Study on Building Settlement Problems & its Remedial Measures

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Abstract— In recent years, high buildings have emerged in large numbers rapidly. Due to the increase of floor and load, building body may produce settlement unevenly. Severe settlement may endanger the safety of building. Therefore, it is of great importance to monitor building in real time. Foundations are key element in construction projects. Identification of foundation failures and providing necessary treatment is very important. Many foundation failures are due to inadequate protection to foundation soils, improper geotechnical investigation and design error, improper sequence of construction and water level fluctuation. Differential settlement between foundations' elements induces additional stresses in the structural elements. In general, the amount of settlement that a structure can undergo without distress is large, provided that the structure settles uniformly. However, based on the fact that the soil under the foundation may not be uniform in nature and the loads transferred from the superstructure to the foundation are variable, differential settlements between the foundation elements are expected. This works on different causes for distress of foundation and also discusses their solutions to overcome and prevent these failures in consideration. The questionnaire survey was conducted to rate the factors that contribute to the problem/defects of foundation construction and remedial approach for foundation failure.

Key words: Building Settlement Problems, Remedial Measures

I. INTRODUCTION

Settlement is the downward movement of the ground caused by a load consolidating the soil below it or causing displacement of the soil. Settlement often refers to the downward movement of the ground around an excavated space, such as that for tunnels, shafts, or basements.

It is usual for buildings to experience some degree of settlement within the first few years after construction. Although the extent to which this ground movement impacts upon buildings depends on several factors, which may include:

- Existing soil conditions.
- Methods of construction.
- Size and depth of the construction works.
- Type of structure, its condition, and its foundations.

The impact of settlement is opposite to the effect of heave which is the upward movement of the ground, and is different from subsidence which occurs where soil is unstable and sinks downward without any imposed load.

Foundation design and construction are two basic requirements of any earth retaining structure, which transfers its load to the underlying earth's crust. The materials that constitute the earth's crust are arbitrarily divided into two types, i.e. soil and rock, which are the main structural materials and in reality, there is no clear distinction between them. Soils and sites are so variable that it is not practicable to formulate any hard and fast rules.

The mechanical properties of soils are far more complex and difficult to determine. No material has greater variation of properties than soil, probably because it is not a manufactured standard product like steel. This is because the soil with which the engineer must work was placed by nature in a great variety of kinds and conditions. The selection of soils for foundation of any structure is not entirely within the engineer's control. The stability and function of a structure will largely depend upon the Behavior of the soil upon which and/ or of which it is built.

In the subsequent chapters, the basic technical information on the subject has been covered in details, covering (i) 'general Behavior of soil' i.e. nature of soil, its profile, stability and properties along with its Behavior under foundation (ii) 'effect of groundwater' i.e. ground water level, importance of water level and effect of under-ground water on foundation (iii) 'foundation settlement' i.e. foundation failures, causes of foundation settlement, time-dependent settlement (iv) 'settlement in shallow and deep foundation' i.e. brief description of the relevant Indian Standards (v) 'preventive measures' i.e. improvement of bearing capacity of soil through soil stabilizing methods, protection of excavation, safety of existing structures.

II. FOUNDATION SETTLEMENT

All foundations settle under load and the general tendency is for some parts of a structure to settle more than others causing relative movement. The critical factor in the settlement of a structure is not the amount of settlement but the differential settlement between the different parts of a structure itself. Excessive pressure is comparatively uncommon cause of settlement. Investigation of all layers under a foundation should be made as even thin layers, which are weak in shear, can cause settlement.

With structures built on sands and gravels the settlement is likely to be partially completed at the end of construction, but when the site is undertaken by clays or silts, settlement is likely to continue for a long time after construction and cracks may appear many years after completion. Due allowance shall, therefore, need to be made for this slow consolidation settlement. In strata of organic soils, settlement may continue almost indefinitely.

A. Uniform Settlement

Uniform settlement is settlement, which is brought about when the entire structure, under uniform pressure distribution on a uniform, homogeneous soil material, settles evenly without causing additional stresses in the structure.

B. Non-uniforms or Differential Settlement

The foundations of different elements of a structure may have un-equal settlements and the difference between such settlements will cause non-uniform or differential settlement, which may be disastrous, leading to cracking of the structural members, impairment of the structural rigidity of the building, and eventually to the collapse of the structure.

This is particularly true with statically indeterminate structures such as continuous beams on more than two supports, frames, arches, vaults, and others. In these structures, settlement of a support induces supplement moments, and if these additional bending moments are not taken into account in proportioning the structural members, the structure may turn out to be too weak to resist the additional moments, and may start to crack.

III. CAUSES OF SETTLEMENT

Some of the main factors contributing to settlement of soils are as follows:

A. Settlement Due to Static Loads on Soil

The weight of the building or structure causes reduction in the volume of soil due to expulsion of water from the voids of the soil. The void ratio decreases while the volume of solid particles remains unchanged. The effect of this decrease in volume is the vertical downward movement of the structure, viz., settlement or a compressive deformation of the soil structure. The compressive soil layer under the foundation of structure is stressed up to large depth due to the weight of the structure.

B. Settlement Due to Dynamic Forces from Vibrations

Dynamic forces from vibrations or impulses are excited by machinery like turbo-generators, turbines etc.; traffic, pile driving operations, explosions, earthquakes, and various impacts on soil due to collapse of structures and/or earthworks. These factors loosen the structural strength of the soil, particularly the strength of non-cohesive soils. The effect of the operation of the machines on settlement is quite large.

C. Settlement due to Excavation of Soil

If an excavation is made in a sandy soil the structure founded near the excavation will be affected and it will cause extra settlement but the settlement due to excavating the cut does not extend beyond a distance equal to the depth of the cut. So, if the depth of cut is 5 meters then the building at a distance within 5 meters from the excavation will only be affected. If the cut is properly braced then the amount of settlement gets reduced and is not likely to exceed about 0.5 percent of the depth of the cut.

D. Settlement due to Lowering of Water table

Whenever a deep excavation is made up to a large depth, the water table is encountered invariably. The water has to be pumped out so that workmen can work in dry condition in the excavated area. The lowering of water table by pumping seriously affects the structure founded in the vicinity. The effective pressure on the sub-soil increases due to lowering of water table. The increase of the effective pressure causes extra settlement of the nearby structures. In case of sandy soil the lowering of water table does not affect the structure so badly as in case of clayey soil. In case of clayey soil the lowering of water table may cause settlements.

E. Settlement due to Deterioration of Foundation Concrete

Sometimes the deterioration of concrete of foundation starts due to sulphate, carbon dioxide, chemically contaminated water and other chemicals. Due to this, large cracks develop in the structure as the deterioration of concrete leads to extra settlement of the structure.

F. Settlement due to Increasing Load on Surrounding of Soil

When any portion of the ground surface has been loaded, it causes the adjacent surface to tilt and settle. The amount of tilt will depend upon a number of factors. If the sub-soil consists of soft clay the effect of the weight of a new structure on the neighboring structure can be quite high and it may cause extra settlement to old structure. It is not necessary that such tilts are always detrimental.

G. Settlement due to other Possible Factors

- Unequal distribution of the weight of the structure on the foundations.
- Earthquake, etc.
- Horizontal movement of the earth adjoining the structure.
- Atmospheric action.
- Transpiration of trees and shrubs.
- Settlement from frost-heaved soils; natural (from thawing) and artificial (under refrigeration houses).

IV. STEPS INVOLVED IN SETTLEMENT COMPUTATIONS

A. Collection of Relevant Information

The following details pertaining to the proposed structure are required for a satisfactory estimation of settlements:

- Site plan showing the location of proposed as well as neighboring structures,
- Building plan giving the detailed layout of load bearing walls and columns and the dead and live loads to be transmitted to the foundation.
- Other relevant details of the structure, such as rigidity of structure, and
- A review of the performance of structures, if any, in the locality and collection of data from actual settlement observation on structures in the locality.

B. Determination of a Sub-Soil Profile

- Generally, it will be sufficient, if two exploratory holes are located diagonally on opposite corners, unless the proposed structure is small, in which case one bore hole at the centre may be sufficient. For large structures, additional bore holes may be driven suitably.
- In favorable cases, all borings may be sufficiently alike to allow the choosing of an idealized profile, which differs only slightly from any individual borings and which is a close presentation of average strata characteristics.
- Adequate boring data and good judgment in the interpretation of the data are prime requisites in the calculation of settlements. In the case of cohesion less soils, the data should include the results on undisturbed samples. In general, in the case of clay layers, for each one of the clay layers within the zone of stress influence at least one undisturbed sample should be tested for consolidation characteristics. In the case of thick clay layers consolidation test should be done on samples collected at 2 m or lesser intervals.

C. Stress Analysis

- Initial Pore Pressure and Effective Stress: The total vertical pressure at any depth below ground surface is dependent only on the weight of the overlying material. To obtain initial effective pressure, neutral pressure values should be subtracted from the total pressure. The possible major types of preloading conditions that can exist are the following.
- In simple static case and the over-consolidated case, the neutral pressure at any depth is equal to the unit weight of water multiplied by the depth below the free water surface.
- In residual hydrostatic case, a condition of partial consolidation under the overburden exists, if part of the overburden has been recently placed as for example in made up lands and delta deposits. In this case, the neutral pressure is greater than that in the previous case, since it includes hydrostatic excess pressure. If allowed sufficient time, this case could merge with the static case.
- In artesian case, there is upward percolation of water through the clay layer due to natural or artificial causes. In this case, in addition to the hydrostatic pressure a seepage pressure acts upwards and reduces the effective pressure in the soil.
- In the pre-compressed or over-consolidated case, the clay might have been subjected to a higher effective pressure in the past than exists at present. This may be due to the water table having been lower in the past than at present or due to the erosion or removal of some depth of material at the top.

D. Settlements in Shallow Foundation

If the soil consists of several regular soil layers, the settlement of each layer below foundation should be computed and summed to obtain the total settlement. The settlement contribution by cohesion less soil layers and cohesive soil layers should be estimated. In variable erratic soil deposits, if the variation occurs over distances greater than half the width of foundation, settlement analysis should be based on the worst and the best conditions and if the variation occurs over distances lesser than half the width of the foundation, the settlement analysis should be based on worst and average condition.

E. Time rate of Settlements

The settlement at any time may be estimated by the application of the principles of Terzaghi's one dimensional consolidation theory. When considering the drainage of clay layer, concrete of foundation may be assumed as permeable. The coefficient of consolidation should be evaluated from the one dimensional consolidation tests using suitable fitting methods. In the case of evaluation of time rate of settlement of structures constructed with certain construction time, the procedure as adopted in relevant Indian Standards may be followed.

V. Remedial Measures

Preventive measures against failures of structures should be adopted to ensure the safety of a fully loaded structure during its planning. The possible reasons of failure due to foundation settlement should be kept in mind while designing and executing the proposed structure. As far as soil strata are concerned, it should be well studied and the findings should be applied before the actual construction is started. The soil, if found weak or its bearing capacity is low, should be improved by adopting suitable methods.

A. Improving the Bearing Capacity of Soil

If foundations are left open for one rainy season it will enable the soil to settle down, and it will also be known whether the natural movements of the soil below due to increment of moisture are likely to cause any damage. Foundations in bad soils can be improved by:

- Increasing the depth of the foundation except when the material grows wetter as the depth increases.
- Compacting the soil by ramming.
- Ramming in sand, gravel, moorum, broken stone or brick bats in-situ between the foundation concrete and soil. This is useful for silt or black cotton soils and clayey soils.
- Cement grouting of the rammed materials will make the foundations much harder.
- Draining out water from wet foundations.
- Driving piles, either of wood or concrete, or driving and withdrawing piles and filling the holes with sand or concrete. This will increase the density of the soil.
- Artificial stabilization can be used to seal off permeable strata for deep foundations, or to give soft soils additional strength if they are likely to flow.

B. Protection of Excavation

- The protection of excavation during construction of timbering and dewatering operations, where necessary, should be done.
- After excavation, the bottom of the excavation should be cleared of all loose soil and rubbish and should be leveled, where necessary. The bed should be wetted and compacted by heavy rammers to an even surface.
- Excavation in clay or other soils that are liable to be affected by exposure to atmosphere should, wherever possible, be concreted as soon as they are dug.
- The bottom of the excavation should be protected immediately by 8 cm thick layer of cement concrete not leaner than mix 1: 5: 10.
- The refilling of the excavation should be done with care so as not to disturb the constructed foundation, and should be compacted in layers not exceeding 15 cm thick with sprinkling of minimum quantity of water necessary for proper compaction.

C. Remedial Measures against Harmful Settlements

- In general, settlements of soil, since they are natural phenomena, are unavoidable. However, the engineer should make provision for keeping down large, intolerable and non-uniform settlements.
- To attain uniform settlements it is not necessary to achieve the same contact pressure intensities under all footings of the foundations of one structure. However, it is necessary to bring into accord the shape and the size of the footings so that all foundations of one and the same

structure attain one and the same amount of settlement. Every non-uniform load distribution leads to unequal or differential settlement.

- To make intolerable settlements harmless, the following constructive measures are applied:
- Structures are supported on foundations designed as statically determined structural systems;
- Structures and their foundations are designed as a rigid, stereo metric unit (for example silos on continuous slab);
- Long structures are subdivided and built as separate units;
- A structure, the parts of which are non-uniformly loaded, is subdivided.
- To achieve uniform settlements, one would design foundations by observing the 'area law' of the loaded footings;
- Use artificial cushions of soil underneath the less settling foundation parts of the structure;
- Build different parts of foundations of different weight and on different soil at different depths;
- Build the heavier parts of the structure first (such as towers and spires, for example) and the lighter parts later.

D. Soil Stabilization Methods

Soil stabilization is the chemical or mechanical treatment designed to increase or maintain the stability of mass of soil or otherwise to improve its engineering properties. It may increase strength, increase or decrease permeability, reduce compressibility, improve stability, or decrease heave due to frost or swelling. The classification of the methods of stabilization is based on the treatment given to the soil (for example, dewatering, compaction, etc.), process involved (for example, thermal, electrical, etc.), and on additives employed (for example, asphalt, cement, lime, etc.). The choice of a particular method depends on the characteristics of the problem on hand.

E. Safety of Existing Structures

There may be some possible reasons by which the safety of existing structures may be affected:

- Excavations in the immediate vicinity which may cause a reduction in support to the structure.
- Mining or tunnelling operations in the neighbourhood.
- Adjacent structures which may impose additional loads on the foundation strata or additional stresses in earthwork and supporting structures.
- Vibrations and ground movements resulting from traffic, piling or explosions in the immediate vicinity.
- Shrinkage of clay soils due to weather, transpiration of plants.
- Lowering of the ground-water level by pumping from wells may cause settlement of the ground surface over a wide area.
- A rise in the ground-water level may cause movement of the foundation strata.

VI. CONCLUSION

This work was carried out to find the damages in building structures, which occur due to foundation settlement. Also find out the various causes of Foundation failure as well as their possible preventive/remedial measures through case studies. Information on available literatures is provided to help in identifying the potential foundation problem in advance and taking necessary and appropriate action for mitigation purpose. Also investigate the present conditions for construction and to identify problems with foundation that occurs at construction field operations. The study of safety aspects related to foundation in construction. Observations and measurements of the feature of the structure to determine the mode of mechanism of failure are first needed, and these will often suggest the origin of the trouble, or at least indicate whether the ground conditions were partly or wholly responsible. The outcome of this research provides the suitable guidelines to avoid these problems.

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