SE-D/C82 at Tai Po

Slope No. 3SE-D/C82 is a southeast-facing soil/rock cut slope adjacent to Bride’s Pool Road, Tai Po. The slope is about 85 m long, up to 25 m high and inclined at an angle of about 50° (see Figure 3).

The slope was formed prior to 1968, probably in connection with the construction of Bride’s Pool Road. The surface of the slope was subsequently covered with shotcrete. The thickness of the shotcrete cover was not known before the TIIA trial.

5 FINDINGS OF THE FIELD TRIALS

5.1 Thermal Infra-red Image Analysis

Infra-red photographic images were taken of the shotcreted cover of slopes Nos. 11NW-A/C58 (Figure 4), 11NW-D/C131 (Figure 5) and 3SE-D/C82 (Figure 6) in August 2002. Infra-red images were taken both in the early afternoon (where the temperature was relatively high) and in the early morning (where the temperature was relatively low). The thermal differential plots for the three slopes are shown in Figures 4, 5 and 6 respectively.

5.1.1 General Observations with Regard to Slope No. 11NW-A/C58

It can be seen from the day-time infra-red photographic image that for slope areas which are covered by the shadow of the vegetation, relatively ‘cold’ spots can be observed on the infra-red image. The result indicates that the temperatures at these locations are lower than that of the other locations with no vegetation.

The specialist contractor who carried out the TIIA survey (i.e. NCL) identified possible voided areas on areas immediately above and below the first berm, as indicated in the infra-red images taken during the day-time (see Figure 4). However, the thermal differential plot of the slope only shows a thin horizontal strip in the vicinity of the first berm that exhibits a large difference in temperature. No follow-up invasive investigations were carried out because the slope area of concern is of private maintenance responsibility.

5.1.2 General Observations with Regard to Slope No. 11NW-D/C131

Based on the infra-red photographic images shown in Figure 5, the preliminary findings are as follows:

(a) The uppermost slope batter gives a relatively colder area as reflected by a darker colour (which corresponds to a lower temperature) than the batters near the slope toe.

(b) Over the uppermost batter, rows of points with a brighter colour (which corresponds to a higher temperature) in a staggered arrangement can be observed. These points are

Table of Contents
Table of Contents
Table of Contents
Table of Contents

likely to be soil nail heads underneath the shotcrete cover. However, the soil nail heads on the lowermost two batters could not be identified from the infra-red images. It is noteworthy that additional shotcrete cover of about 75 mm thick was applied only to these two slope batters (the existing shotcrete cover was left in place, see Section 3.2.2).

(c) As indicated in the infra-red image taken during the day-time, possible seepage (i.e. as reflected by a darker colour) can be observed at the lower portion of the second batter from the slope toe.

(d) As indicated in the infra-red images taken during the day-time and night-time, several areas with a darker colour were observed on the first and second slope batters. These lower temperature areas are probably a result of the shadow created by corestones on the slope. It is noteworthy that these areas were not assessed as voided areas in the thermal differential plot.

NCL has delineated the extent of the possible 'voided' area using two pink boxes on the thermal differential plot (Figure 5). Seepage stains from weepholes can be observed from the photograph. It is inferred that minor washout might have occurred behind the weepholes, thus possibly forming local voids beneath the shotcrete cover.

5.1.3 General Observations with Regard to Slope No. 3SE-D/C82

'Hot' spots (i.e. areas where presence of voids is likely) at the lowermost slope batter were indicated in the infra-red photographic image taken during the day-time (Figure 6). The thermal differential plot also showed that a local area within the middle portion of the lowermost batter exhibits a relatively high temperature difference, which indicates that voids may have been present beneath the shotcrete cover. Signs of deterioration (i.e. presence of cracks on the slope surface which have been sealed with cement mortar) were observed on the slope face.

NCL also identified an area covered with moss on the slope surface (as delineated by the pink dashed ellipses shown in Figure 6). The presence of moss on the slope is reflected by a local low temperature as recorded during the day-time.

5.2 Seismic Sympathetic Vibration Analysis

It was suspected that voids may have been present within the middle portion of the lowermost batter of slope No. 3SE-D/C82 at Tai Po, as indicated by the TIIA test. Hence, the slope portion of concern was selected for SSVA (see Plates 3 to 5).

The area investigated was about 15 m wide by 9 m high (see Figure 7). A 1 m grid was set up over the area for SSVA and readings were taken at every grid point.

Table of Contents

Table of Contents

Table of Contents

Table of Contents

The resonant frequency of the shotcrete cover was determined by NCL as about 760 Hz prior to the SSVA. The resultant vibration at each grid points was displayed on an oscilloscope and recorded by a data logger. A contour plot of the vibration data using the computer program developed by NCL is shown in Figure 7.

As indicated in the contour plot, the locations of possible voided areas are shown in yellow to red colours. These areas are located at both the middle and upper portions of the slope batter under investigation. The darker colours on the plot suggest a high likelihood of good contact between the hard surface cover and the ground below.

6. GROUND INVESTIGATION

6.1 General

A ground investigation comprising 120 coreholes through the shotcrete cover, hammer tapping survey of the shotcrete cover and one slope surface strip was carried out at the middle portion of slope No. 3SE-D/C82 where voids may be present beneath the shotcrete cover as indicated by the TIIA and SSVA tests. The results of the hammer tapping survey, together with the findings from the SSVA tests, are presented in Figure 8. The locations of the coreholes and the slope surface strip are shown in Figures 9 and 10.

Coring of the hard surface cover is required to aid the interpretation of both the TIIA and SSVA tests (see Plates 6 to 8). The objective of coring was to determine the size of void, if any, beneath the shotcrete cover. It was considered that the traditional coring machine commonly used for ground investigation may be too large and the vigorous rotational motion of the core barrel may cause disturbance to any void beneath the shotcrete (e.g. possible filling up of small voids/gaps with dust or soil debris). Based on preliminary field trials, a smaller hand-held coring machine of about 100 mm in diameter was adopted and the disturbance was found to be minimal. After removal of the core barrel, it was possible to measure the depth of any void present beneath the shotcrete cover.

Where a void was encountered during the coring operation, the depth of the void, together with a brief description of soil material exposed, was recorded. The observations are presented in Table 1 and Figure 10.

Following corehole drilling, a slope surface strip of about 1 m wide was carried out at the central portion of the area under investigation where voids are likely to be encountered based on the results of SSVA test and hammer tapping survey. A simplified geological log of the slope surface strip is presented in Figure 11.

A trial was also carried out to examine whether the response from hammer tapping was affected by corehole drilling through the slope surface cover. Hammer tapping carried out at selected locations before and after coring indicated virtually no difference in the level and type of sound generated.

6.2 Observations

Based on the hammer tapping survey, a map showing the locations of the possible

Table of Contents
Table of Contents
Table of Contents
Table of Contents

voided areas beneath the shotcrete cover is presented in Figure 8. In general, the approximate extent of possible voided areas as revealed by the hammer tapping survey is comparable with that interpreted by the SSVA test. However, the findings of these two tests are not consistent at some isolated areas, such as the top left corner and the bottom part of the surveyed area (Figures 8 and 10).

Based on the coreholes, the thickness of the shotcrete was found to be generally in the range of 20 mm to 50 mm, with a maximum of about 120 mm. Eight out of the 120 cored holes identified voids and the corresponding locations are shown in Figure 10. The maximum depth of void encountered was about 30 mm. The typical depths of voids were in the range of 4 mm to 12 mm. All these eight coreholes were located within or in close proximity to the possible voided areas based on SSVA test. However, the results of TIIA test appears to be inconsistent with the coring results, particularly near the edge of the survey area to the left (slope No. 3SE-D/C82) as shown in Figure 9, where the slope was covered with cement mortar instead of shotcrete.

It is noted that apparently good shotcrete/soil contact was observed in some of the other ‘voided’ areas according to both the SSVA test and hammer tapping survey.

The locations of voids as revealed by slope stripping are presented in Figure 10. Voids were generally encountered at between 4.0 m and 6.2 m as measured from the top of the slope surface strip. The voids exposed were about 5 mm deep.

The results of slope stripping indicate that voids were predominantly located at about 4 m to 6 m below the slope crest, where there is a change in slope angle from about 40° to 60° (Figure 11).

7. DISCUSSION

Thermal image equipments had been used in Hong Kong to examine the condition of building claddings. Using similar equipments, field trials of TIIA were carried out on selected cut slopes in Hong Kong to determine the applicability of the technique for assessment of slope condition. Based on the results of the field trials, it would appear that TIIA shows some promise as being able to identify the approximate locations of possible voided areas in a rapid manner. However, the dimensions of the voids and the more precise locations will require further investigation (e.g. by means of SSVA or other invasive investigation techniques). The field trial also highlighted the potential capability of TIIA in identifying:

(a) areas with concentrated subsurface water flow or areas with a high groundwater table, and

(b) locations of covered soil nail heads.

It should be noted that as TIIA is effectively a temperature measurement technique to detect possible presence of void behind a hard surface cover by reference to the thermal differential of the hard cover between day-time and night-time, factors that affect the temperature of the slope surface may potentially influence the test results. Based on the

Table of Contents
Table of Contents
Table of Contents
Table of Contents

observations and experience in the present field trials, the TIIA technique appears to be subject to the following limitations:

(a) Profile of slope surface. TIIA is generally more effective on slopes with a smooth and even surface. Irregularities (e.g. corestones) or vegetation (e.g. trees) on the slope can form shadows on the surface with a lower temperature, which can mask the results and affect the reliability of the test in detecting voids behind the shotcrete.

(b) Presence of seepage. Seepage on the slope surface or within the slope will have a cooling effect on the hard cover, and thus is liable to complicate the interpretation of the results in terms of detection of possible voids.

(c) Presence of cracks. Presence of cracks on the slope surface is liable to allow exchange of air in 'voided' area and the outside, which may result in a faster cooling rate of the hard cover.

(d) Shotcrete cover with variable mix and thickness. A shotcrete with a variable mix and thickness is liable to affect the resolution of the test results given that differing thickness of shotcrete will have a different thermal capacity.

(e) Experienced personnel. Suitably experienced personnel with a good knowledge of the limitations of the testing system need to be engaged to carry out the tests and interpret the results.

As for SSVA, the field trial indicated that the technique is generally capable of determining the horizontal extent of possible voids but it is not able to gauge the depth of a void. Invasive methods, such as coring, are required for the determination of the actual depth of a void.

It would appear that the SSVA test is generally capable of identifying areas with very minor loss of contact (e.g. depth of void <5 mm), as confirmed by the coreholes and slope surface strip, although the reliability is not fully proven because of some inconsistent results in local areas. However, the resolution of the test can be a function of various factors, including the material density and thickness of the hard cover, continuity of the contact between the hard cover and the underlying ground and the characteristics of the near-surface slope-forming material. Some discrepancies for local areas are also noted between SSVA and hammer tapping and between SSVA/hammer tapping and coring.

This series of field trials was the first reported trial application of TIIA and SSVA in Hong Kong. Some useful experience was gained in the practicality and application of the techniques, which are claimed to have been used successfully for some time in Japan. More systematic studies are required to establish the general applicability and resolution of the techniques for different site conditions.

Table of Contents
Table of Contents
Table of Contents
Table of Contents

8. REFERENCES

Nakamura, H. (2004). Field instrumentation and laboratory investigation (Keynote Paper). Proceedings of the Ninth International Symposium on Landslides: Evaluation and Stabilization, Rio De Janeiro, Brazil, vol. 1, pp 541-548.

LIST OF TABLES

Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 1 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of Void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	A	22	No	Nil		Masonry facing
2	A	17	No	Nil		Masonry facing
3	A	40	No	Nil		Masonry facing
4	A	20	No	Nil		Grad IV tuff
5	A	25	No	Nil		Grad IV tuff
6	A	33	No	Nil		Grad IV tuff
7	A	22	No	Nil		Grad IV tuff
8	A	40	No	Nil		Grad IV/V tuff
9	A	17	No	Nil		Grad V tuff
10	A	41	No	Nil		Grad V tuff
11	A	41	No	Nil		Grad IV/V tuff
12	A	43	No	Nil		Grad III tuff
13	A	51	No	Nil		Grad V tuff
14	A	52	No	Nil		Grad III/IV tuff
15	A	50	Yes	15 mm		Fill

Legend: Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 2 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of Void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	B	15	No	Nil		Masonry facing
2	B	20	No	Nil		Masonry facing
3	B	36	No	Nil		Grade IV tuff
4	B	20	No	Nil		Grade V tuff
5	B	40	No	Nil		Grade V tuff
6	B	80	No	Nil		Grade IV/V tuff
7	B	120	No	Nil		Grade IV/V tuff
8	B	50	No	Nil		Grade V tuff
9	B	82	No	Nil		Fill
10	B	44	No	Nil		Grade IV/V tuff
11	B	39	No	Nil		Grade IV/V tuff
12	B	42	No	Nil		Grade IV tuff
13	B	65	No	Nil		Grade III tuff
14	B	50	No	Nil		Grade III tuff/Fill
15	B	35	Yes	30 mm	○	Grade III tuff, 30 mm gap behind mesh

Legend: ○ ← Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 3 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	C	13	No	Nil		Masonry facing
2	C	17	No	Nil		Masonry facing
3	C	60	No	Nil		Grade III/IV tuff
4	C	26	No	Nil		Grade III tuff
5	C	45	No	Nil		Grade III/IV tuff
6	C	25	No	Nil		Grade IV tuff
7	C	24	Yes	7 mm		Grade IV/V tuff
8	C	22	No	Nil		Grade V tuff
9	C	37	No	Nil		Grade V tuff
10	C	60	No	Nil		Grade IV tuff
11	C	48	No	Nil		Grade V tuff
12	C	53	No	Nil		Grade V tuff
13	C	63	Yes	12 mm		Grade IV tuff
14	C	100	Yes	20 mm		Grade III/IV tuff
15	C	27	No	Nil		Grade V tuff

Legend: Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 4 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	D	24	No	Nil		Masonry facing
2	D	36	No	Nil		Masonry facing
3	D	45	No	Nil		Grade IV/V tuff
4	D	48	No	Nil		Grade III/IV tuff
5	D	26	No	Nil		Grade V tuff
6	D	21	No	Nil		Grade V tuff
7	D	26	No	Nil		Grade V tuff
8	D	17	No	Nil		Grade V tuff
9	D	55	No	Nil		Fill
10	D	60	No	Nil		Grade III/IV tuff
11	D	42	No	Nil		Grade V tuff
12	D	55	No	Nil		Grade III/IV tuff
13	D	79	No	Nil		Grade III/IV tuff
14	D	33	No	Nil		Grade III tuff
15	D	30	No	Nil		Grade III/IV tuff

Legend: Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 5 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of Void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	E	20	No	Nil		Masonry facing
2	E	26	No	Nil		Masonry facing
3	E	42	No	Nil		Masonry facing
4	E	19	No	Nil		Grade V tuff
5	E	26	No	Nil		Grade V tuff
6	E	26	No	Nil		Grade IV tuff
7	E	24	No	Nil		Grade V tuff
8	E	25	No	Nil		Grade V tuff
9	E	25	No	Nil		Grade V tuff
10	E	35	No	Nil		Grade V tuff
11	E	18	No	Nil		Grade V tuff
12	E	50	No	Nil		Grade V tuff
13	E	33	No	Nil		Grade V tuff
14	E	32	No	Nil		Grade V tuff
15	E	16	No	Nil		Grade III tuff

Legend: Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 6 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	F	20	No	Nil		Masonry facing
2	F	19	No	Nil		Masonry facing
3	F	40	No	Nil		Grade V tuff
4	F	18	No	Nil		Grad V tuff
5	F	20	No	Nil		Grade V tuff, 1 mm hairline crack to right of corehole
6	F	16	No	Nil		Grade V tuff
7	F	19	No	Nil		Grade V tuff
8	F	15	Yes	7 mm		Grade V tuff
9	F	21	No	Nil		Grade V tuff
10	F	12	No	Nil		Grade V tuff, repaired crack to right of corehole
11	F	25	No	Nil		Grade V tuff
12	F	49	No	Nil		Grade V tuff, repaired crack to right of corehole
13	F	21	No	Nil		Grade V tuff
14	F	40	No	Nil		Grade IV tuff
15	F	35	No	Nil		Grade III tuff

Legend: Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

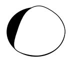
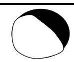
Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 7 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	G	18	No	Nil		Masonry facing
2	G	15	No	Nil		Masonry facing
3	G	44	No	Nil		Grade V tuff
4	G	52	No	Nil		Grade V tuff
5	G	23	No	Nil		Grade V tuff
6	G	40	No	Nil		Grade V tuff
7	G	17	No	Nil		Grade V tuff
8	G	27	No	Nil		Grade V tuff
9	G	36	No	Nil		Grade V tuff
10	G	25	No	Nil		Grad V tuff, repaired crack to right of corehole
11	G	18	No	Nil		Grade V tuff
12	G	15	No	Nil		Grade V tuff
13	G	30	No	Nil		Grade V tuff
14	G	52	No	Nil		Grade V tuff
15	G	38	No	Nil		Grade III/IV tuff

Legend: Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table 1 - Raw Data Obtained from Verification Coring of Slope No. 3SE-D/C82 (Sheet 8 of 8)

Column	Row	Thickness of Shotcrete on Slope (mm)	Void Present	Depth of void	Position of Void in Hole	Description of Slope Material Found in Hole behind Shotcrete
1	H	18	No	Nil		Masonry facing
2	H	20	No	Nil		Masonry facing
3	H	35	No	Nil		Grade V tuff
4	H	11	No	Nil		Grade V tuff
5	H	45	Yes	4 mm		Grade V tuff
6	H	29	No	Nil		Grade V tuff
7	H	35	No	Nil		Grade V tuff
8	H	45	No	Nil		Grade V tuff
9	H	35	No	Nil		Grade V tuff
10	H	13	Yes	12 mm		Fill
11	H	31	No	Nil		Fill
12	H	27	No	Nil		Fill
13	H	29	No	Nil		Fill
14	H	30	No	Nil		Fill
15	H	17	No	Nil		Fill

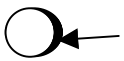
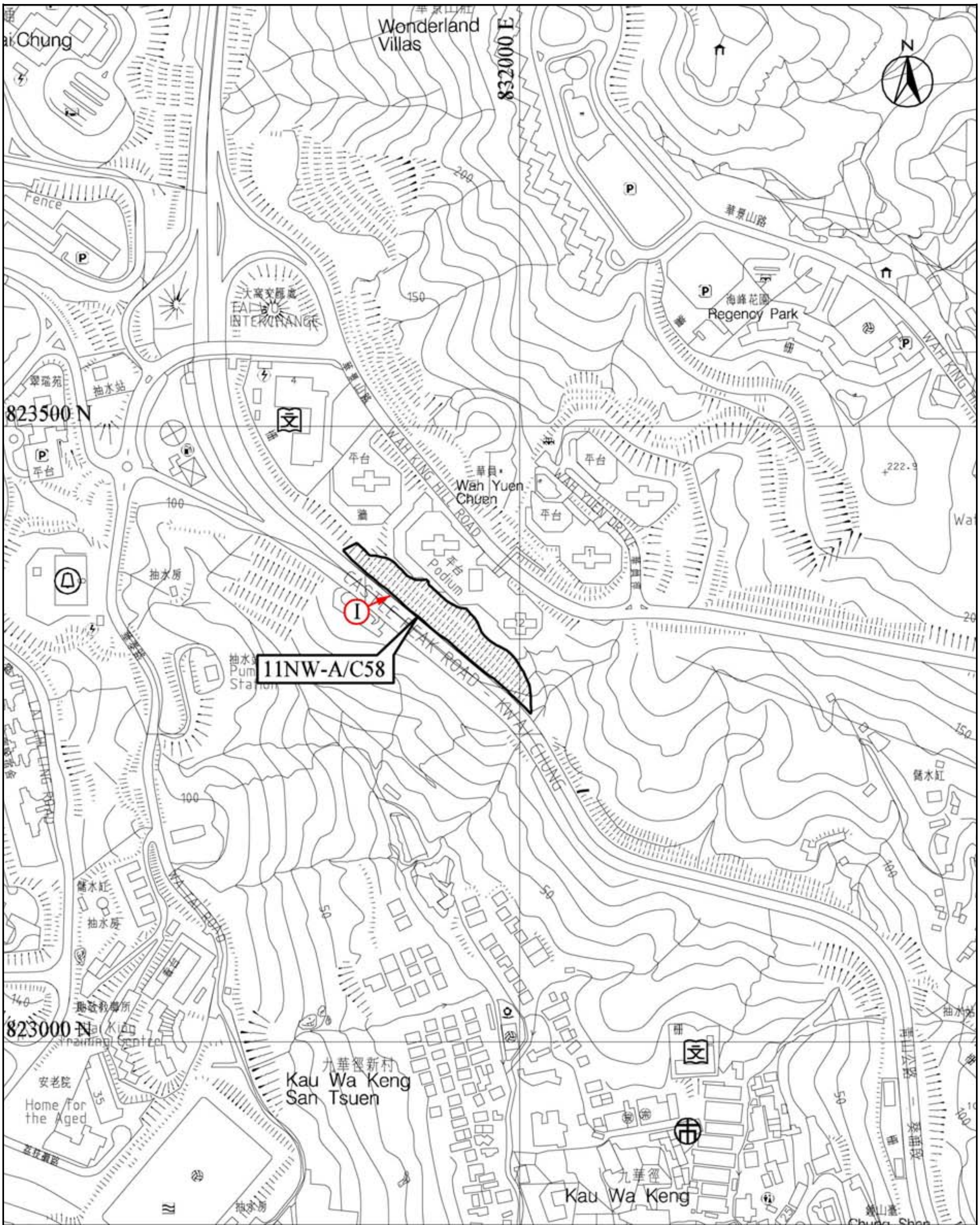
Legend:  Position of void identified by corehole

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF FIGURES



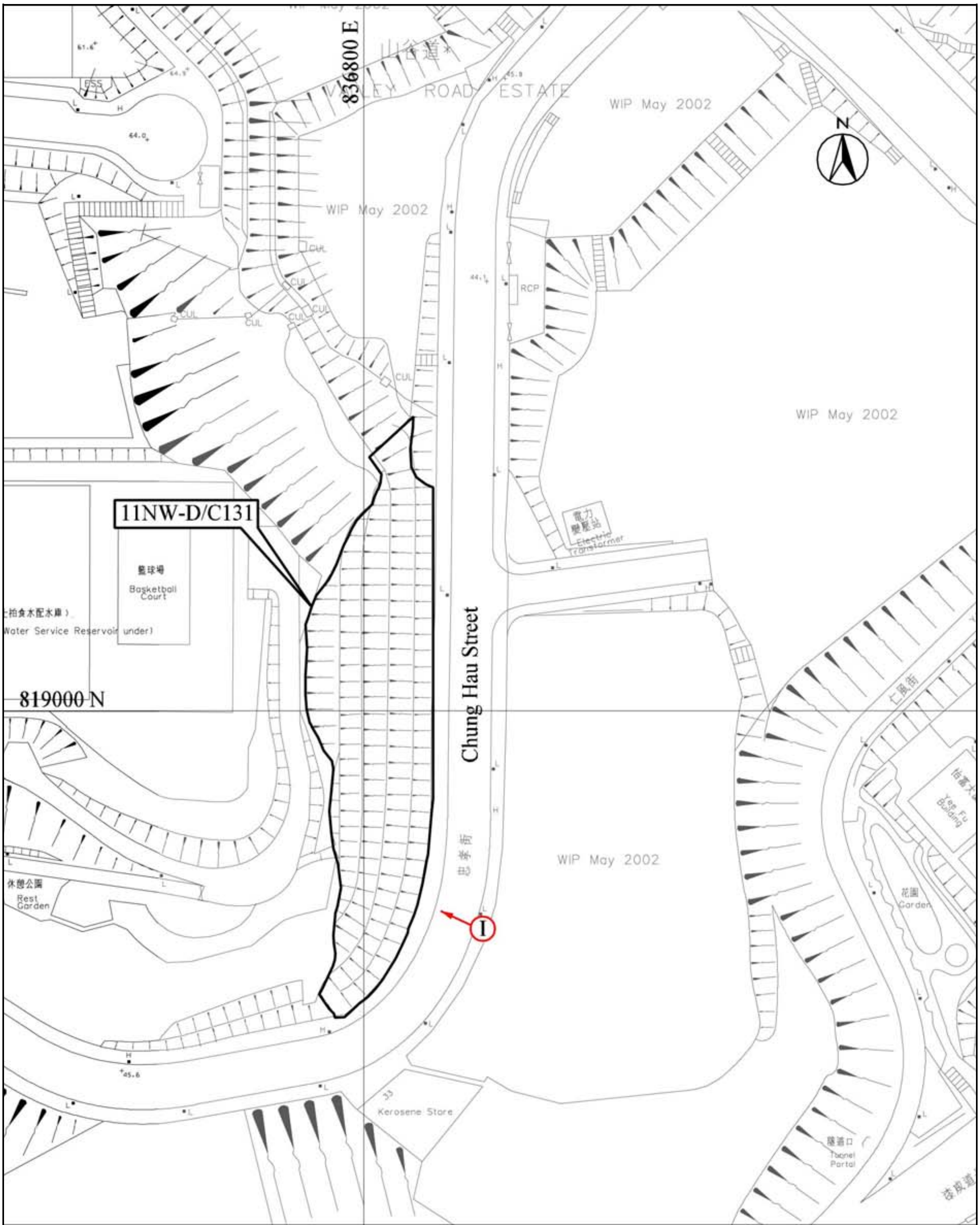
Legend :

I Thermal infra-red image photo taken location

Note : Base plan is extracted from 1 : 5000 survey sheet No. 11NW-A.

Figure 1 - Site Location Plan for Slope No. 11NW-A/C58

Table of Contents
Table of Contents
Table of Contents
Table of Contents



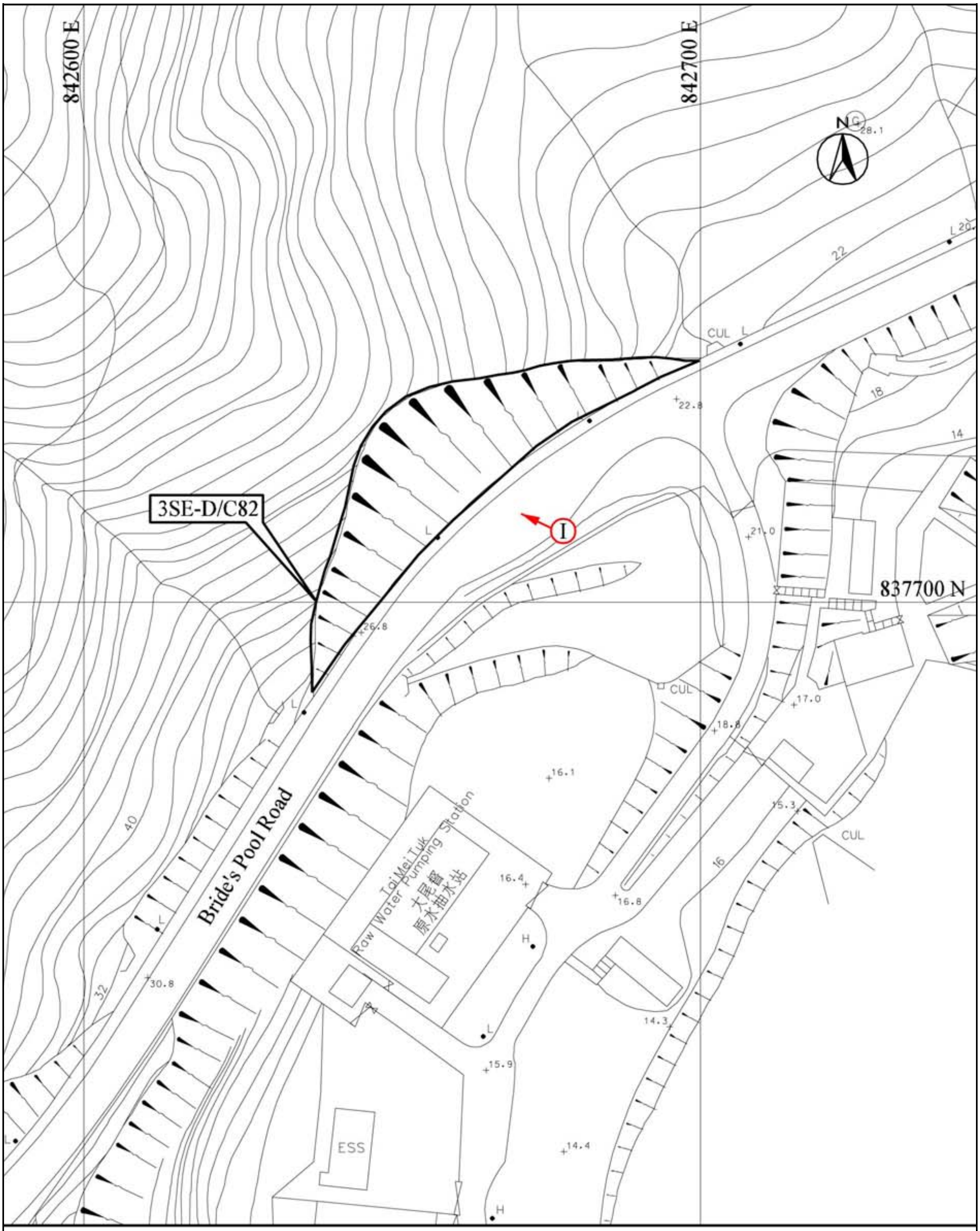
Legend :

Thermal infra-red image photo taken location

Note : Base plan is extracted from 1 : 1000 survey sheets Nos. 11NE-25A and 11NE-25B dated June 2002.

Figure 2 - Site Location Plan for Slope No. 11NW-D/C131

Table of Contents
Table of Contents
Table of Contents
Table of Contents



Legend :	I Thermal infra-red image photo taken location
Note :	Base plan is extracted from 1 : 1000 survey sheet No. 3SE19C dated June 2002.

Figure 3 - Site Location Plan for Slope No. 3SE-D/C82

Table of Contents
Table of Contents
Table of Contents
Table of Contents

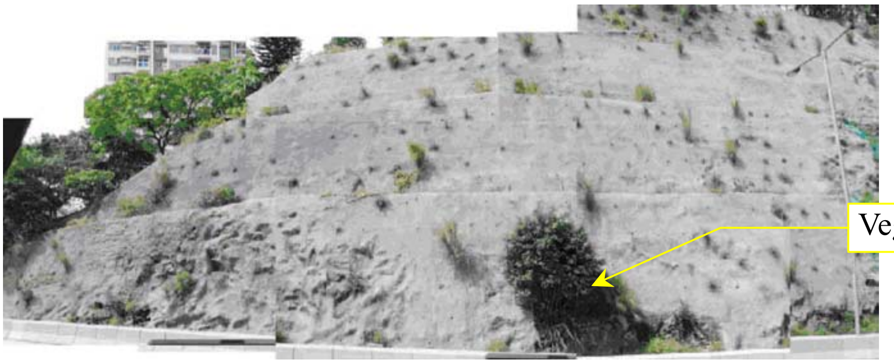
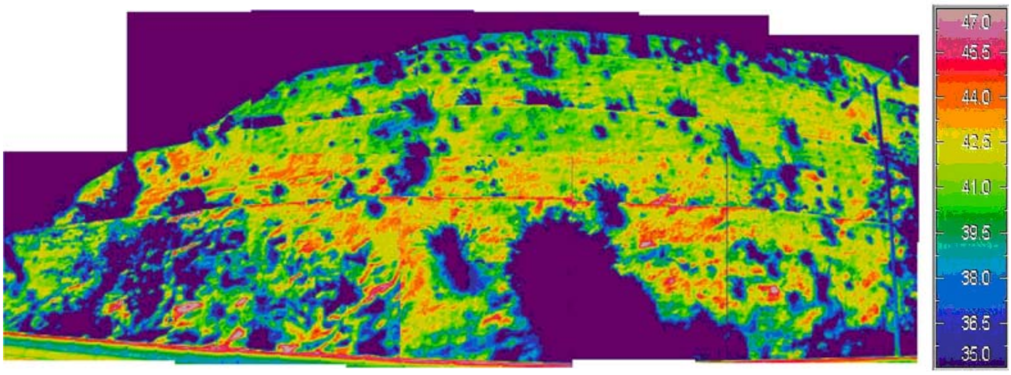
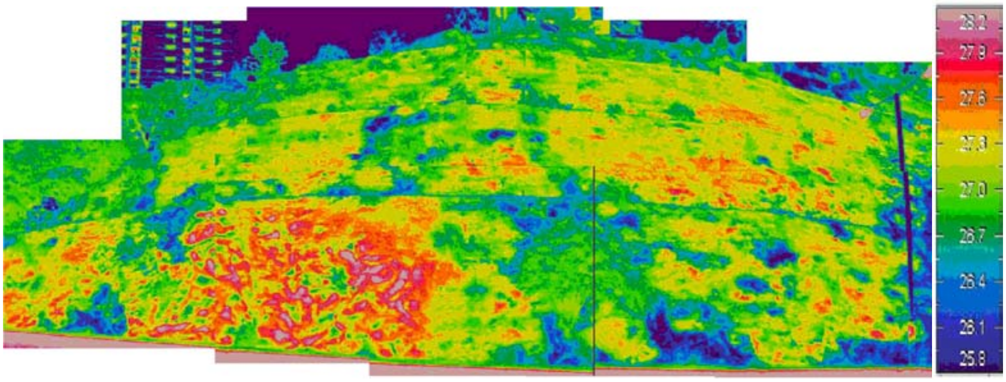
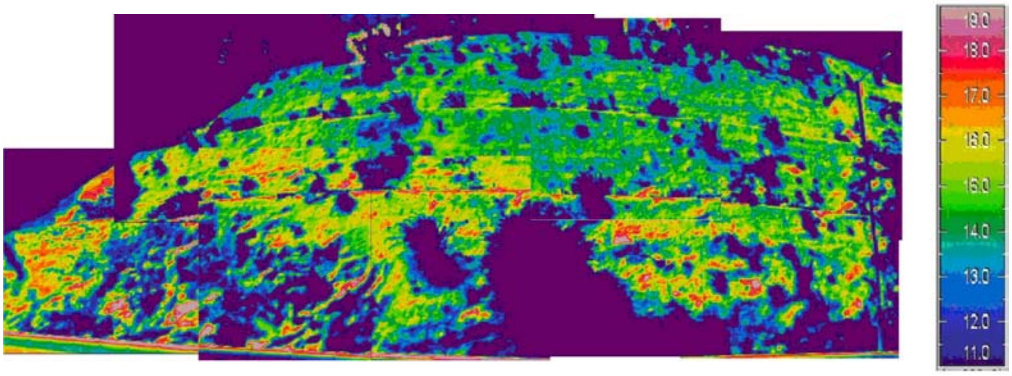
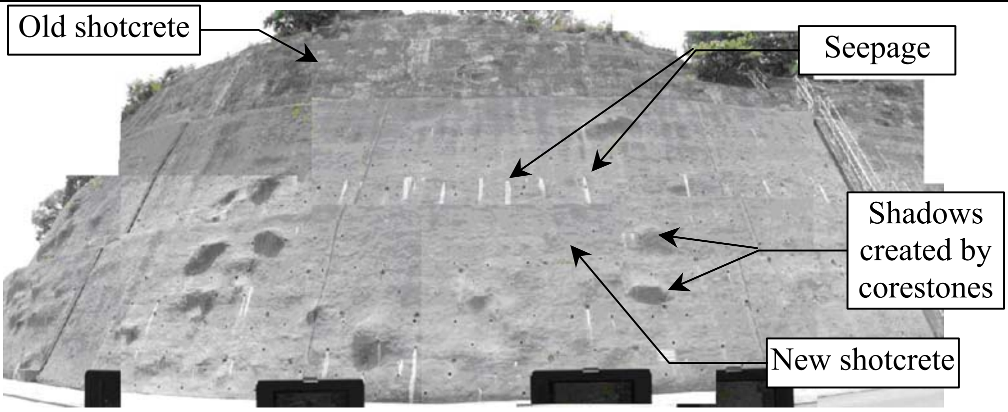
Slope No. 11NW-A/C58, Castle Peak Road, Kwai Chung	
General view	
Infra-red images	
High temperature image	
Low temperature image	
Thermal differential plot	

Figure 4 - High/Low Temperature Infra-red Images and Thermal Differential Plot for Slope No. 11NW-A/C58

Table of Contents
Table of Contents
Table of Contents
Table of Contents

<table>
<tr><td colspan="2">Slope No. 11NW-D/C131, Chung Hau Street, Homantin</td></tr>
<tr><td>General view</td><td>
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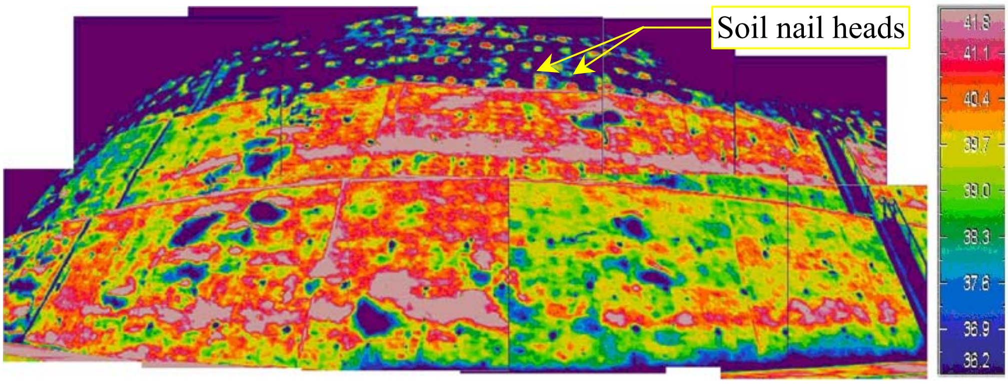
<tr><td colspan="2">Infra-red images</td></tr>
<tr><td>High temperature image</td><td>
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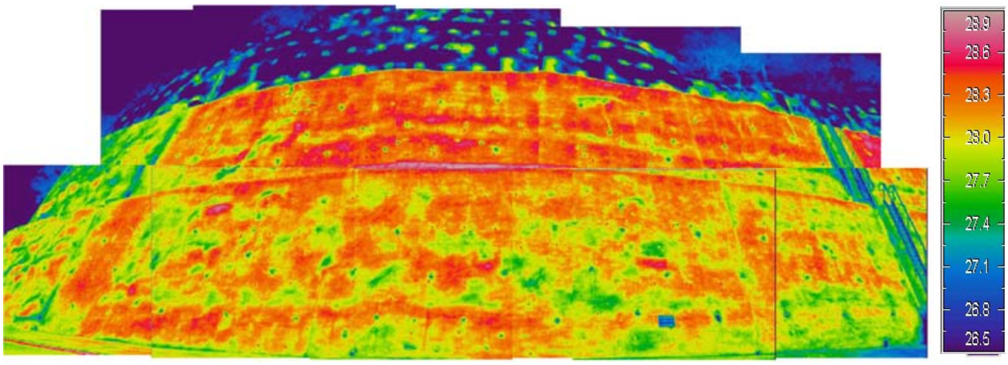
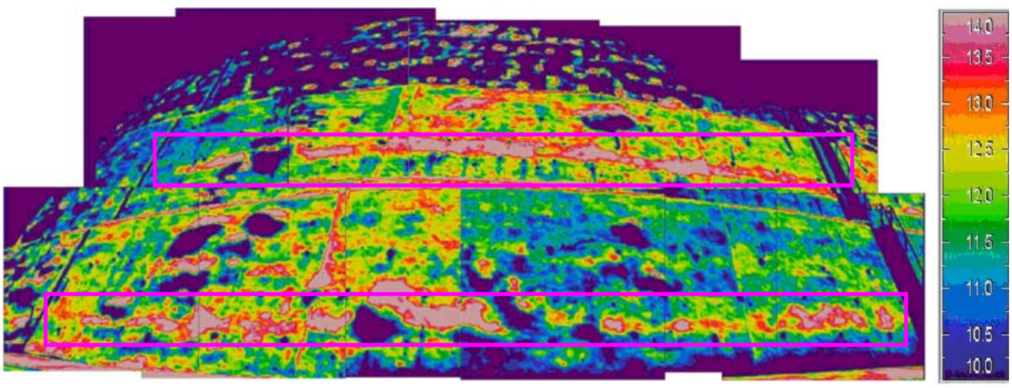
<tr><td>Low temperature image</td><td>
</td></tr>
<tr><td>Thermal differential plot</td><td>
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</table>

Figure 5 - High/Low Temperature Infra-red Images and Thermal Differential Plot for Slope No. 11NW-D/C131

Table of Contents
Table of Contents
Table of Contents
Table of Contents

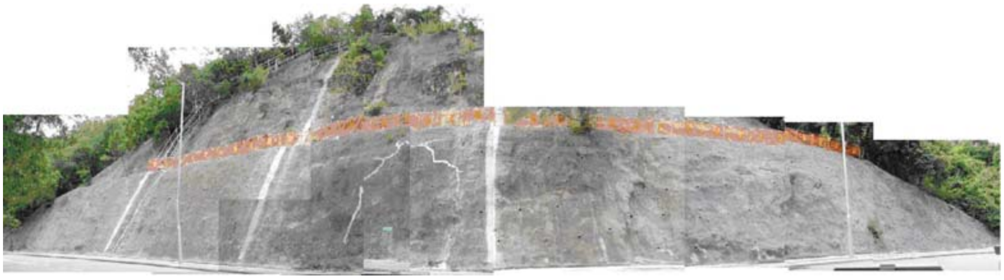
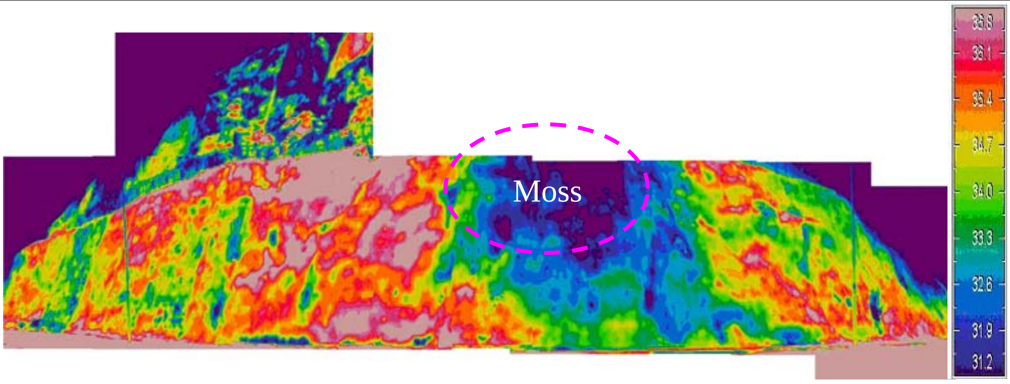
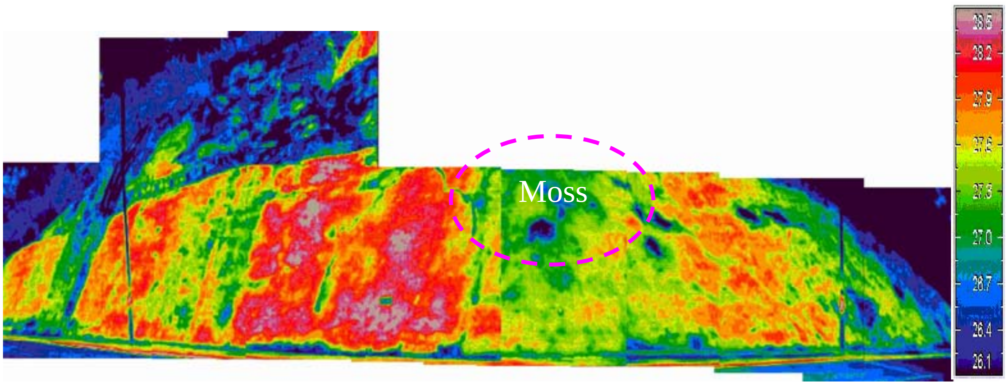
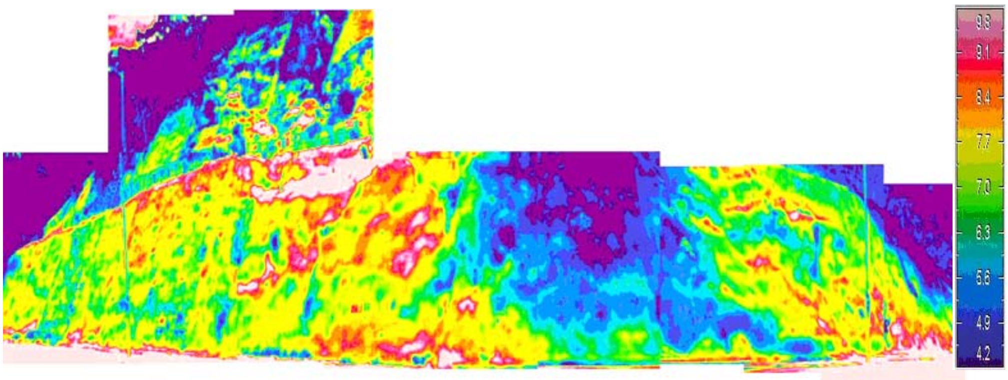
Slope No. 3SE-D/C82, Bride’s Pool Road, Tai Po	
General view	
Infra-red images	
High temperature image	
Low temperature image	
Thermal differential plot	

Figure 6 - High/Low Temperature Infra-red Image and Thermal Differential Plot for Slope No. 3SE-D/C82

Table of Contents
Table of Contents
Table of Contents
Table of Contents

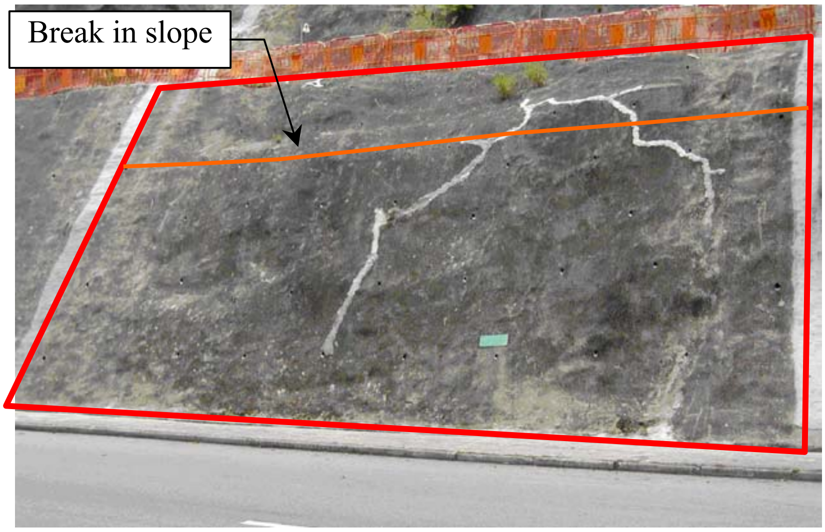
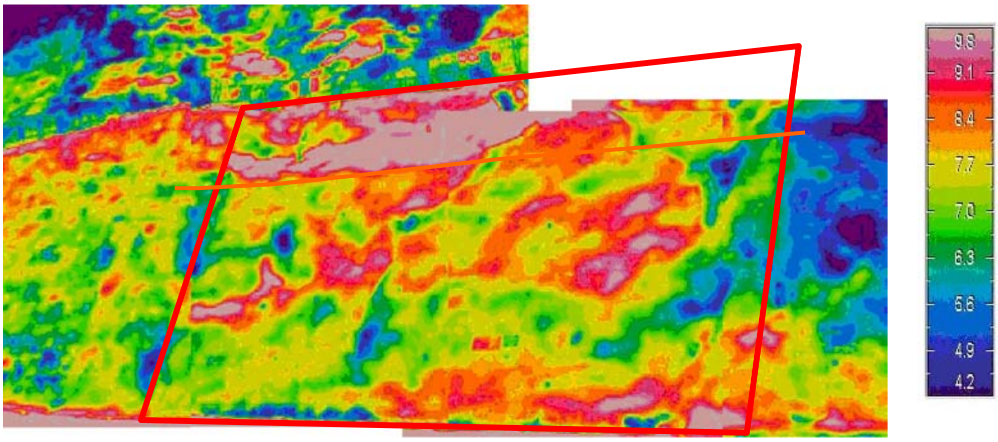
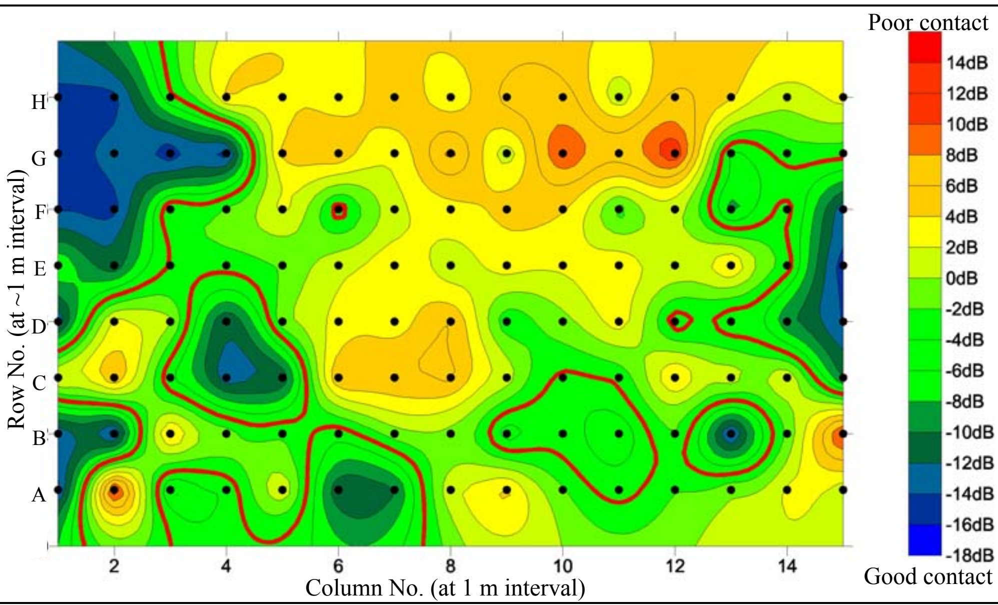
Slope No. 3SE-D/C82, Bride's Pool Road, Tai Po	
View of the test section	
Thermal differential plot based on TIIA	
Contour plot of sympathetic vibration survey results	

Figure 7 - Thermal Differential Plot and Results of Sympathetic Vibration Survey of the Test Section of Slope No. 3SE-D/C82

Table of Contents
Table of Contents
Table of Contents
Table of Contents

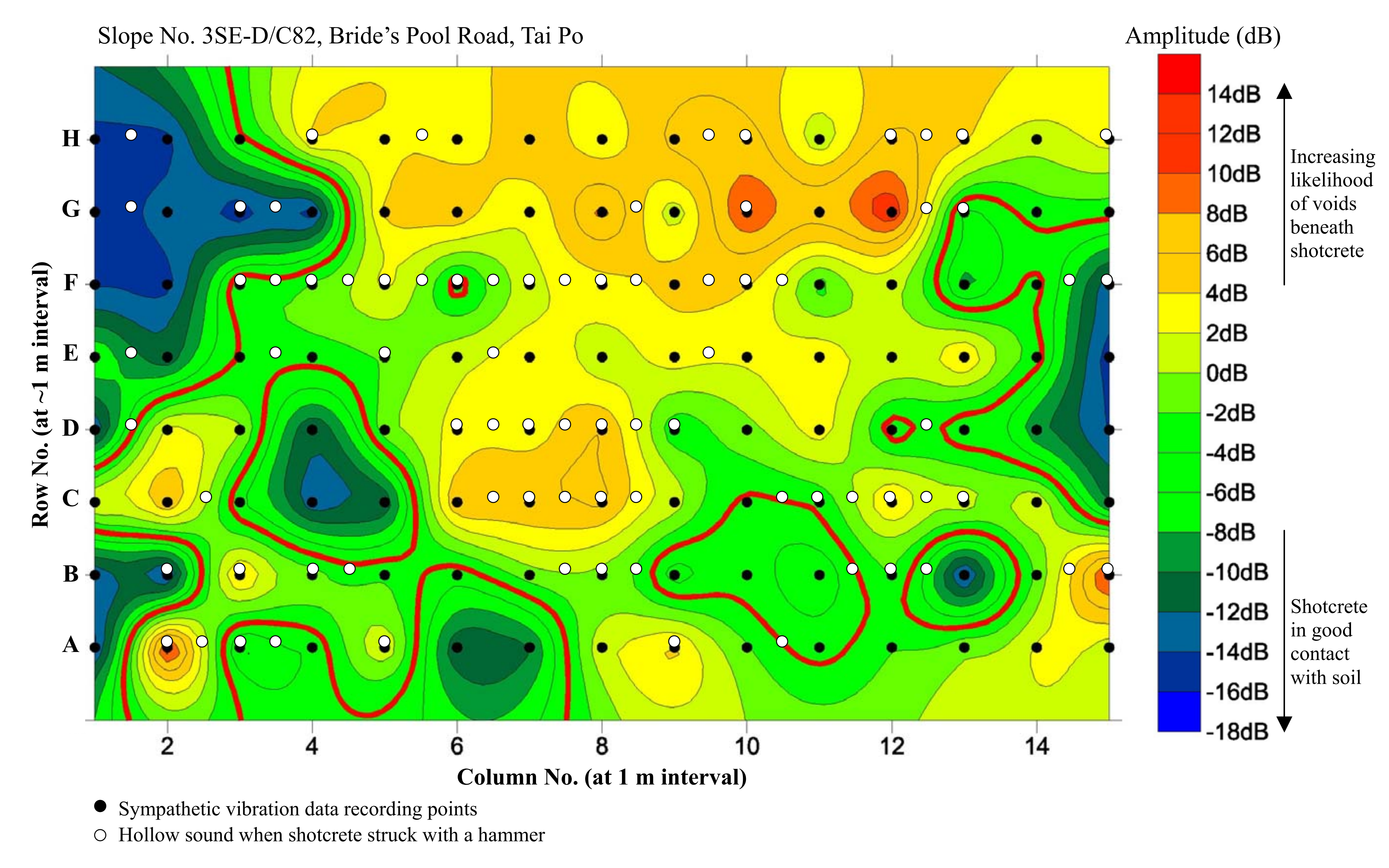


Figure 8 - Results of Hammer Tapping Survey Overlaid on Results of Sympathetic Vibration

Table of Contents Table of Contents Table of Contents Table of Contents

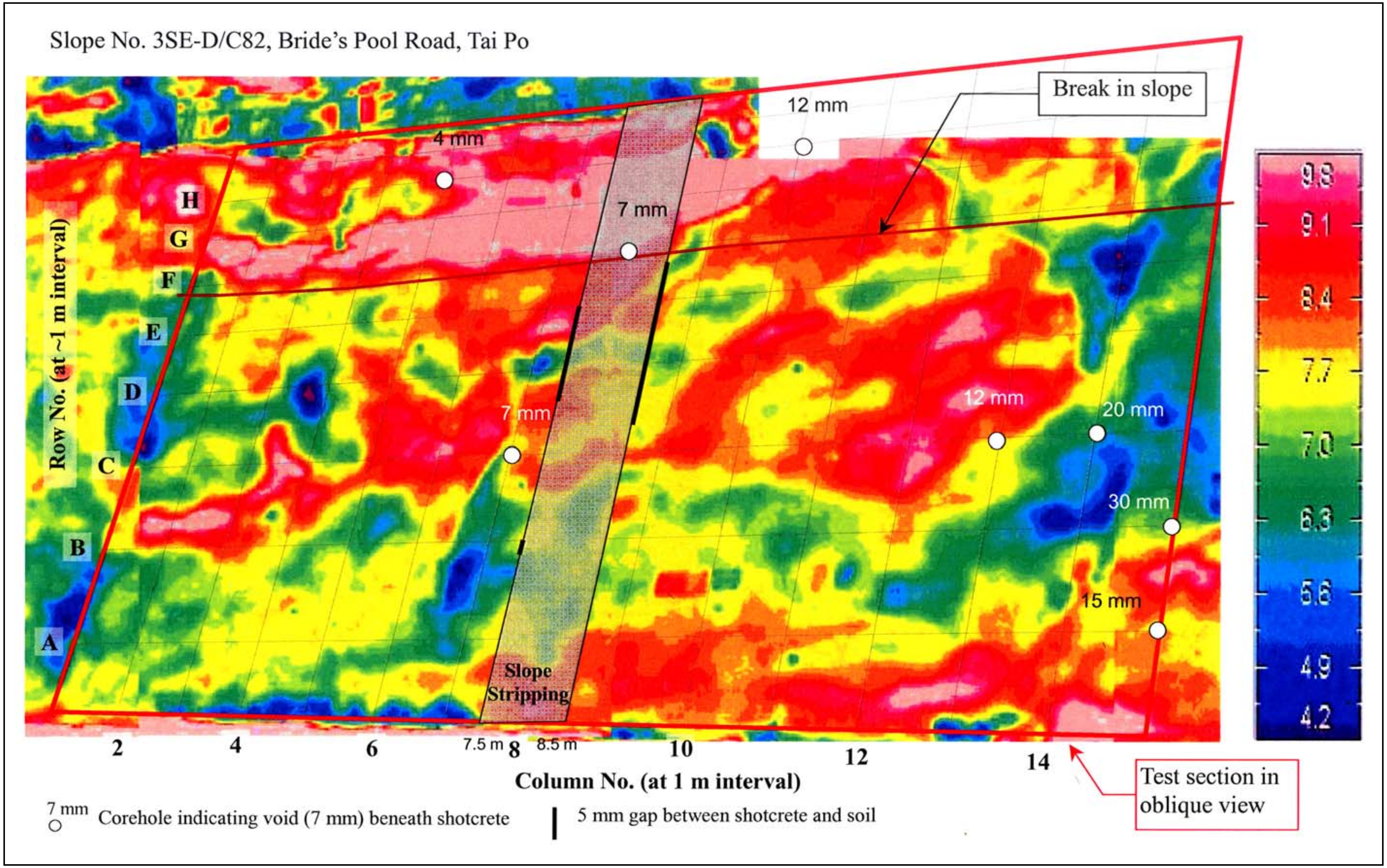


Figure 9 - Results of Ground Investigation Overlaid on Results of Thermal Differential Plot

Table of Contents Table of Contents Table of Contents Table of Contents

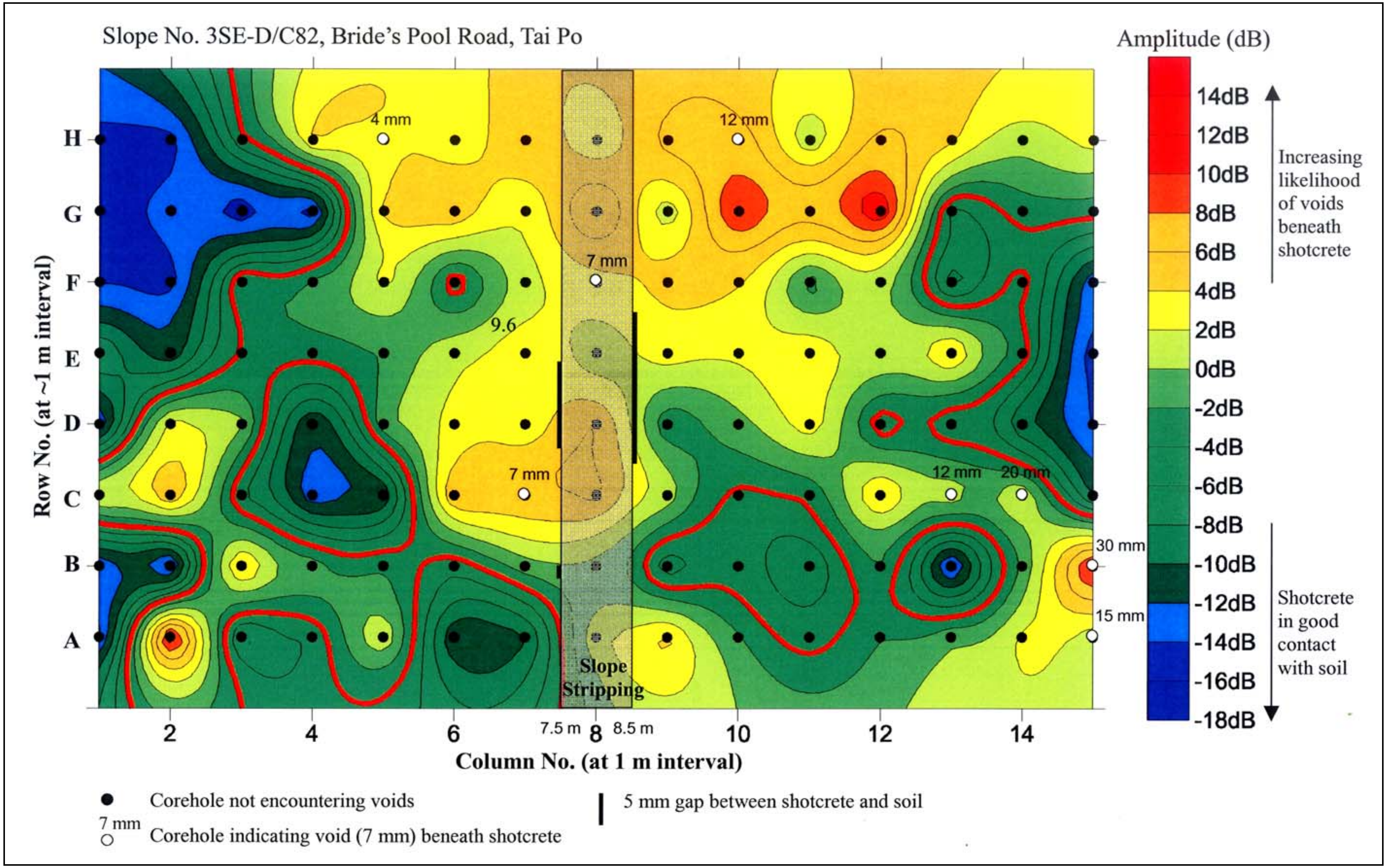
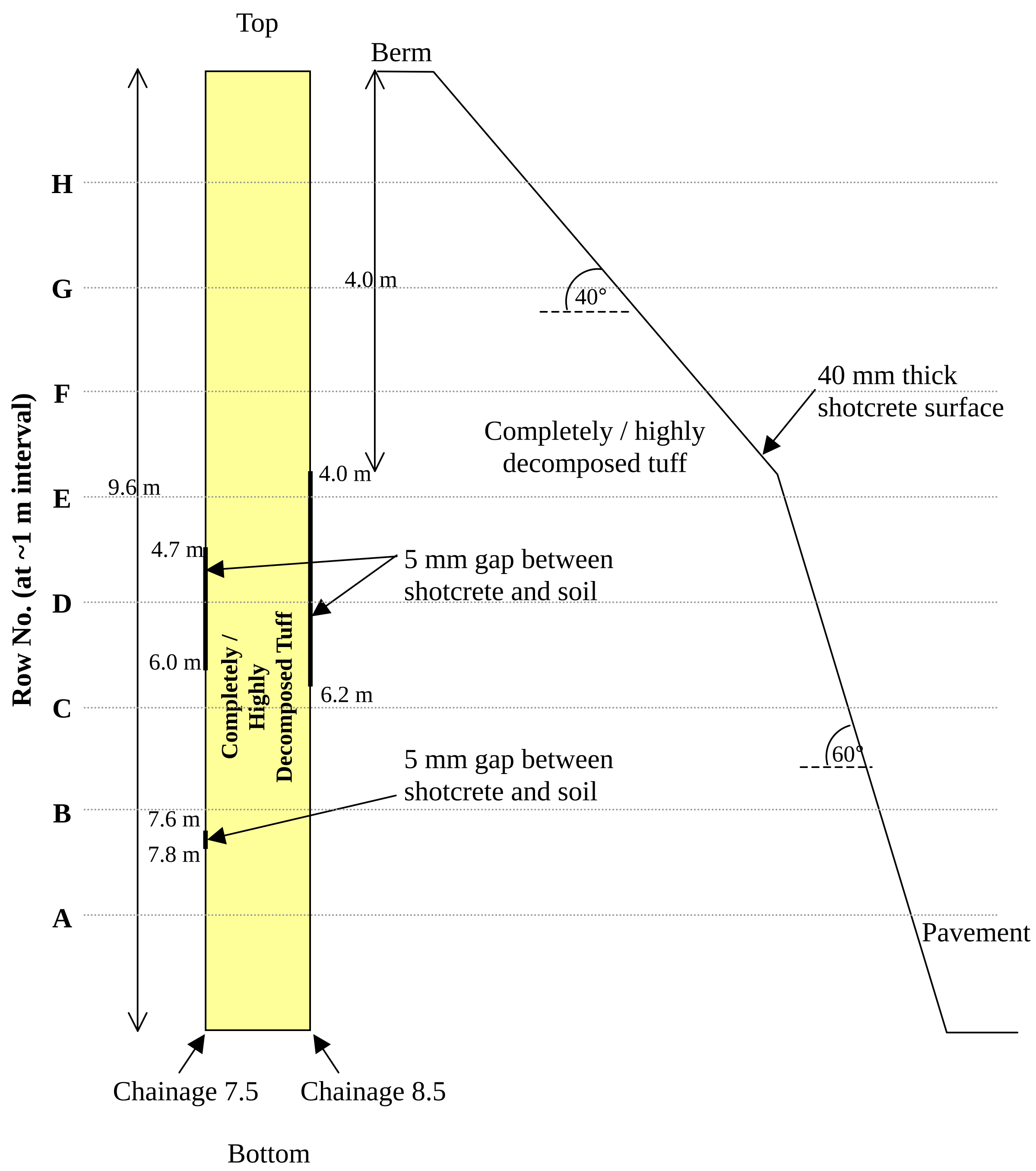


Figure 10 - Results of Ground Investigation Overlaid on Results of Sympathetic Vibration



Note: The cross section of the stripping is illustrative and not in scale.

Figure 11 - Stripping Log of Slope No. 3SE-D/C82

Table of Contents
Table of Contents
Table of Contents
Table of Contents

LIST OF PLATES

Table of Contents
Table of Contents
Table of Contents

Plate 1 - View of Infra-red Camera

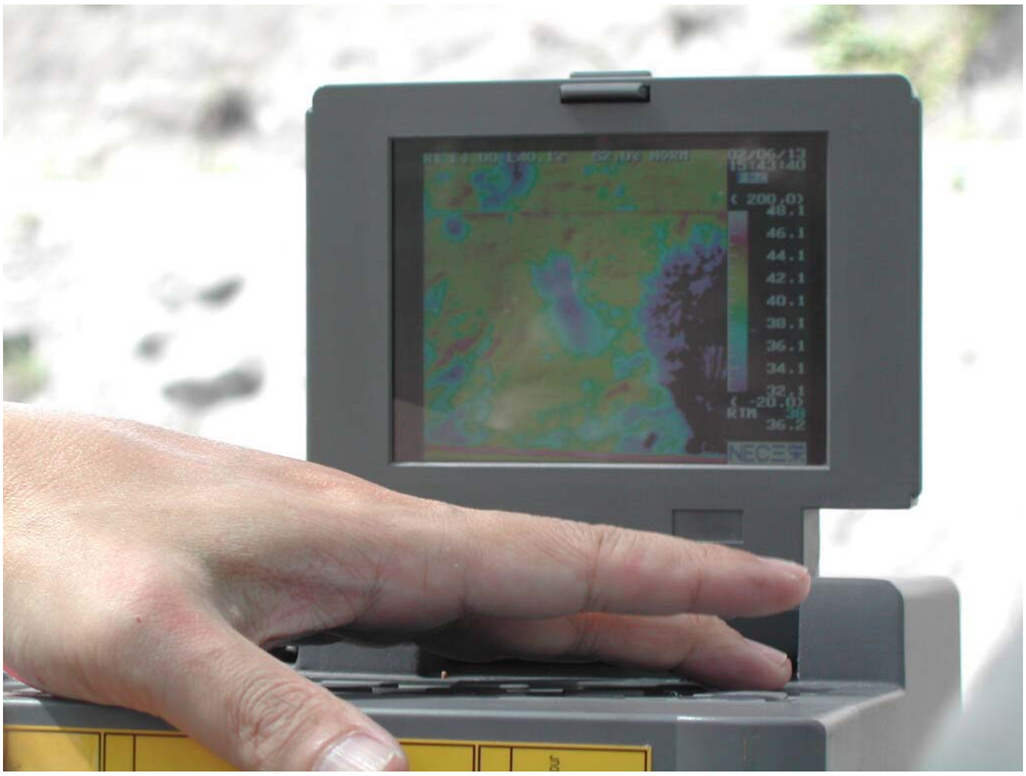


Plate 2 - View of the Display of Infra-red Camera

Table of Contents
Table of Contents
Table of Contents
Table of Contents

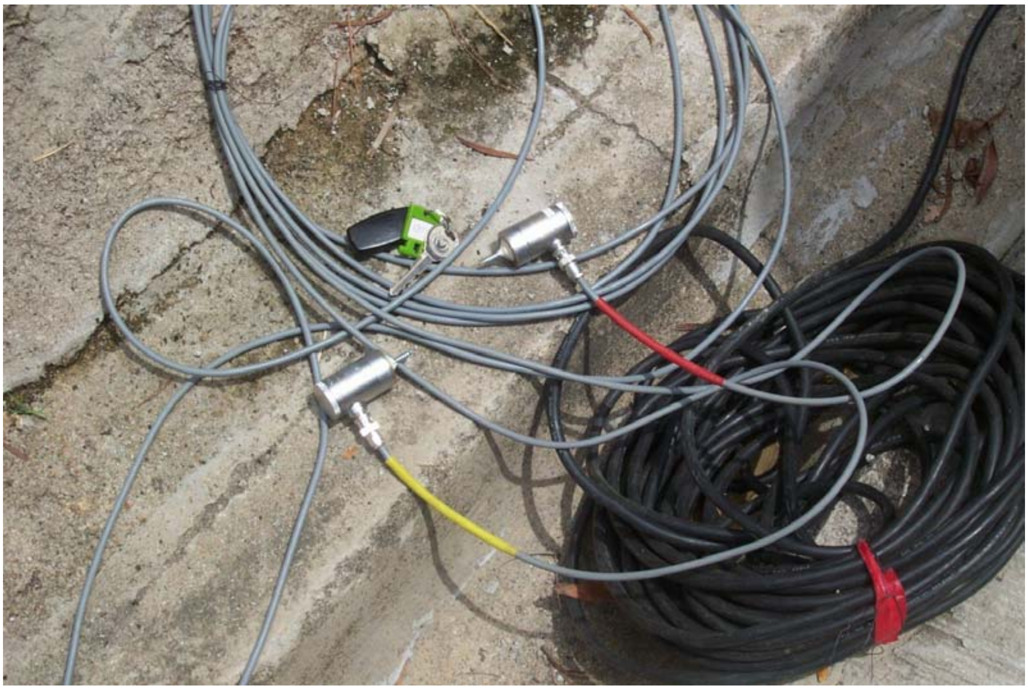


Plate 3 - View of Sympathetic Vibration Transducers

Plate 4 - View of Readout Equipment for Sympathetic Vibration Survey

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 5 - View of Sympathetic Vibration Survey in Progress

Plate 6 - View of Section of Slope No. 3NE-B/C82 Surveyed Using the Sympathetic Vibration Technique and Confirmatory Coring

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Plate 7 - View of 100 mm Diameter Coring in Progress

Plate 8 - View of Coring Bit

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Table of Contents

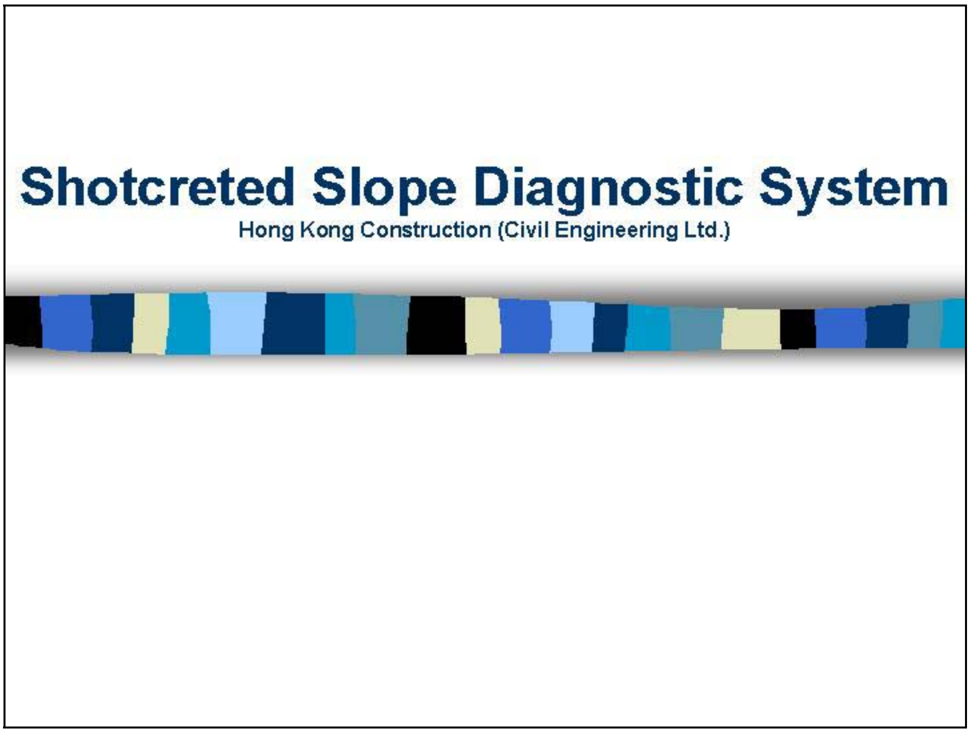
Table of Contents

APPENDIX A

PRESENTATION MATERIAL BY NCL

Table of Contents

Table of Contents



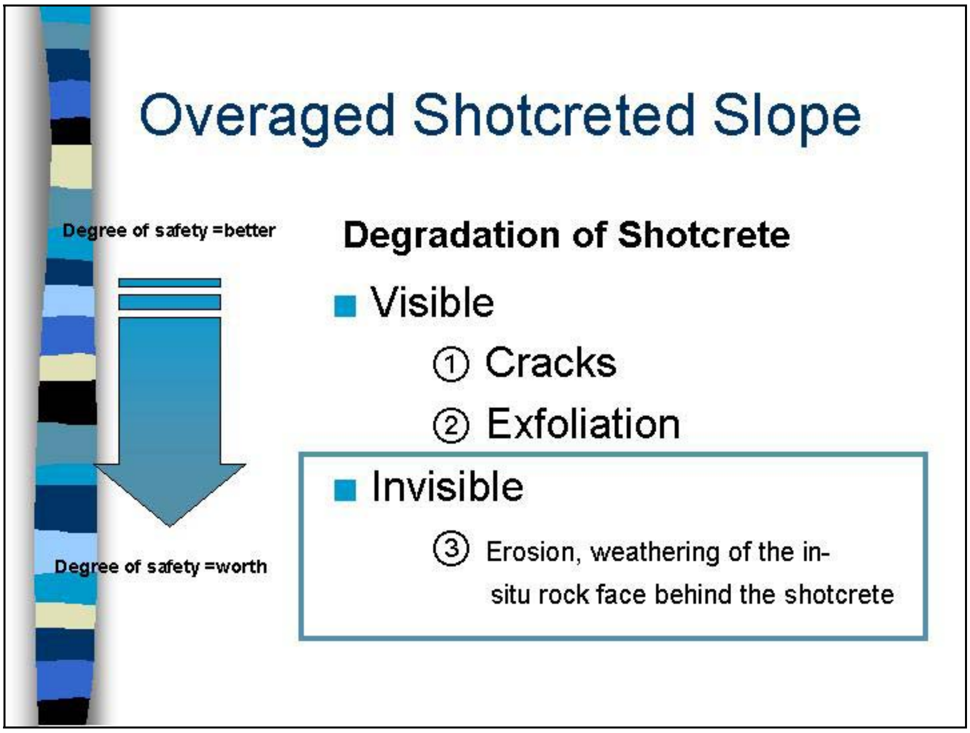


Table of Contents
Table of Contents
Table of Contents
Table of Contents

Target of Slope Diagnosis on this System

Diagnosis by using single method	*By System Combination*
Most of the current method does not have enough accuracy	Accurate and efficient diagnosis by combination of several techniques

Schematic Work Flow of the Diagnosis System of Shotcreted Slope

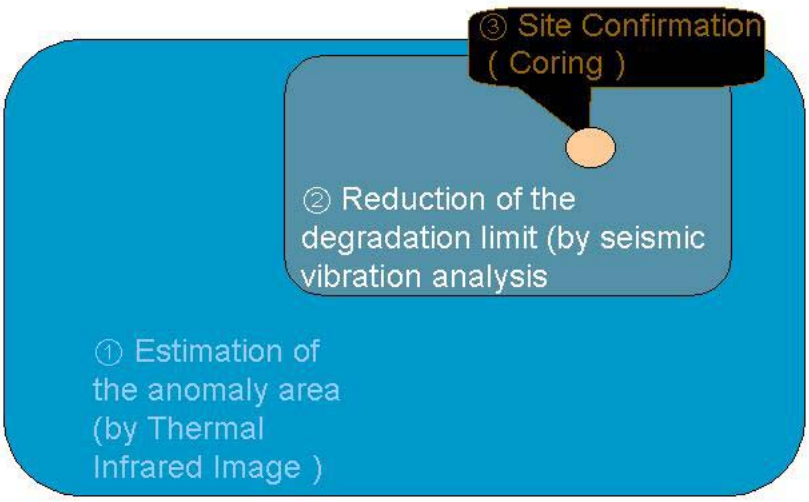


Table of Contents
Table of Contents
Table of Contents
Table of Contents

Actual Site Application

Site Applications (* projects)

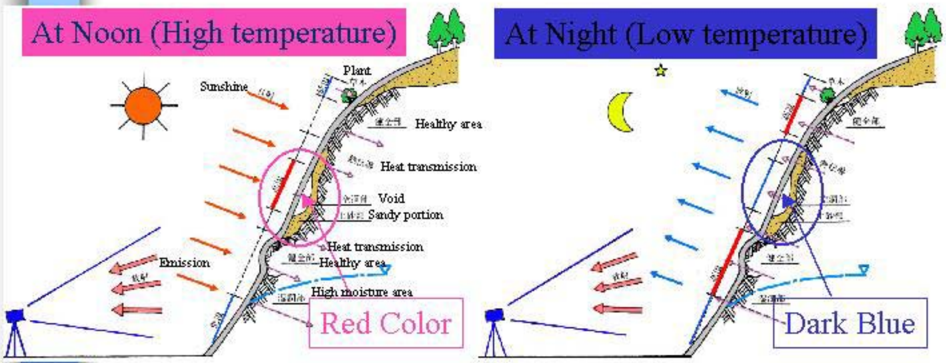
- Road
  - National Road Rout 17
  - Prefectural Highway (Gunma Pref.)
  - Prefectural Highway (Yamanashi Pref.) *
- Dam
  - Takayama Dam (Water Resouces Development Public Corporation)
  - Oyama Dam (Ibaraki Pref.) *
- Steep Slope Area
  - Private High School *

Case History (Takayama Dam)

Table of Contents
Table of Contents
Table of Contents
Table of Contents

Thermal Infrared Image Analysis

Measure the temperature of the shotcrete surface and estimate the area of weathered or eroded zone behind the shotcrete.



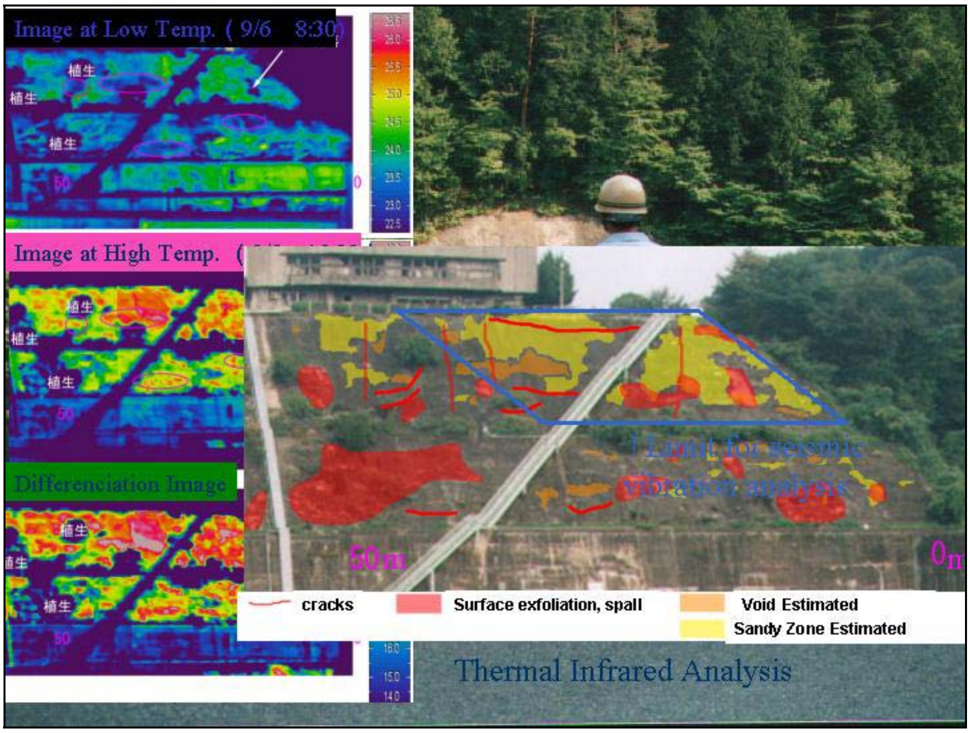
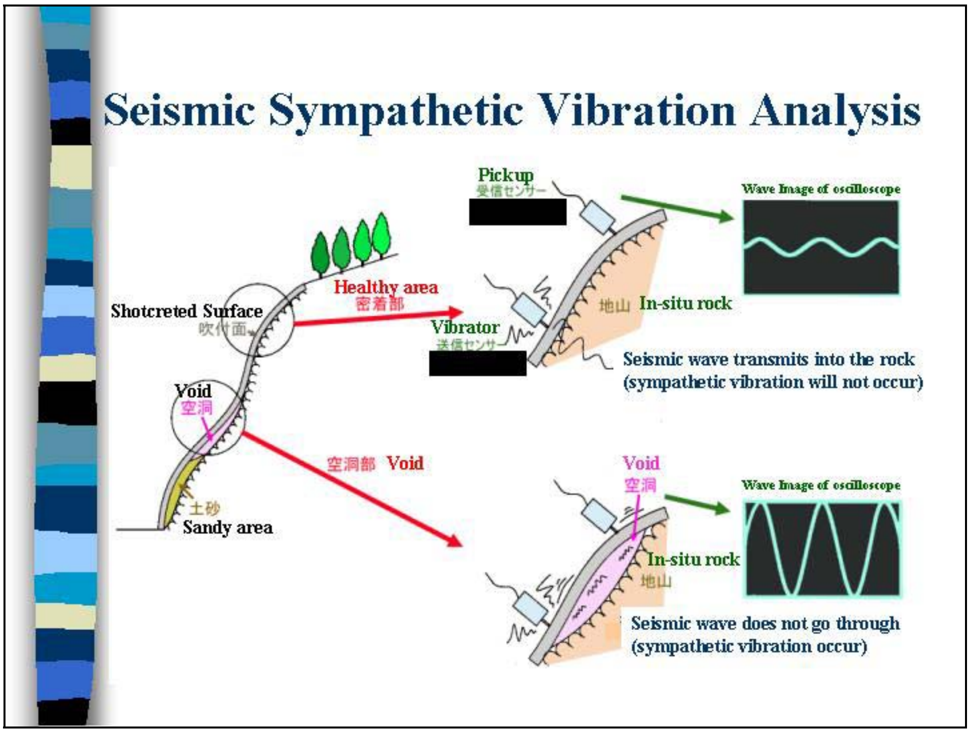


Table of Contents
Table of Contents
Table of Contents
Table of Contents



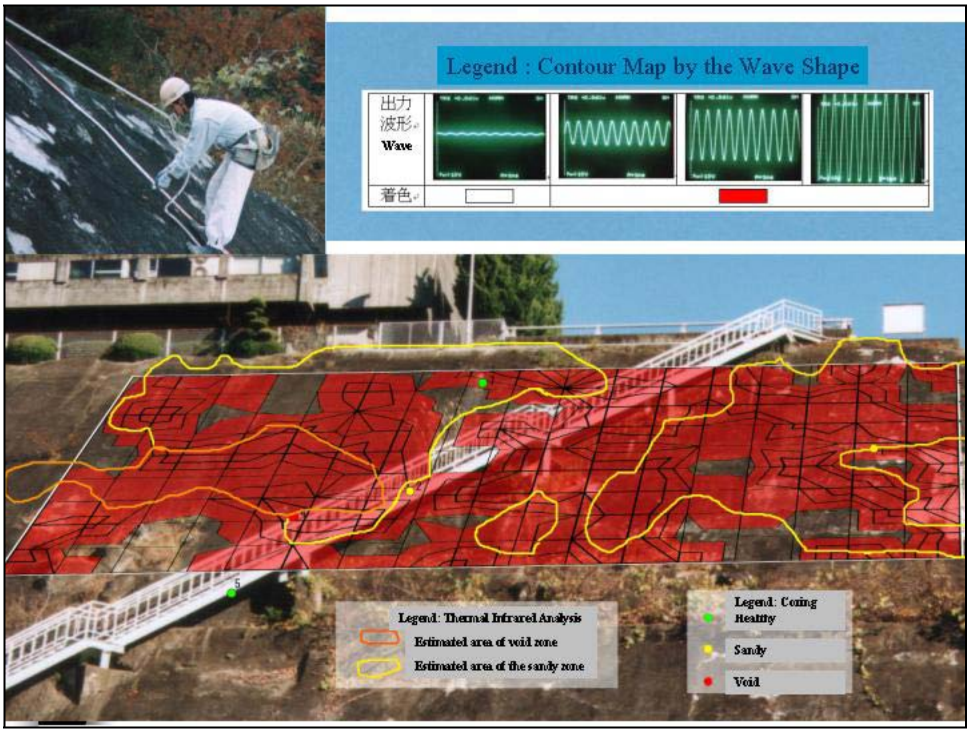
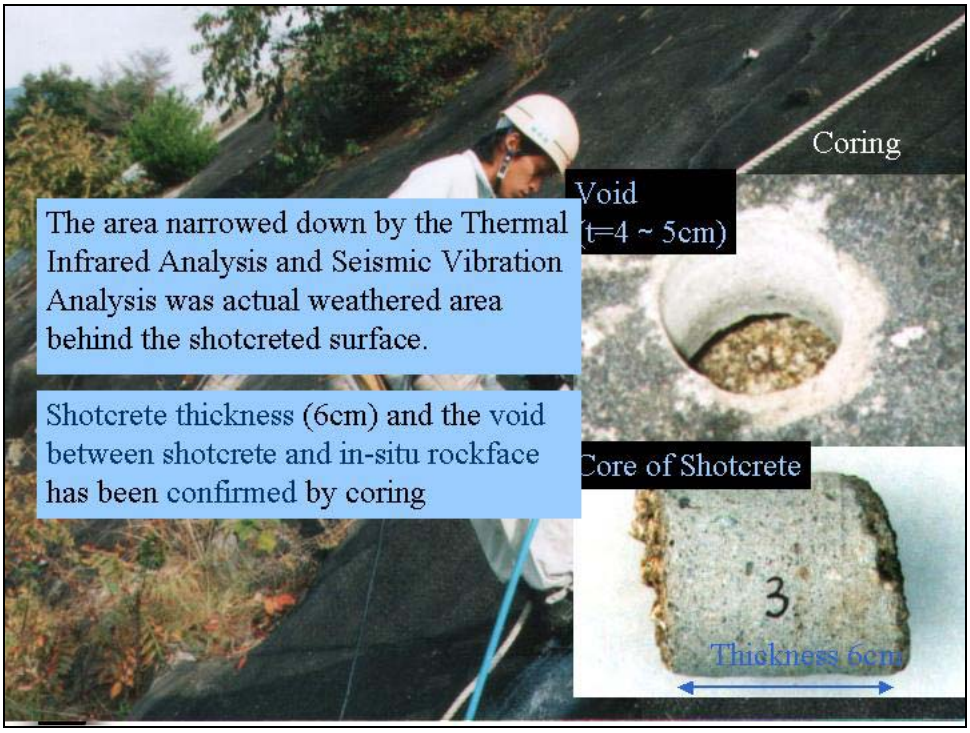


Table of Contents
Table of Contents
Table of Contents
Table of Contents

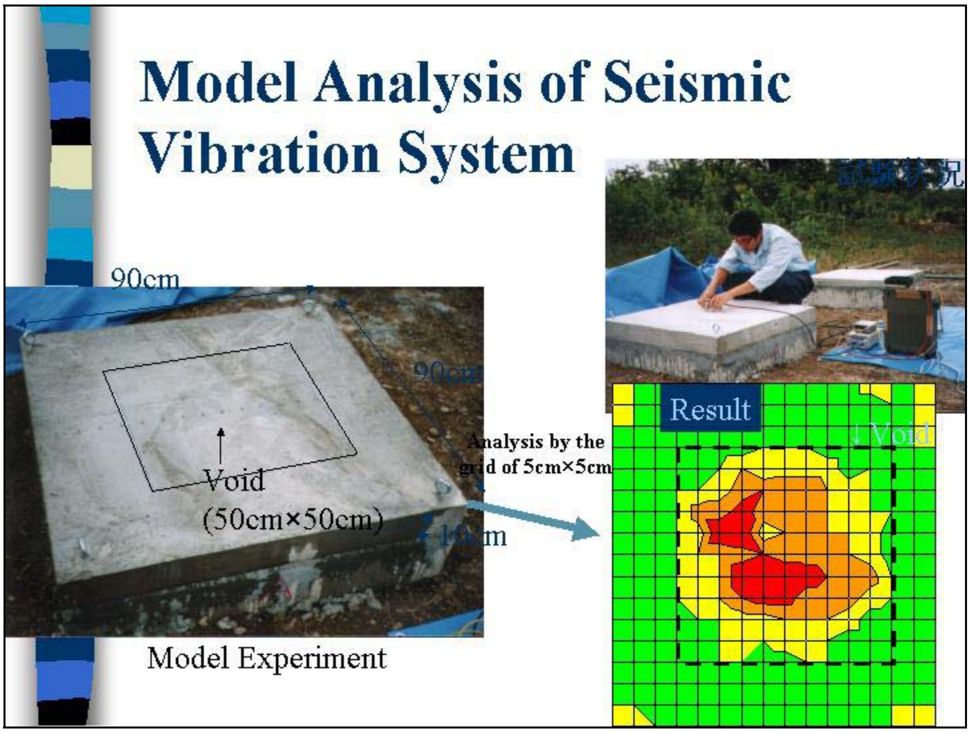


Future Plan

Increase accuracy of the analysis

- Model analysis
- Collect more site information
- Development of diagnostic system

Table of Contents
Table of Contents
Table of Contents
Table of Contents



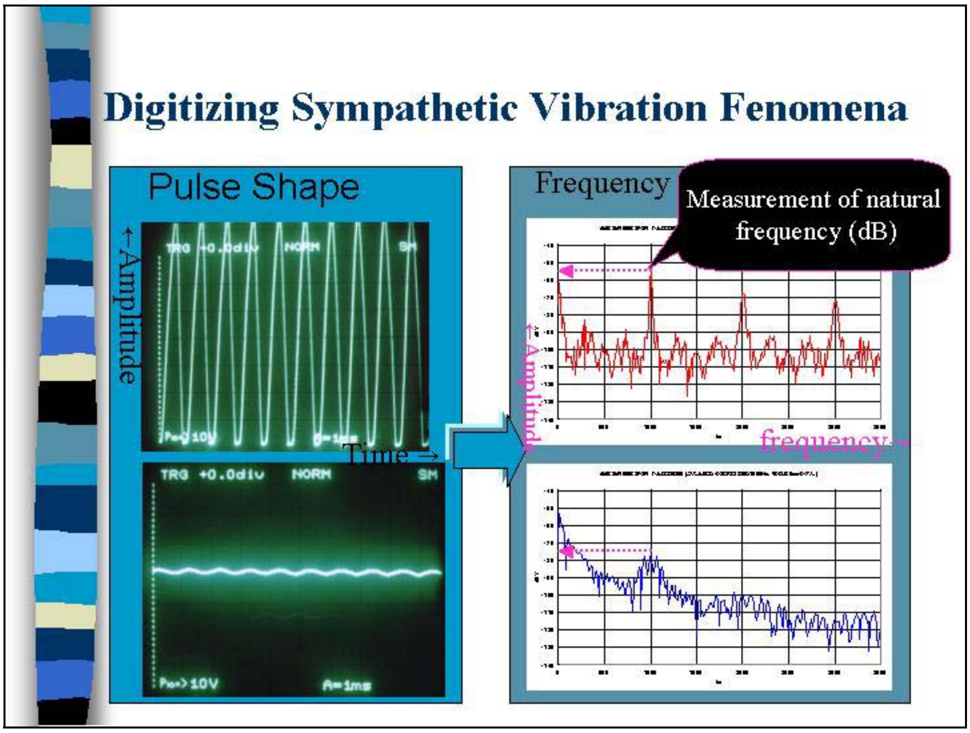
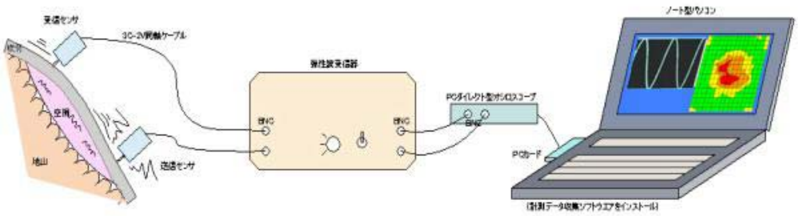


Table of Contents
Table of Contents
Table of Contents
Table of Contents

Development of Software Package for Real Time Analysis



Development of High Position Measurement System

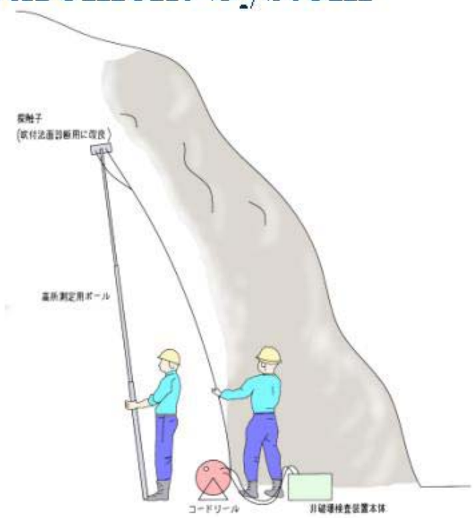


Table of Contents
Table of Contents
Table of Contents
Table of Contents

Confirmation by Fiber Scope

Minimum effect to the structure of shotcrete

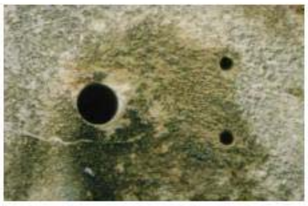


Table of Contents
Table of Contents
Table of Contents
Table of Contents

GEO PUBLICATIONS AND ORDERING INFORMATION
土力工程處刊物及訂購資料

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Geotechnical Engineering Office,
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Table of Contents
Table of Contents
Table of Contents
Table of Contents

MAJOR GEOTECHNICAL ENGINEERING OFFICE PUBLICATIONS
土力工程處之主要刊物

GEOTECHNICAL MANUALS

Geotechnical Manual for Slopes, 2nd Edition (1984), 300 p. (English Version), (Reprinted, 2000).

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The Quaternary Geology of Hong Kong, by J.A. Fyfe, R. Shaw, S.D.G. Campbell, K.W. Lai & P.A. Kirk (2000), 210 p. plus 6 maps.

The Pre-Quaternary Geology of Hong Kong, by R.J. Sewell, S.D.G. Campbell, C.J.N. Fletcher, K.W. Lai & P.A. Kirk (2000), 181 p. plus 4 maps.

TECHNICAL GUIDANCE NOTES

TGN 1	Technical Guidance Documents