UNDERPINNING BUILDINGS DAMAGED BY FOUNDATION CAUSES

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SYMBOLS

- **B** = consistency
- **c** = cohesion
- **c_v** = coefficient of consolidation
- **e** = void ratio
- **G** = specific gravity of solid
- **m_v** = coefficient of volume compressibility
- **n** = porosity
- **S** = degree of saturation
- **I_p** = plasticity index
- **W** = water content
- **W_L** = liquid limit
- **W_P** = plasticity limit
- **γ_w** = density of water
- **γ_d** = dry density
- **φ** = angle of internal friction
INTRODUCTION

Today, interest is more and more connected to the problem of underpinning. One of the most obvious evidents about this was a session formed at the Tenth International Conference on Soil Mechanics and Foundation Engineering held in June 1981 in Stockholm, Sweden. In this session, which was called "Saving Cities and Old Buildings", scientists from various parts of the world offered 29 reports on a large range of topics which were about

a) Geotechnical problems connected with the protection of existing structures against subsidence and floods

b) Investigations on the integrity, durability and bearing capacity of structures

c) Underpinning and other methods of saving structures and ground

Underpinning structures is the introduction of additional support to the foundation of a structure to increase its bearing value. Underpinning of existing foundations may be required for the following purposes:

1. As a remedial measure to stop the settlement of a structure (remedial underpinning).

2. As a precautionary measure carried out in advance to prevent excessive settlements of a structure when deep excavations are to be undertaken close to its foundation (precautionary underpinning).

3. As a strengthening measure to enable existing foundations to carry increased loading, or to replace the deteriorating fabric of a foundation (strengthening underpinning).

The history of underpinning started hundreds of years ago with remedial underpinning, but today precautionary underpinning is the most common type of underpinning, especially in developing cities and in building subway systems.
In Vietnam, underpinning is very necessary, especially in the stage of reconstruction after the war. The reasons for underpinning in Vietnam, in general, are similar to those in other countries. But in many cases, underpinning is needed for lack of experience in design, construction and soil investigation. In some Vietnamese cities such as Hanoi, Haiphong, HochiMinh City... many buildings are now threatened by large settlements, some of them have been out of use and their residents had to move away. That's why it is necessary to study underpinning methods which are now being widely used in the world and chose those suitable for Vietnamese conditions. This investigation has been carried out at the Institute for Building Science and Technology (IBST), Vietnam, according to the programme of cooperation between IBST and the Swedish Geotechnical Institute (SGI), Sweden.
1. **REASONS FOR UNDERPINNING**

If the total or differential settlement of a building exceeds a certain allowable value, dangerous stresses will appear in the structure, cracks will occur and develop rapidly, the building will not be able to be used normally. And, if so the building needs to be underpinned. Settlement of buildings is due to a variety of causes, but the most common cause is the overloading of the soil of a mat or spread footings. A historic example is the Palace of Fine Art in Mexico City which has settled over 300 centimeters since it was constructed in 1904 (Civil Engineering, 1955). A complete failure is wellknown, an example being the collapse of a cement silo in 1940 due to the overloading of a 17 metre strata of soft varved clay (Tschebotarioff, 1951). Mistakes which are made in the links of construction process and result in great settlement of buildings, can be devided into the following groups:

- Mistakes made during construction
- Mistakes made during design and soil investigation
- Mistakes due to improper use of other objective causes.

1.1 **Mistakes made during construction**

Some common mistakes which are made during construction are as follows:

- Local settlement is caused by cushion material which is not dense enough. When there is a thin layer of very soft clay which is needed to replace by, for example, sand cushion, local settlement will also happen if the soft clay is not removed entirely.

- Foundation of an existing building can be damaged during construction of an adjacent building in some of the following ways:
  - The existing foundation is exposed by adjacent excavation. The soil under the foundation, especially if it is fine sand, silty sand or saturated sand, will rush
out when the excavation is deeper than the bottom of the existing foundation. Many cases of building failure in these ways have been recorded in history [9,14]

- Adjacent excavation resulting in lowering the groundwater table and causing additional settlement to the existing building.
- The existing structures are damaged by vibration due to pile driving.
- The deformation gaps are constructed in a wrong way.
- Because of carelessness on the formworks there are slits, through which saturated soil can flow inside during concrete casting. Damages of foundation can be caused if the thickness of the cushion under foundations or the cover layer of reinforced concrete foundations is not great enough. The quality of the concrete is sometimes so bad that columns can penetrate the footing or strip footing can be broken.
- Piles are not driven to required depth. Piles are over-driven or broken by boulders. Piles have low quality (piles are installed in a wrong way, voids in concrete poured in piles, the cover of piles is collapsed...).

1.2 Mistakes made during design and soil investigation

Soil investigation must be carried out carefully in areas which have varied terrain, inhomogeneous soil layers, and especially, cavities in bedrock. In many cases, cavities in bedrock are not discovered.

Sometimes designers have no or wrong information of a layer of very weak soil (its thickness, its characteristics). Incorrect information is received due to many reasons: carelessness in the field investigation, bad instruments, bad testing procedures... All these reasons will result in sample disturbances during the process of sampling, transportation, storage and testing of soil samples.
Fig 1.3 shows the damage of a building which is built on an old foundation which was not found in the soil investigation.

It is easy for designers to make the following mistakes:
- Using incorrect calculation assumptions such as mis-determinating the loads placed on the foundation; disregarding the load placed on the ground floor or an adjacent building.
- Designing in a wrong way, e.g. no gaps which are needed between the building parts which have different heights, different loads or different foundation levels, or the gaps are not in right locations.
- Having a limited knowledge of soil mechanics and foundation engineering, then choosing incorrect type of foundation having no prediction of settlements, not taking into account negative skin friction of piles...

1.3 Mistakes due to improper use and other objective causes

The variation of the groundwater level or of the water content of soil, which takes place permanently or in long term, is one of the most common reasons which cause damages of buildings in use. Fig 1.4 shows a building which is built on the side of a hill. Water which flows down from the top of the hill will increase the water content of the soil and will cause large settlement of the building on one side only. A similar situation will happen when a part of the foundation is flooded due to the failure (or lack) of drainage system after a rain, Fig 1.5. The variation, lowering or increasing, of the groundwater level can be caused by excavating, undermining, pumping of groundwater...However, if the thickness of soil layers, the foundation level and the variation of the groundwater are the same on the whole plan of the building, the additional settlement will be the same too, therefore there is very little or no damage. But if one
of these three factors is varied, the differential settlement will be great and the building will be damaged (Fig 1.6). Lowering of the groundwater level will also cause rotting of timber piles. Fig 1.7 shows a building founded on timber piles. Lowering of the groundwater table causes not only large settlement but large differential settlement as well. Many investigations on the quality of timber piles are recorded [13, 14, 15].

Failure of foundation material is also very common. It is often caused by the following reasons:

- Foundation material is washed out by water used in production or living conditions.
- There are harmful compositions in foundation material
- Ageing of the material
- Influences of technology machines (e.g. vibration)
- Influences of climate and weather.

In one of his investigations, Feklin [6] showed that 41% of the buildings, which were investigated, were damaged by failure of the foundation materials.

Underpinning is also needed in some other cases: subsidence caused by trees which remove water from the ground near a structure, corrosion of steel piles due to chemical or electrolytic action.....

In many developed countries, the most important reason for underpinning is not foundation defects but the necessity of protecting structures due to the construction of adjacent new structures, such as new deep building foundations, tunnels or subways. Underpinning may also have to be made to provide a larger or deeper foundation in existing buildings that are being remodelled, raised in height, or being used with heavier loads.
2. UNDERPINNING METHODS

Many underpinning methods are now being developed. Each method is suitable for some case. These methods can be divided into groups as follows:

- Widening or strengthening foundation
- Pit underpinning
- Underpinning by piles
- Underpinning by injection
- Strengthening super structure.

2.1 Widening or strengthening foundation

When a foundation is damaged by failure of its materials, as mentioned in section 1.3, it has to be strengthened. For masonry foundations, the holes and voids in them can be filled by injection grout (Fig 2.1). In some cases, concrete or reinforced concrete coats are made to strengthen the foundations. The thickness of the coat is 20-30 cm for concrete and not less than 15 cm for reinforced concrete (Fig 2.2) [12].

When decreasing the pressure on the soil or increasing load on the foundation is needed, the simplest method of underpinning is to widen the foundation. Two of effective ways for widening foundation are shown in Fig 2.3 [14]. In many cases, steel beams are needed on one side to support a wall (Fig 2.4a) or two sides (Fig 2.4b). By jacking between the existing structure and the new underpinning, the underlying ground is preloaded before the load of structure is finally transferred to the underpinning. The methods in which jacks are used for preloading the underlying ground has been called "pretest". Some of the underpinning systems involve the use of jacks, see Fig 2.5, [12, 19].
2.2 Pit underpinning

Of the many methods of installing underpinning, the most common is concrete pit underpinning. Pits are installed by excavating sheeted pits by hand under existing foundations to the proper depth and to a suitable bearing strata and filling the pit with concrete and dry packing between the pit and foundation to transfer the load into the concrete piers. This method is basically limited to dry ground because it is difficult to dig below groundwater level without loss of ground causing settlement of the building to be underpinned. And unless a proper dewatering method is used it should not be attempted in wet ground. Large columns can be underpinned by more pits installed one at a time. The size of the individual pits may vary according to the size of the footing but usually not more than 20% of the footing support should be underpinned at one time without shoring the columns. The process of installing underpinning pits is shown in Fig 2.6.

Concrete piers for underpinning may be intermittent or they may be installed next to each other to form a continuous wall. This is determined by the load of the structure being underpinned and by the bearing value of the material under the pit (Fig 2.7) [19, 22].

2.3 Underpinning by piles

If underpinning is necessary to stop settlement it is essential that the underpinned foundations should be taken down to relatively stiff soil below the zone of subsidence (deep underpinning). For example, if the bearing pressures of existing foundations are such that excessive settlement is occurring due to consolidation of a compressible clay soil it is quite useless simply to widen the foundations by shallow underpinning. This will
merely transmit the pressure to the same compressible soil at a lower level and the settlement development will continue. In that case, a deep underpinning method e.g. pile underpinning, is needed.

Underpinning by piles is a convenient method to use if the bearing stratum is too deep for economical excavation or if the ground conditions are too difficult for excavation by hand. Underpinning piles to walls are normally provided in pairs, one on each side of the wall (Fig 2.8a). Piles underpinning columns are placed in groups around or at the sides of the column (Fig 2.8b). If it is difficult to install piles inside a building it is necessary to provide them in pairs on the outside with a cantilevered capping beam (Fig 2.8c).

There are many kinds of piles which are now being widely used in the world. Some of the common pile underpinning methods are:

2.3.1 **Jacked-down_concrete_piles**

Piles of this kind can be installed directly beneath foundation by jacking. The reaction for the jacks is the weight of the building. The Franki Miga system, for example, consists of a number of 305 mm x 305 mm x 762 mm long precast concrete units (pile sections). Piles are installed by first excavating a pit under the foundation in the similar way to that of the pit underpinning. The bottom pile section is placed in the pit and a hydraulic jack, with steel packing plates and short steel beam sections to spread the load, is used to force the pile into the ground until it is nearly flush with the ground at the bottom of the pit. The jack is removed, the next section is added and the process repeated until the desired bearing capacity of the pile is reached. Adjacent pile sections are linked by bolts placed in the axis of the pile (Fig 2.9). When the
pressure gauge on the jack indicates that the required bearing capacity of the pile has been reached (i.e. working load plus a safety factor) the space between the head of the pile and the existing foundation is wedged hard. The jack is then removed and the head of the pile and packings are concreted.

In installing jacked piles it is normal practice to take a safety factor of 1.5, i.e. the jacking force is equal to the calculated working load plus 50%. The final jacking load is maintained for a period of at least 12 hours before the packing is inserted. It is important to insert the packing between the pile and the structure before releasing the load on the jacks. In this way elastic rebound of the pile is prevented and the settlement minimized.

In the United States it is the usual practice to jack down pipe piles in short sections in a similar manner to the Franki Miga pile, except that a pair of jacks is used as shown in Fig 2.9b. The pipe piles are usually installed with open ends and the soil removed from time to time to facilitate the entry of the pipe sections. On reaching the required level as indicated by the jacking force, the pipes are finally cleaned out and filled with concrete.

The method has the advantage that it is free from noise and vibration, that a test loading is made on each pile and that there is some freedom of choice in the positioning of piles. The bearing capacity of a pile of this type is about 500-800 kN, sometimes up to 1200 kN. However, the heavy concrete pile sections with relatively large cross-sectional areas have technical disadvantages when they are installed in a confined space. The weight of jacked concrete piles is approx. 250 kg/m (with pile cross-sectional area of 300 mm x 300 mm). Although the piles normally reach the bearing
stratum, they sometimes stop at timber, older piles remains of foundations or other obstructions, resulting in insufficient bearing capacity which can lead to settlement in the future. The great forces involved in jacking down the pile sections can also locally damage the building.

2.3.2 Some new pile underpinning methods

The above mentioned disadvantage of jacked concrete piles have led to the development of alternative methods better adapted to confined space for underpinning work. Of the methods of this kind three types of jointed steel piles which have been used in Sweden during the last few years should be mentioned [2, 4, 5, 11].

2.3.2.1 Light tubular steel piles

Light tubular steel piles (weight approx. 8 kg/m), e.g. plastic-coated steel piles (Fig 2.10a), consist of steel pipes coated with a 1.8 mm layer of polythene. They have a diameter of 76 mm and are jointed with galvanized sleeves. They are driven with a light hand-held pneumatic pile driver. The pile is filled with cement mortar, which provides internal protection against corrosion. The permissible load has been limited to 140 kN.

The light tubular piles have been developed with the aim of producing a system which is easily handled in the place of work. Handling is simplified by the fact that piles can easily be cut to the required length.

2.3.2.2 Heavy X-section steel piles

Heavy X-section steel piles (weight approx. 48 kg/m). The jointed sections have an X-shaped cross section (Fig. 2.10 b). The sections are jointed by bolting together welded-on joint plates. The piles are protected against corrosion with epoxi paint. They are driven to refusal in the esker with heavy pneumatic pile drivers. The permissible load has been set at 470 kN.
2.3.2.3 Solid steel core piles

The piles of this kind are driven down to the bedrock. At first the casing was drilled down to the rock with heavy drilling equipment. The pile sections were sunk through the casing and were successively jointed by welding. The piles were driven to refusal on the rock surface with a light drop hammer. The space between the pile and the casing was injected with cement mortar. The permissible load for a pile with a steel core with a diameter of 95 mm was set at 710 kN, which corresponds to a load on the rock of 100 MPa. (Fig 2.10c)

The load is normally transferred from the building to the piles with a reinforced concrete construction (beams or raft) fitting into sockets in the foundation walls. The concrete raft is more expensive, but offers a better load transferring system. Such systems are now widely used in Sweden. The three types of piles are made by Swedish companies: BESAB, AB Grundförstärkningar, Stabilator AB...

2.3.3 Small-diameter injected bored piles (Root piles)

Root piles are small-diameter injected bored piles with a diameter ranging from 8 cm to 25 cm. These piles are provided with a central reinforcing steel rod when they have a small diameter and with an additional spiral reinforcement when they have a diameter of 12 cm or more. The piles are installed by rotary drilling combined with jetting, Fig 2.11a. When the tube has been installed the pipe is reinforced and injected with concrete, see Fig 2.11b-c. Then the casing is simultaneously retracted, Fig 2.11d. By applying compressed air the concrete is compacted. The bearing capacity of root piles in different types of soils has been investigated by numerous load tests. Root piles will carry applied loads mainly by skin friction. The ultimate value of the skin friction resistance for these in situ cast piles depends on the
type of soil. From load tests it is known that the ultimate skin friction resistance is approximately 200 to 250 kPa for gravel, 150 kPa for sand and 100 kPa for firm cohesive soils.

Complications resulting from the installation of underpinning outside the existing foundation structure, or from pits beneath the structure, can be avoided by using root piles. Reinforces concrete is cast in place in the drilled holes, which are arranged at various angles to provide support across the full width of the foundation. This system has the advantages of not requiring any excavations or shoring and the piles are bonded to the whole mass of the existing structure through which they are installed. Root piles are widely used since they cause little or no noise and vibration and they can go through obstruction of all kinds. Root piles have been developed in many countries by e.g. Fondereile Foundation Ltd (Italy), Rodio Co (Switzerland).[7, 18, 19].

2.4 Underpinning by injection

Injection of the ground with cement or chemicals to fill voids or to permeate and strengthen the ground is sometimes used as an underpinning method. The work may be done wholly by injections or the ground treatment may be used as a temporary strengthening method while excavating for underpinning by a certain method, Fig 2.12.

Cement grouting is a useful way to fill voids in the ground beneath foundations which have been damaged by erosion or by vibration effects in loose granular soils. It is also a useful method to strengthen old rubble masonry foundation walls before excavating beneath them for normal underpinning operation.

Chemicals can be used for injection into coarse sands or sandy gravels to produce a wall or block of consolidated
ground beneath the foundations to the desired level for underpinning. In favourable ground conditions this is also a useful method of underpinning in connection with deep excavations close to existing structures. Underpinning by injections, like by root piles, can avoid the necessity of shoring or needling.

2.5 Strengthening of super structure

Underpinning is carried out to protect a building from damages caused by settlement, especially by differential settlement. In some cases, to stop the development of cracking, the super structure is strengthened instead of underpinning the foundation. For this, strengthening bands are placed to prevent from dangerous stress which is caused by differential settlement. One should distinguish two contrary cases: relative hog and relative sag, see Fig 2.14. In the first case (relative hog) strengthening bands are needed to be placed on the level of the roof. The bands may be made of reinforced concrete, shape steel (Fig 2.13). In the second case (relative sag) strengthening bands must be placed on the level of the foundation. In intermediate cases, such bands must be placed both on the roof level and on the foundation level. More accurate answers will be given when the soil structure interaction problem is solved. And according to the development of cracking, parts or the whole super structure is decided to be strengthened [12, 21].
Fig 2.9

Fig 2.11
Fig 2.12

Fig 2.13

Fig 2.14  a) Relative sag
b) Relative hog
Fig 2.10
Fig 2.6

Open pit

Vertical 2 x 4 braced top and bottom

2 x 4 cleats

Fig 2.7

Grade

Horizontal wood sheeting

Intermittent

Continuous underpinning

Lateral bracing

Foundation

Concrete underpinning

Fig 2.8

(a)

(b)

(c)

Foot block and wedge
3. INVENTORY INVESTIGATION ON BUILDINGS SERIOUSLY SETTLED IN SOME CITIES IN VIETNAM

The project on "underpinning of existing buildings damaged by foundation causes, which is a part of the programme of cooperation between the Institute for Building Science and Technology (IBST), Vietnam and the Swedish Geotechnical Institute (SGI) Sweden, has been carried out from the beginning of 1981. The purpose of the project is to point out underpinning methods suitable for Vietnamese conditions. The inventory investigation on buildings seriously settled in Vietnam is the first step of the project. Its subjects are civil buildings, especially residential buildings, seriously settled in Hanoi, Haiphong and HochiMinh City. The inventory investigation has many difficulties in HochiMinh City because much information about existing buildings do not longer exist. In Hanoi and Haiphong we have less difficulties because construction works have been carried out mainly by state companies. Because of complicated geotechnical conditions, continuous levelling has sometimes been carried out since the construction of buildings started. This is valuable information. In some cases, however, for lack of experience, the levelling processes were sometimes interrupted or even given up. In some other cases, the reference marks for settlement observation were too few for sure information. In spite of this, large efforts have been made to fulfil the goal of the inventory to discover the buildings which are now being seriously settled and need to be underpinned, and to find out the most common causes for large settlement of buildings in Vietnam.

3.1 Geological background of the Red River delta and the Cunlong River delta

Except for the marine-fluvial and marine-boggy sediments which have been developing in the coastal areas, the Red River delta is mainly formed by three geological
sedimentations: The superior-holocene fluvial sedimentation \( (aQ^3_t) \), the middle-holocene marine-boggy sedimentation \( (m-1Q^3_t) \) and the superior-pleistocene marine sedimentation \( (mQ^3_t) \).

The superior-holocene fluvial sedimentation with a thickness varying from one to more than ten metres has a wide surface exposure and consists of the layers of cohesive and non-cohesive soils. The middle-holocene marine-boggy sedimentation which underlies the superior holocene fluvial sedimentation consists mainly of organic soft soils (mud, peat, and peaty soils) with a thickness varying from 3-4 to 15-20 metres. The superior-pleistocene marine sedimentation which consists of cohesive soils with a thickness of more than 10 metres is exposed in the boundary regions of the delta and is covered by younger sedimentations in the other regions. The distribution of the surface exposure and the thickness of those sedimentations are various.

In Hanoi three subregions can be distinguished. The subregions of Donganh, Tu liem which are completely formed by the stiffest of the superior pleistocene marine sedimentation, are very suitable for construction. The subregion of the city centre which is constituted by the cohesive and non-cohesive soils of the fluvial sedimentation is suitable for construction too. The subregion of Thanh tri, Gia lam and some other areas such as Giangvo, Thanh cong are not suitable for construction because of the presence of organic soft soils of the marine-boggy sedimentation. In this subregion, many buildings have been damaged by big settlement and need to be underpinned.

The geological structure of Haiphong City is more monotone and very unsuitable for construction. The soft organic clay which is found to be up to 20 m deep and spread almost over the whole city. Many buildings in the city have
Fig 3.1 Hanoi City - Soil conditions
been damaged by settlement and need to be underpinned too.

The Cunlong River delta is mainly composed of two geological sedimentations. The holocene marine sedimentation of the soft clay with a thickness varying from 10 to 40 metres overlies the pleistocene marine sedimentation of the stiff plastique clay. HochiMinh City is situated on the Cunlong River delta. A layer of soft soil (organic soils, peat, mud...) of the marine, marine-boggy sedimentations with a thickness more than 15-20 metres is distributed over the regions of Thuduc, BinhCanh, Nhabe, Phunhuan, Tanbinh and the districts No 4, 6, 8, 10 of the city centre. The stiff clay, silty clay of red and red-white colour is the base of the regions of Saigon, Cholon, Hocmon, Badiem, Cuchi, Thaimy.

3.2 Foundation of buildings

Hanoi, Haiphong and HochiMinh City are old cities. Hanoi is one of the oldest cities in Vietnam. According to history, Hanoi was first formed in the beginning of the 11th century when the Ly Dynasty moved the country's capital to Thanglong (old name of Hanoi). Up to now, Hanoi has remained the capital of Vietnam. Buildings in the three cities can be divided into two groups: buildings built before 1954 and those built after 1954.

Buildings built before 1954: Up to the end of the 19th century, houses were mainly low masonries. At the end of the 19th century and in the beginning of the present century, under French colonialist regime, buildings were bigger than before but generally remained small and poor in kinds. During the past few years, some information about foundation on buildings of this period may be gained when they were repaired and reconstructed. Because the load of the super structure was not great, their foundations
were mainly made by masonry (brick masonry, rubble masonry or quarry stone masonry) and rested directly on natural soil and at the depth of 0.6 to 1.0 metres. In some cases, the soil was strengthened by bamboo piles. The cross sections of some typical foundations are shown in appendixes.

Buildings built after 1954: After 1954, in North Vietnam construction is a main task. In big cities, especially in Hanoi and Haiphong, the construction of residential areas have played an important role to meet the increasing need of the inhabitants. There are many kinds of structure of the residential building in our cities: in situ reinforced concrete frames, prefabricated reinforced concrete frames, prefabricated large panels, masonry with prefabricated floor panels... Because the geotechnical conditions are different in various areas, foundation of buildings are different. Strip or spread footings founded on natural soil have been used in the areas where the geotechnical condition is favourable for construction. In unfavourable conditions, e.g. there is a weak soil layer near the surface, bamboo piles have been used as a means of soil improvement, or a sand cushion is used to replace the weak soil. In such cases, mat foundations can be used. If the thickness of the layer of weak soil is too large, concrete piles can be used effectively. Concrete piles, however, have been used only in a few cases because of the lack of good driving equipment in Vietnam.

In HochiMinh City, concrete or steel piles have been widely used for high-rise buildings. For lower buildings strip or mat foundations have been used. Timber piles (bamboo piles) have been used in many cases, for example in the Thanhđa residential area. However, much information about the foundation of buildings built in the period of 1954-1975 has been lost.
3.3 Damages of buildings due to settlement.
The most common reasons

For buildings built before 1954, damages have been caused by adjacent excavations. This situation happened in the house No 33, Hung vuong Street, Hanoi, when excavating for a nearby pipe line. Severe cracks appeared on the building (1975). Similar situations were observed on the Hanoi College of Art, 42 Yet Kieu Street (1980) and the house No 31 Tran phu Street. More and more damages of this kind take place because many buildings have been reconstructed or built in old residential areas.

After 1954, to meet the increasing need of the inhabitants, a large number of residential areas have been developed, such as Kim lien, Trungtu, Giangvo, Thanhcong, Quynh loi, Vinh ho... (Hanoi), and Phungphap, Vanmy, Cautre, Quantoan... (Haiphong). Because of lack of experience in foundation design, in many cases designers chose unreasonable types of foundation. This is one of the most common causes for damage of buildings. The first example is the La thanh Hotel (Hanoi) where strip foundations are founded on natural soil. The recalculation of the bearing capacity of the weak soil layer shows that the condition is not satisfactory. The maximum settlement of this building is now about 340 mm. Its maximum differential settlement is nearly 300 mm. Another example is the building B7 Thanhcong, a five-storey building with strip foundations founded directly on natural soil. Here there is a thick layer of weak soil (soft clay or peat), underlying a layer of fill which is somewhere only 1.5 m thick. The buildings A1, A2, A3, A7 Phungphap (Haiphong) with strip foundation founded on timber piles, are now in the same situation. In these places, there is a weak soil layer with a thickness of ten metres. In some cases, pitiful damages has happened when the designer carelessly used some types of foundation e.g. concrete piramid short piles which have recently been widely used in Vietnam.
Many buildings on this kind of foundation are now in a good state, but some others have settled seriously.

A typical case is the building C1 Thanh cong, which has the maximum settlement of 756 mm (the settlement observation had started about a year after the construction was finished). The damage of the building is now so severe that the dwellers living in it have now had to move away. The building E6 Quynh loi is now in the same situation. Now its maximum settlement is 1260 mm (according to levelling date of June 1982). This is one of the buildings which has the largest settlement in Hanoi. Among buildings which are founded on this kind of foundation and have now settled seriously are 1A, 1B, 1C Vanphuc, E7 Quynh loi.

But it is also confirmed that in many cases designers have been provided with incorrect information about geotechnical conditions. In other words, mistakes made during the soil investigation have sometimes resulted in damages of buildings. Up to now we have little or no chance to evaluate the accuracy of the soil investigation results. Such a mistake was discovered in the Lathanh Hotel. According to the first soil investigation, at the west end of the building the top of the layer of weak soil is at a depth of 4.5 metres. In fact, a later soil investigation showed that it is only 3 metres.

Because of misdetermination of the thickness of soil layers in some cases the tips of short concrete piles were placed in weak soil (E6 Quynh loi, C1 Thanh cong). There have also been many problems in laboratory tests. Incorrect information about soil properties may be caused by backward equipment for laboratory test, for sampling and old test methods for assessment of soil properties which are now widely used in our country. In addition, the sample disturbances which occur in the process of sampling, transportation, storage and testing of soil samples have not been appreciated yet.
In some cases, the reasons of damages are not obvious. This is, for example, the case of the building B6 Giangvo. This building with strip foundation was founded on soils improved by vertical sand drains. Serious cracks have appeared and developed in the structure and the gap between two sections has separated some centimetres at the roof level. Some kind of disturbance could have happened in the soil under the building. In Table No 1 a summary of the information of some typical cases is shown.

3.4 Many buildings need underpinning

Many buildings in Vietnam need underpinning because of damages caused by severe settlement. In this inventory investigation, there are a great deal of buildings which have settlements exceeding the allowable value given by the Vietnamese Building Code (TCXD 45-78) and many of them need foundation reinforcement, the sooner the better. These buildings are now threatened by serious damages, have large settlements or differential settlements and are still settling at a large rate. Some of them can not be lived in, such as the building C1 Thanh cong, E6 Quynh loi, E2 Trung tu, 31 Tran phu St., the Lathanh Hotel. Some other buildings which have large settlements but little or no cracks, and where the settlement rate recently has decreased have to be observed continuously both on settlement development and the state of the super structure. Up to now, the exact number of the buildings which need to be underpinned (sooner or later) is not known, but it is estimated to be almost a dozen only for residential buildings.

3.5 Underpinning work in Vietnam

3.5.1 Some methods have been used

In general, underpinning is a new area in Vietnam. The underpinning methods which have been used in Vietnam are
very simple and are mainly shallow underpinning. The most common method is to widen the foundation. It has been used in many cases, especially in reconstruction buildings (raised in height or used with heavier load). But to stop settlement, this method is only effective in some limited cases, as described in Section 2.1. Another method which has been effectively used when the Haiphong Gynaecological–midwifery hospital, 37 Dinh Tien Hoang Street, was reconstructed is to build concrete piers like rail sleepers to support old foundations. Here, the building was raised in height from one to three storeys and up to now no disadvantage has been revealed [16]. In 1975, when excavating the trench for a pipe line next to the house 33 Hung Vuong Street (Hanoi), this house was damaged seriously: cracks appeared on the whole house and developed rapidly. The underpinning method for this case was as follows: at first two rows of steel piles with a length of 1.5 m were driven next to the old masonry foundation, then a new reinforced concrete beam was made over the piles and was linked with the old foundation. A short time afterwards, the settlements of the building had stopped.

In many cases, to prevent cracks due to differential settlement, as mentioned in Section 2.5, the super structure is strengthened instead of underpinning the foundation. This method has been suggested to use for some buildings, e.g. the Hanoi College of Art.

However, in worse geotechnical conditions, e.g. there is a thick layer of very soft clay near the surface, buildings must be underpinned by piles which will transfer the load of the super structure to stiff soil stratum. However, there are no professional underpinning equipments of any kind in Vietnam. One of the problems which has to be solved is to use available equipment in Vietnam for underpinning works. Among such efforts to do this, it is necessary to
say about that underpinning design variants as for the Lathanh Hotel where jacked concrete piles were used, are expected to be used (see Appendix A). We should also import some new advanced underpinning technology from foreign countries which has proved to be suitable for Vietnamese conditions.

3.5.2 The methods of underpinning that can be used in Vietnam in the future

To stop the development of settlement of buildings the most effective method is underpinning by piles. But it is necessary to use equipment available in Vietnam for this purpose. We suggest that some methods of underpinning can be used in Vietnam.

**Jacked concrete piles:** As described in Section 2.3.1, this is one of the most common methods of underpinning and has been used in many countries. Piles are forced into the ground by hydraulic jacks, section after section to the required depth. This method can be used in our country because no professional equipment and specialists are required except for jacks. However, the jacks which are used in this case need to be neat, light and easy to handle in a confined space. In addition, old rail steel can also be used instead of concrete pile sections.

**Small diameter injected bored piles.** This technique is now widely developed in the world with the familiar name "Root piles" (section 2.3.3). To install piles of this kind a specialized drilling equipment and air compressor are needed. With the drilling equipment both vertical and batter piles with a length of up to 30, 40 m can be installed. This method can also be used in the cases where difficult drilling obstacles as concrete, reinforced concrete, rock, wood and even steel, have to be penetrated. In Vietnam, there is no specialized equipment of this kind. However, we can use available drilling
equipment to create bored piles of shorter length (up to 10 m). The problem to be solved is how to support the drilling holes, especially in very weak soil.

**Screw piles.** Piles of this kind can be installed by hand or machine. By hand they can reach down to the depth of 10-15 m where bearing stratum is expected to be met in Hanoi. Load tests should be performed to determine their bearing capacity. Screw piles can be made by steel or reinforced concrete.

**Driven piles.** The case of a thick layer of very weak soil under a hard soil layer of a small thickness is very common in Vietnam. In fact, it is easy to drive piles through the weak soil even by small loads. To decrease the influence of vibration caused by the pile driving on the building to be underpinned, pre-drilled holes can be used. Through the hard soil layer then piles are placed to the required depth by pushing or driving. The disadvantages of this method is that piles are installed only outside the buildings because the piling equipment is too bulky. But piles of this kind can be installed by available equipment and there exists also experience in this method in Vietnam.

Besides this, shallow underpinning methods and strengthening of structure, as mentioned in Section 2.1 and 2.5, should be developed and used more widely.

Pit underpinning should also be used because it is simple, especially in dry ground. At last, some new advanced techniques in this field should be imported because in many complicated cases specialized underpinning equipments will be necessary.
<table>
<thead>
<tr>
<th>No.</th>
<th>Name of building</th>
<th>Time of construction</th>
<th>Type of superstructure</th>
<th>Type of foundation</th>
<th>Settlements and damages</th>
<th>Reason for damage</th>
<th>Necessity of underpinning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CI Thanh Cong (Hanoi)</td>
<td>In 1976</td>
<td>Prefabricated concrete frame system with brick wall structure, five stories</td>
<td>Spread footings on short concrete piles</td>
<td>Maximum settlement $S_{max}=750$ mm. Max diff.settlin, $S_{det}=400$ mm. Many cracks on superstructure, dwellers had to be removed</td>
<td>Type of foundation is not suitable. Somewhere pile tips penetrate into layer of weak soil</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>B7 Thanh Cong (Hanoi)</td>
<td>Completed in 1976</td>
<td>Prefabricated large panel structure, type TL 71, 5-storeys</td>
<td>Strip foundations on natural soil</td>
<td>$S_{max}=693$ mm (Jan -81)</td>
<td>Pavement of building has sunk under ground surface somewhere</td>
<td>Type of foundation not suitable</td>
</tr>
<tr>
<td>3</td>
<td>D2 Thanh Cong (Hanoi)</td>
<td>1977 to 1978</td>
<td>Prefabricated large panel structure, type TL 71, 5-storeys, one section</td>
<td>Mat foundation on sand cushion</td>
<td>$S_{max}=360.5$ mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>E5 Quynh Loi (Hanoi)</td>
<td>Completed August -79</td>
<td>Prefabricated large panel structure supported by 1-storey concrete frames, 3 sections, 5-storeys in all</td>
<td>Strip foundations on short concrete piles</td>
<td>Seriously settled, $S_{max}=1260$ mm (June 1982)</td>
<td>Type of foundation not suitable</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>E7 Quynh Loi (Hanoi)</td>
<td>Completed July 1978</td>
<td>Prefabricated large panel structure, type TL 71, 5-storeys</td>
<td>Strip foundations on short concrete piles</td>
<td>$S_{max}=655$ mm (June -82) However its differential settlement is not large</td>
<td>Type of foundation not suitable</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>E1 Trung Tu (Hanoi)</td>
<td>1976</td>
<td>5-storey brick masonry</td>
<td>Mat foundation on natural soil</td>
<td>Seriously cracked, large differential settlement, Rate of settlement is great even recently (~20 mm/month) (August -81-June -82)</td>
<td>Type of foundation not suitable</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>C28 Tuong Mai (Hanoi)</td>
<td>1978</td>
<td>3-storey brick masonry</td>
<td>Strip foundations on natural soil</td>
<td>$S_{max}=200$ mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Latham Hotel (Hanoi) (1 of its buildings)</td>
<td>1977-78</td>
<td>5-storey brick masonry, two sections</td>
<td>Strip foundations on natural soil</td>
<td>$S_{max}=370$ mm, $\Delta S=300$ mm (settlemen) observation started 1 year after construct. Gap between its two sections is widely separated, Pavements broken somewhere, Rate of sett. ~6 to 8 mm/month</td>
<td>Type of foundation not suitable</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Al Giang Vo (Hanoi)</td>
<td>1975</td>
<td>Prefabricated large panel structure, type TL 71, 2 sections</td>
<td>Mat foundation on natural soil</td>
<td>Differential settlement is large. The gap is seriously separated, ~30-40 cm at the roof level</td>
<td>Type of foundation not suitable</td>
<td>Yes</td>
</tr>
<tr>
<td>10</td>
<td>B6 Giang Vo (Hanoi)</td>
<td>1976-77</td>
<td>Prefabricated large panel structure, type TL 77, 1 sections</td>
<td>Strip foundation on soil treated by sand vertical drain</td>
<td>Some parts are seriously cracked in 1981 after some years of normal use. The gaps are separated.</td>
<td>The reason is not clear now. Need to be repaired</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Van Phuc (Hanoi)</td>
<td>1979</td>
<td>Combination of brick masonry and concrete frames, 3-storeys</td>
<td>Strip foundation on short concrete</td>
<td>$S_{max}&gt;300$ mm</td>
<td>Type of foundation not suitable</td>
<td>Need to be repaired</td>
</tr>
<tr>
<td>12</td>
<td>11 (Hanoi)</td>
<td>1976-77</td>
<td>Combination of brick masonry and concrete frames, 5-storeys</td>
<td>$S_{max}&gt;700$ mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>NC</td>
<td>1928-1929</td>
<td>2-storey brick masonry</td>
<td>Brick masonry foundation</td>
<td>Seriously cracked</td>
<td>Due to adjacent excavation</td>
<td>Need to be repaired by strengthening superstructure</td>
</tr>
<tr>
<td>14</td>
<td>Hanoi College of Art (1 of its buildings)</td>
<td>1930-1930</td>
<td>2-storey brick masonry</td>
<td>Brick masonry foundation</td>
<td>Seriously cracked</td>
<td>Due to adjacent excavation for pile line</td>
<td>Already underpinned 1946</td>
</tr>
<tr>
<td>15</td>
<td>House 33 HungVuong St (Hanoi)</td>
<td>1930-1930</td>
<td>2-storey brick masonry</td>
<td>Brick masonry foundation</td>
<td>Seriously cracked</td>
<td>Due to adjacent excavation</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>House 31 Tranphu St (Hanoi)</td>
<td>1930-1930</td>
<td>2-storey brick masonry</td>
<td>Brick masonry foundation</td>
<td>Seriously cracked</td>
<td>Due to adjacent excavation</td>
<td></td>
</tr>
</tbody>
</table>

**Reason for damage**

- Maximum settlement
- Differential settlement
- Basements have sunk under ground surface
- Paved road broken somewhere, Rate of settlement is great even recently (~20 mm/month)
- Pavements broken somewhere, Rate of settlement is large
- Some parts are seriously cracked in 1981 after some years of normal use.
- The gaps are separated.
- The reason is not clear now.
- Need to be repaired by strengthening superstructure
- Already underpinned 1946
- Due to adjacent excavation for pile line
- Due to adjacent excavation
- It is being underpinned now
<table>
<thead>
<tr>
<th>No.</th>
<th>Location</th>
<th>Type of Foundation</th>
<th>Condition</th>
<th>Type of Foundation Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Tho Lang Palace</td>
<td>Prefabricated frame</td>
<td>Completed in July 1978</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>18</td>
<td>A2</td>
<td>Strip foundations</td>
<td>Completed in Feb 1978</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>19</td>
<td>A3</td>
<td>Strip foundations</td>
<td>Completed in Jan 1978</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>20</td>
<td>A7</td>
<td>Strip foundations</td>
<td>Completed in Nov 1978 to July 1979</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>21</td>
<td>Hanoi midwifery hospital</td>
<td>Strip foundations on soil improved</td>
<td>Completed in Jan 1978</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>22</td>
<td>No 1</td>
<td>Reinforced concrete</td>
<td>Stripped foundation</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>23</td>
<td>No 2</td>
<td>Reinforced concrete</td>
<td>Stripped foundation</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>24</td>
<td>No 3</td>
<td>Reinforced concrete</td>
<td>Stripped foundation</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>25</td>
<td>No 4</td>
<td>Reinforced concrete</td>
<td>Stripped foundation</td>
<td>Type of foundation suitable</td>
</tr>
<tr>
<td>26</td>
<td>No 6</td>
<td>Reinforced concrete</td>
<td>Stripped foundation</td>
<td>Type of foundation suitable</td>
</tr>
</tbody>
</table>
Fig 3.3 The Lathanh Hotel a), b) broken pavements around the building; c) deformation gap is separated.
Fig 3.4 The building C1 Thanh cong
a) general view, b), c) cracks in superstructure.
Fig 3.5 The building E6 Quynh loi
a) the building under construction
b) the extra part in the back side of the building before being pulled down.
Fig 3.6 The building Al Giang vo
a), b) the gap between two sections
is seriously separated, c) broken
pavement.
4. FUTURE INVESTIGATIONS

4.1 Inventory investigations need to continue

Up to now there is a background survey on buildings damaged by settlement only in some cities. A continuous levelling in these buildings is necessary. Besides, other buildings which have settled seriously need to be investigated. In some cases, the settlement observation should start just from the beginning of construction, especially in buildings founded on complicated geological conditions and with new types of foundation.

4.2 Experimental investigations on some underpinning methods

In order to choose the methods suitable for Vietnamese conditions, experimental investigations are needed. The experimental investigations consist of two aspects, realizing some methods with the equipments available in Vietnam and load test to determine the bearing capacity of the underpinning supports. The methods suggested to be investigated in the future: jacked concrete piles, small-diameter bored piles, screw piles and driven piles with pre-drilled holes. The methods will be used for underpinning of particular buildings. The Lathanh Hotel is now expected to be underpinned by jacked concrete piles (MGA type). The work is expected to be carried out during 1983. After that other buildings will be underpinned, for example, C1 Thanh cong, E6 Quynh loi, E2 Trung tu.

4.3 Special investigations

It is necessary to study the variation of the properties of the soil under the foundation. The variation has taken place during a long period. As the soil has been compressed by the load of the building, its bearing capacity may have increased. Information of this problem will help the designers to choose the most effective and economic method of underpinning. The investigation will be carried out in both field and laboratory.
The additional geotechnical investigations will be carried out in situ and laboratory by weight sounding, static sounding, vane shear test, pore pressure sounding, and sampling undisturbed soil samples in some particular buildings. The investigations are expected to be carried out to evaluate the accuracy of the results of the previous soil investigation. And the prediction of settlement of the building can be based on more accurate data.

The soil structure underpinning support interaction problems will be investigated in some particular cases. If the problem is solved the optimal underpinning method can be chosen.
REFERENCES


The Lathanh Hotel

The Lathanh Hotel is located 6 kilometres west of the centre of Hanoi. The subject, one of the hotel's buildings, is a five-storey building of 50 m length and 8.4 m width. It consists of two sections separated by a gap, Fig A1. The construction of the building began by the end of 1977 and was completed in October, 1978.

Superstructure. The building is a brick masonry of bearing transversal wall type with floor assembled from prefabricated panels, combined with reinforced concrete frames along its corridors.

Foundation. The foundation of the building, reinforced concrete strip foundation under walls and pad foundation under columns, is founded directly on natural soil at a depth of 1.2 m from the ground surface. The load transferred from the super structure is about 180 to 200 kN/m for transversal strip foundation and about 170 kN for each column.

Soil conditions. The soil cross sections are shown in Fig A2. The ground can be described schematically as follows:

1. Fill, 2.5 to 3.0 m thick, half stiff
2. Sandy clay, 1.5 to 2.0 m thick, plastic stiff
3. Clayey mud, with inclusions of organic mixture, 1.0-2.9 m thick
4. Organic peat, 1.0 to 4.0 m thick, impossible to take undisturbed samples
5. Organic mud, 6.7 to 11.0 m thick, impossible to take undisturbed samples
6. Sandy clay, found in only one bore hole
7. Silty sand, medium dense

The physical and mechanical average characteristics of the existing soils are shown in Table 2.

The water table is found at a depth of 0.5 to 1.5 m, average 1.0 m.
The state of the building. The settlement observation started by the end of 1978 just after the construction of the building finished when serious settlement was discovered, especially at the west end of the building.

The maximum settlement of 340 mm has occurred under the west end of the building (at the point H.15). The differential settlement between two edges of the building on the line H is about 281 mm, between the point A.1 and A.15-230 mm, between the points A.15 and H.15-100 mm. The maximum differential settlement of the whole building is about 300 mm (Fig A.3). These values are all much bigger than the allowable ones according to the Vietnamese Building Code. The gap between two sections of the building is now separated obviously about 120-130 mm at the roof level. But the problem is that up to now the rate of settlement of the building does not decrease yet, at some points it is still about 4 to 5 mm/month and especially at point H.15 it is about 6 to 8 mm/month (Fig A.4).

It is obvious that the building need to be underpinned. After discussing some underpinning methods, a decision was made that the building had to be underpinned by concrete jacked piles. The piles will be pushed down to the layer of dense silty sand. The pile is designed to be in 600 mm sections with the cross section of 200x200 mm.
The calculated bearing capacity of each pile, according to the Vietnamese Building Code is about 10.5 tons. The total number of piles needed is about 40. The underpinning work is expected to start at the beginning of 1983 and to be finished in the same year. The figures A5 to A7 show the underpinning design of the building (location of piles, arrangements of underpinning work, joint of piles).
Fig. A1 Foundation plan
LOCATION OF BORING HOLES

CROSS SECTION A-A

CROSS SECTION B-B

Fig A2
CONTOURS OF EQUAL SETTLEMENT (MAR./82)

AXES 1, 5 (MAR./82)

LONGITUDINAL DIAGRAM AXES A, H (MAR./82)

Fig A3
Fig A4
Fig A5. Distribution of underpinning piles.
Fig A6. Arrangement of underpinning work in the Lathanh Hotel
a) under walls, b) under columns

Fig A7. Joint of piles.
The building C1 Thanhcong

Thanhcong is a big residential area located about 5 kilometres sout-west of the centre of Hanoi. The building C1 has five storeys. It is 86.1 m long and 8.4 m wide and consists of three sections. The sections No 1 and 2 were built in 1976 without gap and were 58.5 m in length. The section No 3 which was completed in March 1978 is separated from the section 2 by a gap and is 27.6 m long.

Super structure. The structure of the building is a prefabricated frame system with brick wall and with stiff diaphragms, one for each section at the stair part.

Foundation. The foundation of the building is spread footing founded on concrete pyramid short piles. There are three piles under each column and 20 piles under each stair part. The dimension of each pile is 3.0 m long with a top cross section of 600x600 mm and a tip cross section of 100x100 mm. The loads transferred from the building are about 650 to 750 kN for each column foundation and over 3000 kN for each foundation under the stairs. The foundation plan for the sections No 1 and 2 is shown in Fig B.1.

Soil conditions. The construction site once was a lake. Then it was filled by silty to fine sand. The descending soil succession is:

1. Sand fill, 1.5 to 2.0 m thick, medium dense silty to fine sand, saturated.
2. Sand clay mud, 6.5 to 12.5 m thick (average - 10.0-11.0 m).
3. Peat, 1.0 m thick, main composition is rotting leaves, impossible to take samples.
4. Clayey sand, met at a depth from 8.5 to 15.0 m. All bore holes do not pass this layer but it is expected that the bottom of this layer is at a depth of no less than 20.0 m. Fig B.2 shows the soil conditions under the building.

The water table is found at a depth of 0.4 to 0.5 m. Therefore, all soil layers are saturated.
The physical and mechanical average characteristics of the existing soils are shown in Table 3, except for the layer 3 because it was impossible to take undisturbed samples of this layer.

TABLE No 3

<table>
<thead>
<tr>
<th>No</th>
<th>Soil layers</th>
<th>( w_0 )</th>
<th>( w )</th>
<th>( d )</th>
<th>( G )</th>
<th>( e )</th>
<th>( n )</th>
<th>( S )</th>
<th>( W_L )</th>
<th>( W_P )</th>
<th>( I_P )</th>
<th>( B )</th>
<th>( m_v )</th>
<th>( \phi )</th>
<th>( c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Mud</td>
<td>67.3</td>
<td>1.58</td>
<td>0.966</td>
<td>2.59</td>
<td>1.764</td>
<td>62.9</td>
<td>98.0</td>
<td>57.7</td>
<td>42.4</td>
<td>15.3</td>
<td>1.64</td>
<td>0.190</td>
<td>5.10</td>
<td>0.13</td>
</tr>
<tr>
<td>4</td>
<td>Clayey sand</td>
<td>17.6</td>
<td>2.06</td>
<td>1.17</td>
<td>2.69</td>
<td>0.52</td>
<td>34.3</td>
<td>91.5</td>
<td>18.9</td>
<td>15.7</td>
<td>3.2</td>
<td>0.62</td>
<td>0.013</td>
<td>36.2</td>
<td>0.02</td>
</tr>
</tbody>
</table>

The state of the building. The settlement observation started about one year after the beginning of its construction. Up to now, the maximum measured settlement is about 750 mm, at the point A3. The maximum differential settlement is about 400 mm. The differential settlement on the longitudinal line A is about 250 mm (between the points A3 and A18); and on the transverse line No 3 about 200 mm (between the points A3 and C3), see Fig B.3. On the front side of the building, the line A, there are many serious cracks, especially in the stair parts. This is one of the buildings which have settled most seriously of those in the inventory. The inhabitants who once lived in the building had to move away. The building needs to be underpinned in a near future.
Fig B1. Foundation plan
a) general plan
b) foundation M4
c) foundation M1
d) foundation M5
LOCATION OF BORING HOLES

Fig B2

CROSS SECTION A-A

CROSS SECTION B-B
The building E6 Quynhloi

Quynhloi area is located 6 kilometres south of the centre of Hanoi. The building E6 of this residential area has five storeys and three sections separated by gaps. The whole building is 133.2 m long (each section 44.4 m) and 7.5 m wide excluding the extra part which is a one storey storage behind the building. The construction of the building was completed in August 1979.

Structure. This is a building of the type TL 673. The lowest storey of the building is a reinforced concrete frame. It supports four upper storeys of prefabricated large panel structure.

Foundation. The foundation of the building is strip footings founded on concrete short pyramid piles. The dimension of each pile is 3.0 m in length with a top cross section of 650 x 650 mm and a tip cross section of 100 x 100 mm. The foundation plan for section No 1 is shown in Fig C2. Those for the others are similar. The loads transferred from each column to the foundation are about 1100 kN and the moments are about 280 kN.

Soil conditions. A soil section is shown in Fig C3. The descending soil succession is:

1. Cultivated soil 0.7 to 1.2 m thick, average 0.9 m.
2. Clay 1.6 to 3.0 m thick, wet, plastic.
3. Mud with organic matter: saturated, black-grey, the bottom of this layer is at a depth varying from 12.0 m to more than 21.0 m, fluid state.
4. Sandy clay

The physical and mechanical average characteristics of the existing soils are shown in Table 4.

The water table is found at a depth of 0.5 to 1.0 m.
The state of the building. This building suffers from the largest settlement in Hanoi City. The maximum settlement of the building, up to June 1982 is 1260 mm, at the point C.34, see Fig C.4. The building has settled so seriously that the extra part at the back side of the building had cracked terribly. This part was pulled down, see Fig. But the rate of settlement has reduced recently. The settlement observation of the building is continued.
Fig C1. Building plan

Fig C2. Foundation plan for Section 1.
Fig C4. Longitudinal diagram axes, A, C
1. axis A-A (from Jun 1980 to Jun 1982)
2. axis C-C (from Jun 1980 to Jun 1982)
3. axis A-A (from Aug 1979 to Jun 1982)
4. axis C-C (from Aug 1979 to Jun 1982)
The Hanoi College of Art

The Hanoi College of Art is in Yet Kieu Street, Hanoi. It is a two-storey masonry building which was built in 1928-1929. It is 63 m long and 16 m wide. The building plan is shown in Fig D.1.

Structure. This is a brick masonry. Its walls are 48 cm thick.

Foundation. The foundation that is also brick masonry is 1.0 m wide at a depth of 1.4 m.

Soil conditions. The information of soil condition under the building does not longer exist. But there are some information about soil under a nearby building. The location of bore holes and soil cross-sections are shown in Fig D.3.

The soil layers are shown in Table No 5.

<table>
<thead>
<tr>
<th>No</th>
<th>Soil layer</th>
<th>W</th>
<th>G</th>
<th>e</th>
<th>S</th>
<th>I_p</th>
<th>B</th>
<th>φ</th>
<th>c</th>
<th>m_v</th>
<th>E_o</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fill</td>
<td>36.1</td>
<td>2.15</td>
<td>1.41</td>
<td>46.5</td>
<td>76.0</td>
<td>15.7</td>
<td>1.157</td>
<td>13°16</td>
<td>0.018</td>
<td>0.082</td>
</tr>
<tr>
<td>2</td>
<td>Mud</td>
<td>51.0</td>
<td>2.68</td>
<td>1.45</td>
<td>58.1</td>
<td>98.0</td>
<td>16.2</td>
<td>1.976</td>
<td>40°00</td>
<td>1.312</td>
<td>0.055</td>
</tr>
<tr>
<td>3</td>
<td>Clay</td>
<td>45.0</td>
<td>2.70</td>
<td>1.36</td>
<td>57.4</td>
<td>97.1</td>
<td>19.2</td>
<td>0.673</td>
<td>60°24</td>
<td>0.237</td>
<td>0.072</td>
</tr>
<tr>
<td>4</td>
<td>Mud &amp; peat</td>
<td>57.1</td>
<td>2.58</td>
<td>1.53</td>
<td>61.5</td>
<td>98.0</td>
<td>17.5</td>
<td>1.257</td>
<td>40°37</td>
<td>0.190</td>
<td>0.014</td>
</tr>
<tr>
<td>5</td>
<td>Sandy clay</td>
<td>26.5</td>
<td>2.71</td>
<td>0.76</td>
<td>44.9</td>
<td>98.6</td>
<td>13.6</td>
<td>0.347</td>
<td>110°35</td>
<td>0.291</td>
<td>0.024</td>
</tr>
<tr>
<td>6</td>
<td>Clay &amp; sandy clay</td>
<td>25.9</td>
<td>2.71</td>
<td>0.72</td>
<td>41.8</td>
<td>97.6</td>
<td>15.3</td>
<td>0.13</td>
<td>120°30</td>
<td>0.37</td>
<td>0.018</td>
</tr>
<tr>
<td>7</td>
<td>Dense fine sand</td>
<td>G = 2.685, Natural sloping angle 29°01</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
State of the building

The building had remained normal until some adjacent buildings were built. The building then cracked seriously. Many fissures appeared from the top to the bottom of the walls. Fissures appeared also at every window and door and created with the horizontal direction an angle of 45°. There were some possible reasons for the damage, but the main reason is probably some excavations near the building without any sheet piles to prevent failure of the soil under the building. Fig D.2 shows the location of the excavations near the building. The super structure of the building is expected to be strengthened.
Fig D1. Building plan

Fig D2. The excavation next to the building.

CROSS SECTION A-A

LOCATION OF BORING HOLES

Fig D3. Soil conditions
The buildings A1, A2, A3, A7 Phungphap (Haiphong)

Phungphap is a residential area in Haiphong City which is located three kilometres from the centre of the city. It was built in the period of 1977-1979. There is a group of four buildings A1, A2, A3, A4. The time of construction of the buildings:

A1 from November 1977 to August 1978
A2 from the middle of 1977 to February 1978
A3 from the middle of 1977 to January 1978
A7 from November 1978 to April 1979

Each building consists of three sections, without deformation gaps and is 57.6 m long, 9.4 m wide.

Structure. The buildings are of the type Kg-A1G-V75 which is a prefabricated frame system with stiff diaphragms at the stair place.

Foundation. The foundation of the buildings is a system of strip foundation with a width of 1.5 to 2.0 m on bamboo piles with a length of 3.0 m.

Soil conditions. The area is not suitable for construction. The layers of soil are:

1. Fill. 0-1.6 m thick, no soil sample is taken.
2. Mud. Consists of two sublayers: 2a and 2b. Somewhere the two sublayers are divided by other layers and somewhere the sublayer 2a exposures on the ground surface. Every bore hole with a depth of 12.0 m did not reach the bottom of the layer. It is expected to be 20.0 to 30.0 m deep.
3. Sandy mud. 0-1.7 m thick. Only some bore holes were found.
4. Sand. 0-2.8 m thick. Only some bore holes were found.

The mechanical and physical characteristics of the existing soils are shown in Table No 6.
State of the building. The settlements were observed as early as the beginning of the construction of these buildings. However, the number of settlement observation points is too small, only four for each building. The settlement observation was carried out for only about one year but it showed some interesting results:

A1 (the settlement observation was carried out from November 1977 to October 1978), \( S_{\text{max}} = 271 \text{ mm}, \Delta S_{\text{max}} = 247 \text{ mm} \).

A2 (from October 1977 to July 1979) \( S_{\text{max}} = 438 \text{ mm}, \Delta S_{\text{max}} = 341 \text{ mm} \).

A3 (from November 1977 to July 1979) \( S_{\text{max}} = 237 \text{ mm}, \Delta S_{\text{max}} = 157 \text{ mm} \).

A7 (from November 1978 to July 1979) \( S_{\text{max}} = 333 \text{ mm}, \Delta S_{\text{max}} = 244 \text{ mm} \).

<table>
<thead>
<tr>
<th>No</th>
<th>Soil layer</th>
<th>( W )</th>
<th>( Y_w )</th>
<th>( Y_d )</th>
<th>( G )</th>
<th>( e )</th>
<th>( n )</th>
<th>( S )</th>
<th>( W_L )</th>
<th>( W_P )</th>
<th>( I_P )</th>
<th>( B )</th>
<th>( m_v )</th>
<th>( \phi )</th>
<th>( c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a</td>
<td>Mud</td>
<td>66.6</td>
<td>1.62</td>
<td>0.976</td>
<td>2.7</td>
<td>1.77</td>
<td>63.9</td>
<td>100.0</td>
<td>53.2</td>
<td>32.0</td>
<td>21.2</td>
<td>1.64</td>
<td>0.133</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2b</td>
<td>Mud</td>
<td>55.2</td>
<td>1.65</td>
<td>1.062</td>
<td>2.7</td>
<td>1.54</td>
<td>60.6</td>
<td>96.8</td>
<td>48.6</td>
<td>30.7</td>
<td>17.9</td>
<td>1.37</td>
<td>0.117</td>
<td>2°</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>Sandy mud</td>
<td>37.7</td>
<td>1.79</td>
<td>1.300</td>
<td>2.69</td>
<td>1.07</td>
<td>51.7</td>
<td>94.8</td>
<td>31.3</td>
<td>21.3</td>
<td>10.0</td>
<td>1.64</td>
<td>0.044</td>
<td>13°</td>
<td>0.05</td>
</tr>
<tr>
<td>4</td>
<td>Sand</td>
<td>32.2</td>
<td>1.81</td>
<td>1.360</td>
<td>2.68</td>
<td>0.97</td>
<td>49.4</td>
<td>91.0</td>
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<td></td>
<td></td>
<td>0.016</td>
<td>30°</td>
<td>0.05</td>
<td></td>
</tr>
</tbody>
</table>

TABLE No 6
Fig E1.

LOCATION OF BORING HOLES
Fig E2. Settlement diagram of the building A2.

Fig E3. Settlement diagram of the building A3.