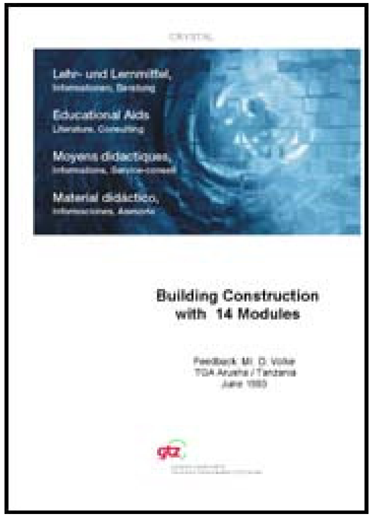


Printable version

Export document as HTML file Help

Export document as PDF file

Building Construction with 14 Modules (TCA; 1983; 618 pages)

5. FOUNDATIONS

REFERENCES:

1. Jack Stroud Foster
MITCHELL'S BUILDING CONSTRUCTION
"Structure and Fabric" Part 1 + 2

2. R. Chudley

"Construction technology"
Volume 1,3,4

3. R. L. Fullerton
"Building Construction in warm climates"
Volume 1,3

4. W. G. Nash
"Brickwork 2"

A FOUNDATION is the BASE on which a building rests and its purpose is to safely transfer the load of a building to a suitable subsoil.

Apart from solid rocks all soils are compressible in varying degrees, so that under the building load foundations will - to some extent - move in a downward direction. This is known as SETTLEMENT and is due mainly to the consolidation of the soil particles.

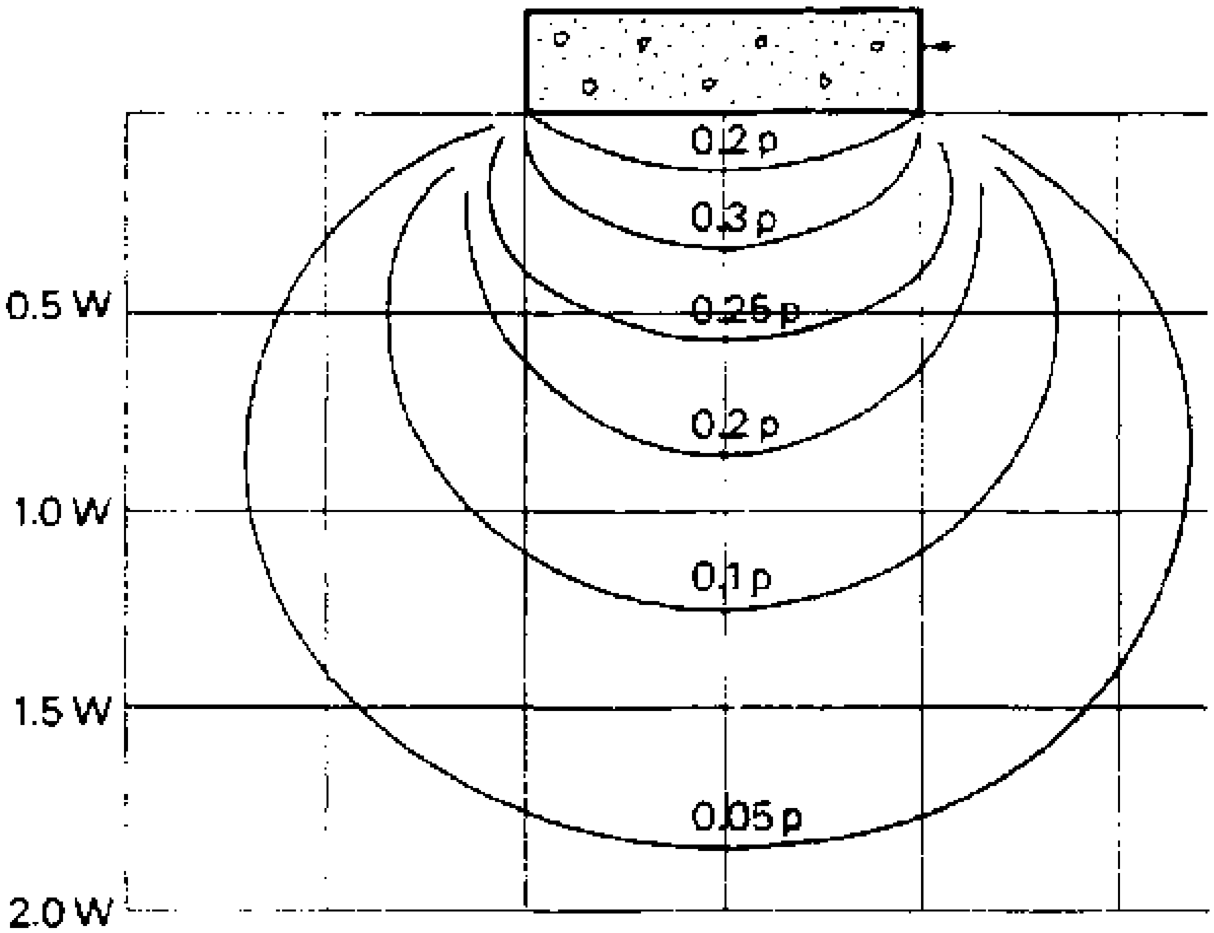
Excessive settlement will result from overloading the soil to such an extent that the loaded area of soil SHEARS past the surrounding soil in what is known as PLASTIC FAILURE of the soil.

In addition, settlement may be caused by a reduction in the MOISTURE CONTENT of certain soils which shring on drying out or by a general movement of the earth due to various causes.

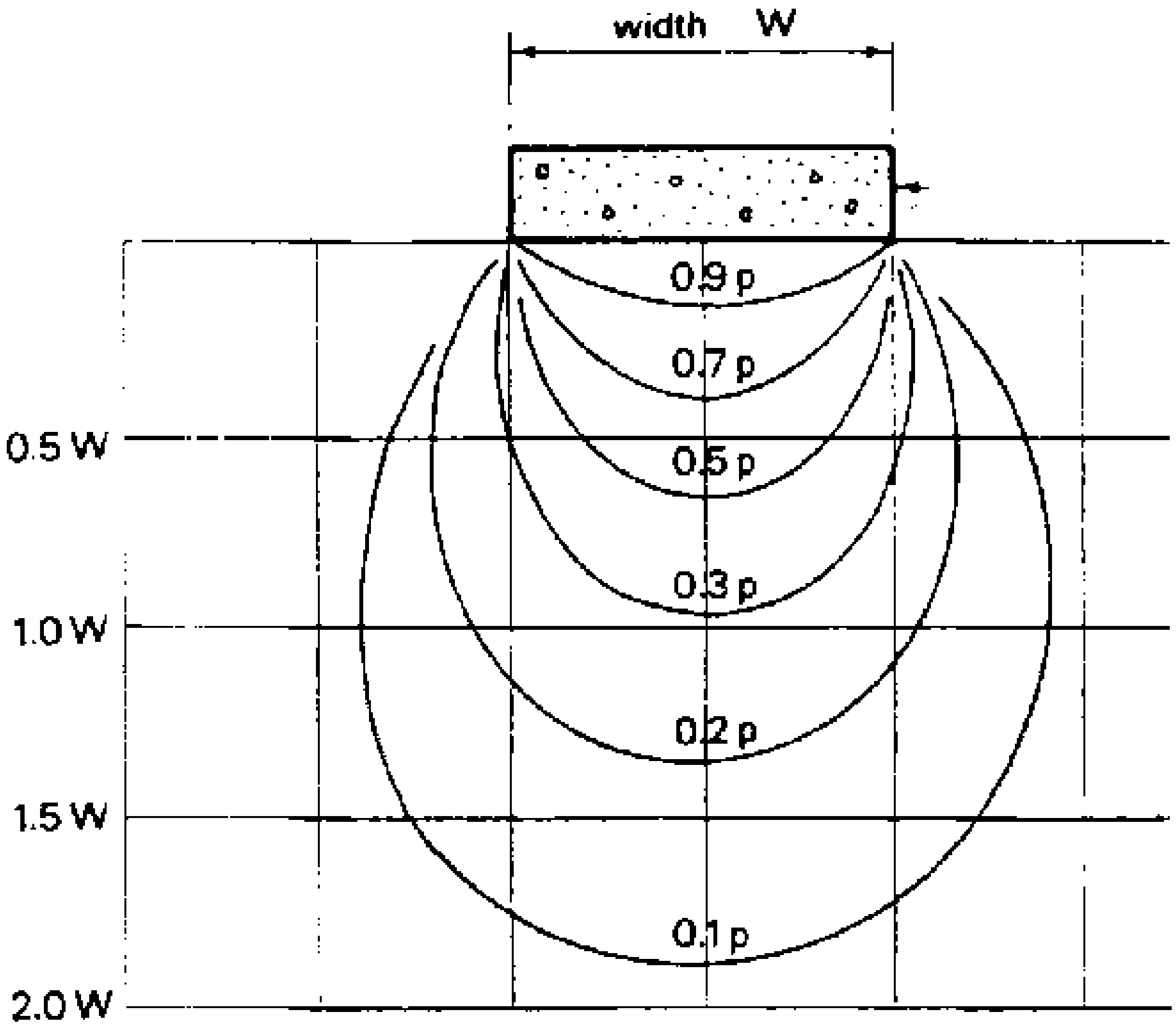
Provided the settlement is UNIFORM over the whole area of the building and is not excessive, the movement does little damage. If the amount of settlement VARIES at different points under the building (known as relative or differential settlement) distortion of the structure will occur which, if too great, may result in damages or possible failure of the structure.

Such differential movements must be kept within limits which avoid harmful distortion. These limits will vary with the type of structure and its ability safely to withstand differential movements.

5.1 SOIL INVESTIGATIONS



Pressure bulb for shear stress



Pressure bulb for vertical stress

5.1.1 SITE EXPLORATION

Tall, wide-span or heavily loaded buildings exert greater pressures on the soil resulting in greater settlements, and lead to greater possibility of shear failure of the soil than do small-scale buildings. To

overcome this, types of foundations may be required which affect the soil and to considerable depths. In such cases the various soil characteristics take on greater significance and a closer consideration of the soil and its properties is required than is often necessary for small-scale buildings.

This may require an extensive examination of the subsoils involving boring to considerable depths and carrying out field and laboratory tests on the soils.

An extensive investigation of the soil is not usually necessary in the case of small-scale buildings on soils of adequate strength, where (by means of simple stripe or pad foundations near the surface) the pressure on the soil can be kept well within the known SAFE BEARING CAPACITY of a particular soil type. What is required is a simple method of establishing the TYP OF SOIL to a sufficient depth and a means of determining its bearing capacity.

The bearing capacity can be found from standard tables and the soil type can be established by exposing the soil to view for the shallow depths by digging holes- known as TRIAL HOLES (or PITS) - and using simple visual and tactile means of identification.

5.1.1.1 Trial holes

- **Should not be further apart than about 30 m and not less than one per 900 m2 of site.**

- **Should be large enough to accommodate a man (say 1.20 m x 1.00 m or larger if timbering is required.**

- **Depth: Usually up to 3.00 m, it rarely exceeds 6.00 m.**

- **The soil should be inspected at all levels as soon as possible after excavation.**

- As a check on the possible existence of a very weak layer of soil below the trial hole, a probe of about 1 m may be made by means of a hand anger. This can also be used when the presence of ground water makes the completion of the trial hole difficult.

- The soils excavated and exposed in the trial holes can be identified within broad types by simple field tests.

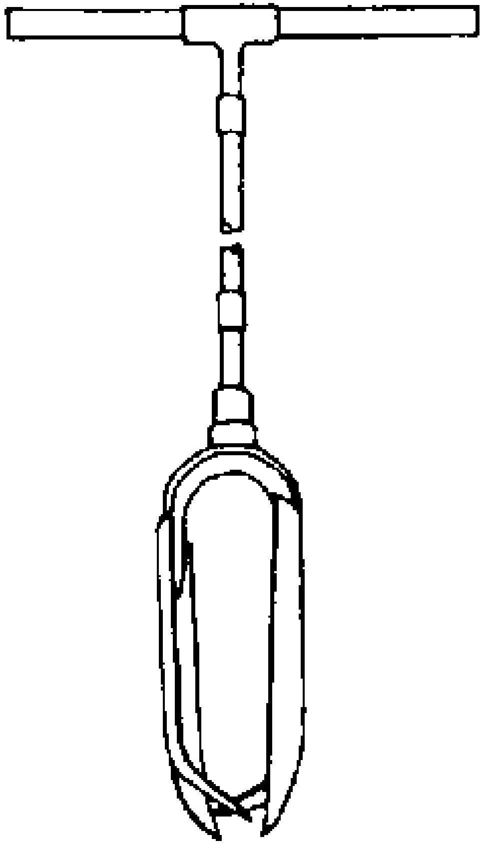
- Foundations are invariably formed in concrete. The durability can be affected by sulphate salts in the soil, particularly in the ground water.

The nature of any groundwater should be checked and where sulphate salts are known to be present precautions must be taken (e.g. by use of suitable cement).

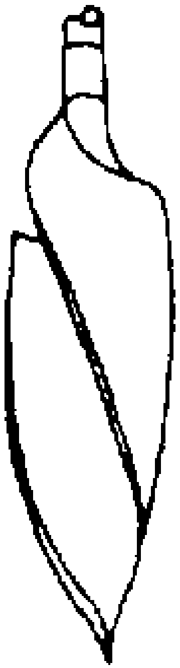
- A trial hole also gives to the contractor valuable informations affecting labour costs (ease of excavation) and amount of timbering, underground water (pumping, dewatering).

- Excavations should not be carried out too close to the proposed foundations, they may be a source of weakness, and the should be filled and consolidated ofertwards.

A Post -hole augers

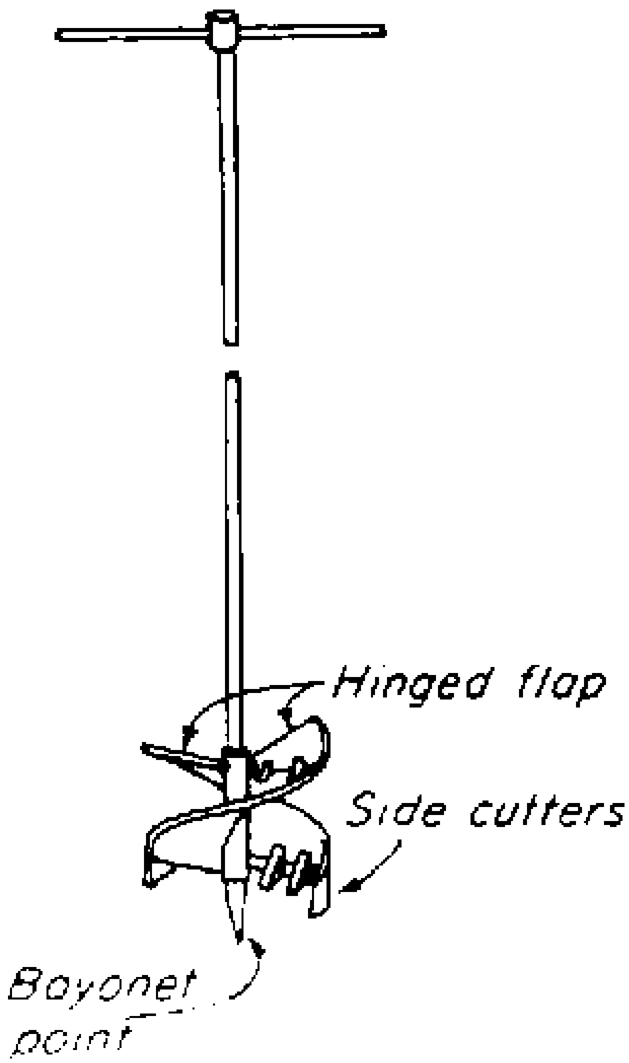


Clay

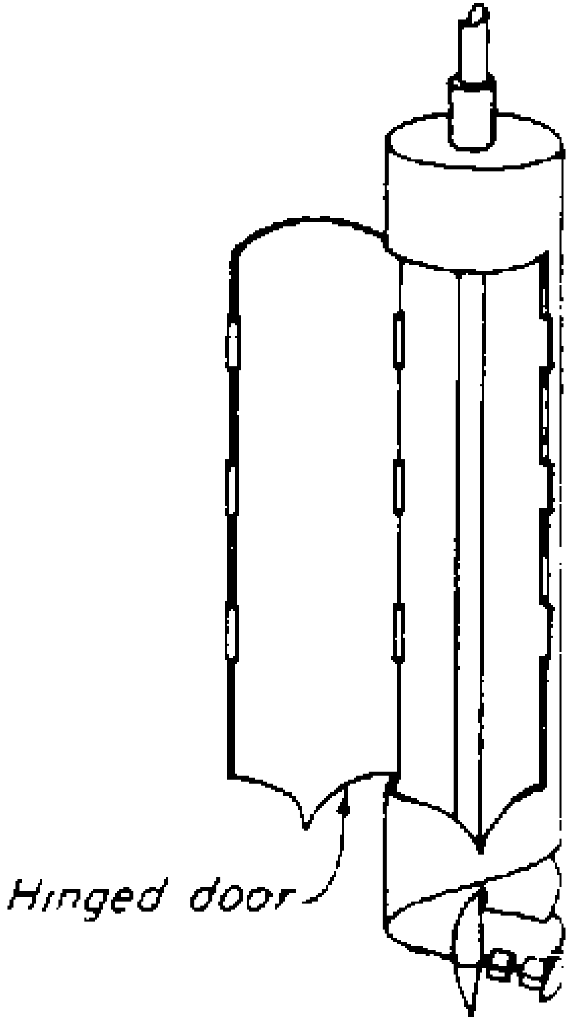


Gravel

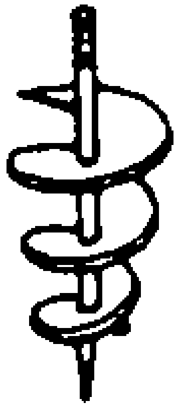
B Stiff soil borer



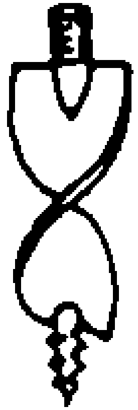
C Cylinder attachment



D Special points

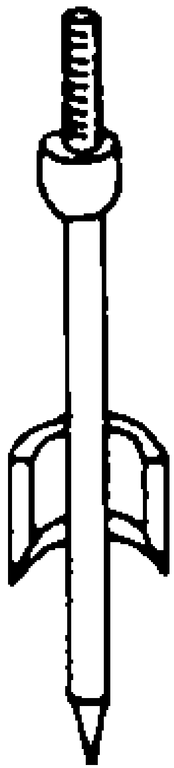


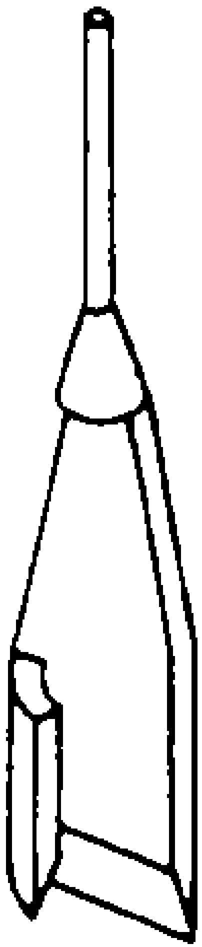
Sand



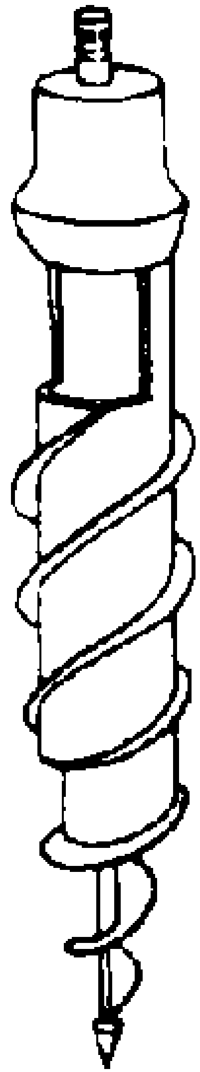
Soft rock

E Chisel bits

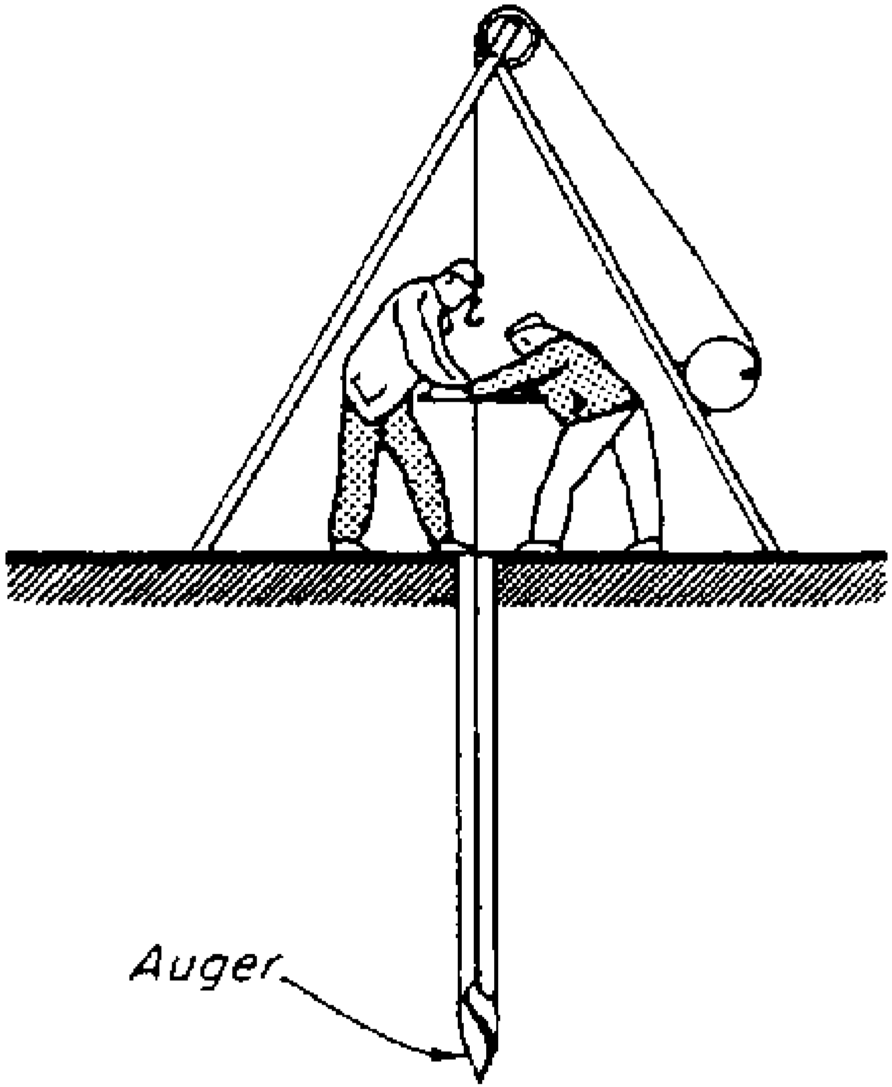




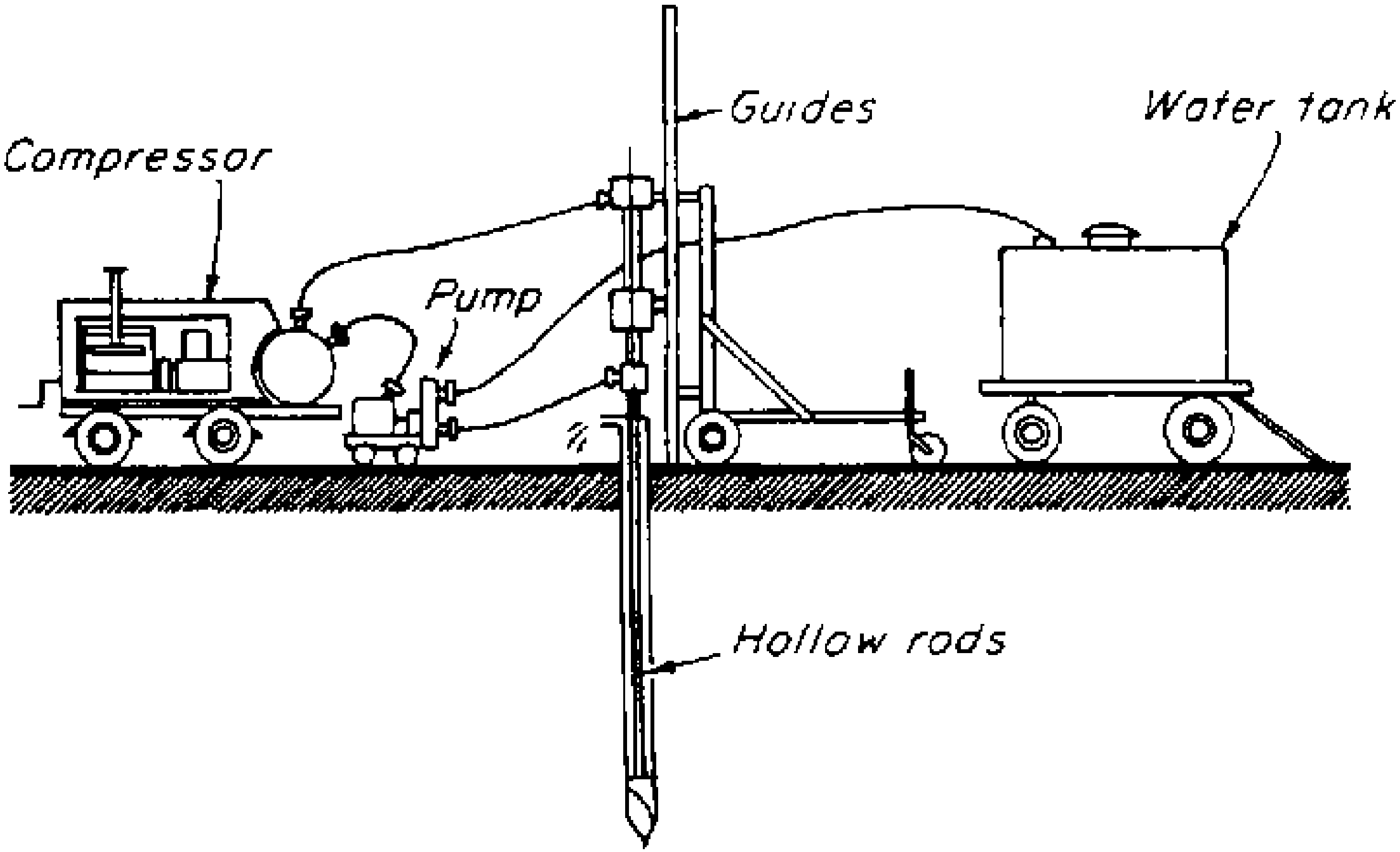
F Sludge cylinder



G Boring tackle



H Wash borer



5.1.1.2 Bore holes

- Are fomed as required on site for the purpose of raising samples of soil for examination.

- Tools:

a) post-hole anger (simple) having arod with crosshead, it is capable of forming holes in clay or soft soils up to about 6 m deep and ø 150 mm or more.

b) for deeper borings or where rock is expected, either the percussion or the rotary method is employed.

A hole is formed by percussion method with a chipsel-shaped steel bit, screwed to a rod; this is driven vertically in to the ground, lifted, partly rotated and again driven. It has to be repeated rapidly until the desired depth is obtained.

Samples of the soil are obtained during the process.

The rotary method is usually applied to rock formations. A small hole (ø 50 mm) is drilled with a rotating bit (having diamonds set round the cutting edge) jointed to a hollow rod. The cylindrical core of rock thus formed within the tool is broken off at intervals and removed for inspection and testing.

5.1.1.3 Sampling

The form of samples depends upon the

- nature of the soil

and whether it was

- disturbed or
- undisturbed.

e.g. an undisturbed sample of rock can be obtained if such stratum has been exposed in a trial pit. It has to be dressed to a cube (at least 75 mm each side).

When it can be tested for

- compression
- permeability etc.

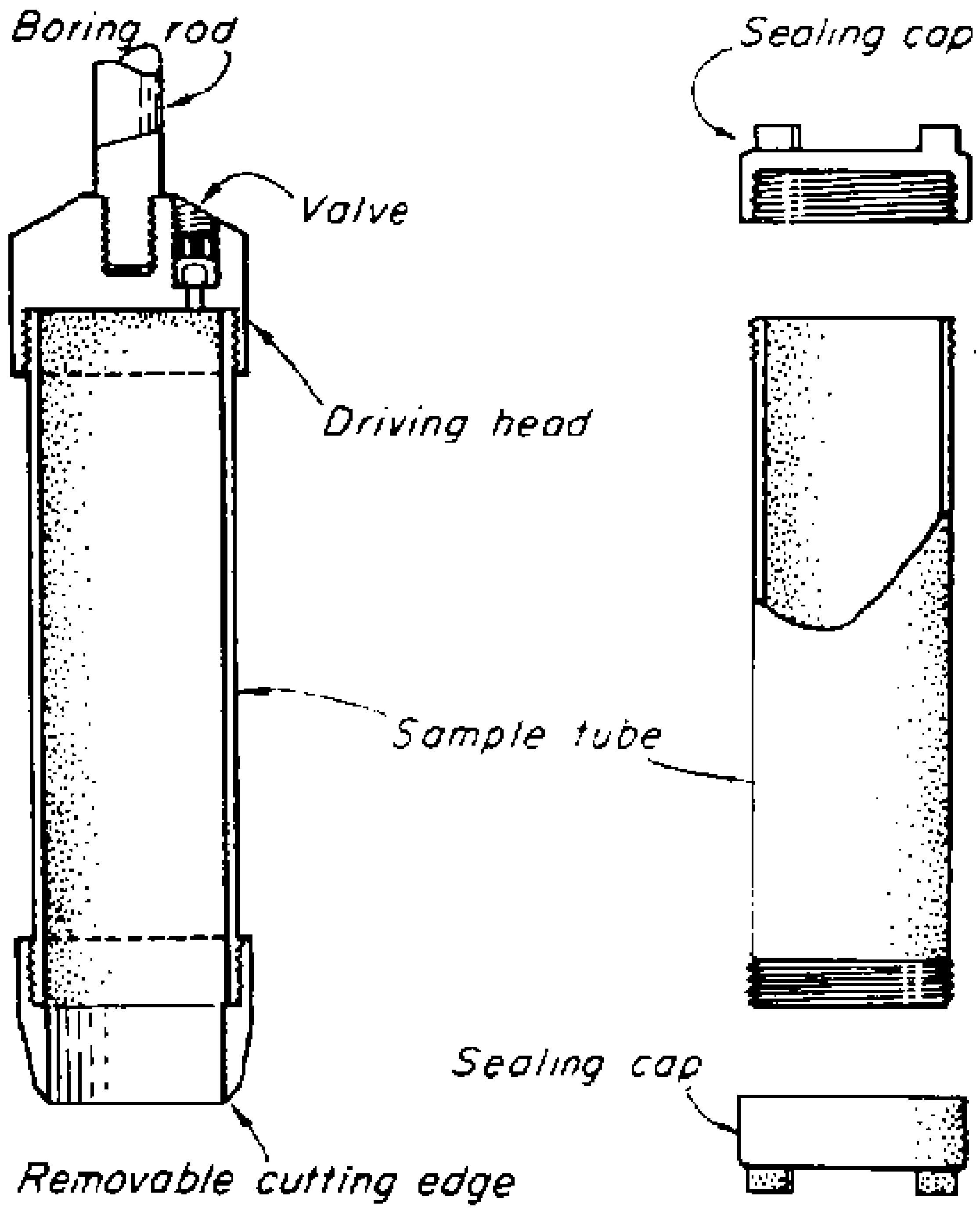
and slides prepared from it can be examined.

An undisturbed sample of clay from a trial hole is cut by a knife in the form of a cube, coated with paraffin wax to prevent loss of moisture, placed in an airtight container and labelled ready for testing.

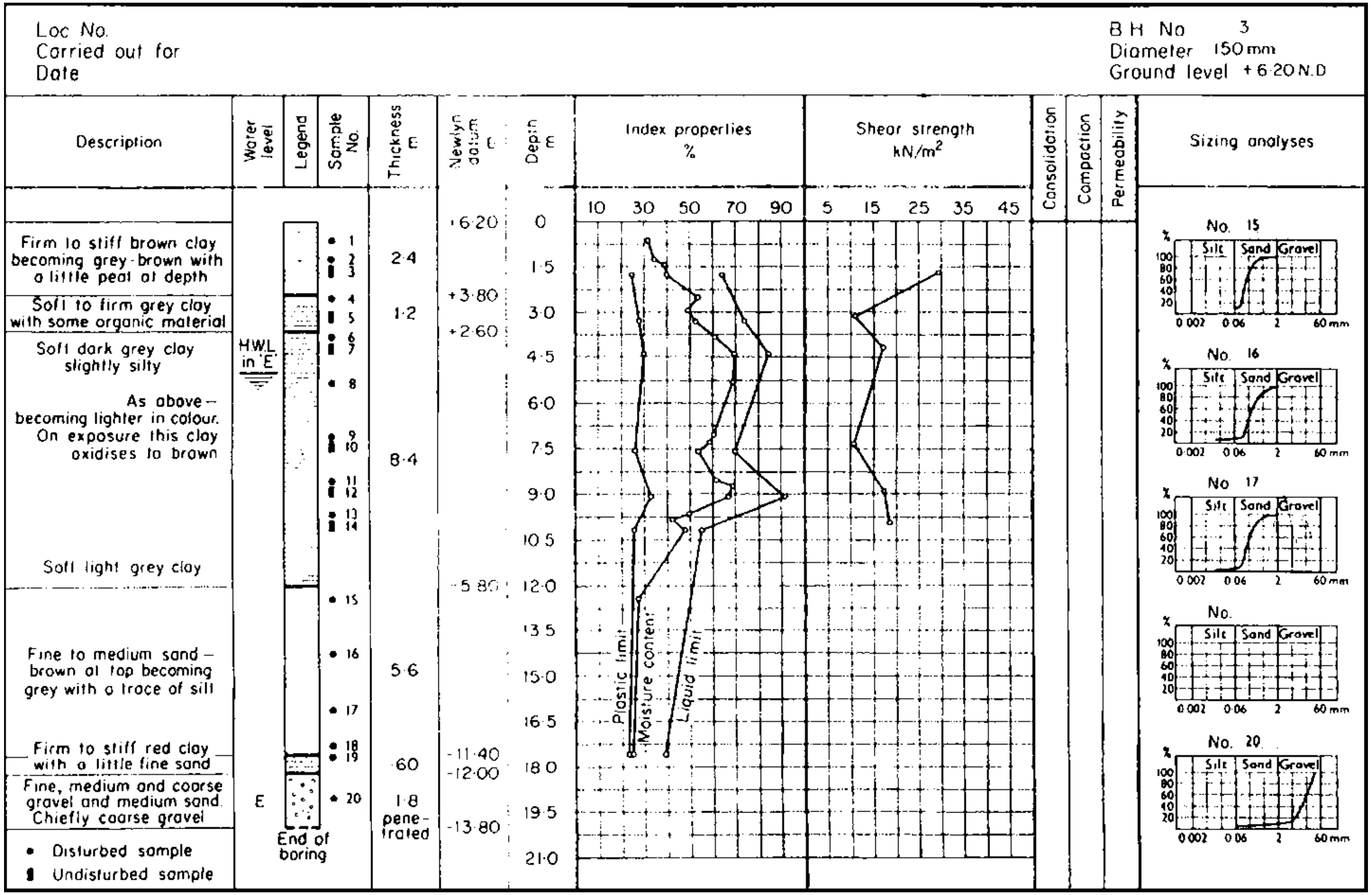
Such a sample can also be obtained from an exposed clay stratum by using a tool called

- 'sampler' or 'spoon'

There are several types of samplers (e.g. a metal tube ø 100 - 150 mm, 1 m - 1,5 m long; having an open end with a cutting edge and at the opposite closed end there is an air valve; as the sampler is driven down it gradually fills with clay (air excaping through the valve) it is withdrawn when full and the sample is removed.


Boring rod
Valve
Driving head
Sample tube
Removable cutting edge
Sealing cap
Sealing cap

Disturbed samples of soils are obtained during the actual boring operation. The sampler is attached to the boring rod in the place of the bit, forced down into the loosened soil and withdrawn when full.



BOREHOLE RECORD

The soil cores are carefully removed from the sampler and placed in a box (about 1,5 m long, divided into compartments) in correct sequence and numbered in their proper order.

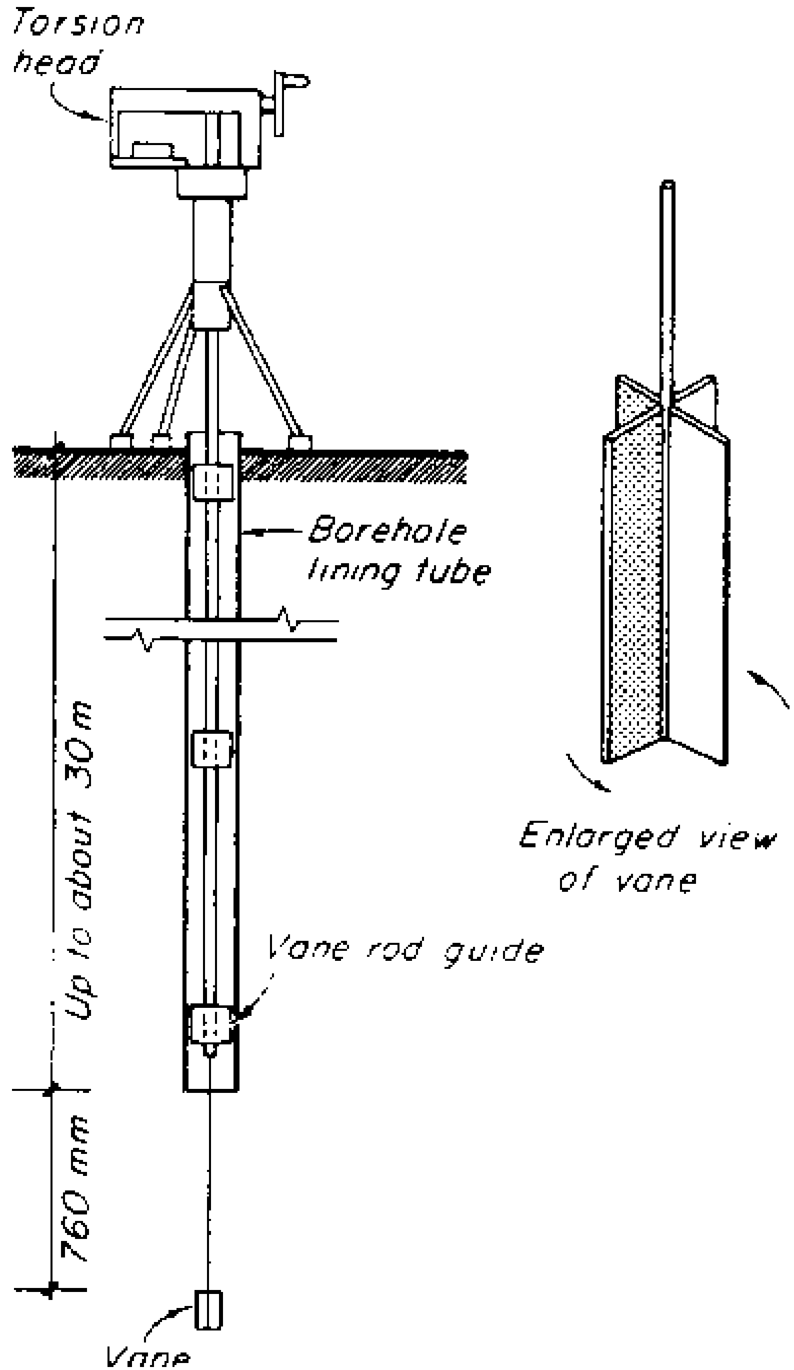
When laid end-to-end according to depth they reproduce a section showing the nature and thickness of each stratum.

Small specimens for laboratory tests are taken from the cores as required. These should be placed in an airtight container until needed.

5.1.1.4 Tests

After having examined the samples carefully and the characteristics of the various soils noted and classified, a complete record is made, including a dimensional sketch of the section showing the thickness and various strata.

In situ soil tests


Torsion head
Borehole lining tube
Up to about 30 m
760 mm
Vane rod guide
Vane
Enlarged view of vane

A Vane test

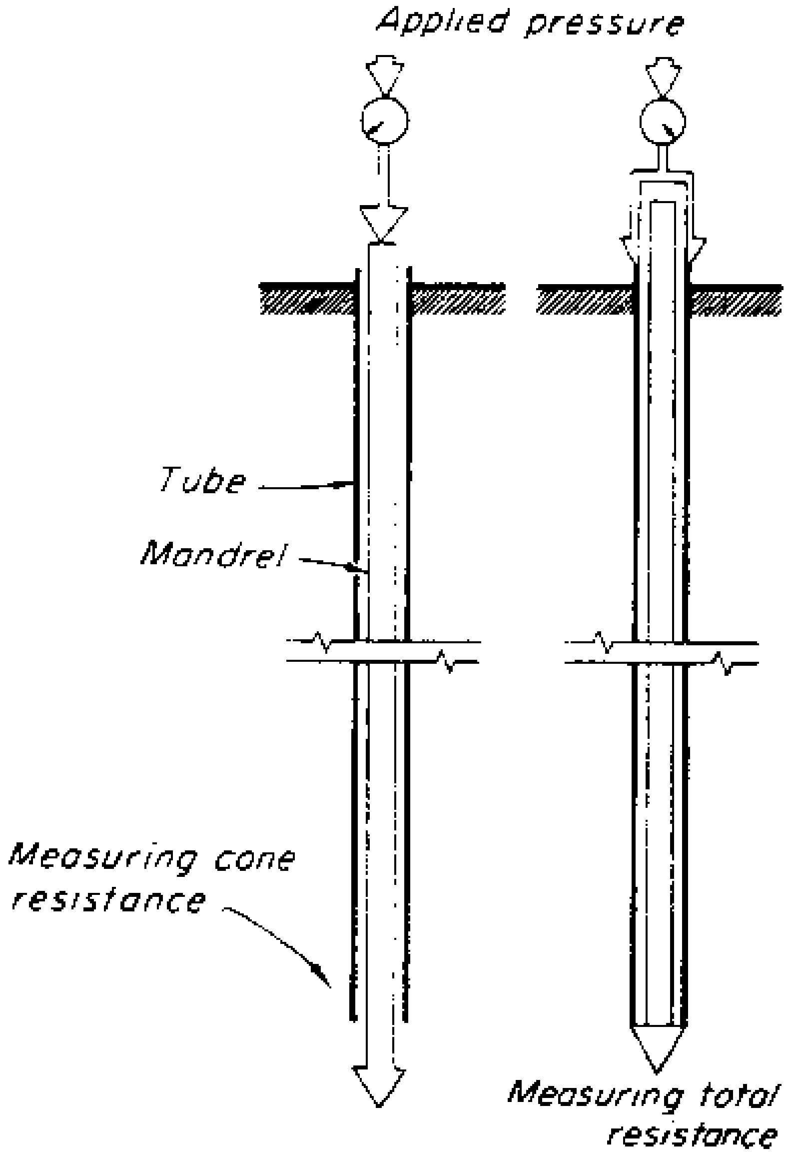
Two tests are most important to the foundation designer:

1) consolidation test
2) shear test.

1) Consolidation test is usually applied to clay soils.

The weight of the Building tends to consolidate the soil by squeezing out the water between the particles -and so producing settlement of the building.

Test: The soil specimen is placed in a metal Cylinder between two porous stone discs. Pressure is applied and increased by stages, the amount and rate are noted at each stage, a time settlement curve is plotted. Result: Probable amount of settlement.



B Cone penetrometer test

2) The load of a building sets up compression and shear stresses in the soil. The soil tends to squeeze out from under the load.

The shear stresses are the forces tending to produce this sliding movement between adjacent portions of soil (clay., normally not gravel) The safe load which can be supported by a soil depends to a large extent upon its shear resistance.

Test: A metal box is used (100 mm2 by about 75 mm deep). Two portions (upper and lower halves) are welded to one side of the top half as a projecting arm to which is fastened a length of wire fixed to a scale pan. The bottom half is clamped to the bench top and the wire is passed over the pulley, clamped at the edge of the bench, suspending the pan. The box is filled completely with clay specimen and weights are placed on the pan until the upper half begins to slide over the lower - as the clay shears through at this level.

The total weight producing this, divided by the internal area of the box gives the shear strength of the soil.

5.1.1.5 Load or bearing test

This test is applied at the proposed level of the foundations (not at ground level!!). There are several forms of equipment used for this test, two will be described below:

1) Consists of a level concrete raft (say 1,5m2; 30 cm thick) formed at foundation level. It serves as the loading table;

2) a hole is dug at foundation level to receive a square or circular steel sole plate of known area (say 1 m2) bedded level on a cushion of sand; This supports centrally a steel tube or spindle (say 1,2 m high) having a cross-head forming the base of the loading platform (say 2 m2). The whole is prevented from tilting by guys or other means, which must be arranged not to restrict the downward movement of the platform. The weight of the apparatus must be known.

TESTS

Loading: (same for (1) and (2)

- the table is loaded carefully and uniformly (bars of pig-iron- each of equal weight or bricks - the average weight of twelve being taken as the unit - may be used.)

- the load is applied in increase (say 204 bricks at a time) and at least two hours must elapse between the time one increment has been completed and the next started.

- Fine readings are taken with a dumpy level (with the staff at the centre and at each corner of the table top) immediately before and after each loading.

- The mean settlement is obtained. A record is kept of the readings and a load/mean - settlement curve is plotted.

- The amount of settlement after each increment - loading will depend upon the character of the soil, but if the bearing capacity is satisfactory it will only amount to a few mm.

- When the 'yield point' of the soil has been reached, as indicated when there is an appreciable in crease in settlement after the last increment, this increment is removed from the table and the readings again taken after an interval of three or four days.

If no further settlement has taken place, half the total load on the table (together with the weight of the apparatus) divided by the area of the sole plate is taken as the safe bearing value of the soil.

Total load table

$\frac{\text{Total load table}}{2}$: area of sole plate = safe bearing capacity of the soil.

5.1.2 SOILS AND SOIL CHARACTERISTICS

The topmost layer of sil at ground level is an unsuitable material on which to found.

- **It has been weathered,**
- **is relatively loose**
- **contains decayed vegetable matter**
- **is soft and excessively compressible**

It is known as:

- **Topsoil or vegetable soil (thickness varies from about 15 - 30 cm).**

Below this lies the

- **subsoil, from which the topsoil has developed and which consists of solid particles of varying shape and size devised from the weathering of solid rock.**

  The spaces between are filled with -water and - to some extent - air.

It is to this subsoil that the word 'soil' refers when used in relation to foundations.

5.1.2.1 Rocks and soils

A broad classification, comprising five groups is:

A broad classification, comprising five groups is:

1) rocks
2) cohesive soils
3) non-cohesive soils
4) peat
5) made ground.

The table below shows how these are classified and distinguished.

Group	Types of rocks and soils	max. safe - bearing capacity (MN/m2)
I Rocks	Ingeous rocks in sound condition	10
	Massively - bedded lime -stone and hard sandstones	4
	Slates	3
	Hard shales, softs and stones	2
	Hard clay shales	1
	Hard solid rock	0,64
	Thinly-bedded limestones and sandstones	To be determined after inspection
	Heavily shattered rocks	
II Cohesive Soils	very stiff boulder clays and hard clays with a shaly structure	0.4 - 0.6

	structure	
	stiff clays and sandy clays	0.2 - 0.4
	firm clays and sandy clays	0.1 - 0.2
	soft clays and sandy clays and silts	0.05- 0.1
	very soft clays and silts	0.05- nil
III non-cohesive soils	compact well-graded sands and gravel-sands	0.4-0.6
	loose well-graded sands and gravel sands	0.2-0.4
	compact uniform sands	0.2-0.4
	loose uniform sands	0.1-0.2
IV	Reat	To be determined after investigate
V	Made ground	To be determined after investigate

These embrace igneons rocks (which include granits) up to heavily shattered rocks

I Rocks

II Cohesive soils

These are soils, the particles of which stick together, such as clays. The degree of cohesion depends upon the size and shape of the particles and the water content. These clays are classified as: very stiff boulder clays up to very soft clays and silts (see fig.)

- Clay soils are subject to shrinkage and cracking in hot dry weather, followed by expansion in wet weather

    - The change in volume according to their water content.

- Adequate precontions have to be taken!

Such movement may cause considerable damages to buildings erected on subsoils of very soft clay.

- As the movement decreases with the depth below ground level it is important that foundations should be relatively deep.

    - under external walls at least 90 cm
    - or of pile and beam type
    - or of raft construction

In addition to having this undesirable property of expanding and contracting, clay soils have a relatively low shear strength and a small safe load bearing capacity.

III Non-cohesive soils include gravel and sands.

The strength or bearing capacity depends upon

- the grading,
- the packing and

- the average size of the particles.

In general: The better the grading (as distinct from uniformity) -the tighter the packing and: the larger the grains, the bigger the load bearing capacity.

These soils are divided into:

- compact well graded sands and gravel sands up to

- loose unform sands (see table)

Non cohesive soils vary considerably in their value as building sites, e.g. A deep bed of dry compact gravel provides an excellent support. A subsoil of loose, uniform sand (if not confined by sheet piling) may develop considerable settlement when loaded.

The presence of groundwater affects the bearing capacity of soils. Thus, pumping operations may loosen a compact bed of gravel (and reduce the bearing capacity).

IV Peat is decayed vegetable matter, black or dark brown in colour. It is highly compressible and quite unsuited to receive foundations (even those of light strictures).

If used for foundations - it must be supported on piles which are driven down to an underlying firm stratum.

V Made ground or fill

This is excavated soil or house refuse, which has been deposited in a depression.

Such sides have to be avoided

Such sides have to be avoided

- house refuse is in sanitary
- injurious conicals may be in industrial waste
- even excavated soil, such as quarry waste well compacted in thin layers beats a risk of unequal settlement. (foundations to be carried down to the original stratum or be supported by piles.)

SOIL CHARACTERISTICS AND BEARING CAPACITIES

Subsoil types	*Condition of subsoil*	*Means of Field Identification*	*Particle size range*	*Bearing capacity*	*Minimum width of strip foundations in mm for total load in kN/m of loadbearing wall of not more than*					
					20	30	40	50	60	70
Gravel	Compact	Require pick for excavation. SO mm peg hard to drive more than about 100 mm Clean sands break down completely when dry. Particles are visible to naked eye and gritty to fingers. Some dry strength indicates presence of clay	Larger than 2 mm	>600	250	300	400	500	600	650
Sand			0.06 to 2 mm	>300						

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	Smaller than 0.002 mm	150-300	250	300	400	500	600	650
Sandy clay			See Sand and Clay	150-300						
Clay	Firm	Can be excavated with graft or spade Can be moulded with strong finger pressure	See above	75-150	300	350	450	600	750	850
Sandy clay			See Sand and Clay	75-150						
Gravel	Loose	Can be excavated with a spade A 50 mm peg can be easily driven	See above	<200						
Sand			See above	<100						
Silty sand			See Silt and	May need to	400	600	For loadings of more than 300			

			Sand	be assessed by test				kN/m run on these types of soil: the necessary foundations do not fall within the provisions of Regulation D7 from which these figures are taken. Pad foundations generally and surface rafts are designed using the bearing capacities for soils given in this Table. *Note* See note on facing page regarding the use of values given in this table for bearing capacities of sands and gravels.
Clayey sand			See Clay and	ditto				

			Sand				
Silt	Soft	Readily excavated Easily moulded in the 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	0-002 to 0-06 mm	75			
Clay			See above	75			
Sandy clay			See Sand and Clay	May need to be assessed by test	450	650	
Silty clay			See Silt and Clay	ditto			
Silt	Very soft		See above	<75			
Clay		A natural sample of clay exudes	See	<75			

		between the fingers when squeezed in fist	above						
Sandy clay			See Sand and Clay	May need to be assessed by test	600	850			
Silty clay			See Silt and 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				

5.1.2.2 Stresses and pressures

Cohesive soils present serious problems when giving consideration to foundation choice and design. The two major conditions to be considered are:

Shearing stress: the maximum stress under a typical foundation carrying a uniformly distributed load will occur on a semi - circle whose radius is equal to half the width of the foundation and the isoshear line value will be equal to about one-third the applied pressure - see Fig. The magnitude of this maximum pressure should not exceed the shearing resistance value of the soil.

Vertical pressure: this acts within the mass of the soil upon which the unacceptable settlement of the structure. Vertical pressures can be represented on a drawing by connecting together points which have structure. Vertical pressures can be represented on a drawing by connecting together points which have the same value forming what are termed pressure bulbs. Most pressure bulbs are plotted up to a value

of 0.2 of the pressure per unit area which is considered to be the limit of pressure which should influence settlement of the structure. Typical pressure bulbs are shown in the fig.

A comparison of these typical pressure bulbs will show that generally vertical pressure decreases with depth, the 0.2 value will occur at a lower level under strip foundations than under rafts, isolated bases and cases in close proximity to one another which form combined pressure bulbs. The pressure bulbs illustrated in the fig. are based on the soil being homogeneous throughout the depth under consideration. As in reality this is not always the case it is important that soil investigation is carried out at least to the depth of the theoretical pressure bulb.

Great care must be taken where an underlying strata of highly compressible soil is encountered to ensure that these are not over stressed if cut by the anticipated pressure bulb.

Contact pressure

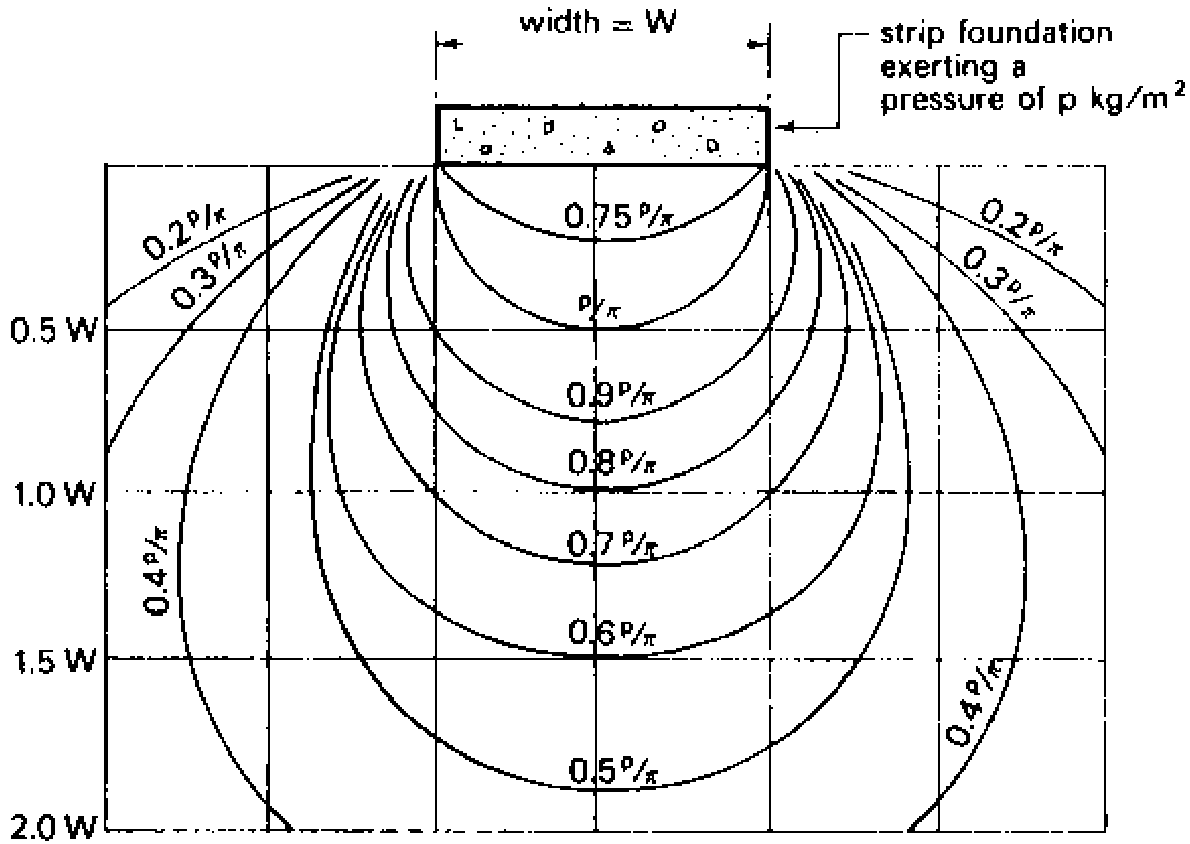
It is very often incorrectly assumed that a foundation which is uniformly loaded will result in a uniform contact pressure under the foundation. This would only be true if the foundation was completely flexible such as the bases to a pin jointed frame. The actual contact pressure under a foundation will be governed by the nature of the soil and the rigidity of the foundation, and since in practice most large structures have a rigid foundation the contact pressure distribution is not uniform. In cohesive soils there is a tendency for high stresses to occur at the edges which is usually reduced slightly by the yielding of the clay soil. Non-cohesive soils give rise to a parabolic contact pressure distribution with increasing edge pressures at the depth below ground level of the foundation increases. When selecting the basic foundation format consideration must be given to the concentration of the major loads over the position where the theoretical contact pressures are at a minimum to obtain a blanced distribution of contact pressure - see fig.

Plastic failure

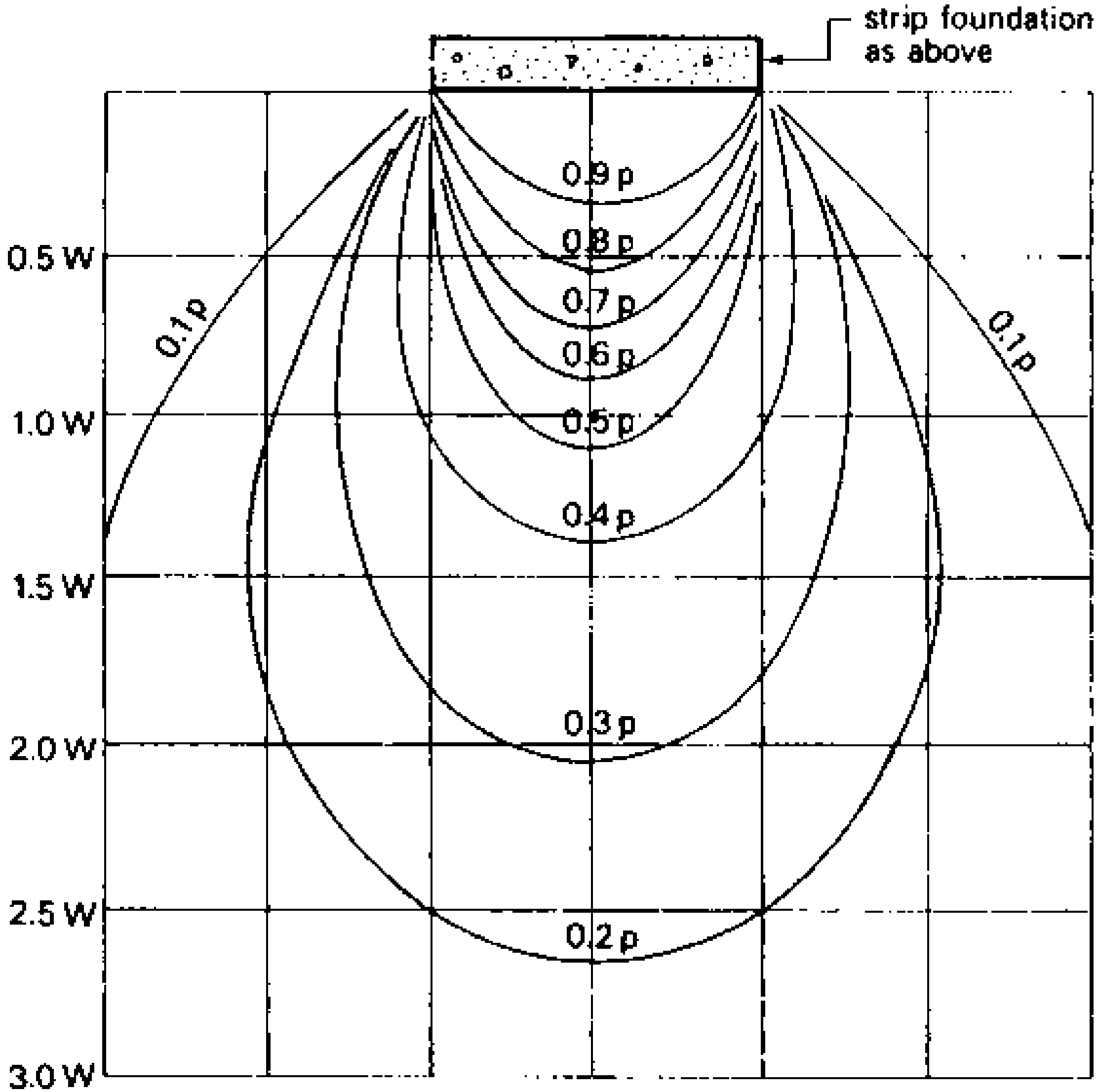
This is a form of failure which can occur in cohesive soils if the ultimate bearing capacity of the soil is reached or exceeded. As the load on a foundation is increased the stresses within the soil also increases until all resistance to settlement has been overcome. Plastic failure, which can be related to the shear strength of the soil, occurs when the lateral pressure being exerted by the wedge of relatively undisturbed soil immediately below the foundation causes a plastic shear failure to develop resulting in a heaving of the soil at the sides of the foundation moving along a slip circle or plane. In practice this movement tends to occur on one side of the building, causing it to tilt and settle -see fig. Plastic failure is likely to happen when the pressure applied by the foundation is approximately six times the shear strength of the soil.

TYPICAL PRESSURE BULBS

STRIP FOUNDATIONS

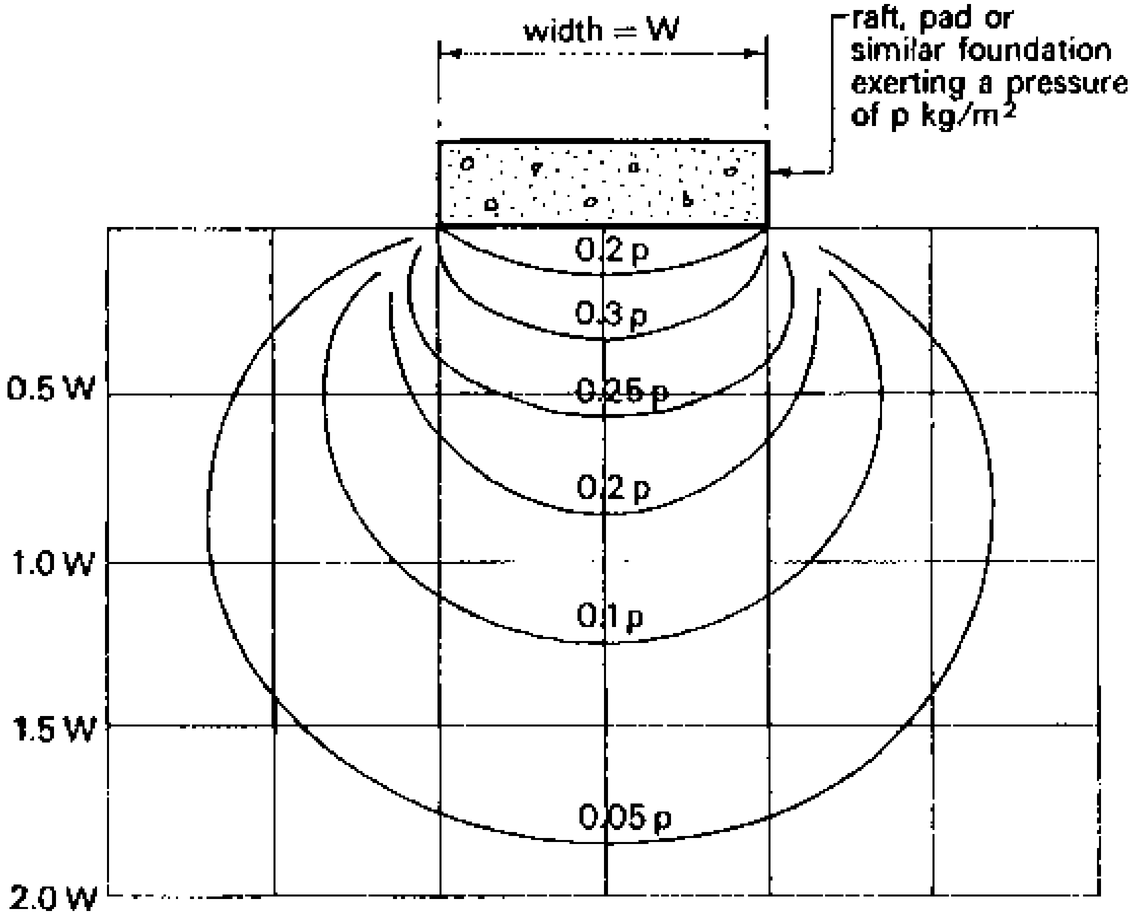


Pressure bulb for shear stress

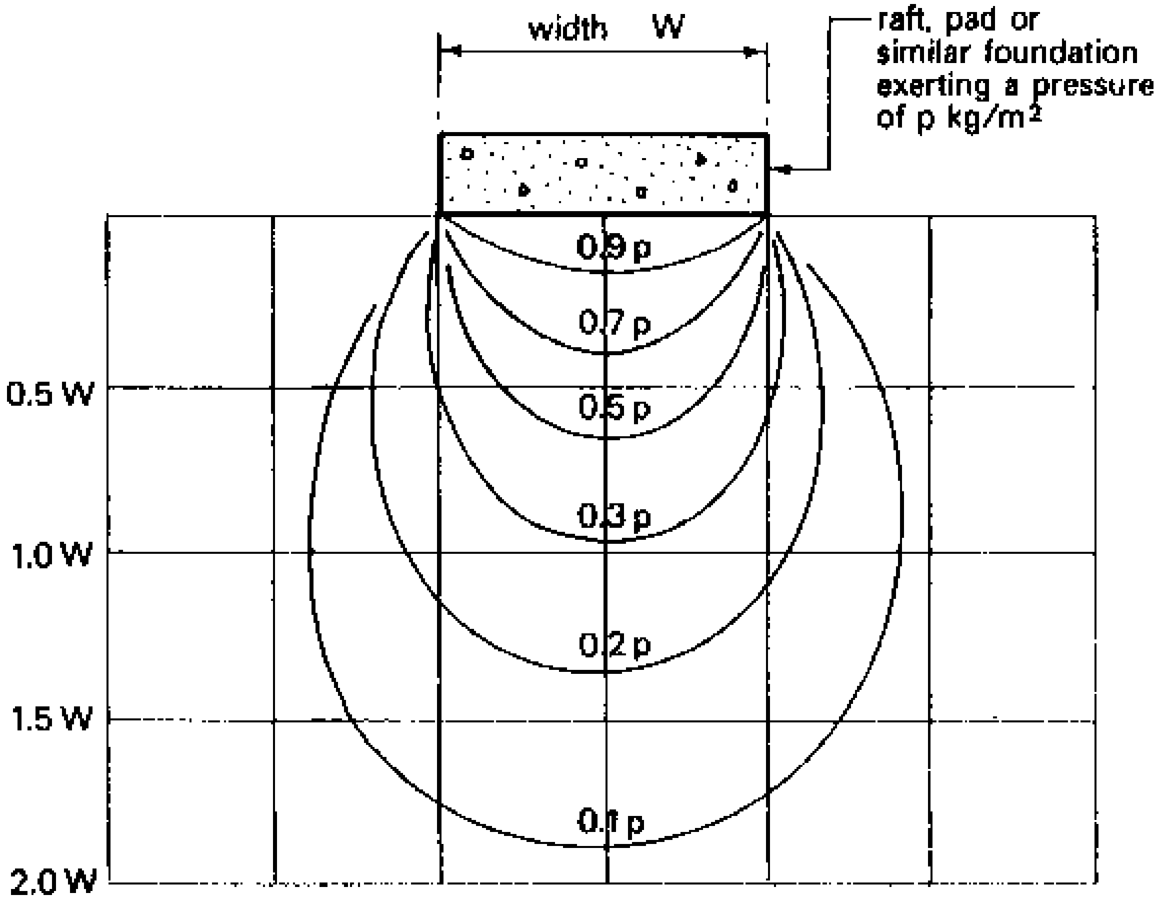


Pressure bulb for vertical stress

RAFT OR SIMILAR FOUNDATIONS

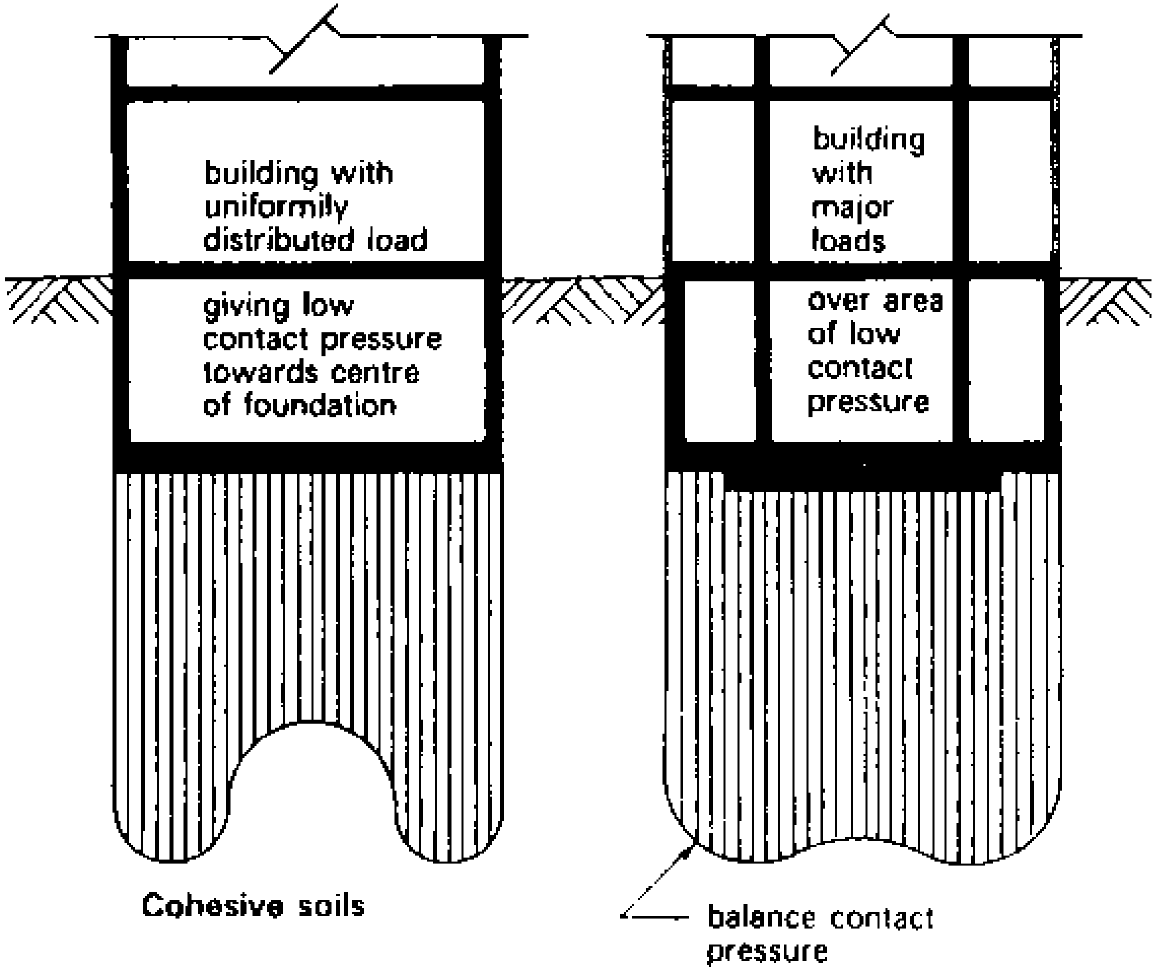


Pressure bulb for shear stress

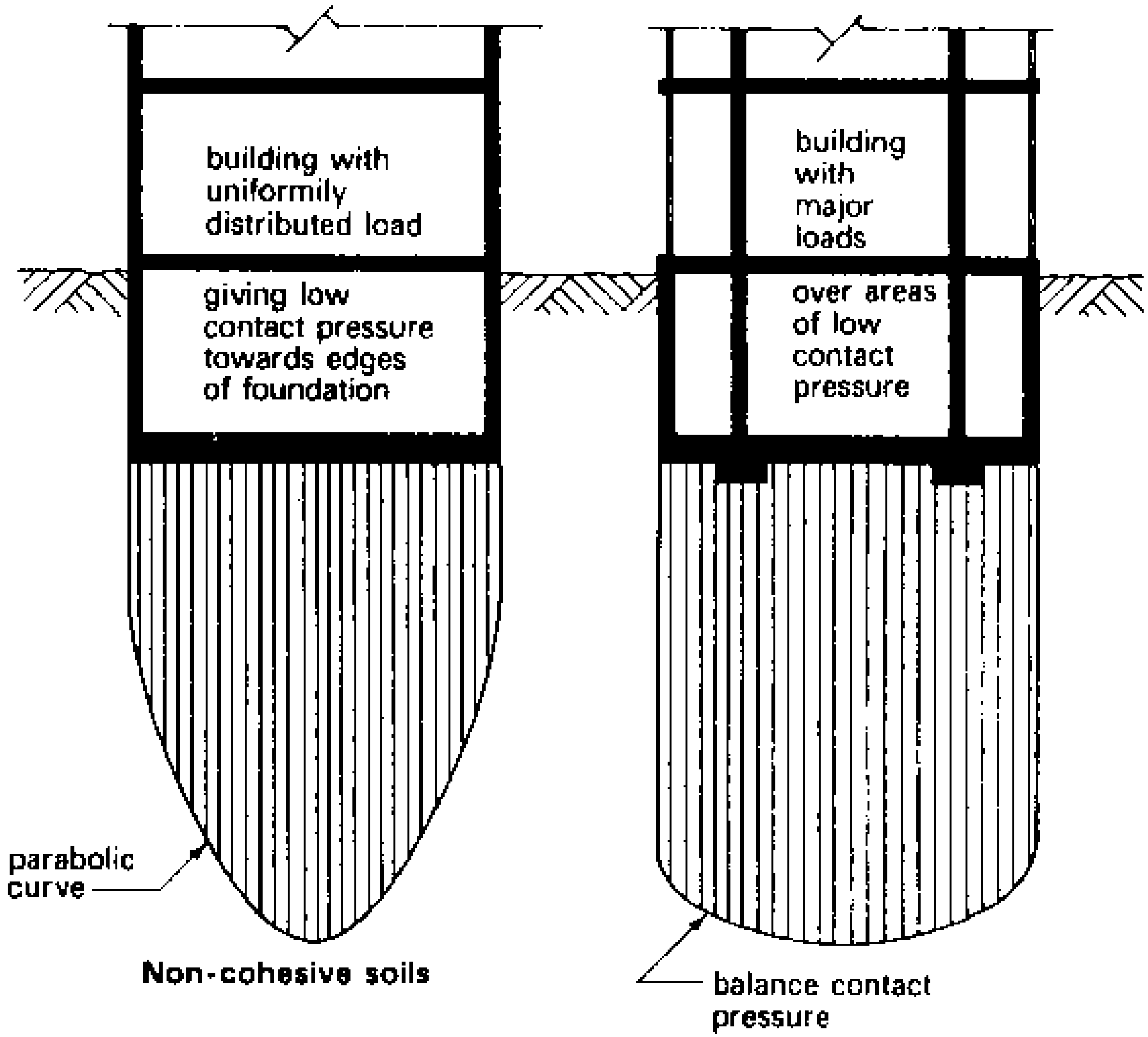


Pressure bulb for vertical stress

TYPICAL CONTACT PRESSURES



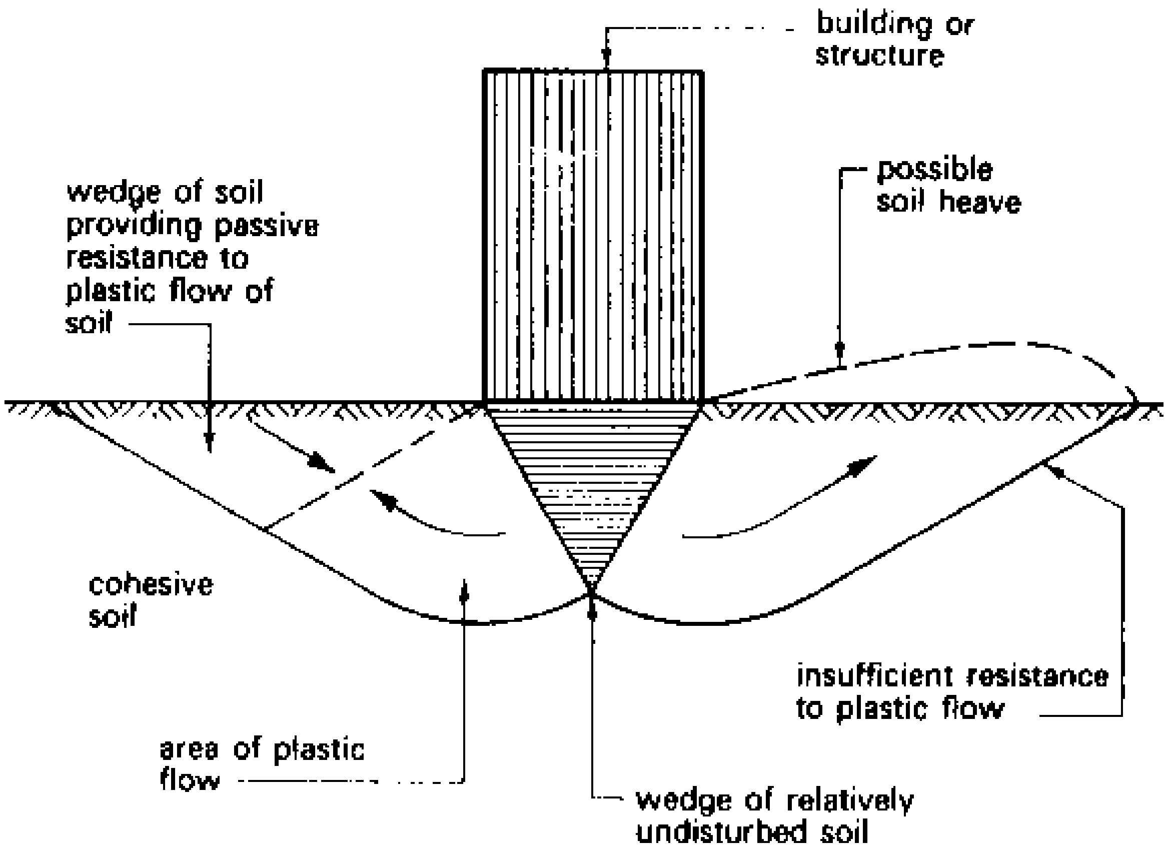
Cohesive soils



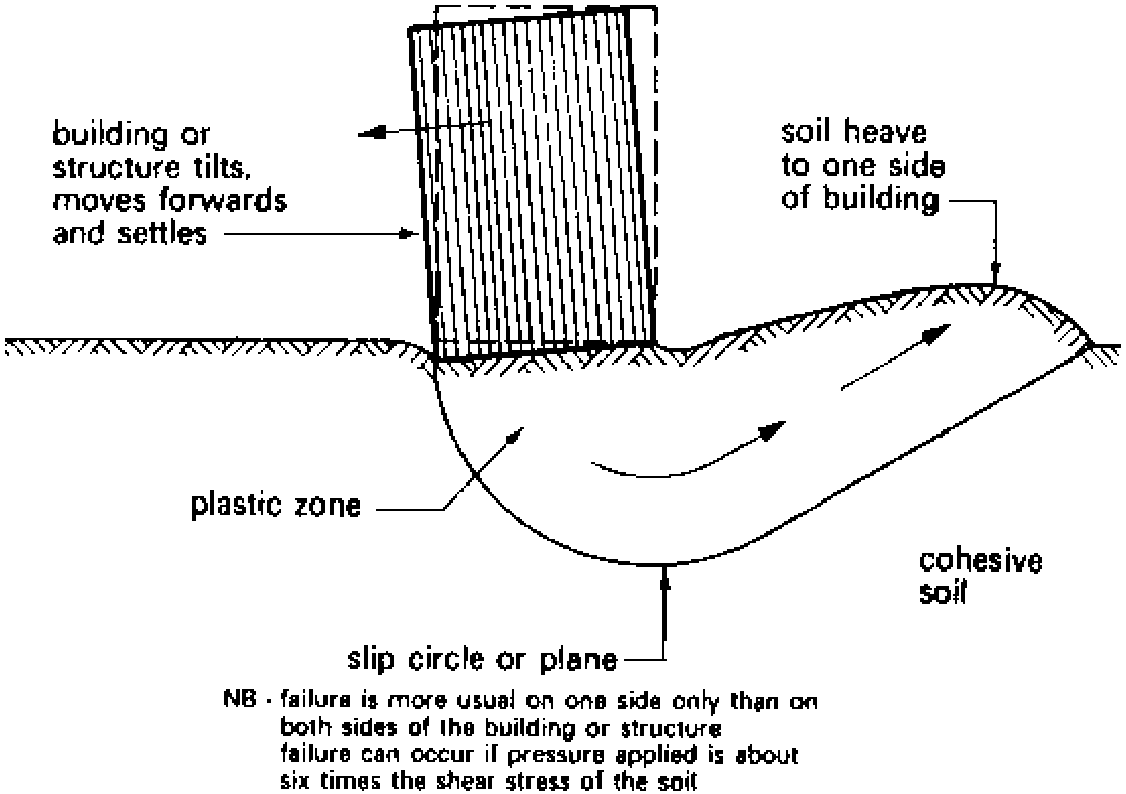
Non-cohesive soils

PLASTIC FAILURE of foundations

Plastic failure theory



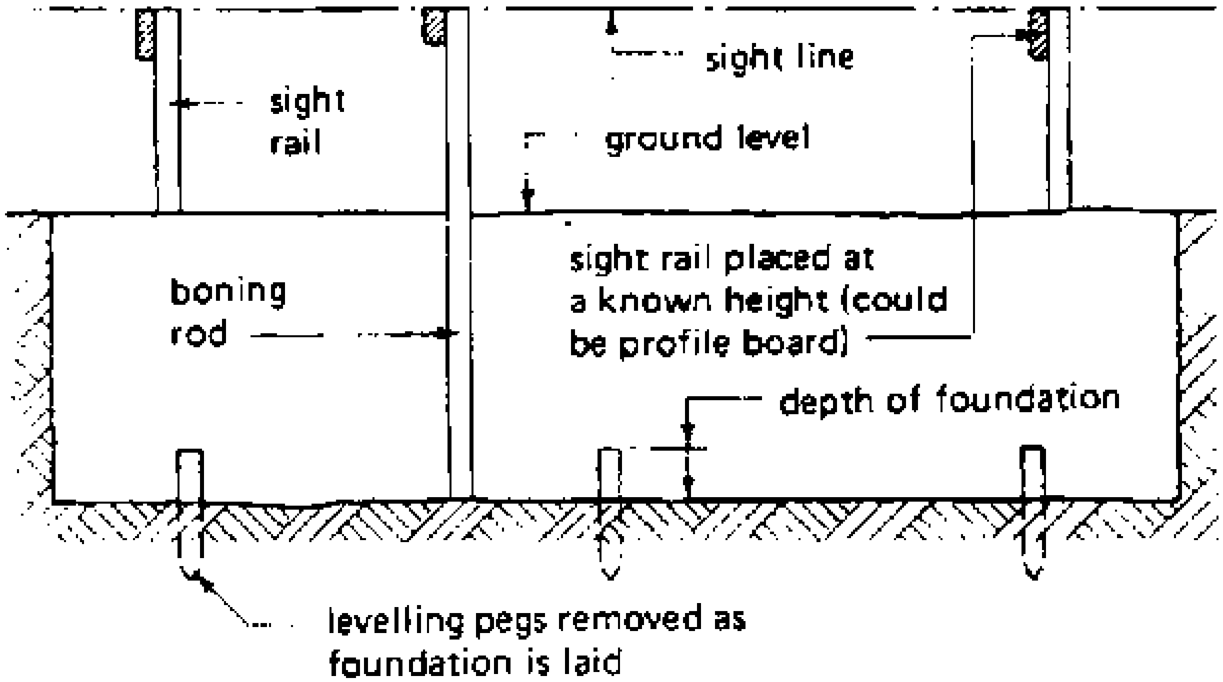
STABLE CONDITIONS

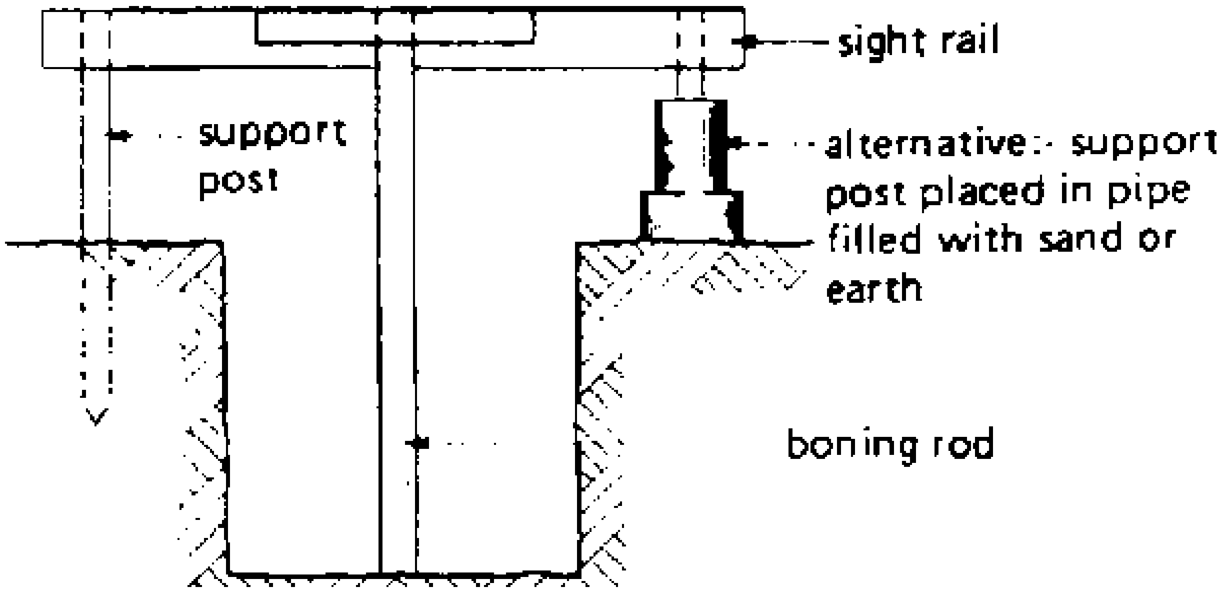


UNSTABLE CONDITIONS

5.2 EXCAVATIONS AND TIMBERING

Trench excavations

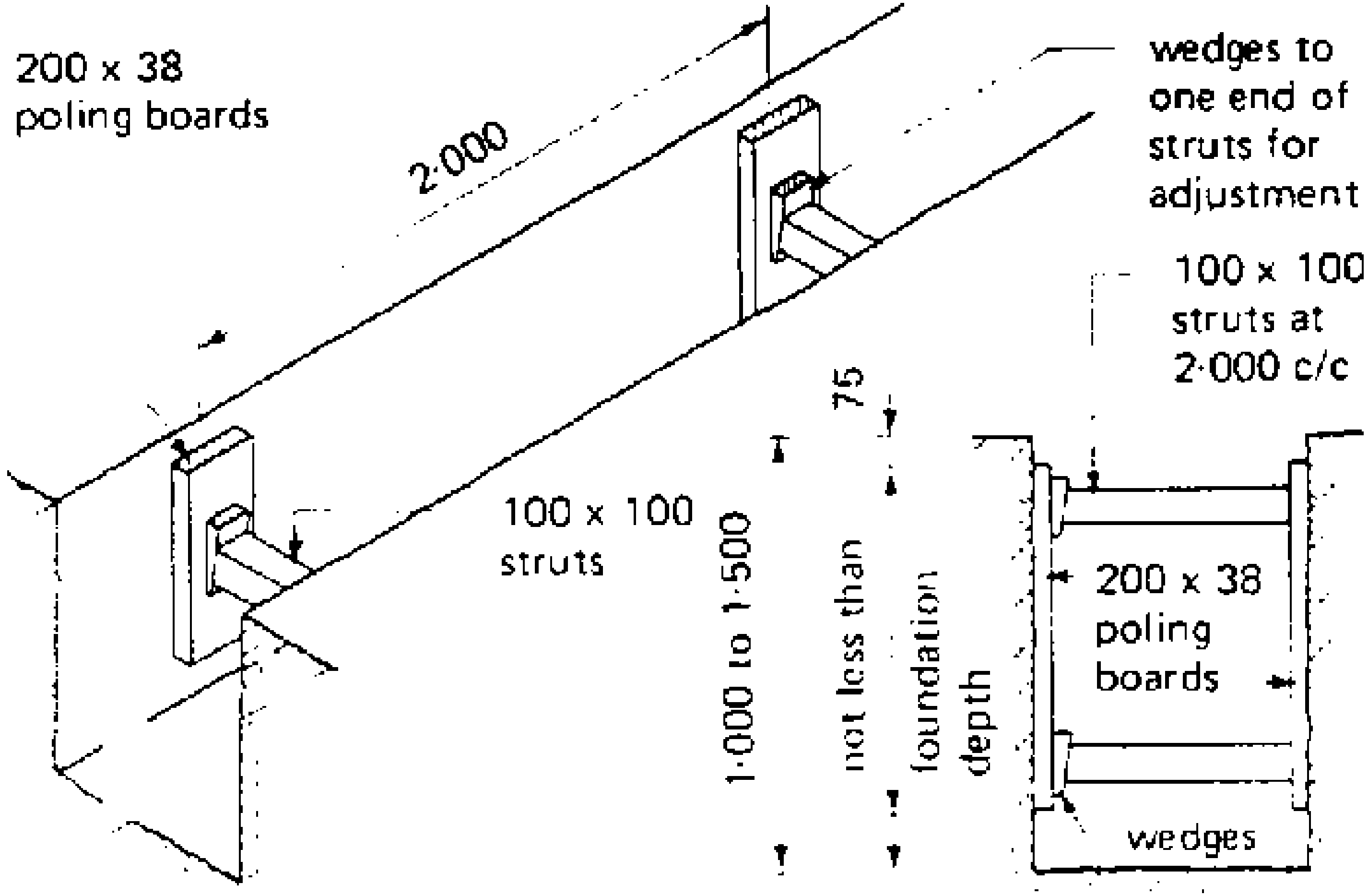

sight line
sight rail
ground level
boning rod
sight rail placed at a known height (could be profile board)
depth of foundation
levelling pegs removed as foundation is laid


sight rail
support post
alternative: support post placed in pipe filled with sand or earth
boning rod

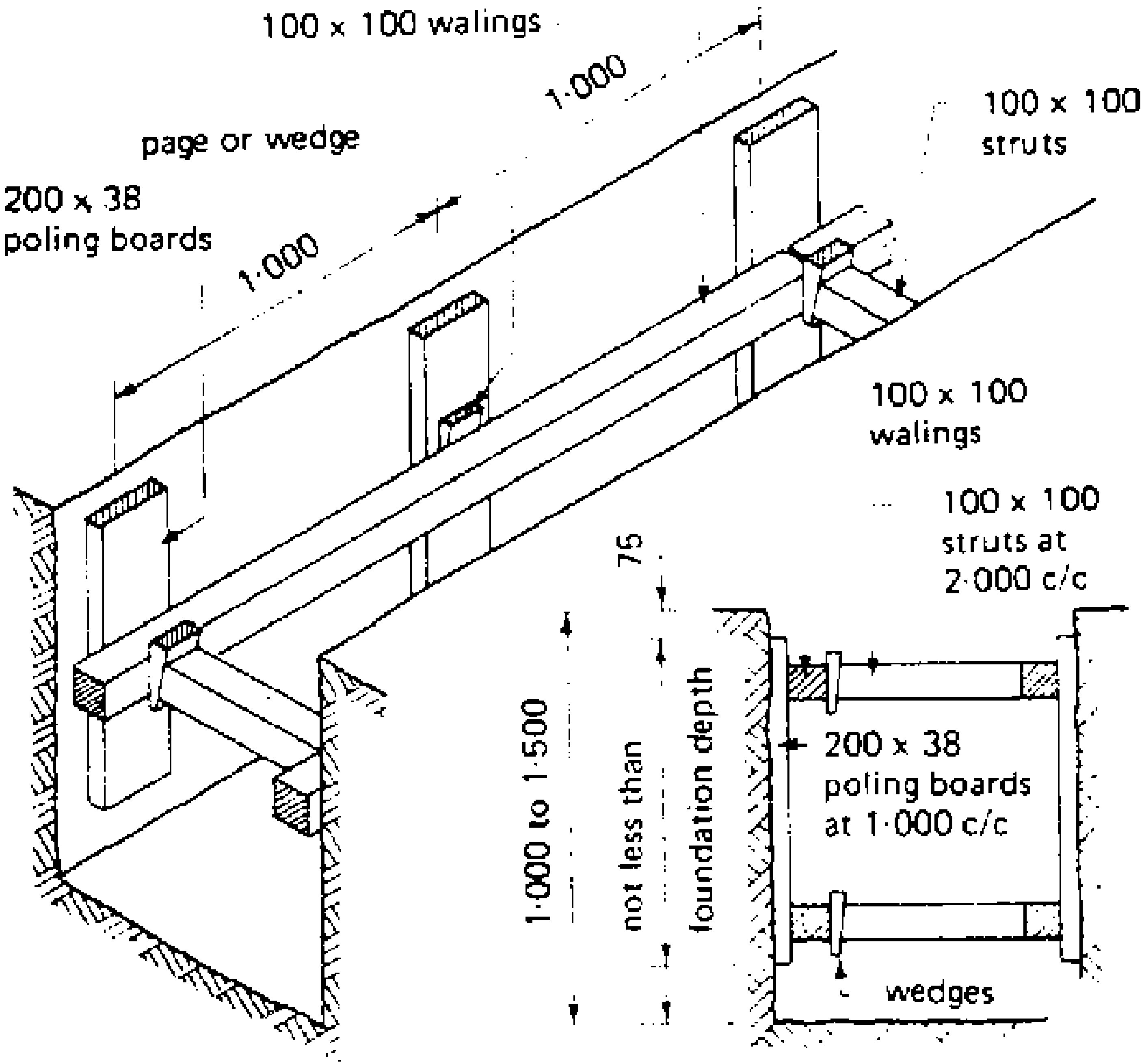
- Trenches which have to be dug for the foundations of walls are usually excavated by hand - in bigger building projects also mechanical trench diggers are used.

- If the trenches are of any depth it may be necessary to erect temporary timber supports to stop the sides of the trench from fallin in.

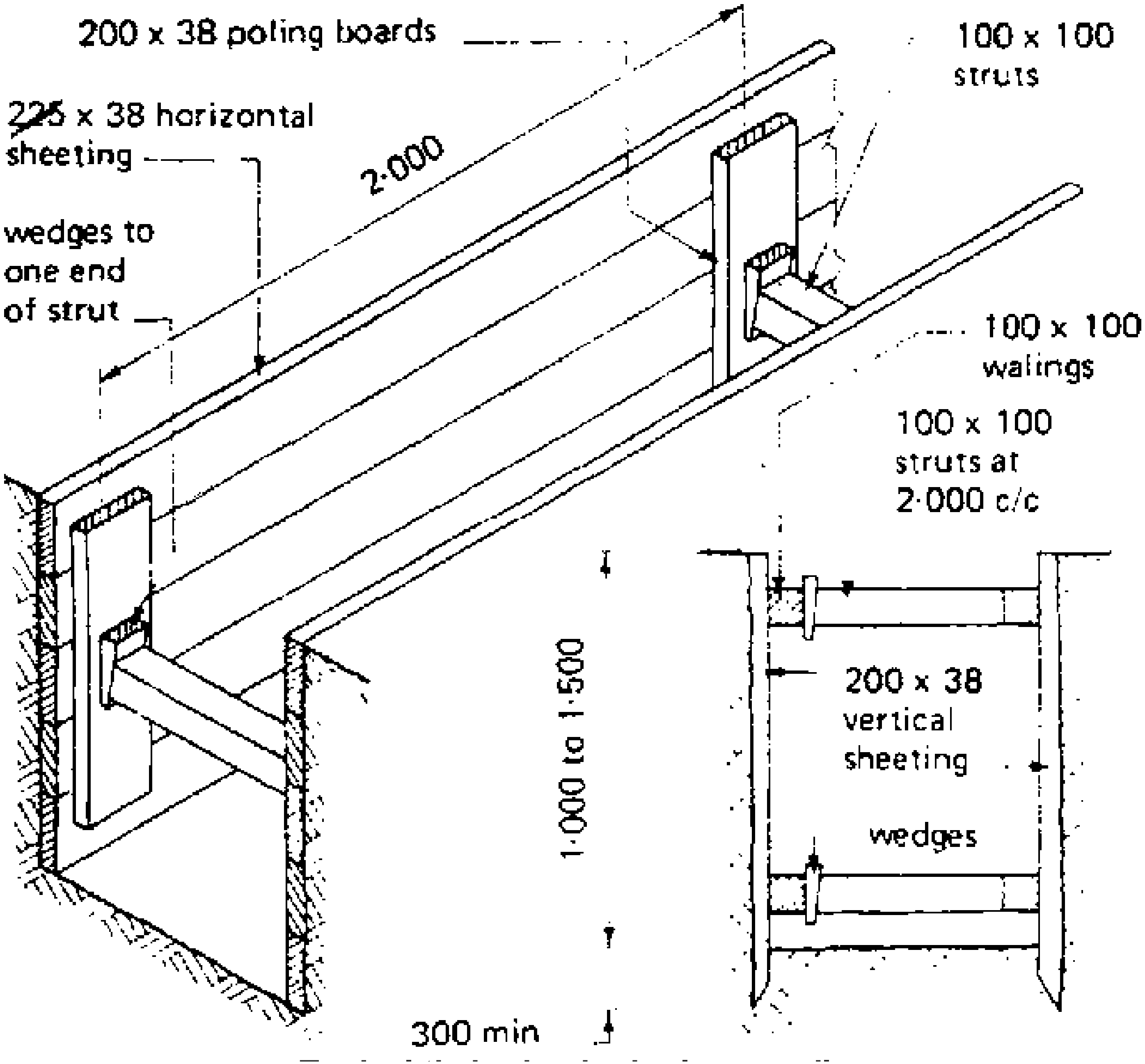
- The nature of the soils being excavated mainly determines at what depth of trench timber supports to the sides should be used.



Typical timbering in hard soils



Typical timbering in firm soils

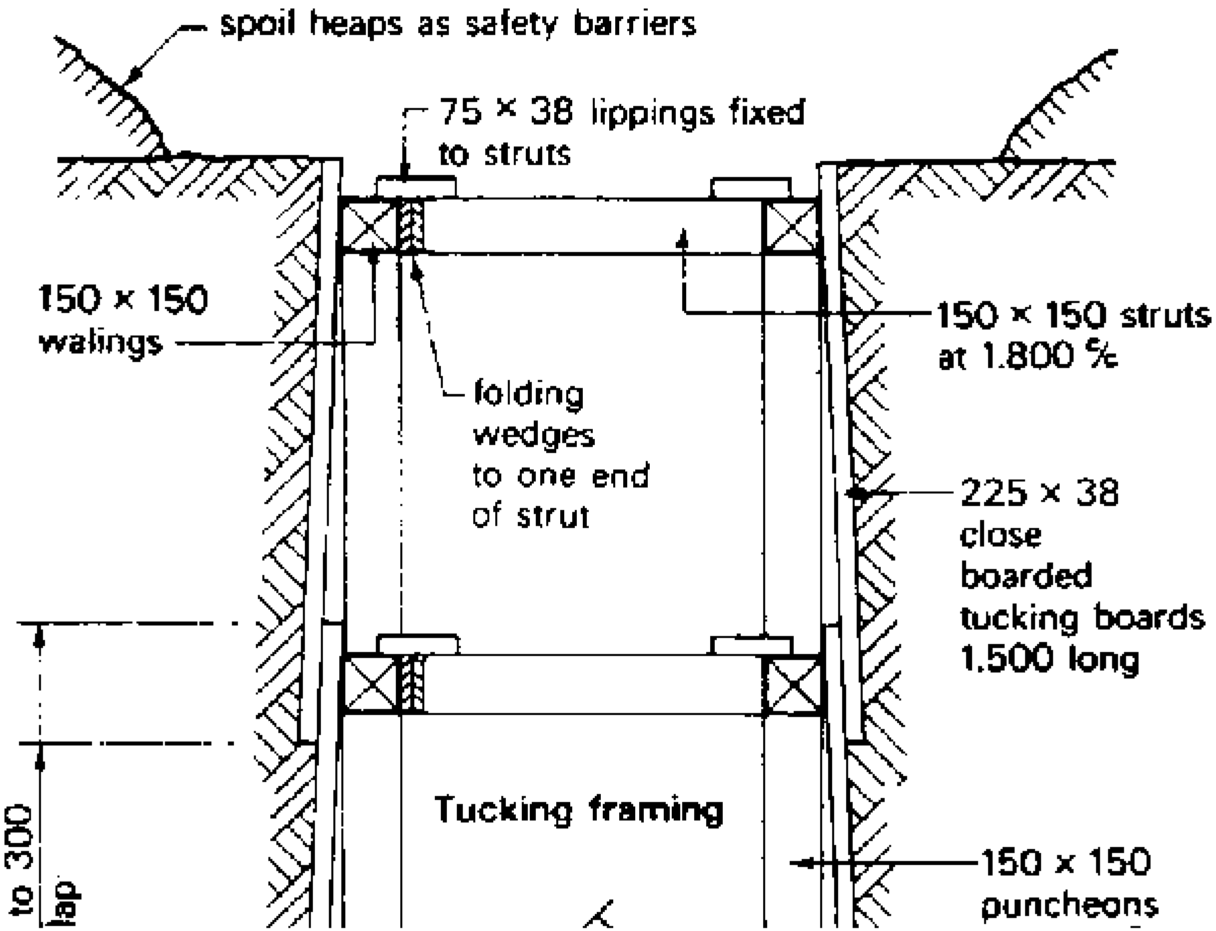


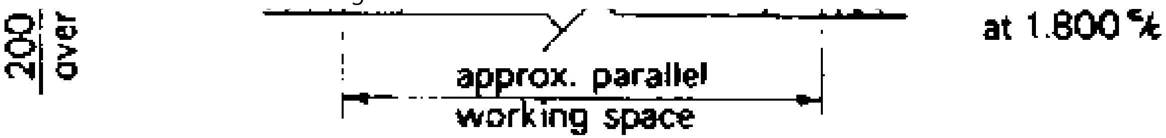
Typical timbering in dry loose soils

- Soft granular soils readily crumble and the sides of trenches have to be supported for the full depth.

- Dry granular soils such as sand and made up ground may need closely spaced timbering to the sides. See fig.

The sizes of timbers shown in the drawings are for guidance only.

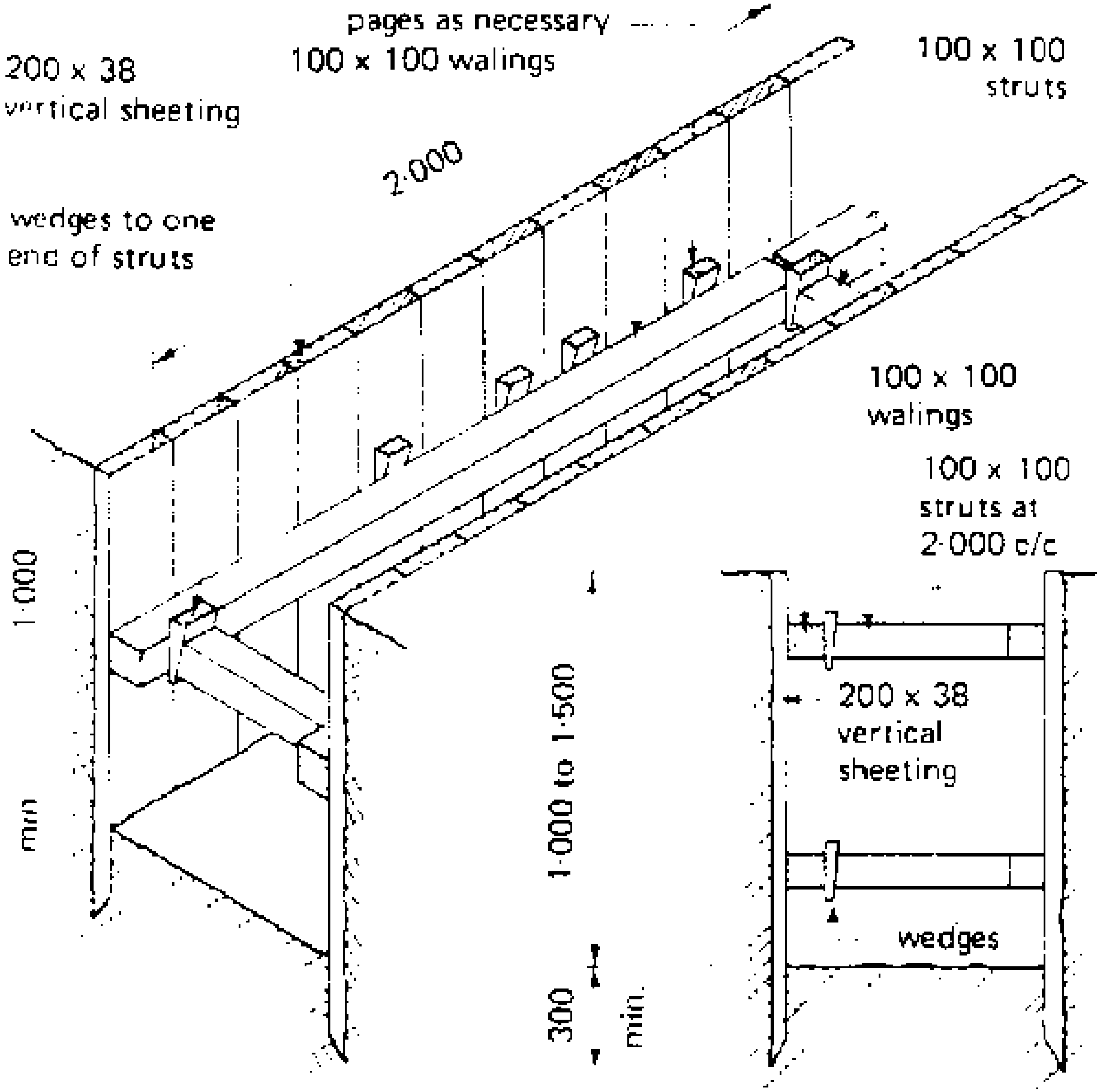




Tucking framing

Once the excavations are finished, the foundations should be laid as soon as possible to prevent the ground from drying out and causing movement by shrinking. The ground immediately below the foundation is called the GROUND BEARING or the NATURAL FOUNDATION and should be levelled of and well rammed to receive the base. This is to ensure that there is no loose earth beneath the concrete base which could fail to hold the loading and thus cause a fracture.

- Clay soils do not usually require support for some depth (say 1.5 it) particularly in dry weather. In rainy weather, if the bottom of a trench in day soil gets filled with water, the water may wash out the clay from the sides at the bottom of the trench.



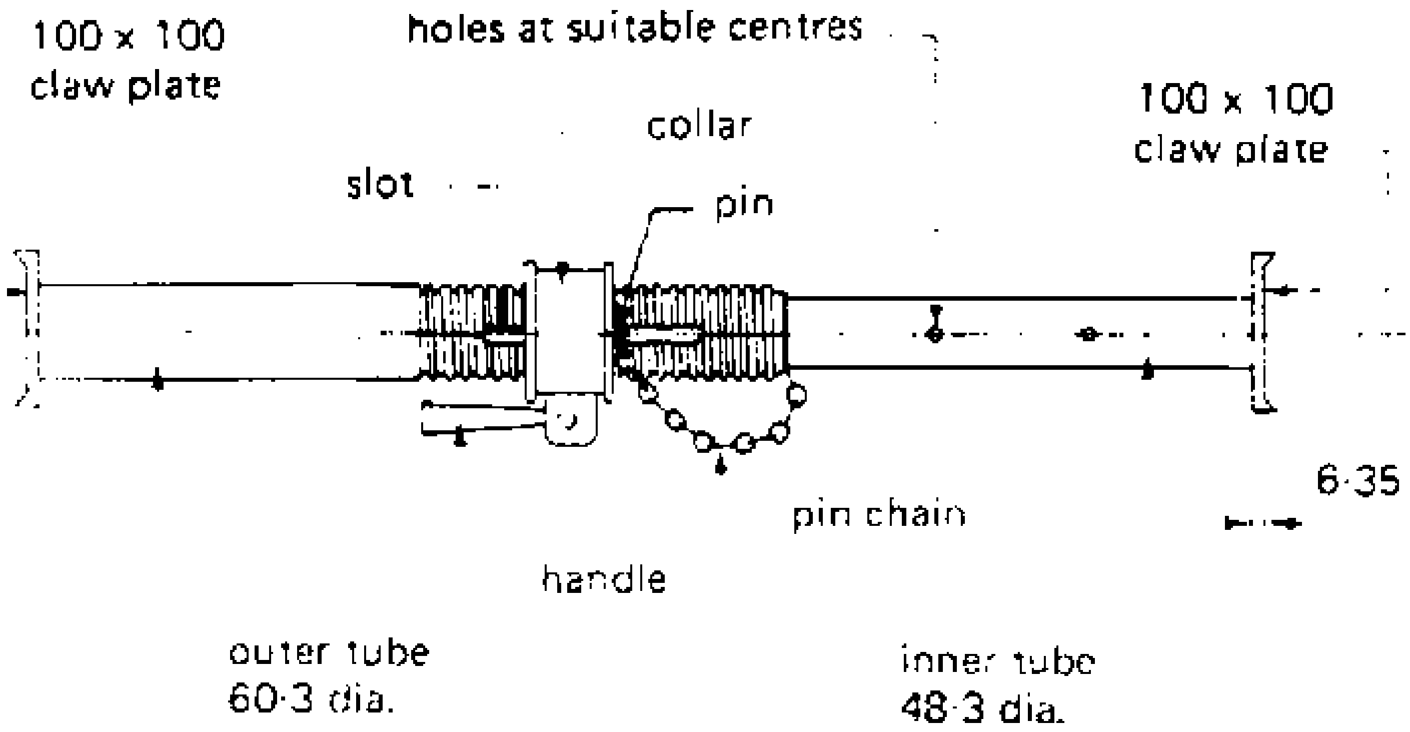
Typical timbering in loose wet soils

- The purpose of temporary timbering supports to trenches is to uphold the sides of the excavation as necessary, to avoid collapse of the sides.

- Whatever timbering is used there should be struts, that is horizontal members, fixed across the width of trenches. All struts must be firmly secured so that they are not easily knocked out of position.

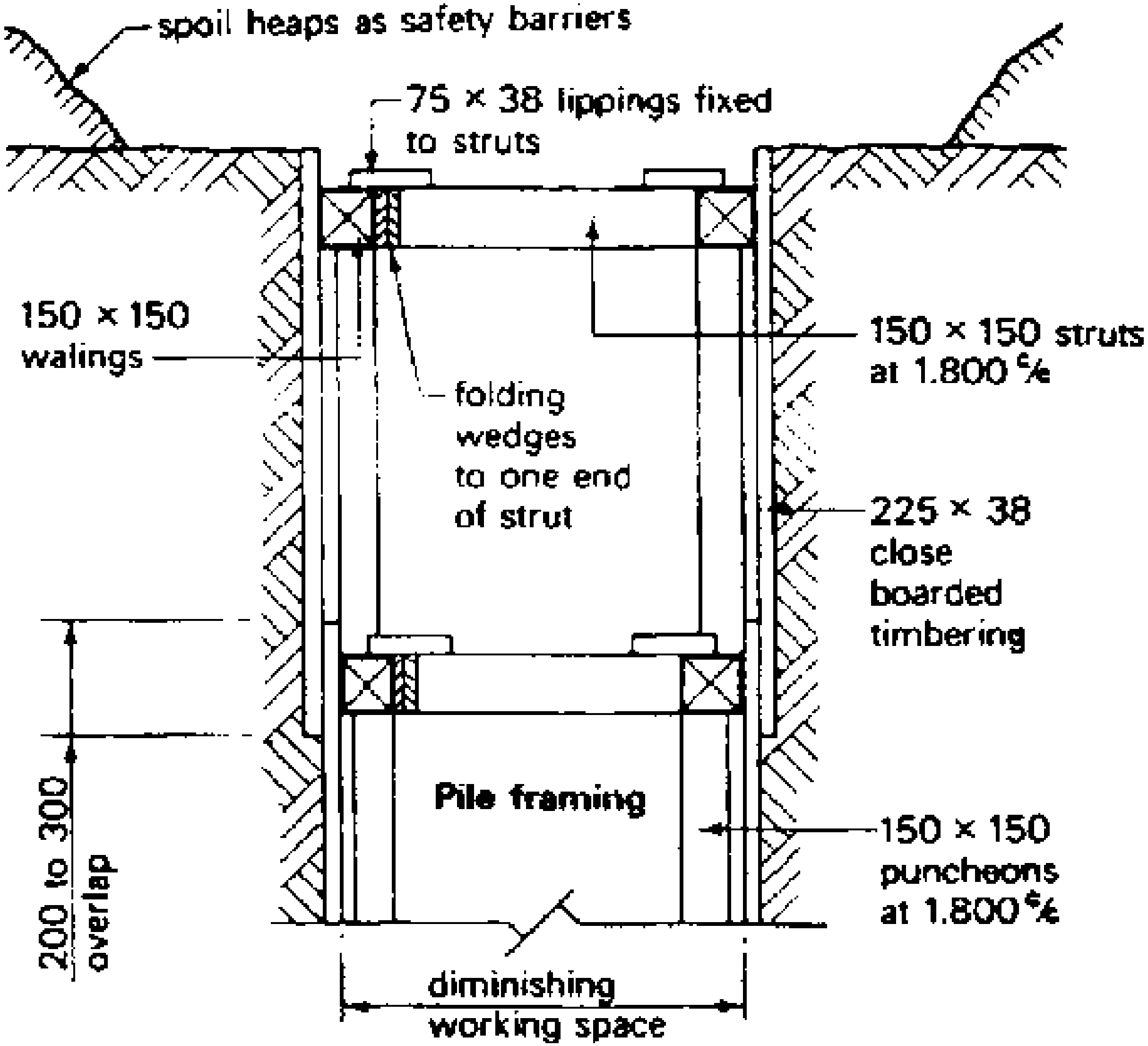
- The sides of deep trenches in com pact soils such as clay should - if necessary - be timbered as shown in the fig.

- If the soil is soft, such as loam, more closely spaced timbering will be needed as shown in the fig.



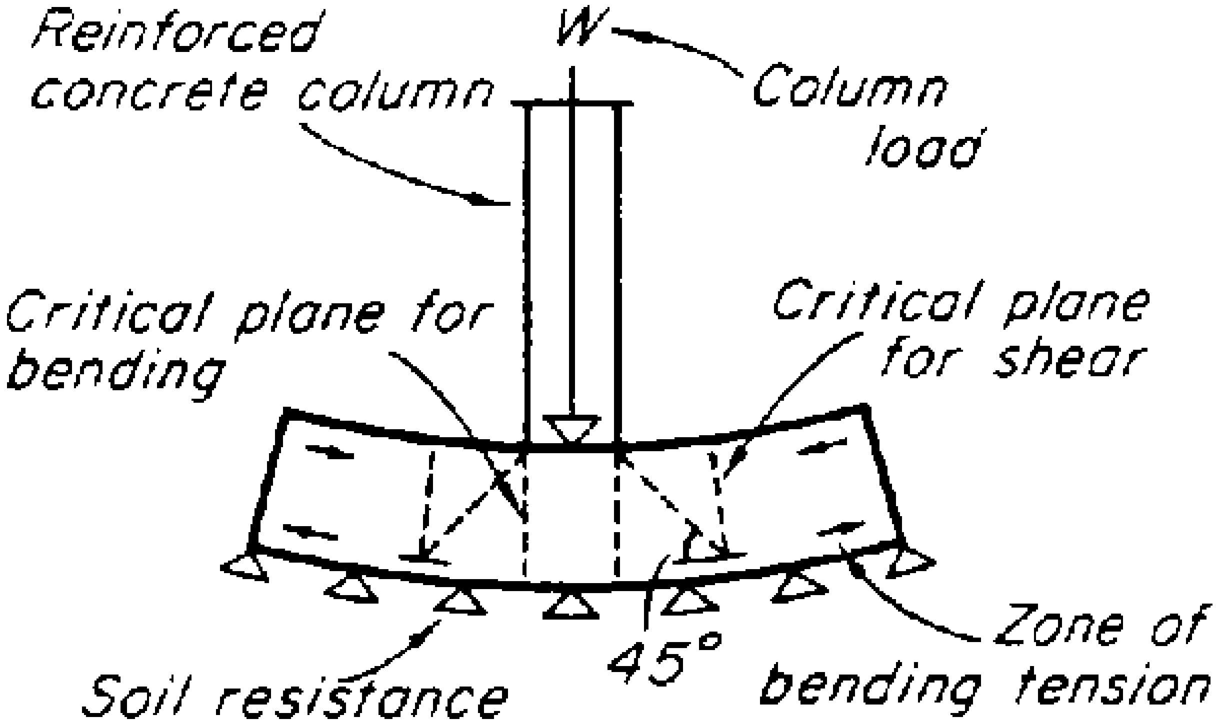
SIZE No.	MINIMUM LENGTH	MAXIMUM LENGTH
0	0·30 m	0·45 m
1	0·45 m	0·68 m
2	0·68 m	1·06 m
3	1·06 m	1·67 m

Adjustable metal struts - BS 4074

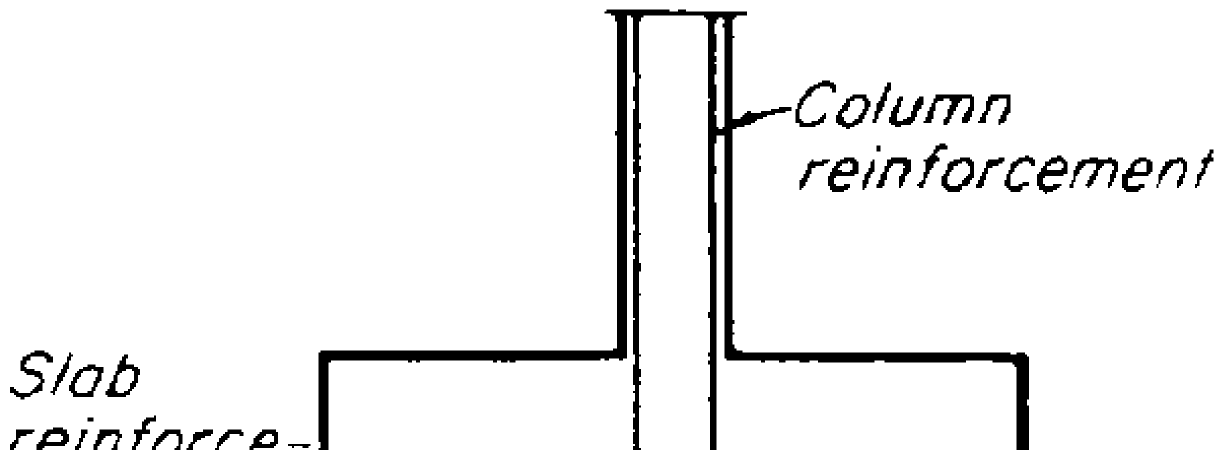


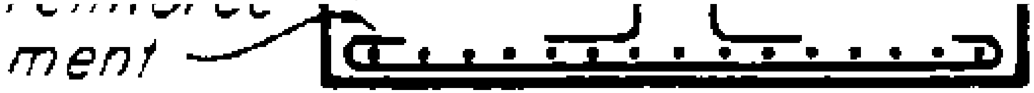
Pile framing

5.3 TYPES OF FOUNDATIONS



Pad or slab foundation - A





Pad or slab foundation - B

5.3.1 CLASSIFICATION

The many forms of foundations used in building work may be divided broadly into

I SHALLOW FOUNDATIONS and

II DEEP FOUNDATIONS

I Shallow foundations transfer the load to the soil at a level close to the lowest floor of the building and include SPREAD FOUNDATIONS in the form of

- **strip foundations**
- **pad foundations and**
- **raft foundations**

II Deep foundations include

- **pile foundations and**
- **various types of piers which transfer their loads to the soil at a considerable distance below the underside of the building.**

Shallow foundations are always the cheapest. An exception may be the use of short bored piles instead of strip foundations in shrinkable clays.

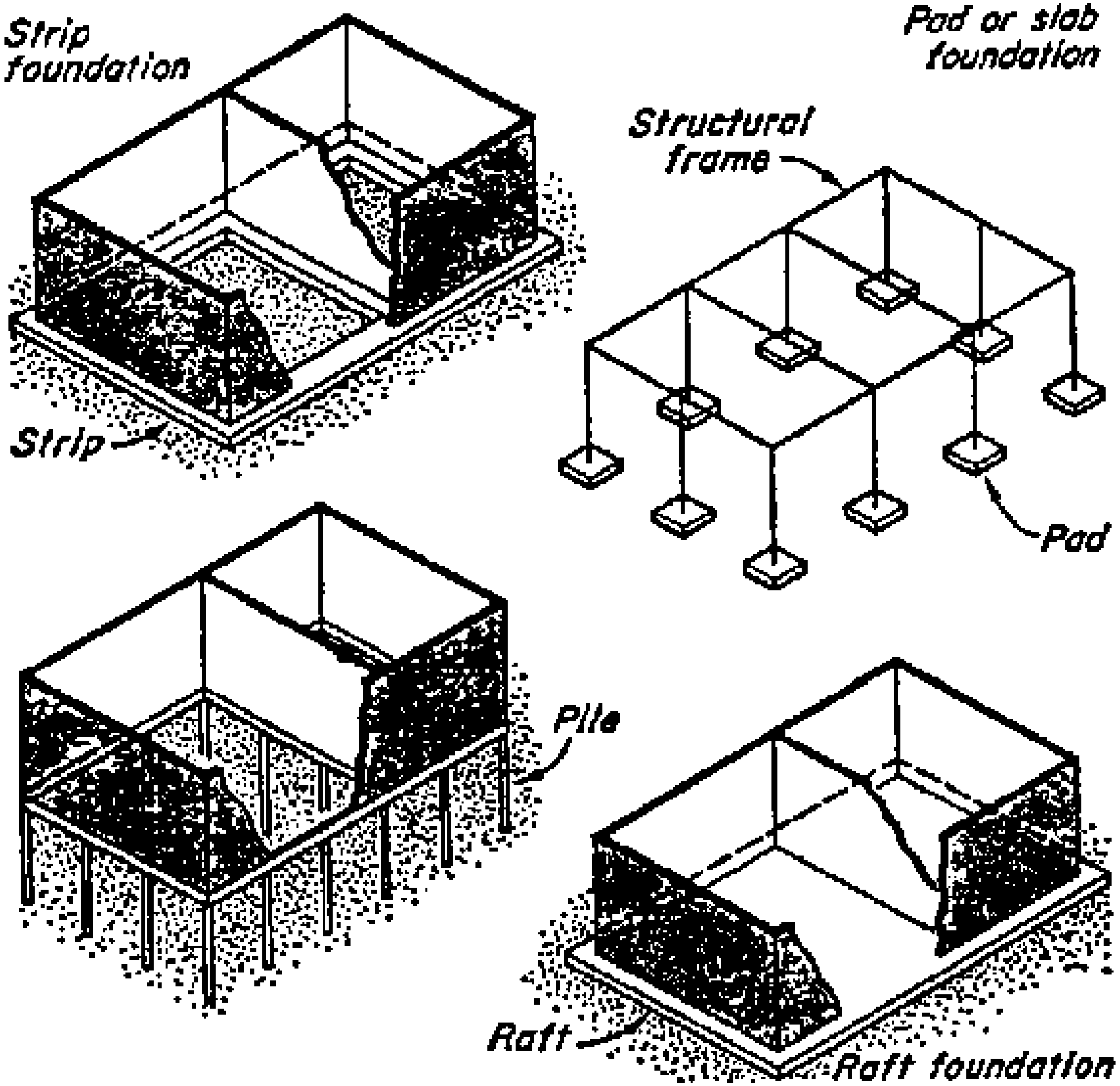
STRIP foundations = under continuos walls

PAD(or slab) foundations = under isolated piers or columns

are used on sites where a sufficient depth of reasonably strong subsoil exists near the surface of the ground.

RAFT foundation = by which the whole of the building area is covered, are used e.g. where no firm bearing strata of soil exists at a reasonable depth below the surface and a maximum area of foundation is required to bring the imposed pressures within the low bearing capacity of the weaker soils and of some made-up ground.

PIERS and PILES = may be viewed as columns passing through weak soil to transmit the building load to lower strata where the pressure can be safely resisted. They may also be used to transfer loads to the soil below the level likely to be affected by moisture movement.



5.3.2 CHOICE OF FOUNDATION

The choice of a foundation must take account of both soil and superstructure

The choice of a foundation must take account of both - soil and superstructure

For example: A stiff rigid building, one with plain monolithic concrete walls, will be affected by differential

movement to a greater extent than one with brick or block walls. Within certain limits distortion can be accommodated in the latter by fine cracks distributed throughout the joints whereas in the former the distortion will rapidly cause large cracks to be formed. In the case of small scale buildings the nature of the structure in respect of different movement is less important.

- Foundation design requires an appreciation of the ability of the structure to withstand relative movements without dangerous overstress and damage to the structure.

- Small scale buildings affect the soil at shallow depth only, so that ac count need to be taken only of soil movement due to causes other than loading.

- Where the soil is stable the possible causes of movement will be changes in moisture content of the soil. Movement can be avoided by placing the foundation at an adequate depth.

- on unstable soils, special measures must be taken whatever the scale of the building.

- Overall or total settlement must be limited so that services and drains connected to the building are not damaged, alter natively, provision must be made for flexible connections.

- The table below indicates the suitability of the foundation types described above to the various types of soil.

Soil type and site condition	Foundation	Details	Remarks

Rock, solid chalk, sands and gravels or sands and gravels with only small proportions of clay, dense silty sands	**Shallow strip or pad footings as appropriate to the load-bearing members of the building**	**Breadth of strip footings to be related to soil density and loading (see Fig. 4.2). Pad footings should be designed for bearing pressures tabled in CP101: 1963. For higher pressures the depth should be increased and Civil Engineering Code of Practice No. 4. 'Foundations' consulted**	**Keep above water wherever possible. Slopes on sand liable to erosion. Foundations 0.5 m deep should be adequate on ground susceptible to frost heave although in cold areas or in unheated buildings the depth may have to be increased. Beware of swallow holes in chalk**
Uniform, firm and stiff clays: (1) Where vegetation is insignificant	**Bored piles and ground beams, or strip foundations at least 1 m deep**	**Deep strip footings of the narrow widths shown in Fig. 4.3 can conveniently be formed of concrete up to the ground surface**	
(2) Where trees and shrubs are growing or to be planted close to the site	**Bored piles and ground beams**	**Bored piles dimensions as in page 65.**	**Downhill creep may occur on slopes greater than 1 in 10. Unreinforced piles have been broken by slowly moving slopes**

(3) Where trees are felled to clear the site and construction is due to start soon afterward	**Reinforced bored piles of sufficient length with the top 3 m sleeved from the surrounding ground and with suspended floors, or thin reinforced rafts supporting flexible buildings, or basement rafts**		
Soft clays, soft silty clays	**Strip footings up to 1 m wide if bearing capacity is sufficient, or rafts**	**See page 63 and CP 101: 1963**	**Settlement of strips or rafts must be expected. Services entering building must be sufficiently flexible. In soft soils of variable thickness it is better to pile to firmer strata (See Peat and Fill below)**
Peat, fill	**Bored piles with temporary steel lining or precast or *in situ* piles driven to firm strata below**	**Design with large safety factor on end resistance of piles only as peat or fill consolidating may cause a downward load on pile (*see Digest 63*) Field tests for bearing capacity of deep strata or pile loading tests will be required**	**If fill is sound, carefully placed and compacted in thin layers, strip footings are adequate. Fills containing combustible or chemical wastes should be avoided**

Mining and other subsidence areas	Thin reinforced rafts for individual houses with load-bearing walls and for flexible buildings	Rafts must be designed to resist tensile forces as the ground surface stretches in front of a subsidence. A layer of granular material should be placed between the ground surface and the raft to permit relative horizontal movement	Building dimensions at right angles to the front of long-wall mining should be as small as possible

Soil type and site condition	*Foundation*	*Remarks*
Rock, solid chalk, sands and gravels or sands and gravels with only small proportions of clay, dense silty sands	Shallow strip foundations, pad foundations, (as appropriate to the load-bearing members of the building) Surface raft See Table 10	Keep above water wherever possible. Slopes on sand liable to erosion. Foundations to be 460 mm below ground level on ground susceptible to frost heave (see text)
Uniform, firm and stiff clays:		With these soils downhill creep may
1 Where vegetation is insignificant	Strip or pad foundations at least 1-07 m below ground level Bored piles See Tables 10 & 12	occur on slopes greater than 1 in 10. Unreinforced piles have been broken by slowly moving slopes

2 Where trees and shrubs are growing or to be planted close to the site	Bored piles See Table 12	
3 Where trees are felled to clear the site and construction is due to start soon afterward	Reinforced bored piles of sufficient length with top 3 m sleeved from the surrounding ground and with suspended floor Thin reinforced rafts supporting flexible superstructure Basement rafts See Part 2	
Soft clays, soft silty clays	Strip foundations up to 850 mm wide if bearing capacity is sufficient See Table 10 Rafts See Part 2	Settlement of strips or rafts must be expected. Services entering building must be sufficiently flexible. In soft soils of variable thickness it is preferable to pile to firmer stratum
Fill (made up ground) Peat	Pier foundations Piles driven to firm stratum below Special raft foundations with or without flexible superstructure	If fill is sound, carefully placed and compacted in thin layers, strip foundations are adequate

	See Part 2	
Mining and other subsidence areas	Special raft foundations with or without flexible superstructure See Part 2	

Table 11 Suitability of foundation types to various soils
Based on information in Building Research Digest 67

5.3.3 SPREAD FOUNDATIONS

Must be designed so that

- the soil is not overstressed
- the pressure on the soil under them is equal at all points in order to avoid unequal settlement under the actual foundation.

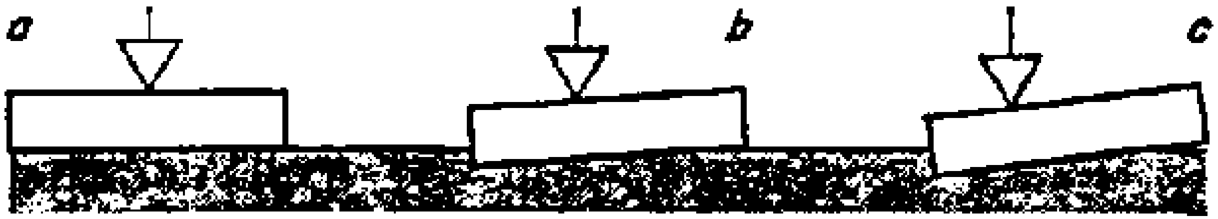
This is ensured by providing sufficient area of foundation and by arranging the centre of gravity of the applied loads to coincide with the centre of area of the foundation.

Strip foundations and pad foundations require the foundation to be placed symmetrically with the wall or column it supports

- If the load is applied eccentrically, the pressure on one side will be greater than the average pressure, causing greater consolidation of the soil on that side of the foundation.

- When the eccentricity is great, the increased stress could exceed the safe bearing capacity of the soil, even though the average stress might be well below it.

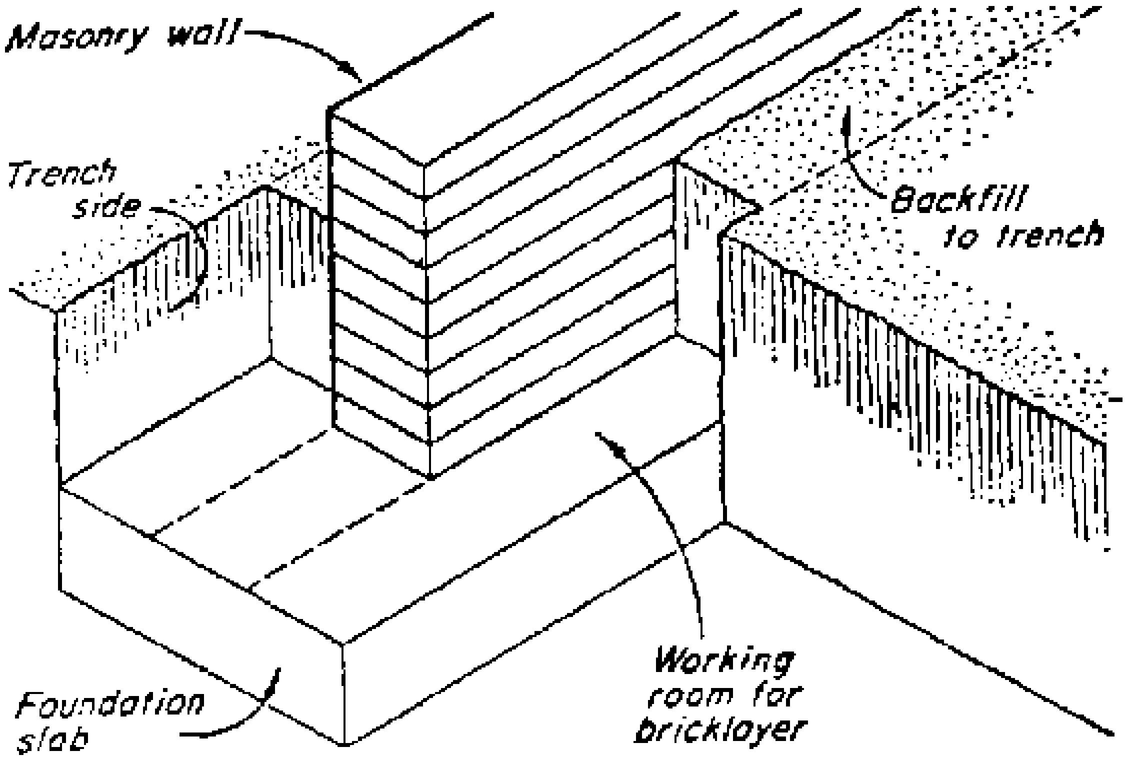
- When the eccentricity is greater than 1/6 of the foundation width, tensile stress occurs and cau ses the foundation to rise off the soil.



Effect of eccentric loading on foundations

5.3.3.1 Strip foundations

Consist of a strip of concrete under a continous wall carrying a uniform by distributed load.



Strip foundation

The required area (as in case of all spread foundations) is related to the imposed load and the bearing capacity of the soil.

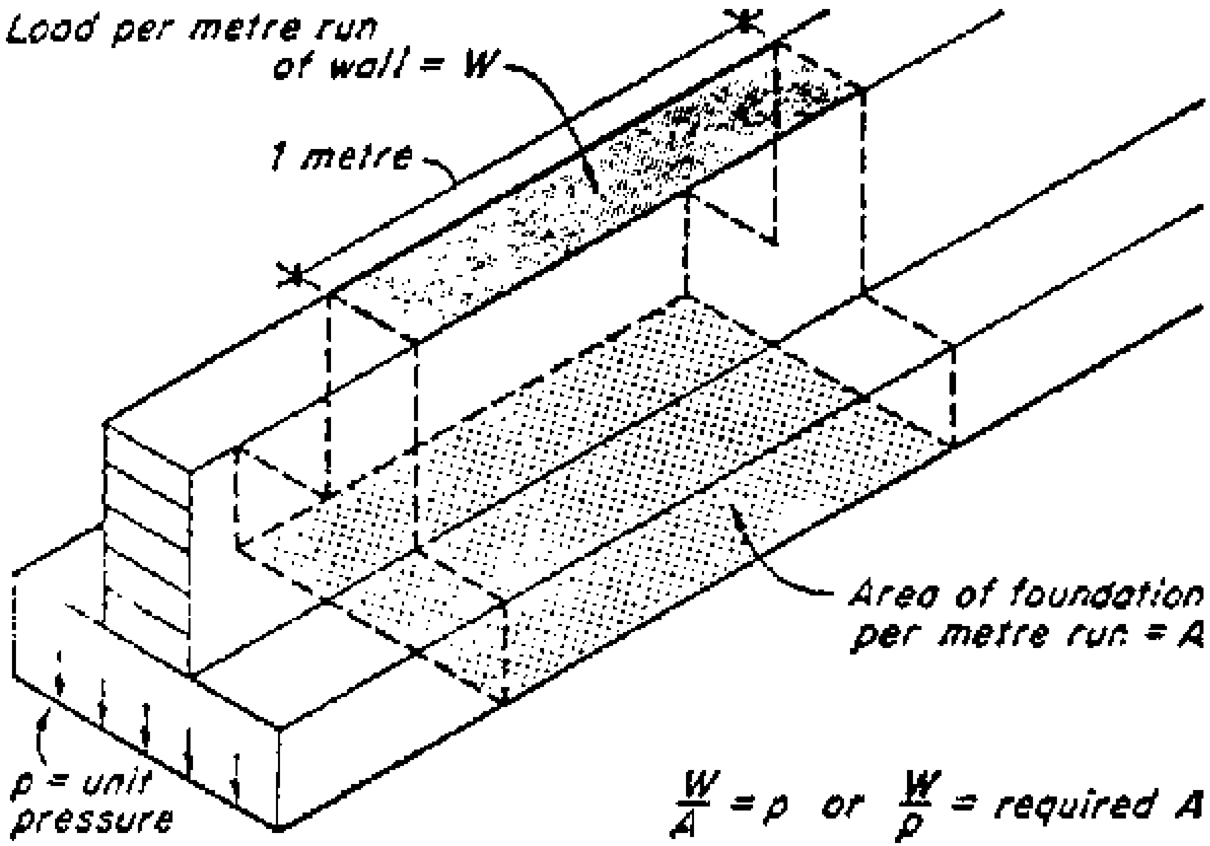
The imposed load is considered as load/m the width of the strip is made such as to give sufficient area/m run of foundation.

e.g. If the loading is 30 KN/m and the soil is stressed not more than 50 KN/m2 the min. width should be 0.60 m. (load: stress). That means: In every metre run of foundation the load of 30 KN will be distributed over 0.60 m2 of soil, resulting in a pressure of 50 KN/m2.

In cases of light loading on reasonably strong soils a strip no wider than the wall it carries may be sufficient.

In practice, with masonry walls some spread is usually provided (12,5-15,0 cm on each side) to allowworking room. This also provides some stability to the wall before it is tied in by floors and roof.

For hand excavation: min. width 60 -75 cm depending on the depth.



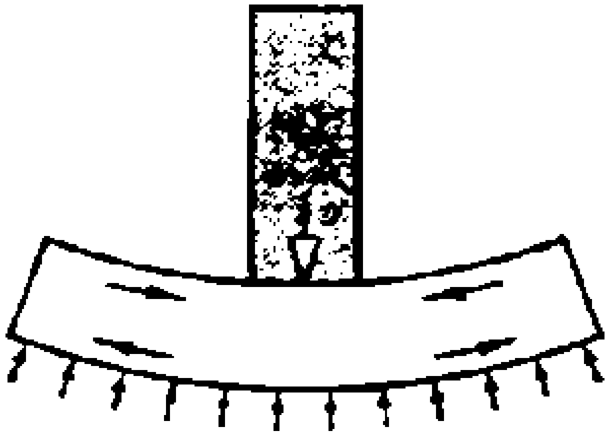
Foundation width

The stresses in the soil due to loading have to be well within the lowest limit of safe bearing capacity for any particular soil type, resulting in wider foundations than those which would fully stress the soil. This

is the basis of the minimum widths laid down for stripe foundations in the Building Regulations and given in the table below.

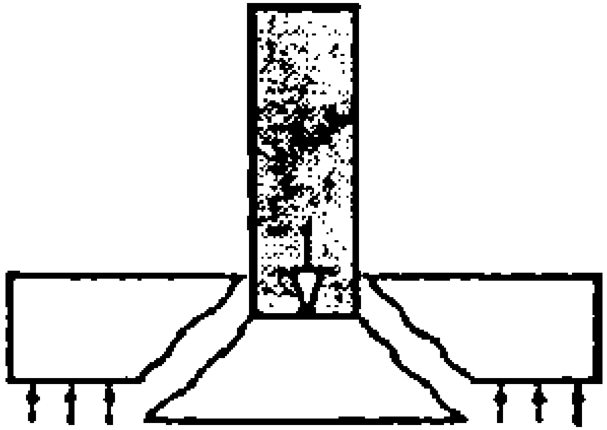
Where the adges of a foundation project beyond the faces of the wall it supports bending due to contilever action will occur as a result of the resistance of the soil, causing bending and shear stresses in the foundation.

The tensile strength of unreinforced concrete is low, and in order to keep these stresses within the capacity of the concrete: the strip must be of adequate depth.



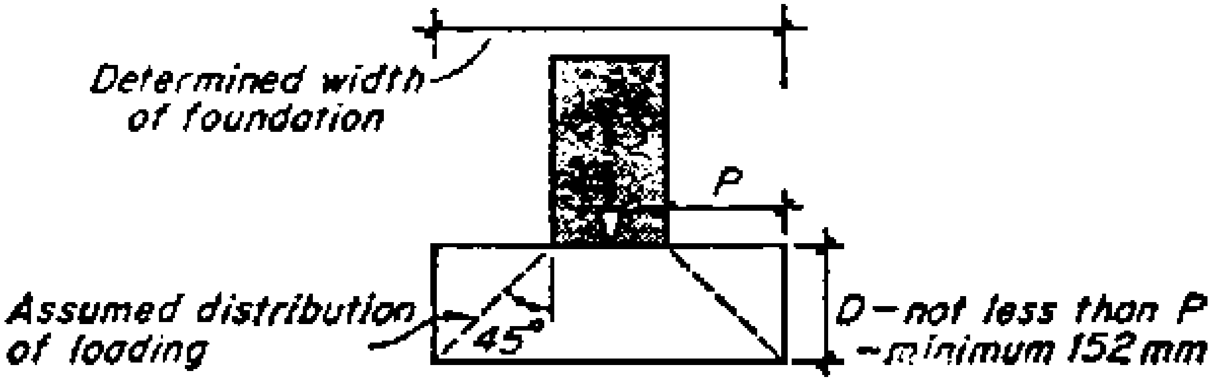
Bending

Foundation depth - A



Failure in shear

Foundation depth - B



Foundation depth - C

Concrete fails under a compressive load usually by tensile shear failure along planes lying at an angle of about 45 to the horizontal.

Code of Practice 101: 1963 requires an angle of spread of load from the wall base to the outer edge of

the foundation of not more than 45° which results in the thickness being not less than the projection of the base beyond the face of the wall it carries.

Vary wide strips are reinforced to keep their depth within economic limits.

Heavy loads concentrated at points in the run of a wall carrying otherwise uniformly distributed load will result in greater loads on the foundation at these points. In order to ensure equal stresses at all points in the soil these extra loads must be distributed to the soil through larger foundation areas.

For mass concr., a 1:3:6 mix is commonly used, with fairly large aggregate - say 38-50 mm. Concrete should be poured as soon as possible after excavation of trences. (Clays and chalk soils losing strength when become wet; clay drying -out causes shrinkage which is followed by expansion). If concr. cannot be placed on completion of excavation, the bottom should be protected by 5 cm of weak concr. blinding, or 7,5 cm to 10 cm of soil should be left for excavation immediately prior to concreting.

Brick footings: Another way of spea-ding the load of the walls to the soil is to make the base of the wall thicker by means of off-sets called footing courses.

The wall is built with 1/4 B offsets each side for every course of bricks.

The effect is: a larger surface area in contact with the ground

5.3.3.2 Deep strip foundations

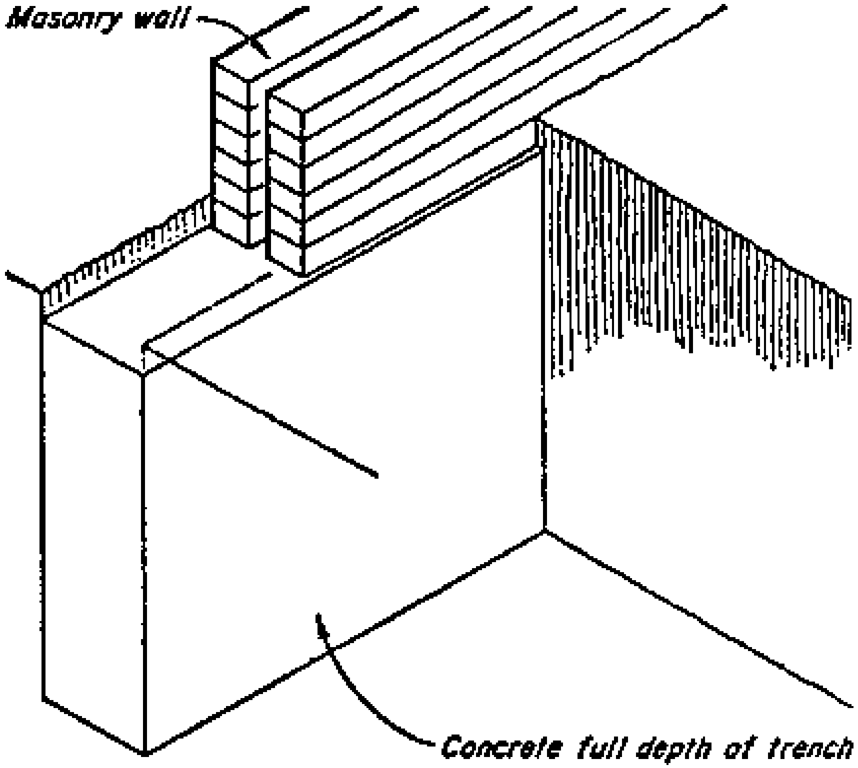
Firm or stiff shrinkable clays are strong and when carrying light loads necessiate quite small foundations (possibly not wider than the wall carried). But these soils move considerably with changes in moisture content, therefore the bottom of the foundation should be at least 1 m below ground level.

Narrow excavation is required (perhaps 30 cm wide and more than 1 m deep)

Narrow excavation is required (perhaps 30 cm wide and more than 1 m deep)

- **it has to be dug by mechanical means and filled with concrete to within a few cm of the ground surface.**
- **much less soil has to be excavated and backfilling is eliminated.**
- **where conditions are suitable it is cheaper to construct and quicker to complete than the wider strip foundations.**

The conditions necessary to make it economic are a self-supporting soil to avoid timbering (firm, shrinkable clays possess this characteristic) adequate runs of straight trenching with a min. amount of corner trimming (to justify the cost of a mechanical excavator).



Deep strip foundation

5.3.3.3 Stepped foundations

Except in certain types of structures transferring inclined thrusts to the ground all foundations must bear horizontally on the soil.

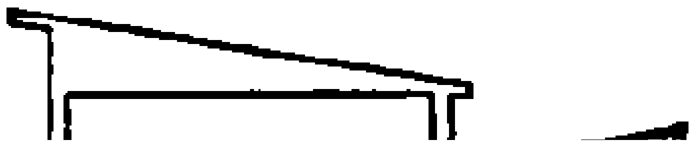
If strip foundations to a building on a sloping site are at the same level throughout, those on the higher side will be greater distance below ground level than the remainer, necessiating deeper trenches and a greater amount of walling in the soil.

There are two ways in which this building into the soil may be reduced:

1) by cut or cut-and-fill to provide a horizontal plane off which to build
2) by stepping down the slope of the foundations to those walls parallel to the slope.

Overlap to be not less than T or 2 x H, which ever is the greater with a min. of 30 cm.

Foundations on sloping sites - A



Foundations on sloping sites - B

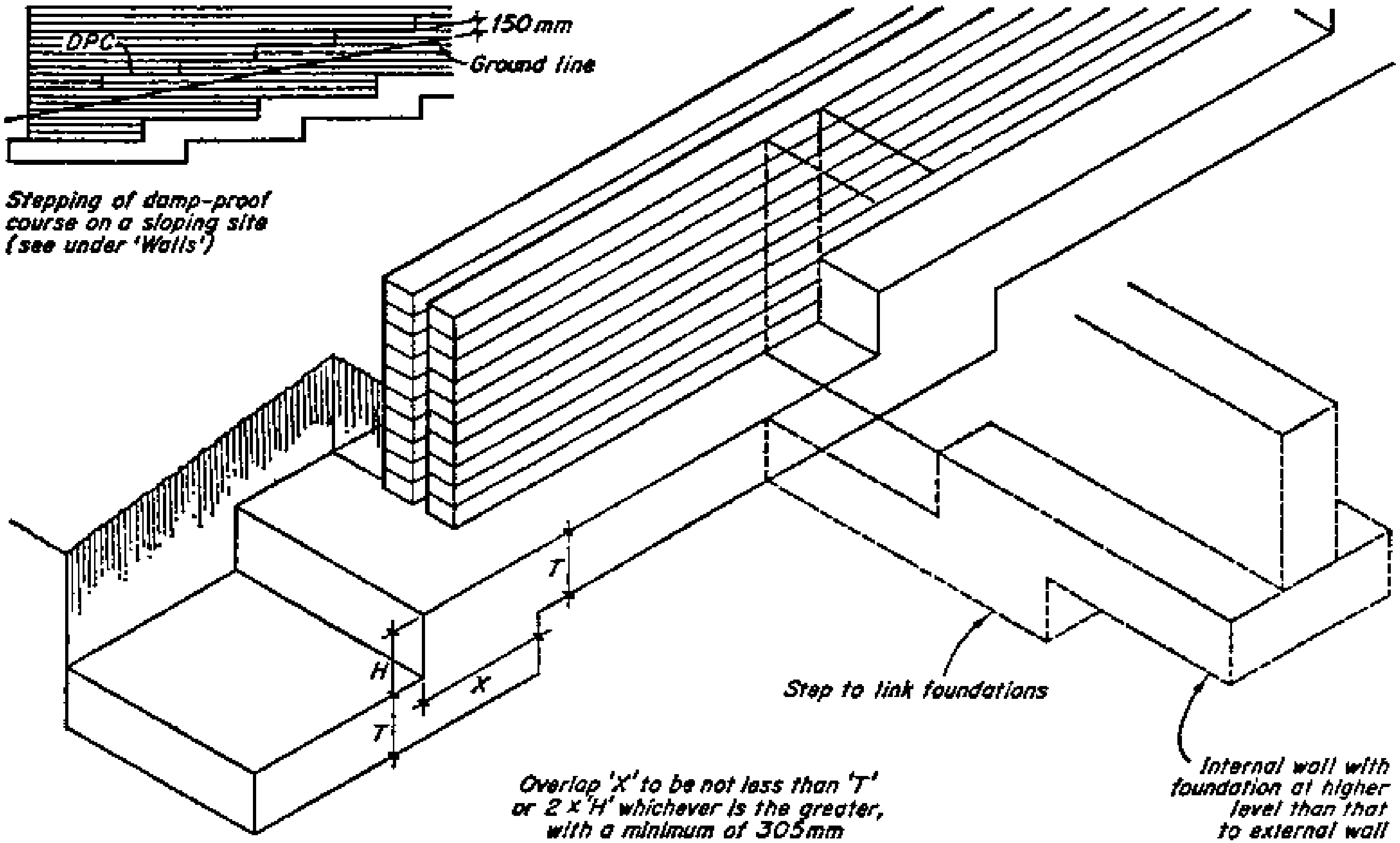
The steps should be relatively short and sufficient in number to keep their heights small and uniform. (Height of step should not exceed the thickness of the foundation).

The lengths need not be uniform, but should be varied (where necessary) to keep the heights as uniform as possible.

Ex each step the higher foundation must lap over the lower.

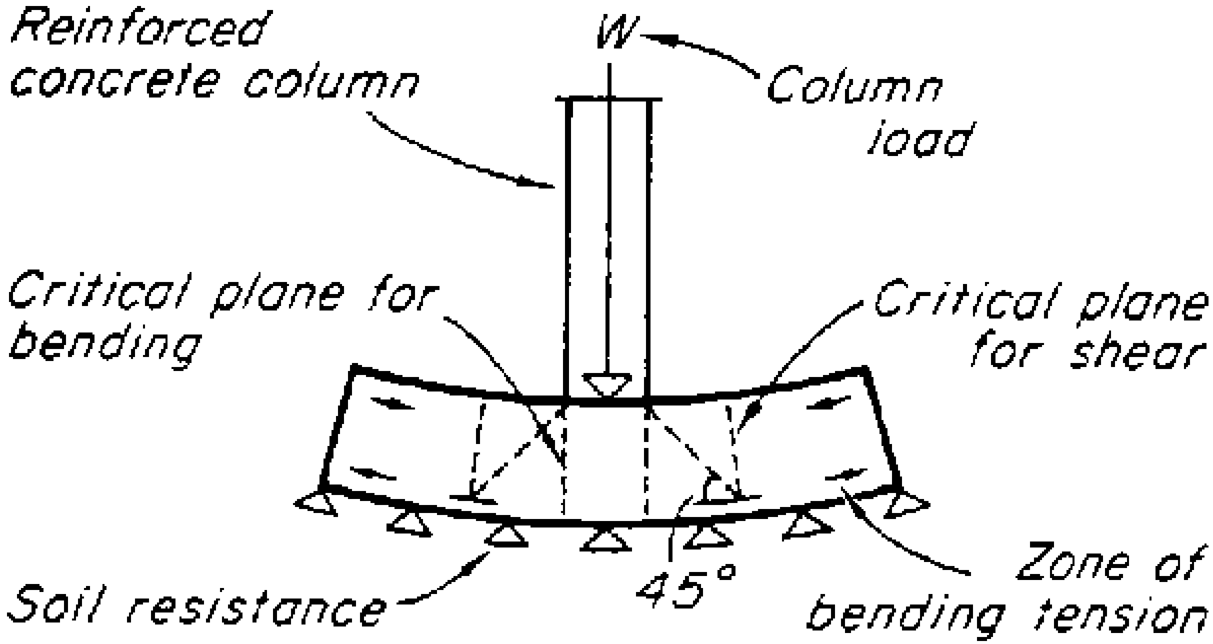
The foundations should be so arranged that a step accurs at any intersection with a cross wall, the step being on the side where the ground-level is highest.

On sloping sites it is advisable to lay subsoil drainage, in the form of land drains, across the slope on the uphill side of the building.

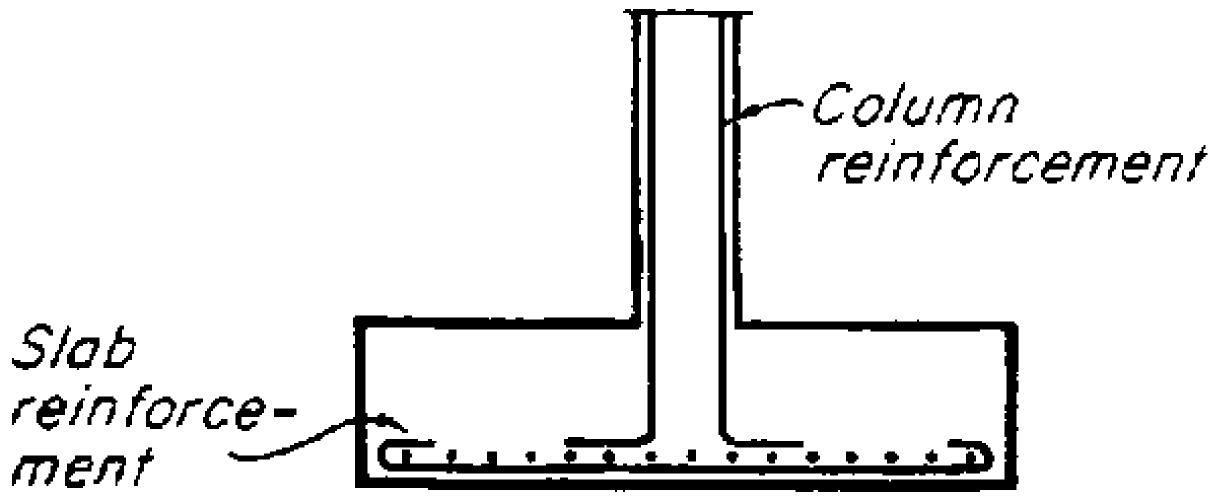


Stepped foundation

5.3.3.4 Pad foundations



Pad or slab foundation - A



Pad or slab foundation - B

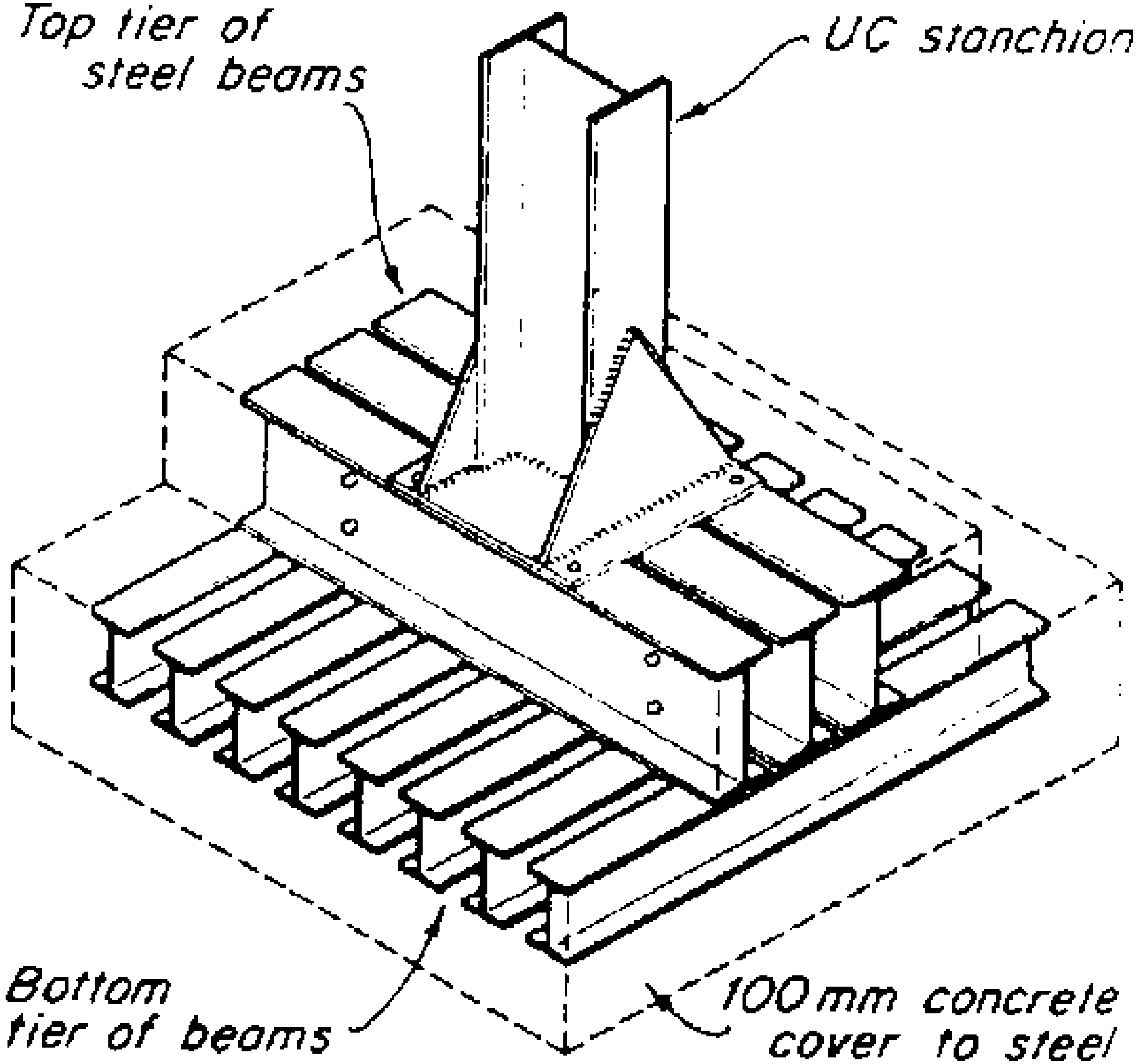
Isolated piers or columns are normally carried on an independet slab of concrete, commonly called a PAD FOUNDATION the pier or column bearing on the centre point of the slab.

The area of foundation is determined by dividing the column load by the safe bearing capacity of the soil and its shape is usually a square.

Its thickness is governed by the same considerations as for strip foundations and is made not less than the projection of the slab beyond the face of the pier or column or the edge of the baseplate of a steel column.

It should in no case be less than 150 mm thick. As in the case of strip foundations when a column base is very wide a reduction in thickness may be effected by reinforcing the slab.

In a framed structure where loads on different columns vary, the sizes of the bases must vary in order to maintain equal soil pressure under each and thus eliminate differential or unequal settlement.



Steel drillage foundation

5.3.3.5 Raft foundations

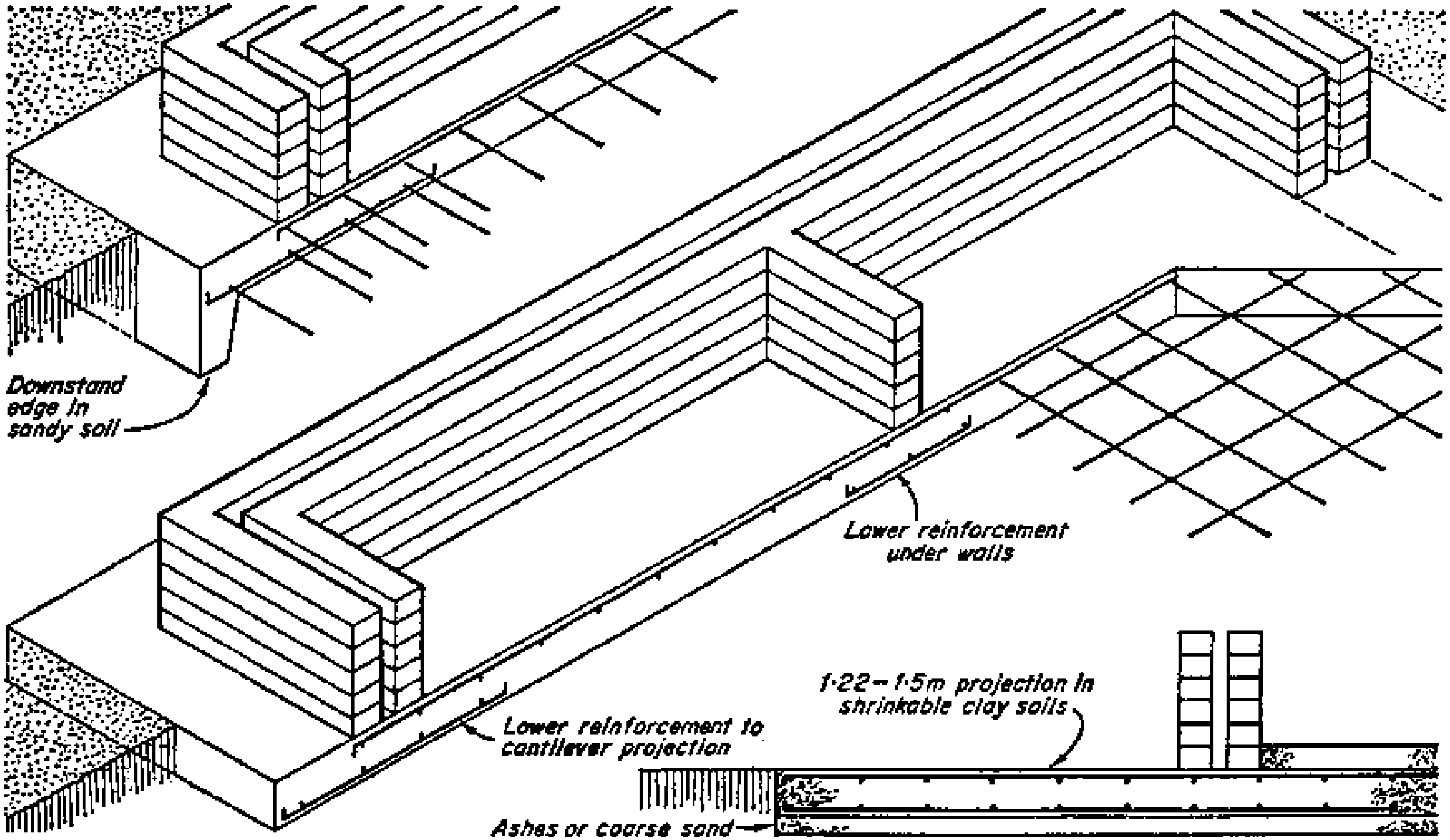
A RAFT FOUNDATION is a large slab foundation covering the whole building area, through which all the loads from the building are transmitted to the soil. When used for the purposes described here they are laid on, or just below the surface of the ground and are termed surface rafts.

Solid concrete ground floor slab construction is normal today. This slab, if about 150 mm thick and lightly reinforced, may be used as a light raft on all types of firm soils. Reinforcement is required at the top for crack control with some steel at the bottom under walls or columns to resist tensile stress in these zones, see fig. The raft should be extended about 300 mm beyond the perimeter walls. On sands it is preferable to form a 'downstand' edge all round to prevent erosion of the soil under the perimeter of the slab. If used on shrinkable clays the soil under the external walls should be protected from moisture changes and consequent movement by an extension of the slab 1.22 m to 1.5 m beyond the walls, see fig.

In this case reinforcement is generally as for rafts on other soils but top and bottom reinforcement must be provided under the external walls and in the extension to resist the tensile stresses at the top due to loads on the extension when the soil has shrunk under the slab edge and at the bottom due to the pressure of the clay when it swells.

Light surface rafts can also be used to carry lightly loaded structures of certain types on soils subject to general earth movement.

As in all spread foundations the centre of gravity of the loads should coincide with the centre of area of the raft. This is facilitated when the building has a simple regular plan form with loadbearing elements such as walls, columns, stacks, disposed symmetrically about the axis of the building. Heavy elements such as stacks are best situated near the centre of the plan Excessive variation of loading results in problems which need careful consideration in the design of the foundation.

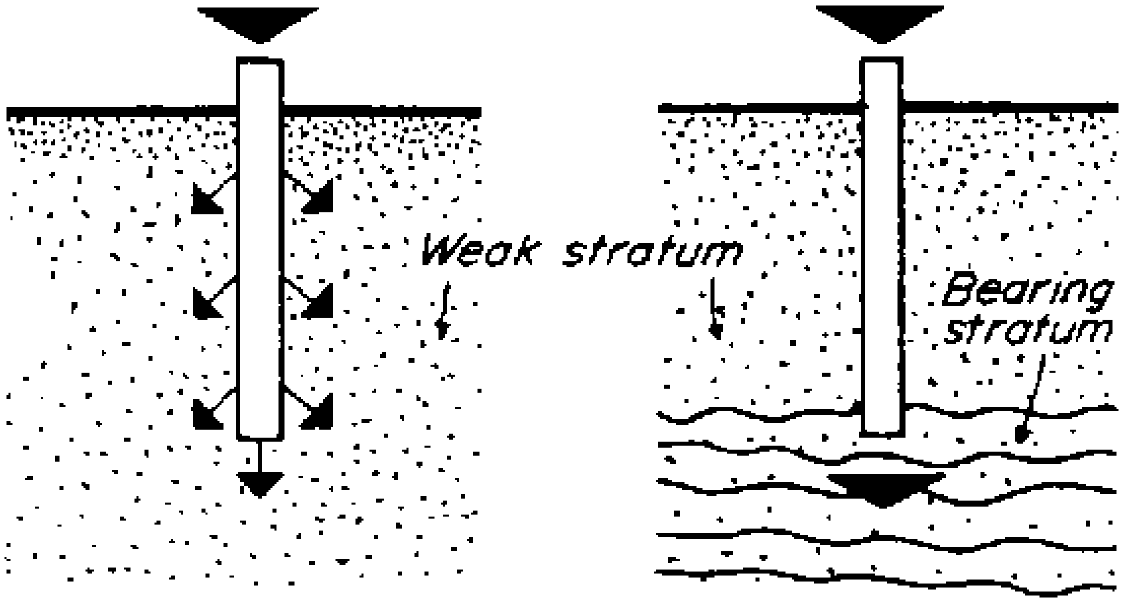


Surface raft foundation

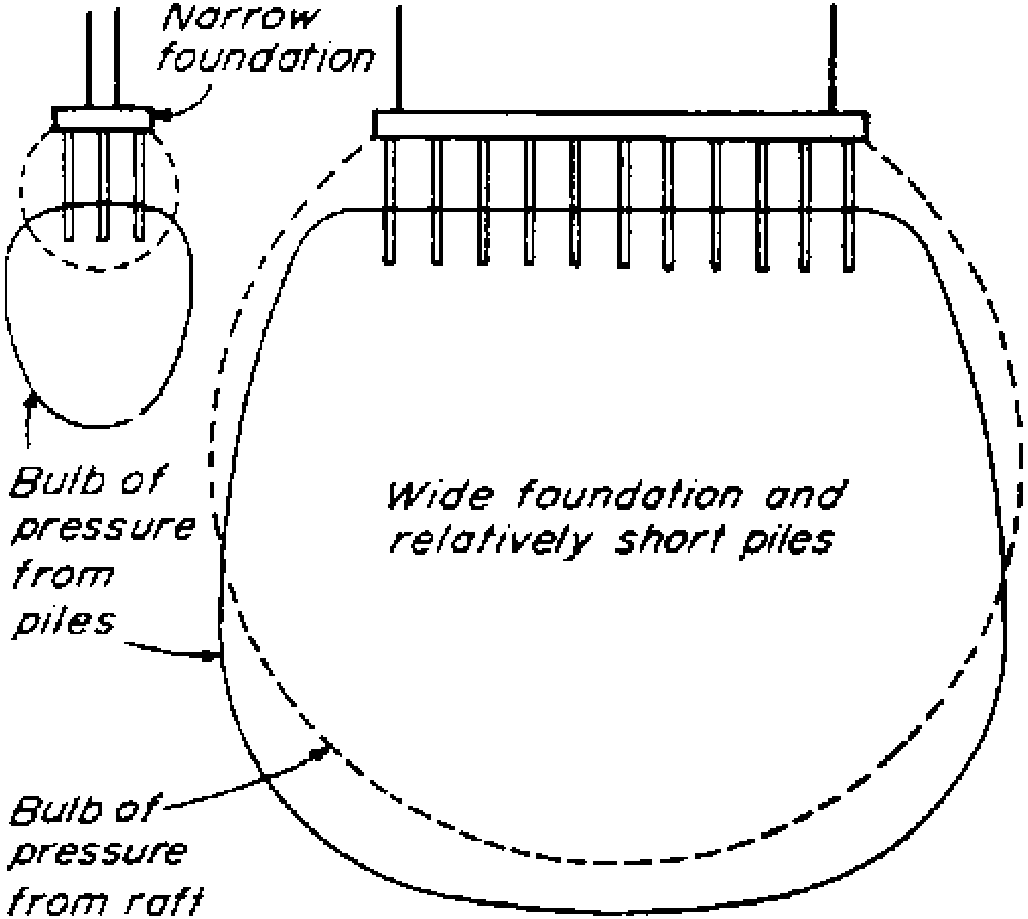
5.3.4 PILE FOUNDATIONS

PILES are often used to transmit loads through soft soils or made-up ground. IN such circumstances, unless large in diameter, the piles will normally need to be reinforced. Piles of relatively short length can, however, be used economically in firm shrinkable clay as a means of founding below the zone of

moisture movement. Such piles require no reinforcement because the diameter being large relative to length, the piles are stiff and they also receive considerable support from the firm soil through which they pass. In this type of soil the piles can be easily and quickly formed by boring. This particular form of pile is, therefore, called a short bored pile.



Friction pile Bearing pile

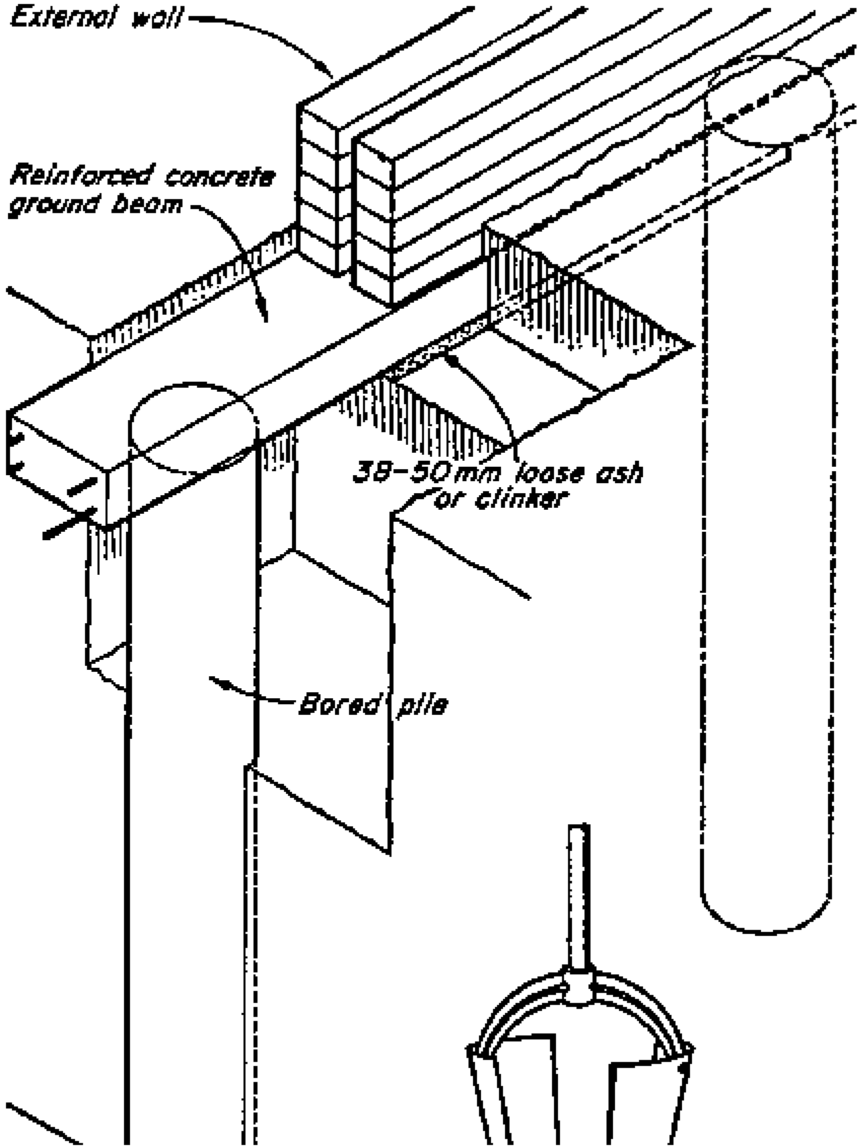


5.3.4.1 Short bored pile foundations

In shrinkable clays this foundation has a number of practical advantages over strip foundations: a reduction in the amount of excavated spoil, a cleaner site, faster construction and the fact that work can continue in weather which would make tranch digging impracticable. When mechanically bored in

continue in weather which would make trench digging impracticable. When mechanically bored in sufficient numbers this type of foundation is competitive in cost with a traditional strip foundation of appropriate depth. For a single building it may be slightly dearer than a deep strip foundation, although against this must be placed the advantages of the piles. Generally speaking, the stiffer the clay the

cheaper will this type of foundation be relative to strip foundations.



Short bored pile foundation

In order to obtain the advantages of greater speed and economy relative to strip foundations the clay must be suitable for easy boring. If many tree roots *are* present and the soil contains a great number of stones, especially if large, trench digging is likely to be quicker and cheaper than boring for piles, although if mechanical boring can be used, auges larger than hand boring will permit can be adopted which cope more easily with stones.

Mechanical boring is much quicker than hand boring, especially when the holes must be large, but to be economic requires a sufficiently large contract of work on one site and, as for any mechanical plant, requires adequate preparation of the site and the programme of work to be carefully planned in advance to avoid idle time.

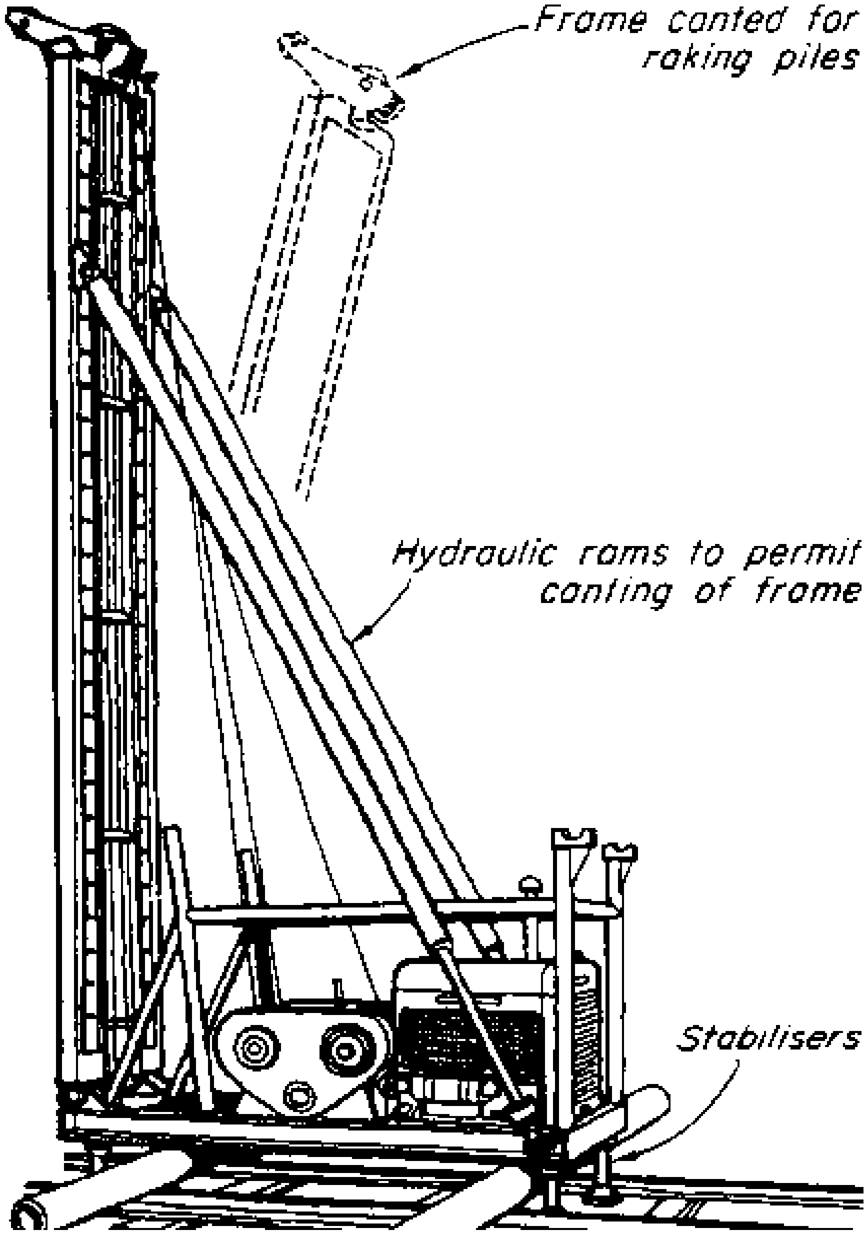
This type of foundation consists of a series of short concrete piles which, in the case of load-bearing wall structures, are spanned by a shallow reinforced concrete beam on which the wall is built (see fig.). Holes for the piles are bored manually or mechanically on the centre line of the beams to the required depth and diameter (see fig.). Small stones and layers of gravel present no problem but large stones must be broken up by a heavy chisel on extension rods. Larger augers cope with stones more easily than smaller ones but above 350 mm diameter the weight of the spil is too great for easy hand boring. A 250 mm diameter hole can be sunk 2.4 m in about 60 minutes, including rest periods, in soil free from stones.

In framed structures a pile or group of piles is placed under each column. In loadbearing wall structures piles are placed at the corners, at wall junctions and under stacks with further piles distributed between, sufficient to carry the imposed load, spaced as far as possible to produce uniform loading and to bring ground floor door and window openings centrally between piles.

Table 12 Permissible loads on short bored piles
Based on information in BR Digest 67 (second series)

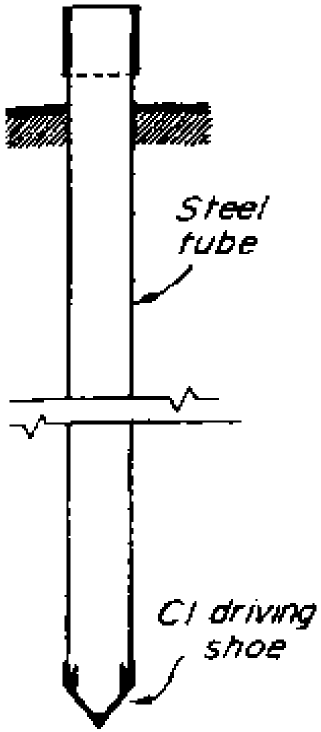
Soil strength classification	*Diameter of pile (mm)*	*Length of pile (m)*			
		2-4	3-05	3-66	4-27
		kN	kN	kN	kN
Stiff - cannot be moulded with fingers	254	40	50	60	70
(unconfined shear strength	305	50	60	75	90
more than 72 kN/m^2 - see Part 2)	356	65	80	95	110
Hard - brittle or tough	254	55	65	80	90
(unconfined shear strength	305	70	85	100	115
more than 143 kN/m^2 - see Part 2)	356	95	110	125	140

The figures are for clay which increases in strength with depth to the 'stiff' and 'hard' classifications near the bottom of the piles. The figures should not be applied to piles in other situations.

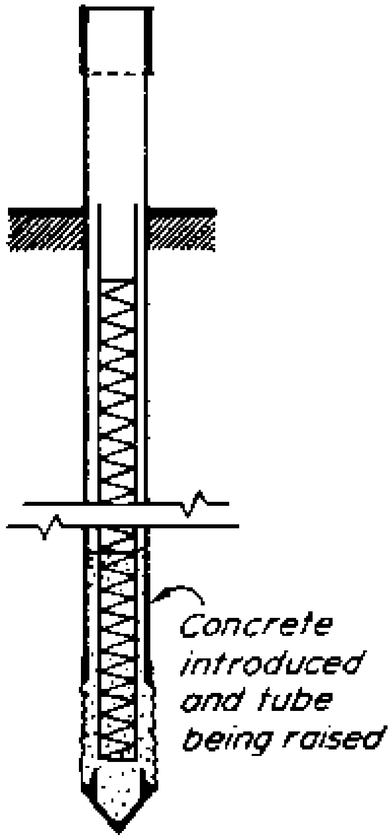

Frame canted for
raking piles
Hydraulic rams to permit
canting of frame
Stabilisers

Piling frame

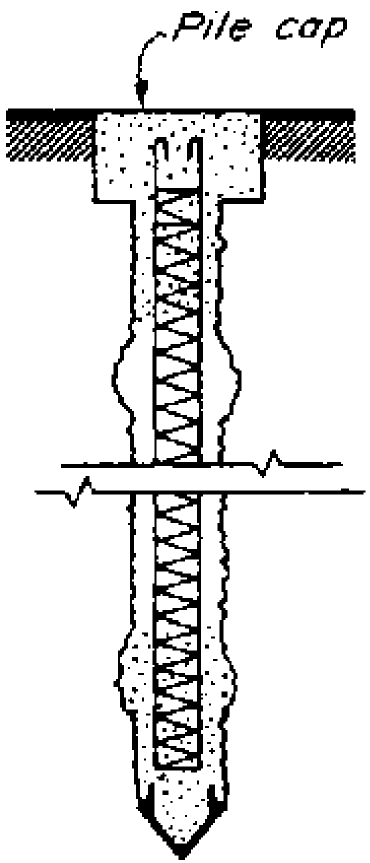
Top driven tube piles



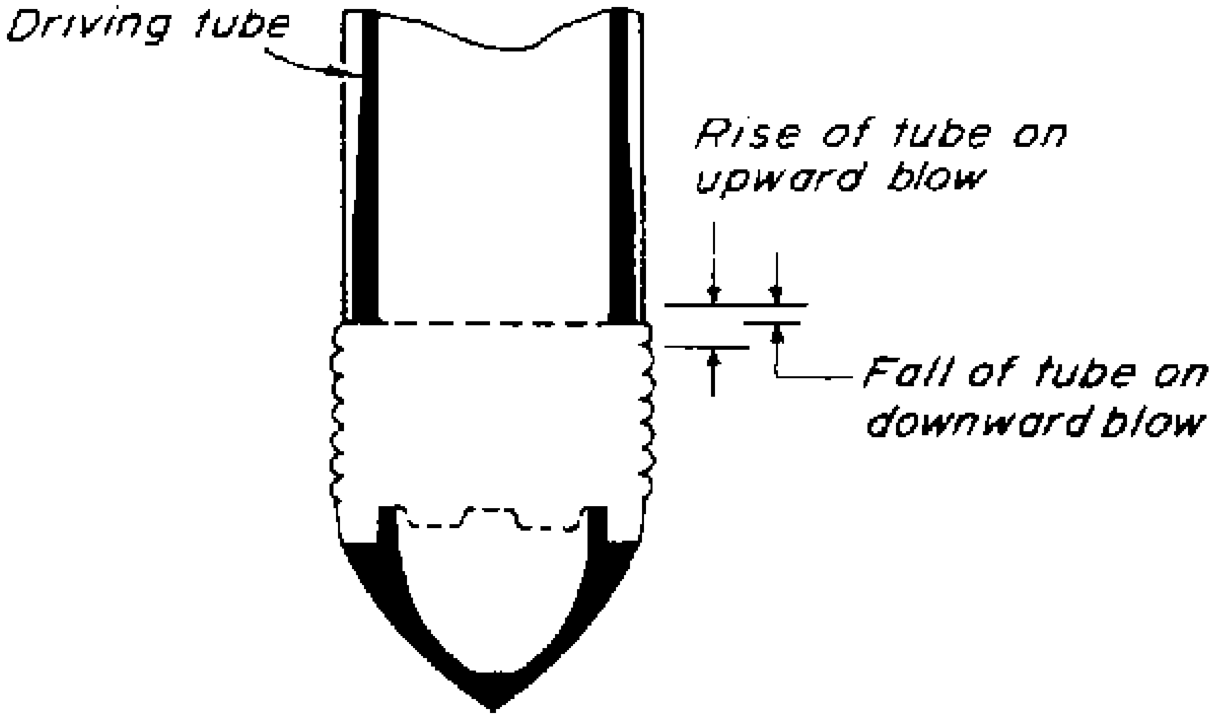
Tube driven



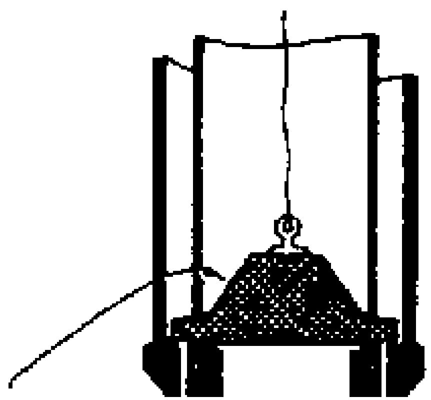
Forming pile

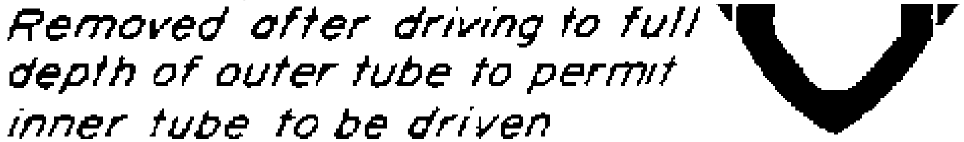


Completed pile



Tamping concrete by tube





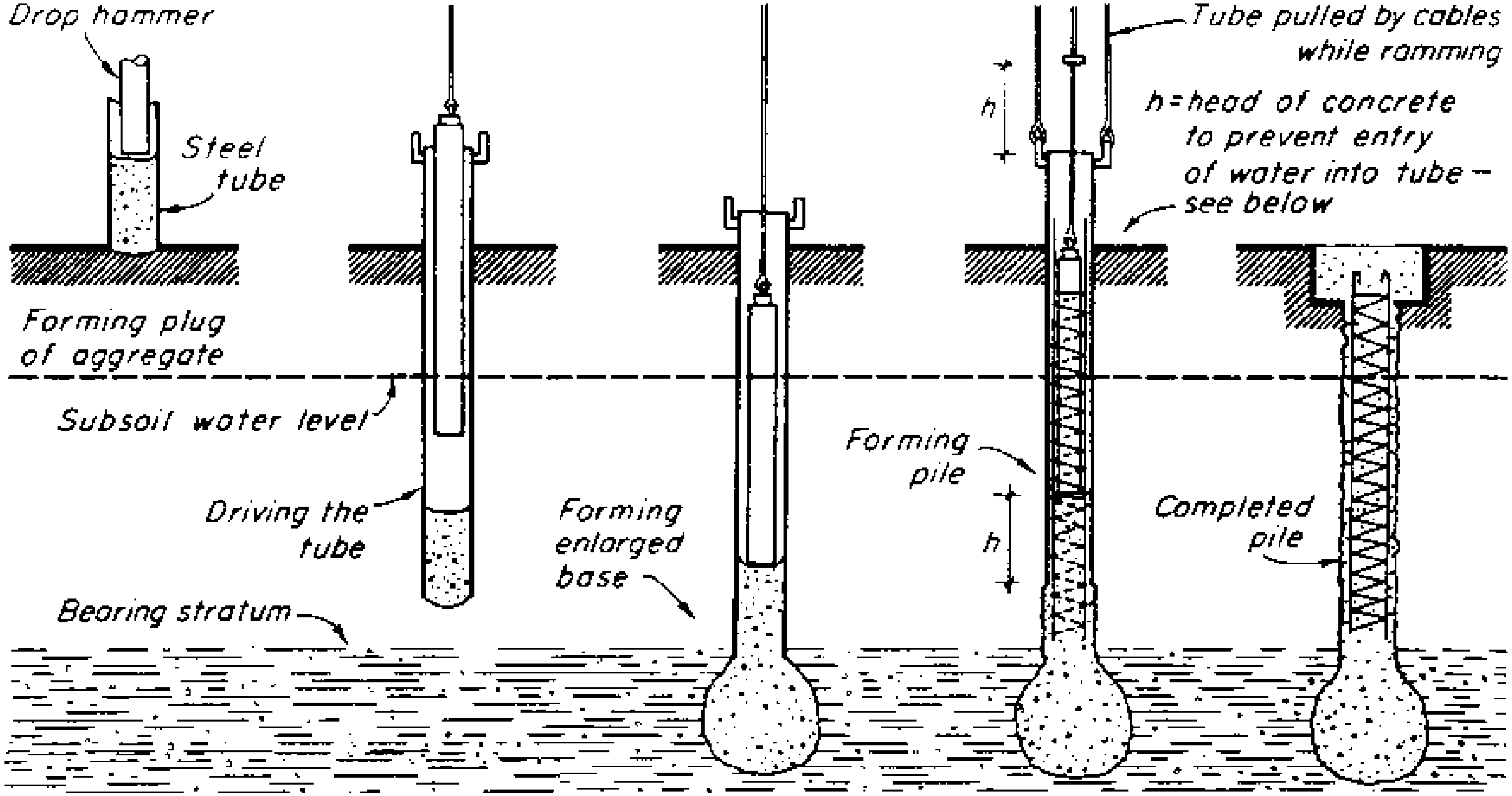
Toe of telescopic tube

The shallow reinforced concrete ground beams should have a depth/span ratio of 1/15 to 1/20. Reduced 'equivalent bending moments' are used in their design taking account of the fact that the brickwork on the beam tends to act with the beam and as an arch tending to concentrate' the load towards the supports. Top reinforcement is placed over the pile positions to take up the negative tensile stresses at these points.

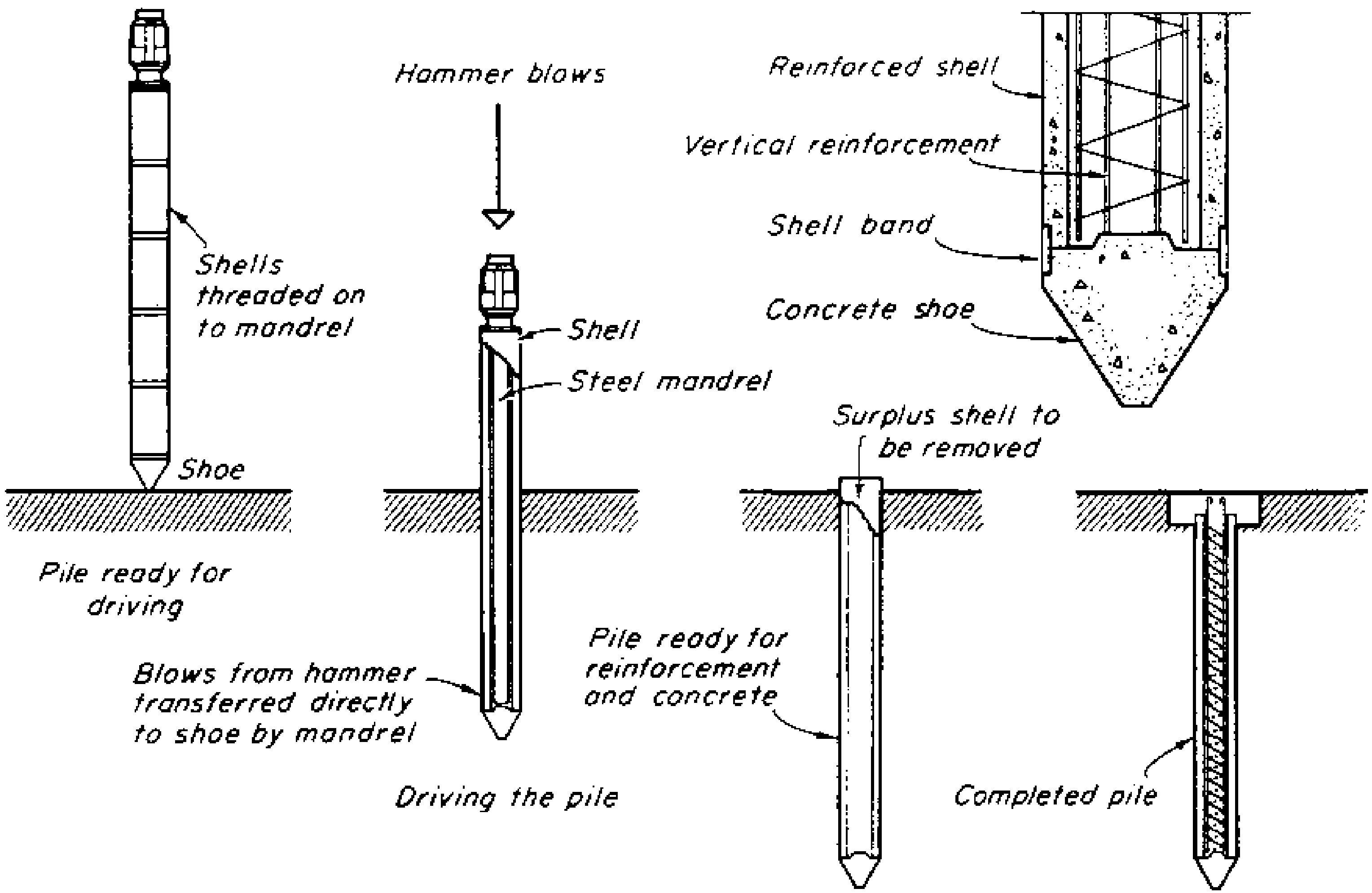
A 1:2:4 mix concrete is used for the work with a miminum water content to prevent excessive wetting and thus weakening of the clay. This is placed immediately each hole is bored, using a hopper to prevent soil entering the hole, each 305mm to 610 mm lift being thoroughly tamped. The beams are normally cast in a trench to avoid shuttering. If this is excavated before the holes are bored the concreting of piles and beams can be done simultaneously. If the beams are to be poured after the piles have set 9.5 mm diameter steel bars should be cast in the tops of the corner piles, set 610 mm in the pile and projecting 610 mm and bent over for casting in with the beams. A layer of 38 mm to 50 mm of loose ash or clinker must be placed under the beam to form a compressible layer to allow for ground movement below the beam.

Where trees exist on shrinkable clay soil closer to a building than their mature height or, in the case of groups or rows of trees, one and a half times their mature height, this type of foundation should always be used.

TOE DRIVEN TUBE PILES

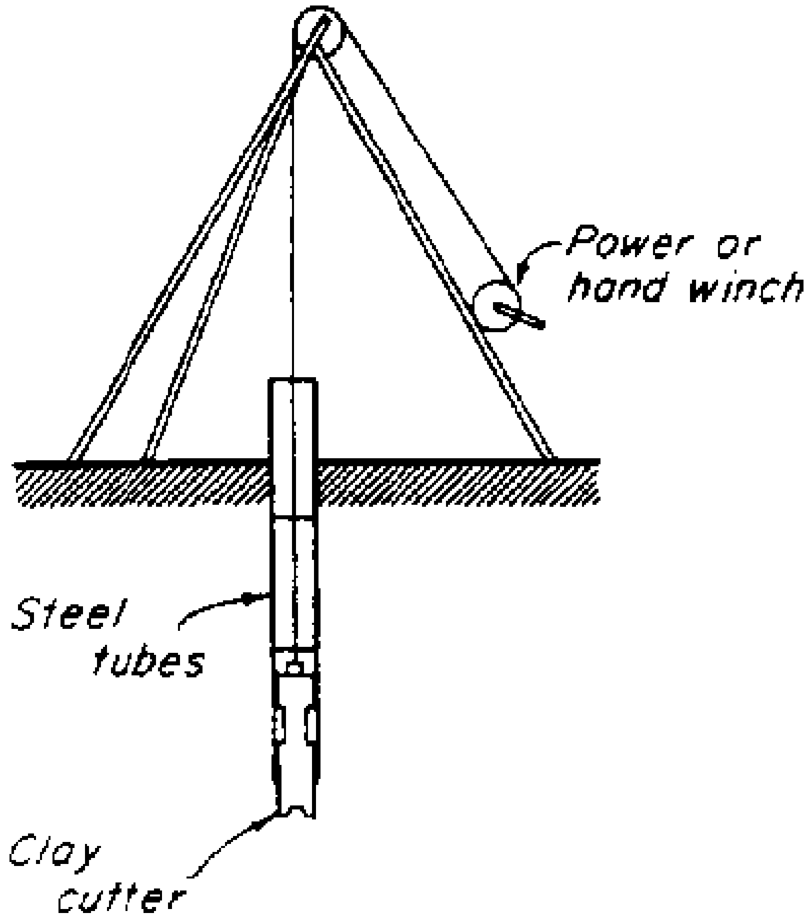


Driving tube by drop hammer

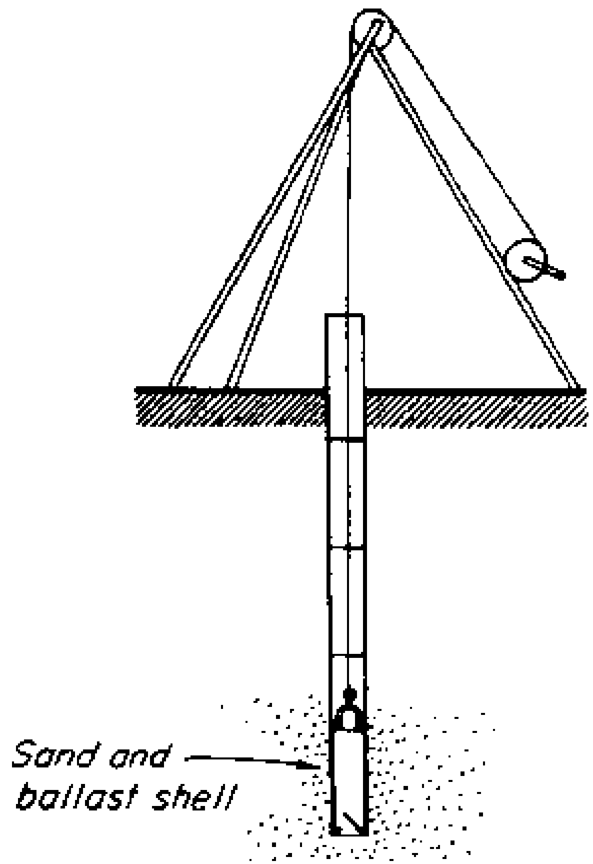


Driving tube by mandrel

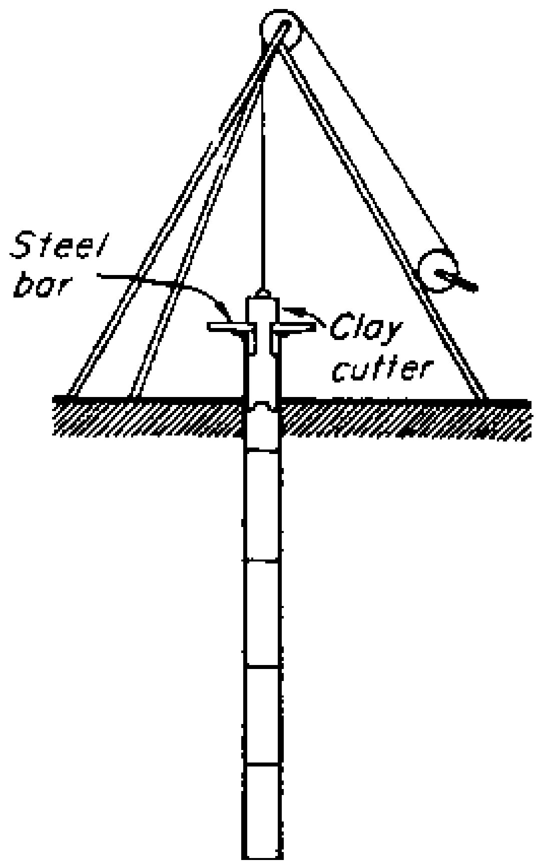
BORED PILES



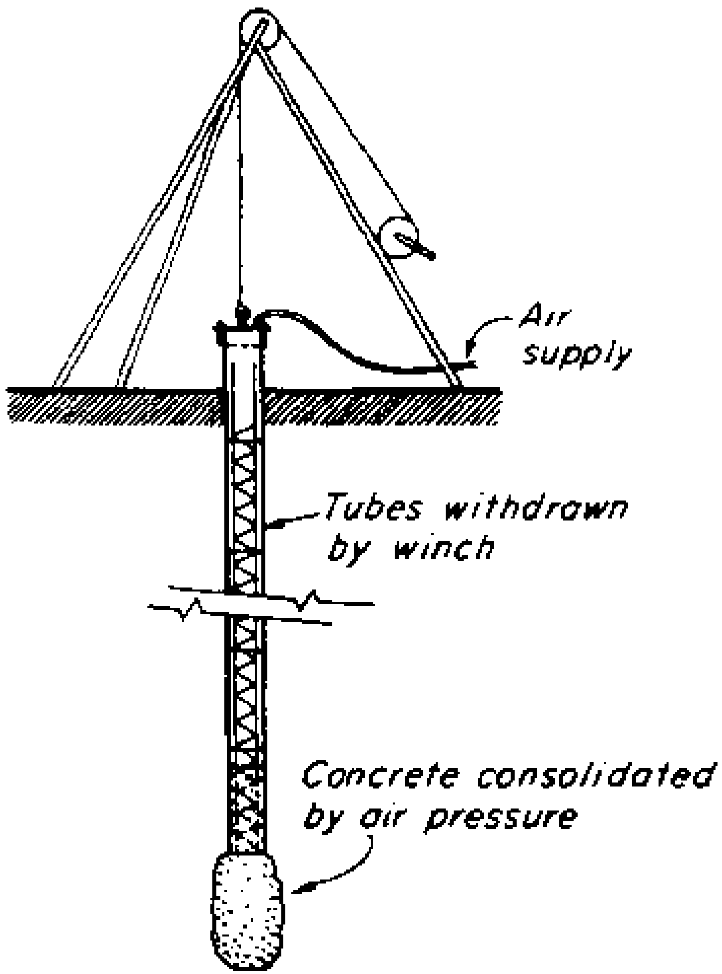
A Sinking tubes through clay



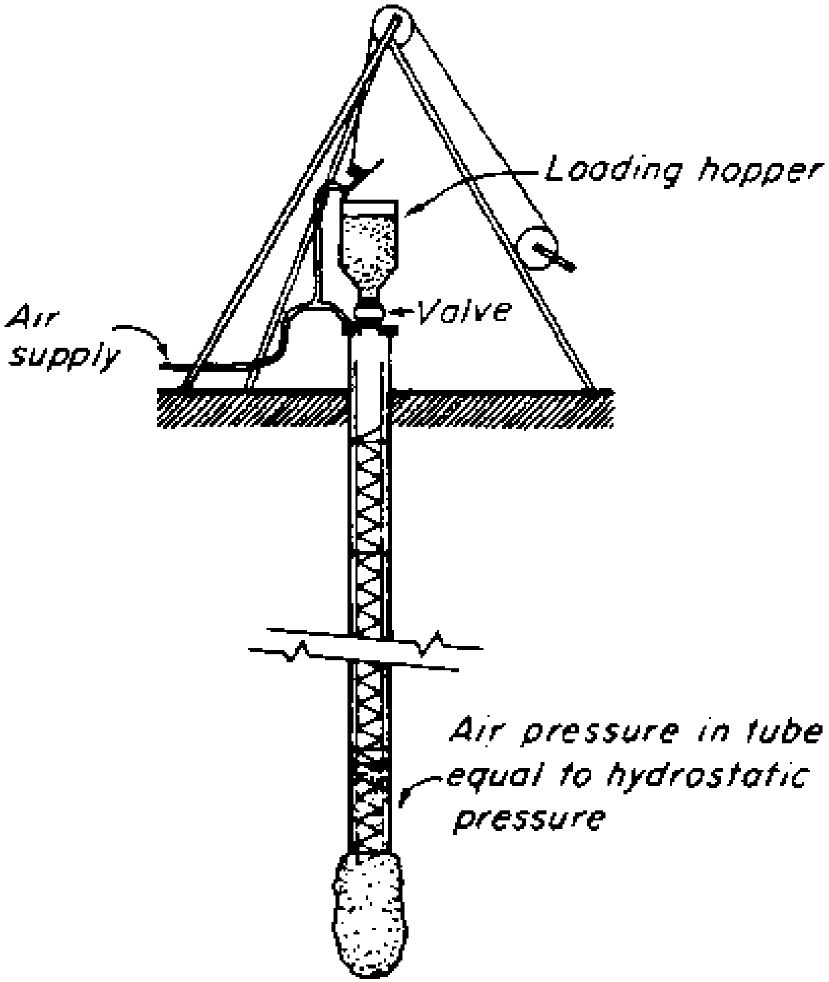
B Sinking tubes through ballast



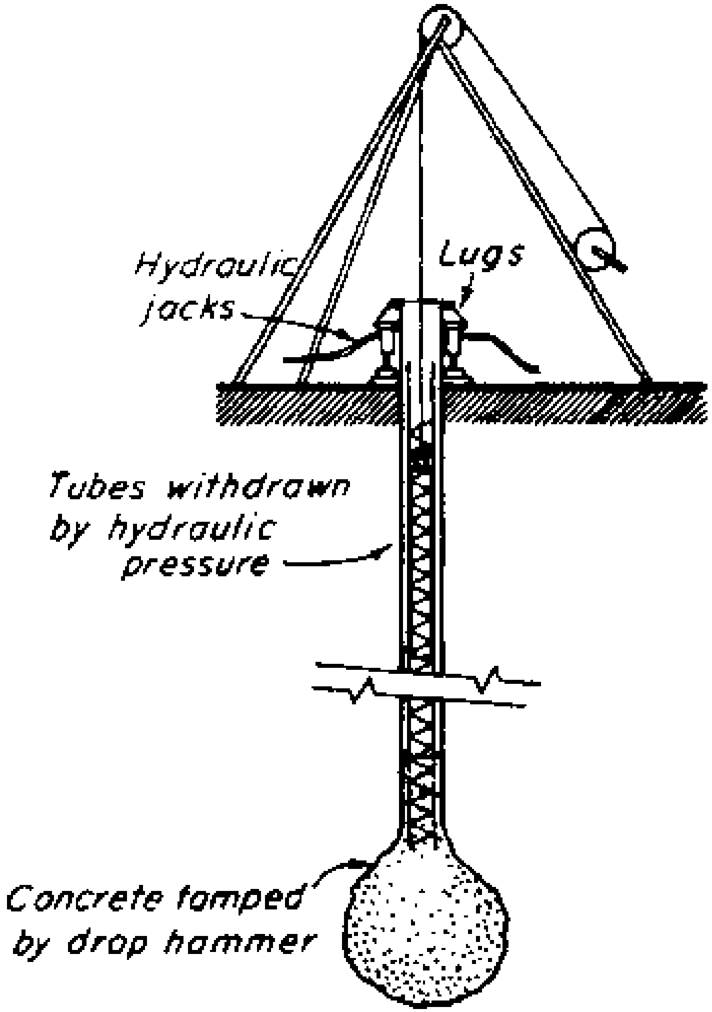
C Tube driving (when necessary)



D Forming pile with compressed air



E Placing concrete through an air lock



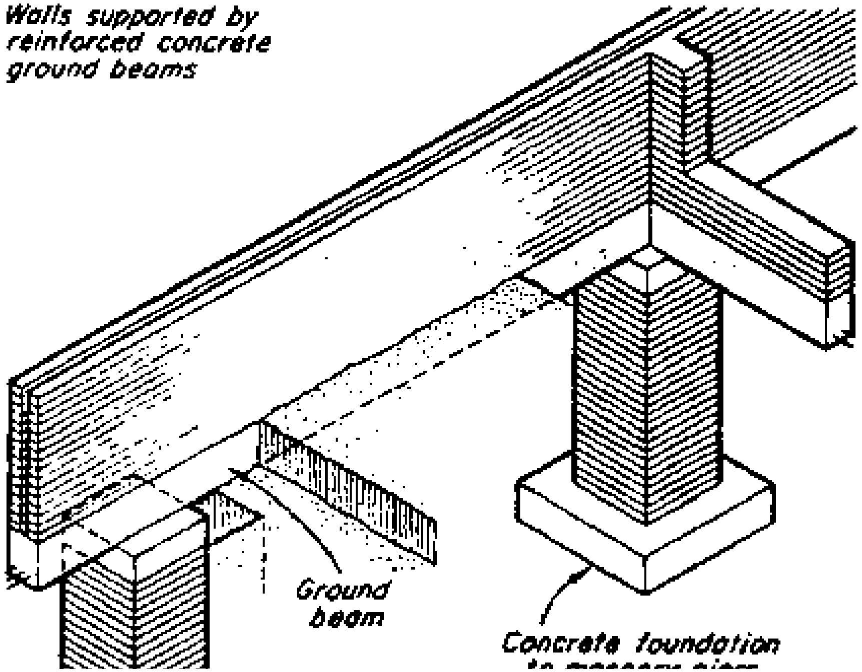
F Forming pile with a drop hammer

5.3.5 PIER FOUNDATIONS

These are frequently used on made-up ground where ordinary strip or pad foundations will often be inadequate to prevent excessive and unequal settlement, especially when the fill is poorly compacted. They can be economic up to depths of about 3.5 m to 4.5 m and consist of piers of brick, stone or mass concrete in excavated pits taken to the firm natural ground below. They are usually square and the size is dependent on the material used and the strength of the bearing soil below, but the smallest hole in which hand excavating can be carried out is about 1 m square. The foundation size is calculated as for a column base.

When this type of foundation is used the structure is carried on reinforced concrete ground beams spanning between the piers as shown in the fig.

Piles may be used in similar conditions but will need to be reinforced and as boring is not suitable through many types of fill on made-up ground piers provide a useful alternative within the economic limits of depth given above.



Pier foundations

• REPETITION • • exercises • • REPETITION •

Try to answer the following questions and use sketches for illustration

1. Foundations

- Define the purpose of FOUNDATIONS!

2. Soil Investigations

- When becomes SITE EXPLORATION necessary?

- What has to be considered digging TRIAL HOLES?

- Where are BOREHOLES used for and how are they made?

- Write notes on soil sampeling!

- Which tests are most important to the foundation designer and how are they carried out?

- Describe the LOAD or BEARING TEST!

- Write notes on SOILS and SOIL CHARACTERISTICS!

- Classify rocks and soils into 5 groups and describe briefly the type of soil of each group as well as their max. safe- bearing capacity.

- Explain the following terms:

    • shearing stress
    • vertical pressure
    • contact pressure
    • plastic failure

3. Excavations and Timbering

- What do you have to consider in EXCAVATIONS and TIMBERING of trenches?

4. Types of Foundations

- Classify the many forms of foundations

- Which factors must be taken into account in the CHOICE OF FOUNDATIONS?

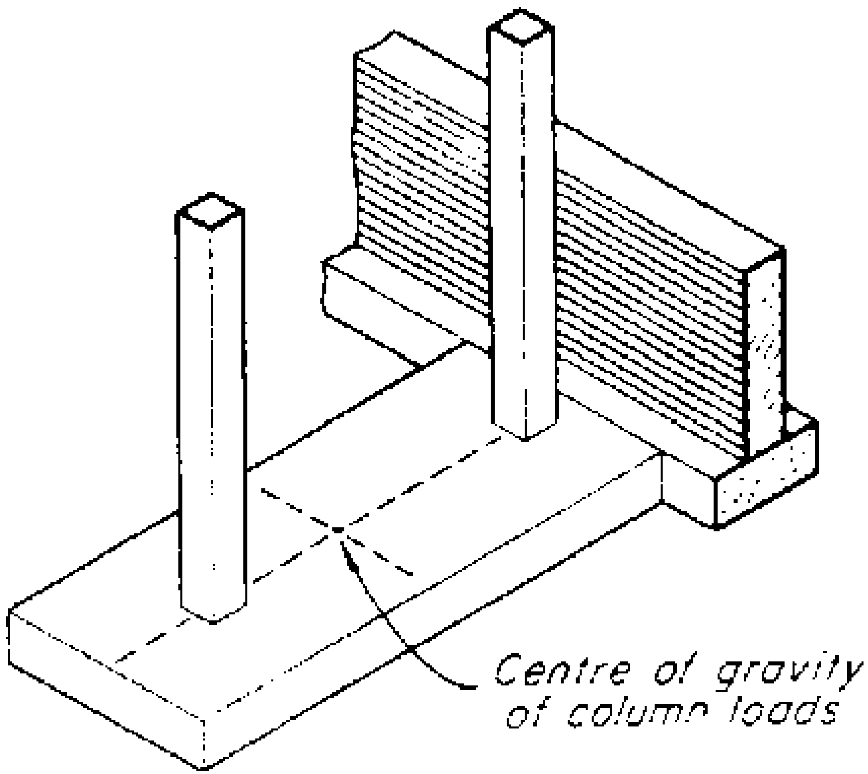
- Write notes on

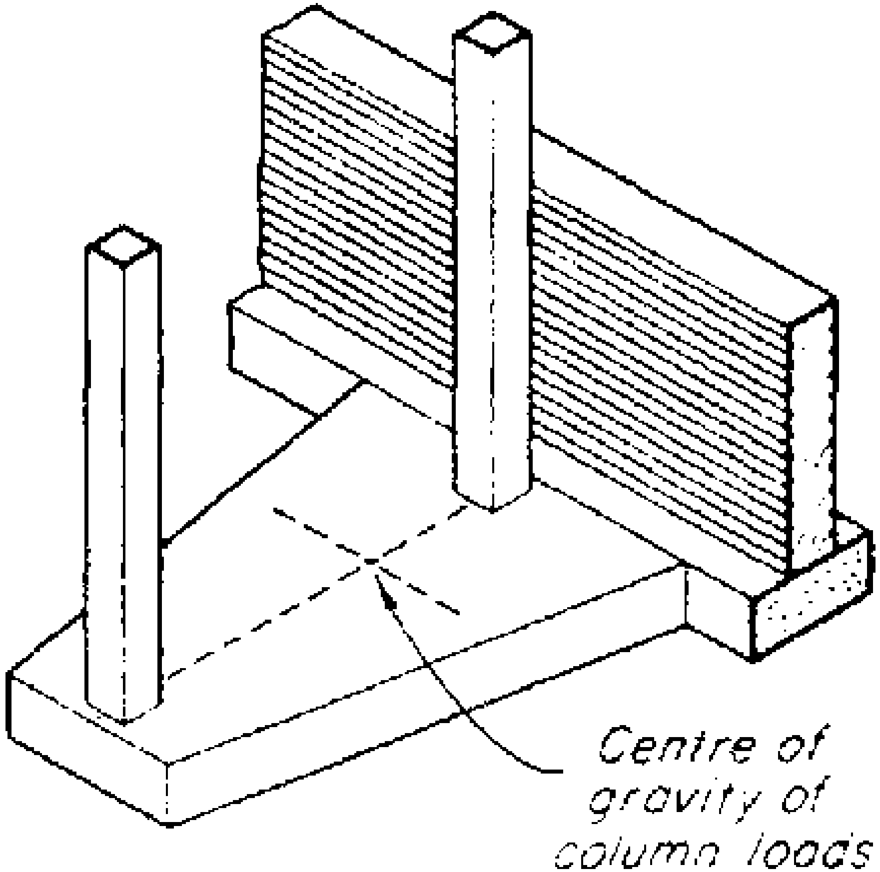
    • spread foundations
    • strip foundations
    • deep strip foundations
    • stepped foundations
    • pach foundations
    • raft foundations

- pile foundations
- short bored pile foundations
- pier foundations

and use neat sketches for illustration.

Combined foundations





Please provide your feedback English | French | Spanish | German