GEOTECHNICAL ENGINEERING IN SOUTHEAST ASIA, PAST, PRESENT AND FUTURE

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GEOTECHNICAL ENGINEERING IN SOUTHEAST ASIA PAST, PRESENT AND FUTURE

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This paper is based on the text of the Author's Special Guest Lecture which he delivered to the Ninth Southeast Asian Geotechnical Conference in Bangkok, Thailand, in December 1987.

INTRODUCTION

The Ninth Southeast Asian Geotechnical Conference, celebrated the 20th Anniversary of the formation of the Southeast Asian Geotechnical Society, formerly the Southeast Asian Society of Soil Engineering. It was an auspicious occasion and an appropriate time to take a look at the development of geotechnical engineering in the Southeast Asian countries, in the past 20 years. As one of the founding members of the Society, it is a great pleasure for the author to undertake this task. The paper will not go into too much technical detail but will attempt to present an overview of the development of geotechnical engineering.

For reasons associated with the formation and membership of the Southeast Asian Geotechnical Society, Southeast Asia is defined in this paper as comprising Hong Kong, Malaysia, the Philippines, Republic of China (Taiwan), Singapore, Sri Lanka, and Thailand, with their geographical locations shown in the map in Fig. 1, The total land area of these countries covers about 1.26 million sq km and stretches for more than 2,700 km from east to west and more than 2,500 km from north to south. With a total population of more than 160 million, Southeast Asia became the most rapidly developing region in the world during the past decade. Three of the countries in the region, i.e. Hong Kong, the Republic of China and Singapore have been recognized as the most important Newly Industrializing Countries (NIC) in the world and have been considered as the Four Dragons in Asia (the fourth one is Korea). Since development of infrastructure is the basis for economic development of a country, the importance of the contribution of geotechnical engineering cannot be over-emphasized.

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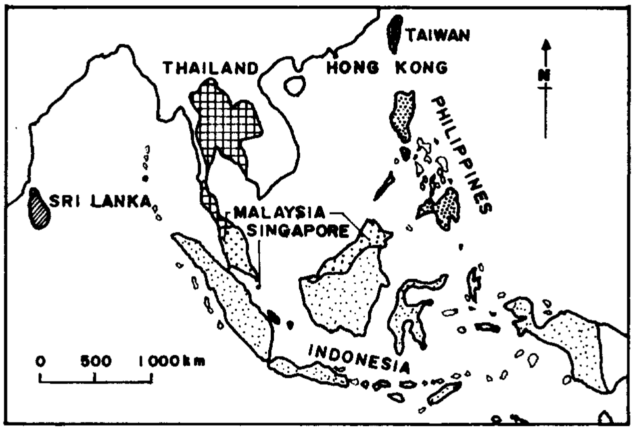


Fig. 1 Map of the Southeast Asian Region.

During the last 20 years, geotechnical engineering activities in Southeast Asia increased exponentially in terms of teaching, research, continuing education and practice. A large number of major projects have been completed or are in progress. Many projects have attained world records or worldwide reputation, such as the largest and deepest caisson foundation (the Singapore DBS Building and the Bank of China in Hong Kong), the largest area of diaphragm wall (the New World Centre, Hong Kong), the longest cable-stayed bridge (Chao Phraya crossing in Bangkok), one of the longest suspension bridges (Penang Bridge in Malaysia), the tallest hotel (the 72-storey Singapore Westin Stamford Hotel), one of the best airports (Singapore Changi Airport) etc.

SOUTHEAST ASIAN GEOTECHNICAL SOCIETY

Founded in 1967, the Southeast Asian Geotechnical Society, SEAGS (formerly Southeast Asian Society of Soil Engineering 1967 – 1982) has made significant contributions to the advances in geotechnical engineering in Southeast Asia related to infra-structure development, resource development, and mitigation and prevention of natural hazards damage. The Society was organized to cater for the needs of geotechnical engineers in countries in Southeast Asia which did not themselves have similar national societies. The objective of the Society is to promote cooperation among engineers, geologists and other scientists in Southeast Asia for the advancement of knowledge in geotechnical engineering. This has clearly been fulfilled over the past 20 years through holding periodic meetings, conferences, symposia, seminars and lectures, publication of a journal, and participation in the activities of international organizations. The Society is now affiliated with the International Society for Soil Mechanics and Foundation Engineering (ISSMFE), International Association of Engineering Geology (IAEG) and the International Society for Rock Mechanics (ISRM). The Society's membership has risen from a mere 28 in 1967 to more than 500 over the 20 year period. A history of the Society was published in the Commemorative Volume in conjunction with the 11th International Conference of the ISSMFE held in San Francisco (Balasubramaniam, et al, 1985). It is, nevertheless, worthy to cite some of the important contributions made by the Society in the past two decades.

Organizing and Co-sponsoring Conferences and Symposia

One of the most important activities of the Society is the series of Society conferences which are held once every two to three years in the various member countries of the Society. These conferences offer unique opportunities for the geotechnical engineers in the region as well as those from outside to meet to discuss and to exchange ideas. To date, nine conferences of the Society have been held. They include: First in Bangkok (1967), second in Singapore (1970), third in Hong Kong (1972), fourth in Kuala Lumpur (1975), fifth in Bangkok (1977), sixth in Taipei (1980), seventh in Hong Kong (1982), eighth in Kuala Lumpur (1985) and ninth in Bangkok (1987).

The papers submitted to these conferences covered a wide range in the field of geotechnical engineering, including soil engineering, rock engineering and engineering geology. By reviewing the papers presented, it is interesting to note that in the earlier conferences, the majority of the papers were prepared by authors from countries outside the Southeast Asian region, and mostly from developed countries. This trend has changed with the years, and the participation of engineers from Southeast Asia has been continuously increasing, as illustrated by Fig. 2. Part of the success of the nine Southeast Asian Geotechnical Conferences and the two Asian Regional Conferences organized by the SEAGS must be attributed to the special lectures delivered by world

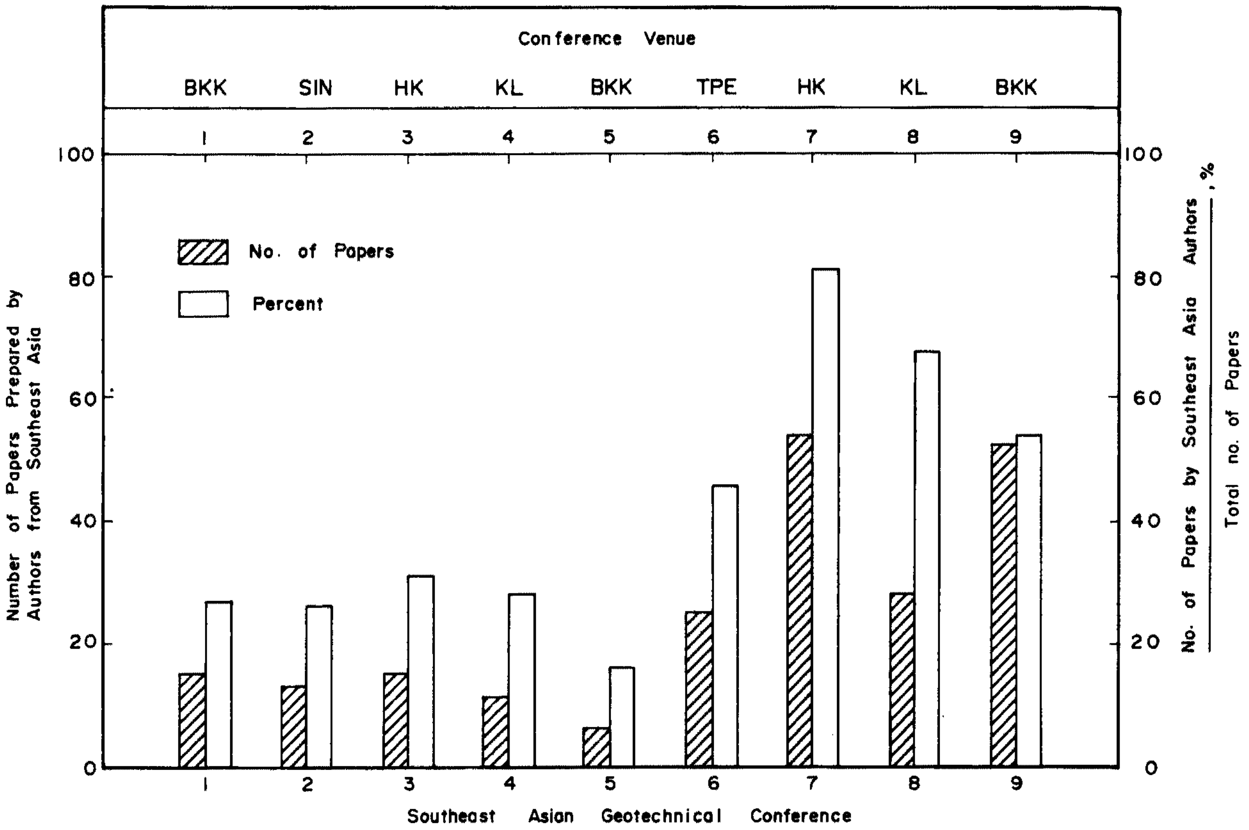


Fig. 2 Number of Papers Prepared by Authors from Southeast Asia at SEAGS Conferences.

renowned authorities in geotechnical engineering. They include Professors T. W. Lambe (1st, 3rd, 4th, 9th and 4th ARC), Ralph B. Peck (2nd), Victor de Mellow (3rd and 8th), L. Zeevaert (6th), E. Hoek (6th), N. Janbu (7th), K. Nash (4th ARC) and B.B. Broms (6th ARC). Special tribute must be given to the contributions made by Professor Lambe who not only delivered the inaugural address of the Society and guest lectures at four other conferences, but also has stimulated discussions by his active participation during the conferences.

Participating Activities of ISSMFE

As a member society of the three major international bodies in geotechnical engineering, SEAGS has been playing a very active role in the activities of ISSMFE, IAEG and ISRM. In addition to the Society's own conferences, the SEAGS has also been responsible for the organization of two Asian Regional Conferences of the ISSMFE, the fourth in Bangkok in 1971 and the sixth in Singapore in 1979. Society members have been active in all the six Asian Regional Conferences by serving as session chairmen, panel members, reporters (Lumb, 1971; Chin, 1971; Akagi, 1979; Chin, 1979; Lumb, 1979; Moh, 1979; Lumb, 1983) and lecturers (Sambhandharaksa, 1987).

The Society was responsible for the organization of specialty sessions including Engineering Properties of Lateritic Soils at the 7th ICSMFE (Moh, 1969) and Geotechnical Engineering and Environmental Control at the 9th ICSMFE (Moh, 1977). During the period of 1981 – 1985, the Society sponsored the Technical Committee on Sampling and Testing of Residual Soils (Brand & Phillipson, 1985). In the current period, the Society is sponsoring two technical committees of the ISSMFE, Tropical Soils, and Environmental Control & Waste Disposal under the chairmanship of Dr. E. W. Brand and Dr. Z.C. Moh, respectively. Other members of the Society, including a number of Past Presidents, have been and are active on ISSMFE Technical Committees on Information Advisory, Soil Sampling, List of Members, Computer Application, Landslides, Professional Practice, etc. Besides committee works, members have also served as chairmen, panel members and theme lecturer (Brand, 1985) of international conferences.

Two of the Past Presidents of SEAGS have served as the Vice President of the ISSMFE, Dr. Z.C. Moh from 1973 to 1977 and Professor F.K. Chin from 1981 to 1985. The immediate Past President, Professor A.S. Balasubramaniam is the current Vice President of IAEG (1987 to 1991).

The SEAGS has indeed made significant contributions to the development of geotechnical engineering in Southeast Asia. Besides the hard work and efforts made by the members and staff of the Society, special credit must be given to Dr. Milton E. Bender, Jr., former Dean of SEATO Graduate School of Engineering and the first President of the Asian Institute of Technology. With Dr. Bender's enthusiastic support, the first conference was held in 1967 at which time the SEAGS was founded. The continuous support given by the AIT's Trustees, administration and faculty is vital to the operation of the Society. It should also be mentioned that one of the most devoted members of the Society is Professor A.S. Balasubramaniam who has served as the Secretary – Treasurer of the Society for 14 years continuously, and as the President from 1985 to 1987.

HUMAN RESOURCES

In the past two decades, growth of geotechnical activities has increased exponentially as part of the rapid economic development in Southeast Asia. Demand for geotechnical engineers, e.g. engineers with specialized training in geotechnical engineering or engineers with accumulated experience in the field, has consequently been on an ever-expanding scale. In order to assess the availability and utilization of human resources in geotechnical engineering in Southeast Asia in the past 20 years, a questionnaire was prepared and sent to all academic institutions of higher learning, major consulting engineering firms, some government agencies and General Committee Members of the SEAGS. Items in the questionnaire included the number of graduates with master's and doctorate degrees in geotechnical engineering from each institution, number of faculty members, research interests, number of geotechnical specialists in governmental services and private practice, significant projects from a geotechnical point of view, important publications and local activities. From the survey, a good picture can be obtained about the human resources in academic institutions, including the number of faculty members and graduates. Figure 3 shows that before 1975, there were very few graduates with degrees in geotechnical engineering. The trend has changed rapidly since then. In 1987, there were more than 100 graduates with a master's degree in this field of specialization. Likewise, the number of faculty members in the academic institutions also increased rapidly in the last 12 years as shown in Fig. 4.

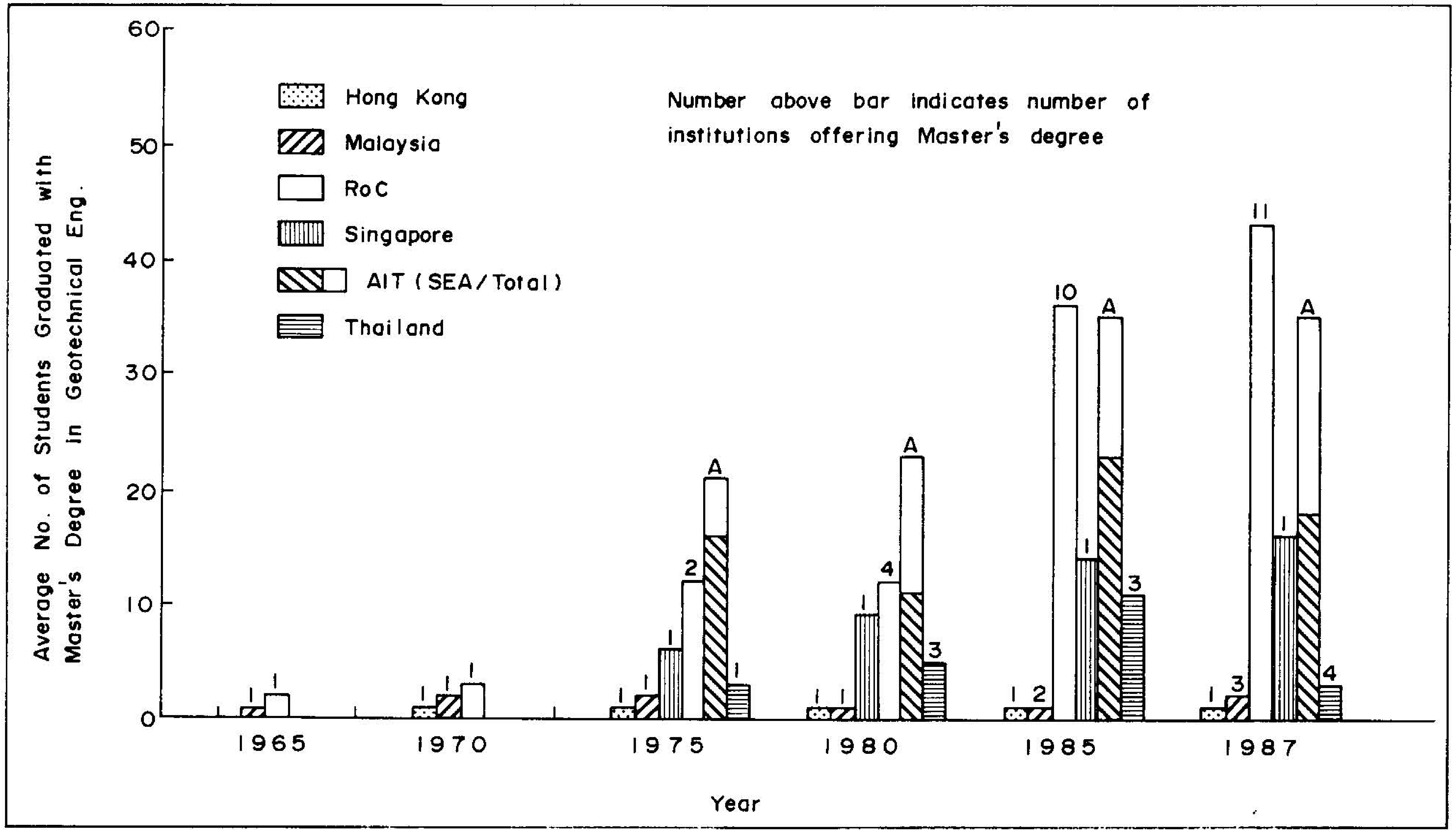


Fig. 3 Number of Academic Institutions offering a Master's Degree in Geotechnical Engineering, and Number of Graduates.

Geotechnical engineers are employed either by the private sector, which includes consulting engineering firms and the construction industry, or governmental agencies or state enterprises. In the government sector, only in Hong Kong is there a specific organization dealing with geotechnical matters, i.e. the Geotechnical Control Office. In the other four countries, geotechnical engineers are spreading over many different departments and agencies. Shown in Fig. 4 are the number of geotechnical specialists engaged by consulting firms, the construction industry, and governmental agencies. Due to the large number of organizations involved, it was very difficult, if not impossible, to get completely accurate statistics, particularly from governmental agencies. Nevertheless, the trend of changes is clearly shown. One interesting point which is worthy of note is the continuous growth in the number of geotechnical engineers employed by the government in Hong Kong although there was a decline in the private sector. In 1987, the number of geotechnical engineers employed by the Hong Kong Government is more than that employed by the private sector and educational institutions together in that territory.

GEOTECHNICAL ENGINEERING IN PRACTICE

Development of Geotechnical Engineering in Southeast Asian Countries

Republic of China (Taiwan)

Development of geotechnical engineering in the Republic of China (Taiwan) in the last two decades can be divided into three stages. In the years prior to 1967, there was very little development in the field of geotechnical engineering except some work connected with the design and construction of Shin-mun Reservoir and a few other small dams.

From 1967 to 1972, was the period when the ten major construction projects took place, including the first North-South Freeway, nuclear and thermal power plants, Ta-jian and Tsuen-wen Reservoirs, integrated steel mill and ship building industry. During that time, most of the geotechnical engineering work, in fact most of the major design work, was undertaken by foreign experts. The teaching and research facilities in the academic institutions were poor and there was practically no graduate program in geotechnical engineering.

The period from 1973 to 1980 can be considered as the initial development stage in geotechnical engineering in the ROC. Due to inadequacy in geotechnical input, many post-construction problems of the ten major projects started to appear. These problems had to be solved by the local engineers. The importance of pre-design geotechnical study, investigation and research was gradually being recognized. The establishment of the first consulting engineering firm specialized in geotechnical engineering, Moh And Associates, Inc. (MAA) in 1975 made a major impact on the practice of geotechnical engineering. Some of the important projects carried out by MAA during this period include the use of special techniques for emergency rehabilitation of the airport runway (Moh & Moh, 1978) and the introduction of instrumentation for safety monitoring of deep excavation in soft ground (Moh & Ou, 1979a; Moh & Song, 1980).

Rapid development in geotechnical engineering occurred in the period between 1981 and 1987. Many special techniques in site investigation, design and construction of geotechnical related facilities were introduced into or developed in the country. These developments were closely related to the fast economic development of the country in the 80s. Excavation in soft ground for construction of building basements was up to 30m depth. Diaphragm walls were constructed up to 54.5m deep. Large diameter bored piles up to 260cm in diameter and PC piles of 80cm diameter were not uncommon. Instrumentation for monitoring of construction safety and soil behavior became routine for all major deep excavations and this has not only resulted in more economic designs but also considerably reduced damage to and losses of surrounding structures. Many soil improvement techniques including sand compaction piles, prefabricated drains, sand drains, and preloading were utilized to improve the poor ground conditions in many parts of the country (Moh, 1985).

Also during this period of time, the teaching and research facilities in the academic institutions improved considerably. The number of institutions which offer a postgraduate Master's program increased from 4 in 1980 to 11 in 1987 and the number of faculty members in geotechnical engineering also increased by about 3 fold (Figs. 3 and 4).

To promote the development of knowledge in geotechnical engineering in the ROC, a Geotechnical Engineering Committee was established under the Chinese Institute of Civil and Hydraulic Engineering in 1974. Professor J.J. Hung headed the Committee from 1974 – 1976 and Dr. Z.C. Moh chaired the Committee from 1976 to 1985. The Committee organized seminars and conferences in addition to participation in the annual meetings of the Institute. A series of three seminars was organized by the Committee between 1977

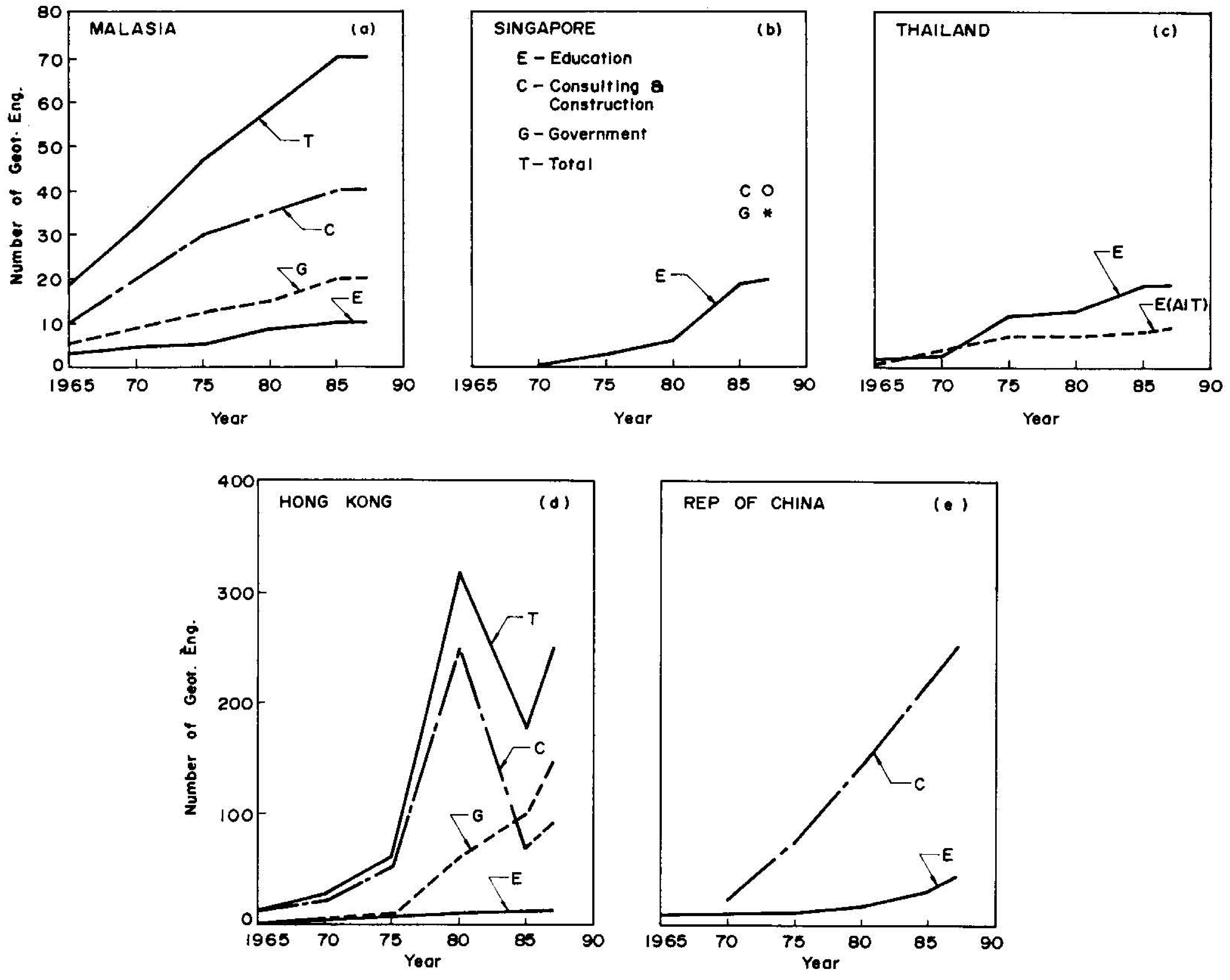


Fig. 4 Number of Geotechnical Specialists in Various Sectors of Employment.

and 1979 and each of these attracted more than 300 participants (Moh, 1977, 1978, 1979). These activities well illustrated the level of interest in this relatively new field in Taiwan.

One of the major contributions of the Geotechnical Committee to the profession, is the publication of the Unified Translation of Geotechnical Terminologies in Chinese (1985). The Committee is also working on codes of practice for site investigation and foundation design. In addition, the Geological Society of China has been very active over the years. Many symposia and meetings have been organized.

The most significant construction projects, from a geotechnical view point, carried out in the ROC during the last 20 years are the Third Nuclear Power Plant, Hsing-Ta Thermal Power Plant, Harbours in Kaohsiung, Suao and Taichung, Ming-Hu Pumped Storage Reservoir, Feitsui Reservoir, Di-Hwa Sewage Treatment Plant and sewerage tunnels in Taipei, Kaohsiung Cross Harbour tunnel, Taipei Railway Underground Project, Taipei Railway Main Station, Keelung River Reclamation, Chung-Cheng Medmorial Hall, Liquid Natural Gas Terminal, and many tall buildings with deep excavations. Some of the projects will be described in later sections.

Hong Kong

In Hong Kong the first major civil engineering works which involved a great deal of 'geotechnical engineering' were all associated with the construction of the Kowloon-Canton Railway (Eves, 1913), which included the Beacon Hill Tunnel (Eves, 1911). Although there are few other published documents about civil engineering in the first half of this century, there was obviously a great deal of work done, particularly on reclamation (Tregear & Berry, 1959) and water supply (Woodward, 1935, 1937).

The first Hong Kong publications which truly deal with a 'geotechnical engineering' topic were those dealt with base course material for roads (Henry & Grace, 1948a, b). The first modern 'foundations' work appears to have been done by Tomlinson & Holt (1953). The design of the Hong Kong Airport was obviously of major geotechnical significance, and Grace & Henry (1957) produced great interest in the UK.

In the late 1950s and early 1960s, tall buildings were beginning to appear, and a Conference on tall buildings was held in Hong Kong in 1961 (Mackey, 1961). Professor Ralph B. Peck took part in this Conference as a Guest Lecturer.

The real 'dawning' of geotechnical engineering in Hong Kong was the Symposium on Hong Kong Soils held in 1962 (Lumb, 1962a). This contained some papers which are important to this day, particularly those by Lumb (1962b, 1962c).

Lumb dominated soil mechanics in Hong Kong from 1962 to about 1975. Apart from references cited above, he made other important contributions on Hong Kong Soils (Lumb, 1962d, 1965). His slope stability work is also important (Lumb, 1975), and his last Hong Kong publication was in 1983 (Lumb, 1983a).

During the early 'Lumb' period, some major civil engineering works were undertaken which involved appreciable geotechnical components, including a submarine pipeline (Goudy, 1965) and a major dam (Ford & Elliott, 1965).

Major landslide disasters occurred in 1972, and a Commission of Inquiry was held, which resulted in two important documents (Govt. of HK, 1972a, 1972b). Later (1976), there was another landslide disaster which resulted in another Inquiry and another important document (Govt. of HK, 1977). As a result of this, some 'scientific' method started to be applied to slope design, largely led by Binnie & Partners employed by the Hong Kong Government (Beattie & Chau, 1976; Beattie & Attewill, 1977).

In 1977, the Government formed the Geotechnical Control Office (GCO) which then as now was headed by Dr. E.W. Brand. Since its formation, the GCO has played a leading role in the development of geotechnical engineering in Hong Kong, by conducting research, investigation, development of mapping and design checks. Due to the nature of Hong Kong's geography and geology, much of the work of the GCO is related to residual soils and slope stability. The standard of practice in geotechnical engineering has improved considerably. The GCO has published a number of manuals and design guides. The most notable one is the Geotechnical Manual for Slopes which was first published in 1979 and revised in 1984 (GCO, 1984). A comprehensive bibiography on Hong Kong geology and geotechnical engineering was prepared by Brand (1988).

In 1978, a Geotechnical Group (now Geotechnical Division) was formed under the Hong Kong Institution of Engineers. The Group is active in organizing lectures and seminars. In addition, there is a Hong Kong Geological Society, formed in 1982 which has sponsored 5 seminars and conferences with published Proceedings.

The most significant projects, from a geotechnical viewpoint, carried out in the past two decades, include large scale marine reclamations, High Island Reservoir, Plover Cove Reservoir, water tunnels from China, Cross Harbour Tunnels, Mass Transit Railway, the New World Centre, Hopewell Centre, Hong Kong Bank, Bank of China, large site formation works for new towns, and large site developments for urban projects.

Thailand

Development in geotechnical engineering in Thailand in the past two decades can be considered in three stages. The first stage was pre-1967, when there was not much development or research work being carried out. Most geotechnical activities were connected with road construction and some water resources development. The late Dr. Chai Muktabhant pretty much dominated the geotechnical scene, and he was the author of the first major paper published on the now famous Bangkok Clay (Muktabhant, et al 1967).

In 1967, both the Division of Geotechnical Engineering at the Asian Institute of Technology (AIT) and the Southeast Asian Society of Soil Engineering (the predecessor of the SEAGS) were established. Much of the development in geotechnics in Thailand following the pre-1967 stage were very much related to the activities of these two organizations. From 1967 to 1973, was the second stage of development, and this was really the foundation stone for later development. Extensive research work was started on engineering behaviour of sedimentary deposits. The use of instrumentation and in situ testing was introduced. Major development projects up to 1973 included several thousand kilometres of roads and highways, small and medium sized dams for hydropower and irrigation, tall buildings for hotel and commercial developments.

From 1973 onwards, the research activities at AIT and the Chulalongkorn University continued to grow and expand, development work also intensified. Some of the most significant projects during this third stage of development include the natural gas project in the Gulf of Thailand with offshore platforms and several hundred kilometres of pipelines, exploration of lignites, construction of large rockfill dams and several long span bridges across the Chao Phraya

River in the Bangkok Metropolis, including the newly completed (December 1987) longest cable-stayed bridge in the world.

Besides prestressed concrete piles, which became popular in the late sixties, hollow prestressed concrete piles having a diameter of 60cm and length up to 35m, were introduced in 1979 for the construction of the first expressway in Bangkok. In the early eighties, large diameter bored piles founded in the second dense sand layer at a depth below 50m were used at the new Sathorn Bridge and new Memorial Bridge across the Chao Phraya River. Soil improvement schemes for accelerating rates of consolidation of the soft Bangkok Clay were also introduced during this period. One of the most serious engineering problems in Thailand today is land subsidence. Although extensive research has been carried out by AIT, no practical solution has yet come forth.

The Division of Geotechnical Engineering of AIT offers post graduate programs in soil engineering, engineering geology and rock mechanics to students from all countries in Asia. In the past two decades, more than 400 students graduated with master and doctorate degrees in these three fields. Many of the alumni now hold key positions both in Asia and elsewhere.

On the Professional side, although the Engineering Institute of Thailand does not have a special branch in geotechnical engineering, it often co-sponsors activities of the SEAGS and AIT. Most of the seminars and conferences are usually organized by these two organizations.

Malaysia

Similar to many other developing countries in Asia and around the world, a major part of the early development in infrastructure construction in Malaysia was dominated by foreign engineers from developed countries. In Malaysia, the two countries which exerted the strongest influence were Great Britain and Australia. A number of major projects including dams and reservoirs, irrigation schemes, highway systems, and offshore energy resource development had been completed before the mid-seventies. In the past decade, much more rapid economic development, particularly in the major urban areas, has occurred. The rise of tall buildings, construction of new transportation facilities such as airfields and expressways, development of mine waste areas, offshore explorations and reclamations, all require the expertise of geotechnical engineers. These construction activities have prompted development in geotechnical engineering in Malaysia especially in the areas of deep foundations, foundation in limestone terrain and tin mine wastes, slopes in residual soils, and soft ground construction.

Professor F. K. Chin can be considered as the dominant figure in geotechnical engineering in Malaysia for many years, particularly in the earlier years of development. He has contributed much to the understanding of behaviour of pile foundations and road embankments. From the early seventies onwards, several prominent geotechnical engineers have emerged, including Dr. W. H. Ting, one of the Past Presidents of SEAGS. Post graduate programmes and research activity at academic institutions, however, have not made much progress.

Since 1979, the Institution of Engineers Malaysia has had a Geotechnical Engineering Division which organizes periodic lectures and seminars. The IEM was responsible for the organization of the fourth and eighth SEAGS conferences.

Some of the more significant projects carried out in the past two decades are marine reclamations, reclamation of abandoned tin mines, off-shore works, North-South Expressway, East-West Highway, tall buildings and the Penang Bridge.

Singapore

Prior to 1976, there was not much development in geotechnical engineering in Singapore. The main contribution to the profession was the publication of the book on the Geology of Singapore by the Public Works Department in 1976. Dr. S. B. Tan was probably the only well-known geotechnical engineer in the country. Large-scale works involving geotechnical problems such as reclamations, were mostly carried out by foreign firms.

The period from 1976 to 1985 can be considered as the most rapid development period in Singapore. Many major infrastructures, new town developments and development of large commercial and residential complexes were carried out or initiated during that period. Large scale reclamations for the expansion of the Singapore Port facilities and the Changi International Airport not only demanded more economical and efficient methods for land reclamation but also enhanced the study and application of various methods of ground improvement. Construction of tall buildings demanded better understanding of behaviour of deep foundations and problems of negative skin friction on piles. During this period, observational methods and the use of field instrumentation for construction monitoring and control were introduced and widely adopted. Research facilities at the National University of Singapore have been greatly improved and research has become more active.

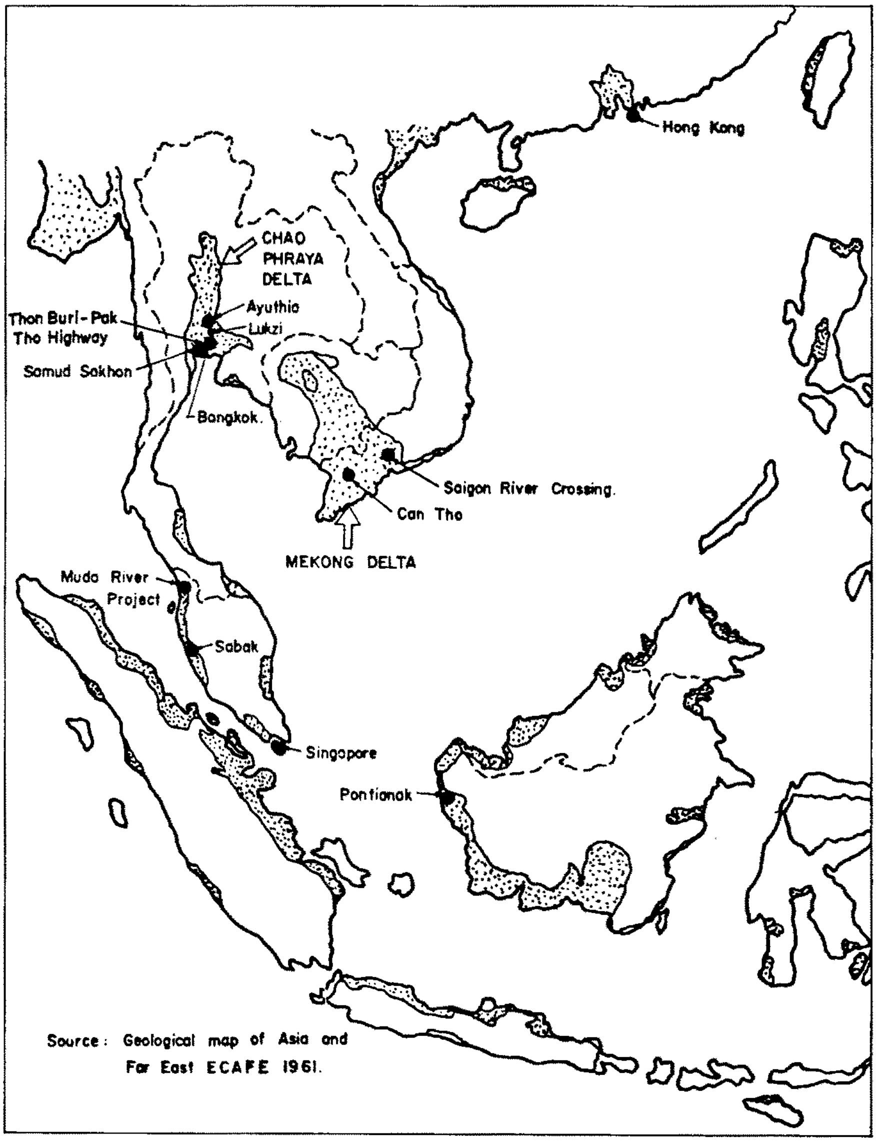
Although there is no special branch or committee for geotechnical engineering in the Institution of Engineers Singapore, the IES was responsible for the organization of two major conferences in geotechnical engineering. They were the second SEAGS conference and the sixth Asian Regional Conference of the ISSMFE. In addition to periodical seminars and some commercially organized conferences, the Nanyang Technological Institute has sponsored a series of five international seminars on geotechnical engineering, from 1983 to 1987.

The most significant projects involving geotechnical engineering are large scale reclamations (over 5000 ha in the last 20 years), Changi International Airport, Singapore Port, Mass Rapid Transit (MRT) System, expressways, highrise commercial and residential developments including the MRT reserve under the Chartered Bank, some of the largest and deepest caisson foundations at the DBS Building and OUB Centre.

Significant Development Studies and Projects

Soil Behaviour

The Southeast Asian archipelago has been described as being physiographically and geologically the most complex area in the world. It covers a total land area of about 3.2 million sq km and a population of over 300 million. Naturally, the existing number of different types of soil deposits in the region is very large. In view of economic development and population concentrations, the most important landform in the region is the low flat deltaic plains which occupy an appreciable portion of the total land area. Soils of sedimentary origin are thus becoming the most important type of deposit from the geotechnical engineering point of view. Besides these coastal areas, most of the terrain of the total land area of Southeast Asian countries is hilly and mountainous. Many developments in these mountainous and difficult terrains, particularly transportation facilities which link one part of a country to another, have emerged in recent areas. Residual soil deposits are the other major soil type of great interest to engineers.



Source: Geological map of Asia and Far East ECAFE 1961.

Fig. 5 Distribution of Recent Clays in Southeast Asia (after COX, 1970).

Sedimentary Soils

Cox (1970) was the first to study in detail the distribution of recent clays in Southeast Asia (Fig. 5). Most of these marine deposits are young in age, i.e. less than 10,000 years and vary in thickness from very thin to about 30m. The extent of the deltaic deposits varies from a few kilometres to more than 100km. The common features or engineering characteristics of these deposits are high natural water content, high compressibility and low strength. The groundwater table is generally very close to the natural ground surface which is another important factor for geotechnical engineering consideration. These deposits are found extensively in the Chao Phraya Plain in Thailand, coastal regions of Malaysia, Singapore, Indonesia, Hong Kong, Philippines and Taiwan, ROC. Among the deposits mentioned herein, the Bangkok Clay appears to have been studied most extensively. During the past 20 years, more than 500 "publications", including journal and conference papers, research reports, theses and dissertations, and other articles have been written and published on the geology, properties and behaviour of the Bangkok Clay. Two of the earliest papers which describe studies on engineering characteristics of Bangkok Clay are Muktabhant et al (1967) and Moh, Nelson & Brand (1969). A comprehensive bibliography on the Bangkok Clay has been compiled by Brand (1986). The Bangkok Clay has certainly attained world-class status along with London Clay, Leda Clay, Oslo Clay and Boston Blue Clay. A state-of-the-art report covering the engineering behaviour of the Bangkok Clay, marine clays in Singapore and Malaysia was prepared by Balasubramaniam et al (1985). The distribution and engineering characteristics of the Taipei silt formation; which is the major soil deposit in the rapidly developing Taipei Basin in Taiwan, ROC, are described in Moh & Ou (1979b), and Moh & Associates (1987a).

Residual Soils

As pointed out in the earlier section, with the notably exceptions of some large deltaic deposits, most of the land area of Southeast Asia is composed of hilly and mountainous terrain. Another common feature of the Southeast Asian countries is the mainly warm and wet climatic condition. This condition has resulted in varying depths of weathering of a wide range of igneous, metamorphic and sedimentary rocks and gives profiles which grade from residual soils at the surface through to unweathered bedrock at depth.

Among the five countries in Southeast Asia, Hong Kong can be considered as the most advanced in research, analysis and design in residual soils. Lumb published papers on Hong Kong residual soils as early as 1962 (Lumb 1962b, 1965, 1983). With the establishment of the Geotechnical Control Office, understanding of the behaviour of residual soils in Hong Kong, or more generally in all semi-tropical or tropical countries, has made significant progress, which has resulted in better site investigation, sampling (Brand & Phillipson, 1984, Brand 1985), analysis and design in this type of soil. As with Hong Kong, many of the studies carried out on residual soils in other countries, were connected to a study of landslides or slope stability. Ting (1979), Ting & Ooi (1976), and Moh, Guo & Huang (1987) presented studies on residual soils from Malaysia. Discussions on some of the residual soils problems in Taiwan can be found in Woo et al (1981), Woo et al (1982), and Moh et al (1987).

Reclamations

Among the five countries and territories covered in this paper, three of them are island countries with limited usable land areas and a relatively high population. Hong Kong, Singapore and Taiwan have populations of about 6.5 million, 2.5 million and 19 million, over land areas of approximately 10,050 sq km, 635 sq km an 36,000 sq km respectively. Because of the high population density and growing industrial and commercial activities, the demand for prime land is high. Vast areas of coastal land have been reclaimed from the sea with hill-cut soils and dredged sands. In Taiwan ROC, most of the newly reclaimed land is along the southwest coast and has been used for industrial development including the industry export zone and heavy industry zone in Kaohsiung, the Hsin-Ta Steam Power Plant and fishery industry such as shrimp farms. In Singapore, approximately 5,000 hectares of land has been reclaimed in the past 20 years and another 1,000 hectares of reclamation projects are currently in progress. Many of the important developments, such as Changi Airport, are situated on reclaimed land. Extensive reclamation has been carried out in Hong Kong. Reclaimed land now exceeds 5,000 hectares, 80 per cent of which has been formed in the last 20 years and extensive further reclamations are in progress or are planned. The proposed replacement airport will be located on a piece of newly reclaimed land.

Most of the land reclamation work in the past has used either hill-cut soil/rock or sea-bed sand. Due to depletion of these materials, the need to search for alternative sources of fill materials becomes evident. Since soft to stiff marine clay is generally present in abundance below the seabed surrounding coastal areas, the use of these clays for reclamation is certainly economically challenging. However, reclamation using hydraulically placed marine clay alone will result in lengthy construction time and will take a prohibitively along time for consolidation. An extensive laboratory and field test program was undertaken by the National University of Singapore to examine the feasibility and practical use of a layered clay-sand scheme for land reclamation. Lee et al (1987) reported that rapid consolidation can be achieved due to the shortened drainage path created by the layered clay-sand formation. A full-scale test for reclamation of 40 hectares of land by using the layered scheme is underway at the present.

Full scale tests on soft ground

Analysis and design in geotechnical engineering, for all practical reasons, are usually based on information obtained from a limited amount of site investigation, in situ and/or laboratory testing, and on assumptions and simplifications using idealized models. The actual behaviour, i.e. the macro-behaviour, of a soil deposit, in fact might be significantly different from that predicted from idealized model and test results of small soil samples. A full scale prototype test is the only way to obtain a realistic understanding of the soil behaviour under any proposed construction. However, due to the cost, full scale tests can only be carried out for projects of significant size. Due to scarcity of available land for infra-structure development in the rapidly growing countries of Southeast Asia, soft ground construction has become more and more important. Many marginal lands, including very soft deltaic plains, swampy areas and reclamation from the sea are being developed for infrastructure and construction of other facilities.

During the past two decades, a number of full scale prototype test embankments with full instrumentation have been constructed on soft ground in Southeast Asian countries. They were usually connected with major developments. One of the first major test embankments on soft ground in Thailand was carried out in 1969 – 1970 in connection with the design of the flood protection bund for the new AIT campus in Rangsit, which is located approximately 40 km north of Bangkok. (Brand, Moh & Nelson, 1970; Moh, Brand &

Nelson, 1972). In the first stage of the research study, the test embankment was built up to 3.2m high which was the proposed design height of the AIT bund. A full set of instruments including piezometers, observation wells, deep settlement points, surface settlement plates and lateral movement stakes were installed to monitor the behaviour of the soft Bangkok Clay. Rangsit Clay is similar to the Bangkok Clay in its geological formation and characteristics and therefore is generally considered as belonging to the Bangkok Clay family. In the second stage of the study, the test embankment was built up rapidly to failure. A classical circular type of failure was observed. The full scale test results were compared with those predicted or calculated from theoretical analysis. At about the same time, another full-scale test on the soft Bangkok Clay was carried out in conjunction with the design and construction of the Nakhon Sawan Highway (Eide & Holmberg, 1972).

Three large scale tests of soft ground under fill loads were carried out during the period of 1972 to 1980 in conjunction with the proposed construction of three international airports in the region. In 1972 – 1974, the Northrop Airport Development Corporation sponsored a research project at AIT to evaluate the performance of test sections for the proposed second Bangkok International Airport at Nong Ngu Hao, which is located approximately 25km east of Bangkok City. Four test sections, were constructed under special control with full instrumentation for monitoring surface and deep settlements, pore pressures at various depths, and lateral deformation. Test section A involved the construction of a 200m long and 40m wide embankment with varying height from 0.5m to 2.9m, for the primary purpose of monitoring long term settlement. Test section B was a 100m long by 40m wide embankment of constant height, 2.9m, for observation of creep and long term settlement. Test section C was an embankment built rapidly to failure. The height of the embankment when shear failure of the supporting subsoil occurred was 3.4m. The fourth test was an excavation of about 100m long and 40m wide at the ground surface. Excavation of the soft soil was carried out at calculated stable side slopes to a depth of 4.0m. This section was then left for long term observation. Although the study was unfortunately interrupted due to abandonment of the airport project by Northrop, extensive research was continued by faculty and students at AIT. More than ten theses and papers were published in relation to the characteristics of the Nong Ngu Hao Clay (which is similar to the Bangkok Clay) and the performance behaviour of the different test sections (for example, Ho, 1975; Ho, 1976; Balasubramaniam et al, 1976).

Ten years after the first study, interest in constructing a new international airport to serve the heavy air traffic of Bangkok was revived. The Government of Thailand commissioned a team of consultants to carry out the master plan and preliminary design for a new airport at the same location as that considered in 1972, i.e. Nong Ngu Hao. Included in this study was a full-scale field test to evaluate the feasibility of soil improvement. Three test sections, each approximately 40m by 40m in size, were constructed. Non-displacement type sand drains of 60 cm diameter were used for improving the soft and compressible subsoil which is about 15 m in thickness under the entire airport site. Two different sand drain spacings, i.e. 3.5 sq m per drain and 5.0 sq m per drain, were used, and two different loading methods were adopted. The conventional fill surcharge, 3.5 m thick or about 6.3 tons per sq m pressure, was placed at one of the test sections, and vacuum loadings were used at the other two sections. From monitored instrumentation results, it was found that large diameter non-displacement type sand drains can be used effectively to accelerate the rate of consolidation of the soft Bangkok Clay (Moh et al 1987). Vacuum loading or dewatering could be an effective way of applying surcharge (Moh et al 1989). One of the findings from that study is of great importance to the practical application of sand drains in areas where there is under-pressure in the subsurface strata. The sand drains should be terminated at a depth above any permeable layer below which under-pressure occurs.

Due to the heavy traffic demand at the present Kai Tak International Airport, the Hong Kong Government has been seriously contemplating construction of a new airport. Among the several potential locations, Chek Lap Kok on the north coast of Lantau Island was considered as the best choice. It would involve levelling two islands and using the fill obtained to reclaim 608 ha of land from the surrounding waters. The reclamation would involve building over highly compressible marine mud which is up to 15m in thickness. With predicted settlements of 3 to 4 m and runways which start on the granite islands and pass over thick mud deposits the potential settlement problems are obvious. Design of the airport reclamation scheme became a choice between removing all the mud at the site and disposing of it elsewhere – a total of 37 million cu. m – or finding a way of building the reclamation with the mud in place. A test embankment was built in 1980 to develop and prove suitable construction techniques (Fig. 6). The main test area, a 100m square was divided into 4 quadrants. One quadrant was a control, with no treatment of the mud. Two of the remaining three quadrants had vertical prefabricated drains at 1.5 m and 3 m triangular spacings and the last quadrant had 50cm diameter sand drains at 3m spacings. Figure 7 presents the settlement data obtained in the mud beneath the four quafrants. Compared with the control, where no treatment was employed, the prefabricated band drains appeared to be effective in accelerating consolidation of the marine mud whilst sand drains appeared to be not very effective. The sand drains used in this project were displacement type and their poor performance was related to their becoming blocked by remolded mud flowing into the drains (Foote, 1982). The feasibility study was completed in 1984 and the project was then shelved.

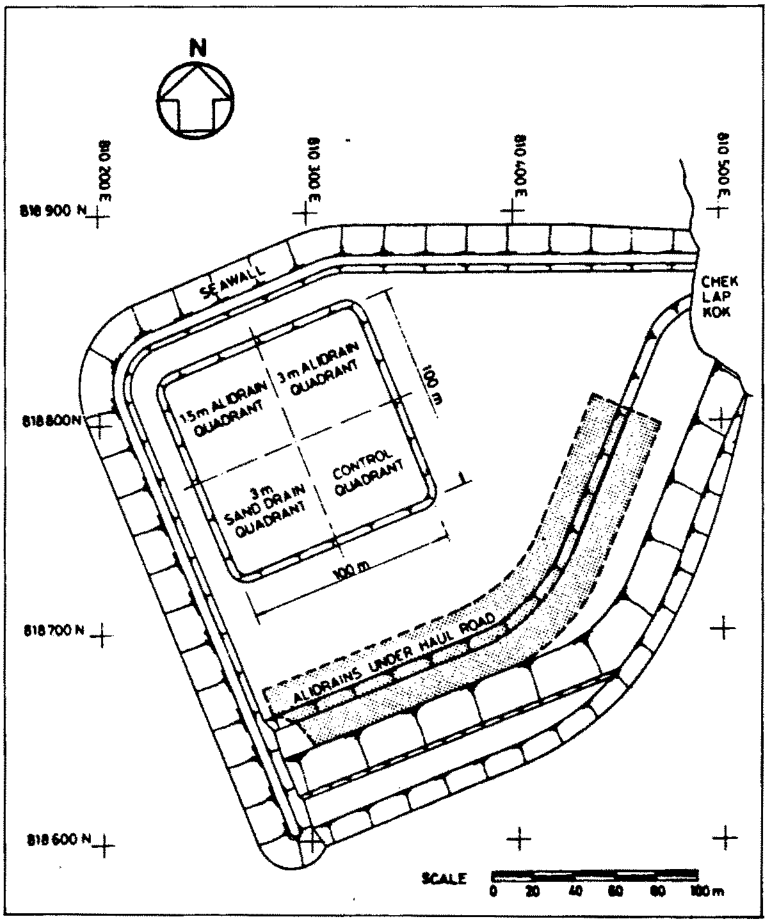


Fig. 6 Plan of Test Embankment at Proposed Chek Lap Kok Replacement Airport Site, Hong Kong (after FOOTE, 1982).

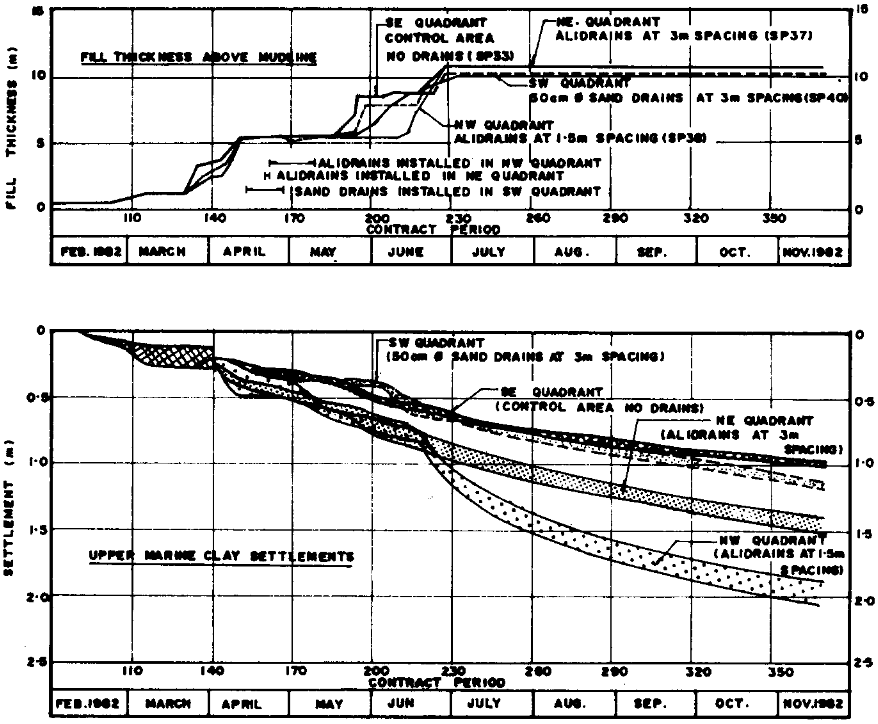
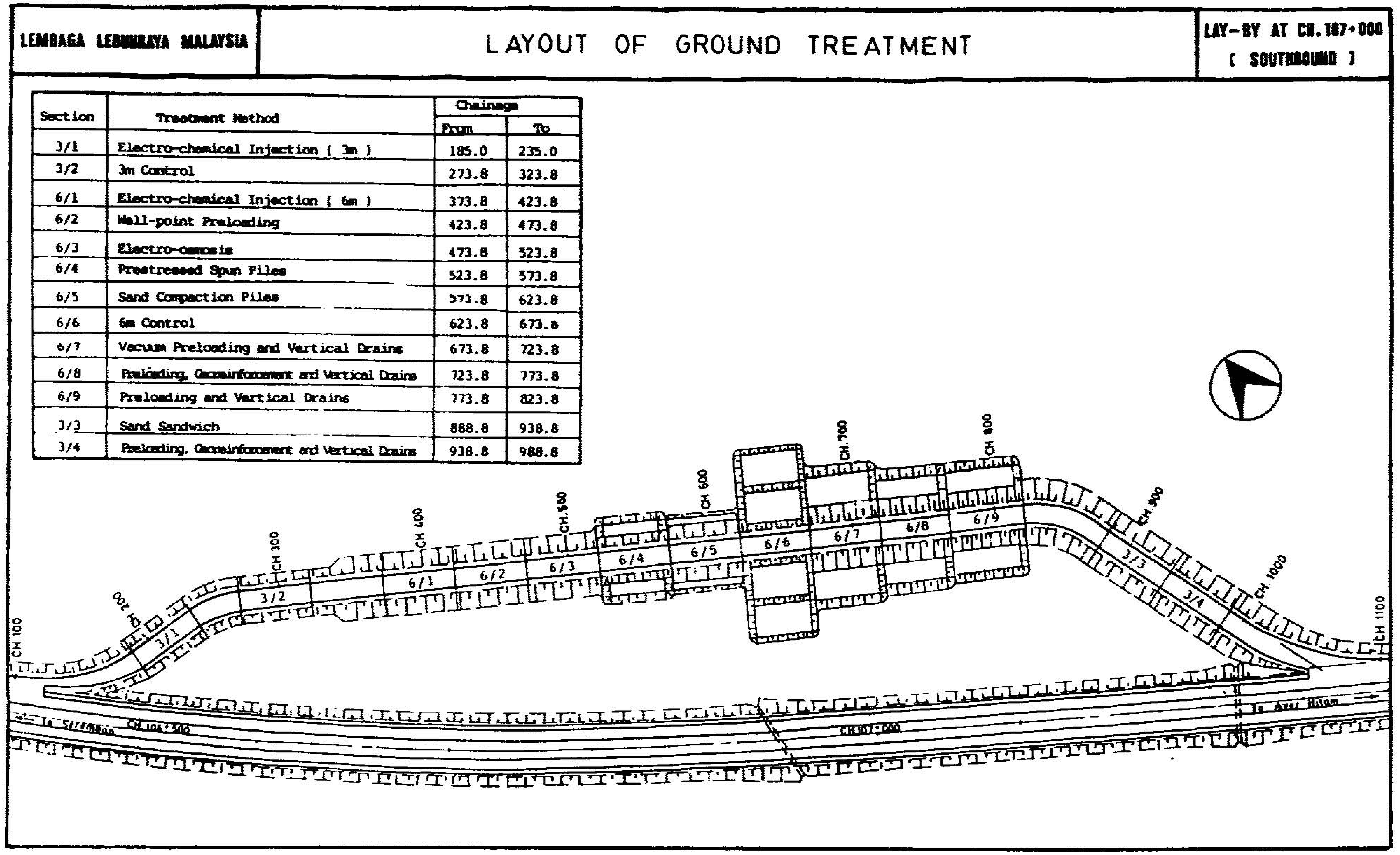


Fig. 7 Settlements in Mud Beneath the Test Area at Chek Lap Kok Replacement Airport Site, Hong Kong (After FOOTE, 1982).

The Changi International Airport in Singapore was constructed on a 645 ha of reclaimed land. About 40 million cu. m of sand fill was dredged from the seabed adjacent to the site. Soil investigation prior to the reclamation indicated that the second runway would be partly on a thick deposit of soft marine clay which exists down to about 40m below the seabed. Long term settlements caused by the 6.5m of hydraulic fill and the runway payment load were estimated to be up to 2m. A pilot test was carried out to compare the performance and feasibility of several soil improvement techniques. The test results were reported by Choa et al (1979).

For the purpose of evaluating relative effectiveness and cost of various schemes of improvement of soft ground for highway construction, the Malaysian Highway Authority is undertaking an extensive study project at a site near the Muar Flats along the Seremban – Ayer Hitam Inter Urban Toll



LEMBAGA LEBUHRAYA MALAYSIA

LAYOUT OF GROUND TREATMENT

LAY-BY AT CH.107+000
(SOUTHBOUND)

Section	Treatment Method	Chainage	
		From	To
3/1	Electro-chemical Injection (3m)	185.0	235.0
3/2	3m Control	273.8	323.8
6/1	Electro-chemical Injection (6m)	373.8	423.8
6/2	Well-point Preloading	423.8	473.8
6/3	Electro-osmosis	473.8	523.8
6/4	Prestressed Spun Piles	523.8	573.8
6/5	Sand Compaction Piles	573.8	623.8
6/6	6m Control	623.8	673.8
6/7	Vacuum Preloading and Vertical Drains	673.8	723.8
6/8	Preloading, Georeinforcement and Vertical Drains	723.8	773.8
6/9	Preloading and Vertical Drains	773.8	823.8
3/3	Sand Sandwich	888.8	938.8
3/4	Preloading, Georeinforcement and Vertical Drains	938.8	988.8

Fig. 8 Layout Plan for Ground Improvement Study by Malaysia Highway Authority.

Expressway which is now under construction. A total of 14 sections of test embankments, each approximately 50m long, will be constructed. The subsoils consist of about 16.5 to 17.5m of very soft to soft silty clay overlying a mixed layer of peaty material and loose sand. Below a depth of about 21m, the subsoil is a compact to dense sand with some gravel. According to stability analysis, the soft subsoil cannot support the weight of a 3m high embankment without special treatment. Furthermore, very large amounts of settlement would occur over a long period of time. For example, over 2m of settlement is anticipated to occur under the load of a 3m embankment. As shown in Fig. 8, the 14 schemes of ground improvement include the use of preloading with vertical drains, with and without geogrid reinforcement; stage loading; sand replacement; prestressed concrete spun piles; electro-osmosis; chemical injection; sand compaction piles; well-point preloading; vacuum preloading and a control section. Four of the schemes will be loaded under a 3m embankment and the other 10 schemes will be loaded with a 6m high embankment at the finished level. The design criterion for all the test sections is that the residual primary settlement as predicted from field observation shall not exceed 100mm at the end of the 15 months construction period. The project is anticipated to be complete by the end of 1989.

Ground Improvement

Ground improvement techniques have been widely used to improve or to change properties of soil deposits for the purpose of increasing strength, settlement control, seepage control, and reducing liquefaction potential under seismic loadings. A large part of the usable land in the Southeast Asia region consists of alluvial deposits underlain by a thick layer of soft silts and clays and loose sands. These types of soil often require treatment or improvement before they can be utilized to support constructed facilities. There are hundreds of methods, many of them patented processes, available on the market today for improving properties of soils and rock. Some of these methods are well developed and have a sound theoretical basis, but many of them on the other hand, are very empirical in nature.

In the Southeast Asian region, development in the techniques and application of ground improvement has taken on significant proportions only in recent years, in parallel with the present upsurge in variety and scope of construction activities. Lee et al (1985) reported on a general survey of some of the more significant developments in the use of various methods of ground improvement in this region. Among the most commonly and widely used methods are the conventional preloading with surcharge, vertical drains (sand drains and prefabricated drains), dynamic compaction and compaction sand piles (Moh, 1982). Other methods, such as stone columns, lime piles, soil nailing and early reinforcement have yet to attain the degree of implementation and acceptance. Use of geotextiles for soil reinforcement is gradually attracting more interest.

Preloading with surcharge without using other ground treatment can be considered as the most conventional type of ground improvement technique. It has been used successfully on many projects in the region. Depending upon the subsoil conditions, preloading is applied either in a single stage or in stages on the basis of instrumentation monitoring data. Due to the large quantities of preloading materials usually required, one of the important features in the design of a preloading scheme is the economical and effective utilization of the preloading material (for example; Moh, 1985).

Surcharge preloading can be effectively used only when the mass permeability of the soft soil is relatively high due to the presence of layers or lenses of pervious soils, and when adequate construction time is available for soil treatment. When the available time is short and/or the thickness of the soft deposit is large, the use of vertical drains in conjunction with surcharge loads becomes necessary. Sand drains, used for over 30 years in assisting acceleration of consolidation of soft soils, have been employed for a number of projects in the region. However, the effectiveness of sand drains, particularly the displacement type, has been questioned in a number of cases in view of their effects on soil disturbance, development of a smear zone, clogging of drains by fines, necking and other discontinuities. For example, Balasubramaniam & Bergado (1984) reported little improvement in soft Bangkok Clay by installation of 5cm diameter sandwick drains at close spacings of 1.5m and 2.5m. On the other hand, successful results in the same type of soil, by using large diameter non-displacement type sand drains were reported by Moh et al (1987 and 1989) as illustrated in Fig. 9.

In recent years, due to the scarcity of sand required and problems associated with sand drains, many large projects have adopted the use of prefabricated flexible drains for accelerating consolidation of soft ground. Two of the more notable projects in the region using vertical prefabricated flexible band drains are Changi Airport in Singapore (Choa et al, 1981) and the Keelung River Reclamation in Taipei (Moh et al, 1985), where more than 1.2 million linear metres of drains were installed in each of the projects.

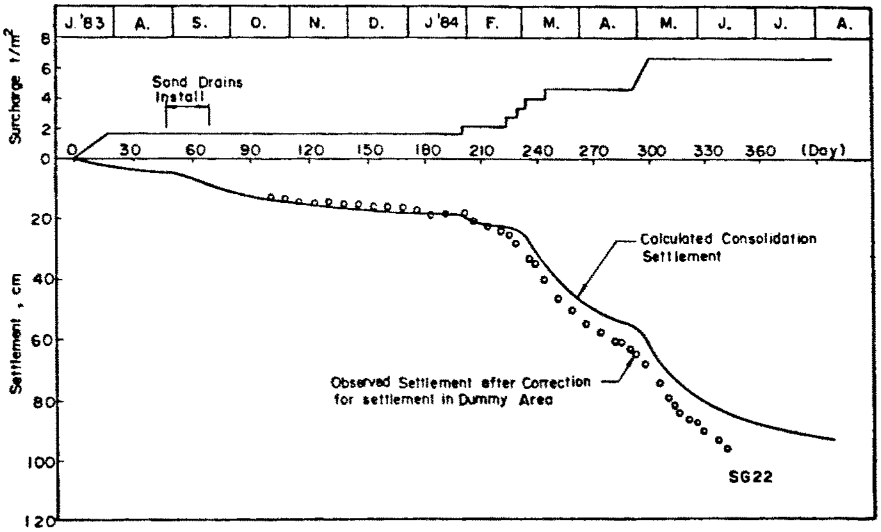


Fig. 9 **Effect of Large-Diameter Non-Displacement Sand Drains on Settlement of Nong Ngu Hao Clay.**

Changi Airport was constructed on reclaimed land, 645 hectares in area. About 40 million cu m of sand fill was dredged from the seabed adjacent to the fill area. Deep marine clay deposits were found under a major part of the site. In order to minimize the problem of uneven settlement and heavy maintenance work on the runway, soil treatment was necessary for the runway and its associated turnoffs and taxiways. On the basis of a full scale pilot test, which compared the performance and evaluation of several soil improvement techniques, vertical prefabricated drains in combination with surcharge were chosen. Approximately 275,000 sq m of land with an average depth of 18.5 m were treated. The Keelung River Project involved the reclamation of an abandoned old river channel, about 3 km long and 200m wide, near the city of Taipei for a new town development. Vertical prefabricated band drains selected for the reclamation to accelerate consolidation of an approximately 30m thickness of soft clay underlying the river bed. This project was not only large in the area to be treated, about 30 hectares, but employed the deepest vertical drains ever used in the region (which is also uncommon by world standards).

Prefabricated drains were also found to be effective in accelerating consolidation of the marine clays in Hong Kong at the proposed Chek Lap Kok Replacement Airport study (Foote, 1982).

In the large scale trial embankment study carried out by the Malaysia Highway Authority, vertical prefabricated drains with and without a geogrid are being studied in conjunction with other soil improvement methods, (Fig. 8).

Most of the prefabricated drains are made of synthetic plastic material, some with an additional filter layer of non-woven material. A new type of drain, called Fibredrain, composed of organic fibres extracted from jute and coir was developed by Lee et al (1987) of Singapore. It was claimed that the fibredrain can be designed and manufactured to suit the needs of specific requirements of a soil improvement project and is flexible, rugged, resistant to weathering and clogging, relatively more permeable and stronger, and sufficiently durable. More importantly, jute material is abundantly available in most of the countries in the region; manufacture of fibredrain can be more economical than other types of prefabricated drains. Although fibredrains have only been used in a small number of projects, and their effectiveness still needs a longer track record to prove, the future of this type of low cost development is certainly promising.

In this region, Taiwan and the Philippines are located in the active seismic zone of the Pacific Ocean and experience over a thousand earthquakes every year. Compaction sand piles have been found to be very effective for densification of cohesionless soils and thus reducing the liquefaction potential of these types of soil during seismic loading. In Taiwan, several million linear metres of compaction sand piles have been installed for ground improvement at sites of power plants, storage tanks and habours, for example (Moh et al, 1981; Moh, 1982). The most commonly used compaction sand piles are 45 cm in diameter, which, expand to about 70 cm in diamater after installation, and to a maximum of 15 m in length. The maximum depth where a cohesionless soil deposit can be treated by compaction sand piles is usually limited by the capacity of the vibrator used for installation. Not much experience has been accumulated using compaction sand piles to improve properties of clayey soil in this region. At the trial embankment project currently underway in Malaysia, this method is also being studied.

Slope Stability and Landslides

As described in an early section, a large part of the terrain of land areas in Southeast Asian countries is hilly and mountainous. The region experiences high seasonal rainfalls, sometimes in excess of 4,500 mm annually with intensities which can exceed 150 mm per hour. In addition, a large part of the region is in the Pacific earthquake belt which runs through Indonesia, Philippines and Taiwan. Several countries including Indonesia, Philippines, Taiwan and Hong Kong are also under the influence of typhoons. Landslides in these countries are often associated with the heavy rain and the natural hazards.

Brand (1984, 1985 a) made a comprehensive review of the State-of-the-Art of landslides and their control in the Southeast Asian region. During the past one and one-half years, since the publication of Brand's paper, there have been few additions to the published literature on the subject relating to this region. Most unpublished reports deal with remedial measures or improvements of specific slide failures. These works are usually well designed, based on geotechnical principles and employ advanced techniques such as the use of horizontal drain systems, rock-anchors, bolts, etc. In so far as the state-of-the-art of landslides is concerned, the overall assessment made by Brand (1985 a) as shown in Table 1 is still more or less valid.

Table 1 Significance of Landslides in Southeast Asian Countries.

Country	Area (sq. km)	Population (millions)	Significance of Landslides	Volume of Relevant Literature	Assessed State-of-the-art of Landslide Prevention & Control
Singapore	580	3	Low	Moderate	Moderate
Thailand	513 517	48	Moderate	Low	Low
Sri Lanka	65 610	15	Moderate	Low	Low
Malaysia	330 669	15	Moderate	Moderate	Moderate
Philippines	299 765	52	High	Very Low	Very Low
Taiwan	35 980	18	High	High	Moderate
Indonesia	1 919 263	157	Very High	Low	Low
Hong Kong	1 050	6	Very High	Very High	Very High

With the establishment of the Geotechnical Control Office (GCO) in Hong Kong in 1977, after two disastrous slope failures at Sau Mau Ping and Po Shan Road which killed 71 and 67 people respectively, a considerable amount of effort has been devoted to research and study on improvement of site investigation, sampling and testing of residual and colluvial soils, on the mechanism of rain-induced landslides, on the methods of analysis of slope stability and on the design of slopes. In 1979, the GCO produced the first edition of the Geotechnical Manual for Slopes which was subsequently revised and published as a second edition in 1984. This manual now not only guides the methods of slope design and stability assessment in Hong Kong but is also being used as a standard guide for slope work in many other countries in the region.

In the past few years, many individual landslides or earthslips have been studied and treated. Three major projects, two in Malaysia and one in Taiwan, involved hundreds of slopes which were systematically evaluated and improved (Moh & Woo, 1986; Moh, Guo & Huang, 1987).

Malaysian Highways

In the mountainous regions of West Malaysia, landslides in natural slopes are fairly common. A large number of slides took the form of shallow slides. Surface erosion has been one of the major causes of slides on steep slopes. Due to the large variations in the residual materials from the geological and weathering points of view, it is generally difficult to apply satisfactory slope design procedures, and so engineering judgement and precedent experience have been heavily relied upon for the determination of cut slope angles for road construction. Two of the major highways in West Malaysia, the East-West Highway and the Kuala Lumpur – Karak Toll Highway have suffered numerous slide failures. They represent a continuing heavy commitment for maintenance, and substantial economic losses and inconveniences due to disruption of traffic. Although no major casualties have been recorded, the threat to the safety of road users has always been a major concern to the authorities.

The 116 km long East-West Highway linking Kampong Jeli in the east (Kelantan state) and Grik town in the West (Perak state) is the only road connection in northern Peninsular Malaysia (Fig. 10). The highway passes through territories near the Malaysia border to Thailand and was a remote jungle classified as a security area by the Government. Construction commenced in 1969 even before designs were made. Detailed survey and geological/geotechnical investigations were severaly limited by security problems.

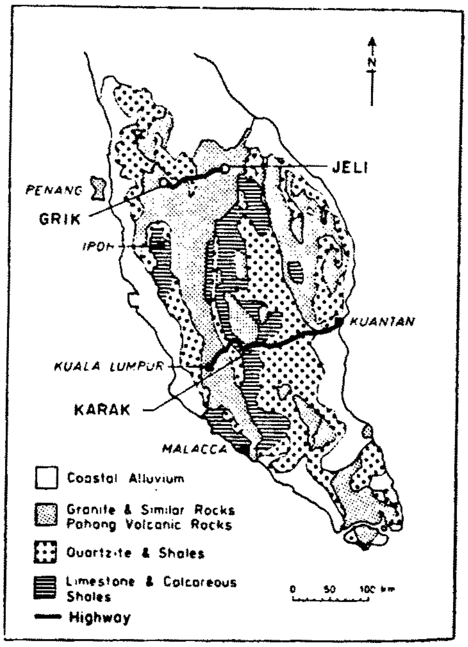


Fig. 10 Geology of West Malaysia.

The alignment of the Highway rises from approximately El 100m to El 1,050m at the highest point on the main mountain range about mid-way along the route. About 25 per cent of the whole length of highway traverses mountainous terrain amidst dense forests. Because of security reasons, the option of constructing long viaducts over deep valleys or tunnels through mountains were categorically ruled out. A total of 27.5 million cu m of earth were moved. At the high points, earthworks average 1.5 – 2.5 million cu m per mile, and formed a series of high embankments connecting the mountain saddles. In the course of construction, which took a period of about 12 years, a number of slope failures have occurred. After opening the Highway in 1982, severe erosion was observed on a number of high-fill embankment slopes. In the monsoon season of 1983/4, a large number of failures took place on both embankment and cut slopes. These failures caused severe disruption to traffic and endangered the safety of highway users. Besides those slopes which were redesigned and reconstructed, over 500 fill and cut slopes were required to be examined.

The Kuala Lumpur – Karak Toll Highway is a part of the overall Federal Route II which is the major east-west link in the Central part of Peninsular Malaysia, passing through the capital of the country (Fig. 10). The Highway traverses varied terrains ranging from flat land to rolling, rugged and mountainous terrain. The construction of the 49 km stretch of the Highway in mountainous and hilly region was characterized by deep cuts with heights exceeding 60m, and fill reaching 24m high. Construction of the Highway was started in 1975 and the final stretch was opened to traffic in the latter part of 1979. About seven years after the opening of the Highway, many of the high cut slopes started to have erosional and stability problems which became progressively more serious. Frequent slides of slopes along this busy highway during rainy days caused serious inconvenience as well as safety problems. A total of 166 slopes, including both cut and fill slopes were identified as problem slopes which could be potentially unstable.

To cope with the vast number of slopes, some of which may be potentially unstable and others which have already failed, a qualitative categorization system was adopted (Moh & Woo, 1986). Categorization of the slopes is based on the potential of failure of the slope (or instability) and the risk to road usage if failure occurs, as shown in Fig. 11.

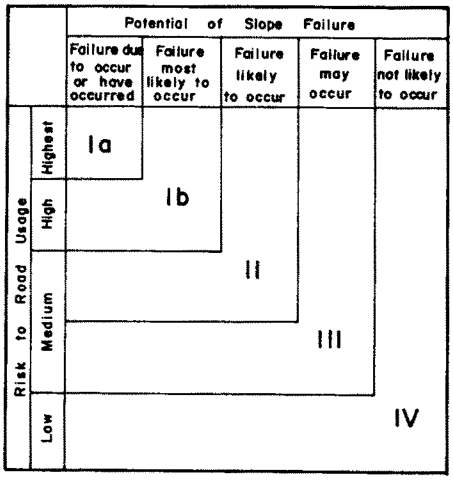


Fig. 11 Qualitative Categorization of Slopes.

Assessments of the degree of potential for failure of the slopes were made on the basis of information collected from a desk study, field reconnaissance, geomorphology and geological appraisal, and hydrological appraisal. All available information including topographic maps, aerial photographs, geological maps, rainfall records, design and construction plans of the slopes, past records of failure and remedial work, all form essential parts of the desk study. Field reconnaissance examines and records the physical features of the slopes, (including height, gradient, surface conditions and signs of failure), the surface geology (including rock outcrops, discontinuities, bedding, weathering state, grain size, lithological characteristics, signs and extent of seepage), the conditions of water courses, and other physical conditions which may affect the stability of slopes.

After carrying out geological, topographical and hydrological appraisals, a qualitative assessement and rating of the degree of failure potential of the slopes are then made. Degree of risk of a slope failure to the road usage depends primarily on the location and geometry of the slope in relation to the roadway, and traffic volume.

On the basis of this categorization system, a total of 590 slopes including 300 fill slopes and 290 cut slopes, along the East-West Highway were examined and classified. Nineteen slopes were found to belong to Category Ia, 70 in Ib, 140 in II, 102 in III, and 259 in IV. For the KL – Karak Highway, among the 166 slopes examined, twenty slopes are in Category I, 46 are in Category II and the remaining 100 in Category III. Detailed geotechnical investigations were carried out for all Category I slopes. Improvement or remedial works were then performed in accordance with geotechnical design principles.

Cross-Island Highway in Taiwan

The Central Cross-Island Highway (Highway No. Tai-8) is the main road system connecting the less developed eastern part with the more populated western part of Taiwan. The highway also serves as the main traffic artery to two important multi-purpose water reservoirs. In addition, there are many scenic locations along the highway which attract a great number of tourists both local and from abroad. The highway plays a very important role in the economic development of the eastern region of the island.

Ever since its completion and opening to traffic in 1960, the 189 km long Central East-West Cross Island highway has suffered numerous disruptions to traffic, and enormous economic losses due to slope failures and landslides. Road safety to human life is another important aspect of great concern. In 1986, Moh and Associates was commissioned by the Taiwan Highway Bureau to establish a Slope Maintenance System for this important highway.

The study covers three sections with a total length of about 59 km, which is about one-third of the total length of the Central Cross-Island Highway. The terrain in all three sections is typical Taiwan mountainous terrain with very steep sideslopes, complicated geological structure, meandering river courses, deep valleys and steep river beds. However, the geomorphology and geological conditions in the three sections are quite different. Figure 12 shows the general geology of Taiwan and the location of the Highway.

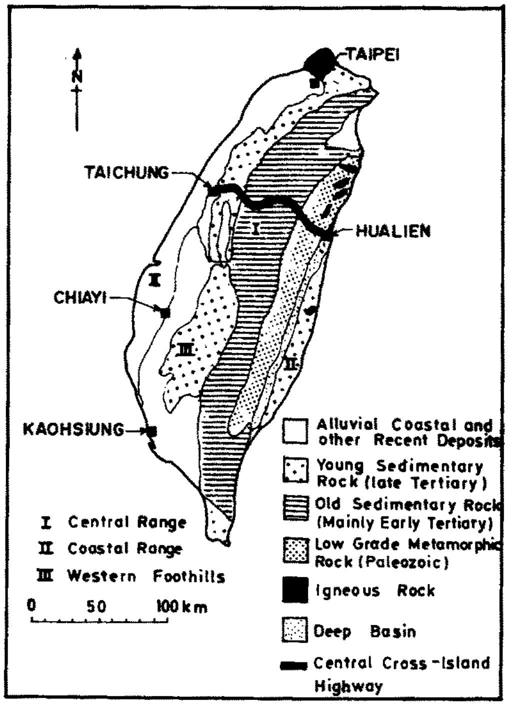


Fig. 12 Geology of Taiwan.

The Kukan-Techi Section covers the area from Station 41K + 250 to 62K + 140 of Highway Tai 8 and 0k + 000 to 16k + 640 of Highway Tai 8A. It is situated on the western flank of the Central Mountain Range with an elevation ranging from 1,000m to 1,500m above the mean sea level. The terrain has an average gradient of about 30 to 40 degrees. Due to construction and widening of the highways, most of the side cut slopes are very steep, in the order of about 70 degrees or more. The outcrops along the section are mainly Tertiary sub-metamorphic rocks with metamorphism increasing in an eastward direction. The geological structure in the area is very complex with many colluvial deposits. Rock type varies from hard shale, inter-bedded shale-sandstone, and sandstone. Small fractures and fault zones are often visible on the cut slope faces. Figure 13 shows the complex geology along a short section of the Highway.

The Yunhai Slide Zone is located near the ridge of the Central Mountain Range. The top of the old slide Zone is at El 2,300m with the toe at about El 2,100m, with a general gradient of about 40 degrees. The area has been developed as fruit orchards but with relatively poor soil conservation. The highway section in this Zone is mainly constructed on colluvial deposits of slate origin. The slate has well developed joints and is easily softened by rain water. Continuous movement of the cut slopes has been observed during every rainy season and this has caused serious settlement of the road foundation.

The third section covers the area from Tayuling to Tzuen (Highway Tai 8 Sta. 112K + 400 to 133K + 000), and is situated on the eastern flank of the Central Mountain Range. The highway runs from El 2,600m to 2,000m with side slopes between 30 and 40 degrees. The major rock formations along the route are Tertiary sub-metamorphic and Pre-Tertiary metamorphic rocks, with increasing metamorphism in a west to east direction. Colluvial deposits, phyllites, meta-sandstones, interbedded sandstones and phyllites, chloritic schists, and meta-calcites are found at different locations.

Due to the restrictions imposed by the topography, the complex geological condition, and more importantly by economics, the Central East-West Cross-Island Highway was constructed without proper engineering design. A major part of the roadway was constructed by direct excavation or cut into the steep natural slopes.

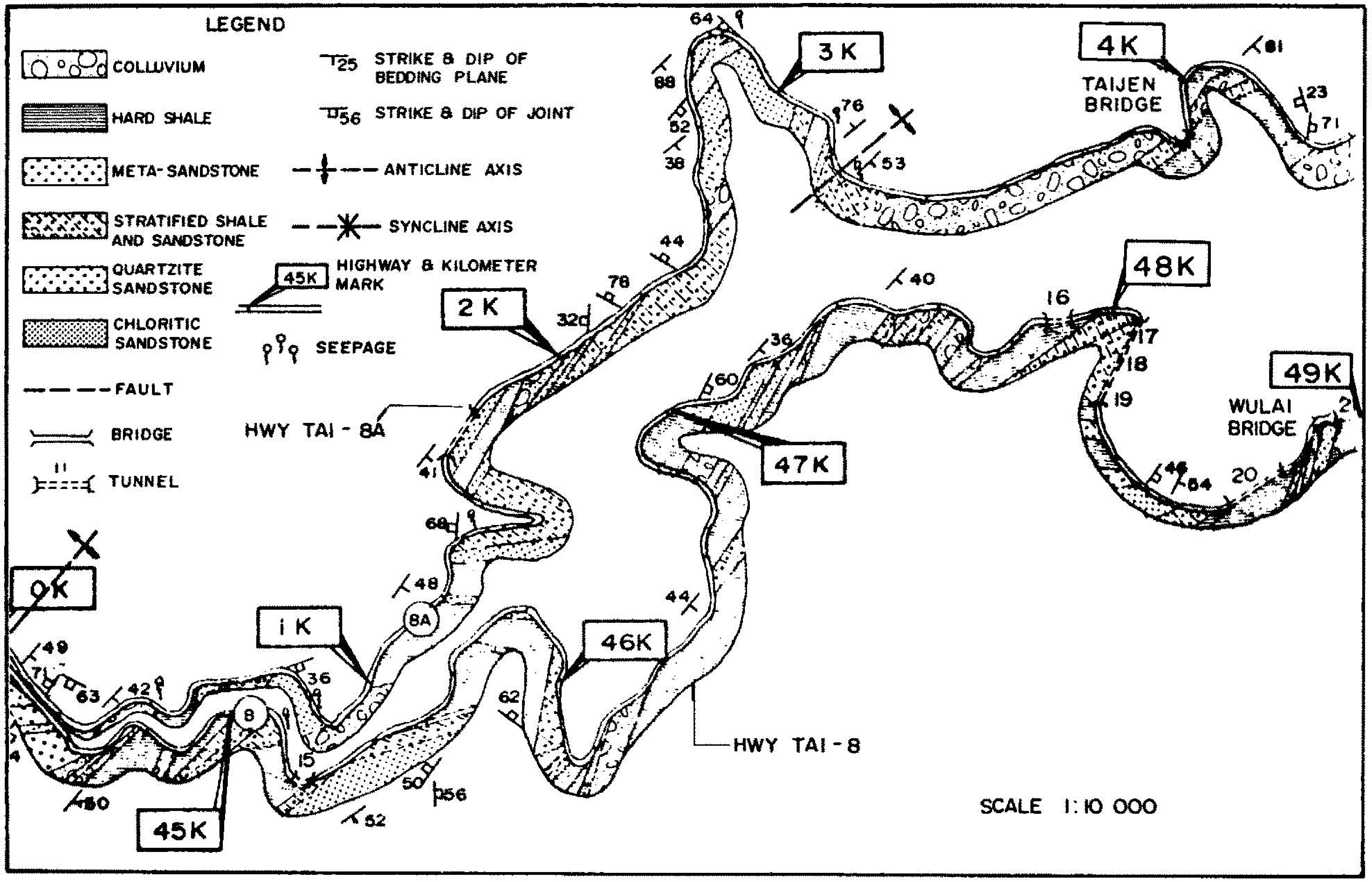


Fig. 13 Geology along a section of the Cross-Island Highway in Taiwan.

Figures 14 shows the flow diagram of processes involved in the slope assessment work. The assessment and rating of the 388 potentially unstable slopes were carried out as depicted in the flow diagram shown in Fig. 14. Besides identifying the type of potential slope failures, two major factors were considered. They were the potential of failure and the hazard to road usage. Semi-quantitative ratings were introduced into the assessment in order to arrive at a final rating.

By using the assessment system, twenty eight slopes were classified as Class I slopes which required immediate attention for more detailed investigation and design of preventive measures. Instrumentation monitoring and a pre-warning system were recommended for some of the 47 Class II slopes. It is believed that this assessment system for potential landslide hazard can be extended to the entire mountainous highway system in Taiwan in order to ensure a good road transportation network and to reduce risks to safety.

Foundations

Practice and problems of foundations in the region have been a popular subject for discussion at the vaarious Southeast Asian and Asian Regional Conferences. Special forums were organized at the 3rd, 4th, 7th and 8th Southeast Asian Geotechnical Conferences. At the 6th Regional Conference, three state-of-the-art papers of foundation practice in Taiwan, Hong Kong and Singapore were presented (Moh & Ou, 1979a; Lumb, 1979; Ramaswamy, 1979).

In this paper, only some of the special foundation systems and foundations for selected structures are briefly mentioned. It should be pointed out that in design of foundations for supporting structures in this region, the effects of several natural hazards have to be considered in addition to the normal dead and live loads. In Taiwan, effects of seismic activity and typhoon have to be incorporated in the design, whilst Hong Kong requires consideration of typhoons. The other three countries i.e. Malaysia, Singapore and Thailand are fortunately free from these problems.

A compensated foundation utilizes the principle of stress reduction due to excavation to compensate for all or part of the building load. This type of foundation has been used very successfully in many cities with soft conditions,

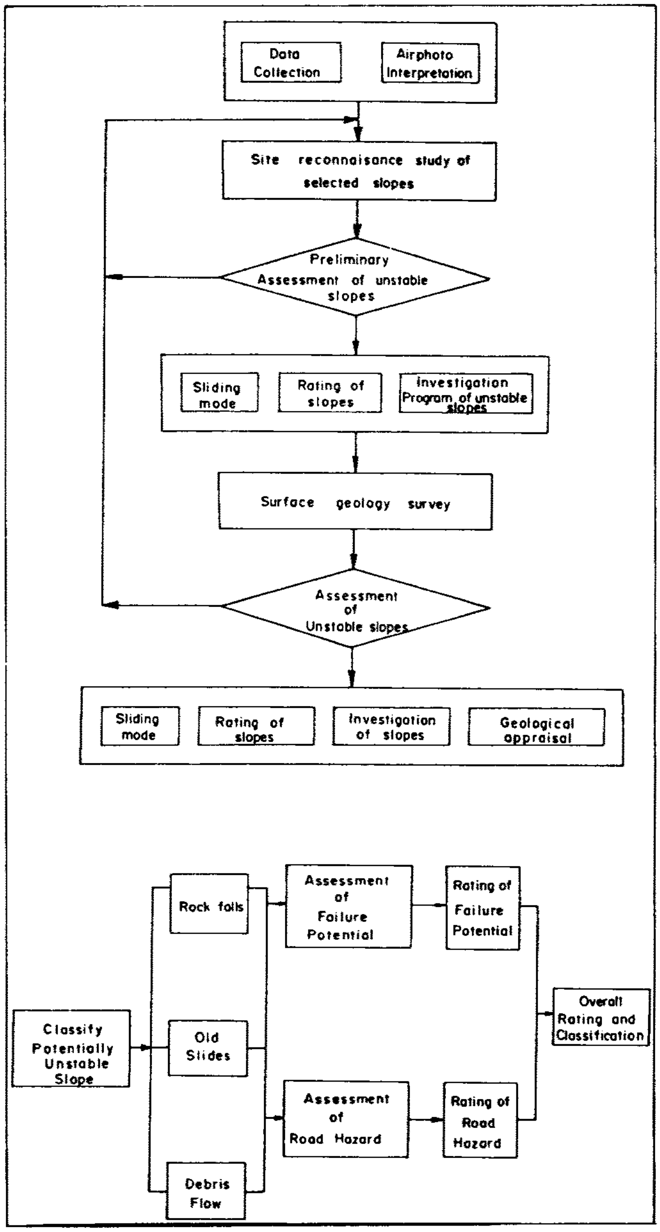


Fig. 14 Flow Diagram for Landslide Assessment.

such as Boston and Mexico City. In Taiwan, partly due to the governmental requirement and partly due to the desire of maximum utilization of ground space, all building structures more than 5 storeys high incorporate at least one level of basement. The use of compensating foundations became very popular. This practical demand has certainly greatly enhanced the knowledge of foundation design. For the subsoil conditions such as that in Taipei City, a compensated foundation for a typical 12-storey building needs to be placed at a depth of 10 to 12m below the ground surface. In design and construction of compensated foundations, problems relating to deep excavation in soft ground must be considered in addition to the problem of settlement control. Some of the better known cases include the 13-storey China Airlines Building (Moh & Song, 1980) with 2-basements and the 26-storey Taiwan Power Company Headquarters Building, with 3 basement levels (Moh & Song, 1984). The latter is the tallest building in Taiwan to date, although several taller buildings are now under construction.

For structures which are too heavy to be supported by shallow foundations or compensated foundations, deep foundations including driven piles, bored piles, and caissons are usually employed. Raymond piles, a step-taper made of corrugated light-steel shells (which is quite popular in the USA) have been used extensively on two major projects in the region. In the construction of facilities for the China Steel Corporation in Taiwan, a total of 22,560 pieces (over 650,000 linear metres total length) of Raymond piles was driven in the first phase work alone. Many thousands more piles were installed in the later, expansion stages. At the Marina Centre Development in Singapore, a total of 9,349 Raymond cast-in-situ piles (with total length over 180,000 linear metres) was installed to support the structures of three hotels varying from 22 to 37 stories high. For installation of driven cast-in-situ piles, it is important to establish "set criteria" for construction control (Moh & Woo, 1984), and the criteria must be continuously reviewed for a large scale project on the basis of driving resistance, pile heave, and pile behaviour under load tests.

Steel pipe piles, though relatively expensive in this region, have become gradually more popular in recent years in view of the high material strength and the speed in installation. Extensive use of open end steel pipe piles was selected as the foundation for the power generating facilities at the Hsin-Ta Steam Power Plant in southern Taiwan. Studies were carried out of the plugging effect of the open-end pipe (Soo et al, 1980) and the distribution of the loading carrying capacity between shaft friction and end-bearing.

The potential development of negative skin friction is one of the major concerns to geotechnical engineers in designing pile foundations at sites where ground subsidence due to long term consolidation of compressible subsoils is anticipated. A full scale testing program and study was carried out in Singapore in 1983 to evaluate the effectiveness of a special asphalt coated pile (the so called NF piles) in reducing the magnitude of potential negative skin friction (Moh, Ou & Woo, 1983). The first application of the use of NF piles in this region was probably the Shangri-La Hotel in Bangkok (Lee et al, 1983).

Large diameter bored piles have been used frequently to support heavy concentrated loads – such as bridge piers. The newly opened (December 1987) world's longest cable-stayed bridge at the Chao Phraya River Crossing in Bangkok is supported by 2.0m diameter reinforced concrete bored piles extending to depths varying from 30 to 70m below M.S.L. The bridge has a total length of 782m composed of a 450m main span and two 166m back spans. Another bridge of world fame is the Penang Bridge connecting Penang Island with the mainland of Peninsular Malaysia. The Bridge, opened to traffic on 14 September 1985, is one of the world's longest bridges. The total length of the linkage is 13.5km of which 8.4km are over the channel. The high level main span is a cable-stayed concrete girder bridge. The major part of the bridge structure is supported on 500mm and 1,000mm diameter prestressed spun concrete hollow piles with a depth of embedment varying up to about 60m (Chin, 1986).

Another type of deep foundation which is particularly popular in Hong Kong is the large diameter hand-dug caisson. This type of caisson has also been used as a retaining structure (for example, Moh et al, 1979). Three well known buildings in the region, certainly among the tallest buildings in the world, are supported on caissons. The 50-storey tower of the DBS Building in Singapore, which was completed in the mid-70's and was the tallest building in Singapore at that time, held the world record at that time for the largest caisson diameter of 7.3m according to the Guinness Book of Structures (Stephens, 1976; The Guinness Book actually stated the diameter as 6.8m). The tower is supported on 4 caissons, carrying a load of 18,350m tons each. The deepest one is 6m in depth (Ramaswamy, 1979). The current tallest building (i.e. 1987) in Singapore is the OUB Centre which is 62 stories, 280m high and the tenth tallest building in the world. The building is supported on 7 caissons founded on bedrock at about 100m below the ground level.

The caissons have shaft diameters of 5.0 and 6.0m, belled out to 6.0 to 9.0m respectively. Construction of the caissons was complicated by an MRT station which was to be constructed by cut and cover methods adjacent to the site. The station excavation was to extend to a depth of 28m, about 8m below the OUB Centre basement excavation. The maximum unfactored design load of the caisson is 38,643m tons (Kurzeme & Rush, 1985).

The world record for the largest diameter caisson at the present is probably held by the Bank of China Building in Hong Kong which is expected to be completed in mid-1989. This 70-storey building is supported on 4 caissons which vary in shaft diameter from 6m to 9m, each being belled out at the bottom. The most heavily loaded one has a diameter of 9m belled-out to 10.5m, with a maximum design load of 51,295m tons.

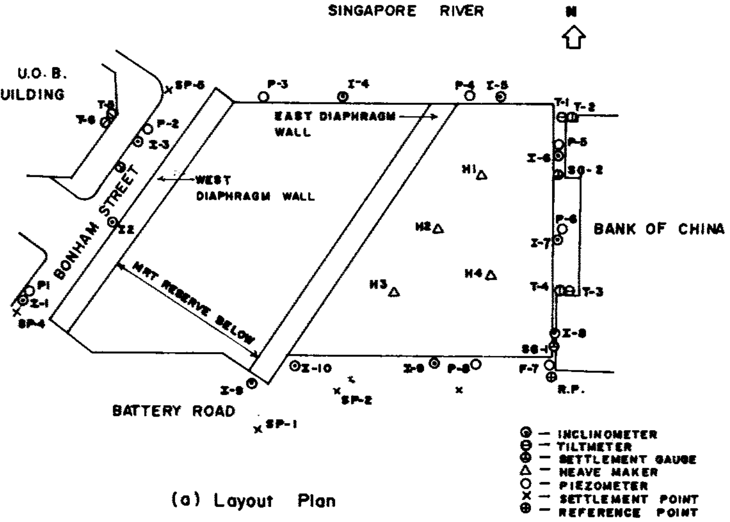
For dam foundation treatment, the commonly used methods are deep foundation excavation, dental treatment, washing and grouting in drill holes, anchoring rock layers with prestressed tendons, fault treatment by mining and backfilling with concrete or treatment by excavating parallel tunnels and excavating thick faults by a high pressure water jet. A new scheme of seam treatment was developed in Taiwan for the construction of the Feitsui Dam on the outskirts of Taipei City. This was needed because of the specially high safety requirement and the presence of very thin clay seams in the bedrock formation. The Feitsui Dam is a three centered, double curvature and variable thickness arch dam having a height of 122.5m, a crest length of 510m and a concrete volume of 700,000 cu.m. The gross reservoir capacity is 406 million cu.m. The dam site is composed of massive and indurated sandstone and siltstone with thin alternating beds in parts. Both types of rock are strong and hard with discontinuous and widely spaced joints. The main problem of concern was the presence of thin (from less than 1 cm to about 15 cm) clay seams parallel to the proposed structure. After a well planned pilot test scheme, a new treatment method was adopted. The method involved the use of high pressure waterknife, with a washing pressure up to 240 MN/sqm, and backfilling the washed seams with non-shrinking mortar. Boring of check holes after the seam treatment work indicated sound bonding and a good shear strength of the contact face between the mortar and the rock.

The performance was further monitored by a series of extensometers, the results from which indicated that there is no relative movement along the treated seams when the reservoir water had risen to about 90 per cent of the full level. The cost of the treatment accounts for only 4.1 per cent of the total direct cost of the project which was US$183.6 million dollars at the time of completion in early 1987 (Cheng, 1987).

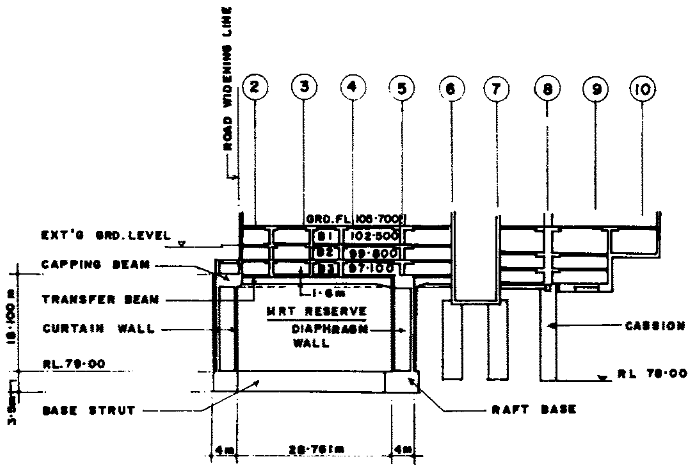
Deep Excavation

Deep excavation is invariably a vital part of urban development. Many highrise buildings incorporate basements. With the increasing scarcity of usable land and soaring prices, deeper and deeper basements are being built. As of 1987, the deepest basement construction in Taipei city had reached six levels. In addition, transportation facilities are also going underground. In the five countries covered by this paper, Hong Kong and Singapore already have a mass rapid transit system, parts of which are underground. Taiwan is planning to construct its first MRT system in the next 5 to 10 years. Deep excavations carried out in soft soil deposits have been studied quite intensively in this region. A number of case studies of deep excavations employing flexible as well as rigid type retaining structures have been reported in the literature (for example Ramaswamy, 1979; Moh & Song, 1980; Moh & Song, 1984; Lee et al, 1985; Tan et al, 1985; Woo et al, 1987). In this region, some of the world records in deep excavation have been made, including the largest area of diaphragm wall at the New World Centre Complex in Hong Kong, constructed in 1976 to 1978.

A unique deep excavation building construction project is the Redeveloped Chartered Bank Building in Singapore located in the central business district of the city. The building consists of a 42-storey tower block with 4 storey podium and three basement carparks. The building is bounded by two highrise buildings on the east and the west, and the Singapore River on the north, Fig. 15 (a). The unique feature is that during the construction of the building complex, a 28.7m wide and 18m deep tunnel reserve had to be provided for the future Mass Rapid Transit (MRT) System, below the basement structure and across the building parallel to Bonham Street. A section of the structure is shown in Fig. 15 (a). Because of the close proximity of the UOB Building and the location of the 42-storey Chartered Bank tower directly on the top of the MRT Reserve, protection of these structures during the excavation for the construction of the MRT is of utmost importance. The subsoils at the site consist of 2 to 5m of soft topsoil underlain by a layer of very dense weathered siltstone a few metres thick. Below the siltstone, extending beyond 76m is a layer of stiff clay containing boulders, with an unconfined compressive strength



(a) Layout Plan



(b) Section

Fig. 15 Layout Plan and Section of Chartered Bank Redevelopment, Singapore.

in the range of 0.5 to 1.0 MN/sq m. The MRT Reserve Protection System consisted of diaphragm walls on the two sides, each 4.3 m wide and 25 m deep, with top and bottom struts as shown in Fig. 15 (b). A comprehensive system of instrumentation was installed to monitor deformation and movement during the construction of the basement structure, MRT Reserve and the subsequent MRT excavation. (Moh and Associates (s) Pte Ltd, 1980; 1981; Chow & Perumalswamy, 1983).

Three projects which are under construction in Taiwan are worthy of mention. The first is the LNG Receiving Terminal of the China Petroleum Corporation in the southern part of Taiwan. The terminal, which is being constructed on reclaimed land, covers an approximate area of 70 hectares. The terminal, besides all the ancillary facilities and infra-structure, will have a total of 7 underground storage tanks of 100,000 kl capacity each. The first phase of construction, including 3 tanks and other facilities, is scheduled for completion in 1990. There were many significant geotechnical activities at the site, including the installation of 25,252 m of compaction sand piles and 11,736m of sand drains. The most significant task was the construction of the deepest and largest diaphragm wall system for the 64.52m inside diameter 44.83m high underground tanks in reclaimed land. The diaphragm wall was cast in 50 segments, each 1.2m thick and 54.5m deep. (BES, 1987).

To provide a central station for the north-south trunk railway and the proposed Mass Rapid Transit System in Taipei City, the existing Taipei Railway was demolished to make way for the new and much expanded Taipei Main Station. The Station consists of 6-storeys above ground and 4-storeys below ground. All station platforms and tracks are to be located below ground with the 1st and 2nd levels for the trunk railway, and 3rd and 4th for the MRT. The excavation covers an area of 350m by 150m. Most of the excavation is 16.0m deep with the deepest part extending up to 30.0m for the MRT. Design and construction of the underground structure are quite complex. Steel sheet piles and diaphragm walls were used for retaining structures which were supported by either internal bracing or prestressed earth anchors and berms. For the entire duration, the excavation and construction were controlled by monitoring of an extensive system of instrumentation including earth pressure cells, piezometers, inclinometers, reinforcing bar stress gauges, steel strut strain gauges, anchor stressing meters, heave stakes, settlement gauges and tiltmeters for surrounding structures (Moh And Associates, 1986 – 1988).

For the construction of the basement structure of the new National Taiwan University Hospital Complex, ground anchors varying in length from 2.3m to 63.4m were used (Chao & Chen, 1986), these are probably the longest ground anchors ever used in Asia. The Complex occupies a land area of 180m by 140m, with the superstructure varying from 1 to 15 stories and excavation extending to a depth of 15.7m. A total number of 1,783 ground anchors were installed with 40 per cent in the range of 40 to 50m long. About 4.27 per cent, or 76 anchors were in the range of 60 to 63.4. The design capacity of the anchors varied from 26 to 65m tons. Figure 16 shows a section illustrating the arrangement of the excavation retaining system.

In the region, there are now two MRT systems in operation, e.g. the Mass Transit Railway in Hong Kong and Phase I of the Mass Rapid Transit in Singapore. During construction of these two systems, many interesting and innovative design and construction methods were adopted. For example, construction of the Marina Bay Station of the Singapore MRT system, which is not yet completed, employs a special submerged excavation method (Denman et al, 1987). It can be anticipated that many new schemes and methods will be employed in the construction of the proposed 72km network of MRT system in Taipei City where most of the underground work will be in soft ground.

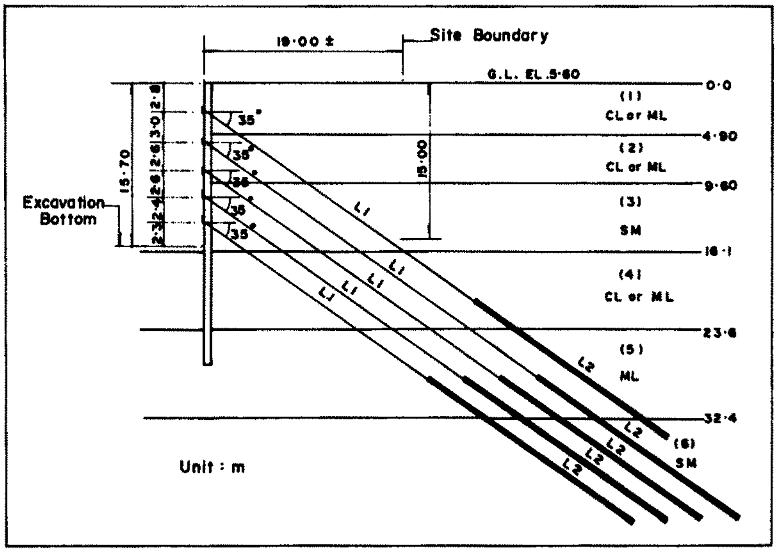


Fig. 16 Excavation Retaining System at the New NTU Hospital in Taipei.

Subsidence

Ground subsidence due to the extraction of groundwater by deep well pumping has long been recognized in many major cities around the world. In the Southeast Asian region, two cities have suffered severe effects of ground subsidence.

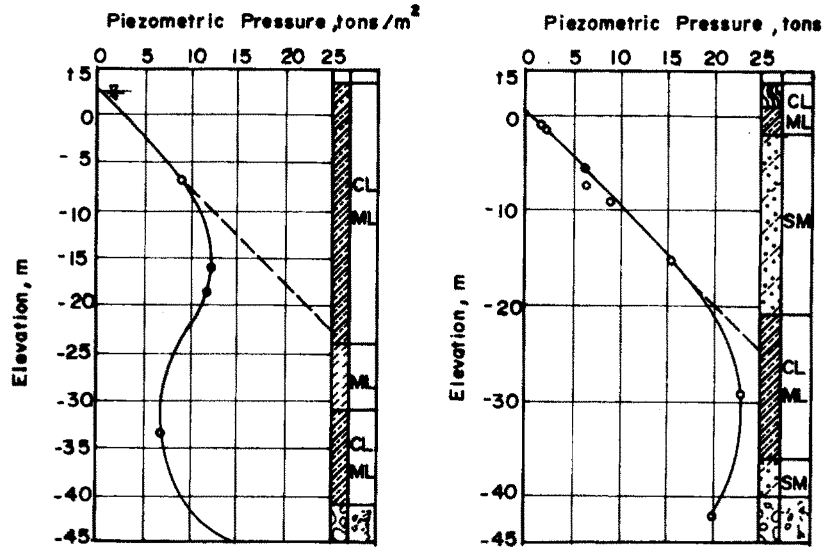


Fig. 17 Variation of Piezometric Pressure with Depth in Taipei.

In the Taipei Basin of Taiwan, deep well pumping has been used to augment water supply since 1946. The subsurface water storage has gradually become less able to supply the large number of deep wells, and the piezometric pressures in the various water bearing layers have became non-static. Records indicate that the piezometric level in the lower water bearing layer has been dropping 2 to 3m per year. Figure 17 shows a typical distribution of the piezometric pressures in the Taipei silt stratum. As a consequence of the drop in the subsurface piezometric pressure, serious regional subsidence has occurred in the basin. Figure 18 shows the total subsidence in the Taipei Basin within a 21 year period from 1955 to 1976. There were 2.98sq km of land area with a subsidence exceeding 2m, and 50.68 sq km with a subsidence more than 1.5m, which is about 21 per cent of the total land area in the Basin (Wu et al, 1976). At the site of the Taipei Domestic Airport, the amount of subsidence settlement during that period varied from 70 to 100cm (Moh & Moh, 1978).

With an effective and stringent control of the well pumping by the government authorities in the past 15 years, the problem of subsidence settlement has greatly reduced. The maximum rate of subsidence in the Basin has decreased from more than 20cm per year to less than 2cm per year. However, this problem becomes much more serious along the coastline of the southern and central-western part of Taiwan due to the rapid development of the fishery cultivation industry which requires a large quantity of fresh water to be pumped. Up to the present, effective control of this indiscriminate use of subsurface water is still lacking in that part of the country.

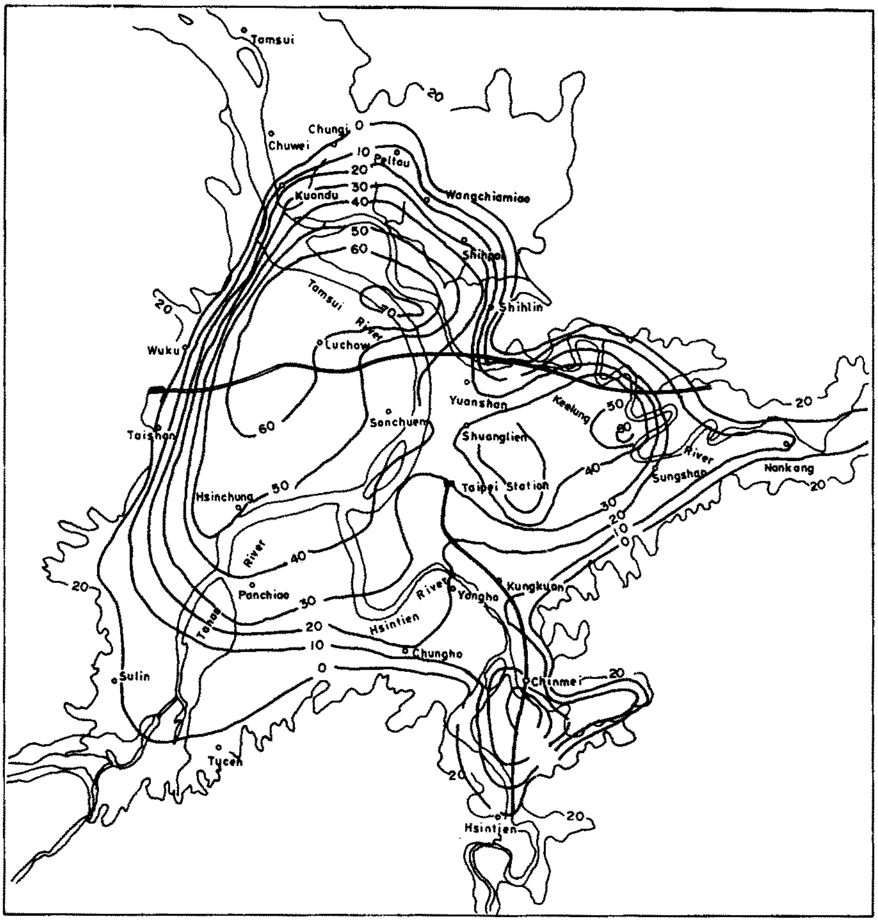


Fig. 18 Subsidence Contours in Taipei Basin 1972 - 79.

Subsidence in Bangkok has become more and more serious. Since the ground elevation of the Bangkok area is only a few metres above sea level, with continuous subsidence, a large part of the city could become lower than the sea level. A serious flood problem has developed in many parts of the city in the past 10 years. Although the problem of subsidence was noticed as early as 1967, not much attention was given to the problem for many years. The first publication on the problem of subsidence in Bangkok was that by Brand & Paveenchana (1971). A comprehensive study was undertaken by the Asian Institute of Technology under the sponsorship of the Thai Government from 1978 to 1981. The report of this study (AIT, 1981) has alerted the attention of people and the government agencies in Bangkok to the seriousness of the problem. As a result of governmental control, the rate of pumped water has been more or less constant since 1983 according to records on authorized wells. The piezometric levels of underground water appear to be rising and the rate of subsidence also appears to be decreasing. Figures 19 and 20 compare the contour lines of the rate of subsidence of the Bangkok Area in 1981 and 1985. However, a recent report (Bangkok Post, 1987) indicates that the problem of subsidence has spread from Bangkok to the new Industrial zones in the surrounding areas, with an estimated affected area of more than 1,000 sq km.

Terrain Evaluation and Land Use Mapping

For a number of years since its creation, the Geotechnical Control Office of Hong Kong has placed considerable emphasis on its Geotechnical Area Studies Programme (GASP) to provide systematic geotechnical input for land use management and development planning purposes (Brand et al, 1982; Burnett, 1986). The GASP was designed to be carried out in three phases. The Regional Studies, each covering an area of 50 to 100 sq km, are an initial geotechnical assessment at a scale of 1:20,000 based entirely on aerial photograph interpretation, site reconnaissance and existing geotechnical information. The Stage One District Studies are an initial geotechnical assessment at a scale of 1:2,500, each covering an area of 2 to 4 sq km. These studies provide information suitable for local planning needs. The third phase are Stage Two District Studies which are expanded geotechnical assessments based on the results of Stage One Studies together with data obtained from a planned program of site investigation.

The GASP approach differs from other known terrain evaluation or hazard mapping systems in a number of aspects. It combines elements of both these

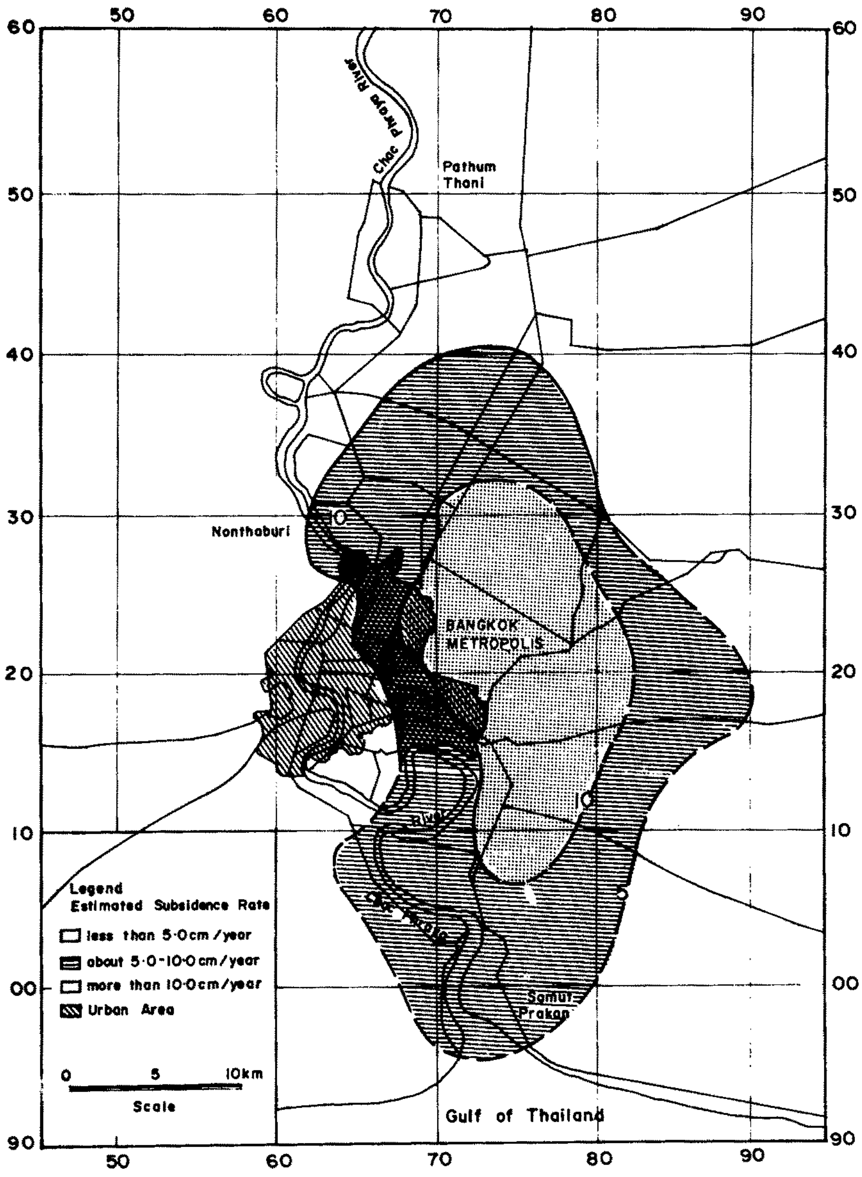


Fig. 19 Rate of Subsidence in Bangkok in 1981.

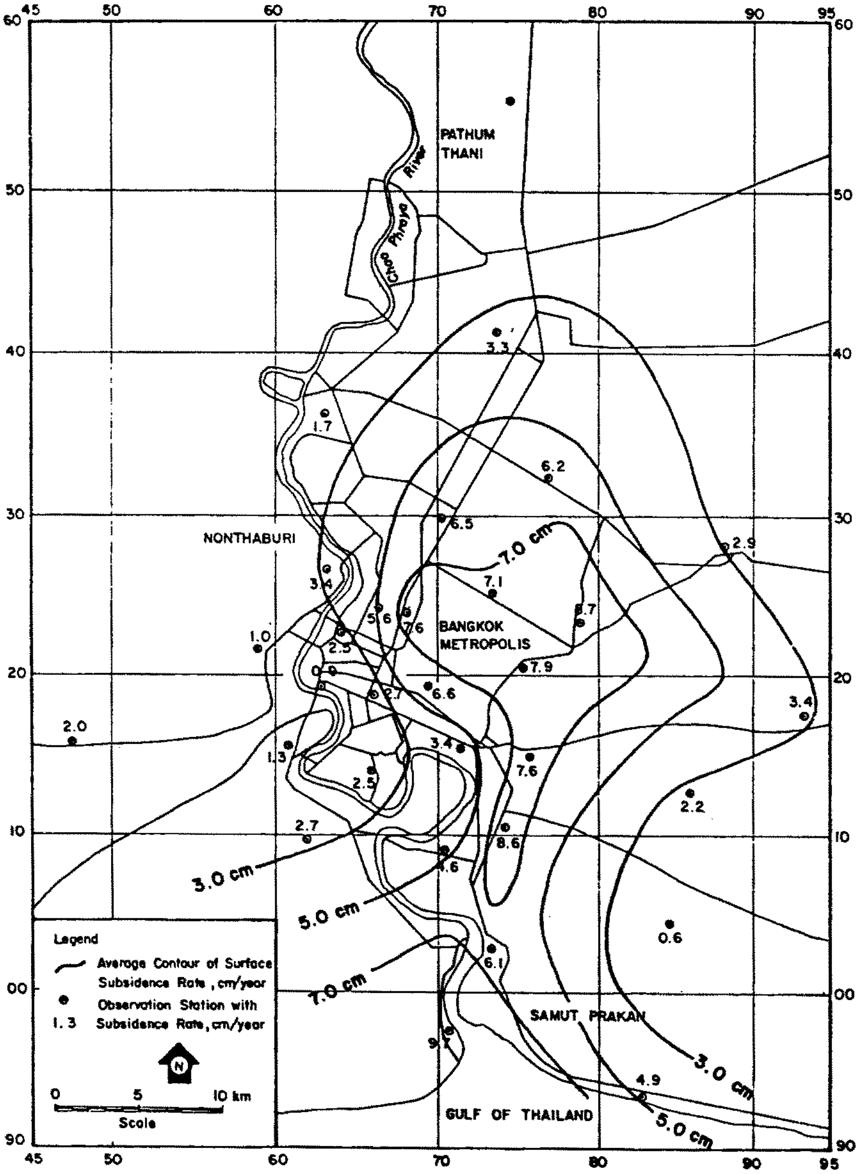


Fig. 20 Rate of Subsidence in Bangkok in 1985.

approaches, but the zonation framework employed is based on the overall geotechnical assessment of the land units, not just on the identification of hazards from a stability viewpoint, although the considerations of stability are dominant.

The main findings of the GASP are incorporated in the Geotechnical Land Use Maps (GLUM). In these maps, land units are classified into four classes on the basis of combinations of attributes from the terrain classification. There are six attributes including slope gradient, terrain component, terrain morphology, erosion, slope condition, and hydrology. Table 2 summaries the essential features of the four classes.

Table 2 The Four Class Classification System Used in Hong Kong for Geotechnical Land Use Maps.

CHARACTERISTICS OF GLUM CLASSES	CLASS I	CLASS II	CLASS III	CLASS IV
GEOTECHNICAL LIMITATIONS	Low	Moderate	High	Extreme
SUITABILITY FOR DEVELOPMENT	High	Moderate	Low	Probably Unsuitable
ENGINEERING COST FOR DEVELOPMENT	Low	Normal	High	Very High
INTENSITY OF SITE INVESTIGATION REQUIRED	Normal	Normal	Intensive	Very Intensive
TYPICAL TERRAIN CHARACTERISTICS. (Some, but not necessarily all, of the stated characteristics will occur in the respective class)	Insitu terrain with gentle slopes (0 – 15°) with severe erosion or instability. Cut platforms in insitu terrain.	Insitu terrain with slopes between 15° & 30° without severe erosion or instability. Insitu terrain of gentle slopes associated with drainage but no instability. Colluvial terrain with gentle slopes (0 – 15°) without severe erosion or instability.	Insitu terrain with slopes between 30° & 60° without severe erosion or instability. Insitu terrain less than 15° with history of landslips. Colluvial terrain less than 15° with evidence of instability. High to moderate fill slopes.	Very steep slopes (>60°) and cliffs. Steep to very steep insitu and colluvial slopes with history of instability. Colluvial terrain with gentle slopes, but with associated instability and drainage.

Taipei City, the capital city of Taiwan, ROC, has developed rapidly in the past 20 years. A large volume of subsurface data has been collected in connection with the construction of infra-structure and building developments. An effort to establish a systematic subsoil databank and to develop geotechnical engineering maps was initiated in 1984 (Moh And Associates, 1987;Huang et al, 1987). A major part of Taipei City is situated on the sedimentary plain of the Taipei Basin. There are three major rivers flowing into the Basin, ie Keelung River from the east, Hsintien River from the south and the Tahan River from the southwest. The Tahan River and the Hsintien River converge to form the Tamshui River which flows into the sea at Tamshui. The Basin's average elevation is about 5m above the mean sea level and the topography is relatively flat. Information on more than 700 boreholes with their associated in situ and laboratory test results was compiled and analyzed. On the basis of their geological origin and sedimentary environment, the subsoils in the Taipei Basin were subdivided into three major regions. From detailed analysis of the composition and thickness of the various strata and engineering characteristics of the soils, the three major regions were further subdivided into seven zones as shown in Fig. 21. A series of geotechnical engineering maps were produced including a geological map, fence diagrams of soil profiles, maps showing isopachs of the various sublayers, isohyp maps of the various sublayers and a geotechnical zoning map.

GOVERNMENTAL CONTROL AND PROFESSIONAL PRACTICE

In all the countries, in the region, except Hong Kong, there are no specific regulations or control in regard to the practice of geotechnical engineering. Most of the control, if any, or review of geotechnical study reports of development projects, is carried out by different governmental authorities, often the agency or authority responsible for the development. For example, geotechnical studies for power, harbour and transportation development in Taiwan are reviewed by the Taiwan Power Company, Harbour Bureaus and Ministry of Communications or other Public Works Departments in charge of the projects. Geotechnical reports for building developments are generally reviewed by the building control authorities in the relevant city or town.

Up to the present time, i.e. 1987, there is no professional registration for geotechnical engineers in any of the five countries in the region. There is no official requirement for a geotechnical engineer to sign or endorse geotechnical reports. All design work relating to geotechnical work such as foundations and retaining structures are endorsed by a Registered Professional Civil Engineer (or Authorized Person in Hong Kong) or Structural Engineer. Recently, both the engineering profession and the governmental authorities have become more aware of the specialized nature and importance of geotechnical engineering, and a considerable amount of discussion was held in Hong Kong and ROC to have geotechnical engineering as a separate discipline and requiring registration for its practice.

The Geotechnical Control Office (GCO) of Hong Kong is a unique governmental establishment. It is probably the largest governmental organization in the world specializing in geotechnical control work. The GCO was established in July 1977, mainly in response to major landslide disasters. It is one of two constituent offices of the Civil Engineering Services Department

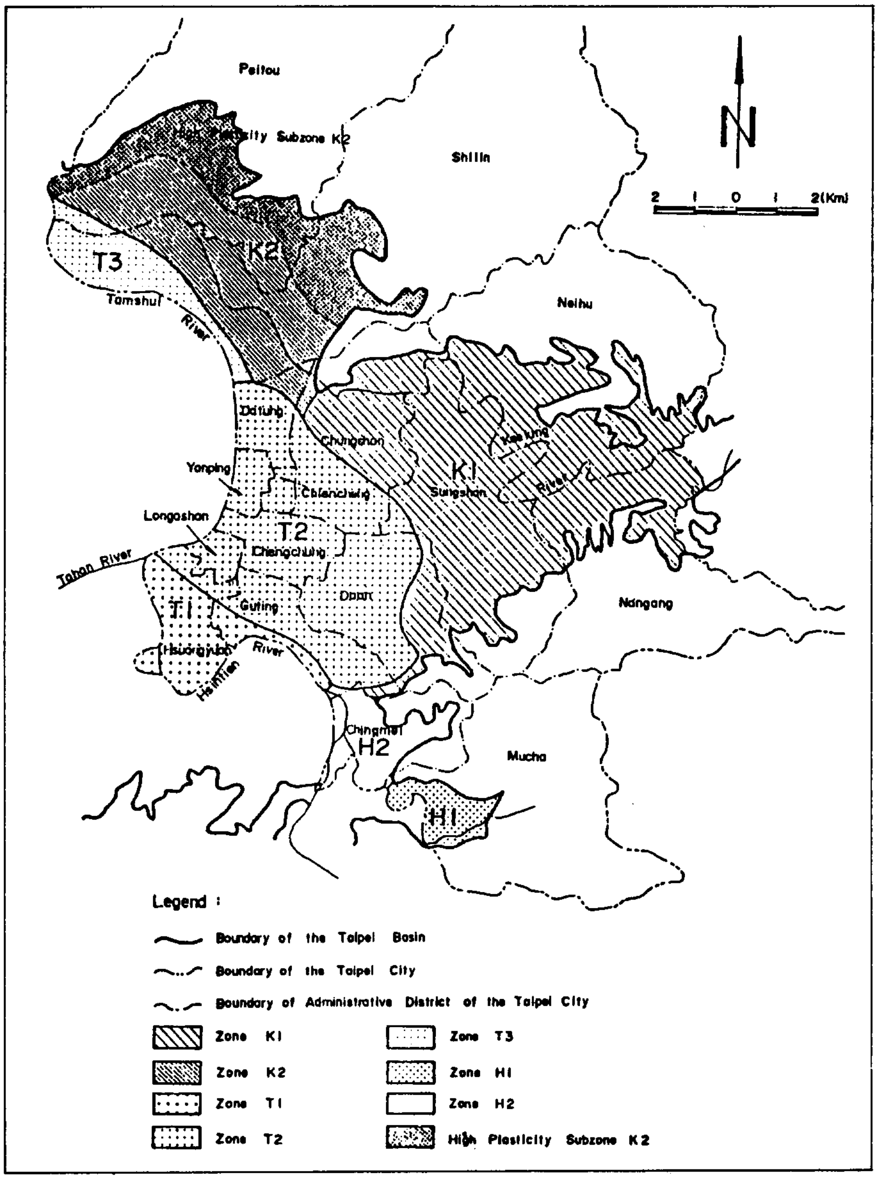


Fig. 21 Geotechnical Zoning Map of Taipei City.

of the Hong Kong Government. The administrative structure of GCO is as shown in Fig. 22. It is headed by the Principal Government Geotechnical Engineer (Dr. E. W. Brand, a past President of the Southeast Asian Geotechnical Society, has held the position since 1977) and is divided into branches and divisions. It currently has a professional staff establishment of 130 and supported by 240 technical grade staff and 280 other supporting staff. The total annual budget of the GCO is approximately HK$160 million (US$21 million) which includes an annual expenditure on landslip preventive works of about HK$65 million (US$8 million).

Some of the major functions of the GCO are:

a) Carry out Governmental checking and control of geotechnical aspects of all public and private building developments and civil engineering works.

b) Provide advisory services to government departments.

c) Manage the GCO's emergency procedures which come into effect during typhoons and periods of heavy rainfall.

d) Carry out design and supervision of preventive and remedial measures to government slopes (the long-term Landslip Preventive Measures Programme).

e) Carry out the geological and geotechnical aspects of the safe and economic utilization and development of land (the Geotechnical Area Studies Programme and Geotechnical Land Use Maps).

f) Operate a soils and materials laboratory, site investigation unit, and government – owned quarries.

g) Conduct applied research and development work.

h) Operate and control 46 automatic rainguages which record the rainfall at 5 minute intervals and which are directly connected by telephone line to the GCO Headquarters.

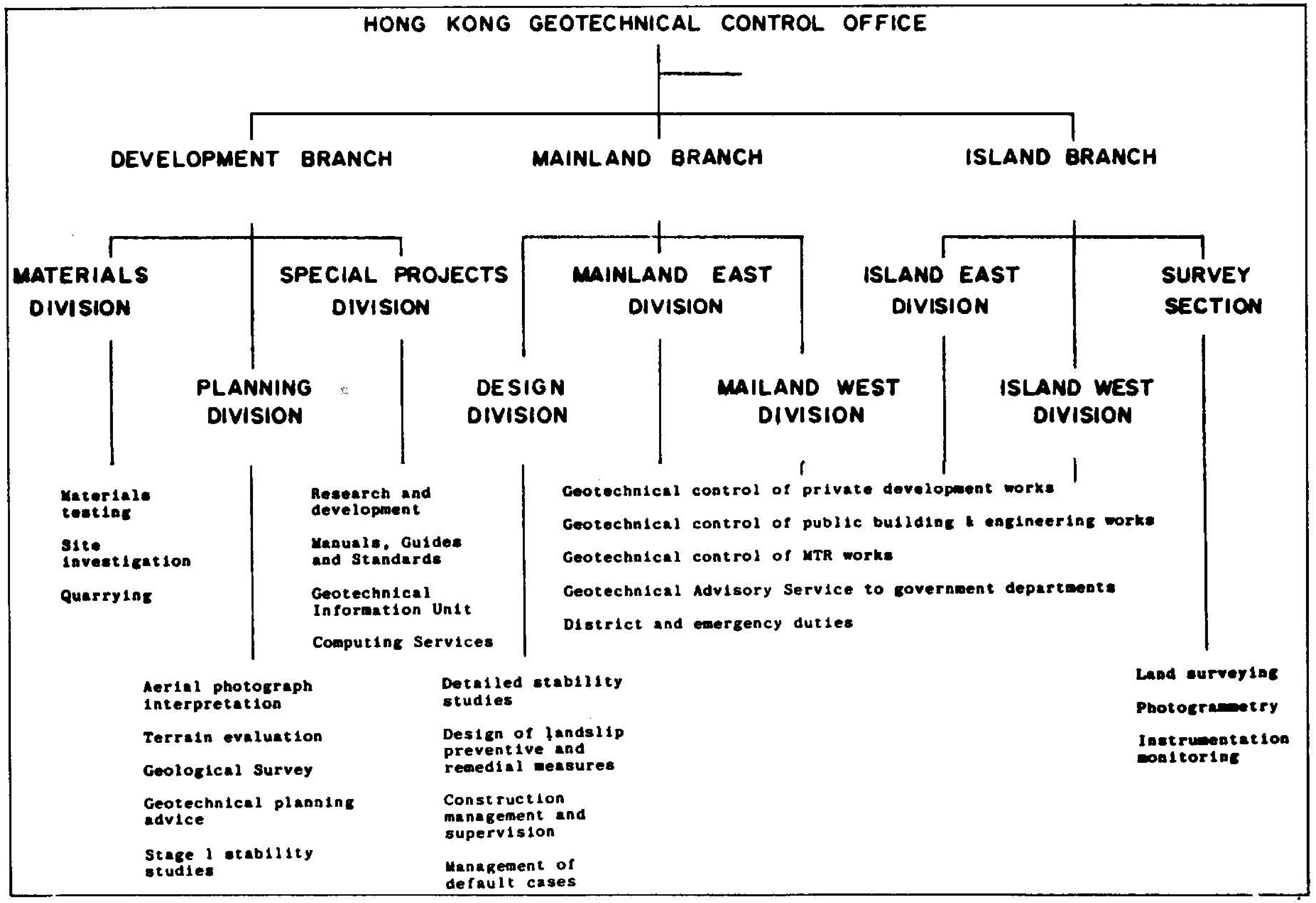


Fig. 22 Setup and Function of the Geotechnical Control Office of Hong Kong Government.

Much of the work carried out in the GCO's Special Projects Division have been published in technical papers and reports. A number of important guides has been issued to the public, including the Geotechnical Manual for Slopes (1984), the Guide to Retaining Wall Design (1982) and the Model Specification for Prestressed Ground Anchors (1984). Other guidance documents are under preparation.

INFORMATION DISSEMINATION

Publications

Conferences

In the past 20 years, there have been nine Southeast Asian Geotechnical Conferences, six Asian Regional Conferences and six International Conferences on Soil Mechanics and Foundation Engineering. A total of 315 papers has been contributed by authors from the Southeast Asian region. Considering those published elsewhere, such as in journals, at seminars and symposia, the geotechnical engineers in the region have authored more than 600 papers. The number of papers relating to activities in the region but authored by people not residing in the region is also very significant. There are two excellent bibliographies on geology, geotechnical engineering and soil deposits in the region, one on Bangkok and the other on Hong Kong. Both of these were compiled by Brand (1986, 1988).

Besides the international and regional conferences mentioned above, there were many conferences, symposia and seminars organized by local institutions. The more notable ones are the eleven symposia organized by the Asian Institute of Technology in Bangkok with co-sponsorship of the Southeast Asian Geotechnical Society from 1977 to 1986, the five symposia organized by the Nanyang Technological Institute in Singapore from 1983 to 1987, the three seminars organized by the Chinese Institute of Civil and Hydraulic Engineering in Taipei in 1977 to 1979, and the joint symposium organized by the Institution of Engineers Malaysia and the Japanese Society of Soil Mechanics and Foundation Engineering in 1986.

Journals

There are two journals published regularly in the region, devoted entirely to geotechnical engineering. First is "Geotechnical Engineering", which has been published by the Southeast Asian Geotechnical Society twice a year since 1970. The other is a Chinese language journal Sino-Geotechnics which is a quarterly publication started in 1983 and published by a group of geotechnical engineers in the ROC. A number of issues of this journal has been devoted to special topics. This journal is quite popular and has a current circulation of about 1,000.

Asian Information Center for Geotechnical Engineering

When representatives of the Asian Member Societies of the International Society met during the Fourth Asian Regional Conference in Bangkok in July 1971, concerns were expressed about the lack of well equipped technical libraries and information centers in the Asian region which was a serious drawback to research and practice in geotechnical engineering. As a result of a resolution at this meeting, the Asian Institute of Technology (AIT) was requested to undertake the establishment of an information centre to deal exclusively with geotechnical information. After active planning and preparation with a generous grant from the International Development Research Centre (IDRC) of Canada, the Asian Information Centre for Geotechnical Engineering (AGE) was established in January 1973 as a joint project of the Division of Geotechnical Engineering and the Library and Information Center of AIT. In April 1976, a workshop was organized by AIT and IDRC to review the status of geotechnical information systems in the world with particular emphasis on the AGE (Brand & Brenner, 1976).

AGE offers engineers and scientists in developing countries services and publications on geotechnical information at a very low membership subscription rate which is less than one-tenth of the much more expensive western based information systems. In addition, AGE provides them with services, not offered by the other systems, which are of utmost importance in developing countries such as: back-up document procurement, reference service, current awareness service, newsletter, database in printed and in tape forms.

Today, AGE is one of the four information centres at the AIT Regional Documentation Center. AGE has a database of some 40,000 classified entries. Currently, the number of entries to be processed annually is approaching 5,000. The current AGE membership covers not only Southeast Asia but has more than 20 per cent from outside the Asia and Pacific region, as shown in Fig. 23. The changes in membership over the first 12 years are shown in Fig. 24.

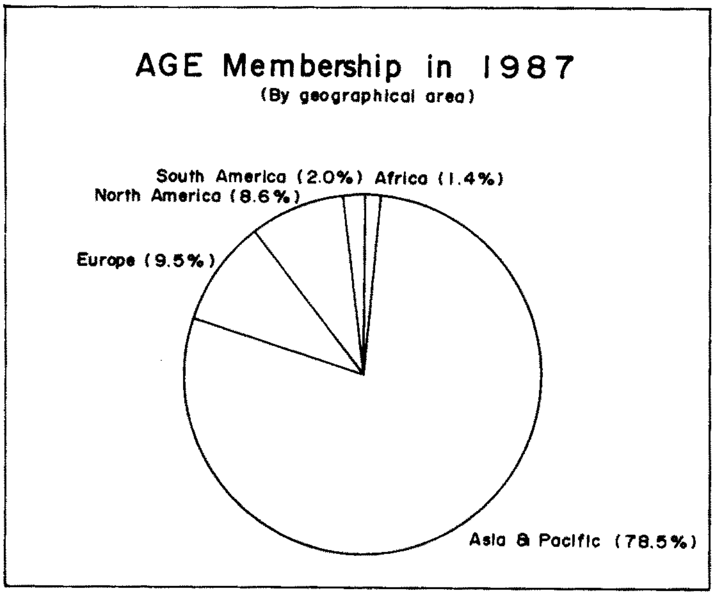


Fig. 23 AGE Membership Distribution.

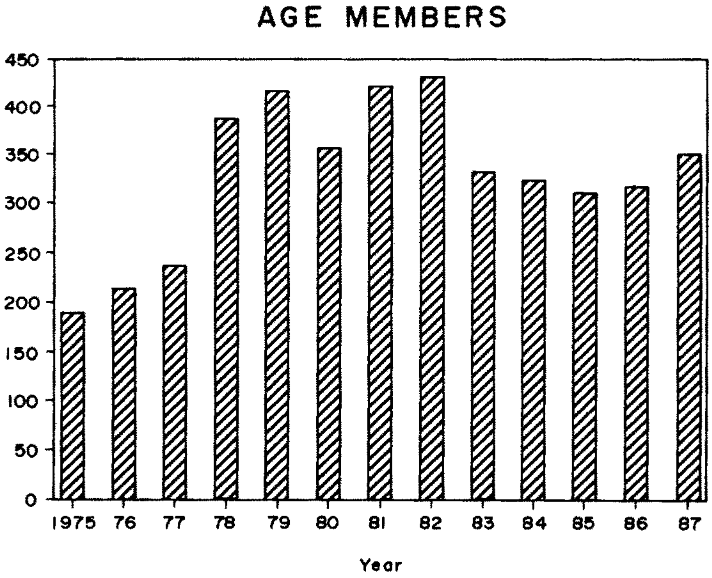


Fig. 24 AGE Membership by Year.

At the present, AGE produces three serial publications and a range of occasional publications. These include:

A) Serial Publications

- i) AGE news – 4 issues per year.
- ii) AGE Current Awareness Service – 6 issues per year.
- iii) AGE REFDEX (yearly) – This publication combines AGE Abstracts and AGE Digest which is a printed version of the AGE computerized database.

B) Occasional Publications

- i) AGE Conference Proceeding Holding Lists.
- ii) AGE Research/Technical Special Reports Holding Lists.
- iii) Selected Bibliographies.

RESEARCH AND CURRENT INTERESTS

Research activities in engineering in a country are normally closely related to post-graduate education and the state of development of that particular branch of engineering practice. In the developed countries, researches in geotechnical engineering are being carried out both in academic institutions and in practising organizations, such as consulting engineering firms and contractors. The emphasis on research in the academic institutions is usually on basic and fundamental studies, whilst research works carried out by engineering organizations are normally more applied in nature. The latter are often problem-oriented or solution-oriented. It is a common practice in developed countries that governmental agencies and private organizations sponsor research work at academic institutions. In some developed countries, there are national level organizations responsible for coordinating and sponsoring fundamental research, such as the National Science Foundation of the USA. In others, there are national level organizations, not only conducting their own research but also sponsoring research work in academic institutions, such as the CSIRO and Road Research Board in Australia; the Building Research

Establishment and the Transport and Road Research Laboratory in the UK; the Waterway Experiment Station of the US Corps of Engineers; the Laboratoire Central des Ponts et Chausees of France; the Public Works Research Laboratory of Japan etc. There are also some private organizations which carry out extensive in-house research work, such as the Kajima Research Institute which is a part of the giant constructor the Kajima Corporation of Japan, and many large geotechnical consulting firms.

In the five countries of the Southeast Asian region, geotechnical engineering research has been mostly carried out in academic institutions, particularly those with post-graduate programs. The nature of the research work in the past 20 years has been more practically or applied orientated. Unfortunately, a fairly large proportion of the so-called sponsored research, (projects sponsored by governmental or private agencies) was more towards testing and routine work rather than true research. The institutions which have a relatively large graduate student body are usually those more involved in research work. They include the National Taiwan University, National Cheng Kung University, National Taiwan Institute of Technology in the ROC; Asian Institute of Technology and the Chulalongkorn University in Thailand and the National University of Singapore. From Fig. 3, it can be seen that the number of academic institutions which offer a post-graduate programme in geotechnical engineering has increased significantly in the last few years, this is particularly true in the ROC.

The most notable governmental organization which has been involved deeply in geotechnical research work is the Geotechnical Control Office of Hong Kong, others include the Singapore Port Authority, Public Works Departments in Singapore and ROC, the Highway Departments in Thailand and ROC. Most of the research works carried out by these organizations are usually directly related to their project developments. Geotechnical consulting engineering firms often incorporate applied research into their project work. Those firms who are active in applied research and often publish technical papers include China Engineering Consultants Inc., CTCI Corp., Sinotech Engineering Consultants, Moh And Associates in ROC, Binnie & Partners, Scott-Wilson-Kirkpatrick & Partners, Ove Arup & Partners, Maunsell Consultants of Hong Kong, Professor F.K. Chin, Dr. W.H. Ting Consultants, Zaidun-Leeng of Malaysia. Not many contractors in the region carry out research work on their own, the exceptions are the Ret-Ser Engineering Agency of ROC and Pilecon Engineering of Malaysia.

A survey on research and development topics of current interest was undertaken by the author in 1987. A questionnaire was sent to most of the academic institutions offering post-graduate programmes in geotechnical engineering and selected governmental organizations, consulting firms and contractors. The results of the survey are summarized in Table 3.

FUTURE DEVELOPMENT

In Table 3 are listed the major topics of current research interest, both fundamental and applied. The author would like to suggest that the following four areas be considered as top priority for future development in the coming decade.

1) Environmental geotechnology

   Environmental degradation has become a severe problem to both developed and developing nations. In the developed countries, this problem has already appeared. The efforts of scientists and engineers are more concentrated towards measures and methods to treat the environmental problems which have already been created and to prevent further degradation of the environment in which mankind has to live for many more years. For developing countries, the problem, however, can be considered to be somewhat different. On the one hand, due to there being less development, there is less awareness of the problem. On the other hand, there is ample opportunity to prevent the environmental problem occurring since many developments are still in progress or at the planning stage.

   The role of geotechnical engineers in environmental control can be broadly classified as: (1) the prevention of environmental risks and (2) the creation of a better environment. Geotechnical engineers in many developed countries, such as the USA, UK, Canada, and Japan are very active in the field of environmental geotechnology. In the Southeast Asian region, this subject has yet to receive sufficient attention.

Table 3 Geotechnical Engineering Topics of Current Interest

Country	Hong Kong	Malaysia	ROC	Singapore	Thailand
Topics of Interest	Slopes	Slopes	Soft Ground	Reclamation	Soft Ground
	Reclamation	Reclamation	Slopes	Soil Improvement	Soil Improvement
	Tunnelling	Waste Mines	Residual Soils	Soft Ground Tunnelling	Soil Structure
	Marine Fill	Soft Ground	Ground Anchors	Residual Soils	Subsidence
	Caisson Design	Foundation in Limestone Area	Piles	Field Instrumentation	Piles
	Soil Improvement	Offshore	Seismic & Dynamic Design Rock Behaviour		Environmental Geotechnics
	Residual Soils		Cone Penetration Test		

2) Mitigation of damage from natural hazards

Typhoon, flood, earthquake and ground failure are four natural hazards which have caused great loss of human lives and to the economy of many Southeast Asian countries. Researches and development in mitigation of natural hazard damage are of utmost importance to these developing nations. Several countries, such as the ROC, already have an intensive research programme in the area relating to large-scale natural Geotechnical hazards/disasters. Immediately following the 9th Southeast Asian conference, also at the same venue, the US – Asia Conference on Engineering for Mitigation of Natural Hazards Damage took place. At this conference, topics relating to the above natural hazards were discussed by participants from the USA and many Asian countries. Areas of research which are of high priorities were identified.

3) Geotechnical Engineering

For better utilization of land, for more economical and safe designs, and for control or prevention of natural hazard damage, the value of properly developed geotechnical engineering mapping cannot be overemphasized. In Southeast Asia, only Hong Kong has made a concerted effort in the development of land use mapping. As described in an earlier section, initial effort in developing geotechnical engineering maps has been made in the ROC for Taipei City. Systems for landslide mapping are also under study in that country. Much more effort will be required to develop these maps for engineering use. The priority for engineering mapping appears to be rapidly developing urban areas and terrain susceptible to natural hazard damage.

4) Subsidence

Problems generated by ground subsidence due to extraction of underground water are becoming more serious and wide spread. Although quite expensive reserach work has been carried out, there is still a lack of practical remedial solutions. Research and development work are needed both for control of subsidence and for reduction of damage due to subsidence.

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