

BUILDING FOUNDATION PARCTICE IN TAIWAN

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INTRODUCTION

The island of Taiwan lies about 150 km off the east coast of China mainland. It is separated from the mainland by the Taiwan Strait which has an average depth of 100 meters. The island is spindle-shaped, with the longitudinal axis extending roughly north-south for a length of 385 km. The maximum width is about 143 km and the total area of the island is approximately 35,960 sq.km.

The island is composed of geosynclinal deposition of Tertiary sediments to a thickness of more than 10,000 meters on a metamorphic basement. All the major rock formations on the island occur in long narrow belts roughly parallel to the longitudinal axis of the island. The prevailing structural pattern of all the rocks is an elongated arc with its convexity facing the west or the Asiatic continent, and all the major structural lines, including the important faults and fold axes, correspond fairly well to this structure throughout the whole island.

Taiwan can be broadly divided into three major geologic provinces as shown in Fig. 1. These are the Central Range, including all the Tertiary submetamorphic and the Pre-Tertiary metamorphic complex, the Coastal Range of Neogene sediments, and the Western Foothill province composed of Neogene clastic sediments. The topography, which has been greatly influenced by geologic conditions, can also be divided into several parts. The Central Range strikes roughly parallel to the longitudinal axis of Taiwan and forms the backbone ridge of the island. It divides the island into two unequal parts, the western flank being about twice as wide as the eastern flank. The western flank declined from the Central Range westward into strips of foothills and then into broad tablelands and terraces. A wide extent of coastal plains and subsidence basins were developed on the southwest part of this foothill region. The coastal plain has a north-south length of about 240 km, and a maximum width of 45 km.

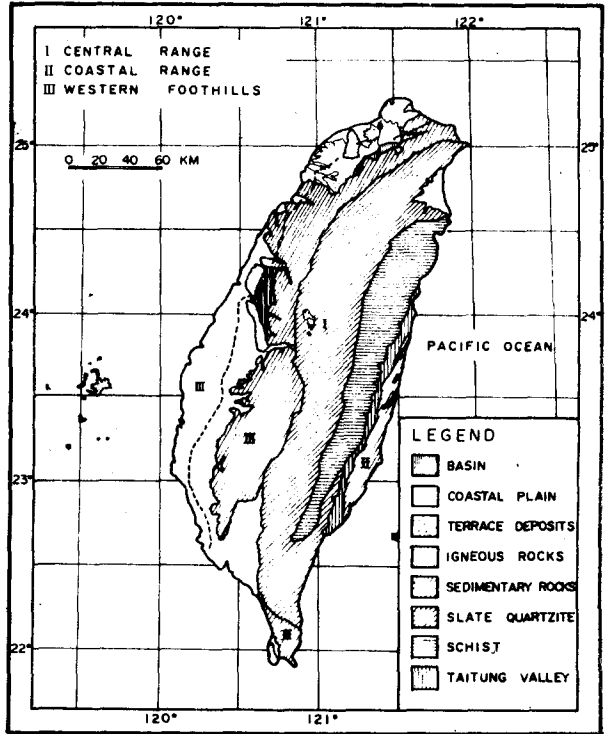


FIG. 1 Geological Map of Taiwan

The total land area, which has elevation less than 100 m above the mean sea level, covers about 31.3% of the entire area of the island. Most of these lands are in the alluvial plains or basins, which are underlain by soft clays and loose to medium dense sands of recent deposits. More than 17 millions of people are crowded in this area which is less than one third of the whole island.

As a result of six successful four-year

economic development plans since early 1950s, the industrial productivity of this island has increased rapidly. To gear with continuous industrial development and modernization program, the government has invested more than US\$5 billion in heavy industrialization plans and construction projects since 1974. These islandwide projects covered both off-shore and inland constructions including the so-called Ten Big Construction Projects of North-South Freeway, Steel Mill, Harbor, Airport, North-Link Railway, Ship Building Yard, Petrochemical Industry, etc. Due to the complex nature of the geological formation and difficult ground conditions of the island, geotechnical engineers in the country have faced interesting and difficult challenges during site selection, foundation design and construction of these major projects. For instance, the north-south freeway with a total length of 381.7 km, which links Keelung Harbor at the north with Fengshan at the south by way of Taipei, Taichung and Tainan, passes through swamp zones, mountain terrains with unstable slopes and recent sediments of soft deposits. The problems to be considered during the design and construction stages involved not only the selection of suitable foundation systems, but also consideration of settlement control, selection of local materials and methods of ground improvement.

Although the types of foundation systems and construction methods used in this country during the past two decades have involved a wide variety of techniques, for the general building structures, the problems are far less complicated. The following sections give a brief summary about the experience of common foundation practice for building constructions in Taiwan.

SITE INVESTIGATION

For building construction, soil investigation by use of boring method is generally required by the building code for structures over four stories high and for buildings which are designed for public use, such as auditoriums; hospitals, etc. The number of boreholes required as stated in the building code is at least one hole for every 650 sq m of building area, and the depth of borehole must reach at least 1.5 times the footing width below the foundation level. Undisturbed soil samples are usually obtained by means of thin wall tube sampler.

In recent years, the importance of geotechnical engineering in civil engineering construction is gradually being recognized and appreciated. More thorough investigations were or are being conducted prior to the design phase for major projects such as nuclear power stations, freeways, etc. Geophysical methods of exploration are also utilized for evaluating geological structures, locating faults and earthquake studies. However, for building structures, besides the code requirement, not sufficient

attention be directed to the significance of site investigation and geotechnical evaluation of the subsoil conditions. The extent of pre-engineering work is often not adequate. Numerous foundation failures or damages to structures have occurred during the past decade. The primary causes responsible for these problems can be attributed to ignorance of some of the owners, unawareness of architects and designers, and outdated building regulations.

DESIGN OF BUILDING FOUNDATIONS

Before 1960, there were very few tall buildings in Taiwan, most of the structures were less than 4 stories. Except in areas of extremely soft soils, the most commonly used type of building foundations is spread footing. The allowable soil bearing capacity was assumed to be 10 t/m². In areas with dense residual deposits, such as Taoyuan and Taichung, bearing capacity value as high as 80 t/m² was used in design. After 1960, due to rapid economical development in the country, the land value increased astronomically. The natural tendency of development of building industry was towards height, more and more tall buildings were constructed. In most major cities on the island, due to poor subsoil conditions, shallow foundations are not adequate to support the heavy loads imposed by tall buildings. Figure 2 illustrates the typical subsoil profile of Taipei, the capital city where a large number of tall buildings has been constructed. As shown by the figure and also reported by the authors in a paper presented to this Conference, the shallow strata of the subsoils in the Taipei Basin are soft and compressible. The good bearing layer of dense sand-gravel is located at a depth of 40 to 50 m below the ground surface. The building regulations in Taiwan require the incorporation of at least one basement level in any building over 5 stories above the ground level. In view of the subsoil conditions and the basement requirements, tall buildings can be either supported by deep foundation founded in the underlying dense gravel stratum or by compensated foundation.

Compensated foundation or floating foundation utilizes the principle of stress reduction due to excavation to compensate full or part of the building load. This type of foundation has been used very successfully in many cities with soft subsoil condition, such as Boston and Mexico City. About 80% of tall buildings in Taiwan adopts this design principle. For the subsoil condition such as that in Taipei City, compensated foundation for a typical 12 - storey building need to be placed at a depth of 10 to 12 m below the ground surface. In design of compensated foundation, problems relating to deep excavation must therefore be considered in addition to

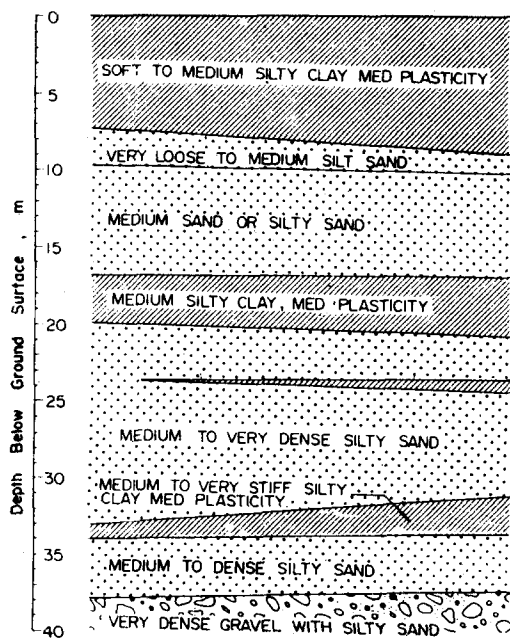


FIG. 2 Typical Soil Profile of Taipei City

the problem of settlement control. A number of cases involving problems or difficulties during excavation will be illustrated by slides.

In areas where the depth of the dense sand-gravel layer is relatively shallow and in cases when the building loads are too heavy to be supported by compensated foundations, pile foundations are used. The most commonly used type of piles are cast-in-situ bored concrete piles with diameter varying from 60 cm up to 240 cm. The boring equipments are of the reverse circulation type using slurries to stabilize the walls of the boreholes. There are more than ten pile contractors in Taiwan who have the capability and experience to install large diameter bore piles. One of the current project in Taipei City involved 386 pieces of bored piles, 100 cm to 180 cm diameter and 50 m long. The piles were installed in 4 months by using 8 machines.

Underreamed bore piles with base size 2 to 3 times the pile diameter were also tried. But due to difficulty in construction control, the full advantage of enlarged base was not realized.

Other types of piles which are frequently used in Taiwan to support structures other than buildings, such as bridges and machine foundations, include precast prestressed concrete piles, vibro piles, steel pipe piles and Raymond piles. The commonly available production sizes of precast prestressed piles are 20 cm to 80 cm, round or octagonal shape. Among them, the 60 cm diameter round piles are most popular. For pile length exceeding 16 m, splicing is generally required. Satisfactory results were obtained by using high tension bolts for splicing. In 1976 and 1977 the annual consumption of prestressed piles was about 350,000 linear meters. At the present, the annual production capacity for 50 cm and 60 cm diameter piles is about 43,000 pieces. For smaller diameters, the production capacity can exceed 60,000 pieces per year.

The usage of steel pipe pile has not been wide spread mainly due to its relatively high cost. Raymond piles have been used extensively in one of the Big Ten Projects. During the first phase construction of the China Steel Corporation, a total of 22,560 pieces (over 650,000 linear meters in total length) of Raymond piles was driven. During the China Steel Construction, the damage rate of Raymond piles was found to be around 8.2% whilst that of the prestressed concrete piles exceeded 12%.

DEEP EXCAVATION

As described in the previous section, compensated type of foundation is generally used for tall buildings in Taiwan. Deep excavation becomes an essential part of the construction program. There are many types of retaining structures which can be adopted as temporary support for deep excavations. Table 1 lists the most commonly used retaining schemes in Taiwan. Prior to 1973, prepackt piles and sheet piles were generally used. Diaphragm walls became popular since 1975 and are gradually replacing the other type of retaining structures. The first diaphragm wall construction in Taiwan was carried out by the Ret-Ser Engineering Agency in 1971 by using the BW System developed by Tone Boring Company of Japan. The diaphragm wall had a thickness of 55 cm, depth of 16 m, and the total area completed was 2944 sq m.

A number of other systems of diaphragm wall construction has been introduced into the market since 1971, including ICOS' clam shell and ELSE method. Up to the present, a total area of diaphragm wall in excess of 200,000 sq m has been completed, more than one-third was completed in 1978. Among the three methods of construction, the clam shell method took about 75% of the market. In 1978, the clam shell method completed 43,300 sq m whilst the BW method completed 29,360 sq m. The ELSE method of excavation was

TABLE 1 Most Commonly Used Earth Retaining Schemes for Excavations in Taiwan

Type of Retaining Scheme	Specifications and Usage
Soldier Piles and Laggings	Mostly use 35 kg/m rails with 2.5 cm thick wooden planks. Rail length 10 to 15 m spaced at 40 to 50 cm. Used for shallow excavations less than 6 m.
Steel Sheet Piles	Locally available type include YSP-II, YSP-III, YSPU-15, NKSP-II, NKSP-III, mostly 12 m or 13 m in length. Only few hundred pieces of 16 m sheet piles available. Used for excavation depth between 7 to 9 m.
Cast-in-situ Prepacked Piles	Commonly used sizes are 25, 30, 35, and 40 cm diameter, for excavation less than 10 m in depth. Main difficulties are control of water seepage and loss of soil particles through spacings between piles. Grouting often needed.
Diaphragm Walls	Thickness used between 40 to 80 cm. Construction technique available includes BW, ICOS and ELSE. Used for excavations exceeding 10 m depth.

introduced only recently which is combined with precast panels. It is estimated that about 8,340 sq m of wall will be completed by using the ELSE method this year. Majority of the wall had a thickness of 50 cm with the thickest one at 80 cm. Depth of the wall is generally around 20 m.

Two major problems were generally encountered during diaphragm wall construction in Taiwan at the present. They are stability of slurry during excavation and water tightness between wall joints. Part of the problem can be attributed to the lack of control during construction and sometime to the use of improper equipment. After experiencing much difficulty and problems, the construction industry started to appreciate the importance of controlling properties of the slurry to be used during construction. The quality of diaphragm walls built during the last two years has improved significantly. Table 2 shows the standard specifications of slurry being used for diaphragm wall construction in Taipei City.

The problem of joint sealing between diaphragm wall units is much more difficult to overcome. Majority of the construction used overlapping joints, however, accumulation of mud at the joints between units often lead to serious seepage of water into

the excavation area. Use of cement or chemical grouting became a necessary remedial measure for many diaphragm wall construction. It is believed that with continuous improvement in the construction technique and quality control, the problem of joint sealing can be minimized.

Internal bracings with steel struts are usually used to support the earth retaining structures during excavation. The size of the struts is generally limited by the availability of steel beams on the local market with maximum size up to 350 mm by 350 mm. Prestressing by means of oil jack is usually applied to the struts after installation. Earth anchors have also been used in a number of projects. Performance of earth anchors varied considerably, being relative satisfactory in sandy soils and unsatisfactory in clays. Some catastrophic failures have occurred in recent years, which have prompted the government regulating agencies to place a more strict restriction on their use as bracing system. It is believed that majority of the unsatisfactory performance of earth anchors is due to lack of proper evaluation of the subsoil characteristics by competent geotechnical engineers.

TABLE 2 Standard Specifications for Diaphragm Wall Slurry Used in Taipei

Slurry Property	Permissible Range	Test Method
Specific Gravity	1.02 - 1.10	Mud Density Balance
Viscosity	21 - 25 seconds	Marsh Funnel Viscosimeter
Filtration	Fluid loss < 15 ml in 30 seconds Cake < 2.0 mm	Filter Press Test
pH	8 - 10	pH Meter
Sand Content	< 5%	Sand Screening Test

FIELD INSTRUMENTATION

Due to rapid development of construction projects and lack of strict control on geotechnical evaluation, numerous cases of damages to adjacent structures due to improper or inadequate safety measures during excavation have been reported. In 1976, within a period of one year, governmental agencies were directly involved in arbitration of 198 cases of damage compensations due to improper construction. Among which majority of the cases involved excavation problems. Direct compensation exceeded US\$0.75 million dollars. Effect of construction delay and other indirect damages far exceeded this value. Since 1978, use of field instrumentation to monitor construction safety of deep excavation is receiving attention. At the present (April 1979), there are five projects in Taipei adopting the monitoring system. Field instrumentations installed include piezometers, inclinometers, settlement points, heave points, strut strain gauges, and earth pressure cells. It is hoped that use of monitoring system will become a routine part for all deep excavation works in the near future in order to ensure safety for the public.