ENGINEERING STANDARD

FOR

FOUNDATIONS

ORIGINAL EDITION

JULY 1995

This standard specification is reviewed and updated by the relevant technical committee on Nov. 1997(1) and Aug. 2004(2). The approved modifications are included in the present issue of IPS.

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APPENDICES :

1. SCOPE

This Engineering Standard gives guidance and recommendations on general criteria relevant to the planning and design of foundations, as may be encountered in various civil engineering projects in the field of Iranian Petroleum Industries.

The Standard covers shallow and deep foundations generally used in buildings with normal range of complexity, as well as foundations subject to dynamic loads from machinery, and soil improvement techniques.

This standard does not cover the following subjects which are covered in relevant IPS as shown below:

- Foundations of onshore and offshore structures; (see respectively IPS-G-CE-470 and IPS-G-CE-480).
- Special foundations like dams etc.
- The structural aspects of foundations i.e: reinforced concrete structures, (see IPS-E-CE-200).
- Pile foundations, see IPS-E-CE-130.

It should however be noted that certain aspects of deep foundations covered in this Standard may be common in both fields of foundations and maritime structures.

This Standard is written in general terms and its application to any particular project may be subject to special requirements of the work under consideration.

Note 1:

This standard specification is reviewed and updated by the relevant technical committee on Nov. 1997. The approved modifications by T.C. were sent to IPS users as amendment No. 1 by circular No 14 on Nov. 1997. These modifications are included in the present issue of IPS.

Note 2:

This standard specification is reviewed and updated by the relevant technical committee on Aug. 2004. The approved modifications by T.C. were sent to IPS users as amendment No. 2 by circular No 239 on Aug. 2004. These modifications are included in the present issue of IPS.

2. REFERENCES

Throughout this Standard the following dated and undated standards/codes are referred to. These referenced documents shall, to the extent specified herein, form a part of this standard. For dated references, the edition cited applies. The applicability of changes in dated references that occur after the cited date shall be mutually agreed upon by the company and the vendor. For undated references, the latest edition of the referenced documents (including any supplements and amendments) applies.

2.1 IPS (IRANIAN PETROLEUM STANDARDS)

IPS-C-ME-100	"Construction Standard for Atmospheric above Ground Welded Steel Storage Tanks"
IPS-E-CE-110	"Engineering Standard for Soil Engineering"
IPS-E-CE-500	"Engineering Standard for Loads"
IPS-E-CE-130	"Engineering Standard for Piles"
IPS-E-CE-140	"Engineering Standard for Retaining Walls"

IPS-E-CE-200	"Engineering Standard for Concrete Structures"
IPS-G-CE-470	"Engineering and Construction Standard for Onshore Facilities"
IPS-G-CE-480	"Engineering and Construction Standard for Offshore Facilities"

2.2 BSI (BRITISH STANDARDS INSTITUTION)

BS 8004: 1986	"Code of Practice for Foundations"
BS 5930: 1999	"Code of Practice for Site Investigations"
CP 2012: Part 1: 1974	"Foundations for Reciprocating Machines"
BS 2654: 1989	"Standard Specification for Manufacture of Vertical Steel Welded Non-Refri- gerated Storage Tanks with Butt-Welded Shells for Petroleum Industry"

2.3 API (AMERICAN PETROLEUM INSTITUTE)

API Std. 650	"Welded Steel Tanks for Oil Storage, 1998"

2.4 DIN (DEUTSCHES INSTITUT FÜR NORMUNG EV.)

DIN 4024 1988	"Supporting Structures for Rotary Machines"

3. DEFINITIONS AND TERMINOLOGY

The following terms are defined for general use in this Engineering Standard. For more information see section 1.2 BS 8004 1986.

Allowable net Bearing Pressure: The maximum allowable net loading intensity at the base of the foundation, taking into account the ultimate bearing capacity, the amount and kind of settlement expected and the ability of the structure to accommodate this settlement.

Caisson: A structure that is sunk through ground or water for the purpose of excavating and placing work at the prescribed depth and which subsequently becomes an integral part of the permanent work.

Box Caisson: A caisson which is closed at the bottom but open to the atmosphere at the top.

Compressed air Caisson: A caisson with a working chamber in which the air is maintained above atmospheric pressure to prevent the entry of water and ground into the excavation.

Open Caisson: A caisson open both at the top and at the bottom.

Factor of Safety: The ratio of the ultimate bearing capacity to the intensity of the applied bearing pressure or the ratio of the ultimate load to the applied load.

Foundation: That part of the structure designed and constructed to be in direct contact with and transmitting loads to the ground.

Pad Foundation: An isolated foundation to spread a concentrated load.

Raft (or Mat) Foundation: A foundation continuous in two directions, usually convering an area equal to or greater than the base area of the structure.

Strip Foundation: A foundation providing a continuous longitudinal ground bearing.

Foundation Engineering: The science and art of applying the principles of soil and structural mechanics, together with engineering judgment, to solve the interfacing problems.

Grouting: The injection of appropriate materials under pressure into rock or soil through drilled holes to change the physical characteristics of the formation. The results are sealing of voids, cracks, seams, and fissures in the existing rock\ or soil, and rendering of them less permeable and stronger.

Natural Frequency: The frequency of free vibration of a body.

Pier: Category applied to columnlike concrete foundations, similar to piles. The pier is generally considered the type of deep foundation that is constructed by placing concrete in a deep excavation large enough to permit manual inspection.

Pier is also used frequently to indicate heavy masonry column units which are used for basement-level and substructural support.

Pile: The relatively long, slender, columnlike type of foundation that obtains supporting capacity from the soil or rock some distance below the ground surface.

Presumed Bearing Value: The net loading intensity considered appropriate to the particular type of ground for preliminary design purposes.

Note:

Values for various types of ground are usually given in the form of a table. The particular value is based either on experience or on calculation from laboratory strength tests or field loading tests using a factor of safety against bearing capacity failure.

Resonance Frequency: A condition which occurs when a periodic force is exerted on a body at a frequency equal to that of its natural frequency.

Soil Stabilization: Manipulation of foundation or base soils with or without admixtures, to increase their load-carrying capacity and resistance to physical and chemical stress of the environment over the service life of the engineered facility.

Properties of soil such as strength, stiffness, compressibility, permeability, workability, swelling potential, frost susceptibility, water sensitivity, and volume change tendency may be altered by various methods of soil stabilization.

Substructure: That part of any structure (including building, road, runway or earthwork) which is below natural or artificial ground level. In a bridge this includes piers and abutments (and wing walls), whether below ground level or not, which support the superstructure.

Ultimate Bearing Capacity: The value of the gross loading intensity for a particular foundation at which the resistance of the soil to displacement of the foundation is fully mobilized.

4. UNITS

This Standard is based on International System of Units (SI), except where otherwise specified.

5. GENERAL CONSIDERATIONS

5.1 Foundation Classification

Foundations for plant, equipment, structures and buildings are broadly classified as follows:

- Shallow foundations which consists of pad foundations, strip foundations, raft (mat) foundations, etc.,
- Deep foundations which consist of deep pad or strip foundation, basement or hollow boxes, caissons, cylinders and piers, piles, etc.,
- Storage tank foundations which consist of tank pads, ring walls, etc.,
- Foundations for machinery.

In the following clauses different aspects of the above mentioned foundation types are discussed. Foundations for storage tanks are discussed under Appendix A.

5.2 Site Investigation

Site investigation consists of assessment of suitability of the site as well as ground explorations and tests. It may range in scope from a simple examination of the surface soils, with or without trial pits, to a detailed study of the soil and ground water conditions to a considerable depth below the surface by means of boreholes and insitu laboratory tests. (see Clause 5.3.1). Depending on the importance of the structure AR* can reduce the extent of investigations. For more detailed information see BS 5930 1999.

*** AR = Authorized Representative of the Owner.**

For a fairly detailed study, the following information should be obtained:

a) The general topography of the site as it affects foundation design and construction. e.g. surface configuration, adjacent property, the presence of watercourses, ponds, hedges, trees, rock outcrops, etc.,

b) The location of buried services such as electric power and telephone cables, water mains, and sewers.

c) The general geology of the area with particular reference to the main geological formations underlying the site.

d) The previous history and use of the site including information on any defects or failures of existing or former buildings attributable to foundation conditions.

e) Any special features such as the possibility of earthquakes or climatic factors such as flooding, seasonal swelling and shrinkage, permafrost, or soil erosion.

f) The availability and quality of local construction materials such as concrete aggregates, building and road stone, and water for constructional purposes.

In addition to the above mentioned items information on soil and rock strata and results of laboratory tests is necessary which is discussed under Clause 5.3.1.

5.3 Ground Considerations

5.3.1 Ground exploration and tests

Ground exploration should be performed to ascertain the character and variability of the strata underlying the site of the proposed structure. Ground investigations should be carried out generally in accordance with IPS-E-CE-110.

For additional information refer to Clause 2.2 of BS 8004: 1986.

5.3.2 Ground movements

Foundation design should ensure that foundation movements are within limits that can be tolerated by the proposed structure without impairing its functions. Ground movement can be divided into two categories:

a) Movements due to application of foundation loads.

b) Movements independent of applied foundation loads.

5.3.2.1 (a) Movements due to application of foundation loads

Application of an increased load through the foundations of a structure results in deformation of the ground and settlement.

Settlements are divided into immediate settlement, which takes place as load is applied and long-term settlement which may continue for some time after application of load.

One type of long-term settlement on soils is known as consolidation settlement and is due to expulsion of air are water from voids in the soil, resulting in volume reduction. In clay soils, this process may takes years to reach an equilibrium condition.

For more detailed information see clause 2.1.2.3 BS 8004-1986.

(a.1) Shear deformation and failure

In order to guard against the possibility of shear failure or substantial shear deformation, the foundation pressures used in design should have an adequate factor of safety when compared with the ultimate bearing capacity for the foundation.

Methods for estimating the allowable net bearing pressure for foundations are outlined in Clause 5.5. In Table 1 presumed bearing values for foundations on various types of ground are given.

(a.2) Settlement

The magnitude of the settlement that will occur when foundation loads are applied to the ground depends on the rigidity of the structure, the type and duration of loading and the deformation characteristics of the ground. In silts and clays consolidation settlement may continue for a long period after the structure is completed, because the rate at which the water can drain from the voids under the influence of the applied stresses is slow; allowance will need to made for this slow consolidation settlement.

It should be appreciated that new construction may lead to additional settlement of adjacent structures. The design of the foundations should take this possibility into account.

5.3.2.2 (b) Movements independent of applied foundation loads

Movements may result from causes not connected with the loads applied by the foundations. The causes of ground and foundation movement are as follows:

- Seasonal changes or the effects of vegetation leading to shrinking and swelling of clay soils ;
- frost heave;
- the application of artificial heat (thermal load) or cold to the supporting ground;
- changes in groundwater level resulting from designed or unforeseeable drainage, or modification of the groundwater regime by construction, or by natural causes ;
- loss of ground due to erosion (including internal erosion) or solution by percolating water, and loss of fines by pumping operations;
- changes in the state of stress in the ground due to adjacent excavations, dredging, scour or erosion by streams or floods, or due to the erection of adjoining structures;
- continuing settlement of natural deposits or fill;
- soil creep or landslides on slopes;
- movement of ground resulting from sink or swallow holes or underground workings (including mining and tunneling);
- vibrations, including seismic disturbances;
- deterioration of made ground or fill;
- alteration of the properties of the ground due to natural or artificial causes; In the design of foundations the possibility of these movements should be considered and, when necessary, steps should be taken to minimize any damage that may result from these causes.

5.3.3 Ground water

In the design of foundations, the effect of groundwater should always be carefully considered.

Substructures should be designed to be stable with any groundwater level that is likely to occur.

For more detailed information see BS5930 1999.

5.4 Foundation Loads

5.4.1 Loads under static conditions

The maximum load on the foundation will be the sum of the dead, live (imposed) and wind loads. The maximum bearing pressure will depend on the distribution, direction and eccentricity of the loads.

However, the load to be considered in the various aspects of design will not necessarily include the full value of these loads. Loads used in the design of foundations should be unfactored values. Where the foundation loading beneath a structure due to wind is a relatively small proportion of the total loading, it may be permissible to ignore the wind loading in the assessment of the allowable bearing pressure, provided the overall factor of safety against shear failure is adequate. Where individual foundation loads due to wind are less than 25% of the loading's due to dead and live loads, the wind loads may be ignored in this assessment.

Where this ratio exceeds 25%, foundations may be so proportioned that the pressure due to combined dead, live and wind loads does not exceed the allowable bearing pressure by more than 25%.

When considering the long-term settlement of foundations the live load should be taken as the likely realistic applied load over the early years of occupancy of the structure.

Consolidation settlements should not necessarily be calculated on the basis of the maximum live load. For more details refer to Clause 2.3.2.4 of BS 8004: 1986.

5.4.2 Dynamic loads

The dynamic loads considered include both impulsive and pulsating loads where the time period is sufficiently short to induce a vibratory response into the structure and its foundations. In regions, where occurrence of earthquake is probable, special attention should be paid to the possible effects of earthquake specially from liquefaction point of view, (refer to IPS-E-CE-110, Appendix A). For more details refer to Clause 2.3.2.5 of BS 8004: 1986.

5.5 Allowable Bearing Capacities

5.5.1 General

Allowable bearing capacities are most important in designing of deep foundations. It is covered in Clause 6.8.8 of IPS-E- CE-130.

For shallow foundations, the ultimate soil-bearing capacity is related to the properties of the soil, including the past stress history and proximity of the ground water table. It is also affected by the characteristics of the foundation, including size, depth, shape and the method of construction.

5.5.2 Presumed allowable bearing value

Foundation design is at present possible only by trial and error methods, it is then, desirable to have some basis for preliminary design assumptions.

Universally applicable values of allowable bearing pressure cannot be suggested. Table 1 gives an indication of values to be used as allowable bearing pressure for preliminary design purposes. It is emphasized that these values should be used by the designer only for preliminary design stages and, in all cases, he should then review and, if necessary amend his preliminary design. This will frequently entail an estimate of settlements.

For more detailed information refer to Clause 2.2.2 of BS 8004: 1986.

TABLE 1 - PRESUMED ALLOWABLE BEARING VALUES UNDER STATIC LOADING

Table 1. Presumed allowable bearing values under static loading (see 1.2.3 and 1.2.4)

NOTE. These values are for preliminary design purposes only, and may need alteration upwards or downwards. No addition has been made for the depth of embedment of the foundation (see 2.1.2.3.2 and 2.1.2.3.3).

Category	Types of rocks and soils	Presumed allowable bearing value		Remarks
		kN/m^2 *	kgf/cm^2 * $tonf/ft^2$	
Rocks	Strong igneous and gneissic rocks in sound condition	10 000	100	These values are based on the assumption that the foundations are taken down to unweathered rock. For weak, weathered and broken rock, see 2.2.2.3.1.12
	Strong limestones and strong sandstones	4 000	40	
	Schists and slates	3 000	30	
	Strong shales, strong mudstones and strong siltstones	2 000	20	
Non-cohesive soils	Dense gravel, or dense sand and gravel	> 600	> 6	Width of foundation not less than 1 m. Groundwater level assumed to be a depth not less than below the base of the foundation. For effect of relative density and groundwater level, see 2.2.2.3.2
	Medium dense gravel, or medium dense sand and gravel	< 200 to 600	< 2 to 6	
	Loose gravel, or loose sand and gravel	< 200	< 2	
	Compact sand	> 300	> 3	
	Medium dense sand	100 to 300	1 to 3	
	Loose sand	< 100	< 1	
		Value depending on degree of looseness		
Cohesive soils	Very stiff boulder clays and hard clays	300 to 600	3 to 6	Group 3 is susceptible to long-term consolidation settlement (see 2.1.2.3.3). For consistencies of clays, see table 5
	Stiff clays	150 to 300	1.5 to 3	
	Firm clays	75 to 150	0.75 to 1.5	
	Soft clays and silts	< 75	< 0.75	
	Very soft clays and silts	Not applicable		
Peat and organic soils		Not applicable		See 2.2.2.3.4
Made ground or fill		Not applicable		See 2.2.2.3.5

$*107.25\ kN/m^2 = 1.094\ kgf/cm^2 = 1\ tonf/ft^2$.

Notes:

1) Peat and organic soils are materials with a high proportion of fibrous or spongy textured vegetable matter formed by the decay of plants, mixed with varying proportions of fine sand, silt or clay.

All these soils are highly compressible, and even lightly loaded foundations will be subject to considerable settlements over a long period if placed on them. For this reason these soils are not suitable for carrying the loads from important structures.

Lowering of the groundwater also produces a considerable and prolonged settlement. In general, it is necessary to carry foundations down through peat and organic soil to a reliable bearing stratum below.

2) All made ground should be treated as suspect because of the likelihood of extreme variability. Any proposal to found a structure on made ground should be investigated with extreme care. Made ground may be insanitary or may contain injurious chemicals and toxic and flammable gases. Industrial waste or town refuse may still be in a state of chemical activity, and waste often ignites and burns below ground. Loading tests may be completely misleading because of the variability of such deposits.

TABLE 2 - UNDRAINED (IMMEDIATE) SHEAR STRENGTH OF COHESIVE SOILS

CONSISTENCY	FIELD INDICATIONS	UNDRAINED (IMMEDIATE) SHEAR STRENGTH kgf /cm^2
Very stiff or hard	Brittle or very tough	Greater than 1.5
Stiff	Cannot be moulded in the fingers	1.0 to 1.5
Firm to stiff		0.75 to 1.0
Firm	Can be moulded in the fingers by strong pressure	0.5 to 0.75
Soft to firm		0.4 to 0.5
Soft	Easily moulded in the fingers	0.2 to 0.4
Very soft	Exudes between the fingers when squeezed in the fist	Less than 0.2

5.6 Design Considerations

5.6.1 General requirements of foundation design

A foundation must be capable of satisfying several stability and deformation requirements such as:

1) Depth must be adequate to avoid lateral expulsion of material from beneath the foundation, particularly for footings and mats.

2) Depth must be below the zone of seasonal volume changes caused by freezing, thawing, and plant growth.

3) System must be safe against overturning, rotation, sliding, or soil rupture (shear-strength failure).

4) System must be safe against corrosion or deterioration due to harmful materials present in the soil. This is a particular concern in reclaiming sanitary landfills and sometimes for marine foundations.

5) System should be adequate to sustain some changes in later site or construction geometry, and be easily modified should later changes be major in scope.

6) The foundation should be economical in terms of the method of installation.

7) Total earth movements (generally settlements) and differential movements should be tolerable for both the foundation and superstructure elements.

8) The foundation, and its construction, must meet environmental protection standards.

5.6.2 General procedures in foundation design

The various steps which should be followed in the design of foundations are as follows.

(i) A site investigation should be undertaken to determine the physical and chemical characteristics of the soilsand rocks beneath the site. The general principles and procedures described in Clause 5.2 should be considered.

(ii) The magnitude and distribution of loading from the superstructure should be established and placed in the various categories, namely:

Dead loading (permanent structure and self-weight of foundations).

"Permanent" live loading (e.g. materials stored in silos, bunkers or warehouses).

Intermittent live loading (human occupancy of buildings, vehicular traffic, wind pressures).

Dynamic loading (traffic and machinery vibrations, wind gusts, earthquakes).

(iii) The total and differential settlements which can be tolerated by the structure should be established. The tolerable limits depend on the allowable stresses in the superstructure, the need to avoid architectural damage to claddings and finishes.

Acceptable differential settlements depend on the type of structure, e.g. framed industrial shedding with pinjointed steel or pre-cast concrete elements and sheet metal cladding can withstand a much greater degree of differential settlement than a presentable office building with plastered finishes and tiled floors. Table 3 specifies the limiting settlements for structures.

(iv) The most suitable type of foundation and its depth below ground level should be established having regard to the information obtained from the site investigation and taking into consideration the functional requirements

of the substructure. For example a basement may be needed for storage purposes or for parking cars.

(v) Preliminary values of the allowable bearing pressures (or pile loading's) appropriate to the type of foundation should be determined from a knowledge of the ground conditions and the tolerable settlements.

(vi) The pressure distribution beneath the foundations should be calculated based on an assessment of foundation widths corresponding to the preliminary bearing pressures or pile loading's, and taking into account eccentric or inclined loading.

(vii) A settlement analysis should be made, and from the results the preliminary bearing pressures or foundation depths may need to be adjusted to ensure that total and differential settlements are within acceptable limits. The settlement analysis may be based on simple empirical rules or a mathematical analysis taking into account measured compressibility of the soil.

(viii) Approximate cost estimates should be made of alternative designs, from which the final design should be selected.

(ix) Materials for foundations should be selected and concrete mixes designed taking into account any aggressive substances which may be present in the soil or ground water, or in the overlying water in submerged foundations.

(x) The structural design should be prepared.

(xi) The working drawings should be made. These should take into account the constructional problems involved and where necessary they should be accompanied by drawings showing the various stages of construction and the design of temporary works such as cofferdams, shoring or underpinning.

TABLE 3 - LIMITING SETTLEMENTS FOR STRUCTURES

TYPE OF MOVEMENT	TYPE OF STRUCTURE	MAX. ALLOWABLE SETTLEMENT OR DIFFERENTIAL MOVEMENT
Total settlement	Masonry-Walled structures Framed structures	25 to 50 mm 50 to 100 mm
Tilting	Tilting OF SMOKE STACKS AND TOWERS	0.004 h(1)
Differential movement	- Machine operation - Crane rails - High continuous brick walls - Reinforced-Concrete building frame - Steel frame, continuous - Simple steel frame	0,002L to 0,003L(2) 0,003L 0,0005L to 0,001L 0,002L to 0,004L 0,002L 0,005L

Notes:

1) h = Hight of the stack

2) L = Distance between adjacent columns that settle different amounts, or between any two points that settle differently.

3) Higher values of allowable settlement are for regular settlements and more tolerant structures. Lower values are for irregular settlements and critical structures.

5.6.3 Protection of foundations

Protection of foundation materials in aggressive environments is a necessity to be taken into consideration in the design stage.

Generally waterfront facilities (particularly in massive and tidal exposures) have a much higher incidence of material deterioration than land-based facilities.

For detailed information on measures to be taken to combat foundation deterioration and methods to prolong their life, refer to Section 10 of BS 8004: 1986.

6. SHALLOW FOUNDATIONS

6.1 General

Shallow foundations are taken to be those where the depth below finished ground level is less than 3m, the various types of shallow foundations are:

- Pad foundations;
- Strip foundations;
- Raft or mat foundations;
- Short piling.

In the following clauses a brief description of the shallow foundations is given.

For more detailed information see section 3.0 BS 8004-1986.

6.2 General Design Considerations

The depth to which foundations should be carried depends on three principal factors:

a) reaching an adequate bearing stratum;

b) in the case of clay soils, penetration with suitable precautions below the zone where shrinkage and swelling due to seasonal weather changes, trees, shrubs and other vegetation are likely to cause appreciable movement.

c) penetration below the zone in which trouble may be expected from frost.

Other factors such as ground movements, changes in ground water conditions, long-term stability and heat transmitted from structures to the supporting ground may be important. Shallow foundations are particularly vulnerable to certain soil conditions, e.g. sensitive clays, loose water-bearing sands and soils that change structure when loaded. Specialist advice should be sought where such conditions are indicated by ground investigation.

The selection of the appropriate type of shallow foundation will normally depend on the magnitude and disposition of the structural loads, the bearing capacity and settlement characteristics of the ground and the need to found in stable soil.

For more detailed information see section 3.2 BS 8004-1986.

6.3 Pad Foundations

Pad foundation is an isolated foundation to spread a concentrated load. Pad foundations are suitable to support the columns of framed structures. Pad foundations supporting lightly loaded columns can be constructed using unreinforced concrete in which case the depth is proportioned so that the angle of spread from the base of the column to outer edge of the ground bearing does not exceed 1 vertical to 1 horizontal.

For buildings other than low rise and lightly framed structures, it is customary to use reinforced concrete foundations.

The thickness of the foundation should under no circumstances be less than 150 mm and will generally be greater than this to maintain cover to reinforcement where provided.

Where concrete foundations are used they should be designed in accordance with the IPS-E-CE-200.

6.4 Strip Foundations

Strip foundations are suitable for supporting load-bearing walls in brickwork or blockwork. Similar considerations to those for pad foundations apply to strip foundations.

In continuous wall foundations it is recommended that reinforcement be provided wherever an abrupt change in magnitude of load or variation in ground support occurs.

Continuous wall foundations will normally be constructed in mass concrete provided that the angle of spread of load from the edge of the wall base to the outer edge of the ground bearing does not exceed one (vertical) in one (horizontal). Foundations on sloping ground, and where regrading is likely to take place, may require to be designed as retaining walls to accommodate steps between adjacent ground floor slabs or finished ground levels.

At all changes of level unreinforced foundations should be lapped at the steps for a distance at least equal to the thickness of the foundation or a minimum of 300 mm. Where the height of the step exceeds the thickness of the foundation, special precautions should be taken.

The thickness of reinforced strip foundations should be not less than 150 mm, and care should be taken with the excavation levels to ensure that this minimum thickness is maintained.

For the longitudinal spread of loads, sufficient reinforcement should be provided to withstand the tensions induced. It will sometimes be desirable to make strip foundations of inverted tee beam sections, in order to provide adequate stiffness in the longitudinal direction. At corners and junctions the longitudinal reinforcement of each wall foundation should be lapped.

Where the use of ordinary strip foundations would overstress the bearing strata, wide strip foundations designed to transmit the foundation loads across the full width of the strip may be used. The depth below the finished ground level should be the same as for ordinary strip foundations.

6.5 Raft Foundations (also called mat foundations)

Raft foundations are a means of spreading foundation loads over a wide area thus minimizing bearing pressures and limiting settlement. By stiffening the rafts with beams and providing reinforcement in two directions the differential settlements can be reduced to a minimum.

In general, raft foundations may be used in the following circumstances:

a) For lightly loaded structures on soft natural ground where it is necessary to spread the load, or where there is variable support due to natural variations, made ground or weaker zones. In this case the function of the raft is to act as a bridge across the weaker zones.

Rafts may form part of compensated foundations (see Clause 7.5).

b) Where differential settlements are likely to be significant. The raft will require special design, involving an assessment of the disposition and distribution of loads, contact pressures and stiffness of the soil and raft.

c) Where mining subsidence is liable to occur. Design of the raft and structure to accommodate subsidence requires consideration by suitably qualified persons; the effects of mining may often involve provision of a flexible structure.

d) When building such as low rise dwellings and lightly framed structures have to be erected on soils susceptible to excessive shrinking and swelling, consideration should then be given to raft foundations placed on fully compacted selected fill material used as replacement for the surface layers.

e) For heavier structures where the ground conditions are such that there are unlikely to be significant differential settlements or heave, individual loads may be accommodated by isolated foundations. If these foundations occupy a large part of the available area they may, subject to design considerations, be joined to form a raft.

The layout of service pipes, drains, etc., should be considered at the design stage so that the structural strength of a raft does not become unduly reduced by holes, ducts, etc.

6.6 Short Piling

Where it is necessary to transmit foundation loads from buildings such as low rise dwellings or lightly framed structures through soft or made ground, or unstable formations or shrinking/swelling clays more than about 2 m deep, the use of short piles should be considered as an alternative to shallow foundations, particularly where a high groundwater table is encountered.

The type, method of construction, size and load capacity should be carefully considered in relation to the associated requirements of pile caps and ground beams necessary to transfer loads from the superstructure to the piles.

For more information refer to IPS-E-CE-130 "Piles".

7. DEEP FOUNDATIONS

7.1 General

Deep foundations are the ones for which D> 4 to 5 B or D>3 , B/H<1/6

Where:

D = The depth of foundation.

B = The width of foundation.

H = The hight of foundation

They are generally used when the soil strata immediately beneath the structure are so weak or compressible that they are not capable of supporting the load and it is necessary to lower the foundation until more suitable soils are reached.

For more detailed information see section 4.0 BS 8004-1986.

7.2 Types of Deep Foundations

Deep foundations may be classified as follows:

a) Deep pad or strip footings.

b) Basements or hollow boxes (floating foundations).

c) Caissons

These may be open well caissons or pneumatic caissons.

d) Cylinders and piers

These may be excavated in the dry by hand, by mechanical means or, in the wet by mechanical means including boring and slurry wall techniques.

e) Piles

f) Peripheral walls

Concrete walls constructed in a slurry-filled trench or as adjoining bored piles, as well as being used as basement or retaining walls, may also carry vertical loads in conjunction with their retaining functions.

g) Mixed foundations

These may be a combination of any of (a) to (f).

h) Ground improvement

Where the ground does not have adequate bearing characteristics and stability, consideration may be given to general or local improvement of the bearing characteristics or to replacement of the ground in depth. It may then be possible to use a shallow foundation or a cheaper type of deep foundation.

7.3 Selection of the Type of Deep Foundations

The choice of foundation type in many instances will depend on a combination of technical, programmatic and economic M factors.

In general, where a deep foundation is unavoidable, a large number of fairly small but dispersed loads can most economically be carried by piles, either prefabricated or cast in situ. Heavy concentrated loads may better be carried on deep footings, piers, cylinders, large bored piles or caissons.

One of the commonest forms of deep foundation is the conventional basement, constructed either in open excavation or in a supported excavation, depending on the nature of the ground, groundwater conditions and the proximity of other structures or services.

In the following paragraphs different types of deep foundations are briefly discussed:

7.4 Deep Pad or Strip Foundations

These are the simplest of all deep foundations and are generally used for carrying heavy column loads, the load being transmitted to the footing by means of a concrete pedestal or directly by the column; such foundations may be of various shapes, including circular, square, rectangular or strip, the shape being adjusted in the design to accommodate the effect of eccentricity arising from imposed moments and shear forces on the column and the method of construction.

They are generally used where groundwater problems are unlikely to arise or where the groundwater if present can be readily controlled.

7.5 Basement or Hollow Boxes (Floating Foundation)

Where the groundwater table is at or below formation level or can be lowered economically for construction, then a basement or hollow box foundation (floating foundation) may be constructed in open excavation. The techniques are then very similar to those for building above ground level, except that special attention will have to be paid to waterproofing when a watertight structure is required and allowance will need to be made for the lateral earth pressure and any negative skin friction which may develop after backfilling. The effect of possible fluctuations in the groundwater table and of flooding during and after construction should be considered.

In addition to the extra space gained by basement construction a further advantage is the reduction in net loading applied to the supporting ground by the removal of the excavated soil and water. Tall structures may then be built on ground which would otherwise be incapable of carrying the same load on shallow foundations without excessive settlement or failure. Such foundation is called a "floating foundation" or sometimes "buoyant foundation" or "compensated foundation".

The problems of heave and swell of clay soils have to be carefully considered as well as buoyancy at times of possible high groundwater levels, particularly in the case of over-compensated foundations such as empty submerged tanks, swimming pools and buried garages.

For more detailed information refer to Clause 4.3.3 of BS 8004: 1986.

7.6 Caissons

Caissons are structural elements of a foundation which are wholly or partially constructed at a higher level and are then sunk to their final position by various expedients. They are used when the final foundation level is at some depth below the water table.

Caissons are frequently used for sewage pump stations and bridge piers, particularly where the foundation needs to be some depth below sea or river bed level to avoid the effects of scour at flood times. Caissons are sometimes sunk through artificial sand islands in order to make possible the construction of the caisson from a working level above water level; they have also been used to form the foundations for buildings. Owing to the high cost of labor in working under compressed air, other possible forms of foundation should be investigated carefully before a pneumatic caisson is adopted.

7.7 Cylinders and Piers

Cylinders are essentially small open well caissons comprising single cells which are of circular cross section. (The term pier is sometimes used for similar foundations of circular or other shaped cross section). The distinction between cylinders and caissons is one of size and is necessarily arbitrary. Because of their smaller size, cylinders lend themselves more readily to the use of precast elements in their construction.

Cylinders are often filled with concrete and are sometimes reinforced.

7.8 Piles

Piled foundations are discussed in IPS-E-CE-130 and section 7.0 BS 8004 1986.

7.9 Peripheral Walls

Concrete walls constructed in a slurry-filled trench or as adjoining bored piles, as well as being used as basement or retaining walls, may also carry vertical loads in conjunction with their retaining functions.

Diaphragm wall techniques are used to form loadbearing foundation structures (sometimes referred to as barrettes) which may be of rectangular, cruciform, hollow box or other plan shapes.

For detailed information on techniques for constructing diaphragm walls of adjoining piles refer to Clauses 4.3.7 and 6.5 of BS 8004: 1986.

7.10 Mixed Foundations

When site investigation indicates that ground conditions are not uniform, it is important to provide the type and size of foundations appropriate to the ground conditions existing on the site.

When ground conditions are not uniform, the use of more than one type of foundation could result in greater economy.

When using mixed foundations, special attention will need to be paid to the effect on the structure, particularly where differential settlements can occur.

For more detailed information see section 4.3.8 BS 8004-1986.

8. MACHINERY FOUNDATIONS

8.1 General

Machinery foundations are subjected to dynamic loading in the form of thrusts transmitted by the torque of rotating machinery or reactions from reciprocating engines.

Thermal stresses in the foundation may be high as a result of fuel combustion, exhaust gases or steam, or from manufacturing processes.

Machinery foundations should have sufficient mass to absorb vibrations within the foundation block, thus eliminating or reducing the transmission of vibration energy to surroundings; they should spread the load to the ground so that excessive settlement does not occur under dead weight or impact forces and should have adequate structural strength to resist internal stresses due to loading and thermal movements.

In addition to the general requirements specified in Clauses 5 to 7 of this Engineering Standard, the following should be considered in the design of machinery foundations:

a) Large machines or any machine which may have large out-of-balance forces shall be supported on structures and foundations which have been designed to minimize:

- Vibration of the machine.
- Transmission of vibration to adjacent foundations, equipment and buildings.

Design of these structures and foundations shall be in accordance with:

BS CP 2012: Part 1 Foundations for reciprocating machines.

DIN 4024 Supporting structures for rotary machines.

b) Machinery foundations shall be adequately reinforced in all surfaces, vertical and horizontal. Where they are integral with floors or paving slabs, the designer shall ensure that adequate reinforcement is provided to prevent the propagation of cracks from the surface due to vibration.

c) Large machines or any machines with large out-of-balance forces shall be grouted in accordance with manufacturers' requirements, using a flowable non-metallic non-shrink grout. Special grouts shall be placed in accordance with the manufacturer's instructions. Placing should be supervised by a qualified representative of the manufacturer. Attention shall be given to the following requirements:

1) Holdingdown bolt pockets and the space under the bedplates shall be filled and all air expelled.

2) Where holdingdown bolts are grouted into pockets formed in the foundation block, the grout shall withstand stresses consistent with the tension forces applied when the bolts are pulled-up, plus forces originating from machine operation. The pulling-up forces shall be agreed with the machine supplier and adequate factors built into the grouting system to allow for the methods of assessing those that may have been used.

3) Grout thickness should be within the range 25-50 mm.

d) Some large machines, particularly those which may have out-of-balance forces, e.g., reciprocating compressors, may require alternative means of mounting such as channels or rails set in the foundation block, in which case details shall be subject to approval by AR.

e) Holding-down bolts shall adequately resist all horizontal forces, in addition to the vetical forces, originating from the machine.

f) The distance from any pocket or bolt to the edge of the block shall be at least 100 mm in order to allow for reinforcement.

8.2 Classifications and Type of Machinery Foundations

There are various kinds of machines that generate different periodic forces. The three most important categories are:

1) Reciprocating machines; machines that produce periodic unbalanced force (such as compressors and reciprocating engines).

2) Impact machines; included in this category are machines that produce impact loads, for instance, forging hammers.

3) Rotary machines; high-speed machines, like turbogenerators or rotary compressors.

Suitable foundations should be selected depending upon the type of machine being installed. Some of the most popular ones are categorized as follows;:

1) Block type foundation, consisting of a thick slab of concrete directly supporting the machine and other fixed auxiliary equipment.

2) Elevated pedestal foundation (table top), consisting of a base slab and vertical columns supporting a grid of beams at the top on which rests skid mounted machinery.

3) Pile foundations are often used to support vibratory loads when soil conditions at a site indicate that shallow foundations will result in unacceptable permanent settlements.

For more detailed information refer to BSI, CP 2012 Part 1: 1974.

8.3 Soil Data

Qualitative information concerning the behavior of foundations under dynamic loading can be obtained from a knowledge of the relative density and of index properties such as bulk density, moisture content and particle size distribution.

It is noted in the case of granular soils in particular that the relative density, rather than absolute density, is significant, and may require laboratory measurements of maximum and minimum densities.

Particular attention should be paid to obtaining samples with a minimum disturbance, and in saturated fine granular material care should be taken that such disturbance does not give rise to apparently very low relative densities in situ.

Estimation of the relative density by means of in situ testing methods may also be employed.

In addition, information is required about the dynamic elastic properties of the ground; the rigidity modulus G or the Mcompression modulus E with Poison's ratio v, or some equivalent, should be determined. For more information about soil tests refer to IPS-E-CE-110.

8.4 Method of Analysis

There are two principal methods of analysis of a machine foundation:

- A method based on linear elastic weightless spring;

- A method based on linear theory of elasticity (elastic half space).

The preferred method of analysis of foundation block response to dynamic load is based upon the theory of the "elastic half space" and requires the dynamic elastic moduli of the ground to be either measured or estimated.

For detailed information refer to BSI, CP 2012: Part 1: 1974.

8.5 Design Considerations

The first essential of a design is to ensure that resonance will not occur between the frequency of the pulsating load and a critical frequency in the foundation-soil system. Resonance may lead to excessive amplitudes of vibration of the system.

Even when resonance is avoided it is still necessary to limit amplitudes to levels that can be tolerated by the machine and the foundation. While the level of vibration may be acceptable by the machine and the soil from the point of view of settlement, it may give rise to resonance in windows, doors and partitions of associated structures, and this may call for reduction of amplitudes or isolation of the vibrating system. (See Clause 8.6)

The natural frequency of the foundation can be decreased by increasing the effective system mass, by decreasing the base contact area, or if possible, by reducing the shear modulus. This frequency should be out of the range of 0.8 to 1.2 times the operating frequency of the machinery.

The natural frequency of the foundation system can be increased by stiffening the soil (compaction, admixtures and compaction, or piles,).

8.6 Anti-Vibration Mountings

Amongst the methods of absorbing vibrations one of the simplest is to provide sufficient mass in the foundation block, so that the waves are attenuated and absorbed by reflections within the block itself. A long established rule in machinery foundations is to make the weight of the block equal to or greater than the weight of the machine. This procedure is generally satisfactory for normal machinery where there are no large out-of-balance forces.

However, in the case of heavy forging hammers and presses, or large reciprocating engines, it is quite likely that the vibrations cannot be absorbed fully by the foundation block.

Where it is found to be impracticable to design a foundation consisting of a simple concrete block resting on the natural soils to give satisfactory dynamic characteristics, it may be possible to reduce the transmitted vibrations to acceptable levels by means of anti-vibration mountings.

Depending upon the nature of the machinery and the installation, the anti-vibration mountings may be utilized;

1) between the machinery and its foundation;

2) between a foundation block and a supporting foundation.

The former arrangement is generally suitable where the out-of-balance forces are not severe and it should be noted that the natural frequencies of the system will be modified to a degree which depends upon the resilience, design and position of the anti-vibration mountings. The latter course may be used where it is necessary to increase the moments of inertia so that frequencies and amplitudes may be modified to acceptable limits.

The many forms of commercially available anti-vibration mountings can be classified broadly as follows.

1) Unit mountings

Unit mountings may utilize a spring support consisting of either a steel spring,. with the addition of some damping device, or rubber which may be loaded in compression, shear or a combination of compression and shear. Alternative suspension media may be used in unit mountings, for example, pressurized air springs and viscous devices.

2) Area mountings

The simple form of the area-mounting type of installation consists of a carpet of resilient material upon which the foundation block is cast. Many proprietary examples are available and selection may be made from a wide range of cork, agglomerated cork, felt and rubber products.

3) Foundation block suspension

Foundation block suspension is an alternative method of isolating a foundation block from a supporting foundation. The block together with all the machinery is suspended by utilizing leaf or coil springs or some equivalent form of resilient support.

For more detailed information refer to Clause 3.5.8 of BSI, CP 2012 Part 1: 1974.

9. GEOTECHNICAL PROCESSES FOR GROUND IMPROVEMENT

9.1 General

Several methods are available to decrease the permeability, increase the strength or decrease the compressibility of the ground. In the following clauses a brief description of various ground improvement techniques is given.

9.2 Control of Ground Water

Ground water control is one of the most important foundation engineering problems. There are many methods to control the ground water which depend, upon such factors as: the dimensions of the excavation; the thickness and type of soil strata; the position of the excavation and permanent structure relative to the soil strata; the magnitude of the water pressures in the various strata; the prevention of damage to adjacent structures; the length of time for which the excavation has to be open and the overall economics of any particular solutions.

In the following sub-clauses different methods of ground water control is discussed.

9.2.1 Gravity drainage

Where site conditions permit, water should be drained by gravity from an excavation; this may be possible on a sloping site where ground water can be collected in a sump in one corner on the downhill side of the excavation, or a gravity drain can be installed to a discharge point farther down the slope.

9.2.2 Pumping

Water may be removed from excavations by pumping from sumps, well points or deep wells. The method adopted will depend upon soil conditions, depth of excavation below ground water level, the method of supporting the sides of the excavation etc.

A well point is a suction device used as a small well that can be readily installed in the ground and withdrawn.

The well point system has the advantage of low capital cost; it is quickly installed and can readily be moved from one position to another. Deep well system is primarily devised for use in connection with deep excavations and is of special value where artesian water is present below an impermeable stratum.

For more detailed information refer to Clauses 6.4.3 and 6.4.4 of BS 8004, 1986.

9.2.3 Special methods for excluding water from excavation

In certain cases excluding water from excavations may be implemented by using special methods like:

- use of compressed air;
- freezing the surrounding ground;
- cast-in-situ diaphragm walls;
- use of injection methods to form an impervious wall around the excavation;

The choice of each method depends, to a great extent, on site conditions, the soil characteristics and the availability of technology etc. For detailed information on the above- mentioned methods refer to Clause 6.5 of BS 8004, 1986.

9.3 Methods of Improving the Physical Properties of the Ground

Several methods are available to improve the physical properties of the ground. These methods are: preloading compaction, installation of vertical drains, injection of grouts and electrochemical and thermal hardening of the ground. In the following clauses a short description about various methods are given. For more information see section 6.6 BS 8004 1986.

9.3.1 Shallow compaction

Loose or disturbed granular soils at the base of excavations for strip or pad foundations can be compacted by rolling or ramming. Vibratory rollers or plate compactors work efficiently in granular soils but the depth of compaction with ordinary equipment is unlikely to exceed about 300 mm.

For more detailed information see section 6.6.2 BS 8004-1986.

9.3.2 Preloading

The preloading is applied by means of a mound of soil or rubble imposing a bearing pressure on the ground equal to or higher than that of the permanent structure. The preloading material is kept in place until level measurements show that the time-settlement curve has flattened or that the settlement has decreased to a very slow rate.

When preloading soft clays or clay fills the rate of settlement of the mound may be rather slow, requiring the load to be in place for many months. In such cases consideration should be given to accelerating the rate of consolidation of the soil by the introduction of vertical drains, (see Clause 9.3.6).

9.3.3 Deep compaction by vibration

The settlement due to loading of loose non-cohesive granular soils or fill materials above or below the water table can be improved by deep compaction, achieved by introducing large tubular vibrators into the ground to depths of up to 25 m. This process may be an economical alternative to piling or other methods of improving the bearing capacity of such soils. Liquefaction risk of loose soils under earthquake shocks can also be reduced by compaction.

For more detailed information refer to Clause 6.6.3 of BS 8004, 1986.

9.3.4 Ground improvement by vibro-displacement and vibro-replacement

Large vibrators are also used to place columns of coarse granular material in soft silts or clays or weak compressible fills with the primary objective of reducing their compressibility but also to improve shearing resistance.

Foundations can then be constructed directly on groups or rows of these columns.

Clays strong enough to permit a stable unlined bore may be displaced by penetration of the vibrator which is then removed to allow gravel or stone to be tipped and compacted by the vibrator in about 1 m stages to fill the hole.

Some forced compaction of the ground surrounding the column is achieved; this is known as vibro displacement.

In soft unstable soils, water circulation is used to support the bore as in washboring.

For more details refer to Clause 6.6.4 of BS 8004, l986.

9.3.5 Deep compaction by heavy tamping

This process is for compacting granular soils and silts or mixtures of these including a large variety of fills. It may also be employed to displace soft organic soils with a stronger fill.

It involves simply dropping a free-falling weight, usually of 10 t to 15 t, from heights varying between 5 m and 25 m or more onto the ground surface. Forced compaction results from dissipation of energy of successive impulses inducing a degree of irreversible compression of void spaces.

For more detailed information refer to Clause 6.6.5 of BS 8004, 1986.

9.3.6 Vertical drains

The natural process of consolidation of compressible soils can be accelerated by improving the drainage conditions within the soils, so assisting in the outward migration of the water.

This condition can be anticipated and exploited to accelerate drainage of the compressible soils by installing vertical columns of sand or strips of preformed permeable material within the ground to enable the excess water to escape more rapidly. These columns are called sand drains, vertical drains or wick drains, and are frequently considered for improving the strength of the soil.

9.3.7 Electro-osmosis

The electro-osmosis system can be used to reduce the moisture content of a very silty clay or clayey silt and thus increase its shear strength and reduce its compressibility.

It consists of an electrical potential to drive the water to negative electrodes at the wells, using expandable metal rods as the positive electrodes.

Electro-osmosis has been employed to remedy a difficult situation where other methods have failed.

9.3.8 Grouting

Grouting is used to reduce the permeability of the ground or to improve its strength, or to do both.

The geology of the ground will influence the choice of method of grouting and it is axiomatic that no treatment can be properly considered until an adequate site investigation of the relevant ground and water conditions has been undertaken.

Possible variations in the nature of the ground on any particular site may call for the use of more than one grout. For example, saving may be effected by using cheaper coarse grouts to fill the larger voids, followed by a more expensive penetrative grout to fill the remaining fine voids.

For more detailed information refer to Clause 6.7 of BS 8004, 1986.

APPENDICES

APPENDIX A

FOUNDATIONS OF OIL STORAGE TANKS

A.1 General

This Appendix gives general guidance and recommendations on the design of foundations for vertical oil storage tanks.

The recommendations should, in general, comply with the principles stated in the main text of this Engineering Standard for Foundations.

For more detailed information see Appendix B API std. 650 1998.

A.2 Soil Investigations

At any tank site, the nature of the sub-surface conditions should be known in order to determine the variation of soil properties over the site and to estimate the amount of settlement that will be experienced. A soil investigation should be carried out in accordance with IPS-E-CE-110 to identify the ground conditions under the complete area of each tank to a depth over which significant settlements may occur. Where the founding material is sound or weathered rock, the soil investigation shall be supplemented by geophysical mapping of the tank pad formation.

Additional useful information can be obtained from a review of sub-surface conditions and the history of similar structures in the vicinity.

The allowable soil loading can then be decided in relation to the reliability of predictions of ultimate bearing capacity and the permissible settlements by a certified soil mechanics establishment.

A.3 Types of Tank Foundations

Depending on the situations and soil conditions several types of foundations may be utilized, among which the following may be stated:

- Earth mound foundations;
- Reinforced concrete raft foundation;
- Concrete ring wall under the shell:
- Other types of foundations (including piling).

The most widely used type, is earth mound foundation which is covered in Clause A.4 and other types are briefly discussed under clause A.5.

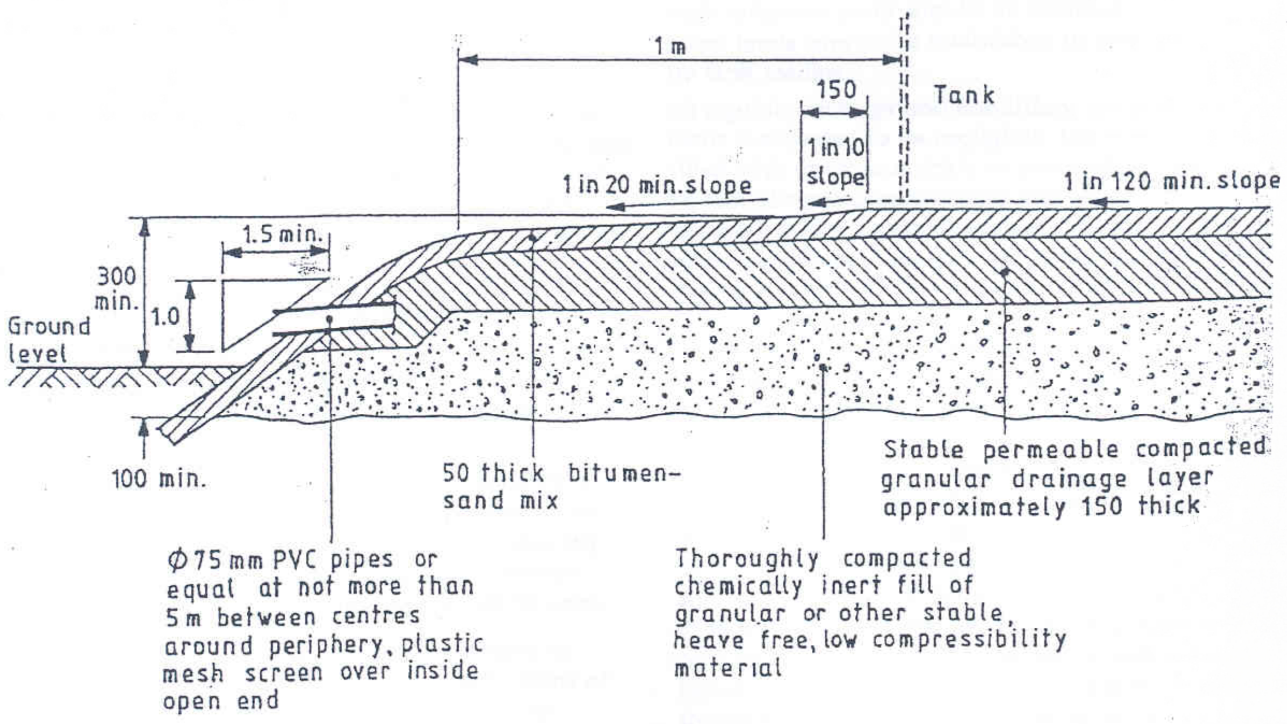
A.4 Earth-Mound Tank Foundations (Tank Pads)

Tank pads comprise well compacted oiled sand pads, rock fill, and granular or sandy silty clay mounds, to support vertical steel storage tanks of low height to diameter ratio. Mounds should normally be built sufficiently high to allow for possible settlements of the tanks. They should be surfaced with a bitumen-sand mix to protect the underside of the bottom plates from ground water, unless an alternative open texture coarse granular surface is specified.

Earth-mound foundations may range from 150 mm thick pads of selected fill where ground is firm, to larger mounds of earth, oiled sand, hard-core, ballast, rockfill, etc., Fig. A-1 shows a typical earth mound tank foundation.

(to be continued)

APPENDIX A (continued)



*** All dimensions are in millimeters, unless otherwise stated.**

TYPICAL TANK FOUNDATION

Fig. A-1

The functions of a tank pad are:

- To spread and transfer the load from the tank and its contents via the tank pad body and shoulder to subgrade such that the resulting settlements, both total and differential, remain within allowable limits.
- To raise the tank bottom above ground water, capillary water, surface water and minor spillages.
- To provide a smooth surface with sufficient bearing capacity for tank construction.

The requirements of the shoulder to the tank pads are:

- To provide sufficient lateral support to the tank foundation under all conditions. The shoulder shall be capable of resisting damage due to construction, operating and maintenance activities.
- To resist edge cutting beneath the tank shell.
- To resist wash-out of the tank foundation as a result of tank bottom leakages and possible ingress of water.

For more details refer to Clause A-3 of BS 2654: 1989.

A.5 Alternatives to Typical Foundation Pads

Where poor sub-soil conditions necessitate, other types of foundation for storage tanks should be used. In the following paragraphs several possible types are discussed:

(to be continued)

APPENDIX A (continued)

A.5.1 Reinforced concrete raft foundation

For small tanks a concrete raft is sometimes used as a foundation . In this case the top of the concrete raft shall be covered with a layer of sand-bitumen mixture of at least 50 mm to allow movement of tank bottom and to prevent corrosion.

Possible settlements and differential settlements, stress distribution under the slab, and the strength of this slab, taking into account final settlement, shall be taken into consideration.

A.5.2 Concrete ringwall under the shell

Large tanks and tanks with high shells impose substantial loads on the foundation under the shell.

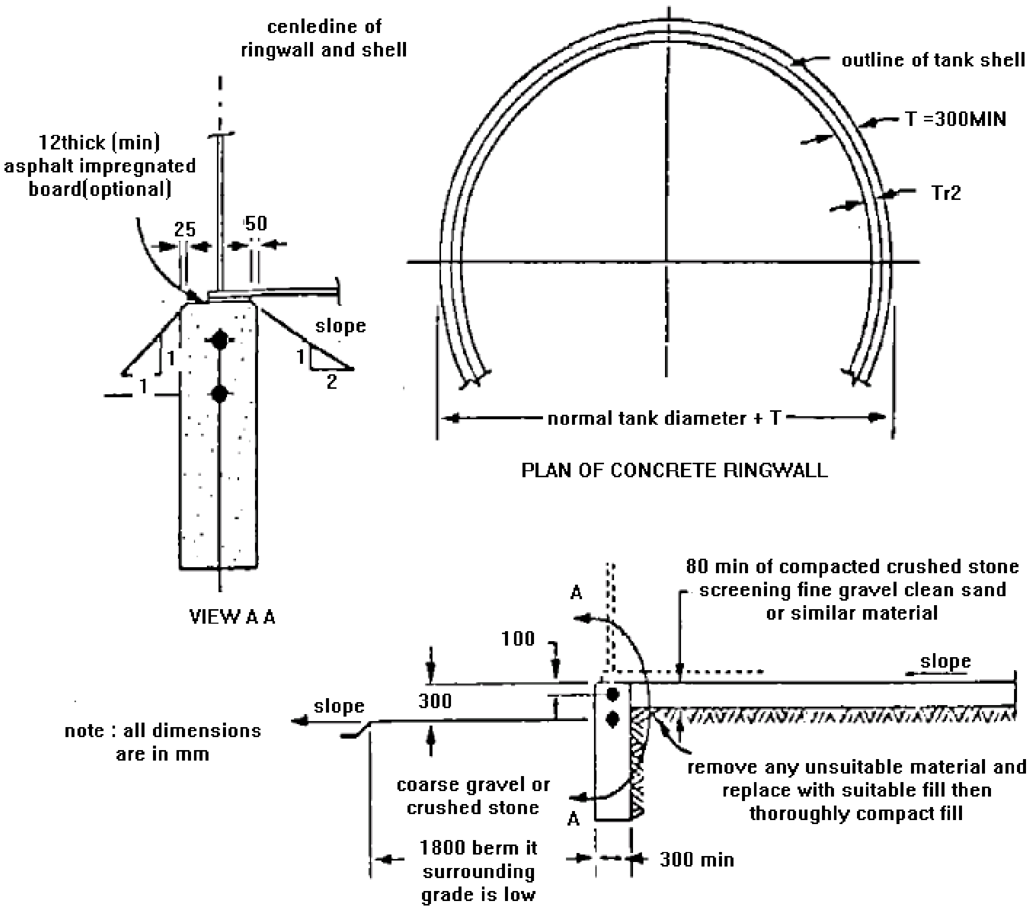
This is particularly important with regard to shell distortion in floating-roof tanks. In this or any other case where the ability of a foundation to carry the shell loads directly is doubtful, it is recommended that a ring wall foundation be used. (See Fig. A-2). A foundation with a ringwall has the following advantages, compared with a foundation without a ringwall:

- It provides better distribution of the concentrated load of the shell to produce a more nearly uniform soil loading under the tank.
- It provides a level, solid starting plane for construction of the shell.
- It provides a better means of leveling the tank grade and preserving its contour during construction.
- It retains the fill under the tank bottom and prevents loss of material as a result of erosion.
- It acts to minimize moisture under the tank.

For high-pressure tanks, it may be necessary to prevent uplift of the shell due to the combined effects of vapor pressure and wind movement by means of an anchorage around the shell built into a suitable concrete ring or raft.

(to be continued)

APPENDIX A (continued)



FOUNDATION WITH CONCRETE RINGWALL (TYPICAL)

Fig. A-2

Where the foundation design incorporates a ring beam, care should be taken to ensure that the relative settlement characteristics of the ring wall and the infill are not such as to result in excessive differential settlement local to the inner wall of the ring beam. Consideration may need to be given to the provision of a hinged transition slab in this area. A minimum thickness of 50 mm of bitumen-sand should be maintained over the concrete.

A.5.3 Other types of foundations for storage tanks

Where poor sub-soil conditions necessitate the use of a reinforced concrete raft and piled foundation, the raft should be designed in accordance with normal reinforced concrete practice (see IPS-C-CE-200) and surfaced with a reduced thickness of bitumen-sand mix as described in A.5.1. The pile system should be designed in accordance with requirements of IPS-E-CE-130.

(to be continued)

APPENDIX A (continued)

A.6 Additional General Considerations

A.6.1 Settlement

As a general rule, the tank center will settle substantially more than the tank edge because of variation in stress distribution. After settlements due to hydrostatic testing, (see A.6.2), and a number of years of operational service, the remaining minimum elevation of the tank pad measured at the position of the tank wall shall be 0.60m above the highest floor level of the bounded area.

During hydrostatic testing of the tank, 30 to 70% of the total settlement will take place already and the remaining settlements will take place mainly during the first few years when the tank is in operation.

A.6.2 Hydrostatic testing

The water test pressure is an integral part of the foundation design and should be agreed with a soil mechanics establishment. All tank tests will be carried out to provide adequate measured load/settlement records.

The first tank in a new area will be the most critical and subsequent testing arrangements on other tanks should be adjusted in the light of the first test results where the tanks are on similar sub-soil conditions.

A minimum of four points on tanks under 25 m diameter and eight points on tanks over 25 m diameter should be marked around the base of the tank for subsequent leveling reference.

A greater number of points may be required for large tanks and/or where a complex settlement pattern is expected. Before water is added to the tank, the levels at each reference point should be recorded.

Permanent reference levels have to be established in locations unaffected by tank loading. The filling should be done under controlled conditions to ensure that foundation failure does not occur during filling. For more detailed information refer to Clause A.5 of BS 2654: 1989.

A.7 Water testing

While it is normal practice to test all tanks by filling with water before commissioning, this filling should be done under controlled conditions to ensure that foundation failure does not occur during filling. The water test pressure is an integral part of the foundation design and should be agreed with a soil mechanics specialist.

All tank tests will be carried out to provide adequate measured load/settlement records.

The first tank in a new area will be the most critical and subsequent testing arrangements on other tanks should be adjusted in the light of the first test results where the tanks are on similar sub-oil conditions.

A minimum of four points on tanks under 25 m diameter and eight points on tanks over 25 m diameter should be marked around the base of the tank for subsequent leveling reference. A greater number of points may be required for large tanks and/or where a complex settlement pattern is expected. Before water is added to the tank, the levels at each reference point should be recorded. Permanent reference levels have to be established in locations unaffected by tank loading.

As a guide, when ground conditions are good and settlement is expected to be negligible, the tank may be half filled with water as quickly as practicable, having regard to its size, the pumping facilities and water supply available. No further filling should proceed until levels have been taken and checked against the readings when empty to ensure that no uneven settlement is occurring in which case filling can proceed until the tank is three-quarters full, when level readings should be taken again. Provided the tank remains level with only slight settlement due to load, filling can then proceed until the tank is full, when level readings are again repeated. The full water load should be maintained for 48 h and provided levels remain sensibly consistent, the tank can be offloaded prior to calibration for service. Provided this tank is satisfactory and subsequent tanks are founded similarly, the level readings at one-half and three-quarters capacity may be omitted for small tanks of less than 25 m diameter. On weak ground where significant settlements may be expected or where the initial factor of safety against slip failure is low, the rate of filling should be greatly reduced. Some guidance on the safe heights for initial filling and where pauses in filling are required may be deduced from the soil investigation and from piezometric monitoring of pore water pressures.

Typically, where settlements of over 300 mm may be expected, water should be added to the tank at about 0.6 m per day until about 3 m of water is stored. At such a head, filling should cease and levels at the reference points should be recorded daily. Daily reference point levels should be plotted on a timescale to follow the pattern of settlement.

When the daily rate of settlement begins to decrease, water should be added to the tank in decreasing increments of head when the settlement graph shows that the rate of settlement under each new increment of load is reducing. The water load nears the full capacity of the tank, water should preferably be added after an early morning check of reference levels so that further readings can be taken during the day and the tank offloaded should the rate of settlement increase unduly. On very weak soils, these tests may extend over considerable periods and where such conditions apply, the weak builder should be advised so that adequate provisions can be made in his programme for the necessary testing and acceptance procedure.

Some guidance on safe heights for initial filling and where pauses are desirable may be deduced from the shear strength data and strata thicknesses of the underlying soil. In carrying out such test procedures adequate arrangements should be made for the emergency disposal of water if off-loading became necessary. Discharge should be to a safe area, clear of all foundations and structures and such that no danger of erosion can occur.