BUILDING DIGEST

CENTRAL BUILDING RESEARCH INSTITUTE INDIA

BEARING CAPACITY OF SOILS

Introduction

The design of building foundations tends to be empirical in spite of the advances in the field of Soil Mechanics. The Engineer or the Architect usually relies on his experience in a locality or looks up a Civil Engineering hand book to find out the "safe bearing capacity" of the soil which can be used as the basis of footing design. For small buildings, this practice may be adequate but for major structures, this method does not cater to all the relevant factors. For instance, it makes no allowance for the type of the structure or for the differential settlements which may occur. There is also the difficulty that the soil type is rarely fully described and the designer has to choose a value in a given range according to his experience and judgement.

The 'bearing capacity' of a soil is the maximum load the soil can carry without any rupture or breaking up due to shear failure. The 'allowable pressure' is the maximum load that can be put on a soil without causing either a rupture of the soil or excessive settlements.

Bearing capacity against rupture is fairly easily satisfied by keeping the pressure to a suitable fraction of the breaking load. The condition for keeping the settlement within allowable limits is not so easily determined as various structures have different capacities for settlements. The allowable settlement in a structure depends to a great extent on the structure itself.

Most structures can withstand uniform settlement, but when the settlement is not uniform the additional stresses brought about cause damage to the structure. It is therefore necessary to have some knowledge of the ability of structures to withstand differential settlements.

In general, most framed concrete structures can withstand differential settlements, up to about 3/4 inch without damage. Brick structures however have been known to withstand upto 2 inches or more of differential settlement. Generally, the more flexible the structure the more resistant it is to damage. It has been observed that the differential settlement does not normally exceed 75 percent of the maximum settlement occurring under a footing. For concrete structures therefore the design pressure on the soil is so adjusted that the settlement under the largest footing does not exceed 1 inch. Thus the differential settlement is maintained within 3/4 inch which is permissible.

Of the two values viz. (a) the safe bearing capacity against soil rupture and (b) the maximum allowable load intensity to keep the settlement of a footing within permissible limits, the lesser called the 'allowable pressure' on the soil, should govern the design.

In this digest the most convenient method of obtaining the allowable pressure on soils is briefly described. Part I deals with sandy and Part II with clayey soils.

PART I

Determination of allowable soil pressure on sandy soils

The plate load test is a convenient method of finding out the bearing capacity of sands and sandy soils containing a low percentage of clay. The results are applicable if the soil strata is uniform up to a depth of at least one and a half times the width of the largest footing. If weaker strata exist, load tests at lower depths may have to be carried out and the lowest value adopted for design.

The equipment required and the procedure for the plate load test are detailed in the Appendix. Essentially the test consists of recording the settlement of a plate of a particular size subjected to increments of load until the soil fails by shear, and subsequently plotting a load settlement curve.

Recording of results

The stress is plotted against settlement on a log-log scale. The plot generally gives two straight lines, the intersection of which may be taken as the yield value for the soil. Beyond this point the rate of settlement for load-increments increases and sometimes progressive failure may also ensue. The yield value therefore indicates the start of shear failure or rupture in a soil and is a measure of its ultimate bearing capacity. A factor of safety of 2 is usually applied to obtain the safe bearing capacity.

The size of footing and its depth influences the safe bearing capacity of the soil. For dense sandy soils, an increase in the size and depth of footing leads to an increase in the safe bearing capacity. For loose and medium compact soils, usually met with, a variation in depth and size of footings results in inappreciable changes in the ultimate bearing capacity and as such may be ignored.

Settlement considerations

It is observed that in sandy soils, settlement of a footing under a given load intensity increases with an increase in the size of the footing up to about 15 ft. width of footing.

For the same intensity of loading, the ratio of settlements of a footing of size b_f (in feet) to that of the test plate of size b_p (in feet) is given by the formula—

$$S_f = S_t \left[\frac{b_f\,(b_p+1)}{b_p\,(b_f+1)} \right]^2$$

where s_f and s_t are the settlements of the foundation and test plate respectively.

This relationship can also be utilized to determine the intensity of loading for a footing of known size for a known settlement. For example, if the test plate used is 2 ft. square and the permissible settlement for 10 ft. square footing is 1 inch, then

$$S_t = S_f \left[\frac{b_p\,(b_f+1)}{b_f\,(b_p+1)} \right]^2 = 0.54 \text{ inch.}$$

The load intensity for 0.54 inch settlement may be read from the load test curve and this will be the required intensity of loading for the 10 ft. footing for 1 inch settlement.

Effect of water-table

In sandy soils the allowable soil pressure is greatly affected by height of the water-table. If the highest level of water-table below the footing is at a depth equal to the width of the footing or more, no reduction in the 'allowable soil pressure' is necessary. If it is at the ground level, the 'allowable soil pressure' should be reduced to half. For intermediate levels a proportional reduction should be made in the 'allowable soil pressure' values.

The position of the water-table should be ascertained at the time of the plate load test. If it is close by the test should be carried out at water-table level, when no further reduction in the allowable soil pressure value is necessary. Otherwise it should be carried out at least 1.5 times the width of the test plate above the water-table level and the allowable soil pressure value modified as recommended in the above para.

PART II

Determination of allowable soil pressure for clayey soils

Clays and clayey soils can be readily distinguished by their stickiness, plasticity or ability to be rolled into thin threads and their capacity to retain moisture. Pure clays are rare. Generally they are found in combination with some coarser material like silt and sand.

Clay deposits are either normally consolidated or precompressed. The former are rare, and precompressed deposits are more general. As the name indicates they are deposits which have been subjected to compression under very high loads during their geologic history. These high loads subsequently disappeared due to the action of water or wind and the deposits presently occur under a smaller load, usually the existing over-burden load. The maximum pressure to which the soil has been subjected to is called the precompression load. The chief characteristic of such deposits is that so long as the applied load is less than thè precompression load, settlement is comparatively small.

As with sands, the allowable soil pressure of a clay is governed by its shear strength against soil repture on the one hand and its compressibility on the other, which determines the settlement of structures founded on it.

Procedure

The shear strength of a clayey soil can be easily determined by finding the unconfined compression strength of an undisturbed specimen of the soil. This test is similar to the compression test carried out on concrete cylinders. Small cylindrical samples, with length/diameter ratio of 2, are tested in an apparatus which is capable of recording low strengths accurately. An apparatus commonly used is shown in fig. 1. The

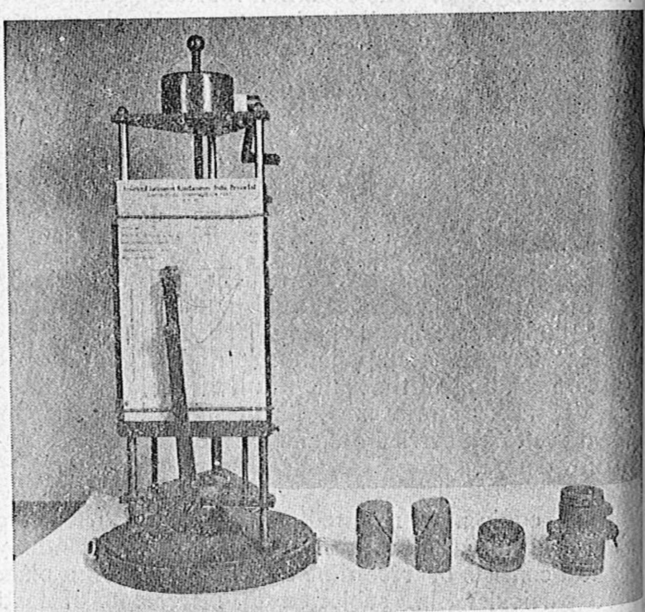


Fig. 1 : An Unconfined compression Test apparatus.

shear strength of saturated clays is half the value of the unconfined compression strength. Undisturbed specimens for the test may be obtained by using 1½ in. thin steel sampling tubes*.

The ultimate bearing capacity can be expressed as $q=\frac{1}{2} q_u KN_c=CK N_c$ where q_u is the unconfined compression strength, C is the shear strength, and N_c the bearing capacity factor, the value of which is 5.7 and K the shape factor.

For a continuous footing K=1 and for circular or square footing K=1.3. For a rectangular or oblong footing with width B and length L, K is given by $\left(1+\frac{0{\cdot}3B}{L}\right)$.

A factor of safety is applied to the ultimate bearing capacity for practical use. This factor should not generally be less than 3. If the loads for which a footing may have been designed, for example, dead load plus maximum live load combined with maximum snow and wind load, are extremely unlikely to develop, then only a minimum factor of safety of 2 may be tolerated.

The safe bearing capacity determined using the above factor of safety has also been found to satisfy the settlement condition in the case of uniform deposits of precompressed clays. This value may therefore be called the allowable pressure in clayey soils. In major structures, however, computation of settlements at different points may be necessary from consolidation tests carried out on undisturbed specimens and the foundation design may be modified accordingly.

APPENDIX

Plate load test for determination of bearing capacity for Sandy soils.

Equipment

The equipment required for this test consists of the following :—

(a) 2 Nos. M.S. Plates 1 inch thick 18 inches square and 24 inches square in size.

(b) A steel truss of 16 ft. span and designed to take a reaction of 30 tons.

(c) 12 Nos. Holdfasts, 96 nos. spikes and a sledge hammer.

(d) 2 Nos. rails or I beams 5 inch×3 inch,—12 ft. long; 12 nos, channels 4 inch×¾ inch,—2½ ft. long; 24 nos. 10 inch long bolts with nuts.

(e) 1 No. hydraulic jack—30 tons capacity fitted with pressure gauge; 1 no. 1 inch thick plate 1 ft. square.

1 no. ¾ inch dia. ball bearing.

(f) 2 nos. dial gauges with 1 inch play and of .0001 inch accuracy.

(g) 1 no. datum bar 16 ft. long having supporting legs at either end; 2 nos. dial clamps or magnetic holders and a spirit level.

Procedure of Test

The depth of foundation is first ascertained and a pit 10 ft. square is dug at the selected position of test to the required depth of the proposed foundation.

The loading truss is placed along the centre line of the pit and properly aligned. It is held vertical with wire ropes on either side, the other ends of the ropes being held by fixed pegs in the ground. The truss is anchored down to the ground by holdfasts** which are semi-round slotted steel pipes held down to the ground by spikes driven through slots provided in them. The truss is anchored by putting a rail (or an RSJ) at right angles over the ends of the truss and the holdfasts. Cross channels are then placed over the rail and are bolted down to the holdfasts. The load test set-up is shown in figs. 2 and 3.

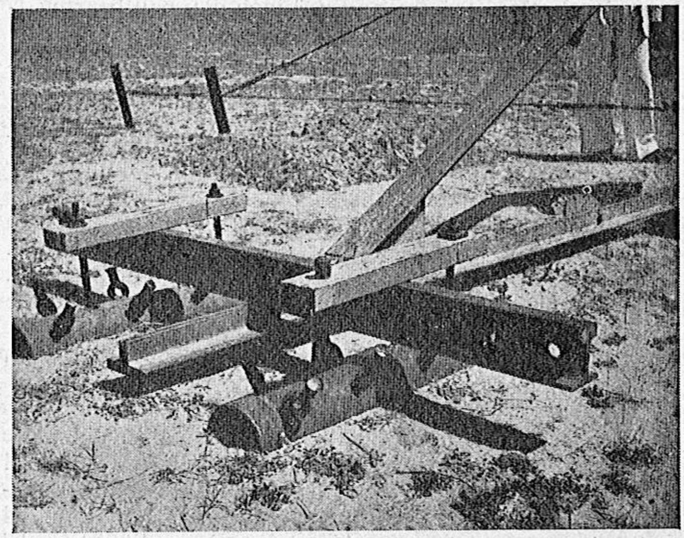


Fig. 2 : General arrangement for a Plate Load test set-up.

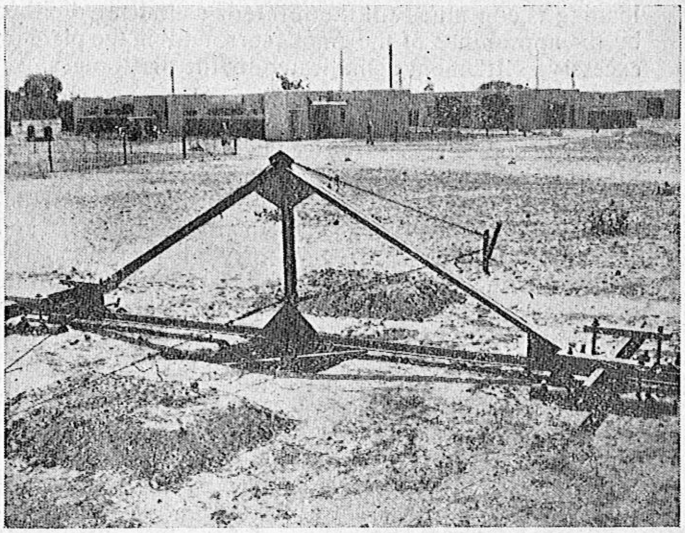


Fig. 3 : Close-up of holdfast arrangements.

*Building Digest No. 7 on "Undisturbed sampling of soils."

**"A new method of anchoring loading frames in a plate load test"—A.K. Deb. Jour. Nat. Soc. S.M. & F.E., April 1962, 1 (2).

The holding power of the holdfast depends on the nature of the soil, its density and moisture condition. It generally varies between 1 and 2 tons. Four holdfasts on either side of the truss are adequate under normal conditions.

The bottom of the pit is levelled and a layer of fine sand spread over it. The test plate 2 ft. square in size is carefully placed at the centre over the sand layer. A uniform contact between the plate and the ground is ensured by turning and pressing the plate in position and checking the imprint, the plate makes on the sand layer. The $1\frac{1}{2}$ ft. square plate is next placed over the 2 ft. square plate concentrically for uniform distribution of pressure over the latter and to prevent bending.

The hydraulic jack is then placed over the $1\frac{1}{2}$ ft. square plate and the ram worked upto butt against the truss. The truss is provided with a steel plate fixed at its bottom centre and a $\frac{3}{4}$ inch dia. ball bearing is placed between the steel plate and the centre of the ram for uniform distribution of the load over the test plate. The ball bearing is held between grooves provided on the top centre of the ram and below the bottom centre of the steel plate. If the pit is deeper than the reach of the jack a steel channel column may be interposed between the jack and the test plate. The datum bar is placed with its supports equidistant from the centre of the pit on either side, so that it is not affected by any movement of the soil below and surrounding the plate. Dial gauges are fixed to the datum bar by means of magnetic holders or dial clamps and the tips of the dial gauges are put in contact with the test plate at two diagonally opposite ends.

A seating load of 500 lbs. is applied to the plate for about a minute. The pressure is released and all the gauges set at zero. The load is applied in increments of 2000 lbs. Each increment of load is maintained till the rate of settlement is not more than 0.0001 inch/min. The mean settlement on the two dial gauge readings is recorded for each load increment. The loading is continued till the soil fails as indicated either by the appearance of the cracks surrounding the plate or excessive settlement as indicated by the dial gauges.

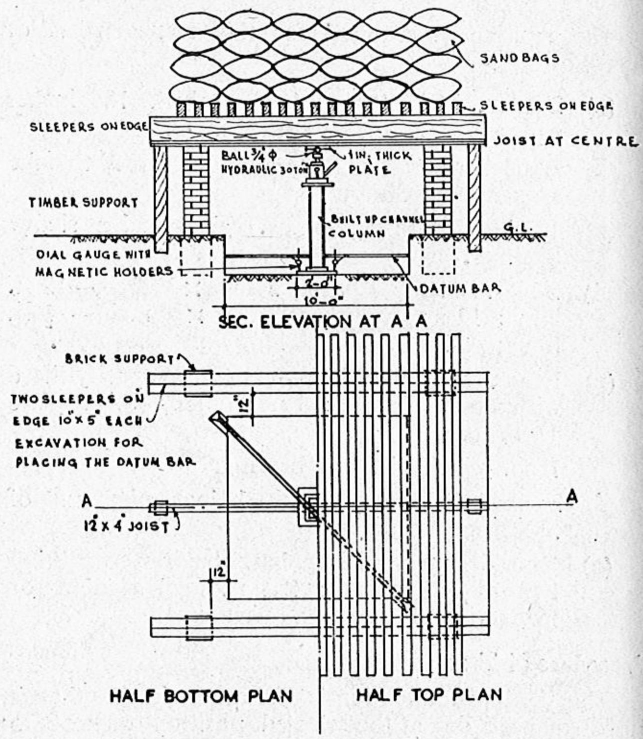
The stress is plotted against settlement on a log-log scale. The plot generally gives two straight lines, the inter-section of which may be considered as the yield value for the soil. Beyond this point the rate of settlement for particular load increments increases and sometimes progressive failure may also ensue. The yield value therefore indicates the start of shear failure or rupture in a soil and is a measure of its ultimate bearing capacity. A factor of safety of 2 is usually applied to obtain the safe bearing capacity.

Alternate arrangements for loadings

Where loading truss is not available, the following alternative arrangements are suggested.

(a) Jacking against the back-axle of a heavily loaded vehicle e.g. a 5 ton truck (gross wt. 10 tons), chassis of a loaded trailor, D-8 Tractor, a heavy motor grader, or other such heavy equipment. The load should be transferred through a ball bearing on the jack.

(b) Jacking against a loaded platform with a steel joist placed centrally underneath. The hydraulic jack should butt against the joist with a ball-bearing placed in between. The platform should be loaded with kentledge to a little more than the expected failure load before the test is started. A simple design of the platform is given in Fig. 4.



PLATFORM LOADING ARRANGEMENT FOR PLATE LOAD TEST

FIG. 4

There is a demand for short notes, summarising available information on selected building topics for the use of Engineers and Architects in India To meet the need this Institute is bringing out a series of Building Digests from time to time and the present one is the eleventh in the series.

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