BACKFILLED MUD ANCHOR TRIALS FEASIBILITY STUDY

GEO REPORT No. 18

C.K. Wong & C.B.B. Thorley

GEOTECHNICAL ENGINEERING OFFICE
CIVIL ENGINEERING DEPARTMENT
HONG KONG

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PREFACE

In keeping with our policy of releasing information of general technical interest, we make available some of our internal reports in a series of publications termed the GEO Report series. The reports in this series, of which this is one, are selected from a wide range of reports produced by the staff of the Office and our consultants.

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A. W. Malone
Principal Government Geotechnical Engineer
April 1995

FOREWORD

This report presents the final results of the feasibility study into the backfilling of Tsing Yi Marine Borrow Area. The study has been carried out by the Geotechnical Control Office of the Civil Engineering Services Department in liaison with the Marine Department. Maunsell Consultants Asia Limited were engaged to assist in the study and have carried out and reported on the field anchor trials under an agreement titled BMAT (Backfilled Mud Anchor Trials). The first stage of the Feasibility Study, which involved a literature review and desk study, was described in the Preliminary Report issued in March 1989 (Wong, 1989).

The study commenced in October 1988, at the recommendation of the Land Development Policy Committee, to assess the feasibility of using marine mud backfill to reinstate the seabed of the Tsing Yi Marine Borrow Area after proposed dredging of the available sand deposits. A preliminary report on the desk study was presented in March 1989 and recommended further site investigation in some available backfilled pits at Urmston Road, followed by the performance of field trials to assess actual anchor performance. The recommendations were endorsed by the Fill Management Committee in June 1989 and the field trials and investigation works were subsequently carried out.

This report describes the results of the investigation of the properties of the mud backfill at Urmston Road and summarises the results of the field trials carried out by Maunsell Consultants Asia Limited, the findings of which were then related to the desk study and literature review.

The study was carried out by Mr C.K. Wong and Mr C. Thorley of the Geotechnical Control Office in conjunction with Mr J.S. Lambourn of the Marine Department. Maunsell Consultants Asia Limited carried out the anchor field trials, under Agreement No. CE 34/89, employing London Offshore Consultants, Mr R. Taylor and Dredging Research Limited as sub-consultants. The assistance of Mr N. Wragge-Morley, Senior Resident Engineer/Marine and Mr C. Van Den Berg of Bilfinger & Berger and their staff is gratefully acknowledged in providing assistance in the site investigation and trials at Urmston Road, the borrow area for the Tin Shui Wai Development.

(W.C. Lee)
Government Geotechnical Engineer/Island

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*** These appendices of the original report have been excluded.**

REPORT SUMMARY

This report presents the final results of the feasibility study on restoring the anchorage capacity of completed marine borrow areas by backfilling with dredged marine mud. A preliminary study completed in March 1989 (Wong, 1989) concluded that backfilling could be feasible and recommended that further site investigation of the backfilled borrow pits at Urmston Road and field anchor trials should be carried out to confirm its findings. This initiated the BMAT (Backfilled Mud Anchor Trials) Study which is the subject of this report. The BMAT Study consisted essentially of two parts : anchor field trials in Urmston Road and Tsing Yi waters designed and conducted by Maunsell Consultants Asia Ltd. (MCAL) and their sub-consultants, and site investigation work in the backfilled pits at Urmston Road consisting of drillholes, field and laboratory tests carried out by the GCO.

The main findings of the BMAT Study are summarized as follows :

(a) Comparative anchor pulling tests in virgin and backfilled sea floors, as reported by MCAL (1990b & f), have demonstrated that the anchor holding resistance in virgin and backfilled mud is similar, and that backfilled mud is an acceptable anchoring material. The test results are consistent with the historical performance data for stockless type anchors in muddy sea floors.

(b) The only difference in anchor performance in virgin and backfilled mud would be the depth of embedment in the seabed. Site investigation in the backfilled pits at Urmston Road has found that as expected the shear strength of the backfilled mud is lower than that of virgin mud. Anchors would therefore penetrate deeper in backfilled seabeds. The difference in penetration depth as evaluated from the shear strength profile of the backfilled mud would be of the order of 6 metres for a 5 tonne anchor and up to 10 metres for a 15 tonne anchor. Heavy anchors of 10-15 tonnes or anchors of High Holding Power type might therefore penetrate through a thin layer of backfill and dig into the sand bottom of the borrow pit to acquire the required resistance. The overall effect of this on practical anchoring, however, is not significant, because anchor weight of smaller ships would not result in this happening whereas for large ships equipped with heavy anchors, this factor would not affect performance.

(c) The marine mud and the method of dredging and backfilling being used at Urmston Road have been proven to the suitable for backfilling. As the mud at Urmston Road is a typical Hong Kong marine mud, it is expected that other Hong Kong marine muds could also be used. As the properties of the backfilled mud will depend on the dredging and backfilling methods employed, backfilling and anchor field trials could be required if significantly different dredging

and backfilling systems, such as floating pipeline delivery for example, are proposed.

(d) The trial installation of a mooring sinker block in the backfilled pit at Urmston Road has indicated that the performance of sinker in backfilled seabed is satisfactory. The settlement of the sinker block in backfilled mud was found to be not excessive and therefore would not pose any significant practical installation problem (MCAL, 1990f).

The findings of this study have corroborated the conclusion drawn in the preliminary study that backfilling with dredged mud for anchorage restoration in areas with hydraulic conditions similar to Urmston Road, such as the Tsing Yi Marine Borrow Area, is likely to be feasible.

For the Tsing Yi Marine Borrow Area, and any other potential borrow areas where it is necessary to restore the anchorage capacity of the seabed after dredging, the main design considerations for the engineering of the backfilling operation are :

(a) Properties of source mud;

(b) Hydraulic conditions of the borrow area to be backfilled;

(c) Configuration of the finished borrow area;

(d) Backfilled seabed level;

(e) Dredging and backfilling methods; and

(f) Backfill properties required.

Available data from the study and preliminary guidelines relating to the above design considerations are presented in this report.

Recommendations are made concerning the methods, materials and levels for the dredging and backfilling of Tsing Yi Marine Borrow Area, and also on further studies that may be required for general backfilling operations for anchorage restoration purposes. The information that should be made available to port users is discussed and recommendations on the type of information to be provided are made. Recommendations are also given on the control and monitoring of backfilling operations.

1. INTRODUCTION AND BACKGROUND

In 1987, during the investigations carried out as part of the GCO's Marine Source of Fill Study (Choot, 1988), an area to the south of Tsing Yi Island was gazetted as a marine borrow area for the extraction of sand for use as reclamation fill (Figure 1). Subsequently, in April 1988, HAM Dredging applied to extract sand from the area to use as fill for Container Terminal 7. The proposal by HAM, the contractor for Hong Kong International Terminals Ltd (HIT) was to use trailing suction hopper dredgers to extract the seabed marine sand and part of the underlying alluvial sand (Figure 2) over the eastern half of the originally gazetted area. These proposals, and any future extraction, would result in a lowering of the seabed which Marine Department then saw as a constraint to the safety and capacity of the area as one of the main anchorage areas and fairways in Hong Kong. Conversely, the sterilisation of the area for dredging would involve the loss of up to 100 million cubic metres of potential fill for the proposed urban reclamations which were currently in the planning stage.

After extensive discussions between Hong Kong International Terminals Ltd (HIT), Marine Department, the District Lands Office, Civil Engineering Services Department and the then Lands and Works Branch, a proposal was developed for GCO and Marine Department to liaise on a study to assess the feasibility of using unwanted marine mud to backfill dredged borrow areas and thus reinstate the seabed to a level acceptable for the safe anchoring of shipping. On 23rd September 1988, the proposal for the feasibility study was endorsed by a meeting of the Land Development Policy Committee, who also recommended, due to Government commitments, that HAM be allowed to extract the sand required for Terminal 7 and the Replenishment of Repulse Bay Beach (Appendix A). Further dredging in the borrow area was to be suspended until the results of the feasibility study were known.

The study, which consisted of a desk study, literature review and some minor site investigation in some backfilled borrow pits at Urmston Road, was completed in March 1989 (Wong, 1989). The study concluded that backfilling appeared to be feasible and that the anchoring of ships in backfill should not pose any problems. It was also recommended in that report that further site investigation be carried out in the backfilled pits at Urmston Road and that those pits be used to carry out anchor field trials to confirm, or otherwise, the results of the study (see also Section 3). These recommendations were endorsed by the Fill Management Committee in June 1989 (Appendix B) and the site investigation work and field trials subsequently commenced. The results of the further study and the anchor field trials were also urgently required for the Container Terminal 8 (CT8) Study which was concurrently being carried out and was due for completion by March 1990. Based on the final results of this study, a decision on whether the marine borrow area at Tsing Yi could be available for the development of CT8 had to be made by April/May 1990.

The investigation and trials, which are the subject of this report, were carried out by both the GCO and Maunsell Consultants (Asia) Limited (MCAL). Maunsells were engaged to carry out the field anchor trials and to report on the results while GCO concurrently carried out the site investigation works at Urmston Road. The appointment of MCAL under Agreement No. CE 34/89 was completed on 7th December 1989 and the anchor field trials were carried out in January 1990. The study brief is enclosed as Appendix C. Before and after the trials, MCAL and their sub-consultants also carried out a review of shipping using Hong Kong and estimated the likely anchoring forces required by shipping. This information was used to assess the results obtained from the measurement of the anchor loads during the field trials.

The site investigation works at Urmston Road was carried out in December 1989, under the GCO term drilling contract. The results of the drilling and associated laboratory testing programme are described in this report. This report also includes a review of the field trials carried out, a reassessment of the results of the preliminary desk study, in light of the fieldwork, and provides conclusions on the feasibility of backfilling at Tsing Yi using marine mud. Recommendations for further work, including design requirements, are also given.

2. STATEMENT OF PROBLEMS

The problems caused by lowering of the seabed at Tsing Yi, or other fairway or anchorage areas, can be summarized as follows :

(a) For permanent sinker moorings, several of which are affected by proposed dredging at Tsing Yi, the lowering of the seabed results in a greater length of the mooring buoys chain being supported by the buoy alone. Marine Department has indicated that for water deeper than 30 metres, the buoys may cease to function properly. In addition, the swing radius of the buoys increases in deeper water and the anchorage capacity of a given area is reduced.

(b) For ships at anchor, and using a single point anchorage, the swing radius increases in deeper water as for mooring buoys, and thus the capacity of a given area is reduced. The amount of chain to be laid out, which is a function of water depth, also increases in deeper water. In smaller vessels a limit is reached whereby the amount of chain on board is insufficient to maintain effective anchoring. This problem is aggravated in storm or typhoon conditions when practice dictates that additional chain be laid out to resist the wind and wave forces on the vessel.

(c) For ships at anchor adjacent to deepened areas, it is a not infrequent occurrence during typhoons that they drag their anchors due to the excessive wind and wave forces on the vessel. In this event, and should they drag into a deepened area, the total anchorage force provided by the anchor and the chain on the seabed will reduce as the water deepens. This could therefore cause increased dragging, and an increased risk of collision unless extra chain is paid out, a difficult operation under typhoon conditions.

(d) For ships moving in fairways, it is possible that an engine or steering failure could lead the master to decide to use his anchor and chain to slow or stop the vessel. In a deepened area this will be less effective, due to the decreased length of chain on the seabed, and due to the increased difficulties in having to quickly pay out extra chain.

The problems listed above are obviously less of a concern to larger vessels using the harbour as they tend to anchor in deeper water by necessity. For small to medium ship however, which forms the bulk of those using the anchorage areas, the problems can be significant. The relative importance of each problem will be discussed later in light of the results of the anchor trials.

3. RESULTS OF PRELIMINARY DESK STUDY

The main findings of the preliminary desk study (Wong, 1989) are summarized as follows :

(a) Dumping process

Field observations as reported in the literature or from previous studies indicate that the bottom dumped mud descends very rapidly down the water column as a coherent mass. As a result, only a small percentage of the volume of the mud dumped is reported to be carried away from the descending mass by the currents prevailing at the site during dumping.

(b) Mud Containment

A shallow pit of depth in the order of a few metres is sufficient to contain the dumped mud. Escape of backfill from the borrow pit as a bottom surge is considered unlikely at the Tsing Yi Marine Borrow Area provided that the mud is discharged well within the pit boundaries.

(c) Backfill erosion

Preliminary WAHMO studies output for the Tsing Yi Marine Borrow Area, based on an emperical relationship between the density of the muddy seabed and the critical shear stress for erosion, indicates that net erosion of the backfilled mud by tidal currents would occur when the surface bulk density of the backfilled mud falls below a threshold value of about 1.3 Mg/m^3.

(d) Tidal Environments

The preliminary WAHMO study using the Tidal Flow Models indicates that the current regime at Urmston Road and Tsing Yi Marine Borrow Areas are generally similar. As the marine mud at Urmston Road is a typical marine mud found in Hong Kong, it is concluded that the results of the backfilling operations as carried out at Urmston Road can be broadly applied to the Tsing Yi site.

(e) Mud properties

Two drillholes in one of the backfilled borrow pits at Urmston Road showed that the properties of the backfilled mud were comparable to that of the original in-situ marine mud. Hence it was considered likely that the anchorage capacity of a backfilled seabed would not be significantly reduced. The report recommended that this conclusion should be substantiated by more data on the geotechnical properties of the backfilled mud using Urmston Road as a trial area.

On the basis of the above findings, it was recommended that a detailed investigation of the backfilled borrow pits at Urmston Road be carried out. It was recommended that the investigation should consist of :

(a) a more detailed site investigation of the backfilled mud and,

(b) pulling tests of ship anchors in the backfilled pits to obtain the actual holding power of anchors in a backfilled seabed.

4. SCOPE OF STUDY

As mentioned in the preceding section, the objective of this study is to verify the findings of the preliminary study (Wong, 1989) that backfilling the finished borrow pits with dredged mud for anchorage restoration is likely to feasible, and that the anchor holding resistance in virgin and backfilled mud could be similar. To this end, the study comprised two main parts as follows :

(a) Anchor pulling tests in the virgin and backfilled sea floors at Urmston Road, and in the virgin muddy seabed at the anchorage areas and the dredged (but not backfilled) borrow areas to the south of Tsing Yi. The purpose of these tests was to obtain data on the holding power and performance of anchors in virgin and backfilled mud, and in the dredged areas.

(b) Site investigation, including drillholes, field vane shear testing and soil laboratory testing, in the backfilled borrow pits at Urmston Road, to obtain more data on the geotechnical properties of backfilled mud.

In addition, at the request of Marine Department, a trial installation of a 90 tonne sinker block was carried out in a backfilled pit at Urmston Road. The objective of this trial was to examine whether a sinker placed in a backfilled area would undergo excessive settlement thereby making its retrieval extremely difficult.

5. URMSTON ROAD SITE INVESTIGATION

5.1 Previous Investigation of Original Site Conditions

The marine borrow area at Urmston Road is located about 2 km to the west of Black Point (Figure 3). In 1985, during the planning of the Tin Shui Wai Development, a site investigation was carried out in the proposed borrow areas. The hole locations are given in Figure 4 and a simplified geological section across the borrow area is given in Figure 5.

An interpretation of the geological profile in the area has been described previously by Dutton (1987). In general, the area shows a 10 m thick layer of marine mud overlying a 15 to 20 m thick stratum of alluvial sands, clays and gravels. The alluvial deposits reach to a level of about -45 mPD to -50 mPD. A basal layer of clean, fine to medium sand is present in some areas below the marine mud. This basal layer has been found in many parts of offshore areas in Hong Kong and is probably associated with the low-energy deposition during the marine transgression.

The grading envelope of the mud (Figure 6) indicates that the sand content of the mud ranges from about 5% to 40%. Also shown in Figure 6 are the grading envelopes of the marine mud at Chek Lap Kok and Kellet Bank. They are found to be well within the envelope of Urmston Road mud, with Chek Lap Kok mud tending to be at the finer limit and Kellet Bank mud at the coarser limit.

5.2 Investigation of Backfilled Mud for the BMAT Study

The field investigation work for this study was carried by Gammon Construction Limited using a drilling barge (Plate 1) under the GCO Marine Investigation Term Contract. The investigation of the backfilled mud in the Urmston Road borrow pits consisted essentially of fourteen boreholes (Figure 7). The depth of the holes was generally 10 to 15 m below seabed, or less if the bottom of the dredged pit was reached. Starting from seabed level, 75 mm piston samples were taken at 2 m intervals, alternating with SPT liner samples. In some of the boreholes in the partially backfilled borrow pits (Nos. 5 and 10, Figure 4), where retrieval of the upper extremely soft backfill mud was found difficult using a piston sampler, 3 m long Vibrocore tubes equipped with core-catchers were adopted. The Vibrocore samples are not undisturbed however, and therefore were used for logging and index properties testing only.

To determine the shear strength profile of the backfill mud, vane shear tests using the Geonor Vane Borer were carried out at positions adjacent to the boreholes. Because of the extremely low consistency of the upper backfill mud, it was found in all vane tests that the casing supporting the Vane Borer sank to a depth of about 3 m below the backfilled seabed level as measured using a weighted line. All vane tests were therefore started at a depth of 3.5 m below seabed level, and terminated at a level where sand or stiffer clay in the backfill, or the base of the pit, was encountered.

Laboratory tests were carried out on selected borehole samples to determine the index properties and the unconsolidated-undrained triaxial shear strength of the mud backfill.

5.3 Properties of Mud Backfill

The borrow pits at Urmston Road were backfilled by bottom dumping from a trailing suction hopper dredger, the 'Wiesbaden' (Plate 2) which was used to dredge the marine mud overburden in the borrow area. At the time of this study, only borrow pit No. 2 at Urmston Road was backfilled to the original seabed level at about -18 mPD, and all other finished borrow pits were only partially backfilled to the level of about -22 mPD to -25 mPD. According to site records (MCAL, 1990e), the dates of backfilling of the borrow pits are as follows :

Pit No.	Start Date of Filling	End Date of Filling	Source of Mud
2	31.10.88	8.12.88	Pits 5, 6 & 10
	12.88	3.89	Marine/Alluvial Clays grab-dredged from Deep Bay
5	7. 2.89	13. 4.89	Pits 10 & 13
10	16. 8.89	12. 9.89	Pits 11, 12 & 15
	6.89	11.89	Clays grab-dredged from Deep Bay

Hence from the above records, the approximate average filling rates and the time over which consolidation of the mud has taken place up to the end of December 1989 before the pulling tests are as follows :

Pit No.	Time since Start of Filling	Time since End of Filling	Rate of Filling (days per metre)
2	15 months	9 months	12.4
5	11 months	8.5 months	8.7
10	4.5 months	1 month	17.4

Schematic logs for the boreholes within the backfilled borrow pits Nos 2, 5 and 10, where anchor pulling tests have been carried out, are given in Figures 8 to 10.

The backfill materials as found from the boreholes are extremely heterogeneous. No particular layering or trend of the materials could be deduced, as expected due to the randomness of the dumping process. As shown in Figures 8 to 10, the backfill consists predominantly of a very soft greyish clayey and sandy marine silt (mud), mixed randomly with pockets of greyish clayey silty sand of marine origin and stiff light grey or yellowish brown clay of alluvial origin. The approximate proportions of the soft mud, silty sand and alluvial clay in the backfill,estimated from the boreholes for different pits are :

Backfilled Pit No.	Percentages (by volume) of Mud	Sand	Alluvial Clay
2*	79	18	3
5+	75	21	4
10+	69	17	14

* Completely backfilled

\+ Partially backfilled

The particle size distribution of the marine mud in the backfill is shown in Figure 11, alongside with the grading envelope of the insitu marine mud. It is apparent from Figure 11 that the mud backfill defined as consisting of more than 35% of fines (silt and clay size particles), is of similar grading to that of the in-situ mud but with slightly more coarser particles. This could be due to the loss of the fines in the process of dredging and backfilling. The silty sand constituent of the backfill, representing about 19% of the dumped materials, originates probably from the in-situ sandy marine deposits. Contrary to the site records, very little amount of stiff alluvial clays (only 3% of the backfill) was found in Pit 2 (Figure 8). On the other hand, in Pit 10, about 14% of the backfilled materials was found to be alluvial clay. Nevertheless, the drag loads measured from the anchor trials in these two pits appear generally similar (Section 6.3), indicating that the presence of alluvial clay in Pit 10 may not have any practically significant effect on the performance of the test anchor.

In the boreholes within the partially backfilled pits (Nos. 5 and 10), a layer of thin muddy slurry was found at the top 1 to 2 metres. This slurry layer is absent in the boreholes in pit No. 2 which has been backfilled to original seabed level. This suggests that during the backfilling process, a layer of less dense slurry material sits above the denser volume of the bulk of the backfill. While the pits are only partially full, the pit walls effectively prevent the movement of this material by the tidal currents. On complete filling of the pit however, when the slurry is no longer contained by the pit walls, it would appear that the slurry is most likely transported away by the prevailing currents. This then leaves a denser seabed composed of the backfill that underlies the slurry. The significance of this slurry layer is discussed in later sections. In the context of this discussion, 'slurry' is defined as a material less dense than the bulk of the backfill. Its surface can be identified by a weighted line, or by echo-soundings, but it cannot be sampled using conventional methods and is unable to support about 20 metres of borehole casing or vane test rods.

The field vane shear strength profiles of the backfill has been compared with the field vane shear strength profile of the original muddy seabed (Figure 12). All vane tests in the backfill, (except those at Borehole BH12), were terminated at depths less than 10 m due to the obstruction of sand layers or stiffer clay. Figure 13 shows the undrained shear strengths of the mud backfill measured by field vane tests and unconsolidated-undrained triaxial tests. It is apparent that the shear strength of the backfilled mud is rather erratic because of the variable nature of the backfilled mud but is generally lower than that of the insitu mud as may be expected (Figure 12). In particular, the shear strength in Borehole BH12 was found to be exceptionally low, being less than 1 kPa at 9.5 m depth and only about 4 kPa at 14.5 m depth. However, generally there is no marked difference in the shear strength profiles in different pits, although it is known that the backfill was placed over different periods in different pits. To summarize the results, the shear strength of the backfill at 3.5 m depth is about 2 to 4 kPa, increases generally to about 5 to 10 kPa at 8 m depth, giving an average strength gradient of about 0.9 kPa/m (Figure 13).

The surface bulk density of the backfill in the completely backfilled pit was found to be 1.6 to 1.7 Mg/m^3, which is higher than the erosion threshold value of 1.3 Mg/m^3 obtained from WAHMO Studies in the preliminary desk study.

6. ANCHOR FIELD TRIALS RESULTS

6.1 General

Maunsell Consultants Asia Ltd (MCAL) were engaged under Agreement No. CE 34/89 to carry out and report on the Anchor Field Trials. In conjunction with their sub-consultants, London Offshore Consultants, MCAL carried out field work in January 1990 at both Urmston Road and in the area to the south of Tsing Yi. The trial specification, proposals, test methods and various analyses are contained in a series of reports (MCAL, 1989; 1990a; 1990b; 1990c; 1990d; 1990e; 1990f).

6.2 Test Methods

A total of 36 field pulling tests on a 3.4 tonne Ordinary Standard Stockless (OSS) Anchor were carried out by MCAL in Urmston Road Marine Borrow Area and the borrow areas and anchorage areas south of Tsing Yi Island in January 1990. The locations of the pulling tests are shown in Figures 14 & 15 and the general arrangement of the pulling test is shown in Figure 16. The 3.4 Tonne OSS anchor was used as it was considered to be typical of the size and type of anchor used by shipping in Hong Kong. A 5 Tonne anchor was originally preferred but investigations revealed that the largest OSS anchor readily available at the time of the study was the 3.4 Tonne version.

An anchor handling tug boat, the 'Tai-O' (Plate 3), was used to apply the pulling load either dynamically with its engine power, or statically, using the deck winch of the boat to pull against a mooring buoy (Plate 4). The anchor was connected to a 64 m long 50 mm diameter chain which was linked to a 175 m long 36 mm diameter pennant wire (Plate 5). A calibrated shackle installed with a shear-bolt type load-cell was connected to the end of the pennant wire for measurement of the pull load on the boat deck (Plate 6). The pull load was monitored during the tests (Plate 7) in parallel with the position of the tug boat which was determined using a surface-based electronic positioning system. The test procedures were designed to simulate the normal practical anchoring situation. Full details of the test equipment and procedures are given in MCAL's reports (1990a, 1990b, 1990f).

It was intended to monitor the depth of penetration of the anchor in the seabed during the tests by attaching a graduated pennant wire and buoy to the crown of the anchor, and then measuring the distance to the anchor after pulling the wire taut. This method of measurement was not successful however as during anchor drag the pennant wire was pulled horizontally into the mud, the surface buoy was dragged underwater and the pennant wire was lost as a result. Consequently, three separate anchor burial tests were carried out at

Urmston Road to establish some idea of the depth of penetration of the anchor, both prior to and after load application. Details of these burial tests are provided in MCAL's Report (1990b).

6.3 Test Results/Conclusions

The results of the anchor pulling tests at Urmston Road and at Tsing Yi Area are summarized in Tables 1 and 2 taken from MCAL's report (1990b), and the results of the burial tests are provided in Table 3.

The main conclusions drawn from the anchor trial results (MCAL 1990b) are :

(a) The tests results for Urmston Road Marine Borrow Area indicate that there is little practical difference between the anchor holding resistance in backfilled mud and the virgin muddy seabed for the 3.4 tonne test anchor. As reported by the consultants, the peak holding power in both backfilled and virgin seabed is in the order of 10 to 13 tonnes. Considering the mean peak loads, and eliminating the three results that were identified on site as exhibiting irregularities, the results, to the nearest tonne, are :

In-situ seabed :	13 Tonnes
Backfilled seabed:	13 Tonnes

For the drag loads, the mean values determined are :

In-situ seabed :	9 Tonnes
Backfilled seabed:	10 Tonnes

(b) The limited burial tests at Urmston Road indicate that initial anchor burial ranged from 2 to 6 m with the partially backfilled pit (No. 5) giving the maximum penetration of 7.8 m. In this pit however, the capacity of the anchor to resist normal loads does not appear to be compromised, when compared with that in the fully backfilled pit or virgin seabeds.

(c) Due to the non-homogeneous nature of the backfill, fluctuations in the resistance of the anchor in the backfill were observed but there are no apparent signs that these fluctuations would yield poor quality anchoring material.

(d) The results of the limited number of anchor trials in the muddy seabed of the anchorage areas south of Tsing Yi indicate that the anchor holding resistance at Tsing Yi is comparable to that at Urmston Road. The mean peak load is 12 tonnes and the mean drag load is 11 tonnes.

(e) The trials carried out in the dredged (but not backfilled) borrow areas for CT6 and CT7 indicate that when the anchor made contact with the hard sand layer after passing through the layer of soft sediments which were built up naturally over the dredged sand bottom, significantly high loads of 15 to 27 tonnes were generated. Quite low loads (around 8 tonnes) were however recorded when the anchor was dragging through the covering soft sediments.

(f) The tests on the dredged slopes in the borrow areas at Tsing Yi, which were covered with natural soft sediment, yielded results which were not significantly less than the original seabed in the existing anchorage areas, the mean peak load being 11 tonnes and the mean drag load being 10 tonnes.

(g) At the Tsing Yi Borrow Areas, when the anchor was dragged to or was placed on a relatively level seabed, very high resistance was generated as it dug into the sand bottom. This resistance was not always obtained on first pull, hence, high "snatch" loads (of the order of 52 tonnes) were noted.

7. SINKER MOORING TEST RESULTS

During the anchor field trials, a sinker mooring was also placed in the backfilled Pit No. 2 at Urmston Road. This sinker block was then monitored to determine its settlement behaviour with time. The objective of this test was to determine the actual performance of one of the Harbour Mooring Unit's (HMU) standard Harbour Mooring Buoy assemblies (Premchitt, 1985) when installed in a backfilled marine borrow pit. A standard 90 tonne concrete sinker mooring buoy assembly was used and placed at a location as shown in Figure 14 (Plate 8). Settlement of the concrete sinker was monitored immediately following placement and then at two to four week intervals. The details of sinker installation and settlement monitoring are provided in MCAL's report (1990e, 1990f).

Results of settlement monitoring of the sinker block are found to be very erratic probably due to errors in the measurement of sinker level (MCAL, 1990f). However, the results generally suggest an initial penetration of about 1 m of the sinker into the backfilled seabed immediately following placement and the subsequent settlement being insignificant.

8. PERFORMANCE OF ANCHORS AND MOORINGS IN BACKFILL

8.1 Anchor Performance

8.1.1 Assessment of Trial Results

As assessment of the anchor pulling tests results is given in a report prepared by Dr R.J. Taylor, a specialist sub-consultant to MCAL (MCAL, 1990d). The report examines the typical dragging behaviour of a standard stockless type anchor and concludes from the tests results that:

(a) The test data are consistent with the historical performance data for stockless type anchors in muddy sea floors.

(b) There should be little practical difference in anchoring in the virgin and backfilled mud. The primary difference in anchor performance would be the depth of embedment, which is inversely proportional to the shear strength gradient of the seabed soil. The difference in penetration depth in the backfilled mud and virgin mud would be of the order of only a few metres.

8.1.2 Geotechnical Model Review

The test data can also be inspected using the simplified geotechnical model described in the preliminary study report (Wong, 1989). Figure 17 shows the efficiencies of an anchor in muddy seabeds of different shear strength, evaluated on the basis of the simplified model. The limited data of anchor burial tests indicates that the depth of penetration of the test anchor in the backfill can be down to about 6 to 8 metres. From the vane shear strength profiles shown in Figure 12, the average shear strength of the backfilled mud at this depth is in the order of 5 kPa. Hence the efficiency of the 3.4 tonne test anchor, predicted from model shown in Figure 17, is in the range of 1.6 to 3.4 (mid-range 2.5) i.e. the holding resistance would be in the range of 5.4 to 11.6 tons (mid-range 8.5 tons). The tests results as shown in Table 1 indicate that the average peak holding resistance in backfilled mud is in the order of 11 to 14 tons. The higher resistance measured could be due to the contribution of the anchor chain, which provides resistance during dragging with the anchor in the seabed, and also as a result of the non-homogeneous nature of the backfilled mud.

On the other hand, from the historical performance data of stockless anchors (MCAL, 1990d), the depth of penetration of the test anchor in virgin muddy seabed could be in the order of 2 to 3 metres. The shear strength of virgin mud at this depth in Urmston Road is about 7 kPa (see Figure 12). Hence, the efficiency of the anchor in virgin mud, from Figure 17, is in the range of 2.2 to 4.3 (mid-range 3.2), i.e. the holding resistance would be in the range of 7.5 to 14.6 tons (mid-range 11 tons). The measured peak holding resistance in virgin mud is in the order of 11 to 17.3 tons which again is higher than the predicted value, possibly due to the contribution of the dragging resistance of the anchor chain. The model however predicts slightly higher holding power of the anchor in virgin mud than in backfilled mud but generally the average holding power would be of the same order in both seabed materials as confirmed by the test data.

Because of the limited amount of data of anchor burial tests and the expected erratic shear strength profile of the backfilled mud, extrapolation of the test data for heavier anchors is not easy. There is however a general trend of increase in the shear strength of the backfilled mud with depth, resembling that of a normally consolidated clay. The shear strength gradient in the backfilled mud, from the field vane tests results, is about 0.9 kPa/m (Figure 13). It is found from historical performance data of stockless anchors (MCAL, 1990d) that the depth of penetration is inversely proportional to the shear strength gradient and that the depth of penetration of a stockless type anchor in virgin mud is about 2 fluke lengths. For a 5 tonne anchor therefore, penetration in virgin mud would be about 3 metres and in backfilled mud about 6 metres. The embedment depth of a 15 tonne anchor could be in the order of 5 metres for virgin ground and 11 metres for backfill respectively. This means that if the backfilled mud is of sufficient thickness, the heavier anchor could penetrate to a depth about 6 metres more in backfilled mud than in virgin mud in order to attain the required holding resistance. However, if the thickness of the backfilled mud is less than about 11 metres, the 15 tonne anchor might sink through the soft mud, hit the sand bottom of the pit and acquire the resistance from the sand bottom eventually.

8.2 Effect on Sinker Moorings

The sinker mooring settlement results were rather inconclusive as regards predicting long term settlement. What is concluded however (MCAL, 1990) is that the backfill, (in this case in Pit No. 2), has sufficient bearing capacity to support the sinker block on the surface with a minimal initial penetration of about 1 metre. Furthermore, after 3 months of monitoring, the settlement recorded has been minimal and appears less than the accuracy of the pressure meter/tidal gauge system used. As discussed in Section 7, the available settlement data suggest that the final consolidation settlement of the sinker block would be insignificant and that retrieval of the sinker block should not pose any practical problems.

Nevertheless, since the data obtained from the trial installation are still very limited, it is recommended that any sinker installed in backfilled mud be inspected by divers initially at six-monthly intervals. The optimum frequency for sinker maintenance could then be determined once the results of such diving inspections are known (MCAL, 1990f).

9. FEASIBILITY OF BACKFILLING MARINE BORROW PITS

9.1 Backfilling at Urmston Road & Tsing Yi

The major technical problems associated with the bottom-dumped backfilling operation are described in the preliminary study report (Wong, 1989) and are outlined below :

(a) Strong tidal currents in the borrow area could disperse and carry away the backfilled mud from the release point such that normal bottom-dumping placement method becomes ineffective.

(b) Backfilled mud could be eroded in the long term by strong tidal currents prevailing in the borrow area.

(c) Backfilled mud may not provide adequate holding resistance to ship anchors.

As mentioned in Section 3, the first two problems above have been addressed in the preliminary study on the basis of preliminary WAHMO studies on the Tsing Yi Marine Borrow Area and observations and theoretical studies reported in the literature. It was concluded that normal bottom-dumping method using barges or hopper dredgers is effective to backfill the borrow pits at Tsing Yi, and that the minimum surface density of the placed mud, based on the preliminary sensitivity studies using the WAHMO models, has to be greater than about 1.3 Mg/m^3 for long-term stability against tidal erosion.

Evidence of successful backfilling operations by bottom dumping has been found at Urmston Road where the current regime is similar to the Tsing Yi Marine Borrow Area. Apart from the hydraulic conditions of the site, the properties of the backfilled mud are much dependent on the methods of dredging and backfilling employed. At Urmston Road, the backfilled mud is mainly dredged hydraulically with a trailing suction hopper suction dredger which is also used to transport and bottom-dump the dredged mud into the borrow pits. Hydraulically dredged mud represents probably the worst scenario of dredged mud properties as it is generally known that mechanically dredged mud would have better mechanical and hydraulic properties (Wong, 1989). The capacity of the hopper used to dump the dredged mud is 4 000 cubic metres. From observations reported in the literature (Bokuniewicz & Gordon, 1980), it is known that the effectiveness of the bottom-dumping placement method would not be affected qualitatively by dumping lesser quantities of mud provided that normal commercial dumping plant and facilities are used. However, with lesser quantities of the dumped mud, it is likely that a higher proportion of water would be entrained in the descending mud, resulting in a higher slurry proportion in the deposited mud. The actual amount of slurry or the resulting properties of the deposited mud can only be determined by carrying out backfilling trials and site investigation.

The results of the site investigation in the backfilled borrow pits at Urmston Road, as described in Section 5.3, indicate that the backfilled mud in the partially filled pits consists of a top layer of slurry of thickness 1 to 2 metres. This slurry layer is missing in the fully filled pit probably due to erosion by tidal currents. The density of the surface mud in the fully filled pit is 1.6 to 1.7 Mg/m^3 which is higher than the threshold density of 1.3 Mg/m^3 determined from the WAHMO studies. The deposited mud in the fully filled pit is apparently stable against tidal erosion. As the hydraulic conditions at Tsing Yi and Urmston Road are similar, it is expected that the backfilling operation at Tsing Yi using similar backfilling and dredging methods would be feasible.

With regard to the holding resistance of ship anchors in backfilled mud, it has been proven at Urmston Road, from a series of field trials, that the holding capacity in backfilled mud is of the same order of that in virgin muddy seabed (MCAL, 1990b & f). The shear strength of the backfilled mud at Urmston Road is found to be lower than that of virgin mud (Figure 12) but the anchor would penetrate deeper into the backfilled mud until the resistance is attained (MCAL, 1990d). The results of the field trials have demonstrated that under most normal practical situations, the backfilled mud at Urmston Road is an adequate anchoring material. Hence if the backfilled mud is of similar characteristics to that at Urmston Road, backfilling should be a technically viable proposition for restoring the anchorage capacity of the dredged area, provided that similar dredging and backfilling methods are employed.

9.2 Design Considerations

The borrow area backfilling operation is a complex large-scale engineering project requiring thorough planning, investigation and design. The properties of the backfilled mud would depend on many different factors. The following are some of the major factors that should be considered at the planning and design stage of the backfilling operation :

(a) Properties of Source Mud

The insitu mud at Urmston Road consists of a variable content of sand ranging from 5 to 40% as shown in Figure 6. The grading envelope of the insitu mud shown in Figure 6 brackets approximately the gradings of some of the typical marine muds at Kellet Bank and Chek Lap Kok. It is therefore likely the mud (backfill) tested at Urmston Road is representative of most typical marine muds in Hong Kong. However if the fines content of the source mud is substantially higher than that of Urmston Road mud, then further assessment may be needed.

(b) Hydraulic Conditions of Site

The test site at Urmston Road is situated in a tidal stream with strong currents, the peak tidal current being in the order of 0.7 m/s, representing probably the most unfavourable scenario for a successful backfilling operation. At Urmston Road, the water depth to original seabed is around 18 metres and the lowest bottom level of the borrow pit is about -45 mPD. Increasing water depth would not have any significant effect on the effectiveness of normal bottom-dumped backfilling operations but would probably result in a different slurry content in the deposited mud. The current regime of the site would dictate the required minimum surface density of the backfilled mud to maintain long term stability against tidal erosion. It is likely, as found from this study, that most of the slurry in the backfilled mud would be carried away by currents once brought level with the seabed.

(c) Site Configuration

It is essential that the backfilled mud be contained within the borrow area to be backfilled. To this end, the finished borrow area should have a confinement provided by the pit walls of a few metres height (Bokuniewicz, 1983, 1985). If the sand bottom of the borrow area is in the form of a slope instead of a pit, there could be a danger of continuous spreading of the backfilled mud down the slope and escaping from the area to be backfilled.

(d) Backfilled Seabed Level

The site investigation and anchor trial results of this study indicate that there is no significant difference in material properties and anchor performance in a completely or partially backfilled seabed. Geotechnically the only difference would probably be the presence of a one to two metres thick slurry layer on top of the partially backfilled seabed. This would perhaps increase the depth of penetration of the anchor in order to achieve the required resistance. It is therefore advisable that the seabed level be restored to the original level in order to minimize the problems that could arise due to the presence of excessive amount of slurry. The required backfilled level would also be dictated by the envisaged anchorage requirements in the area determined by the port planner (MCAL, 1990f). For maritime operations reasons, the pits should also be backfilled to original seabed level so as to ensure any slurry if present is dispersed unless site specific circumstances dictate otherwise.

(e) Dredging and Dumping Methods

The tested mud at Urmston Road is dredged hydraulically and backfilled with a trailing suction hop-per dredger with a hopper capacity of 4 000 m^3. As the properties of the backfilled mud will depend heavily on the dredging and backfilling operations employed, the effect of using different hydraulic dredging systems or smaller capacity dredgers or barges may have to be investigated by backfilling and field anchor trials.

(f) Required Backfill Properties

The grading composition and field vane shear strength profile of the backfilled mud at Urmston Road as shown in Figures 11 and 12 respectively can be used as reference data for acceptable anchoring backfilled material. The minimum shear strength of the backfill should be in the order of 3-5 kPa, increasing at a gradient of about 1 kPa/m. The surface density of the backfill should be higher than 1.3 Mg/m^3.

10. EFFECTS OF PERMANENT SEABED DEEPENING

In this section, the effects of permanent seabed deepening in marine borrow areas on ship anchorage are reviewed in the light of the results of anchor field trials at the marine borrow areas of Tsing Yi.

In the case of deepened fairways such as that in CT7 Marine Borrow Area, there should not be any effect on anchorages in the long term as ships are not allowed to anchor in fairways under normal conditions. During the short-term typhoon periods when ships are allowed to anchor in some normally prohibited anchorage areas, the sand bottom of the area should provide the same holding resistance as the original seabed before dredging. In fact, from the anchor pulling tests in the CT6 and CT7 borrow areas, it was found (MCAL, 1990b & f) that very high holding resistance can be obtained from the sand bottom of the borrow areas. Therefore the overall effect of deepening fairways on anchorages would probably be insignificant.

In areas of existing anchorages, deepening the seabed could render the installation of sinker mooring buoys impracticable due to the increased swing of the buoy and the additional weight of the sinker mooring chain. The deepened anchorage area may also preclude anchoring of small ships because they are not provided with anchor chain of sufficient length. But there should not be any practical problems for large container or cargo ships which are equipped with long anchor chain of length 500 to 700 metres (MCAL, 1990c). The predominant effect would probably be a reduction of the anchorage area capacity as a result of the increased swing circle described by an anchored ship. An estimate has been given in the preliminary study report (Wong, 1989) on the reduction of the number of the ships that could be anchored in a deepened area. The reduction of the number of anchored ships when the seabed level is deepened from -25 mPD to -35 mPD and -45 mPD would be up to 30% and 45% respectively.

In the scenario of ships dragging across the deepened areas during a typhoon, results of the pulling tests at CT6 and CT7 Borrow areas indicate that rather high resistance (15 to 27 tonnes with a 3.4 tonne stockless anchor) would be available from dragging along the sand bottom or down the sideslopes of the areas, but sudden high snatch loads (of the order of 52 tonnes) may be expected. It is noted from MCA's estimate of environmental loads during a typhoon (MCA, 1990c) that most anchors would be of inadequate efficiency to withstand the typhoon loading. It is accepted that ships do not rely only on single anchors for safe mooring during typhoons and most ships would have to use their engines to reduce the likelihood of dragging, however these actions must be regarded as safety factors used only when conditions are extreme.

In an emergency situation when ships have to use their anchors to stop in the deepened area, it is likely that high snatch loads may be encountered due to the kinetic energy associated with the drifting ship and anchor dragging across an undulating sand bottom of the area. However, this undesirable circumstance could also occur in normal seabed conditions and would not be restricted only to deepened areas.

11. ADVICE TO MARINERS

Port users should be advised of any changes made to the natural seabed, to avoid allegations that the port is 'unsafe' to mariners by virtue of inadequate information. The following information could therefore be made available to port users on Admiralty (and other Port) charts with respect to an area fully backfilled with materials of similar characteristics to the original seabed material (MCAL, 1990f) :

(a) Limits of dredging and backfilling;

(b) Backfill levels (including the date of the last survey);

(c) Depth of backfilling;

(d) Quality (or type) of material used for backfilling; and

(e) Quality (or type) of material at the bottom of the dredged pit.

In case the dredged area is not backfilled to its original seabed level or not backfilled at all, or the backfilled material has characteristics quite different from the original seabed material, then additional information would need to be provided.

12. CONCLUSIONS

As an initial attempt to address the technical problems associated with the concept of backfilling marine borrow pits with dredged mud for restoration of ship anchorage areas, a study on the backfilled borrow pits at Urmston Road has been carried out, consisting of seabed soil investigation, anchor pulling trials and a mooring buoy sinker trial. The main conclusions drawn from this study are :

(a) The bottom-dumped backfilling operation has been proven to be feasible at Urmston Road. In areas with hydraulic conditions comparable to those at Urmston Road, such as the Tsing Yi Marine Borrow Area, backfilling using the bottom-dumped method is feasible.

(b) Comparative anchor pulling trials in virgin and backfilled sea floors have demonstrated that the backfilled mud at Urmston road is an acceptable anchoring material. Although the shear strength of backfilled mud is found to be lower than that of virgin mud, the performance of ship anchors are found to be comparable in both types of seabed. It is likely that anchors would penetrate deeper into the backfilled seabed to achieve the required holding resistance. Estimates indicate the additional penetration to be about 3 metres for a 5 tonne anchor and up to 6 metres for a 15 tonne anchor. For very heavy anchors of 10-15 tonnes, or anchors of High Holding Power type, there is a likelihood that in a thin layer of backfill, say less than 10 to 15 metres, they may penetrate through the backfilled mud and dig into the sand bottom of the pit. However, the overall resulting effect of this on practical anchoring is not significant, because anchor weight of smaller ships would not result in this happening, whereas for large ships equipped with heavy anchors, this factor would not affect performance.

(c) The marine mud and the method of dredging and backfilling being used at Urmston Road have been proven to be suitable for backfilling of exhausted borrow pits. As the mud at Urmston Road is typical of marine mud in Hong Kong, it is likely that marine muds from other locations in Hong Kong would also be suitable provided that they have similar insitu properties to the mud at Urmston Road. Until more extensive data is available, the properties of the source mud and placed backfill at Urmston Road appear to form an acceptable standard for backfilling operations. Since the properties of the backfilled mud will also be dependent on the dredging and backfilling methods adopted, any proposal to use dredging and backfilling systems which are significantly different to those employed at Urmston Road, might require further backfilling and anchor field trials.

(d) The trial installation of mooring sinker in the backfilled pit at Urmston Road has indicated that the performance of sinker in backfilled seabed is satisfactory. The settlement of the sinker block in the backfilled mud was found to be not excessive and should not pose any significant practical installation problem.

13. RECOMMENDATIONS

This study has concluded that it is feasible to use marine mud to backfill exhausted borrow pits in order to restore the anchorage capacity of the seabed. The information provided in this report, and in Maunsell Consultants (Asia) Limited Final Report on the Anchor trials, is at present the only data available describing the nature of backfilled mud and the performance of ships anchors in both virgin and backfilled seabeds in Hong Kong. To allow exploitation of borrow areas in the harbour areas therefore, the following recommendations are made concerning the engineering of any proposed backfilling operations for anchorage restoration purposes :

(a) As a result of the conclusions of this study, the Tsing Yi Marine Borrow Area should now be made available for the extraction of fill for reclamations. The anchorage capacity of the seabed should be restored by backfilling with marine mud. It is recommended that the backfilling operations be carried out using the material types and methods described in this report and which have been shown to be acceptable in the Urmston Road borrow areas.

(b) The particle size distribution envelope and in-situ shear strength envelope of Urmston Road mud before dredging should be adopted as a specification for mud to be used as backfill until further information is available to allow amendment of these limits. The backfill shear strength properties at Urmston Road, as described in Section 9.2, should also be used as design guidelines for backfilling operations until further information is available.

(c) For proposed backfilling operations where any of the design considerations listed in Section 9.2 vary significantly from those described in this report, it is recommended that a detailed assessment of the individual circumstances should be carried out before embarking on large scale backfilling operations for anchorage restoration purposes. Additional site investigations, and if necessary and practicable, trial backfilling or anchor tests should be considered to assess the effects of the circumstances that apply.

(d) After dredging, and where backfilling is to be carried out, the level of backfilling should be to original sea-bed level unless maritime operational reasons allow a lower level to be adopted.

(e) Adequate information with respect to any backfilled area should be made available to mariners, by the most appropriate means, in accordance with the points discussed in Section 11. Comprehensive hydrographic surveys should also be carried out before, during and after all backfilling operations.

(f) Harbour mooring buoy sinkers should be inspected at six monthly intervals if placed in backfilled mud seabeds until a data-base of their long-term performance has been established. The design of the harbour mooring buoys may also need to be reviewed if they are proposed to be used in deeper water than is currently the practice.

(g) Adequate clauses be included in contract documentation to ensure that control is exercised over the dredging and placing of the mud backfill.

(h) A centralised data bank should be established, under the control of the Fill Management Committee, for all proposed backfilling operations to allow the collection and periodic review of data relating to dredging methods, mud types and backfill performance. As a result of these reviews, specifications for backfilling methods and materials should be drawn up initially and then reviewed at regular intervals.

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Table 1 - Summary of Results of Anchor Pulling Tests at Urmston Road

Test No.	Borrow Pit No.	Seabed Materials		Seabed Level at Anchor (mCD)	Load (Tonnes)	
		Virgin	Backfill		Peak (No Drag)	Mean Drag
1A	5	/		See Note 1	20.0	8.0
1B	5		/	-24	12.5	12.5
1C	10		/	-24	18.0	10.0
2A	10	/		-20	17.3	8.0
2B	10		/	-24	9.9	8.0
3	5		/	-26	10.0	9.5
4A	5		/	-23	10.0	9.0
4B	5		/	-23	12.0	9.0
5A	2		/	See Note 2	11.1	8.0
5B	2		/	-19	10.0	8.0
6A	2	/		-16	11.5	9.0
6B	2	/		-19	11.0	7.0
6C	2		/	-17	12.8	9.0
7	2		/	-17	14.0	12.0
8A	2	/		-19	12.0	11.0
8B	2	/		-19	6.7 See Note 3	4.8
9	2	/		-19	11.0	11.0
10	2		/	-16	16.3	14.0
11	2		/	-18	12.3	13.5
Total		7	12			

Notes:

1. The recorded load represents probably that in dredged sand slopes which have not been covered by dumped mud, rather than virgin seabed.
2. The anchor probably failed to 'trip' in this case.
3. The anchor was found to be choked with clay when recovered.

Table 2 - Summary of Results of Anchor Pulling Tests at Tsing Yi Area

Test No.	*Site No.	Seabed Level at Anchor (mCD)	Test Type		Load (Tonnes)	
			Dynamic	Static	No Drag	Mean Drag
12	C	-28	/	/	27.3	-
13	C	-20	/		10.7	7.5
14	C	-28	/		20.3	-
15	C	-21	/		12.3	12.3
16A	C	-20	/		11.4	10.0
16B	C	-21	/		11.0	10.0
16C	C	-23	/		25.1	-
17	A	-20		/	11.5	-
18	A	-23		/	10.0	-
19A	B	-15	/		14.5	14.0
19B	B	-15	/		12.6	8.0
20A	B	-15	/		12.0	11.0
20B	B	-15	/		13.0	10.5
21A	D	-40	/		11.0	-
21B	D	-40	/		8.4	8.0
22A	D	-40	/	/	8 to 24	-
22B	D	-40	/		15.8	8.0

* 1. Site A is at the southwestern corner of the Kellet Bank Anchorage Area.
2. Site B is in the Naval Anchorage just to the east of Kau Yi Chau Island.
3. Site C is the Ma Wan CT6 Borrow Area.
4. Site D is the CT7 Borrow Area.

Table 3 - Summary of Results of Anchor Burial Tests at Urmston Road

Test No.	Location	Initial depth[1] of penetration below seabed	Final depth[2] of penetration
1	Partially backfilled borrow pit No. 5	6.3 m	7.8 m
2	Completely backfilled borrow pit No. 2	2.0 m	Unknown[3]
3	Virgin seabed	3.0 m	3.0 m

Notes:

1. The initial burial depth was measured after the anchor was dropped and prior to application of load.
2. The final burial depth was measured after a load of 9.6 tons was applied to the anchor with no drag.
3. Drag of the anchor occurred after application of 9.6 tons to the anchor and the measuring wire was lost after dragging into the seabed with the anchor. Measurement of the final burial depth was therefore impossible.

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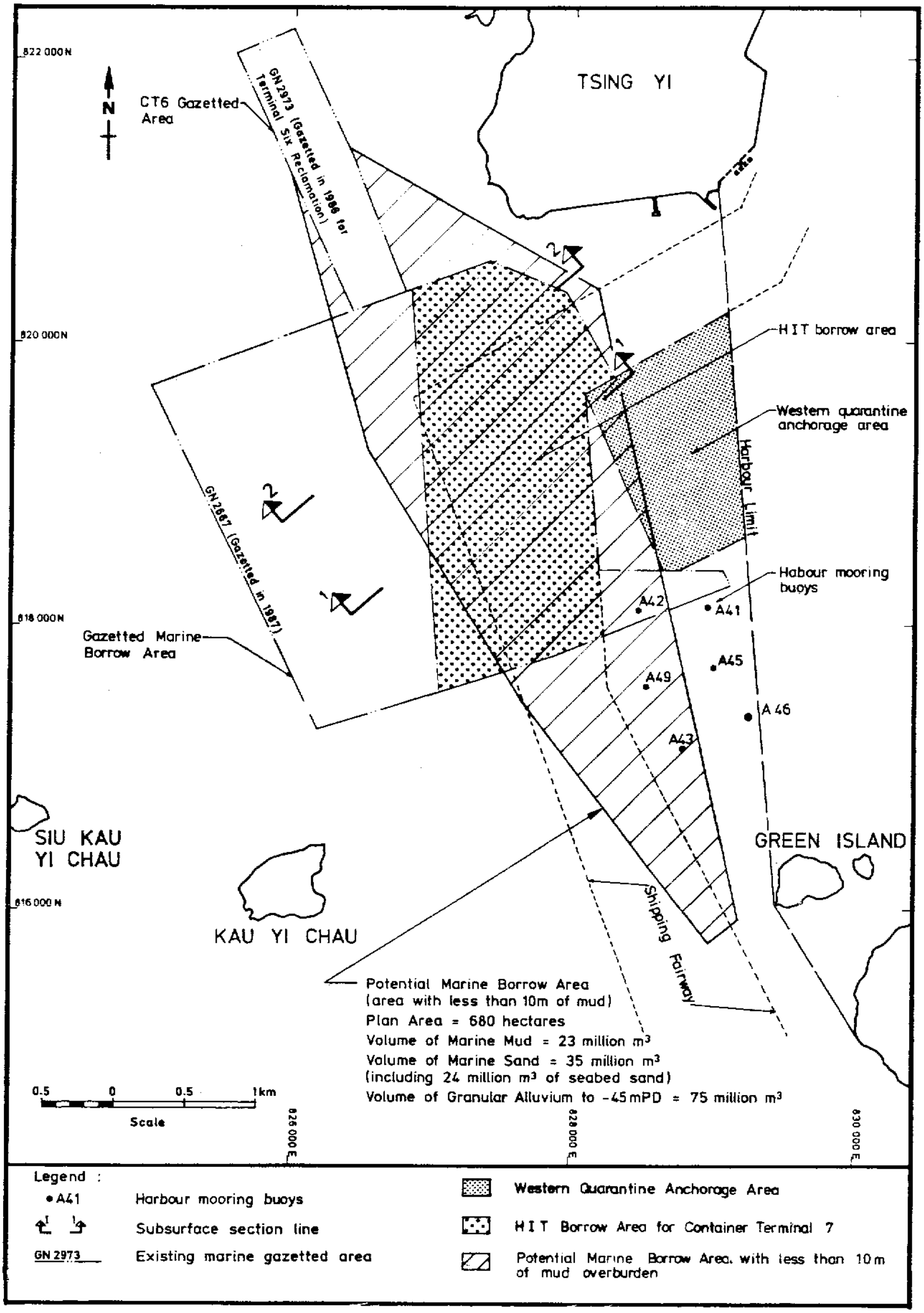


Figure 1 - Location of Tsing Yi Marine Borrow Area

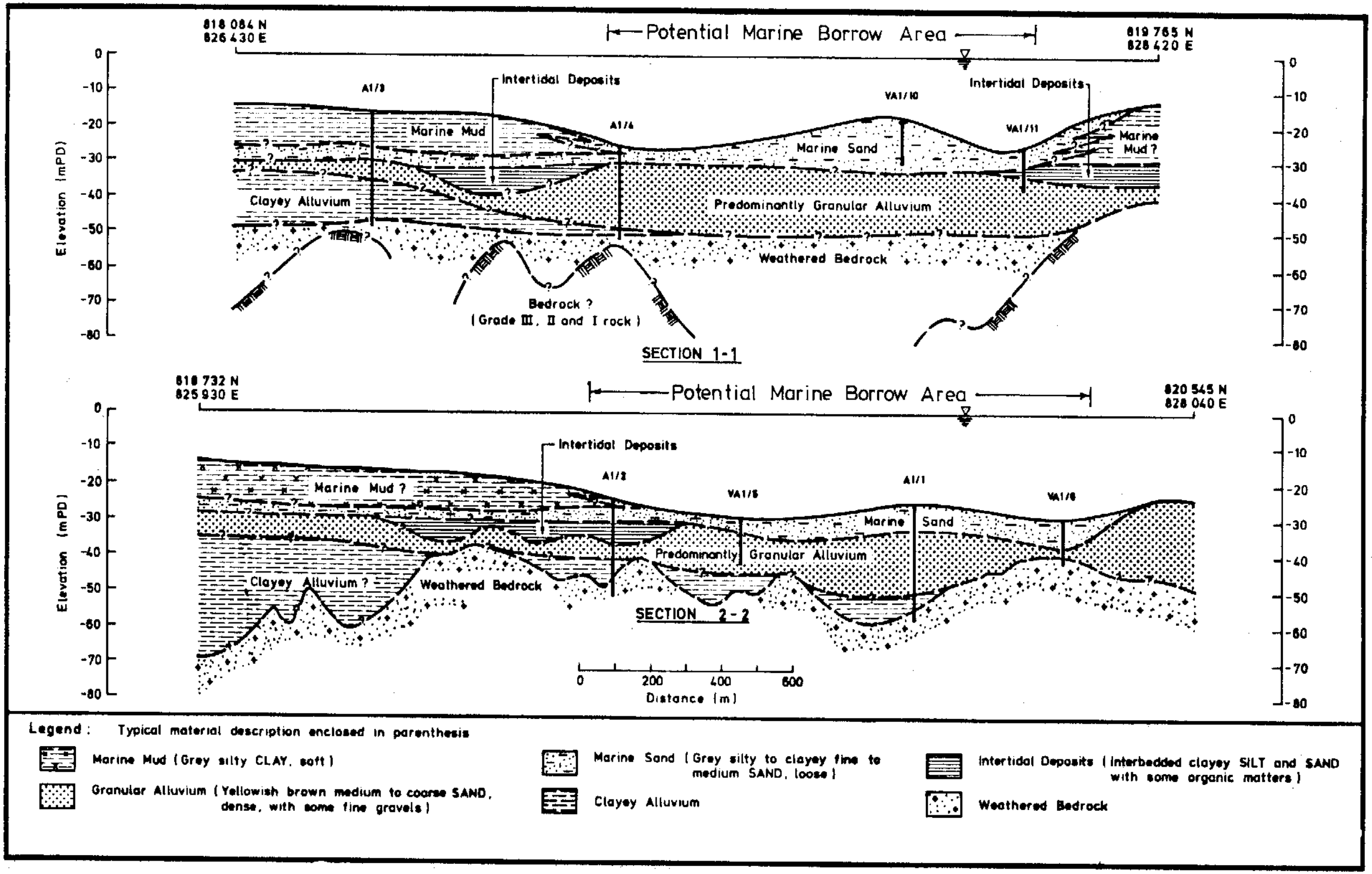


Figure 2 - Geological Profile of Tsing Yi Marine Borrow Area

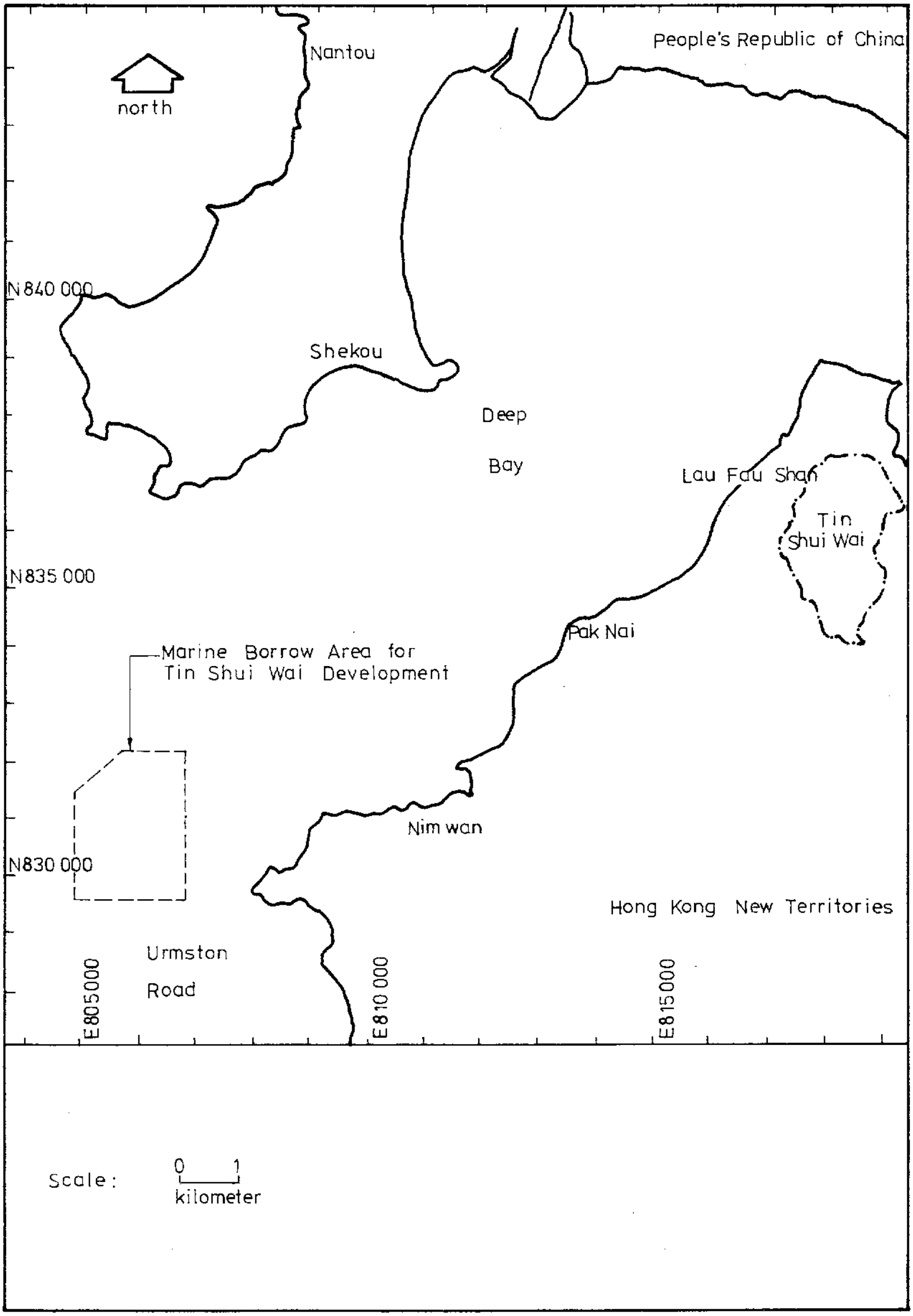


Figure 3 - Location of Urmston Road Marine Borrow Area

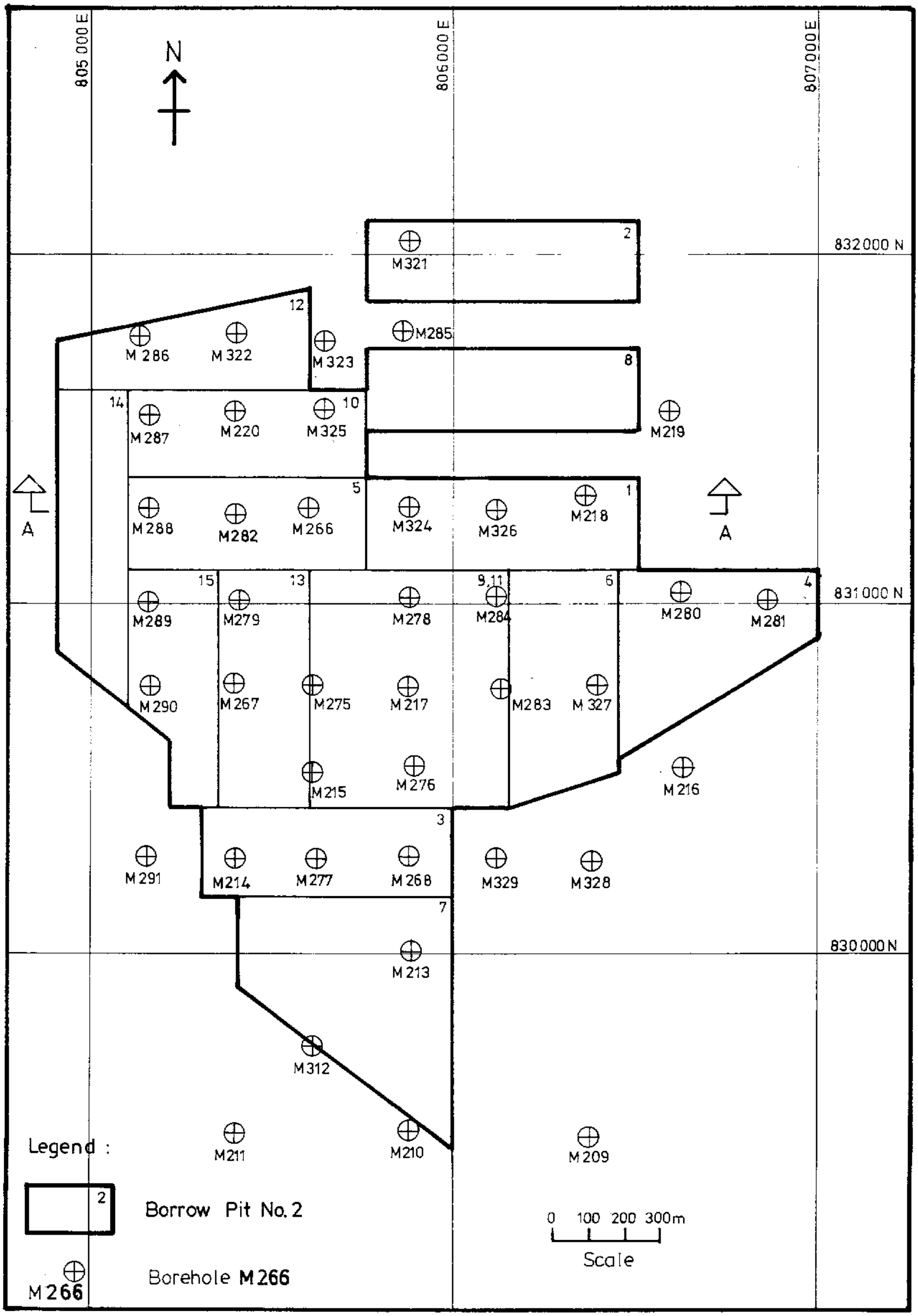


Figure 4 - Locations of Boreholes Sunk at Urmston Road before Dredging

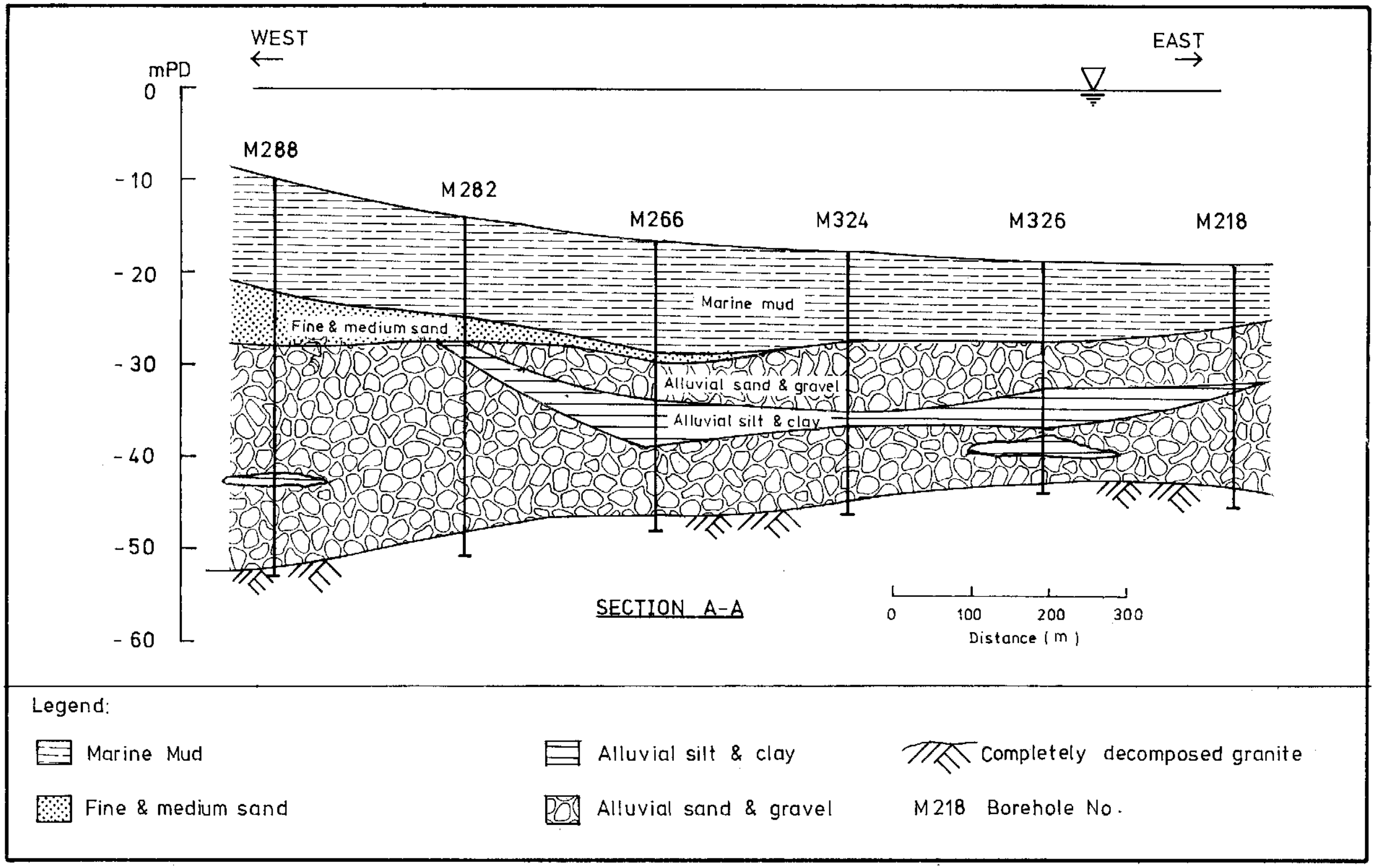


Figure 5 - Geological Section A-A of Urmston Road

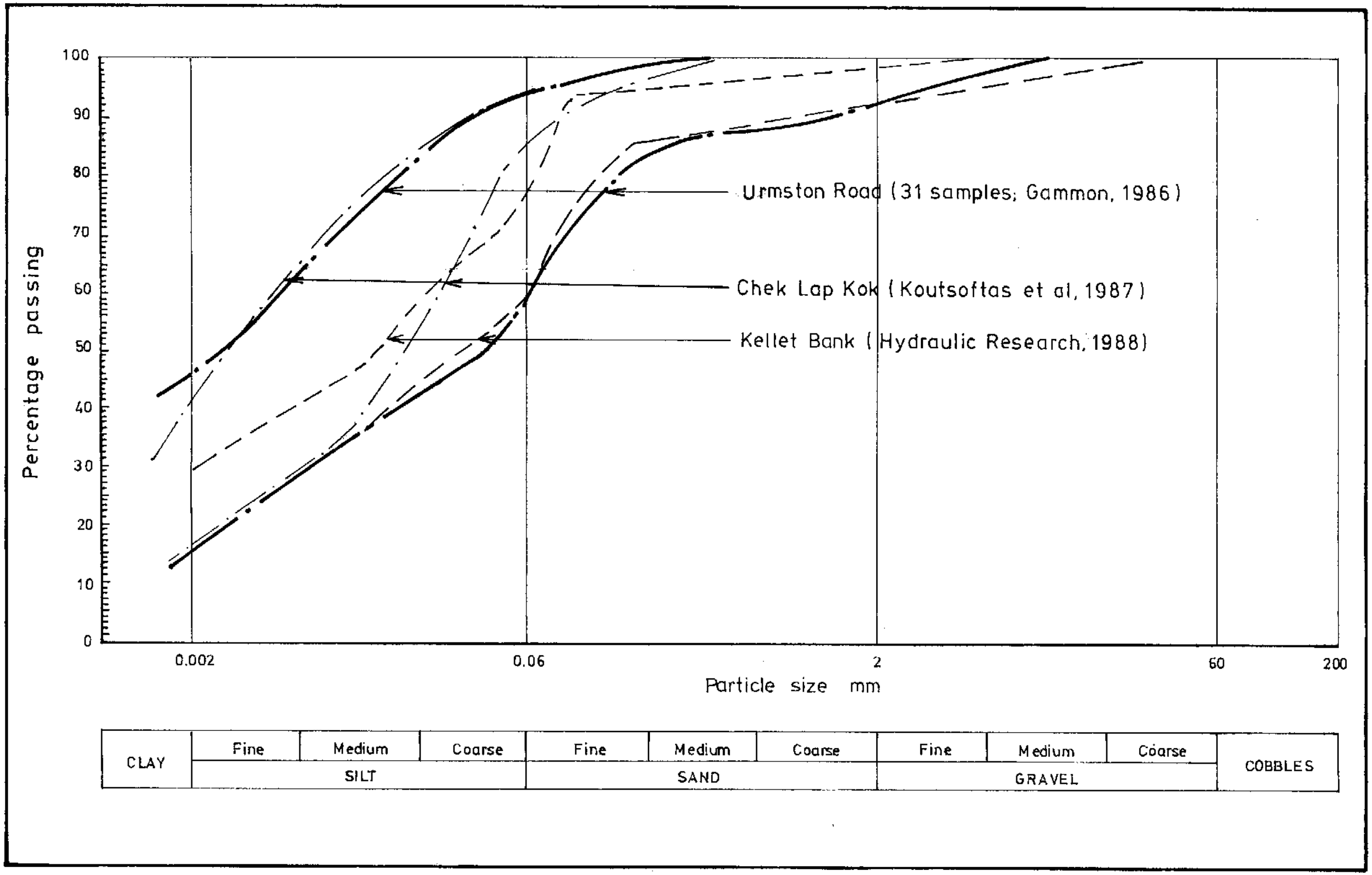


Figure 6 - Grading of Insitu Marine Mud at Urmston Road

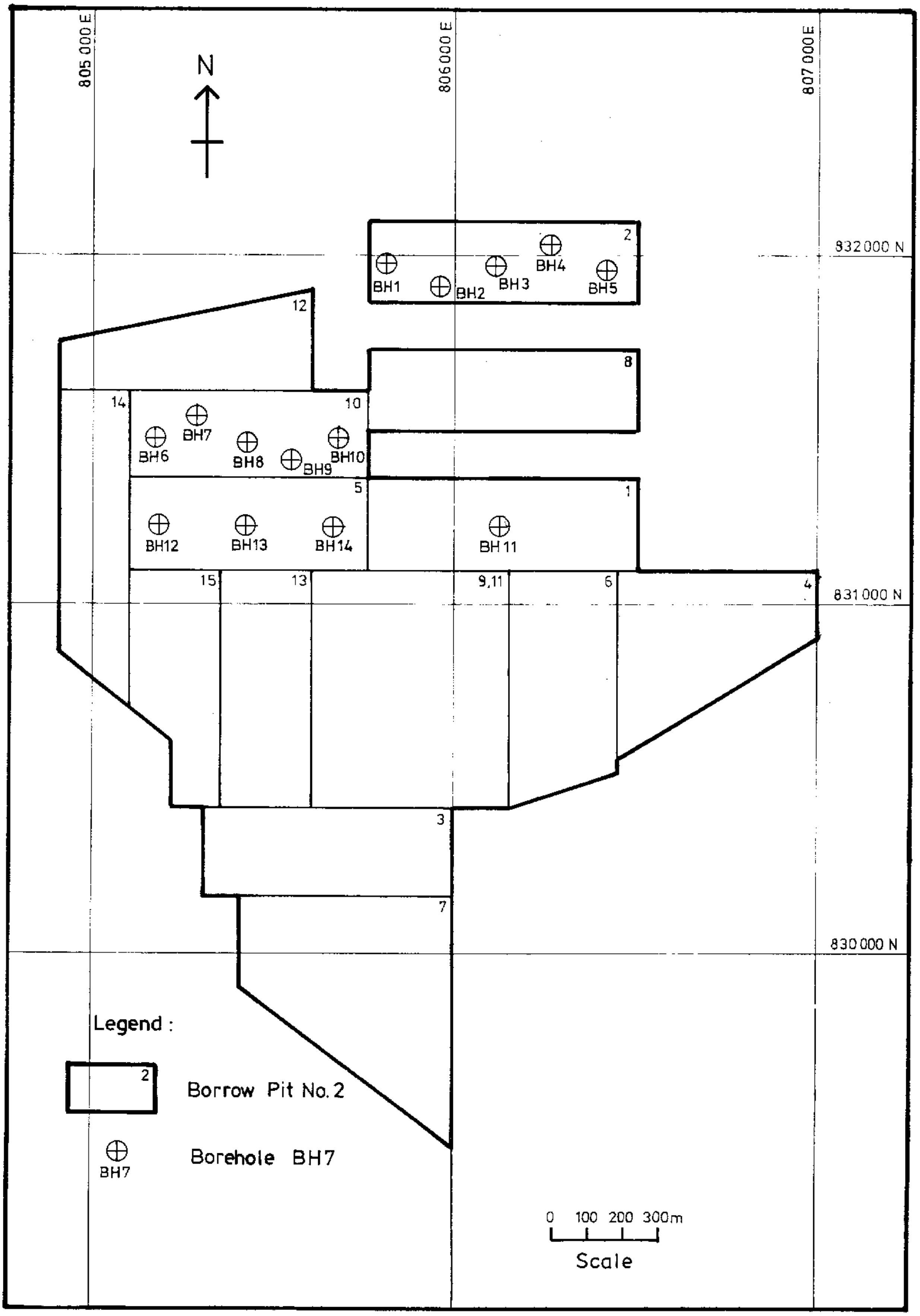


Figure 7 - Locations of Boreholes Sunk in the Backfilled Pits at Urmston Road

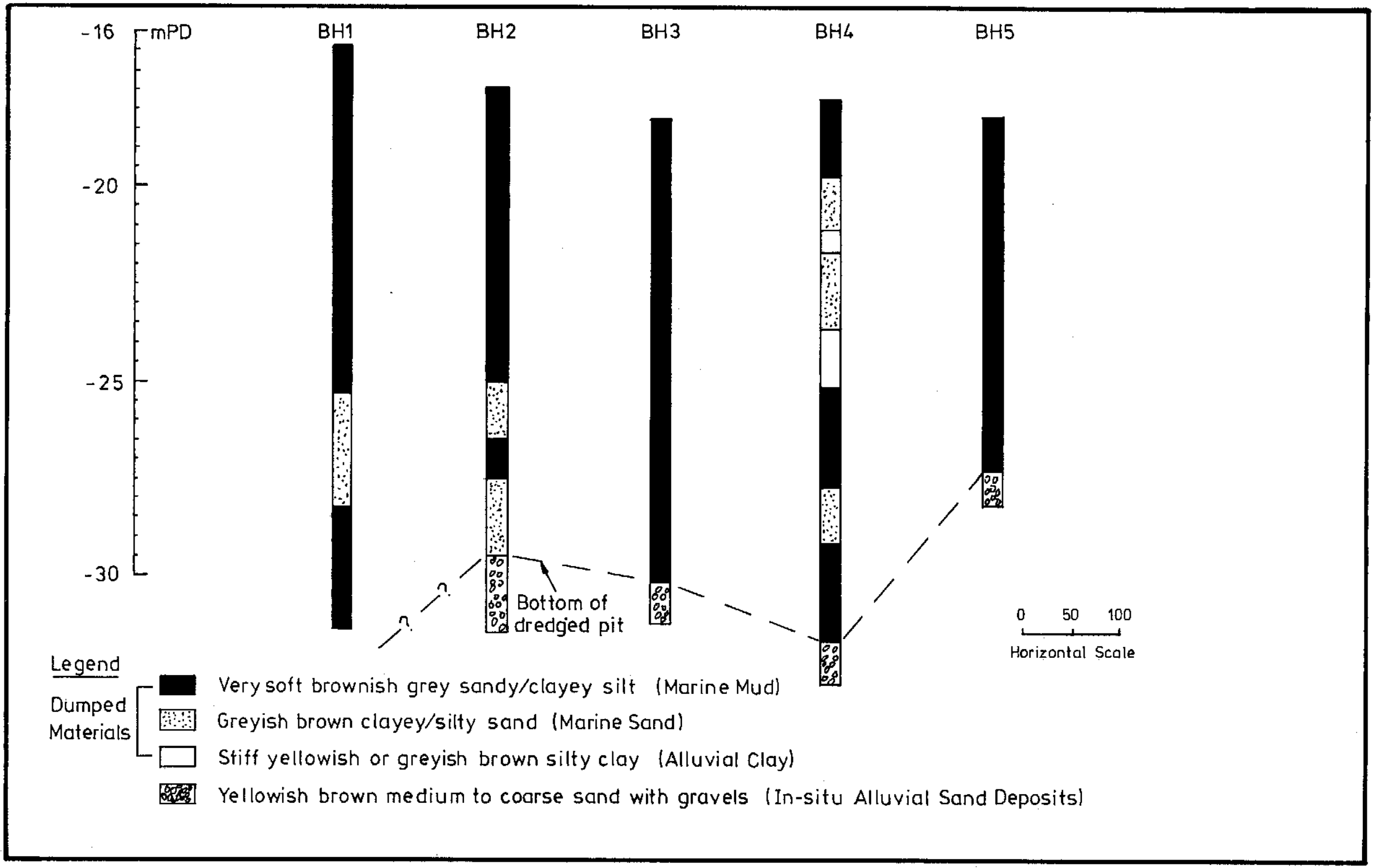


Figure 8 - Schematic Logs of Boreholes in Borrow Pit No. 2

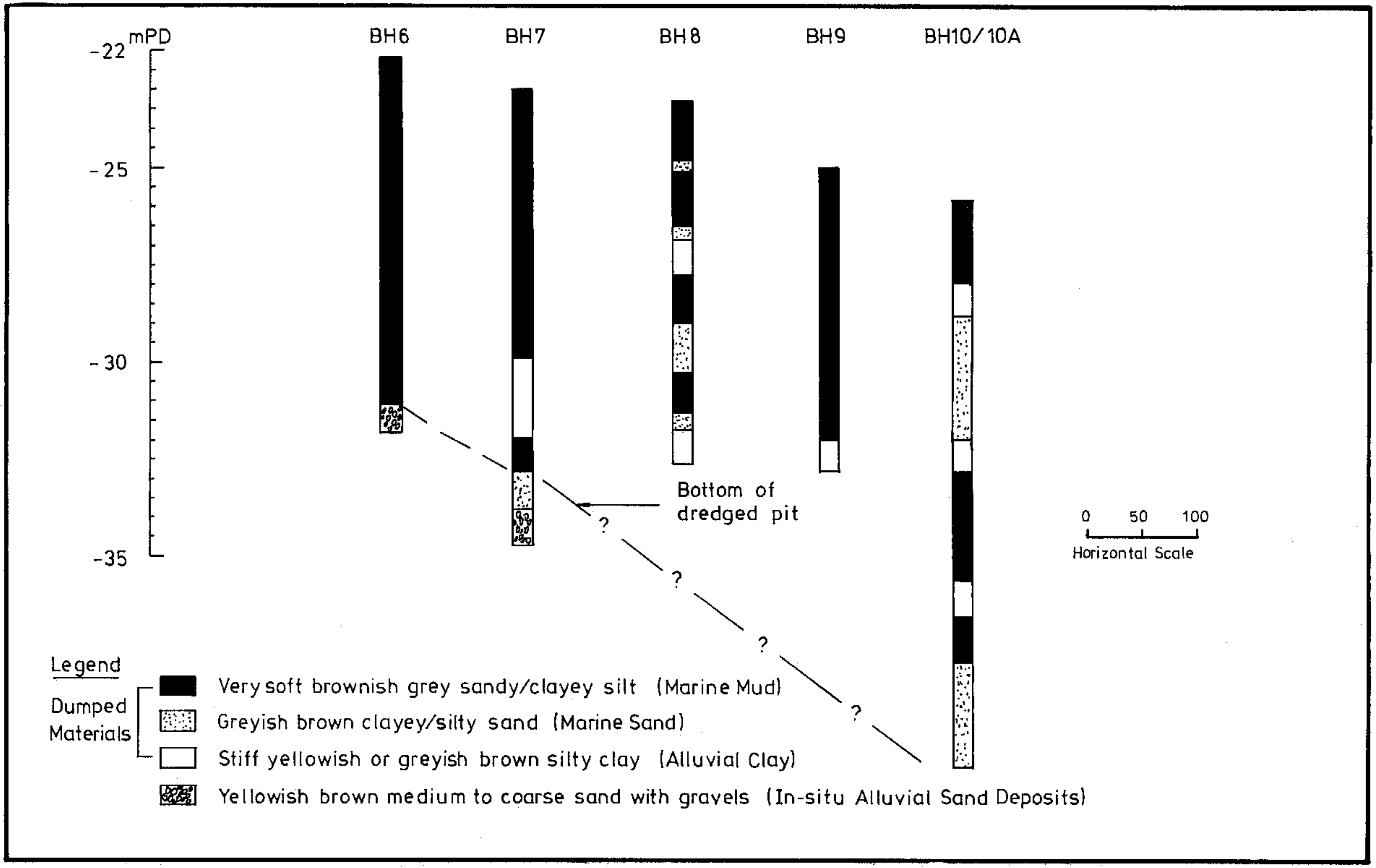


Figure 9 - Schematic Logs of Boreholes in Borrow Pit No. 10

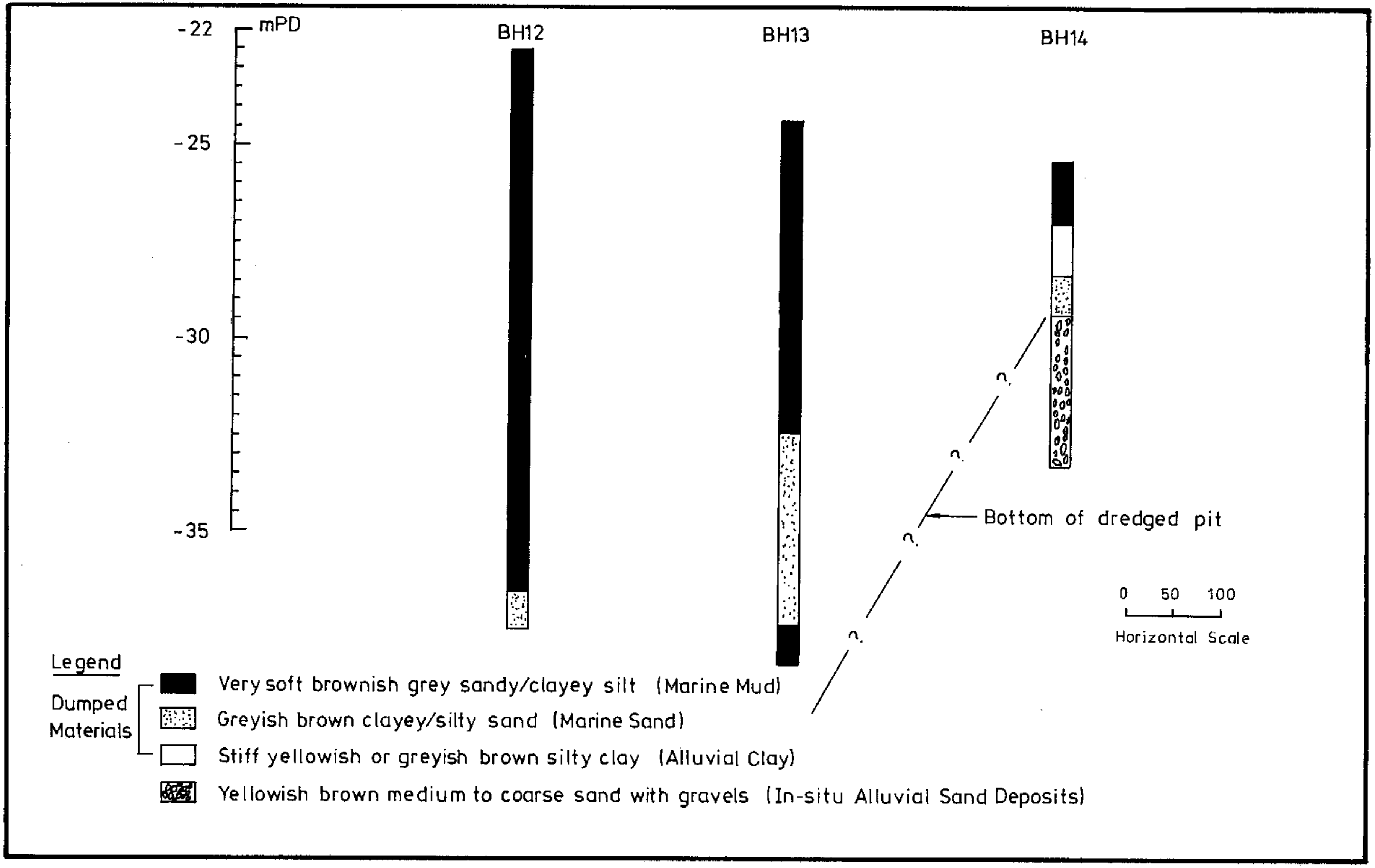
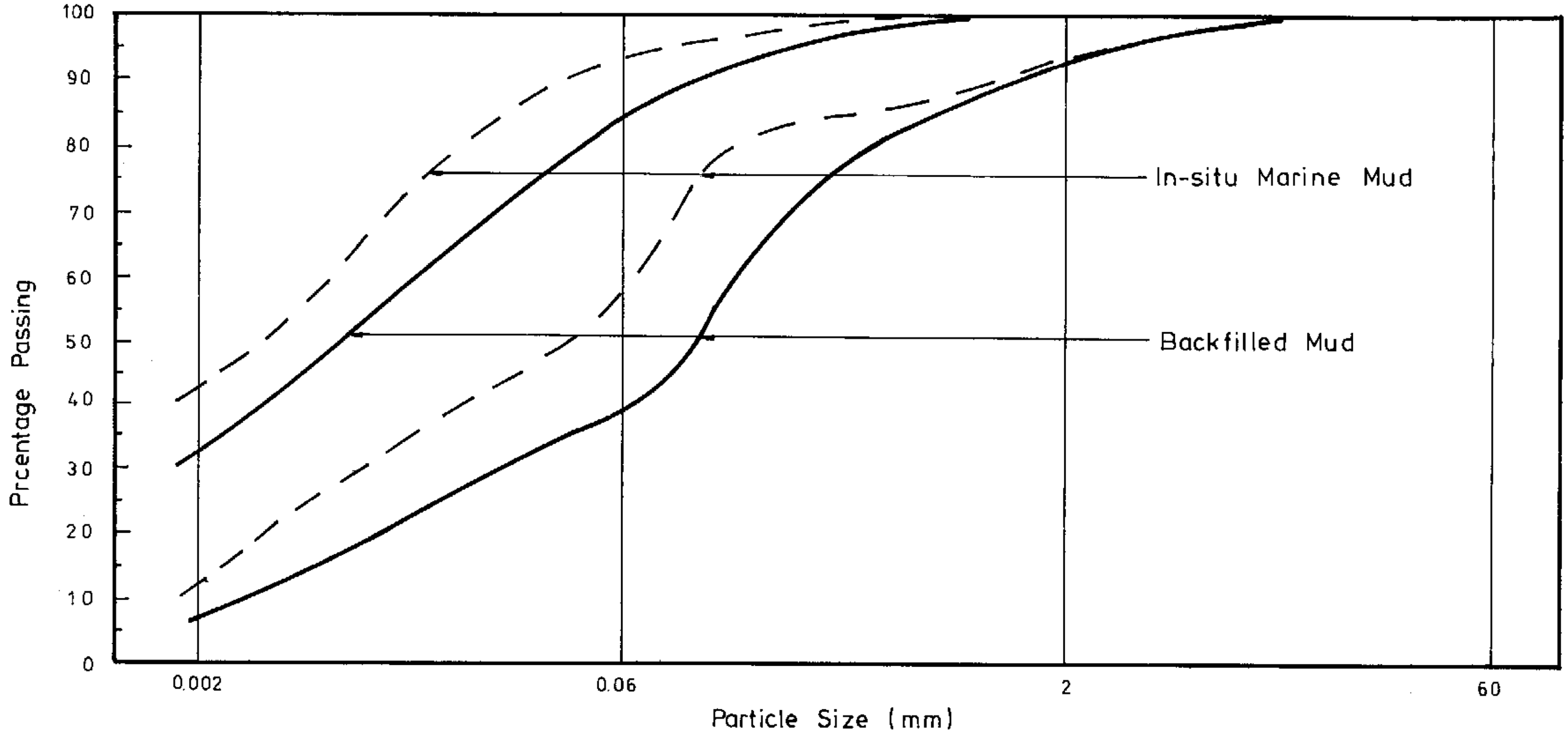


Figure 10 - Schematic Logs of Boreholes in Borrow Pit No. 5



CLAY	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse
	SILT			SAND			GRAVEL		

Figure 11 - Particle Size Distribution of Backfilled Mud

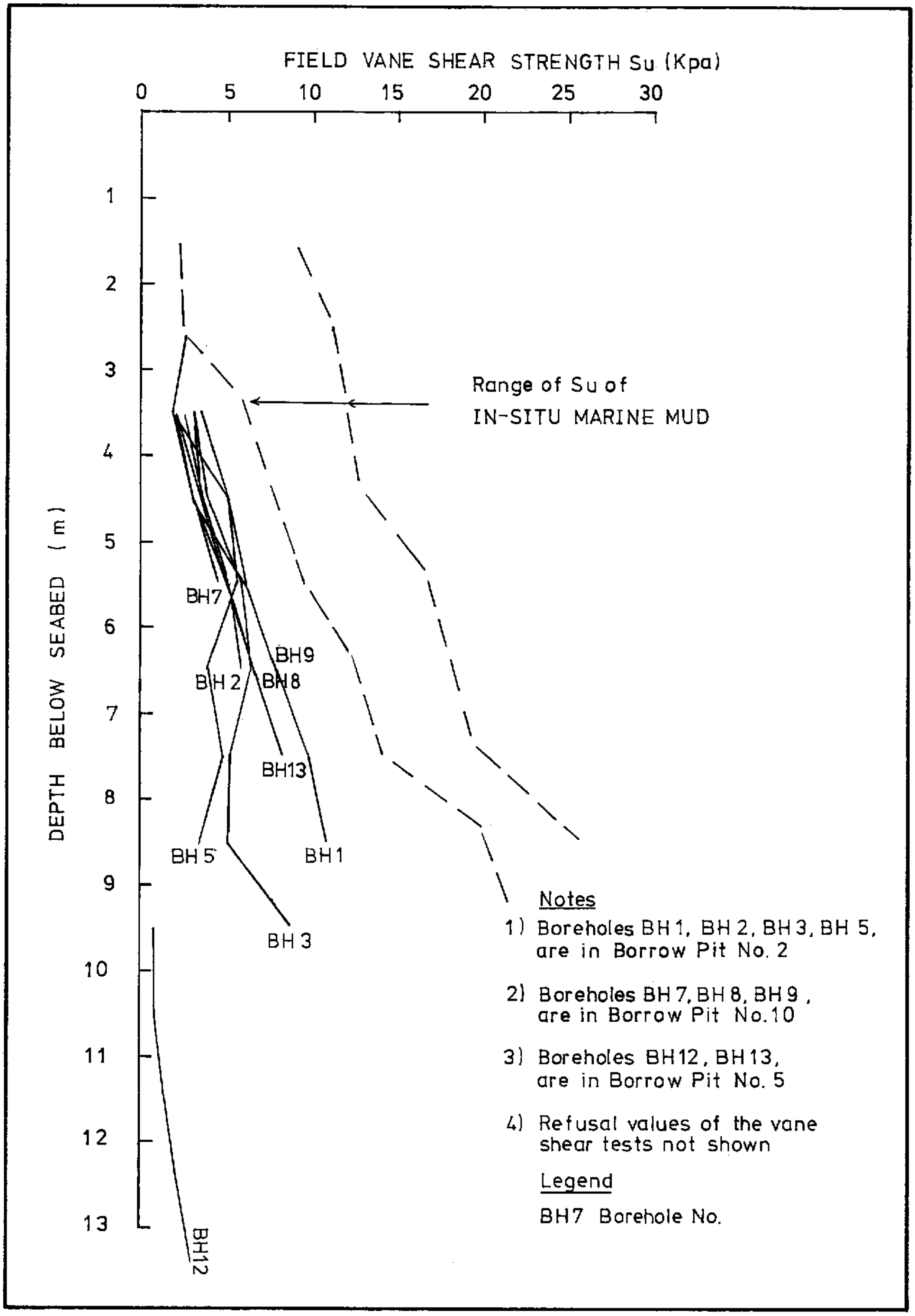


Figure 12 - Field Vane Shear Strength Profile of Backfilled Mud

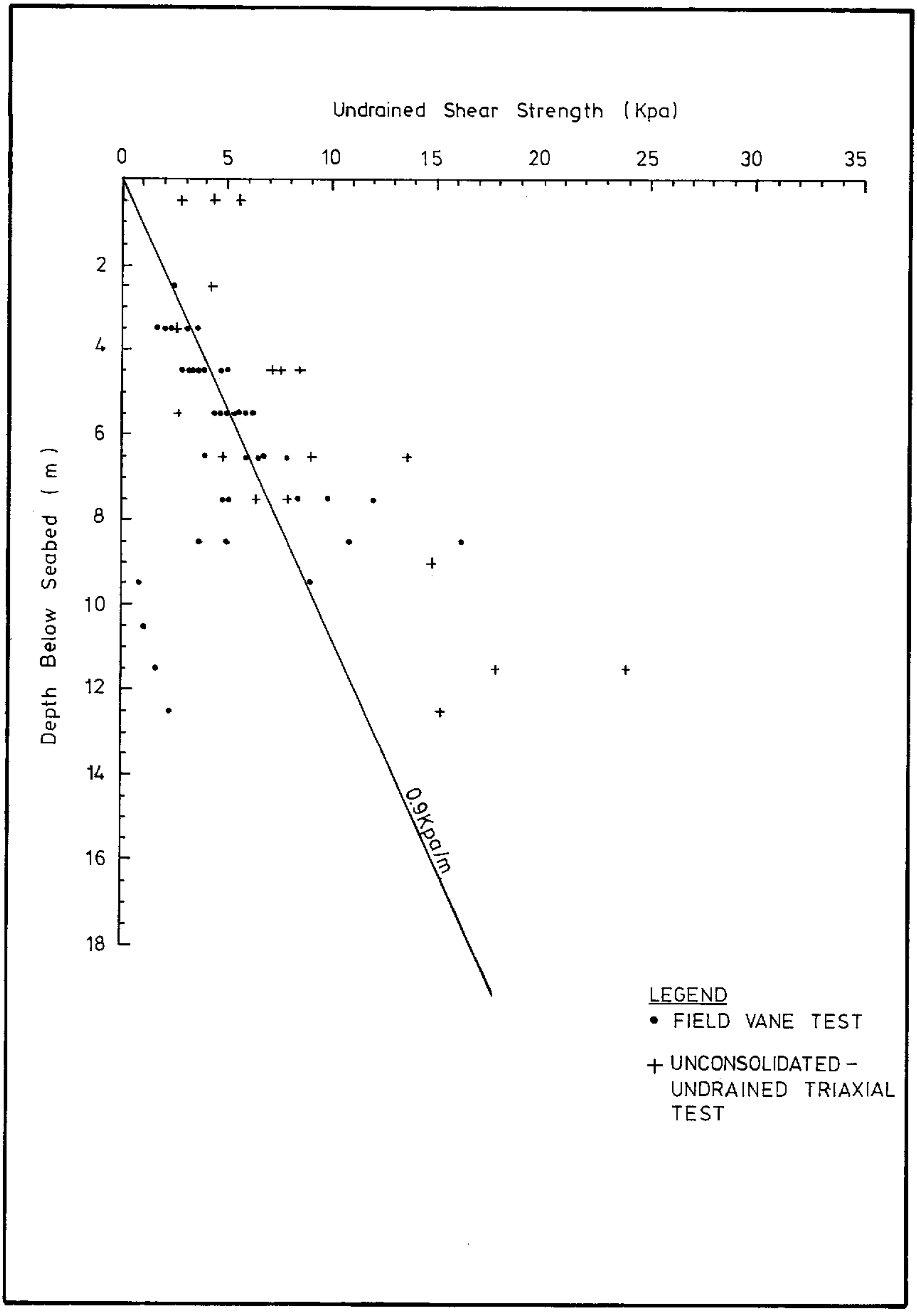


Figure 13 - Undrained Shear Strength of Backfilled Mud

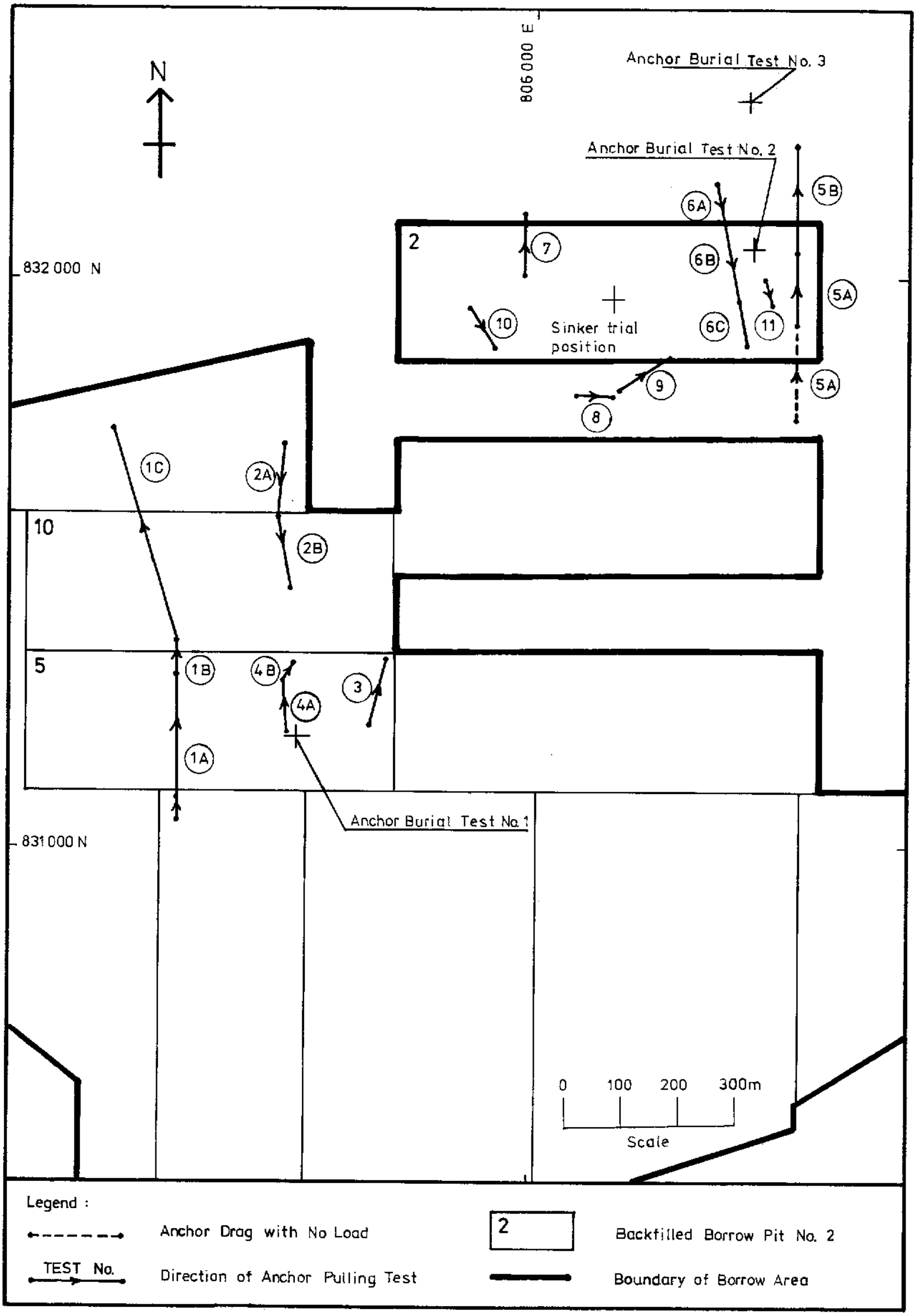
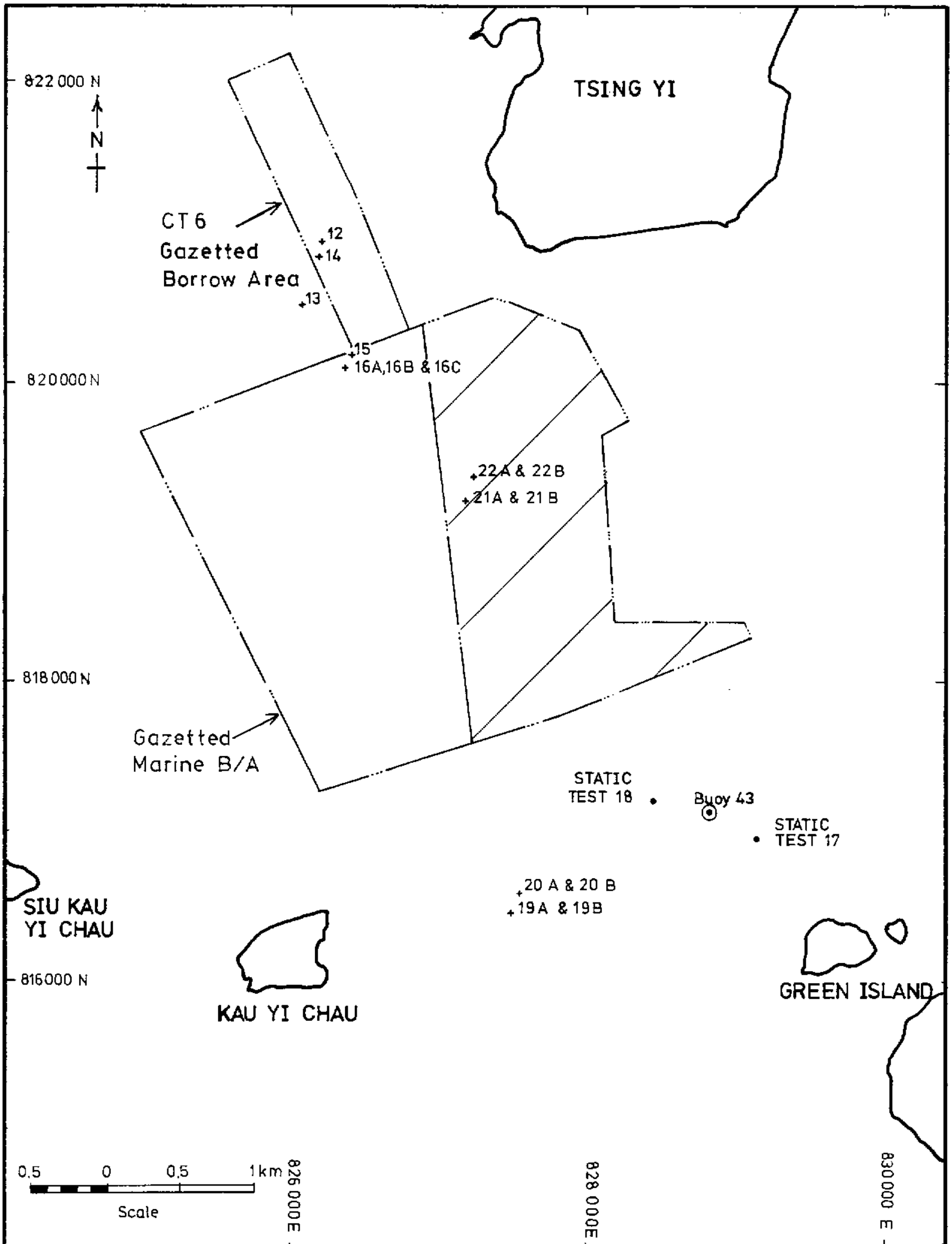


Figure 14 - Locations of Anchor and Sinker Mooring Trials at Urmston Road



Legend:

15+ Dynamic pulling test No.

18. Static pulling test No.

CT 7 Borrow Area

Figure 15 - Locations of Anchor Trials at Tsing Yi Area

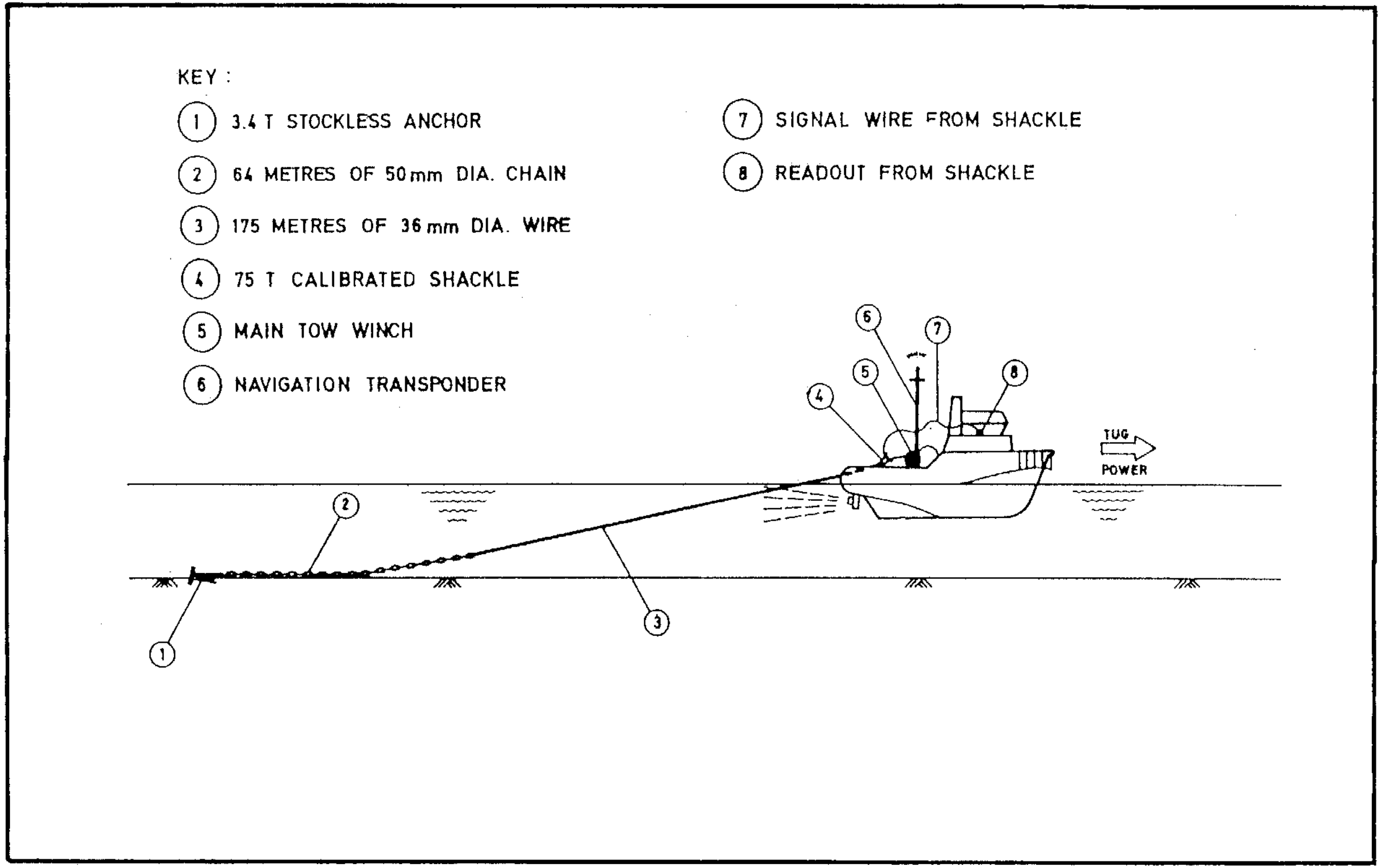


Figure 16 - General Arrangement of Dynamic Anchor Pulling Test

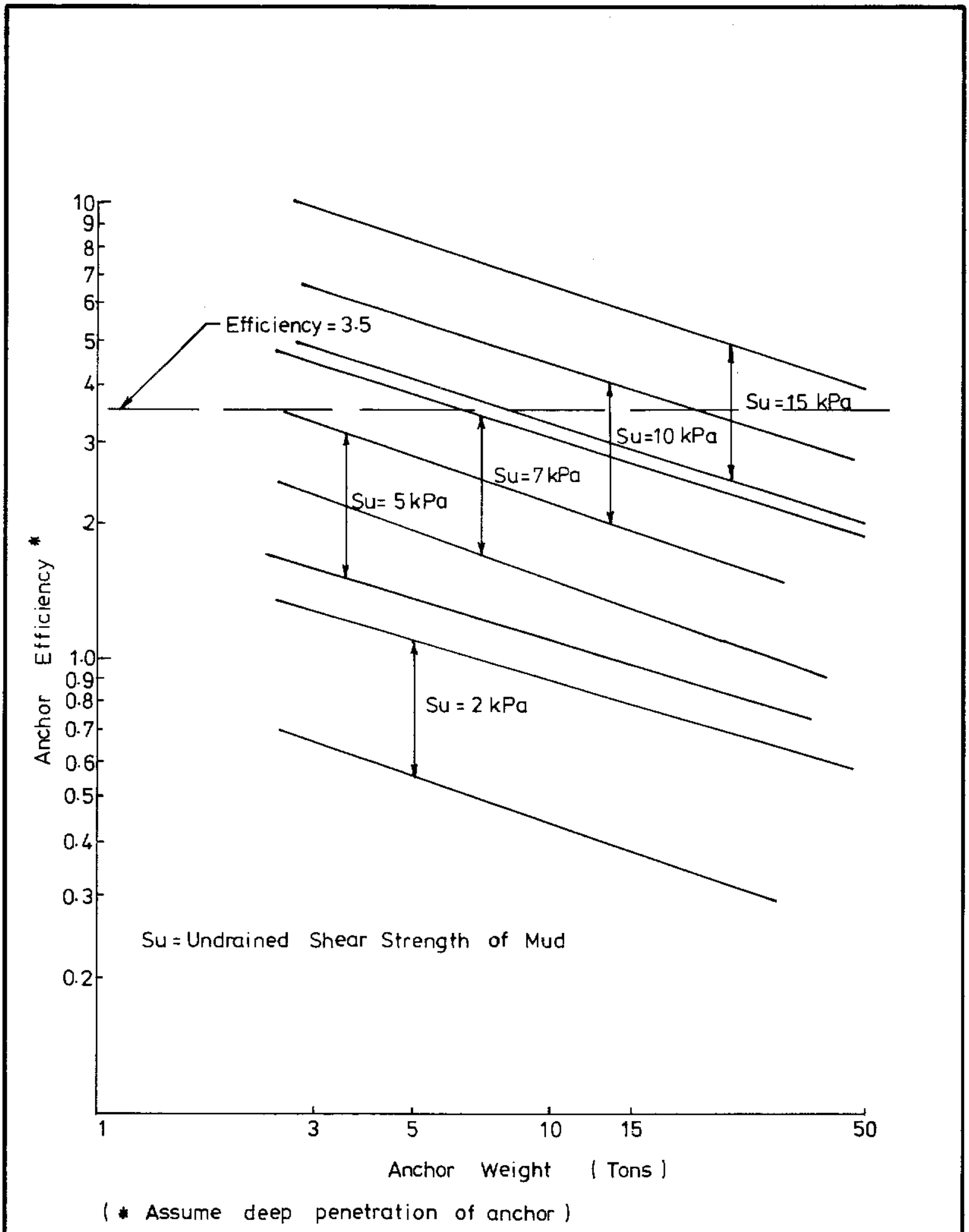


Figure 17 - Efficiency of Anchors in Mud

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