Foundation Design

General Principals

Foundation Function

A foundation is defined in the British Standard Code of Practice for Foundations (CP 2004) as "that part of the substructure in direct contact with and transmitting loads to the ground". The substructure is defined in the same Code as "that part of structure (including building, road, runway, or earthwork) which is below natural or artificial ground level".

Foundations have the function of spreading the load from the superstructure so that the pressure transmitted to the ground is not of a magnitude such as to cause the ground to fail in shear, or to induce settlement of the ground that will cause distortion and structural failure or unacceptable architectural damage. In fulfilling these functions the foundation, substructure and superstructure should be considered as one unit. The tolerable total and differential settlement must be related to the type and use of the structure and its relationship to the surroundings. Foundations should be designed to be capable of being constructed economically and without risk of protracted delays. The constructions stage of foundation work is not infrequently subjected to delays arising from unforeseen ground conditions. The latter cannot always be eliminated even after making detailed site investigations. Thus elaborate and sophisticated designs and construction techniques which depend on an exact foreknowledge of the soil strata should be avoided. Design should be capable of easy adjustment in depth or lateral extent to allow for variations in ground conditions and should take into account of the need for dealing with ground water.

Foundation design must take into account the effects of construction on adjacent property, and the effects on the environment of such factors as pile driving vibrations, pumping and discharge of ground water, the disposal of waste materials,, and the operation of heavy mechanical plant.

Foundations must be durable to resist attack by aggressive substances in sea and rivers, in soil and rocks and in ground waters. They must also be designed to resist or accommodate movement from external causes such as seasonal moisture changes in the soil, frost heave, erosion and seepage, landslides, earthquakes and mining subsidence.

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 soils and rocks beneath the site, to observe ground water levels, and to obtain information on all factors relevant to the design of the foundations and their behavior in service.

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 loadings (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 cladding and finishes, and the surrounding works such as damage to piped connections or reversal of fall in drainage outlets. Acceptable differential settlements depend on the type of structure, e.g. framed industrial shedding with pin-jointed steel or pre-cast concrete elements and sheet metal cladding can withstand a much greater degree of differential settlement than a 'prestige' office building with plastered finishes and tiled floors.

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 piling loadings) appropriate to the type of foundation should be determined from a knowledge of the ground conditions and tolerable settlements.

vi. The pressure distribution beneath the foundations should be calculated based on an assessment of the foundation widths corresponding to the preliminary bearing pressures or pile loadings, 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 mathematical analysis taking into account the 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 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.

Foundations Loading

A foundation is required to support the dead load of the superstructure and substructure, the live load resulting from the materials stored in the structure or its occupancy, the weight of any materials used in backfilling above the foundations, and also wind loadings. When considering the factor of safety against the shear failure of the soil the dead loading together with the maximum live load may be either a statutory or code of practice requirement (e.g. the requirement of the British Standard Code of Practice for Loading, CP 3) or it may be directly calculated if the loads to be applied are known with some precision.

With regard to wind loading, “where the foundation loading beneath a structure due to wind is a relatively small proportion of the loading, it may be permissible to ignore the wind loading in the assessment of allowable bearing pressure, provided the overall factor of safety against shear failure is adequate. For example, where individual foundation loads due to wind are less than 25% of the loadings due to combined dead, live and wind loads does not exceed that 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.

Loadings on foundations from machinery are a special case and require further consideration.

The design of foundations to eliminate or reduce total and differential settlements

The amount of differential settlement which is experienced by a structure depends on the variation in compressibility of the ground and variation in thickness of the compressible material below foundation level. It also depends on the stiffness of the combined foundation and superstructure. Excessive differential settlement results in cracking of cladding and finishes and, in severe cases, to structural damage. Differential settlement can be expressed in terms of angular distortion of the structure. Differential settlement may be eliminated or reduced to a tolerable degree by one or a combination of the following measure:

a) Provision of a rigid raft either as a thick slab, or with deep beams in two directions, or a cellular construction.
b) Provision of deep basements or buoyancy rafts to reduce the net bearing pressure on the soil.
c) Transference of foundation loading to deeper and less compressible soil by utilizing basements, caissons, shafts or piles.
d) Provision of jacking pockets within the substructure, or brackets on columns from which to re-level the superstructure by jacking.
e) Provision of additional loading on lightly loaded areas by Ballasting with kentledge or soil.
f) Ground treatment processes to reduce the compressibility of the soil.

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