GROUND IMPROVEMENT WORKS IN SOUTH-EAST ASIA

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Ground Improvement Works in South-East Asia

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INTRODUCTION

Soft ground deposits can be found in the subsoil profile of a number of cities in the South-East Asian region. Bangkok, Jakarta, Penang and Singapore are some of the major urban centres where soft ground conditions pose numerous geotechnical problems. With the recent economic growth in this region, more land is required for developments of high rise buildings and the associated infrastructure. Consequently, through various ground improvement techniques usable land is reclaimed from the sea, swampy areas and relatively weak and compressible ground.

Work in these areas of ground improvement has only recently taken on significant proportions in this region, in parallel with the present upsurge in variety and scope of construction more often requiring specialist services. Some methods such as soil nailing and geotextiles for soil reinforcement have yet to attain the degrees of implementation and acceptance of ground improvement techniques like deep compaction and the speeding up of consolidation, hence the corresponding lack of publication on their application in projects. The following report provides a general survey of some of the more significant developments in the use of various methods of ground improvement in this region, with reference to published material where available.

IN-SITU AND LABORATORY TESTS FOR DESIGN AND CONTROL OF GROUND IMPROVEMENT

Methods of in-situ testing used for ground improvement works vary depending on whether the material treated is cohesionless or cohesive soil. With cohesive soils, soil improvement may be based on the principles of either consolidation, compaction-replacement or electro-chemical phenomena.

Soil improvement works involving vertical drains require coefficients of consolidation in both vertical and horizontal directions. These are normally laboratory-determined from thin-walled piston samples and modified suitably with field permeability determinations and/or full scale field tests. Fig. 1 shows a typical full scale instrumented field test conducted on deep deposits of soft marine clay at Changi airport in Singapore (Choa et al 1981). To study settlement behaviour and stability of embankments and excavations in Bangkok clay similar field tests have been conducted by Asian Institute of Technology (Balasubramaniam, 1980). Analysis of such test results has yielded relevant soil parameters prevailing under field conditions and construction techniques. Both surface and deep settlement gauges should be used to monitor rates of compression of soil with depth. Piezometers of high standard of accuracy and reliability should be used to supplement settlement gauge readings. Inclinometers placed at strategic locations would be able to reveal lateral movement of soil.

The extent of improvement can be measured through field monitoring of settlement and pore pressure where anomalous behaviour of pore pressure is not encountered. Undisturbed soil sampling for the determination of soil properties such as bulk density, natural void ratio, undrained shear strength, water content and preconsolidation pressure can be carried out in order to assess the extent of improvement. It is noticed that there is difficulty in relying on any single soil parameter for such purposes. If the aging of the soft clay can be accounted for, the laboratory determination of preconsolidation pressure using improved techniques is believed to yield more reliable indication of the extent of soil improvement in normally consolidated soils. Fig. 2 illustrates a method of determining coefficient of permeability of clayey soil using a constant head device, while Fig. 3 shows the variation of both coefficient of permeability and void ratio with consolidation pressure. It is noted (Karunaratne et al, 1983) that the bilinear plot of coefficient of permeability in log scale vs void ratio has a sharp deviation at the void ratio corresponding to the preconsolidation pressure.

Among in-situ tests, vane shear test has been widely in use in determining soil improvement through undrained shear strength. Factors such as speed of rotation, plasticity index, clay anisotropy and aging of clay may mask the interpretation of data. Other in-situ tests such as standard penetration test, cone penetration test and pressuremeter test are far less sensitive in soft clay for any reliable evaluation.

Compaction of fills are usually designed based on empirical findings and experience from

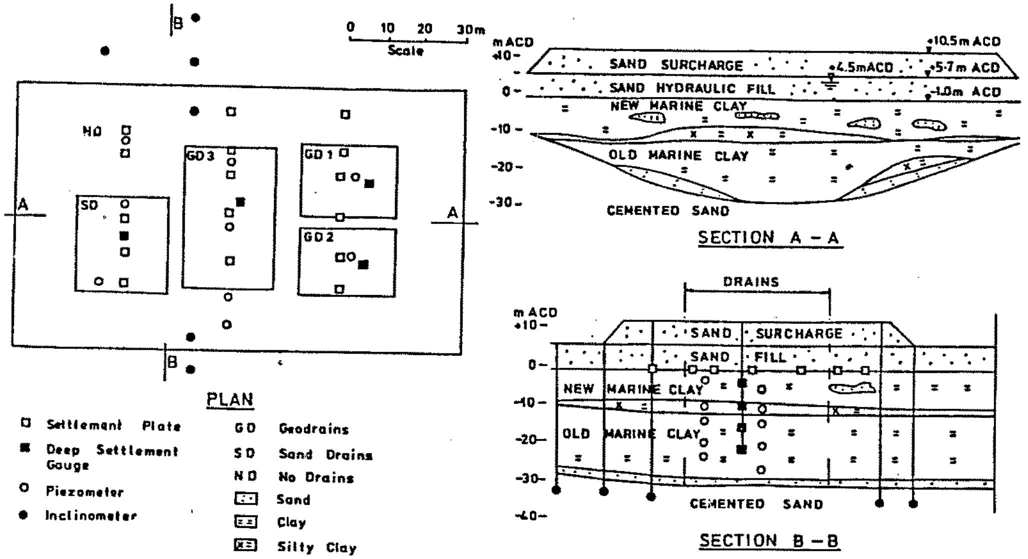


Fig. 1 Pilot Test Area

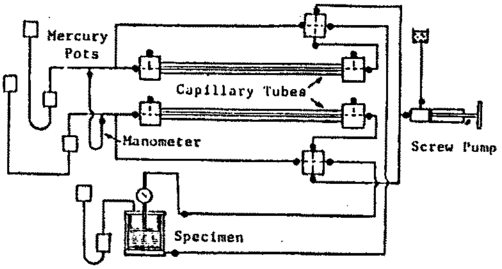


Fig. 2 Schematic Diagram of Apparatus

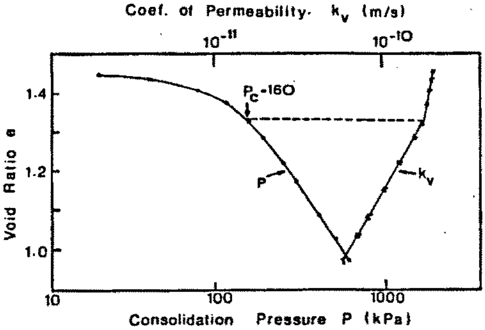


Fig. 3 Vertical Flow Permeability in Undisturbed Singapore Marine Clay

previous works. The depth of treatment, in metres, required for compaction using dynamic consolidation is considered to vary between $1/2\ \sqrt{MH}$ and $\sqrt{MH}$ where M is mass (tonnes) of the pounder and H is height (metres) of fall. Energy applied may have to be increased if loose material at great depths need to be treated. Installation of inclinometers, accelerometers and strainmeters at strategically important locations may be necessary for controlling the impact energy radiating to adjacent sites (Ramaswamy et al 1980).

Standard penetration test, static cone penetration test and pressuremeter test are used extensively to evaluate the densification of sand deposits by dynamic compaction (Ramaswamy and Yong, 1983). It appears that these three testing methods can give different relative density values for the same type of sand at similar effective overburden pressure. However, if any one of the methods is used consistently with a careful field or laboratory calibration (Moh et al, 1981) and the other methods used for confirmation purposes, the degree of densification after compaction can be satisfactorily evaluated. In this regard screw plate test has not received wide application as yet in this region. However, it is believed that not only the insitu properties of cohesibnless soils but also the undrained elastic modulus and the undrained shear strength of clayey soils can be evaluated successfully using this method (Selvadurai, 1984). These soil parameters can be used in the evaluation of soil improvement.

ACCELERATION OF CONSOLIDATION

Many coastal areas and flood plains of South-East Asian countries have widespread distribution of soft clay of marine or estuarine origin. Majority of this is believed to have deposited along with thick deposits of marine clay on the sandy Sunda shelf (Pitts, 1983). The soft clay is characterised by a high natural water content close to the liquid limit. For instance soft Bangkok clay has a typical natural water content in the range 112% to 130%, liquid limit 118% and plastic limit 43% (Balasubramaniam, 1980) whereas Singapore marine clay has these values around 50% to 65%, 70% to 95% and 20% to 35% respectively (Choa et al, 1981; Tan et al, 1982). The construction of lightly loaded structures such as embankments for roadways, low-rise buildings, industrial estates and reclamations on such clay deposits require improvement in ground conditions in order to reduce or eliminate excessive settlement.

One such technique is the placement of surcharge fills with or without vertical drains. Surcharge fills can be effectively used only when the mass permeability of soft clay is comparatively large, due to the presence of previous layers or lenses of soil, and when adequate construction time is available for soil treatment. Where available time is short the use of vertical drains for consolidation of soft clay deposits has become a standard technique.

Sand drains, used for over 30 to 40 years in assisting accelerated consolidation of soft clay, have been incorporated in several projects in this region (Tan et al 1982, Moh 1982). Both displacement and non-displacement types of sand drains have been employed in soil improvement projects involving soft clay. There is a great deal of uncertainity regarding the efficiency of these two types when the disturbance of adjacent soil, clogging of sand drains due to fines, necking and other discontinuities, soil fabric and sand column effect are taken into account. Many instances in which satisfactory as well as unsatisfactory results have been observed are reported. Balasubramaniam and Bergado (1984) reported, for instance, little improvement in soft Bangkok clay due to installation of 5 cm diameter sandwick drains at spacings of 1.5 m and 2.5 m and they attributed it to smearing, disturbance in soil fabric, hydrofracture and stress variations in soil. These uncertainties (Akagi, 1979) together with the difficulty in accurate prediction of settlement on soft clay deposits (Poulos, 1983) make it important to review the necessity of further research in this area.

In recent years, due to the scarcity of sand required for sand drains and the rapid treatment required within a short time, large projects in the region (Choa et al, 1981) have been attracted towards installation of prefabricated flexible drains in accelerating consolidation of soft clays. Some of the more important properties of this type of drains are adequate carrying capacity of water, sufficiently permeable non clogging and strong filter cover, durability during the project period, adequate anchorage capacity and adequate tensile strength.

Instances of having to densify a recent fill placed on a thick deposit of clay which needs soil treatment with vertical drains are not uncommon. Densification of a fill partly submerged in water cannot be undertaken with standard methods of compaction. To speed up fill densification and consolidation of underlying clay both processes have to be carried out simultaneously. At Changi airport reclamation, the sand fill was densified using dynamic consolidation method of applying heavy impact energy and the fill was consolidated using flexible drain. To ensure that in case the flexible drains used happen to rupture by the dynamic consolidation pounder, a stronger and more impact resistant flexible drain, known as Fibre Drain, was developed using natural jute and coconut fibres (Lee et al, 1980). The performance of this flexible drain in Singapore marine clay has been comparable with those of other commercially available drains.

The horizontal coefficient of consolidation most useful in the design of vertical drain systems is rarely determined in commercial laboratories. Where an attempt is made for its determination, standard consolidation test with a 90° turned specimen is wrongly used without realising the effect of change of coefficient of volume decrease in the process.

In the selection of coefficients of consolidation of soil, laboratory values are used from standard oedometer tests. In the absence of reliable test data the horizontal coefficients of consolidation is assumed to be 3 to 5 times the vertical coefficient of consolidation. Occasionally, in-situ coefficient of permeability is determined to check the validity of the design. Sand drain systems are designed based on Barrons theory of radial consolidation. The effects due to smear and well resistance are considered but incorporated with approximate properties estimated based on engineering judgement.

Flexible drains are designed using an approximate method similar to that proposed by Hansbo (1977) in which equivalent drain diameter is assumed to account for smear and well resistance or estimated on engineering judgement. These drains are in wide use in large scale projects due to their economic competitiveness. However, the effects of smear, well resistance, filter cover permeability and durability are yet to be investigated more thoroughly.

Moh (1982) gives an account of these techniques and poses difficulties in field evaluation of these methods. Tan et al (1982) presented an evaluation of non-displacement sand drain installation and Choa et al (1981) described the use of flexible vertical drains in treating soft marine clay. It is customary to base the success of vertical drain-surcharge systems incorporated in treating soft clay deposits on the determination of the extent of improvement in soil properties such as natural water content, void ratio, bulk density and undrained shear strength. Settlement at the surface and in depth and the excess pore pressure in the clay are important observations normally monitored for assessment of the treatment. Several instances of slow dissipation or virtually stagnated pore pressure have been reported. Choa et al (1981, 1984) described the pore pressure in a thick deposit of marine clay treated with vertical flexible drains and surcharge. The treated plan area of the clay was confined to a long strip of a reclamation 700 ha in extent. Fig. 4 shows the nearly stagnated pore pressure in piezometers installed in the clay within the drain system, despite the settlement observed in depth. A strong reason suggested for this phenomenon is the fact that a small strip of clay is treated in a largely untreated clay underlain by a recently filled reclamation. The untreated clay has a large pore pressure spreading into the area being treated. The effect due to the surcharge load beyond the width of the treated area is also shown to have contributed to retardation of the pore pressure dissipation. Anomaly of stagnated excess pore pressure with continuing settlement made Choa et al (1981) to recommend settlement and pre-consolidation pressure determination as criteria for evaluation of improvement. The success of soil improvement with vertical drains seems to depend on the method of assessment of settlement (Brenner et al, 1982), the type of loading in relation to the original stress conditions in the treated soil, (Al Alusi and Al Alusi, 1977; Choa et al, 1981), geometry of vertical drain system, soil behaviour after drains and surcharge placement.

DEEP COMPACTION

The standard methods of rolling soil materials in thin layers fail to satisfy densification needs of deep deposits of loose material. In such circumstances deep compaction techniques such as dynamic consolidation, vibroflotation and compaction piles have been successfully used.

Dynamic consolidation is the application of high impact energy by allowing a heavy pounder to drop from a great height freely onto the loose deposit. Fig. 5 shows the pitted appearance of the surface of the sand fill after the application of several drops of the pounder. This method has been successfully used (Choa et al, 1979) to compact a reclaimed sand fill which

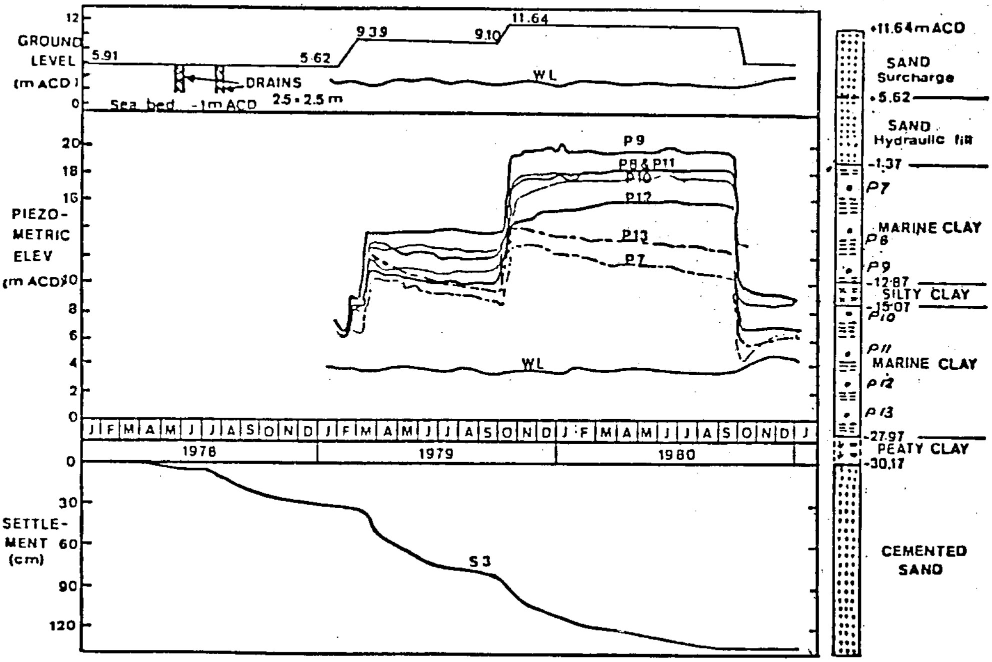


Fig. 4 Observations in Main Works

Fig. 5 D.C. Prints After One Pass

had fines up to 30%. Higher percentages of fines under water table were also treated after application of a surcharge to reduce the water content of fines. The efficiency of the application seems to depend on the energy per blow, number of blows per phase, grid spacing of the impact print of the pounder and the total energy. Thickness and type of the soil to be compacted, position of the water table and the characteristics of the underlying material also exert a great deal of influence. Fig. 6 shows the improvement in density, measured through Standard Peneration test, of a sandy fill (Choa et al, 1979) with respect to the spacing of prints. Fig. 7 and 8 show the effect of the underlying material and the amount of energy applied per blow respectively.

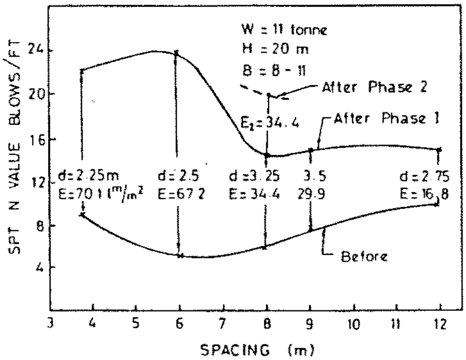


Fig. 6 Effect of Grid Spacing

This method has also been used successfully to treat 10 m deep loose soils containing upto 1 m diameter boulders (Mori, 1977), 10 m deep soft to medium stiff sandy silty clay (Ramaswamy et al, 1980) and peaty soil (Aziz et al, 1980; Lee et al, 1984).

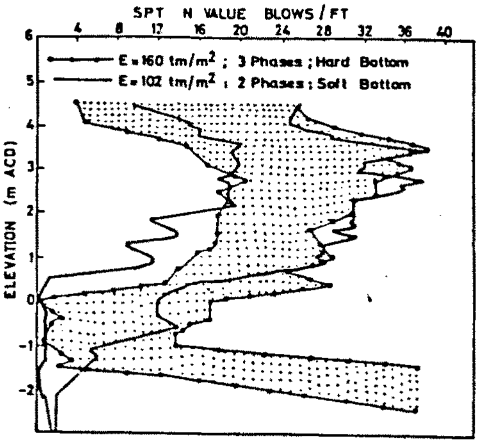


Fig. 7 Effect of Underlying Material

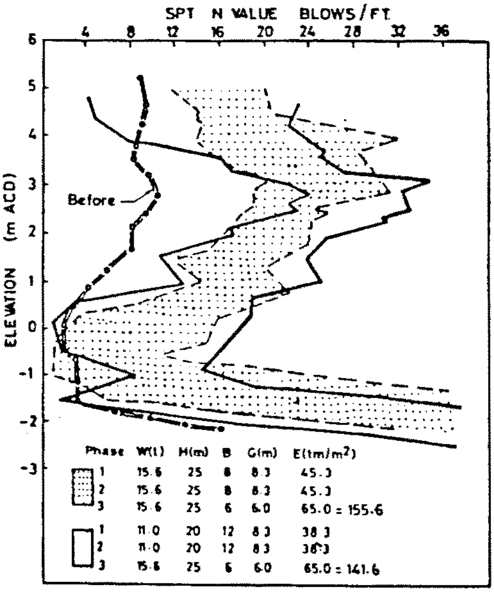


Fig. 8 Influence of Energy per Blow

With compressible peaty soils, inclusion of gas bubbles seem to lock up the pressure created in the pore water. Tamping can only be continued after partial dissipation of pore pressure. Field monitoring for pore pressure and ground movement is very important for these trials. Dynamic compaction has been used to compact loose fill slopes in Hong Kong (Phillipson,

1982) at appropriate sites away from occupied buildings and services.

Deep compaction of granular deposits has also been achieved using vibroflotation technique the success of which depends on the amount of fines in the deposit. Bhandari (1978) showed that effectiveness of vibroflotation reduced greatly beyond 25% fines in the soil. Due to low confining pressures at shallow depths the soil up to 1 m depth was also not adequately treated. In reporting deep compaction using vertical vibration of a casing and vertical vibration of a probe, Wallays (1983) showed that an open ended casing with an enlarged end of about 324 mm diameter increased the soil resistance 3.75 times in a 7.5 m deep deposit of fine sand. Fine sand was backfilled in the casing during vibration. Similar effect could be seen with vertical vibration using probes. In general, as the sand becomes coarser, the probing spacing can be generally increased. Sand has to be kept saturated in order to negate capillary cohesion. As the silt content rises it becomes less effective with a breakdown of effectiveness of such probes at a silt content of 12%.

Deep vibratory energy in the form of vibro-compaction and vibro-replacement has been described (Engelhardt and Kisrch, 1977) as suitable for densifying great depths of cohesive as well as non-cohesive soils. Moh et al (1981, 1982) describe the incorporation of compaction sand piles for improving the density of fine sand deposits so as to reduce the risk of liquefaction in earthquake prone regions. For designs of such soil improvement works, empirical approaches based on site conditions and operational methods are found to be more reliable.

SOIL STABILIZATION

Stone column

Stone columns used to stabilize soft soils perform as a reinforcement and drainage medium. When installed at close intervals, the stone columns are known to act as load-bearing stone piles enabling construction of light structures. This technique is popularly used in India and Japan and case study papers have been published in various proceedings of conferences held in the Southeast Asian region. The stone columns as such have been used as foundations for an oil tank built on soft or loose reclaimed land in Hong Kong (Loh, 1982). Ground improvement of a power plant by the use of stone columns has also been reported by Sheng et al (1982). Stone columns may also be used to reinforce non-cohesive soils (Rao and Bhandari, 1979).

Grouting

Grouting has been extensively used in relation to geotechnical construction, prior to construction for soil improvement, during construction for preventing problems and for the purposes of remedial works to solve problems arising after construction. Grouting has been used mainly to fill the voids in the soil in order to make it more impermeable and strong. During construction, grouting has been resorted to prevent seepage and to increase stability. For remedial works, grouting has been used in underpinning works and to seal the cracks.

Grouting has been used to seal decomposed granite and as grout curtain for a dam in Malaysia (Hooi and Yong, 1982). In connection with the underground construction of the mass rapid transit system in Singapore, jet grouting is being used extensively. A French grouting technique which uses the Tube-a-Manchette and Double-Tube methods has been used for a sewerage project in Taipei City (Chi, 1982). The Hong Kong Mass Transit Railway Corporation conducted a test chemical grouting programme at the location of a trial tunnel drive at Tsim Sha Tsui in the South of the Kowloon Peninsula. Morton and Leonard (1980) have reported the treatment procedure for both the shaft and the short tunnel (Fig. 9) and the estimated order of permeability reductions (Table 1) for the Argyle Station.

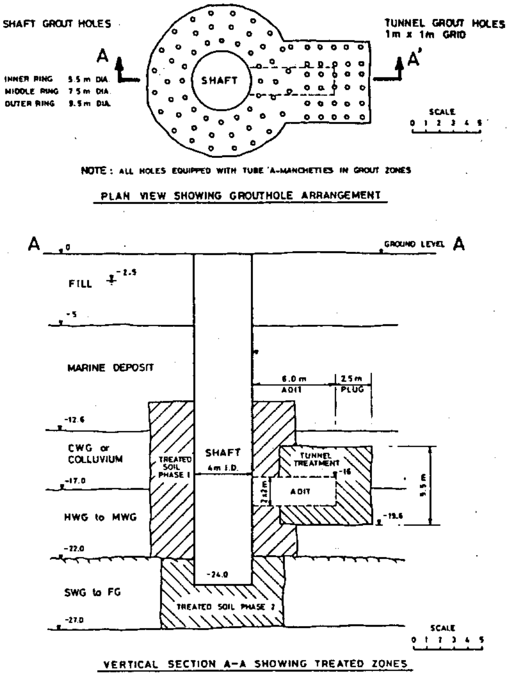


Fig. 9 Trial Ground Treatment Around Shaft and Tunnel

Table 1
Argyle Station: Estimated permeability reduction

Section	Permeability Reduction	Remarks
1	1/307	3 line curtain
2	1/507	3 line curtain
3	1/337	3 line curtain
4	1/1202	3 line curtain
5	1/115	1 line curtain

Deep cement and deep lime mixing

The process of deep cement mixing (DCM) and deep lime mixing (DLM) are methods of stabilization suitable for soft soils which involve in-depth mixing of cement or lime with the insitu soil to form cement stabilized or lime stabilized columns. There is no known application of this deep mixing technique in South East Asia, although it has been used in Japan and Sweden (Terashi et al, 1979, Broms and Borman, 1977). Research has indicated (Ramaswamy et al, 1982) that the method is applicable to marine clay of Singapore. Use of deep hole lime stabilization to stabilize an unstable clay shale embankment in Thailand has been reported (Ruenkrairergsa and Pimsarn, 1982). From a recent investigation made in Singapore, it appears that the DCM or DLM methods, although effective, are not as cost effective as alternative stabilization techniques.

Use of Admixtures

Admixtures such as emulsified asphalt (Ruenkrairergsa, 1979), lime-rice hull ash (Lozaro and Moh, 1970), emulsions with lime or cement (Rananand and Pussayanarin, 1971), common salt (Lua, 1978), cement (Ramaswamy et al, 1984; Ramiah and Alani, 1979; Ramaswamy, 1983; Ting 1971) have been used for shallow stabilization of subgrade soils for pavement construction. Cement stabilization has also been tried on weathered rocks (Ruenkrairergsa and Sanguandeekul, 1977) and on granitic soils (Ruenkrairergsa, 1980).

Extensive application of cement as admixture for lateritic soils involving more than 1400 km of soil cement roads in Thailand (Fig. 10) has been reported Ruenkrairergsa 1983) and Rananand (1973). Soil cement roads in Northeastern Thailand have generally used lateritic soil as road material. Their performance in service for over 15 years has been quite satisfactory. Only 3% to 8% of cement by weight was found necessary for the lateritic soil of Thailand to develop an unconfined compressive strength of 2 MN/m^2 which makes it suitable for road base construction. Ruenkrairergsa (1980) has described the occurence and distribution of granitic soil in Thailand and the estimation of strength parameters for such soils from the regression equations derived for a specified range of cement content. Most silty clay types occurring in Singapore are possible to be economically stabilized by using cement admixture. The effect of cement content on 7-day unsoaked CBR values on silty clay samples obtained from 16 different locations from Singapore is shown in Fig. 11 (Ramaswamy, et al 1984). Details of locations of samples are noted in Fig. 12.

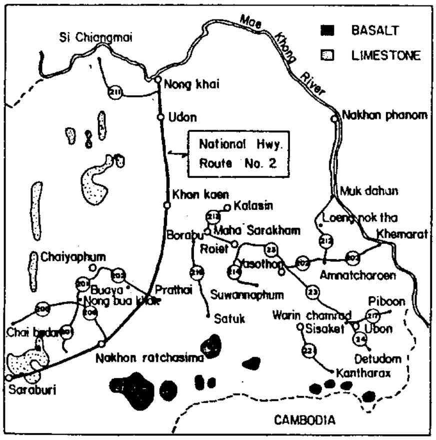


Fig. 10 Soil-Cement Treated Routes in North-eastern Thailand

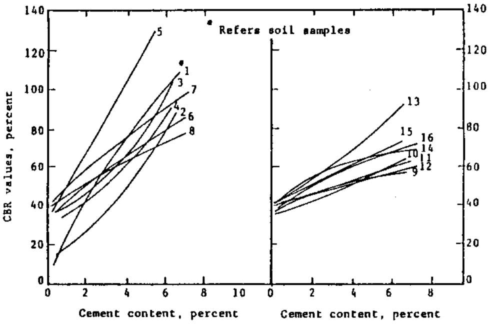
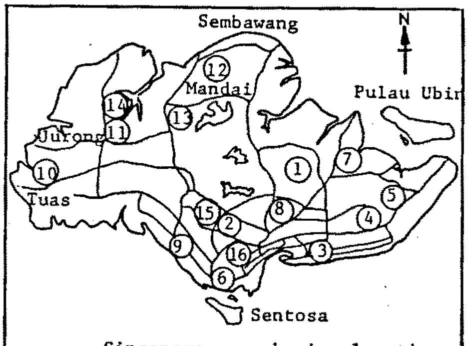


Fig. 11 Effect of Cement Content on 7-days Unsoaked CBR Values

The feasibility of using lime to stabilize fine grained soils has been investigated by Ramaswamy et al. (1982). The increase in strength of marine clay from Singapore with the lime admixture is shown in Fig. 13. Combinations of cement and lime to stabilize silty clay soils have also found to be practical (Ramiah and Alani, 1979, Ramaswamy et al, 1982). Lime in combination with rice hull ash (Lozaro and Moh 1970) has been used to stabilize deltaic clays. Sandy silt stabilization has also been accomplished by the use of emulsions with lime or cement (Rananand and Pussayanarin, 1971).



Singapore map showing locations of collection of soil samples

Sample	Location
1	Boundary Road
2	Farrer Road
3	Kampong Arang
4	Jalan Eunos
5	Upper Changi
6	Telok Blangah
7	Ponggol
8	Toa Payoh
9	Kent Ridge
10	Tuas Village
11	Chua Chu Kang
12	Sembawang
13	Mandai
14	Lim Chu Kang
15	Bukit Timah Road
16	Sepoy Lines

Fig. 12 Location of Soil Samples

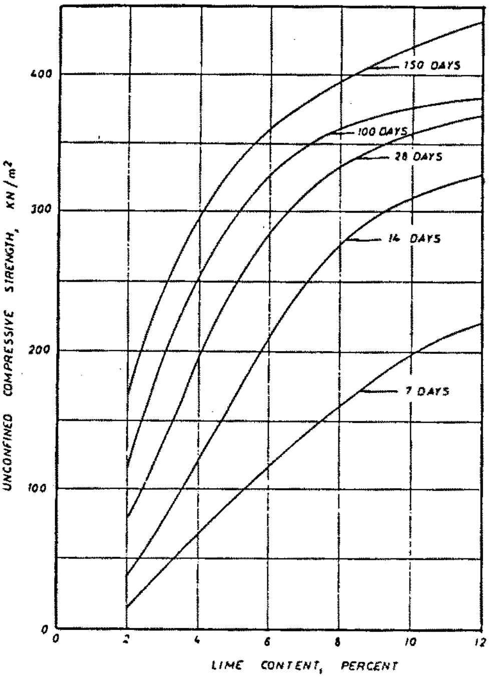


Fig. 13 Variation of Unconfined Compressive Strength of Lime Treated Marine Clay with Time

Electro-osmosis

The phenomenon of electro-osmosis and its applications for soil treatment are quite well known. Although, there have been a number of applications of electro-osmosis stabilization in Europe, USSR and USA, somehow in Southeast Asia, the technique has not found much popularity. The reason is probably the lack of confidence and expertise arising out of lack of experience on the one hand and the reluctance to try a method which is known to be quite expensive on the other. However, electro osmosis was found to be the only suitable technique to solve a problem of embankment stability in Singapore when circumstances prevented adoption of other soil improvement techniques. The case study on this successful application has been published (Chappell and Burton, 1975; Ramaswamy, 1979). It was observed that the electro-osmotic stabilization could be accomplished very economically and quickly contrary to the common belief that it may not work and may be a costly method. Fig. 14 shows the details of soil profile and typical layout of electro-osmotic stabilization used in Singapore (Chappel and Burton, 1975). The possibility of economical stabilization by electric-osmosis in Southeast Asia based on the Singapore experience has been attributed to the high salt (3% to 5%) content in the soil which promotes electro-osmotic flow whereas in the northern hemisphere, the process is retarded by a no more than 1% salt content in the soil.

Reinforced Earth

Reinforced earth structures made their debut in this region in 1981 with the construction of a road embankment wall of 7.5 m maximum height on 4 to 6 m of soil overlying medium stiff residual soil in Singapore (Tan et al, 1982). Interlocking precast concrete panels were used as facing elements and ribbed galvanised steel strips employed as reinforcement elements in gravelly sand backfill. During construction, instruments were installed and a pull-out test performed to study wall behaviour and check design assumptions. The second such structure was a 11 m high road embankment wall in Hong Kong providing, in combination with an underlying box culvert, an alternative crossing over a stream to the originally proposed prestressed concrete bridge (Kennard et al,

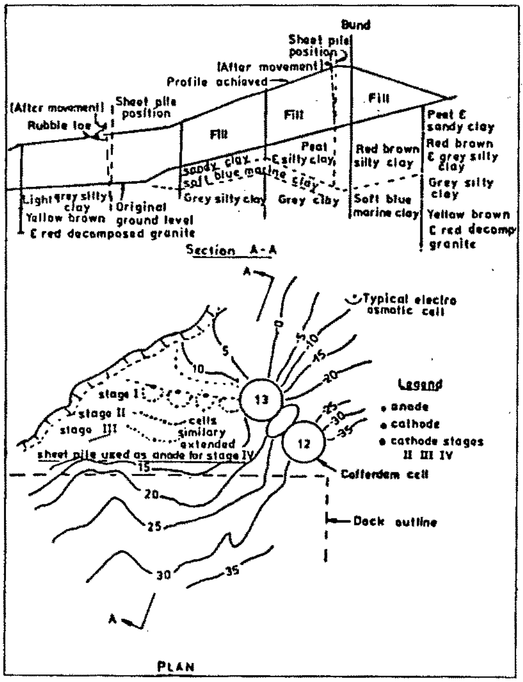


Fig. 14 Details of Unstable Embankment Showing Soil Profile and Typical Layout of Electrosmotic Stabilization of Sembawang Shipyard

1982). A wide range of physical and chemical tests were carried out to confirm the suitability of the available granular fill, and pull-out tests performed to determine the coefficients of friction between ribbed galvanised steel reinforcement strips and the proposed fill. Concrete panels were adopted as facing material.

Subsequent cases of reinforced earth structures adopted in Malaysia include a 4 m retaining wall to a slope at Tasek Utama golf Club, Johor Baru, upon which a grandstand was supported, a 7.5 m road embankment wall at Jalan Mahamery and 17.5 m embankment wall for a highway project at Jalan Dato Onn, Kuala Lumpur, and a similar 7.5 m wall at Tanjong Bunga, Penang constructed in the presence of nearby piling. At the Jalan Dato Onn site, seven reinforced earth structures were incorporated and mining sand found suitable as backfill.

In industrial usage, two 9.75 m reinforced earth walls were built for a quarry at Pulau Ubin in Singapore while blasting operations proceeded unhindered. At Kalimantan, Indonesia, five LNG tank containment walls are being built to the stringent requirements of the US National Fire Protection Association Standards.

Soil Nailing

Soil nailing is beginning to make its impact in Singapore with its current application in excavations for Orchard Boulevard mass rapid transit station in mainly stiff residual soil. Maximum depth of excavation is some 20 m of which the upper 5 m slopes at 1 : 1 and is faced with 75 - 100 mm of shotcrete, and below which the excavation face steepens to 5 : 1, where a similar surface layer of shotcrete, requiring the support of 5 - 12 m long steel bolts of 16 - 32 m diameter grouted in 50 - 100 mm diameter boreholes at 1 m spacing, is placed. The soil nails are threaded at the exposed end to receive a bearing plate tightened against the shortcrete facing by a nut.

Geotextiles

Geotextiles are in fairly widespread use throughout the region and, in Singapore, non-woven synthetic fabrics are routinely laid on subgrades of highways by the Public Works Department as filter material receiving the road base and wearing course. Furthermore, the Port of Singapore Authority and, more recently, Jurong Town Corporation have been employing such materials in large-scale reclamation projects as filter material between the surface stone armour and embankment fill of dykes. Ramaswamy and Aziz (1983) have investigated the feasibility of adopting jute fabric alternative to synthetic geotextiles for road construction in developing countries. Younger and Rananand (1982) reported the use of geotextiles in Thailand since 1978, for instance, Fibertex in river bank protection works, and widespread use of Terram in drainage works as protective filter or for erosion control in embankment works. An indication was provided on the extent of works undertaken with the latter material most commonly used in Thailand, as reproduced in Table 2. They also quoted comparative tests undertaken on Bidim, Terram and Typar by the Thai Department of Highways in 1980.

IMPROVEMENT OF SPECIAL SOILS

Two important types of special soils of this region requiring treatment are mine tailings and soft peaty deposits. In Singapore, the former material takes the form of silt ponds as a result of quarrying for sand. The Housing & Development Board has treated the coarse materials near the point of discharge of tailings with a combination of prefabricated vertical drains and surcharge. The mud-like tailings discharged at the furthest points as well as tailings of intermediate location, and hence consistency, tend to be pumped out to discharge at sea, the latter materials requiring preliminary loosening by jetting. The tin mining ponds of Malaysia have similar distributions of materials and consistencies as silt ponds. A current project in Kuala Lumpur proposes pre-treating the tailings of mud-like consistency, referred to as "slime", with prefabricated drains and surcharge after which sufficient lateral support is expected to be available for stone columns introduced by vibroflotation to support foundations of a low-rise housing development.

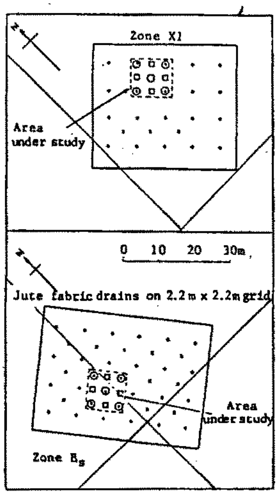
TABLE 2

GEOTEXTILES — MAIN USAGE OF TERRAM SINCE 1980

(Courtesy of East Asiatic Company (Thailand) Ltd.)

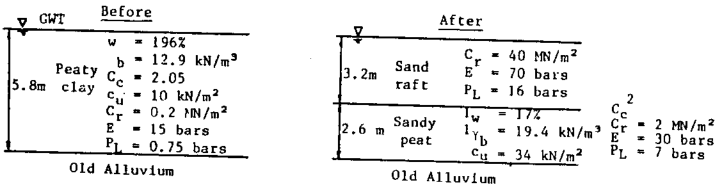
YEAR	No	CLIENT	CONTRACT	T700-m^2	T1000 — m^2	T1500 — m^2	T2000 — m^2	T3000 — m^2
1980	1	Royal Bangkok Sports Club	Surface Water Drainage and Separation	2,000	450			
	2	Royal Bangkok Sports Club	Cricket Field Drainage	1,650	1,460			
	3	Royal Irrigation Department	Krasian Dam, Suphanburi		1,000			
			TOTAL 1980	3,650	2,910			
1981	4	Harbour Department	Coastal Defence		2,700			
	5	Royal Bangkok Sports Club	Surface Water Drainage	675				
	6	Department of Highways	Pasak River Bank Protection		2,000			
	7	Royal Irrigation Department	Irrigation Canals	2,700	2,700			
			TOTAL 1981	3,375	7,400			
1982	8	Commercial Warehouse Auth.of Thailand	Warehouse, Bangkok	2,700	706			
	9	Department of Highways	Ping River Bank Protection	4,275	1,800			
	10	British Club, Bangkok	Tennis Court Drainage	1,422				
	11	Khon Kaen University	Sewage Treatment Plant		1,800			
	12	Department of Highways	Road Construction				1,800	
82/83	13	National Energy Authority	Huai Mong Dam, Nongkai		33,000		32,000	
			TOTAL 1982	8,397	37,306		33,800	
1983	14	Bank of America	Embankment Stability Bangkok		1,400			
Advance Orders	15	Royal Thai Navy Dockyard	Bank Protection			13,500		
	16	National Energy Authority	Huay – Sapan Hin Hydroelectric Dam, Chanthaburi	1,000	40,000		1,000	1,000
	17	Public Works Department	New Memorial Bridge	20,000				

In Singapore, a process of dynamic replacment with sand columns at close spacing, using standard dynamic consolidation equipment, is being employed to provide support for strip foundations of heavily-loaded structures in an area of suspected past quarrying and associated tailings. A similar process was reported (Lee et al, 1984) of a field trial on swampy ground where the main depot of the Singapore mass rapid transit system will be located. The upper 5-8 m of soft peaty clay deposits were thus initially treated by dynamic replacement and mixing (DRM) with sand to improve their strehgth and compression characteristics and practically negate potentially large secondary compressions, after which these and underlying soft fluvial deposits were further stabilised by surcharging with prefabricated drains to accelerate primary consolidation. Fig. 15 shows the treatment carried out in shallow peaty deposits and peaty deposits underlain by fluvial deposits to greater depths, respectively. The ground properties determined before and after treatment of an area of peaty soils only is shown in Fig. 16. As shown, considerable improvement was achieved after treatment, the settlement-time curve in Fig. 17 confirming the negation of secondary compression characteristics of the original peaty soil and virtual completion of settlement within the 5-month treatment period specified. Another project involving similar dynamic replacement of 3 - 4.5 m of peaty clay with 3.5 - 6 m of medium silty clay surface cover, for warehouse construction in Singapore, has also been reported by Ramaswamy et al (1979).



◆ 1st & 2nd pass prints – on 8 x 8 m grid 15 blows of 15 tonne falling 15 m
x 3rd pass prints – 15 blows of 15 tonne falling 15 m
□ 4th pass – 15 blows of 15 tonne falling 10 m
○ 5th pass – 35 blows of 15 tonne falling 20 m

Fig. 15 D.C. Print Locations



[1] Based on mainly sandy sample; average properties between these and values shown in Fig. 9 for Zone B_s

[2] No tests carried out in Zone X1, $C_c = 1.0$ in Zone B_s is applicable except note 1

Fig. 16 Inferred Ground Conditions at Zone X1 Before and After Treatment

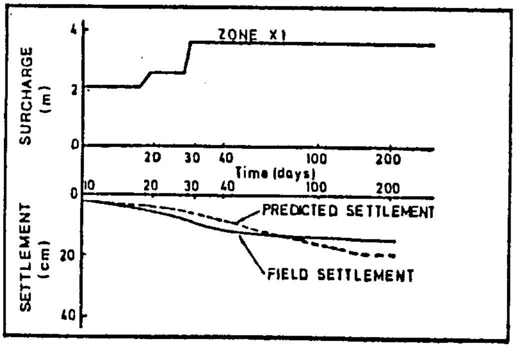


Fig. 17 Field Settlement Versus Long-term Prediction

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