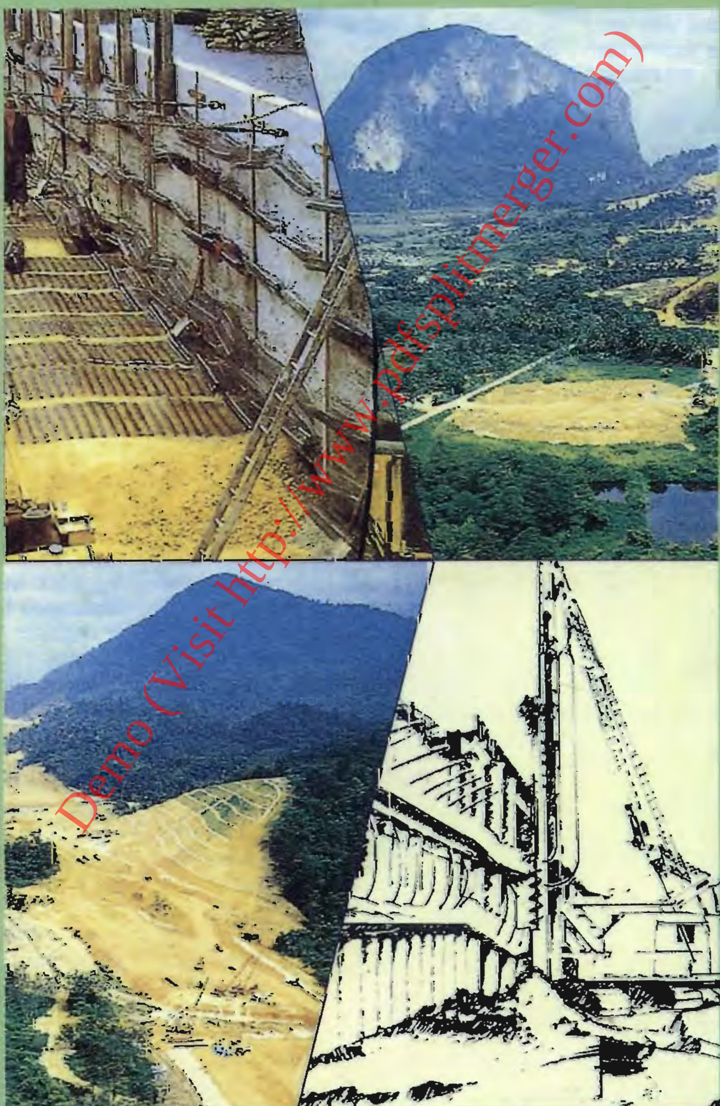
Geotechnical Engineering Conference

Proceeding of the Sixth Geotechnical Engineering Conference

(GEOTROPIKA 2001)



Organised By:

Universiti Teknologi Malaysia (UTM)

Universiti Malaysia Sarawak (UNIMAS)

Proceeding of the Sixth Geotechnical Engineering Conference

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Edited by

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PREFACE

GEOTROPIKA 2001 is the sixth in a series of GEOTROPIKA conferences that have been organised by the Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia. However, this sicth conference is co-organised with the Faculty of Engineering, Universiti Malaysia Sarawak (UNIMAS). The theme for this conference is "Geotechnical Problems and Solutions for Construction Practices".

In the last decade, we have seen some of the largest and most ambitious projects ever undertaken in this country. In addition, we would also hear of failures or problems associated with the construction industry. Through the conference, the experiences of engineers and other related professionals via technical papers, case studies, discussions, and practical applications would generate better understanding amongst practicing geotechnical engineers and other related professionals on the importance of their professions and its impact on construction industry. It is hoped the conference would open a new horizon and thus allowing newer techniques to be adopted. It is hoped that this compilation of proceedings would serve as important means of disseminating Geotechnical Engineering knowledge. Technical papers are presented under four themes:

- Geological, Mineralogical and Chemical Properties
- Characterisation and Deformation of Soils
- Soil Erodibility and Slope Failures
- Geotechnical Engineering Related Studies

The conference proceedings are compiled from camera ready manuscripts provided by the authors of the papers. It should be noted that the authors are solely responsible for the quality of the text and figures contained herein.

We would like to express our gratitude to all members of the GEOTROPIKA 2001 organizing committee of both UTM and UNIMAS for the contribution towards the success of the conference.

Editors
Fauziah Kasim
Aminatin Marto
Mohd. Zain Yusuf

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GEOLOGICAL INPUT IN CONSTRUCTION DEVELOPMENT AND PLANNING

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ABSTRACT

In any construction project, engineers conduct site investigations to acquire the engineering characteristics of the site before designing the substructure and superstructure. Most projects do not encounter problems as engineers adhere to the engineering Codes of Practice. However, some projects did encounter problems as certain geological factors were not addressed.

A number of geological factors such as bedrock morphology, bedrock lithology, geological structures in the bedrock and mineralogy of the rocks may affect the safety of a civil structure. There are a number of case histories outlining the role played by geology in construction development, such as the change in design of the Pan Pacific Hotel in Kuala Lumpur to avoid sitting over a large overhang in the limestone bedrock, the oxidation of pyrite in concrete in Batu Dam, Kuala Lumpur which led to the formation of cracks in the spillway, or the failure of a rock slope in Taman Rawang Perdana along a day-lighting fracture plane.

In the process of planning the landuse of an area, planners require basic information such as the geology, topography and landform of the site, as well as other geotechnical details such as whether the area is prone to landslides. Geological mapping and a rational evaluation of the overall terrain would serve the purpose.

In the past, the role of geology in the construction industry was not accorded much importance, but in recent years, the scenario has changed and civil engineering consultant companies now employ geologists.

INTRODUCTION

In any construction project, site investigations are conducted to acquire the engineering characteristics of the site prior to the design of the substructure and superstructure. Investigations carried out include boring to study the lithology of the soil profile and conducting in-situ tests such as Standard Penetration Tests (SPT), Shear Vane Tests or Cone Penetration Tests (CPT) to acquire the engineering strengths and bearing capacities of the soil profile. Based on these information, engineers design the substructure and superstructure, adhering to the approved Codes of Practice.

Most of the time, engineers adopt a factor of safety acceptable to the industry, and as such, most projects do not encounter problems. However, as we know, some projects did encounter problems where cracks had propagated on the walls, ceilings and floors of buildings, or designed slopes which were supposedly safe, had failed, causing damages to nearby buildings and cutting off access roads. Such problems might not be due to improper design, but rather could be attributed to certain geological factors which were not addressed appropriately.

GEOLOGY IN ENGINEERING PRACTICES

Both geologists and civil engineers are concerned with rocks, but from different points of view. In geology, rocks are classified according to origin, composition and texture, whilst in civil engineering, the physical and engineering characteristics of the rocks are emphasised. It is interesting to note that despite their differences in viewpoint, geology and civil engineering have always been closely connected, and in fact the first geologic map of England was prepared by William Smith, a civil engineer.

Engineering works often provide tests to geological theories, for example, when the tunnels in the Alps were constructed, geologists were requested to furnish engineers with their conception of the subsurface geology and the geological structures. The geologists came out with sections showing extremely complicated and folded masses of rocks, and blasting and tunnelling through the hills showed that the actual conditions corresponded fairly closely with the theoretical concepts.

In recent times, geology has diversified from the conservative fields of mineralogy, petrology, stratigraphy, paleontology etc. to hydrogeology, environmental geology and engineering geology. Engineering geology fosters the bond between geology and civil engineering and provides accurate and detailed geological information vital to the solution of engineering problems at hand.

Geological information has been widely utilised in civil works development and planning and frequently has contributed to the viability, cost savings and success of a project.

GEOLOGICAL FACTORS AFFECTING CIVIL WORKS DEVELOPMENT

There are a number of geological factors such as the bedrock morphology, the bedrock lithology, the geological structures in the bedrock, the mineralogy of the rock etc. which may affect the safety of a civil structure. There are a number of incidences whereby adverse geological conditions had led to a change of the design or realignment of the civil structure.

Morphology of Bedrock

The most important geological factor is the morphology of karstic limestone bedrock which is the dominant bedrock in parts of Kuala Lumpur and Ipoh. About 40% of Kuala Lumpur is underlain by limestone bedrock. Dissolution of the limestone bedrock by the percolating acidic rainwater results in a karstic morphology with steep pinnacles and troughs. Dissolution of the limestone also gives rise to cavities of varying sizes within the bedrock. In places, the roofs over the cavities are thin, with thicknesses of not more than a few centimetres (Fig 1). The karstic morphology poses geotechnical problems to foundations of structures, particularly if driven piles are used. Omar and Hon (1985) pointed out the various problems encountered when concrete and steel piles were driven to rest on karstic limestone bedrock. Driven piles might be resting on the pinnacles or on the thin roof of a large cavity. With time, the piles might slip. The number of piles rejected due to misalignment was reported to be substantial. It was reported that in one instance, each pile had to be replaced by two extra piles. Mitchell (1985) discussed the problems encountered in the design of foundation for the construction of the 30-storey Pan Pacific Hotel in Kuala Lumpur. Investigations showed that the limestone bedrock at the project area had a 15-metre overhang. This led to the modification of the design of the hotel where no foundation was placed on the top of this overhang (Figs 2 and 3).

To have a representative profile of the karstic bedrock in a construction site, close drilling to a reasonable depth within the bedrock is necessary. A cheaper and faster technique is to conduct geophysical surveys. Seismic reflection combined with microgravity, and georadar methods have been proven to be successful in such studies. In mined-out ponds, the use of side-scan sonar had been successful in plotting the bedrock profile.

Lithology of Bedrock

Limestone / marble is soluble in acidic waters and on many occasions, construction in limestone / marble country has led to the formation of sinkholes. A sinkhole is a collapse of the ground surface into a large circular depression with steep to vertical sides. Its size may vary from as small as 0.5 m to as large as 30 m in diameter. On some occasions, properties such as houses or buildings have been severely affected with cracks being formed on the roofs, ceilings and floors.

The primary cause leading to the development of sinkholes is the dissolution of limestone/marble bedrock by acidic groundwater. The groundwater which percolates through joints or faults within the bedrock slowly dissolves the rock, and in time, results in the formation of funnels and cavities. The soil above the bedrock falls through the funnels into the cavities, forming voids within the soil. If the groundwater table is high, the hydrostatic pressure on the roof of the void prevents the collapse of the soil into the cavities. However, if there is a lowering of the groundwater table, there will be a rapid collapse of the soil, thereby hastening the formation of a sinkhole (Fig. 4). In the construction of foundation of large buildings, there are usually some excavation works. If the groundwater table is high, removal of the groundwater in the excavated area is necessary. This lowering of groundwater table has, on many occasions, triggered off formation of sinkholes.

Sinkhole formation could also be triggered off by an influx of water into the ground. On one occasion, water discharged from drilling operations in the compound of the High Court in Ipoh triggered off the formation of a sinkhole.

To locate potential sinkhole areas, geophysical techniques may be applied. The resistivity and microgravity techniques have been found to be useful in the location of cavities in the bedrock and voids in the subsoil.

Geological Structure

The orientation of geological structures (such as faults, joints, bedding planes) and the presence of relict structures in completely weathered (Grade V) bedrock are often overlooked. If a building is constructed on a platform and the beddings, fractures, faults or open joints day-light (i.e. dipping outwards away from the cut slope) there is a strong possibility of a sliding failure should there be a triggering mechanism such as a heavy rainstorm. The recent rockslide at Taman Rawang Perdana in Selangor is one such example. In Kuala Lumpur, there are many cut slopes which are potentially dangerous such as in the Bangsar-Damansara area where the bedding planes of the interbedded Kenny Hill sandstone and shale day-light, in the Setiawangsa area where the beddings of the Hawthornden schists day-light and in the Cheras area where there are day-lighting joints in the granite cut slopes.

Geological structures also influence the stability of cliff faces in the karstic limestone hills, which are found in numerous parts of Malaysia. There are over 40 limestone hills in the Kinta Valley, with about 30 of them located in or around Ipoh . Numerous rockfalls had already occurred and two of the more recent rockfalls had caused some fatalities. The Gunung Cheroh Rockfall which occurred in October 1973 when a massive cliff face with a subvertical shear plane intersecting a large undercut detached from the main hill, had crushed about 40 people to death.

The second fatal rockfall occurred in December 1987 where the entire eastern face of Gunung Tunggal collapsed, killing one person. The failure occurred along a sub-vertical fracture plane which intersected a large undercut at the base of the hill.

Relict structures in completely weathered bedrock are most commonly over-looked during the design of slopes. The landslide which occurred at Km 303.8 of the North-South Highway near Gunung Tempurong in January 1996 is a good example where the failure plane was the weathered contact between granitic soil and a completely weathered aplite dyke. Soil nails were in fact installed, but unfortunately, most of the nails did not penetrate the granite-dyke contact (GSM, 1986).

Mineralogical Composition of Rock

Certain mineralogical compositions of rocks at times. are deleterious and can pose problems. due to their physico-chemical properties.

Carbonaceous Shale/Graphitic Schists

Numerous cut slopes in areas underlain by carbonaceous shale/graphitic schists have experienced slope failures and ground settlement. Examples of such problems are along parts of the North-South Highway near the Yong Peng and Air Hitam areas (Tan and Azwari, 2001) and more recently, along a section of the yet-to-be completed trunk road connecting Pos Slim in Perak to Kg. Raja in Cameron Highlands, Pahang.

The predominance of monovalent cations (such as Na^+ or K^+) over the divalent cations (Ca^{2+} or Mg^{2+}) in such soils contribute to the high dispersivity of the soil.

Soils derived from carbonaceous shale/grapitic schists are poor choices for use in fill embankments as the high carbon/graphite contents contribute to low compacted densities of the fill.

Pyrite in Rocks

Pyrite is present as accessory minerals in some rocks, such as in graphitic schists/carbonaceous shales or even in granite. On exposure to the elements, the pyrite undergoes oxidation and hydrolysis reactions, producing sulphuric acid and iron oxides/hydroxides. Typical chemical reactions are as follows :

$$2\,FeS_2 + 2\,H_2O + 7\,O_2 == 2\,FeSO_4 + 2\,H_2SO_4$$
(Pyrite)

$$4\,FeSO_4 + O_2 + 2\,H_2SO_4 == 2\,Fe_2(SO_4)_3 + 2\,H_2O$$

$$Fe_2(SO_4)_3 + 6\,H_2O == 2\,Fe(OH)_3 + 3\,H_2SO_4$$

The practical implications of these chemical reactions are that turf on cut slopes fail to grow due to high acidicity, staining of concrete pavements and drains due to the release of iron oxides/hydroxides, swelling and disintegration of the soil structure, hence leading to a drop in the shear strength due to the formation of secondary minerals. Steel reinforcements in concrete structures located in areas underlain by carbonaceous shale/graphitic schists are often corroded.

Pyrites are occasionally present in sand tailings from ex-tin mine dumps and these sand tailings are commonly used to make concrete. These pyrites in the concrete undergo the chemical reactions as above, and the formation of secondary minerals results in an increase in volume, causing cracks to form in the concrete. The Batu Dam near Kuala Lumpur experienced such a problem when in the early 1990s, engineers detected some cracks in the spillway of the dam. The cracks widened from 0.1 mm to 0.7 mm over a seven-month observation period from May to December 1997. Today, the cracks measure about 25 mm wide (Chow and Abdul Majid, 2001).

Reactive Siliceous Minerals in Rocks

Certain siliceous minerals in rocks are reactive with the alkaline pore fluids from Portland cement, resulting in the formation of a calcium alkali silicate gel. The gel produced from this reaction, commonly called alkali-silica reaction (ASR) absorbs water, resulting in volume expansion which induces expansive force, resulting in the development of cracks in the concrete.

The reactivity of the different siliceous minerals depends on the degree of order in the crystal structure. Opal, which has a very disordered structure, is the most reactive form of silica. Other forms of silica like natural glass. microcrystalline and cryptocrystalline quartz, strained quartz, chalcedony, tridymite and cristobalite are of intermediate activity.

Most of the aggregates used in the construction industry in Malaysia are composed of granitic rocks. Normal granitic rocks do not have ASR. Exceptions are granitic rocks which have undergone stress or shearing where microcrystalline quartz and strained quartz are present.

In areas where granitic rocks are not found. metamorphic rocks such as quartzites are used for aggregates. These quartzose rocks may contain microcrystalline quartz which are reactive to ASR.

In the East Coast and in Johor Bahru in Peninsular Malaysia and in East Malaysia, some of the aggregates are composed of volcanic rocks. Some of the volcanic rocks contain unstable siliceous minerals. such as cristobalite, tridymite or chalcedony which are reactive to the alkali content of the cement. In fact, the Singapore Government had banned the import of tuffaceous volcanic rocks from the Pengerang area in Johore some time in the early 1990s.

Other Deleterious Minerals in Rocks

Free micas, even in quantities of a few percent, can affect the strength of a concrete as the micas expand to form clays or zeolites during the hydration of the cement.

Montmorillonite and illite, which are common clay minerals occurring in shales and tuffs, can expand considerably upon absorption of water. As such, roads built over ground containing such clay minerals are often "bumpy".

GEOLOGY IN CONSTRUCTION PLANNING

In the process of planning the landuse of an area, town planners would require basic information such as the geology, topography and landform of the area, as well as other relevant geotechnical details such as whether the area is potentially unstable due to the presence of landslides or severe erosion. Such information will assist engineers in preparing the layout plans, designing the foundation system and deciding on the appropriate type and method of construction.

For easy assessment and utilisation of the information required, a rational evaluation of the overall terrain is conducted and the data presented in the form of various types of thematic maps for the use of the town planners and engineers.

Terrain Mapping

Terrain mapping is carried out by the Minerals and Geoscience Department Malaysia, based on a modification of the technique by the Hong Kong Geotechnical Engineering Office.

The fundamental step in terrain mapping is to conduct terrain classification which is carried out on topographical map sheets on a scale of 1: 10,000 based on four attributes (Table 1), that is the slope gradient attribute, the terrain or morphology attribute, the activity attribute and the erosion and instability attribute. Based on these four attributes, polygons are defined, reflecting on the steepness of the terrain, the morphology of the slope, the activities that are conducted on the slope and the degree of erosion or instability on that slope. Such definition of polygons is best conducted in the field, but in areas which are inaccessible, recent aerial photographs may be used.

The polygons in the resulting Terrain Classification Maps are digitised and analysis is carried out with a GIS programme (Arc Info or Arc View software) producing the various thematic maps as listed below :

Landform Map.

This map summarises the broad terrain pattern in the map sheet where slope angles and terrain attributes are delineated. This map is designed for the use of technical and non-technical users who require general landform data for planning purposes.

Erosion Map.

This map delineates the broad pattern of erosion and instability, and is designed for technical and non-technical users who require information regarding the general nature, degree and intensity of erosion and instability for planning and engineering purposes.

Physical Constraints Map.

This map represents the major physical land resource constraints and is designed for technical and non-technical users who require information relating to the types of physical constraints which affect the terrain. It is designed to be used as an assessment of the physical resources for general planning and engineering purposes.

Engineering Geology Map.

Data from the Terrain Classification Maps are used in conjunction with geological data from other sources such as geological maps, geo-hazards maps etc. This map displays the broad distribution of geological materials, based on their engineering characteristics. It is designed for technical users who require geotechnical information for strategic planning and engineering purposes.

Landuse Classification Map.

Based on attributes from the Terrain Classfication Map. a Landuse Classification Map is produced whereby there are 4 classes, with Classes 1 and 2 having low to moderate geotechnical limitations respectively, Class 3 high geotechnical limitations, and Class 4 extreme geotechnical limitations (Table 2).

As such, Classes 1 and 2 are suitable for development and should not encounter much geotechnical problems, whereas Class 3 is not so suitable and Class 4, probably unsuitable. In terms of engineering costs for development, land under Class 1 will probably be having low development costs, Class 2 normal, Class 3 high and Class 4 very high. One of the reasons is that Classes 1 and 2 will require only normal site investigations (Table 3), whereas Class 3 will require intensive and Class 4, very intensive site investigations.

Safety Zones in the Vicinity of Limestone Hills

There are about 30 limestone hills in and around Ipoh and development has encroached towards these hills. A number of housing and industrial estates have already been built close to some of the hills. Since the occurrence of the Gunung Cheroh Rockfall in 1973, the Ipoh Municipality (now the Ipoh City Hall) had consulted the Minerals and Geoscience Department on the approval of housing projects which are close to limestone hills.

The Minerals and Geoscience Department has prepared a guideline for the demarcation of safety zones (i.e. very dangerous zone, dangerous zone & safe zone) in the vicinity of a limestone hill.

As a means of confirming whether a rock block is potentially unstable, the orientations of the geological discontinuities (such as joints, sheared zones, open bedding planes etc.) in relation to that of the cliff face are investigated and plotted on a stereonet. All potentially unstable rock blocks are then accorded hazards rating (Figure 5), that is, whether they are of very high hazards rating, high hazards rating or low hazards rating.

A cliff with a very high hazards rating is one which has deep undercut at its base, large overhang, visible vertical/subvertical discontinuities intersecting the undercut and overhang and prominent day-lighting discontinuities. In this category, the very dangerous zone will be demarcated as twice the height of the critical cliff face and the dangerous zone, thrice.

A cliff face with a high hazards rating is one with small overhang, insignificant undercut at its base, and discontinuities intersecting the overhang and undercut are not prominent. There may be some day-lighting discontinuities and some loose blocks at the top which may topple. In this category, the very dangerous zone will be demarcated as one and a half times the height of the critical cliff face and the dangerous zone, two and a half times.

A cliff face with a low hazards rating is one which does not have any overhang or undercut, without any visible or clear day-lighting discontinuities and no potential toppling rock blocks. In such a case, the very dangerous zone is estimated to be equal to the critical height of the cliff face and the dangerous zone, twice.

The Department recommends that within the very dangerous zone, there should be no houses or permanent buildings. Within the dangerous zone, houses or permanent buildings may be constructed provided a boulder trap (which may be a ditch with a bund/retaining wall as designed by a qualified engineer) is constructed at the edge of the very dangerous zone.

To optimise usage of land, public utilities like reservoir and oxidation pond may be sited within the very dangerous zone.

CONCLUSION

In the past, perhaps up to twenty years ago, the role of geology in engineering construction was not given much attention in Malaysia. Engineers designed substructures based solely on the engineering characteristics of the soil. Design of cut slopes in residual soil was based solely on the cohesion and friction angle of the soil without due consideration for relict geological structures like weathered joint planes, bedding planes etc.

However, in recent years, in the light of disastrous landslide occurrences like the Highland Towers Landslide, the Genting Sempah Debris Flow, or the Gunung Tempurong Landslide, engineers are more aware of the role played by geology. Geological input are now incorporated into engineering designs and most consultant firms have engaged the services of geologists.

In the near future geology will play an even greater role in civil works development and planning.

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UNDERSTANDING MECHANISM OF PILE BEHAVIOUR THROUGH PHYSICAL MODELLING

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ABSTRACT

Centrifuge modeling is a well-established and versatile technique to investigate geotechnical problems. In this paper, examples are shown to demonstrate the use of centrifuge and physical modeling to understand the mechanism of pile behaviour. The findings presented include those on the studies of performance of pile subject to lapses during pile installation, pile under sustained load, rock-socketed piles, piles subject to uplift loads, pile responses due to negative skin friction and excavation-induced lateral soil movement.

Keywords:- centrifuge modelling, mechanism, pile, settlement, soil pressure, stability

INTRODUCTION

Although many research studies had been carried out on pile foundation, the mechanism of pile behaviour under various conditions is still not well understood. Laboratory model tests are common means of investigating pile behaviour but the results may not be representative of field conditions when the tests are conducted under conventional laboratory conditions. This is attributed to the fact that soil behaviour is non-linear and dependent upon the soil stress level. Centrifuge model study provides an attractive alternative as in many cases, the prototype stresses can be correctly reproduced in a centrifuge model under a forced gravitational field. The principles of centrifuge modelling technique and relevant scaling laws are given in Leung et al. (1991).

For the past 10 years, a comprehensive research program has been in force at the National University of Singapore to investigate various pile problems using centrifuge modelling technique. The problems examined include the behaviour of pile subject to lapses during installation, pile behaviour under sustained load, piles in tension, piles subject to vertical and lateral moving soils. The findings of these studies are summarized in this paper to illustrate that the mechanism of pile behaviour under various conditions can be examined beneficially through physical modelling.

PILE INSTALLATION

Occasionally, a pile may experience stoppages during installation due to machine breakdown, weather condition, overnight/weekend stoppages or other reasons. It is well established that the force required to re-install a pile into the soil after installation lapses can be quite different from the case on a pile without installation lapses. A series of centrifuge model tests has been conducted to investigate the behaviour of pile subject to lapses during installation in dense sand. To simulate an installation lapse, a model pile instrumented with strain gauges along the pile shaft is jacked to a desired depth, then allowed to rest for a desired duration before being jacked deeper into the sand during centrifuge flight. The vertical and lateral earth pressures in the soil in the vicinity of the pile were also monitored regularly throughout the tests. Details of the findings are reported in Leung et al. (2001a).

The test results reveal that a pile installed in sand experienced a reduction in penetration resistance between the end of initial installation and the beginning of reinstallation, as illustrated in Fig. 1. The magnitude of reduction in pile penetration is noticeable even for short lapse duration and increases with the duration of installation lapse. Figs. 2 and 3 show a close-up view of changes in lateral and vertical earth pressures, respectively, at around the one-third, two-third and close to the base of the pile shaft during a typical installation lapse. The miniature pressure transducers are placed fairly close to the pile. It is evident that the changes in lateral earth pressure is more significant that those of vertical earth pressure. In addition, there is a considerable reduction in lateral earth pressure close to the pile base. This observation is consistent with the stress changes in the pile shaft during an installation lapse. The strain gauges mounted on the pile shaft reveal that during an installation lapse, there are little changes in the load transfer along the upper pile shaft but considerably more changes in the load transfer along the lower pile shaft. The change in the load transfer is most significant for the strain gauges placed close to the pile base. The test results illustrate that during a pile installation lapse, there is a progressive redistribution of the stresses in the surrounding soil around the pile, in such a way that it leads to a reduction in pile penetration resistance. Thus it can be deduced that stress reduction in sand around the pile tip and along the lower pile shaft is a cause for the observed reduction in pile penetration resistance during an installation lapse and therefore a possible contributing factor to pile relaxation in the field.

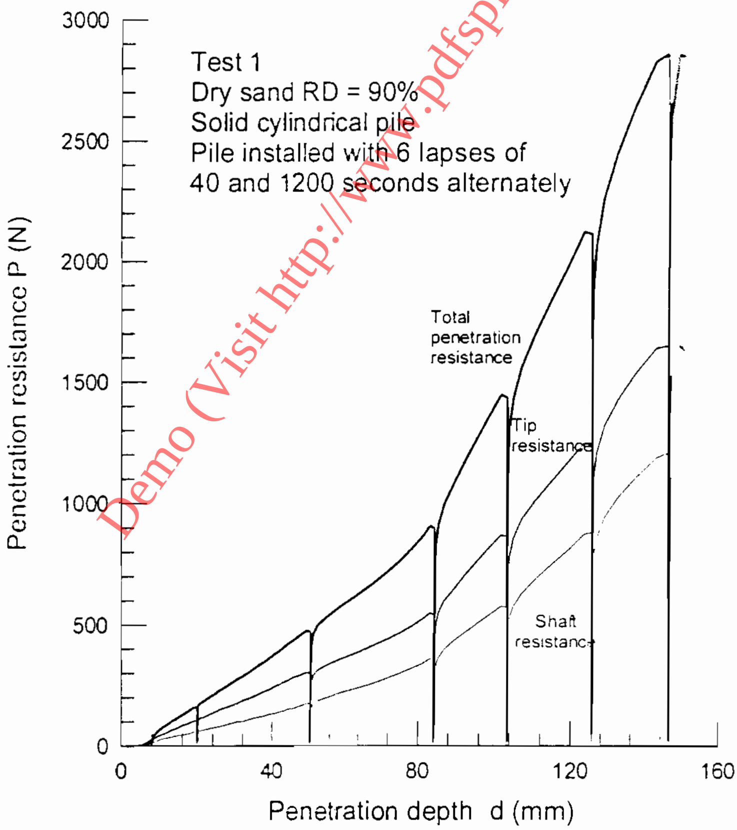


Fig. 1 Variation of model penetration resistance with depth (Leung et al., 2001a)

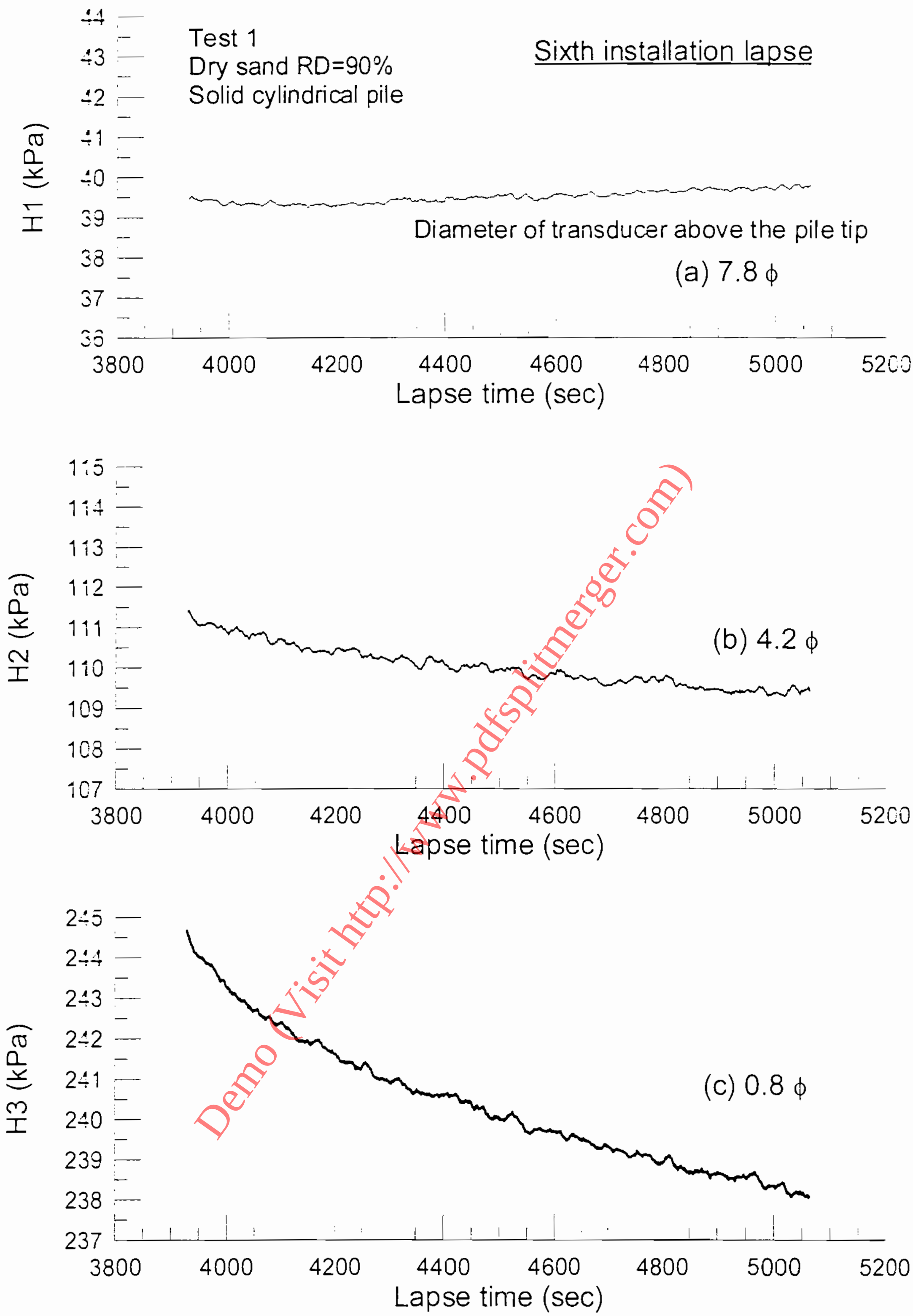


Fig. 2 Close-up view of changes in lateral earth pressure (Leung et al., 2001a)

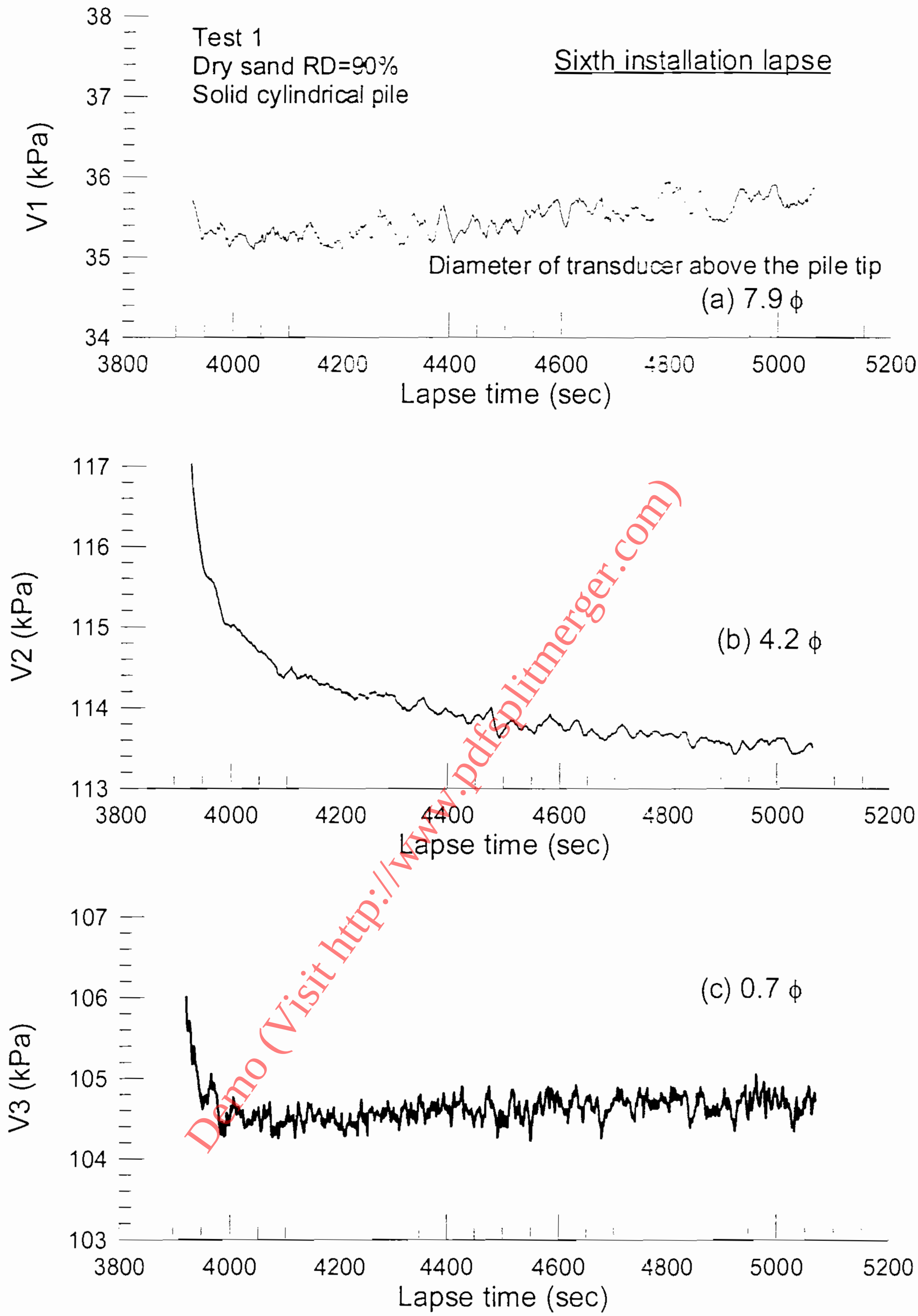


Fig. 3 Close-up view of changes in vertical earth pressure (Leung et al., 2001a)

Tests were also conducted on piles jacked into clay and subject to lapses during pile installation. An opposite phenomenon is noted in which additional force is required to jack a pile further into clay after an installation lapse. Pore pressure measurements indicate that excess pore pressure in the clay had built up during pile installation and the excess pore pressure subsequently dissipates with time. The test observations generally support the commonly observed 'set-up' effect for clay in which the clay strength increases with time due to the dissipation of excess pore water pressure developed during pile installation.

PILE UNDER SERVICE LOADS

Pile Subject to Sustained Load in Sand

Pile foundations are often subjected to heavy sustained structural loads throughout their relatively long working life. Another series of centrifuge model tests has been carried out in dense sand to evaluate the variation of pile settlement with time under a constant sustained load. A typical test result is shown in Fig. 4(a), which reveals that the pile continues to settle with time under a sustained load. A re-plot of the same set of test data on a settlement-log time relationship (Fig. 4(b)) reveals that the pile settlement increases approximately linearly with log time. Leung et al. (1966) provided a detail interpretation of the test data.

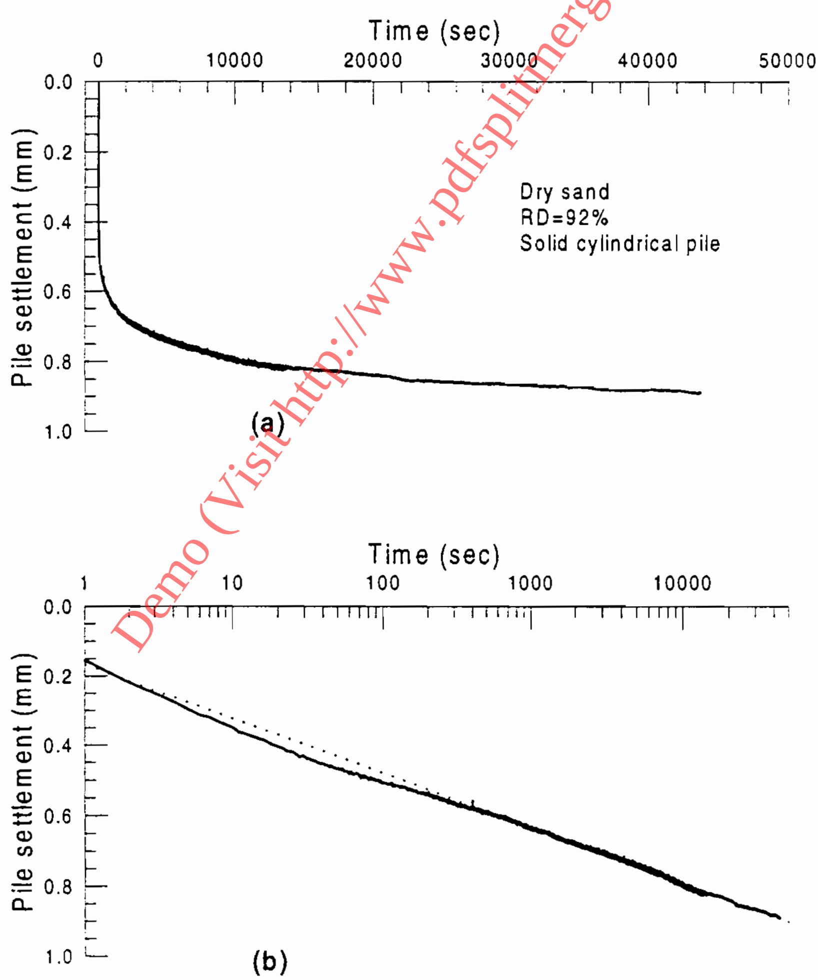
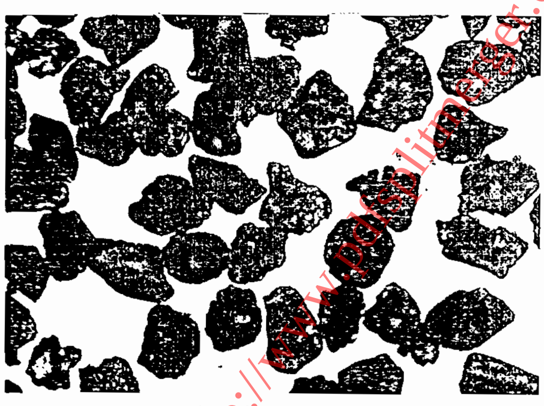
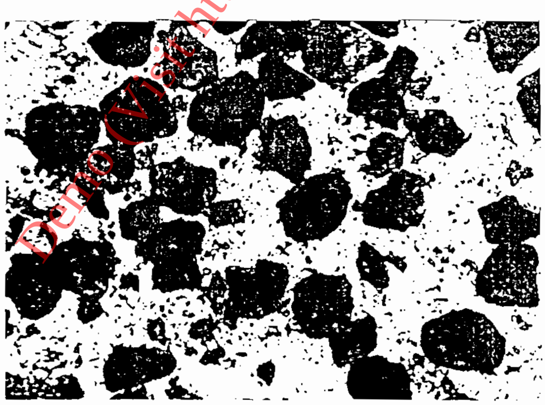


Fig. 4 Settlement of pile under sustained load in model scale (Leung et al., 1996)

During the centrifuge model tests, the strain gauges mounted close to the pile base and the pressure transducers placed around the pile base area reveal very high pile and soil stresses around the pile base area. To further investigate the pile creep phenomenon, a series of one-dimensional compression tests was performed by placing the same sand of identical relative density in a conventional oedometer cell and subject the sand to similar magnitude of high pressure experienced by the soil in vicinity to the pile base. Microscopic photographs were taken on the sand samples before and after the tests. Before sustained loading, the sand particles maintain its original shape and sizes as shown in Fig. 5(a). Upon sustained loading, the angular protrusion of the sand particles have been ground off, resulting in a mixture of predominantly more rounded large particles mixed with smaller particles and fines, see Fig. 5(b). Moreover, microscopic inspection of the particles at an oblique angle reveals the presence of shiny smooth breakage surfaces on the larger rounded particles after sustained loading. Fig. 6 shows the grading curves obtained from sieve analysis on sand samples after two different load durations. Before sustained loading, all the sand particles were retained on the 212 μm sieve. After 290 seconds of sustained loading, about 5% of the particles (by weight) pass through the 212 μm sieve. However, after 5 days of sustained loading of the same magnitude, about 25% of the particles are smaller than 212 μm.



(a) Before test



(b) After test

Scale (mm)

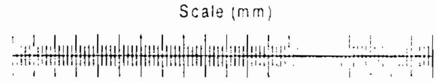


Fig. 5 Microscopic pictures of sand particles before and after test (Leung et al., 1996)

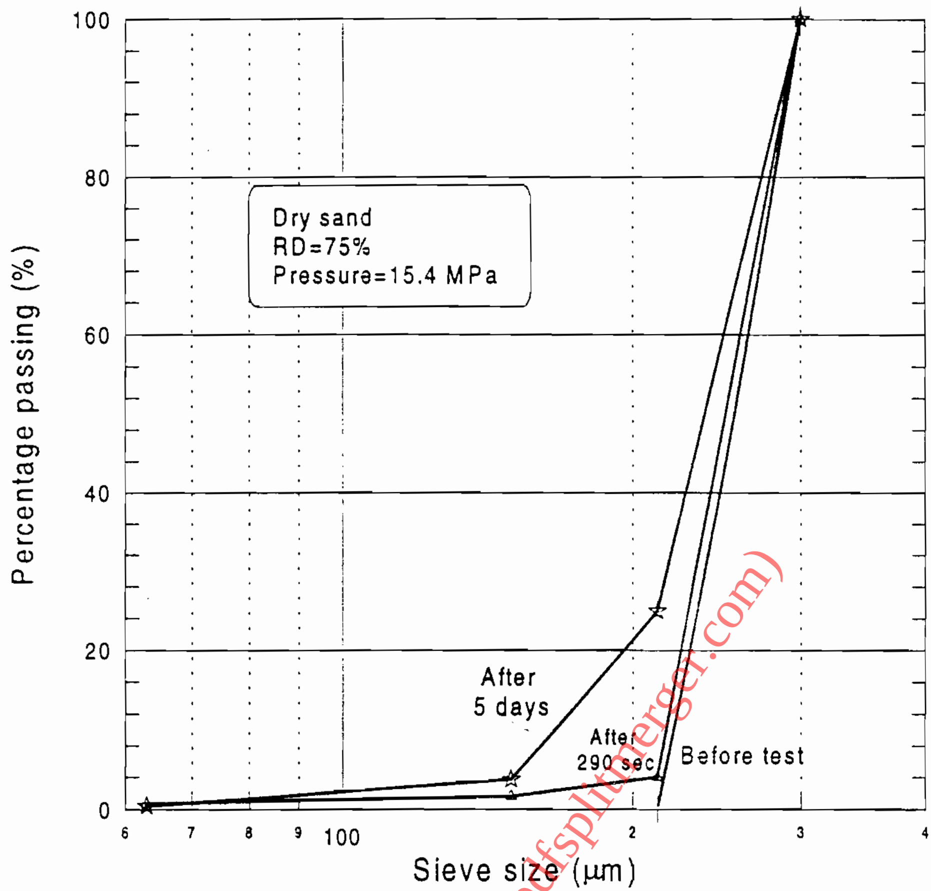


Fig. 6 Variation of sand particle size distribution (Leung et al., 1996)

The centrifuge tests and one-dimensional compression tests essentially show consistency of creep settlement-time responses under sustained load. The progressive breakage of sand particles results in a loss of contact between particles, which leads to a gradual decrease in soil resistance and stiffness and an increase in settlement with time. Further test results reveal that pile creep settlement is insignificant if the applied load is less than 50% of ultimate load. This demonstrates that for pile design in sand, it is prudent to adopt a minimum factor of safety of at least 2 against bearing capacity failure to prevent any excessive long term pile creep settlement under working load condition.

Piles socketed in rock

In many urban areas around the world, large-diameter cast-in-situ concrete bored piles socketed in rock are commonly used as foundations to support heavy concentrated structural loads. Many studies were conducted to evaluate the shaft resistance of rock sockets while relatively little work has been carried out to examine the failure mechanism of rock below the pile base. A series of centrifuge tests has been conducted to examine piles socketed in artificial rock made of gypsum cement having the same range of compression and stiffness parameters as sedimentary rocks in the Southeast Asia region. In the experimental setup, the model bored piles were cast using cement mix with an appropriate amount of water at 1g. The test results are provided in detail in Leung and Ko (1993). The rock socket shaft friction values obtained from the centrifuge tests are found to be comparable with those deduced from existing theories, as illustrated in Fig. 7. This demonstrates the validity of using artificial rock in the model setup.

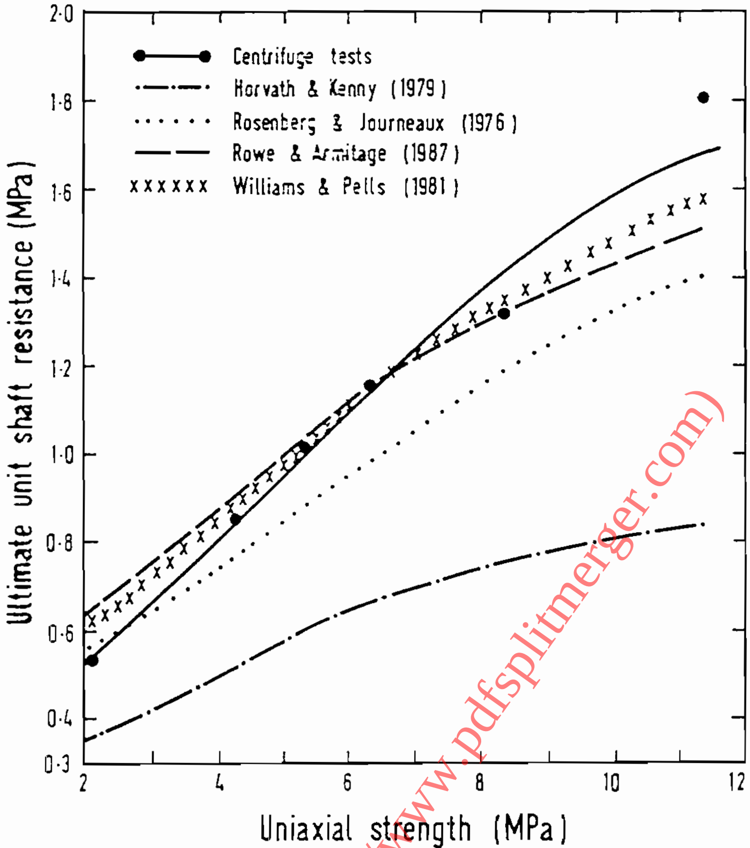


Fig. 7 comparison of test data with existing theories (Leung and Ko, 1993)

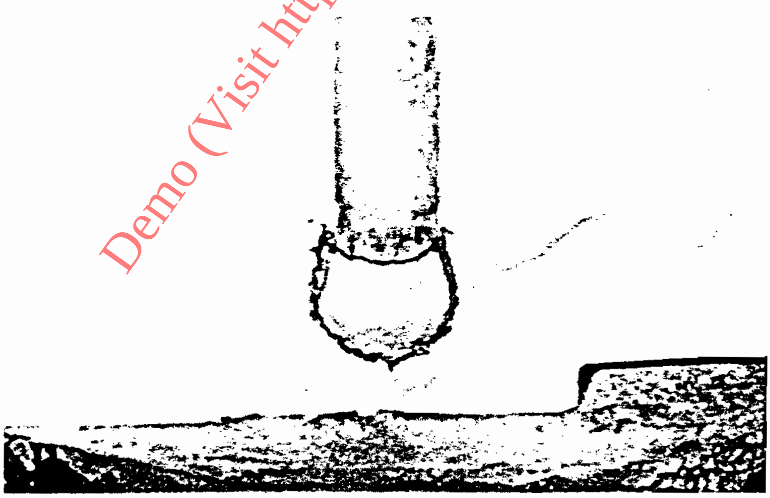


Fig. 8 Failure bulb below pile base (Leung and Ko, 1993)

To reveal the failure bulb below the pile base, the pile was subject to a very high load such that it settled by over 40% of its pile diameter. After the test, the artificial rock specimen including the model pile was cut open carefully and a failure bulb beneath the pile base was clearly evident, as shown in Fig. 8. The bulb typically had a height of about 1.35 times the pile diameter and a diameter of 1.25 times the pile diameter at its widest part. There appeared to be no significant differences in geometry and size of the failure bulbs for pile socketed in rocks of various strengths.

PILES IN TENSION

Piles subject to uplift loads

The behaviour of pile subject to uplift loads is still not well understood. Recently, the use of Osterberg cell in static load test has become more popular. As Osterberg cell is placed some distance down the pile shaft or at the pile base, the application of test load via Osterberg cell essentially pushes the pile shaft above the cell upwards resulting in uplift shaft friction. In a test program recently carried out at the National University of Singapore, three loading cases were considered. The first case is on a test pile subject to conventional compression loading and the second case is on a test pile being pulled upwards at the pile head. The last case is on a test pile being pulled upwards from the pile base partially simulating the Osterberg cell test setup. A sketch of the model pile setup for the three cases is shown in Fig. 9 and the mobilized shaft friction shaft movement results obtained from the tests are shown in Fig. 10. The results clearly reveal that for sand, the uplift shaft resistance is only about half of that of a pile in compression regardless whether the pile is being pulled at the pile top or pile base. Details of the test results are provided in Goh (2001).

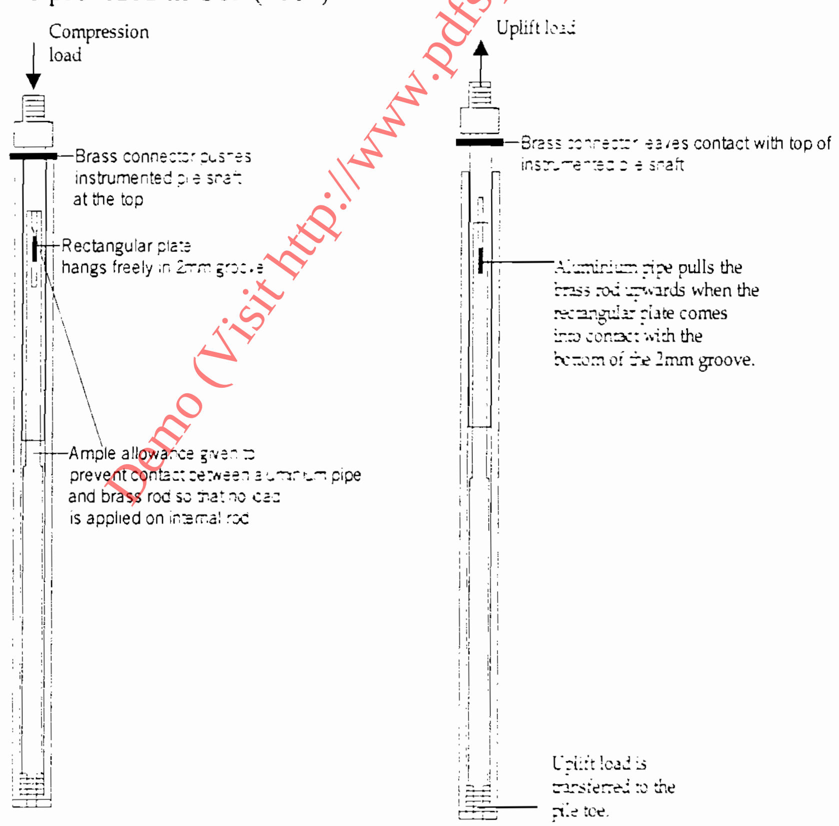


Fig. 9 Model test setup (a) compression or uplift load at pile top (b) uplift load at pile base