National University of Singapore
SCHOOL OF DESIGN AND ENVIRONMENT
DEPARTMENT OF BUILDING
BU 3102: CONCSTRUCTION TECHNOLOGY III

Q3) Discuss soil characteristics and their relation to foundation selection with case studies

1.1 GENERAL CLASSIFICATION OF SOIL

There is a large variety of soil and rock types which can be encountered in any particular project. It is important to have a concise and systematic method of classifying these soils and rocks so as to enable the engineers to draw some useful conclusions from the type of soil available from the ground conditions of the site.

For practical purposes, geological deposits are divided into two major groups, namely soil and rocks. Soils refers to the comparatively soft, loose and uncemented deposits, while rocks refers to the hard, rigid and strongly cemented deposits.

1.1.1 Rock Types

Rocks can generally be classified into 3 broad groups, namely sedimentary, metaphoric and igneous rocks, as shown in **Table 1.1**

Group	**Rock Types**	
Sedimentary	Sandstones (including conglomerates)	Siliceous Calcareous Ferruginous Argillaceous
	Some hard shales and tuffs	
	Limestone	Massively bedded (including chalk) Thinly bedded
Metaphorphic	Some hard shales Slates Schists Gneisses	
Igneous	Granite Dolerite Basalt	

1.1.2 Soil Types

Soil is defined as an unconsolidated assemblage of solid particles which may or may not contain organic matter with the voids between the particles being occupied by air and water. Soils are generally described and defined by the size of the particles of which they are constituted. Sand, for example, is readily recognizable as consisting of small particles which are easily seen by eye. Silts are soils which are made up of particles finer than those found in sand but not as fine as those that make up clays. These finer particles cannot be seen by eye, but there are laboratory methods of determining their size so that it is possible to lay down certain limits for the accurate description of soil types.

These sizes relate to soils consisting of aggregations of particles of approximately the same size. There are naturally many soils that consist of mixtures of particles of different size, such as are described by terms like “sand and gravel”, “silty sand”, “sandy clay”. Glacial till is perhaps the best example of a soil mixture since it usually consists of particles ranging all the way from boulders to clay.

If one looks carefully at a sample of any such soil mixture, it is not hard to appreciate that between the individual soil particles there are voids. These can clearly be seen in sand or gravel; they can be imagined on a much smaller scale in the case of silts or clays. In the case of a dry soil, the voids are filled with air. When all the voids are full of water, a soil is said to be saturated. This type of mixture of soil mineral material, air and water is described technically as a “3 phase system”

In general, soils can be classified into 3 categories, namely cohesive, non-cohesive and organic. A clearer description of these types of soil are listed in Table 1.2 below.

Table 1.2 Classification of soil

GROUP	SOIL TYPE	DESCRIPTION
Non-cohesive Soil	Cobbles & Boulders	Larger than 3 inches in diameter
	Gravel	A natural deposit consisting of rock fragments in a matrix of finer and usually sandy material. Many of the particles are larger than 2mm in size. Particles smaller than 3 inches and larger than No. 4 sieve (approximately ¼ inch)
	Sand	A natural sediment consisting of angular and mainly siliceous products of rock weathering. It is gritty with no real plasticity. Particles smaller than No.4 sieve and larger than the No. 200 sieve (particles smaller than the No. 200 sieve are not visible to the naked eye).The particles normally range between 0.06 and 2.00mm in size.
Cohesive Soil	Silts	A natural sediment of material which is of a finer grades than sand. The particles normally range between 0.002 and 0.06mm in size and most of the grains will pass a 75 micrometer test sieve. It possesses some plasticity but is not very gritty. When it is dry, it has considerable cohesion. Particles smaller than 0.02mm and larger than 0.002mm in diameter

GROUP	SOIL TYPE	DESCRIPTION
	Clay	A natural deposit which consists mainly of the finest siliceous and aluminous products of rock weathering. It is smooth and greasy to touch. It is sticky and dries slowly. On drying, it shrinks appreciably. It has considerable strength when dry. Particles smaller than 0.002mm in diameter.
Organic	Peat	Peat is made up of fibrous particles of decayed vegetable matter. It is light to dark brown in colour. It is highly compressible and is considered to be entirely unsuitable to support any type of foundation.

Soils encountered at any site would not be in its purest form. It is most likely to be in a mixture of a few types of soils. So, instead of solely sand or clay, one would expect to find a mixture such as sandy clay, silty sand or silty clay etc. The proportions of the constituents depend on the geological formations of the site.

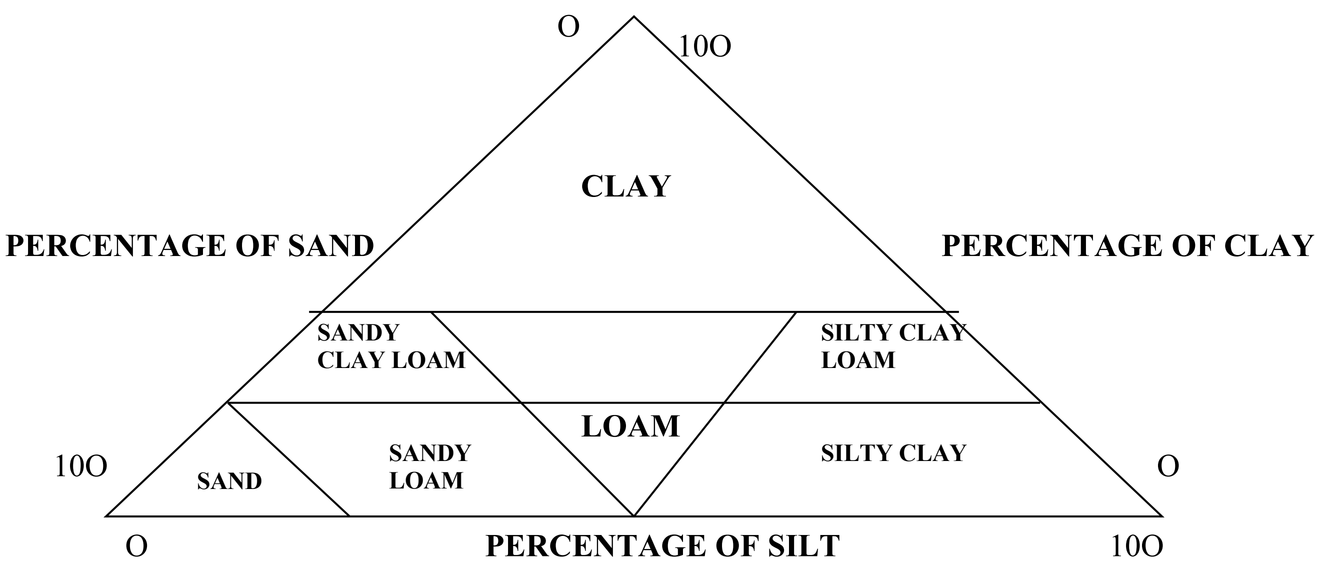

Fig 1.3 shows a triangular diagram a breakdown of the various types of soil

Table 1.5 Soil characteristics and bearing capacities

Subsoil Types	**Condition of subsoil**	**Means of Field Identification**	**Bearing capacity kN/m^2**	**Minium width of strip foundation in kN/m of loadbearing wall of not >**					
Gravel	Compact	Require pick for excavation. 50mm peg hard to drive more than about 150mm. Clean sands break down completely when dry. Particles are visible to naked eye and gritty to fingers. Some dry strength indicates presence of clay	> 600	20	30	40	50	60	70
Sand			>300	250	300	400	500	600	650
Clay	Stiff	Require a pick or pneumatic spade for removal. Cannot be moulded with the fingers. Clays are smooth and greasy to the touch. Hold together when dry, are sticky when moist. Wet lumps immersed in water soften without disintegration.	150-300	250	300	400	500	600	650
Sandy clay			150-300						
	Firm	Can be excavated with graft or spade. Can be moulded with strong finger pressure	75-150	300	350	450	600	750	850
Sandy clay			75-150						
Gravel	Loose	Can be excavated with a spade A 50mm peg can be easily driven	<200	400	600	For loading of > 30kN/m run on these type of soil, the necessary foundation do not fall within the provisions of Approved Doc A, Sect 1E from which these fig are taken Pad foundations generally and surface rafts are designed using the bearing capacities for soils given in this Table.			
Sand			<100						
Silty sand			May need test						
Clayey sand			Ditto						
Silt	Soft	Readily excavated and easily moulded with fingers. Silt particles are not normally visible to the naked eye. Slightly gritty. Moist lumps can be moulded with the fingers but not rolled into threads. Shaking a small moist pat brings water to surface which draws back on pressure between fingers. Dries rapidly. Fairly easily powdered.	<75	450	650				
Clay			<75						
Sandy cay			May need test						
Silty clay			ditto						
Silt	Very Soft	A natural sample of clay exudes between the fingers when squeezed in fist	Ditto	600	850				
Clay			Ditto						
Sandy clay			May need test						

Silty clay			Ditto	
Chalk	Plastic	Shattered, damp and slightly compressible or crumbly	-	Assess as clay above
Chalk	Solid	Requires a pick for removal	600	Equal to width of wall

Clay	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	Cobbles Boulders
	Silt			Sand			Gravel			

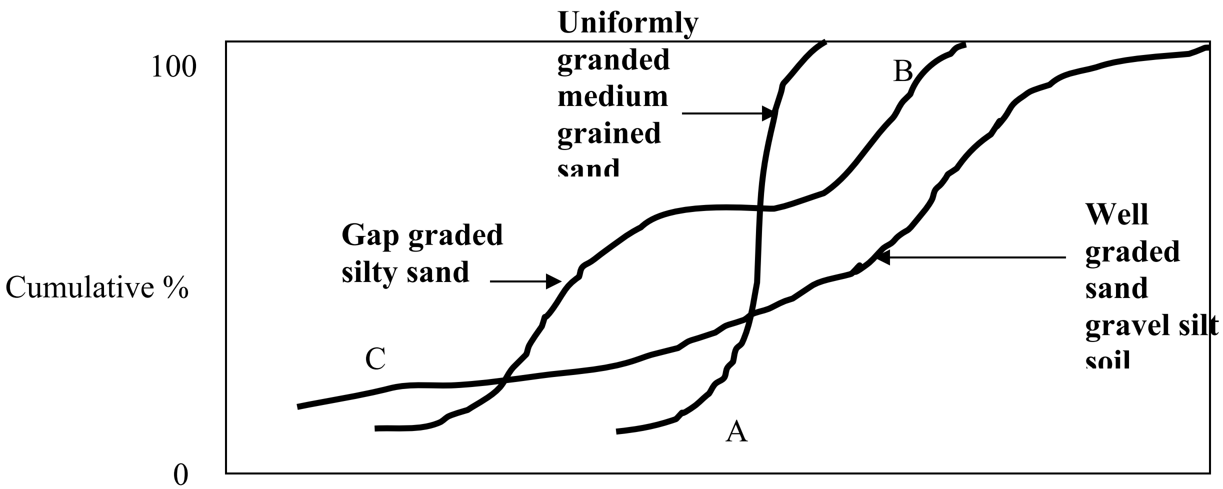

Fig 1.4 Grading Curves (engineering properties of soils & rocks)

The soil is uniformly sorted, whilst curve B represents a well sorted soil. The sorting or uniformity of a particles distribution has been expressed in a great many ways but one simple statistical measure which has been used by engineers is the coefficient of uniformity (U).

2.1 GEOLOGY OF SINGAPORE

Although Singapore is a relatively small island, there are considerably large varieties of subsoil conditions. The possible types of soil that can be encountered here are marine clay, silty clay, peaty clay, peat, silt, sand, weathered to fresh rock such as sandstone, granite and norite. The soil condition of Singapore is basically made up of different major geological formations, namely the Bukit Timah, Jurong, Old Alluvium and Kallang Formations, as shown in Fig.2.2. Sub-soil conditions could be a combination of these formations.

2.1.1 Bukit Timah Granite

The Bukit Timah Granite is mainly distributed in the central part of the island. It has been located in Bukit Timah, Thomson, Sembawang, Mandai, Bukit Panjang and Upper Changi areas.

The Bukit Timah Granite is usually completely decomposed near the surface due to chemical and physical weathering. This weathering is due to the hot climate and humidity. The degree of weathering decreases with depth. The weathered deposits, which are named residual soil, formed a thick overburden over the parent granite. This residual soil, which consists mainly of sandy clayey soil, can be in excess of 45 meters but abrupt changes in depth to the granite rocks can occur over very short distances. A typical soil profile of this formation is shown in Fig.2.3.

The weathered granite residual soil is of sandy clay or silt nature and consists of between 25% to 65% silt and clay sized particles with increasing stiffness and percentage of coarser fraction with depth. Large boulders are often encountered within this central Singapore. At some low-lying areas, a layer of alluvium or marine clay may overlie the granite formation.

SOIL PROFILE	N VALUE	MOISTURE (%)
Clayey Silt Fill	20-30	20-40
Stiff to very stiff sandy clayey silt	40-60	20-40
Weathered granite	>80	

Fig.2.3. Typical soil profile of Bukit Timah Granite

The Bukit Timah granite is the ideal bearing stratum due to the hardness and low compressibility. Shallow foundation may be adopted if the level of the bedrock is near to the ground level. The allowable bearing capacity of the granite is high, so the compressive strength of the pile may be the critical factor in design. If the surface of the rock is extremely irregular with hills and deep canyons, steel H pile has the advantage over concrete pile in lower costs and shorter time for cutting and joining.

2.1.2 Jurong Formation

The Jurong Formation covers the western and southern coastal areas. Normally, the Kallang Formation or loose stratum consisting of sand, gravel and very sticky clay with boulders is overlying it.
This formation consists of sedimentary rocks formed in the Triassic period. Mudstone, sandstone and shales can be found interbedded in this formation at a depth ranging from 5 meters to 45 meters. Generally, the structure of this formation is complex due to folding and faulting.

Furthermore, due to weathering, the top portion is generally reduced to residual clayey soil with the degree of weathering decreasing with depth. The mudstone portion weathers faster than the sandstone portion, because of this, the weathered zone is thicker at the mudstone portion than the sandstone area. Sandstone is generally harder than mudstone. Shale will become weaker and unstable if left exposed for a long time and tends to fragment under heavy load or impact. The subsurface material are generally of low to medium plasticity (LL= 30-45 and PI= 10-20) with fines content ranging from 48% to 90%. In general, the materials are of high strength and low compressibility, as of "over-consolidated" soil.

Jurong formation is the bearing stratum for shallow and deep foundations. It is preferable to rest the pile into the sandstone instead of mudstone because of higher strength and less soil compressibility. The hardness of the rocks and the properties and depth of the overburden soil will decide the type and length of pile to use.

SOIL PROFILE	N VALUE	MOISTURE (%)
Medium Stiff Sandy Silty Clay	10-20	20-40
Soft Sandy Silty Clay	10-20	20-40
Very Stiff Sandy Silty Clay	20-40	20-40
Hard Silty Clay	60-80	20-40
Very dense Clayey Silt	>100	20-40
Silty Clay with Shale	>100	20-40

Fig.2.4. Typical soil profile of Jurong Formation

2.1.3 Old Alluvium Formation

The Old Alluvium Formation lies to the northern and north-eastern part, and also to the north-western part of Singapore island.

Old Alluvium is the product of heavily weathered sedimentary rocks. It is a semi-consolidated, horizontally stratified Pleistocene deposit, consisting primarily of clayey to silty coarse sand with layers of silty clayey, as shown in Fig.2.5. It is often thick, in excess of 30 meters, having been recorded. The soil is practically impervious in compacted form, possesses good shearing strength and low compressibility. However, the sandy soils are generally poorly graded, with relative densities ranging from 5% to 90%.

This formation has high value in firction. It provides sufficient pile bearing capacity. This type of soil condition is suitable for the use of bored pile without casing. Sometimes, driven pile is adopted too. Since the soil provides good frictional resistance, it is uneconomical to have penetration reaching the hard stratum. Basically, piles in this formation is designed as friction pile.

SOIL PROFILE	N VALUE	MOISTURE (%)
Sandy Silty Clay	10-20	20-40
Stiff Silty Clay	20-30	20-40
Hard Silty Clay(with some sand)	40-50	20-40
Very dense cemented silty sand	>100	10-20

Fig.2.5. Typical soil profile of Old Alluvium Formation

2.1.4 Kallang Formation

The Kallang Formation consists of soils with marine, alluvial, littoral and estuarine origins, which cover much of the coastal plain, immediate off-shore zone and the deeply incised river valleys, which penetrates to the center of the island. The marine member of the Kallang Formation has a wide distribution of nearly 25% of the total land area of Singapore. The thickest marine clay layer found is 40 meters thick along Rochor Road.

Basically, Kallang Formation comprises of two layers, the the upper and lower marine clay, separatedby a thin layer of stiff silty clay, as shown in Fig.2.6. The upper member and the lower member are present in the plains of Kallang, Geylang, Bedok and Changi, and appeared adsent in Kranji, Sembawang and Serangoon. In Jurong, only the upper member had been detected.

SOIL PROFILE	N VALUE	MOISTURE (%)
Clayey fill	10-20	20-30
Soft to firm marine clay	<3	60-80
Stiff Clay	20-30	
Firm marine clay (lower member)	<5	40-60
Medium to dense cemented clayey sand	>100	20-30

Fig.2.6. Typical soil profile of Kallang Formation

The marine clay is kaolinite rich, its in-situ moisture content is close to the liquid limit and its cohesive strength is low. The marine clay does not become siltier with depth, hence retaining its essential characteristic of 65% to 70% clay throughout. It is normally consolidated with average shear strength of 10 kN/m^2 and 40kN/m^2 for the upper and lower marine member, respectively. The intermediate stiff clay layer is over-consolidated and has undrained shear strength of 50 to 120kN/m^2. The moisture content of the upper marine member is high, about 70% to 100% and this layer has high compressibility. The thickness of 40 mters in Rochor as well as in Changi.

3.1 SOIL TESTING

Soil testing is based on the premise that the behaviour of soil masse under imposed conditions can be predicted if certain soil properties can be measured. Because soil is a natural material that is much more variable than man-made building materials, and because it is a multi-phase system composed of solid particles with their intervening void spaces filled with either air or water or a combination of both, the results of soil tests must be interpreted in the light of past experience, the climate, and the geology of site.

One of the most significant requirements is that soil tests be conducted on samples that are truly representative of the soil at the site. To be successful, soil sampling, testing and test interpretation must be conducted under the guidance of specially trained and experienced personnel.

The various tests may be divided into three categories; consolidation, shear strength and compaction test. We shall now zoom into the consolidation first, when a saturated soil is acted upon by an ambient stress, the soil mass may deform on account of shear stress induced but no volume change can take place if the soil water is not permitted to escape, the soil grains and water being themselves incompressible. Under this condition, the external stress is taken partly by the soil particles and also by the soil water known as the pore water pressure. If the soil water is now permitted to drain away, the pore water pressure drops that is known as the dissipation of pore water pressure and the volume of soil decreases. The process involving a reduction of soil volume resulting from the dissipation of pore water pressure with time is known as consolidation. Generally speaking, the consolidation test is conducted to evaluate the compressibility characteristics of the strata encountered.

The tests on consolidation are more accurately described as a one-dimensional consolidation test because the sample is enclosed in a tight fitting metal ring and the load is applied in one direction only. The apparatus used is known as the oedometer, or sometimes known as the consolidometer. From the results the coefficient of consolidation is obtained which in favourable soil conditions, enables the rate of settlement of the full-scale structure to be calculated. The load-settlement data obtained from the full cycle of loading and unloading are used to draw a pressure-voids ratio curve from which the coefficient of volume compressibility is derived. This is used to calculate the magnitude of a consolidation settlement under any given loading.

3.1.1 Shear strength

The unconfined compression test is the simplest form of shear strength test and is usually performed directly on 40mm samples ejected from tube samples of the same diameter, or on 40mm test specimens cut from tube samples of larger diameter. In soils containing gravel making it impossible to cut 40mm specimens, the unconfined compression test can be made directly on 100mm specimens ejected from sample tubes of the same diameter.

This type of test cannot be made on cohesion-less soils or on clays and silts that are too soft to stand in the machine without collapsing before the load is applied. In the case of fissured or brittle soils the results are lower than the true in-situ strength of these soils.

The triaxial compression test is a more adaptable form of shear strength test that can be applied to a wider range of soil types than the unconfined compression, and the conditions of tests and observations made can be varied to suit a wider range of engineering problems.

The three types of triaxial are:

1) Undrained
2) Consolidated-undrained
3) Drained

In the undrained test the specimen is not allowed to drain during the application of the all-round pressure or during the application of the deviator stress, and therefore the pore pressure is not allowed to dissipate at any stage of the test. The test procedure for the Consolidated-undrained test is to allow the specimen to drain while applying the all-round pressure; thus the specimen is allowed to consolidate fully during this stage of the test. Drainage is not allowed during the application of the deviator stress.

In the case of the drained test, drainage of the pore-water from the specimen is allowed both during the stage of consolidation under all-round pressure and for application of the deviator stress. The time allowed for consolidation under all-round pressure and for application of the deviator stress must be slow enough to ensure that no build-up of pore pressure occurs at any stage of the test.

Triaxial tests are limited to clays, slilts, peats and weak rocks.It is gerally pointless to test sands and gravels since a test cannot in any case be made directly on an undisturbed sample. Even if it is possible to obtain satisfactory undisturbed samples of sands and gravels from boreholes or trial pits, it is impossible to extract specimens for the triaxial tests from the sample test tubes without disturbing the soil. The best that can be done is to determine the density of the soil in the tube by weighing the contents and measuring the volume. The test specimen can then be made-up to the same density.

3.1.2 Compaction

If a soil mixture is compacted in a lab in a container of known volume, under standard conditions, a certain value will be obtained for its density. If water is added to this soil and thoroughly mixed, and the resulting soil mixture again compacted in the same container under the exact same conditions, the dry density will be found to have increased. This process can be continued until certain optimum moisture content is reached, after which the dry density will decrease with the addition of more water. This result may be explained by the fact that the water present can be said to lubricate the contents of the soil, which are therefore forced closer together to give an increasingly compact mass so long as there are any voids left in the soil mixture. Once all the voids are filled, the addition of more water will merely tend to separate the soil particles and reduce the effective dry weight.

On large jobs, the soils encountered can be tested in a lab in order to determine their optimum moisture content and corresponding maximum density. This is clearly impossible on small jobs. Fortunately, however, there is a simple way to roughly determine the optimum water content at which this maximum density may be obtained. For many soils, this point may be distinguished by mixing small quantities of soil with water and testing them by squeezing a lump in ones hand. When it is of such consistency that it will break up into smaller lumps when pressure is applied to it, this indicates the right amount of water in the soil to give optimum density, therefore if the soil to be used is not sand or gravel it should be subjected to this simple test.

CONCLUSION

The results of these tests will indicate the suitability of a site and the various design alternatives for a foundation. It is still necessary, however to evaluate the test results, for the properties of sol are influenced by both the geological and climatic conditions on the site.

FOUNDATION

1. INTRODUCTION

A foundation can be defined as that part of the substructure designed and constructed to be in direct contact with and transmitting loads to the ground. The function of the foundation is to spread the load from the superstructure, be it dead or live load, so that the pressure which is transmitted to the ground would not cause shear failure or induce excessive settlement of the ground that will, in turn, cause distortion and structural failure or unacceptable damage.

Foundation of the various forms can be broadly classified into shallow and deep foundations. Shallow foundation is suitable for low-rise, lightly loaded and firmly grounded structures while deep foundations are suitable and indeed necessary for high-rise buildings, which produces highly concentrated load especially in soft soil conditions. In Singapore, where the density of land usage is so high, deep foundations are most commonly used. This is especially true in the CBD area where optimum usage of space is so critical to the owners of the buildings.

2. CLASSIFICATION OF FOUNDATION SYSTEMS

There are various ways in which foundation systems can be classified. Foundation systems can be classified according to the materials they are constructed of, their function, nature and method of analysis.

Shallow foundations are those that transfer the load to the earth at the base of the column or wall of the substructure. They either form individual spread footings or mat foundation, which combine the individual footings to support an entire building or part of it.

Deep foundations are usually used where soil properties are inferior for shallow foundations. Inferior soil are weak, non-homogeneous and compressible which may not be able to support the load from the buildings, therefore deep foundations would be used to transmit the load to a firm stratum at a greater depth. Similarly, if a firm stratum of soil or competent rock is so deep that shallow foundations cannot reach it economically, then deep foundations will be used.

Deep foundations can be sub-classified into displacement and replacement systems.

a. DISPLACEMENT SYSTEM

Displacement systems consist mainly of piles such as precast reinforced concrete piles, steel piles and timber piles. A pile is defined as a long structural member used to transmit foundation loads to an underlying soil mass. A pile, which, while being install in the ground, displaces its own volume of soil, is called a displacement pile. Generally, the transmission of load can be achieved through end bearing, skin friction or a combination of both. The selection of the appropriate type of pile depends on 3 main principles factors: location and type of structure, ground condition and durability.

✓ PRECAST REINFORCED CONCRETE PILES

Precast reinforced concrete piles are one of the most common piles used in Singapore. They are used when a high resistance to lateral forces is required or when the soil conditions are unfavorable to cast-in-place piles.

Precast reinforced concrete piles are usually square or hexagonal and of solid cross-section for units of short or moderate length, but for long piles are usually manufactured with a hollow interior in hexagonal. Octagonal or circular sections for saving in space. Normally, square section piles with size ranging from 150 x 150 mm to 600 x 600 mm are used. To avoid excessive flexibility while handling and driving, the usual maximum lengths of square section piles and the range of working loads applicable to each size as shown in table below. The load bearing capacity of precast reinforced concrete piles can range from 15 tonnes to 190 tonnes.

Table: working loads and maximum lengths for ordinary precast concrete piles of square section

Pile size (mm^2)	Range of working loads (kN)	Maximum length (m)
250	200-300	12
300	300-450	15
350	350-600	18
400	450-750	21
450	500-900	25

During the design of the precast reinforced concrete piles. One important consideration that has to be taken into account is to ensure the availability of adequate strength to withstand stresses induced by lifting, handling and driving of the piles. Once the piles are driven to their positions, the stresses caused by foundation loading would be much lower than those caused by handling and driving. Stresses would be more concentrated at the head and toe of the piles, therefore, additional reinforcement must be provided at these points to resist the stresses.

In addition, it is recommended that when hard driving is expected, a steel or iron shoe should be bonded on to the toe of the piles to prevent any possible damage.

Precast reinforced concrete piles are driven by drop hammers or vibrators using a pile-frame, a crane and leaders, or a pile driving rig. Markings are made along the pile sections a regular intervals to enable the length actually driven to be recorded and to serve as a rough guide to estimate the set during driving.

There are several advantages and disadvantages associated with precast reinforced concrete piles. Some of these are as follows:

Advantages:

(1) They are precast before installation, this allows for better quality control.
(2) It also allows for thorough inspections and checks before actual installations on site.
(3) It is stable in squeezing ground, e.g soft clays, silts and peats.
(4) In cases where there is ground heave; the piles can be redriven into their positions.
(5) If the geological stratum is known, pre-determined length can be casted.
(6) It is possible to cast the piles on site and this reduces the problems and expenses of transportation.

Disadvantages:

(1) It can cause considerable displacement of soil, which may danger, an adjacent building.

(2) When heavy stresses are imposed on the piles, any damage to the piles due to the stresses is not noticeable.
(3) There is considerable noise and vibration during installation.
(4) Precast concrete piles are not flexible. They are not available in exact required length; therefore excess lengths are always cut-off as waste.
(5) Excessive lengths add to its overall cost.
(6) It cannot be driven with very large diameter or in conditions of limited headroom.
(7) There is considerable time and cost wastage associated with the trimming and cutting of pile heads.
(8) There is a common problem of cracking and bending failure of piles during driving. This problem can be prevented if precautions are taken against eccentric hammer blows, uneven jetting and direct bending, etc.
(9) The piles are constructed of several sections joined together to obtain the required length. This presents an inherent weakness at the joints.

✓ **STEEL PILES**

Steel piles can be formed from a variety of steel sections. For example, H-beams or pipes. In general, steel piles are used and driven as plain rolled steel sections. However, tubular pipe piles and box piles are sometimes fitted with shoes and may be filled wholly or partially with concrete or other materials.

Steel piles do not cause large displacement of the soil. Because of this characteristics, they are very useful where upheaval of the surrounding ground would damage adjoining properties. Steel piles can also be used in situation where deep penetration is required through loose or medium dense sand.

In Singapore, H-pile or universal steel beam is the most popular form of steel pile. They are usually in the form of wide flange sections. H steel piles belong to the family of displacement systems. Like precast concrete piles, drop hammers or vibrators using a pile frame, a crane and leaders or a pile-driving rig drive them. Unlike precast concrete piles, there is no need to take into consideration the presence of induced stresses during lifting and handling of the piles.

However, care must be taken in the welding of joints to ensure that they are capable of withstanding driving stresses without failure. A protective steel guard should be welded at the joints. There should also be provision of adequate driving heads so that the end of the steel sections is protected. The use of pile shoe for pile driving is not necessary in normal installation conditions. In situations where the driving of the piles are expected to be exceptionally hard, cast steel plates, welding plates or angles are added to the bottom end of the piles to strengthen them.

The advantages and disadvantages of steel piles are summarized as follow:
Advantages:

(1) Steel piles are prefabricated off site in factory conditions; therefore it allows opportunity for inspection and checks. Quality is thus assured.
(2) Steel piles have a high bearing capacity provided they are driven on to a hard stratum.
(3) Steel piles are strong in withstanding hard driving. In situation where hard driving has caused the pile head to buckle, the damaged pile head can readily be cut down and the pile reshaped for further driving.
(4) They provide good resistance to lateral forces and buckling.
(5) They do not cause large displacement of the soil; therefore they do not cause upheaval of the surrounding ground and would not damage adjoining properties.
(6) They are robust and no special care is required during handling.
(7) They are flexible in that they may be shortened and lengthened easily by cutting and welding respectively.
(8) Excess steel sections that are cut-off can be reused.

Disadvantages:
(1) expensive due to high cost of material.
(2) They cause considerable noise and vibration during installation.
(3) Steel piles are prone to corrosion.

✓ **BORED PILES**

Bored piles are cast-in-situ concrete piles. Generally, piles exceeding 600 mm in diameter are known as large diameter bored piles although there is no precise dividing line. There are three main types of bored piles, namely percussion, rotary and flush bored piles. Among them, rotary pile is the most commonly used in Singapore.

Before the actual boring commences, site investigation is carry out to determine the soil condition at the site. A few bore logs would be taken at regular intervals at the site. From the bore logs, the soil profile and the corresponding physical soil properties will then be determined. From the soil profile, a study of the general changes in soil layers can be made. The soil properties will facilitate in the determination of the size and length of the bored pile under consideration.

Boring can commence after the pile positions are set up. The open auger is the most common cutting tool employed in the boring work. It is rotated by means of a Kelly bar. The auger consists basically of a central stern carrying auger flights, which may be single or double flighted. For deep boring of depths up to 45 metres, a triple telescopic type of Kelly bar may be used.
As the auger starts boring, the flights would be gradually filled with spoils. When it is full, it is lifted out of the hole and the flights emptied. After that it is reintroduced into the hole and the boring process continues. This cycle of operation is repeated until the required depth has been achieved. Upon achieving the required depth, the auger would be withdrawn from the hole.

Then, a cleaning bucket would be used to clean up the loose spoil at the bottom of the hole and also to ensure a clean base for concreting. Inspection of the hole is done and a reinforcement cage is inserted into position. This is followed by concreting. The top portion of the reinforcement cage is left projecting above the cut-off level of the pile to act as a tie between the pile and the superstructure.

This is the basic cycle of operations, which can be used only where the ground consists of dry cohesive strata for the full length of the pile. However, such favorable soil conditions may not be always present. In situation where the soil is collapsible, temporary metal casing may have to be inserted during boring to prevent the soil form collapsing into the bored hole. The usage of bentonite slurry is another way of preventing collapsing of soil, especially very soft clay, loose and water bearing sand. However, for bentonite slurry to be effective, it has to be of a suitable viscosity and it requires a proper mixing and cleaning plant on site to recirculate the slurry.

The advantage sand disadvantages of bored piles are summarized as follows:

Advantages:

(1) Testing and inspection can be done on the soil removed in boring.
(2) The pile can be installed in long lengths and large diameters.
(3) Boring rig is light, portable and versatile.
(4) There is no problem of ground heave from boring operations.
(5) They are flexible in that their length can be readily varied to suit varying ground conditions.
(6) The installation of the piles does not cause much noise and vibration.
(7) They can be installed in conditions of low headroom.
(8) They can withstand high working loads.

Disadvantages:

(1) expensive equipment are used, therefore may not be economical for small jobs.
(2) In case of collapsible soil, the use of temporary casing and bentonite slurry results in higher cost.
(3) The pile may not be properly casted due to the inflow of ground water.
(4) Under reamed cannot be formed in cohesionless materials.
(5) Its replacement nature tends to loosen the surrounding strata, especially sandy or gravelly soils or change soft rocks to a slurry.
(6) Bored piles are susceptible to necking in squeezing ground.
(7) Once casted, the piles cannot be inspected and it is known whether the piles are properly casted.
(8) Drilling a number of piles in group can cause loss of ground and settlement of adjacent buildings.

✓ CAISSONS

The word 'caisson' is derived from the French word caisse, a chest or box. In civil engineering, a caisson has come to mean a boxlike structure, round or rectangular, which is sunk from the surface of either land or water to some desirable depth.

The function of caisson foundation is to enable structural loads to be taken down through deep layers of weak soil on to a firmer stratum, which will give adequate support to lateral loads. They fulfill the same function as piled foundations, the main difference being in the method of construction.

Caissons are extremely suitable for multi-storey buildings and other heavy structures since they can be designed to take very high column loads. They are more commonly seen in civil engineering works such as bridges and wharves.

The type of caissons are as varied as the multitude of purposes for which they are intended and as the many types of ground, other than rocks that are encountered. Generally, they can be classified into two main types, namely drop caissons, and hand-dug and machine-bored caissons.

CAISSONS & CYLINDERS

The word 'caisson' is derived from the French word "*caisse*", a chest or box. In civil engineering, a caisson has come to mean a boxlike structure, round or rectangular, which is sunk from the surface of either land (often unstable soil) or water to some desirable depth. They fulfil the same function as piled foundations, the main difference being in the method of construction. A foundation will be termed a caisson if the diameter is large enough for a person to stand inside for inspection purposes. The diameter of the structure in this case has been taken to be 750 mm or more by the ACI Committee 336 [1972].

Very often, the term "caisson" will be used for cylinders. The difference between the two is that the cylinders have single walls and are generally sunk by addition of kentledge, by impact or jacking down while caissons sink under their own weight or by the addition of concrete or other permanent filling.

The function of caisson foundation is to enable structural loads to be taken down through deep layers of weak soil on to a firmer stratum, which will give adequate support to lateral loads. The depth of the firm stratum does not restrict a caisson. However, a soil, which can be easily grabbed during excavation, is an advantage. Soft alluvial clays are usually good for caisson sinking. Boulders can delay the sinking and affect the verticality of the caisson.

Caissons are extremely suitable for multi-storey buildings and other heavy structures since they can be designed to take very high column loads. They are more commonly seen in civil engineering works such as bridges and wharves. They are particularly useful in situations where the construction of the foundation is obstructed by boulders or when the soil will tend to flow into the open excavation.

Caissons are constructed of steel or reinforced concrete. The concrete increases the weight of the structure making the sinking easier. An alternative to it may be a steel shell being filled with concrete as sinking proceeds. On the other hand the advantages of steel are that its weight of flotation is less and it is flexible and more resistant to torsional stresses.

Caisson are generally classified as:

<u>Drop Caissons</u>
Open caisson with the top and bottom open
Pneumatic caisson where the top is closed and the working chamber is under air pressure
Box caisson with the bottom closed

Machine/man/drilled caisson
Open Caissons

The simplest caisson is circular in plan and consists of a heavy exterior wall. Large open caissons are often rectangular and have many interior cross wall which divides the space into many dredging wells. Other large caissons may contain double wall. To sink the caisson concrete is then poured in between the walls.

As soil is excavated from within the caisson and under the edges, the caisson sinks to the required depth under its own weight or with the aid of additional weight added on top of the caisson. To enable the caisson to sink more readily and to withstand weight without crushing, the bottom edges are usually fitted with iron ‘ cutting edges and are heavily reinforced. The cutting edge may be cast on site where the caisson will be located. The skin friction of the soil may also be reduced by lubricating the sides of the caisson with compressed air or bentonite. Vibration may also be used or a kentledge may be utilised to increase the weight of the caisson.

<u>Sequence of construction:</u>

A trench is first dug accurately to some grade and the ring and the first shaft segment are fabricated. Excavation the proceeds through the ring and successive shafts are added until the required bearing stratum is reached. A steel shoe protects the cutting edges. Guide piles may be necessary to ensure the caisson is plumb.

After sinking, the caisson is left permanently in position

Open cylinders may also be driven down using a hammer. This is used when the skin friction is very high and mechanical excavation is difficult. However, the driving of the cylinder will cause a lot of noise and vibration.

This type of caisson is usually used on dry land or on “sand islands” which are created by the building of a cofferdam then filling it with dredged sandy material to create a dry area to work. A concrete seal may latter be tremie-placed at the bottom. Alternatively grout may be injecting in the voids of the coarse aggregates.

In very soft and unstable soil steel domes may be placed over the caisson and compressed air is pump through to achieve stability and a regular rate of sinking.

The other types of cylinders include the steel cylinder and precast concrete cylinder. The steel cylinder is used when a water-bearing stratum may be encountered. Prestressed concrete cylinders have also been used. The construction of the latter is relatively economical and rapid.

Monoliths are another type of caissons. They are made of mass concrete with heavy walls. They are sunk in a similar way to open caissons. However, after sinking the cells in the caisson are filled with concrete to resist overturning. They are usually used in quay walls.

Box caissons

A box caisson is a prefabricated box with sides and a bottom which is set on a prepared foundation and filled with concrete. It is usually used in the construction of bridge piers and other structures in water.

A precast concrete box or a steel box will be used if the bottom can be predredged to form an even surface. At times a bottomless box will be sunk and later a concrete seal is tremied in. A sand carpet may be added to ensure evenness of the surface.

Box caissons may also use buoyancy to aid in the support of the load especially in piers. This is achieved by casting the whole box offsite and sinking it at the desired location. The caisson contains watertight compartments and thus buoyancy supports a great deal of the load. The remaining dead load and live load is passed down to piles at the bottom of the box.

Pneumatic Caisson

The main characteristic of pneumatic caisson is that workers have to work under pressurized conditions. Because of the high pressure in the caisson, workers can work in a water-free environment. This is especially useful where excavation work is required under water or where obstruction such as boulders or tree trunks need to be removed from below the cutting edges so that sinking can continue. However care should be taken when using the pneumatic caisson as staying too long in the compressed air environment may result in health problems. Decompression chambers also need to be present.

Because of the inherent dangers associated with the pneumatic caisson, robots are now used in the excavation.

The main advantage of this type of caisson is that it permits excellent control of the sinking rate. It may also be used to when a caisson is to be sunk adjacent to an existing structure.

Hand-dug / machine-bored / drilled caisson.

The second main types of caissons are hand-dug and machine-bored caissons. These are also known as shaft foundations. This type of caissons is more commonly used for building construction. They are basically concrete-filled pier holes for the support of columns. The holes are dug through soft materials to a harder bearing stratum. A caisson usually consists of two sections, the shaft and the bell, which is an enlargement at the bottom of the shaft. The purpose of the bell is to serve as a spread footing to reduce the load on the bearing stratum to allowable limits. The bell can only be created if the soil is cohesive so that the bell will retain it shape when concrete is poured. The bearing stratum needs to be impervious as well to prevent water from flooding the hole. If the bearing stratum is rock of high quality, no bell is necessary, and the caisson then consists merely of the shaft to rock.

An usual way of constructing this type of foundation is to excavate vertical holes to the required depths with the sides of the hole supported by timber sheeting, steel sheet piling, steel tube rings, cast-in-place concrete rings, or bolted steel, cast-iron, or concrete segments. A concrete base is formed at the bottom of the hole and then, the column or shaft section of the foundation is constructed. The space around the shaft is backfilled as the sheeting is withdrawn. The bell is formed using a belling bucket with retractable cutters.

The second type of drilled caisson is the socketed caisson which is drilled into the rock at the bottom. Its bearing capacity is derived not only from its end bearing but also from the frictional forces between the sides of the caisson and the rock.
At one time, caisson was nearly always constructed by hand excavation method. However, several types of large-diameter boring machines have been designed in recent years. These machines for example the auger have sufficient versatility to deal with almost any types of soil or rock in diameter up to 8 metres with the result that hand methods of excavation have been, to a greater extent, superseded. Hand method has the disadvantages of being slow, ground support is often costly, and there is always a risk of losing lives due to sudden inrushes of water or leakages of gases into the excavations. The latter may come from fractured gas mains, from decomposing organic matters, or concentration of natural gases. Adequate safety equipment must be provided.

Hand methods can still be used in conditions where the job is small and it is uneconomical to bring large machine to site, and where labour are comparatively cheap. Hand excavation can be advantageous for deep shaft foundations in weak rocks, which cannot be drilled economically by mechanical auger and where there are obstructions such as boulders. Hand excavation makes it possible to inspect the rock closely at foundation level. Reassessments can be made of allowable bearing capacity and where necessary, plate loading tests can be made on the exposed rocks to obtain values of deformation modulus as a check on the parameters used at the initial design stage.

Machine-bored method is very similar to bored pile construction, using mechanical auger in boring of the ground. In fact, there is no established dividing line between a large diameter bored pile and a caisson foundation constructed in a mechanically excavated shaft. The only difference may be that caissons have larger diameters and workers are allowed to work inside the shaft. However, it may be interesting to note that machine-bored method is not common in Singapore. Instead other mechanical means of excavation, such as grabbing or using of mini-excavator, are employed in conjunction with trimming by hand. Like the hand-dug method, concrete rings or linings are provided in stages to support the soil around the caisson shaft.

Buoyancy Rafts and Basements (Box Foundations)

The function of a raft foundation is to spread the load over as wide an area as possible and to give a measure of rigidity to the substructure to enable it to bridge over local areas of weaker and more compressible soil. The degree of rigidity given to the raft also reduces the differential settlements.

Buoyancy rafts and basement foundation apply the same principle of the simple raft foundation add to it the advantage of using buoyancy to reduce the net load on the soil. Buoyancy is achieved by providing a hollow substructure of such a depth that the weight of the soil removed while excavating for it either balances or is a little less than the weight if the structure. The building can then be considered to be “floating”. The total settlement is thus less and the differential settlement is also reduced.

In theory a building can be built with raft foundation without any settlement. However, in practice settlement does occur because of fluctuations in the ground water table, consolidation of the soil and miscalculation of the intensity and distribution of live loads as well as the soil bearing pressure.

A true buoyancy raft is built only as a foundation and the basement is not used to increase the space in the building. The raft should be as light and rigid as possible. For this purpose the basement may be divided in to a number of cells.

Buoyancy Raft

Uplift must be prevented while the raft is being constructed, as this will cause the substructure to tilt. This can be prevented by keeping the ground water table low by pumping or ballasting the structure by flooding or otherwise. At times the superstructure can be built to a certain height before the construction of the basement commences, hence providing sufficient dead load to prevent the “floating” effect (Top-Down Construction). Anchorage like friction piles and anchor bars and cables may also be used.

Negative friction may also develop between the walls of the basement and the backfill as the latter consolidates. Hence the basement will be pulled down. This effect is often observed in buildings built on soft silt or clay. This will not only cause excessive disturbance to the soil but also will cause the soil underneath to heave and surrounding soil to slump.

Buoyancy raft can be constructed either as open caissons or they can be built *in situ* in an open excavation.

The caisson method is suitable for soft clay because the soil within the cells is cohesive making the grabbing easy. When using the caisson method the cellular rafts are sunk side by side to cover the whole foundation area. The cells have to be designed in such a way that the weight of the displaced soil will be equal to the combined weight of the caissons and the superstructure. The superstructure should also be as evenly distributed as possible to ensure a uniform bearing pressure over the foundation area. However, it is not suitable for ground conditions where heavy walls are required for stiffness weight required to aid sinking.

The *in situ* method is possible where the ground water table can be kept low by pumping or other methods and where the soil heave will not be excessive.

Basement (box) Foundation

A basement contrary to a raft will need reasonable large floor area without close-spaced wall or columns. The floor will generally consist of a slab or slab and beam or fairly heavy construction to give the required degree of stiffness.

The three main ways to construct a basement are:

In excavations with sloping sides (open excavation)
In excavation with temporary support (shoring and ground anchors)
In excavation supported by a permanent embedded wall constructed in advance of the main excavation. (Diaphragm walls and contiguous piles) Sheet piling may also be used.

The choice of the method depends on the depth of the basement, the soil conditions as well as the proximity to buildings, roads and services.

3. SELECTION OF FOUNDATION SYSTEMS

The type of foundation to be used for a particular building depends on many factors. The merits and demerits of each system need to be considered in conjunction with the various factors. Usually, the soil condition of the site has the most influence on the type of foundation used. If the ground condition does not give any major problem in installation, cost and time constraints would be the next considerations in the selection of the foundation system.

In both private and public projects, developers desire an early completion of their project in order to have an early return of their investments or for early occupation. Therefore, economical design and early completion are their main concerns.

The environmental effects are usually not critical in any projects. Noise, vibration and air pollution are more significant in CBD areas where nuisances caused are intolerable to many important establishments in the surroundings.

A general selection guideline based on soil condition and properties are shown in Appendix 1

In general, factors governing the selection of foundation systems are

(1) ground conditions
(2) types of structure to be supported
(3) location and environment of the structures
(4) availability of materials
(5) obstruction such as low headroom
(6) durability of piles
(7) adjacent buildings
(8) time and
(9) cost constraints.

4. FACTORS AFFECTING THE SELECTION OF FOUNDATIONS:

- **SITE CONDITIONS**

  Site conditions that affect the selection of foundations include the locations and environment of the structures, adjacent buildings, etc. A site condition that has great influence on the selection of foundation type is the presence for any trees, which are close enough to the building for the roots to affect the characteristics of the ground.

  A site in CBD area will have site constraint and the piles use are normally replacement piles so as not to affect the adjacent buildings. Noise, vibration and air pollution are more significant in CBD areas where nuisances caused are intolerable to many important establishments in the surroundings.

- **GROUND CONDITIONS**

  The soil characteristics (e.g. the bearing capacity of the soil) will also affect the choice of foundations.

  The selection of a foundation type to suit given site conditions involves mainly a study of horizontal and vertical variations in soils and rocks, including groundwater, and the determination of the compressibility and bearing capacity of different strata. Permeability of strata can be important where excavation and construction methods influence the selection of foundation types.

A soft bed implies relatively high compressibility and low bearing capacity and a firm bed relatively low compressibility and high bearing capacity. Bearing and settlement characteristics of soft or loose soils can sometimes be improved by geotechnical processes so that they become more like firm beds. Table 1 shows the selection of foundation according to the soil type and other site factors.

Table 1: Choice of foundation

SOIL TYPE AND OTHER SITE FACTORS	FOUNDATION TYPE TO USE	NOTES
1. Rock, hard sound chalk, sands and gravel.	Strip foundation and trench fill	1. Minimum depth for protection against frost heave 450mm for frost-susceptible soils. 2. Beware of swallow holes in chalk. 3. Keep base of the trench above ground water level where possible
2. Uniform firm and stiff clays: • No nearby trees	Strip foundation and trench fill	1. Depth to underside foundation must be at least 1m.
• Where trees are near the building	Concrete piles and ground beams Or Concrete piles and in-situ R.C. floor Or Specially designed trench fill	1. Clay type and tree distance will dictate piling details. 2. Trench fill can be used in low- to medium-shrinkage clay in the perimeter zone of tree root system. 3. Allow for void below floor for expansion of clay if floor is casted in very dry weather.
• Where trees are cut down just before foundation constructed	Concrete piles and ground beams	1. Piles must be long enough to resist clay heave. 2. Top of pile to be sleeved to reduce friction and uplift.
3. Soft clay Soft silty clay Soft sandy clay Soft silty sand	Wide strip footing Or R.C. raft Or Piles	1. Footings must be reinforced. 2. Settlement of footings and raft will occur. 3. Service entries must be flexible. Piles taken down to firmer strata

SOIL TYPE AND OTHER SITE FACTORS	FOUNDATION TYPE TO USE	NOTES
4. Peat	Concrete piles R.C. raft	1. Piles must penetrate to firm strata. 2. If peat layer is shallow, dig it out and use wide strip footings or consolidated fill and raft. 3. If peat layer is thick (3 – 4m) and firm with no firm strata below consider R.C. raft.
5. Filled site	Concrete piles R.C. raft Wide strip Trench fill	1. Piles taken down to underlying firm strata. 2. R.C. raft and reinforced wide strip can be used if the fill was selected and well compacted. 3. Trench fill can be used if the depth of made ground is less than the depth of the trench. Take precautions against combustion, toxic wastes and methane gas

- **STRUCTURAL FACTORS / TYPES OF STRUCTURES TO BE SUPPORTED**

The nature and structure of the building to be supported will affect the choice of foundation. For example, very light air-supported structures need more holding down than support. Some structures are rigid and will crack at the least sign of movement. Some structures impose a continuous load while others are designed with the load concentrated at specific points.

The characteristics of the superstructure, which are relevant to the selection of foundation types, are principally the distribution and magnitudes of loads and the allowable settlement. For example:

i) Tall buildings:
The type of foundations employed for tall buildings (in which column loads may exceed 10^4 kN) include independent reinforced concrete footings, steel grillages and predestals, raft, piles and piers. Independent foundations commonly lead to maximum settlement beneath the centre of the structure, it is desirable to attain as nearly uniform settlement as possible by adjusting the proportions and depths of the foundations. A raft, more particularly when it is of box-form increases the stiffness of the structure as a whole and thus tends to reduce differential settlement.

ii) Spacious Buildings:

Two important factors to be taken into consideration in the design of foundations for spacious buildings are lateral thrust and uplift. Lateral thrust arises from both vertical loads and wind loads and is generally catered for by abutments on rock, raking piles driven to a resistant stratum or by underfloor ties between opposite pairs of abutments. Uplift can be catered for by the means described below for towers, pylons and masts. The superstructure of single storey spacious buildings is commonly relatively light and wind load may become very important.

- **RELATIVE COSTS / COST CONSTRAINTS**

The choice of foundation is also affected by the economic factor. Not only must be the foundation design be shown to be the best technical solution, it must also offer the best economic solution when related to the contractor's expertise.

For example, trench fill foundations, although more concrete is used, can be less expensive than normal strip foundations because of savings in labour and the timber which would have been needed in shuttering if traditional trench support methods had been used. Modern hydraulically operated steel trench shuttering can alter this cost balance but only if the equipment is readily available and known to the men on site.

- **WORKING CONDITIONS**

The working conditions include weather conditions, ground conditions (mention earlier), etc.

Any work below ground level must take into account the effect the condition of the ground can have on the method employed. A foundation system that can only be carried out with the assistance of heavy equipment is not a good choice on wet site of low bearing capacity where vehicles and transporters can get bogged down. A type of foundation system where this could apply is driven piling; and yet in some wet conditions, say during winter months, pile driving can continue at times when the construction of strip foundations, with its open trenches, would have to stop.

5. CAUSES OF DEFECTS IN THE FOUNDATIONS

Ground movements, which are independent of stresses imposed by the foundation loading, can occur. Examples of these are movements due to swelling and shrinkage of the soil under varying moisture and temperature conditions, frost heave, hillside creep, mining and regional subsidence, and settlements due to shock and vibration.

It is necessary to take precautions against the effects of these movements on the structure. It can be done either by deepening the depth of the foundations to place the them on ground that is not susceptible to movement, or if this is not economically possible, to adopt special forms of construction which will allow appreciable movement without damaging the structure.

In the design and construction of the foundations, there are many factors, which have to be considered in order to prevent future defects in the structures. If these factors are not taken into consideration in the design and construction of the foundations, defects may occur. Here are some of the examples of the causes of the defects in the foundations.

a. SHRINKAGE OF CLAYS

One of the causes of defects in the foundations is the shrinkage of clay. Shrinkage of clay may be due to seasonal moisture changes or to absorption of water by plants. Both horizontal and vertical shrinkage may be experienced. Cracking and shrinkage of structure arising from seasonal effects is usually cumulative over a period of years since the cracks close only partly during the wet season. Since any clay having a moisture content exceeding the shrinkage limit will shrink to some extent on drying, the term shrinkable is a relative one.

However, for the purpose of accessing the potential shrinkage of clays beneath foundations, the change in moisture content should cover the estimated or observed seasonal range of moisture content in situ and the volume change should be expressed preferably s a percentage of the volume at the lower moisture content.

Remedial measures may necessitate underpinning an entire structure. Preventive measures essentially involve founding at a level below which seasonal shrinkage is negligible.

Evidence that distress in a building is due to differential movement of foundations is generally afforded by cracks visible both internally and externally, which extend downwards to the foundations and which become wider upwards.

b. SWELLING OF CLAYS

Fundamentally, shrinkage and swelling of clays are related and are generally responsible for distress in structures. However, swelling appears to be the dominant factor under certain conditions with some clay. Distress is experiences in particularly in light buildings. High capacity for shrinkage and expansion is generally associated with clays having high montmorillonite content and the degree of movement depends on the proportion of the mineral present and on the kind and amount of exchangeable bases.

c. CLIMATIC FACTORS

There are, however, two further factors, which greatly increase the problem of swell and shrinkage and which may necessitate special methods of foundation design. The first factor is the effect of a wide difference in seasonal rainfall and soil temperature conditions.

The physical chemistry of swelling is not fully understood, but in some regions expansion appears to be due primarily to infiltration of moisture into the ground during the wet season. The development of the cracks is progressive from season to season and the width of gaps is often several centimetres. In the hot climates, swelling may due primarily to thermo-osmotic transfer of moisture towards the zone of lower temperature beneath the centre of a building

d. EFFECTS OF VEGETATION

The second factor, which aggravates the swell and shrinkage problem, is the effect of the roots of vegetation. The roots of the trees and shrubs can extract considerable quantities of water from the soil.

The problems caused by the root systems are twofold. First, there is the problem of heave of foundations on sites which have recently been cleared of trees and hedges, and the second there is the problem if settlement in existing structures sited close to growing trees or caused by subsequent planting of trees and shrubs close to them.

Where shrinkage of clay is associated with trees, the remedy is to cut down the immature trees or to underpin the structure. Mature trees can be left standing, as they are unlikely to cause serious settlement. Preventive measures for new buildings are to construct beyond 15-30m radius of fast growing trees and to carry foundation 1-3m below ground *level.* More specific recommendations depend on the local conditions such as the species and age of trees etc

e. GROUND MOVEMENT DUE TO WATER SEEPAGE AND SURFACE EROSION

Troubles with water seepage and surface erosion normally occur in sandy soils. Internal erosion can result from ground water seeping into fractured sewers or culverts carrying with it fine soil particles. The consequent loss of ground from beneath foundations may lead to collapse of structures. It is liable to occur in mining subsidence areas where sewers and water mains may be broken. It can also occur as a result of careless technique in deep excavation below the water table when the soil particles are carried into the excavation by flowing ground water.

Surface erosion may take place as a result of loss of material in strong winds or erosion by flowing water. Fine sands, silts, and dry peat are liable to the erosion by wind. Surface erosion by flowing water may be severe if structures are sited in the bottom of the valleys, especially in regions of tropical rainstorms. Normal foundation of inadequate depths may be inadequate for erosion by floodwaters, however, this can be avoided by providing adequate drainage and paving or other forms of surface protection, of paths taken by periodical discharges of flood water.

f. GROUND MOVEMENTS DUE TO VIBRATIONS

It has been found that high frequency in vibrating plant is more effective than low frequency for consolidating soils and concrete. The same effects of consolidating and subsidence can occur if foundations on sands or sandy gravel (or soils themselves) are subjected to vibrations from external source. Damages to existing structures resulting from the pile driving vibrations are not uncommon, and it is usual to take precautions against these effects when considering schemes for piled foundations in sands adjacent to existing structures.

g. GROUND MOVEMENT DUE TO HILLSIDE CREEP

Certain natural hillside slopes are liable to long-term movement, which usually takes the form of a mass of soil on a relatively shallow surface of sliding or slipping downhill. Normally, the weight of structures erected on the slope is insignificant in relation to the mass of the slipping ground. Consequently, foundation loading has little or no influence on the factor of safety against slipping. However, other construction in operations may have a serious effect on the slope stability, e.g. the terracing of the slope may change the state of stress both in cut and fill areas, or the natural drainage of subsoil water may be intercepted by retaining walls.

There is little that can be done to restore the stability of hillside slopes in clays since the masses of earth involved are so large, and regarding operations on the scale required are usually impossible. The best thing is to avoid building in such areas, or if this cannot be done, to design the foundations so that the whole structure will be move as one unit with provision for correcting the level as required. Suitable methods of construction should be adopted.

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