Use of Preloading and Vertical Drains for Soil Consolidation

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Abstract

Previously, because of availability of more sites, people used to choose the best one having geotechnical properties of soil favourable for construction of a project. Accordingly, people would choose the site requiring no ground improvement technique for construction of a project. In view of rapid urbanisation/industrialisation, people are getting limited options/alternatives to choose sites for new projects. In fact, many a time, it happens that people have no choice but to accept the only available site for construction, no matter how poor its soil properties. These types of sites with unfavourable geotechnical properties for projects need improvement of soil properties by any suitable and economically viable method. Preloading is a technique by which consolidation of soil can be achieved by a substantial amount before imposition of actual construction load. However, the preloading technique alone may not be found to be satisfactory in reduction of consolidation time to the desired extent. Installation of vertical drains, particularly prefabricated vertical drains, followed by preloading is one of the most economical techniques to consolidate poor soils within a limited period.

Key Words: Soil Consolidation, Preloading, Vertical Drains

1. Introduction

Consolidation is one of the main methods for improvement of geotechnical properties of soil to make it suitable for construction of structure. Consolidation with preloading only is a long-term process, more so for some types of soils. People cannot wait for an indefinite period to achieve the required degree of consolidation for their project construction.

Previously sand drains were used for acceleration of consolidation of soft soils. With the increasing use of polymer-based products and change in construction requirements, synthetic or polymer-based prefabricated vertical drains have replaced those drains to a great extent. This has made consolidation much faster and thereby the construction time has been reduced.

2. Discussion

2.1. Preloading

The process of compression of soil under application of vertical load, before actual construction i.e. placement of final construction load, is known as preloading.

Preloading is generally of two types:
i) Conventional preloading – like embankment.
ii) Vacuum preloading.

2.2. Objective of Preloading and Consolidation

The additional stress on the soil increases its early settlement, which in turn reduces the settlement when actual construction takes place at site. This ultimately reduces the risk of collapse/defect/damage to the structure, resulting from differential settlement, be it building, road, runway or a big industrial structure, which is of prime importance in civil engineering construction.

2.3. Conventional Preloading

The most common and simple method of physical preloading is by means of an embankment or by a similar type of arrangement. Pore water initially takes care of the load once it is placed on soft soil. The water pressure gradually decreases because the water flows in the vertical direction very slowly. From the stability point of view, the load should be placed in stages, not in one stage.

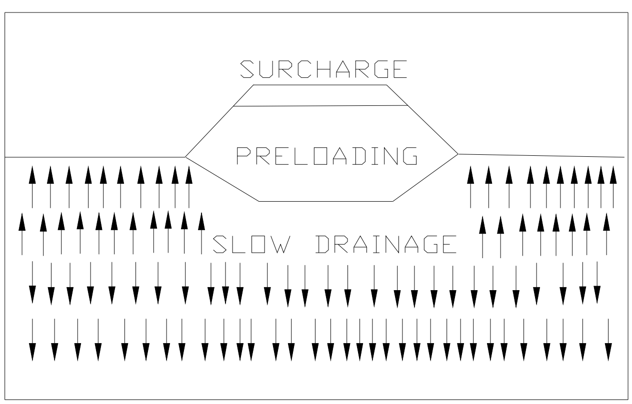

Fig. 1: Preloading

By increasing the time of preloading or the magnitude of the preload, the secondary settlement can be reduced or eliminated. This can be achieved by application of higher surcharge than the working load and the soil will be over-consolidated. This over-consolidated soil has less secondary consolidation than normally consolidated soil, which ultimately is of benefit in geotechnical design at later stages.

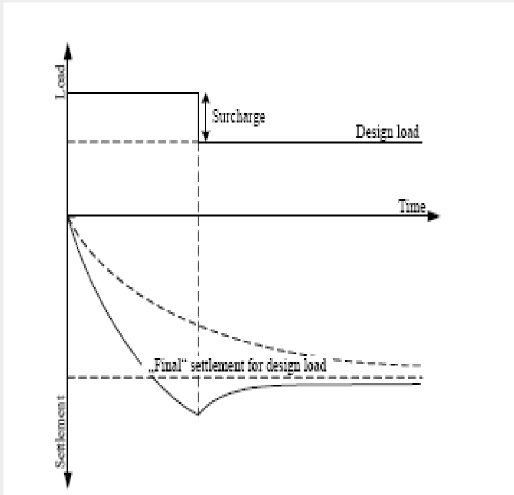

Fig. 2: Resultant settlement

There is a different type of loading used for preloading when the conventional preloading is not feasible because of soft soil being too weak to take even a small height of embankment. In such cases, vacuum preloading can be applied. Kjellman first introduced vacuum preloading in 1952 to accelerate consolidation where atmospheric pressure replaces surcharge load.

Arrangement for consolidation of soil through vacuum preloading consists of a set of vertical drains and a sand layer (drainage path) over it that is sealed from atmosphere by an impervious layer/membrane. Horizontal drains are placed in the drainage path and finally connected to a vacuum pump. Further to this, extra arrangement may be arranged to make it airtight. The vacuum pump creates negative pressure in the drainage path. Negative pore water pressure is generated with the application of negative pressure, which results in increase in effective stress in the soil which ultimately leads to an accelerated consolidation.

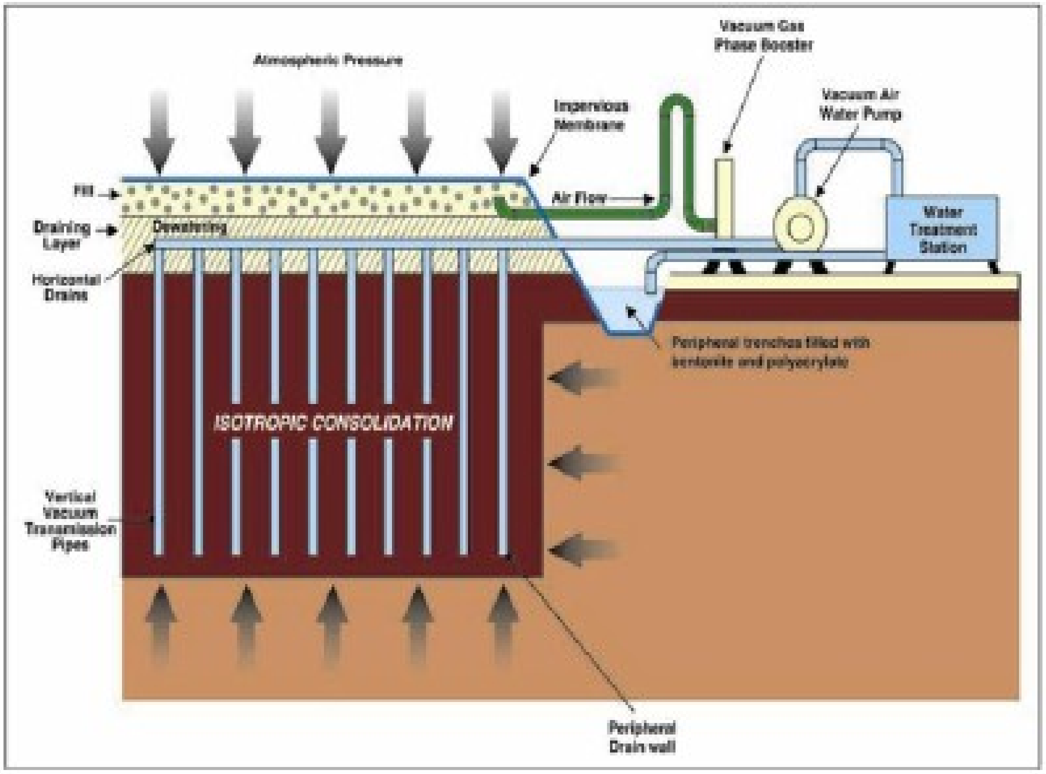

Fig. 3: Vacuum Preloading

2.5. Critical Analysis of Vacuum Preloading

Advantages:
1. No extra filling is required
2. Shorter construction time.
3. No heavy machinery is required.
4. No chance of penetration of chemical admixture in ground and hence environment-friendly.
5. Isotropic consolidation eliminates the risk of failure under additional permanent construction load.
6. There is no risk of slope instability beyond boundaries.
7. Rate and magnitude of loading can be controlled and thereby settlement can be controlled.

Disadvantages:
1. Keeping the drainage system effective under the membrane that expels water and air becomes difficult throughout the whole pumping duration.
2. Maintaining a leak-proof system is also a very difficult task.
3. Maintaining an effective level of vacuum is not also an easy task.
4. There are difficulties in anchoring the system at the periphery.
5. Lateral seepages are reduced towards the vacuum area.

2.6. Vertical Drains

In preloading, the time for consolidation may run into years because of the low hydraulic conductivity of soft clay and the drainage path being long. To reduce the time for consolidation, vertical drains are used together with preloading either by conventional preloading or by vacuum preloading over soft soils. This enables completion of final construction in a reasonable time with minimum post-construction settlement. Also, the vertical drains also accelerate the rate of strength gain of the in-situ soft soils. Further, vertical drains decrease the amount of surcharge/preloading required to achieve a settlement in a given time. Without installing vertical drains, bearing failure may occur during placement of fill and settlement of soft soils may extend over many years. Due to highly efficient drain installation methods, preloading associated with vertical drains has become an economic and acceptable alternative to other ground improvement techniques.

2.7. Types of Vertical Drains

There are different types of vertical drains. The following two types are widely used for ground improvements:
i) Sand drains
ii) Prefabricated vertical drains
Sand Drains: Sand drains are boreholes filled with sand. Diameters, lengths and spacing are designed based on requirement of degree and time of consolidation desired.
Prefabricated Vertical Drains: Prefabricated vertical drains (PVD) are a composite geosynthetic system consisting of an inner core and outer filter jacket. The most commonly used PVD has 100 mm width and 6 mm thickness. The inner core is constructed with polymer-based products like polypropylene having fabricated channel-shaped flow paths on both sides along its length. The outer jacket serves as a filter to allow passage of water to the inner core by preventing clogging by soil particle intrusion. These filter jackets are generally constructed with non-woven geotextile. Like sand drains, length and spacing of PVD are designed keeping in view the requirements.

2.8. Consolidation with Vertical Drains

When a vertical load is applied, an initial uniform excess pore pressure is assumed to be generated instantaneously throughout the soil stratum. This excess pore pressure will dissipate gradually or instantaneously depending on the hydraulic conductivity of soil and drainage condition at the boundaries of the stratum, by vertical drainage through the soil to the horizontal boundaries and/or by radial drainage into the pre-installed vertical drains. The average degree of consolidation indicates how much of the imposed load is transferred to the effective stress of soil and is defined by

$$U_t = \frac{S_{c(t)}}{S_{c(\max)}}$$

or,

$$U_t = \frac{u_i - u_t}{u_i} X100\% \quad \text{E1}$$

$S_c(t)$ = Settlement of clay layer at a time t after application of load.
$S_c(max)$ = Maximum consolidation settlement that the clay will undergo under a given loading.
U_t = Average degree of consolidation of a homogeneous soil strata at a particular time.
u_i = Initial excess pore pressure upon application of a vertical load.
u_t = Average excess pore pressure at a particular time.

2.9. Consolidation without Vertical Drains

Terzaghi's theory of one-dimensional consolidation predicts the excess pore pressure under vertical drainage alone. Based on equation (E1), Terzaghi's theory gives the following expression for the average degree of consolidation due to vertical drainage.

$$Uv(\%) = \left[1 - \frac{8}{\pi^2}\sum_{N=0}^{N=\alpha}\frac{1}{(2N+1)^2}\varepsilon^{\frac{-(2N+1)^2}{4}\pi^2.T_v}\right]X100 \quad \text{E2}$$

This equation can be written as follows:

$$Uv(\%) = f(T) \quad \text{E3}$$

This also shows that the degree of consolidation is a function of the time factor
U_v = Average degree of consolidation due to vertical drainage alone.

$$T_v = \frac{C_v.t}{d^2}$$

d = Length of longest drainage path.
T = Time from load application.
C_v = Coefficient of consolidation due to vertical drainage.

2.10. Consolidation with Vertical Drain due to Radial Drainage only

Barron (1948) arrived at the solution from the excess pressure at any radial distance from the drain and at any time during consolidation. Based on equation (E1) and the assumption of equal vertical strain, the following equation can be established for the average degree of consolidation due to horizontal drainage.

$$U_r = 1 - \varepsilon^{-\frac{8T_r}{F(n)}} \quad \text{E4}$$

T_r = Time factor for radial flow

$$T_r = \frac{C_{vr} t}{D^2}$$

C_{vr} = Coefficient of radial consolidation

D = Diameter of equivalent cylinder of soil drained by each vertical drain = 1.13 x drain spacing for square grid
= 1.05 x drain spacing for triangular grid

F(n) is a function mainly related to drain spacing and size and the extent of soil disturbance due to drain installation (smear effect). It has more than one version as addressed in detail in Barron (1948) and HOHZ (1991). The basic form of F(n) for ideal drain with no smear effect can be expressed as follows:

$$F(n) = \left(\frac{n^2}{n^2-1}\right)\ln(n) - \frac{3n^2-1}{4n^2} \qquad \text{E5}$$

Where, n = D/d
d = drain diameter = drain circumference / Л

Regarding the well resistance, the effect depends on the hydraulic conductivity of the vertical drains and the surrounding undisturbed soil as well as on the drain diameter.

2.11. Consolidation under Combined Vertical and Horizontal Drainage

Presence of vertical drains does not prevent the vertical drainage of water in the normal way. In reality, both vertical and horizontal drainage take place simultaneously. Carrillo (1942) derived the average degree of consolidation for combined vertical and radial water flow. U is calculated to be

$$(1-U) = (1-U_r)(1-U_v)$$

or,

$$U = U_r + U_v - U_r U_v \qquad \text{E6}$$

Where U = Average degree of consolidation under combined vertical and horizontal drainage.
Time rate of total settlement, S_t, with vertical drains can be calculated at any particular time for the various surcharge heights by the following equation:

$$S_t = S_{ult}(U_{vr}) \qquad \text{E7}$$

3. CONCLUSION

Prefabricated vertical drains associated with preloading accelerate the consolidation of soft soil/clay having low hydraulic conductivity. The accelerated consolidation reduces the consolidation time by a substantial amount. This is a very useful and widely accepted technique for improvement of soft soils having low hydraulic conductivity, less shear strength and this makes construction faster and thus reduces project execution time.

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