Pore Pressure Response of Soils under Dynamic and Static Loading Conditions

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Abstract: **Pore pressure controls the overall behavior of soils. Pore pressures and soil structure combines to produce a response which is an interaction of the two. Both static and dynamic load transfer is accomplished through a soil particle structure which is primarily a function of any unexpelled pore water pressures.**

Positive pore pressure responses reduce the normal effective stress (strength) of soils and generally have a destabilizing effect on any geotechnical structure. On the other hand contractive soil responds to loading with a negative pore pressure.

The resulted outcome of such pore pressure responses includes liquefaction which requires careful assessment in geotechnical engineering and construction.

Keywords: **Pore Pressure, Soil, Dynamic Loading, Static Loading, liquefaction.**

1. INTRODUCTION

Soil, when subjected to loading produces a response. The responses produced depend on the soil type, type of loading (dynamic or static) and a number of other factors such as pore water pressures.

According to the principle of effective stress, the strength and compressibility properties of a soil mass depends not on the total stress applied to the soil, but rather on the difference between the total stress and the stress carried by the pore fluid. This difference is termed the effective

Pore pressure controls the overall behavior of contractive and dilative soils. Positive pore pressure response reduce the normal effective stress (strength) of soils and generally have a destabilizing effect on any geotechnical structure. This study examines pore pressure response of soils under dynamic and static loading conditions. It also explains results of an outcome of such pore pressure responses such as liquefaction.

1.1 DEFINITION OF TERMS:

1.1.1. *Soil:*

A soil mass is a discrete particle that are the product of decomposition and disintegration of rock and organic matter by natural processes. Soil as described by Steve (1971) is composed of;

a. The composition of its solid

b. The composition of the liquids, gases and sometimes solid in its pores

c. The distribution of size, shape and angularity of its grains.

Any change to any of the mentioned constituent (solid grains, pore size, liquid and pressure) in the pores, the property of the soil changes (Steve, 1971)

For the purpose of this discussion soil will be classified for engineering use as either

1. contractive soil

2. dilative soil

Contractive soil: A soil is said to be contractive if it tends to decrease in volume when the shear stress is increased during loading, while on the other hand dilative soil tends to increase in volume when shear stress is increased. (Casagrande and Poulos, 1964) these properties are compressibility behavior of soil. Dilative soils develop negative pore pressure response.

Sand which is a dilative soil have been shown to dilate with an increasing effective stress (Roscoe, Schofield and wroth, 1958). Increasing effective stress under steady loading is synonymous to decreasing pore water pressure.

1.1.2. DYNAMIC LOADING:

This is the type of loading in which the forces that act on the soil is reciprocating within a short time range. This includes loads such as traffic wheel loads, earthquake loads. Dynamic loading has larger effect on soils than static loading of the same magnitude due to the soils inability to respond/recover quickly to its previous state.

Example of dynamic load is load from earthquake, large reciprocation machine foundations, and load from rail wheel traffic load.

Considering the effect of free water contained in the voids between the soil particles of a saturated clay soil, due to the impermeable nature of clay soils and the short time duration of dynamic loadings, this free pore water is, during loading, trapped within the confines of its local void. Load transfer is then accomplished by the soil particle-pore water system. According Terzaghi consolidation theory, when clay is initially loaded, practically the entire imposed load is transferred to the incompressible pore water. Terzaghi referred to this process of slow change in soil structure and pore water dissipation as consolidation.

1.1.3. STATIC LOADING:

This is the load that is exerted on a soil by the effect of gravity. This type of loading also exerts a constant amount of force on a soil for a relatively long duration without significant variation in position and magnitude. Static load can also be said to be the type of loading that varies very slowly when applied. Example of static load includes load from foundation of buildings.

1.1.4. PORE PRESSURE:

This refers to the pressure of groundwater held within soil or rock, in gaps between particles maintained at depth. In the absence of any other processes, the pore pressure is simply equal to the weight of the overlying fluid, in the same way that the total vertical stress is equal to the weight of the overlying fluid and rock. This pressure is often referred to as the "hydrostatic pressure." A number of processes may cause the pore pressure to be different from hydrostatic pressure. **Increase pore pressure** include: undercompaction, lateral compression, expansion of fluids, fluid density contrast sand fluid injection while processes that **decrease** pore pressure include: fluid shrinkage, unloading, rock dilation and reservoir depletion

1.1.5. LIQUEFACTION:

Liquefaction is a phenomenon in which the strength and stiffness of a soil is reduced by earthquake shaking or other rapid loading. Liquefaction occurs in saturated soils, that is, soils in which the space between individual particles is completely filled with water. This water exerts a pressure on the soil particles that influences how tightly the particles themselves are pressed together. Prior to an earthquake, the water pressure is relatively low. However, dynamic loading such as earthquake shaking can cause the water pressure to increase to the point where the soil particles can readily move with respect to each other.

Seed et al (1966) defined liquefaction as a phenomenon wherein a mass of soil losses a large percentage of its shear resistance when subjected to monotonic cyclic or shock loading and it flows in a manner resembling a liquid under the shear stresses acting on the mass are as low as the reduced shear resistance. During liquefaction the soil mass losses it shear strength. This behavior of loss of strength occurs in non cohesive soil. This is principally due to large build up of pore water pressure such that it equates the soil shear stress. The soil in this condition cannot support any weight.

On a lesser note, is cyclic mobility which refers to limited soil deformation without liquid like flow (Castro and Poulos 1977). Soil subject to cyclic mobility will first soften under cyclic loading but then stiffen when monotonically loaded, the

residual shear resistance remains greater than the driving static shear stress and deformation accumulate only during cyclic loading.

1.1.6. PRELOADING:

Preloading is aimed at achieving consolidation. This is the application of surcharge load on the site prior to construction of the permanent structure, until most of the primary settlement has occurred Stapelfedlt (2011). It is achieved using static loading. The pore water in the soil mass is expelled and soil particle/voids allowed settling under the influence of the overburden load.

2. PORE PRESSURE RESPONSE UNDER DYNAMIC LOADING

2.1. LIQUEFACTION:

This is a state of saturated cohesionless soil when its shear strength is reduced to zero due to pore pressure response that is caused by vibration during earthquake. In liquefaction, the pore pressure responds in such a way that the soil starts behaving like a liquid.

Terzaghi presented the shear strength of sandy soil as given by the Mohr-Coulomb equation:

$$s = c' + \sigma \tan\varphi'$$

Where, c' and φ' are cohesion intercept and the angle of shearing resistance in terms of effective stresses.

Taking the cohesion intercept $c'=0$ for cohesionless soil

Thus, $\qquad\qquad s = \sigma \tan\varphi'$

If the sand deposit is at a depth of z below the ground and the water table is at the ground surface, the effective stress is therefore

$$\sigma = \gamma_{sat}z - \gamma_w z = \gamma'z$$

Therefore, $\qquad\qquad s = \gamma'z\tan\varphi'$

If the sand deposit is shaken due to earthquake or any other oscillatory/reciprocation load, extra pore pressure (u') develops, and the strength becomes

$$S = (\gamma'z - u') \tan \varphi'$$

It can also be expressed in terms of extra pore pressure head h, where $u' = \gamma_w h$

Thus, $\qquad\qquad s = (\gamma'z - \gamma_w h)\tan\varphi'$

As indicated in the equation above, the shear strength of the soil decreases as the pore pressure increases, therefore a stage is reached when all the soil losses all its strength.

Thus, $\qquad\qquad \gamma'z - \gamma_w h = 0$

In this case, the soil is said to have lost its shear strength and any structure resting on such soil sinks. Saturated, fine and medium sands f uniform particles are the soils that are prone to liquefaction.

2.2. TRAFFIC LOADING:

In this case, we look at the response of pore pressure of soils subjected to traffic loading under saturated and unsaturated conditions. The development of pore pressure contributes to the degradation of the resilient modulus of unbound materials. According to a testing program carried out by Cary, C (2011) to characterize the pore pressure response of low plasticity fine clayey sand subjected to dynamic loading. The bulk stress, initial matric suction and dwelling time parameters were controlled and their effects were analyzed and the results got from the test were used to attempt models capable of predicting the accumulated excess pore pressure at any given time during the traffic loading and unloading phases. The accumulated excess pore pressure was found out to be higher for unsaturated soil samples than for saturated soil samples. Also, the maximum pore pressure always increased when the high bulk stress level was applied. In addition, higher dwelling time was found to decelerate the accumulation of pore pressure and the higher the dwelling time, the lower the maximum pore pressure.

3. PORE PRESSURE RESPONSE DUE TO STATIC LOADING

3.1. *PRELOADING:*

The purpose of preloading is to increase the shear strength of the soil, to reduce the soil compressibility and to reduce the permeability of the soil prior to construction and placement of the final construction load. This prevents large and/or differential settlements and potential damages to the structures. In this, we look at how pore pressure responds when subjected to conventional and vacuum preloading.

In conventional preloading, when the load is place on the soft soil, it is initially carried by the pore pressure. When the soil is not very permeable, which is normally the case, the pore pressure will respond by decreasing gradually because the pore water is only able to flow away slowly in vertical direction. Also, the total stress will increase due to the additional load and therefore, the effective stress will increase as well whereas, the pore pressure remains unchanged. Therefore in other not to create any stability problem, the load must be placed in two or more stages.

In vacuum preloading, this is when conventional preloading is not common. In a situation whereby a soil is so soft that it becomes not feasible to place a fill embankment. In this preloading, it consists of a system of vertical drains and a drainage layer (sand) on top. It is sealed from the atmosphere by an impervious membrane. Horizontal drains are then installed in the drainage layer and connected to a vacuum pump. Here, the negative pressure is created in the drainage layer by means of the vacuum pump. The applied negative pressure generates negative pore pressure which results in an increase in effective stress in the soil which in turn leads to accelerated consolidation. Also, it can also be said that the total vertical stress remains unchanged and the increase in effective stress is due to a reduction of pore pressure that is applying negative pressure.

3.2 *PILING:*

Pile driving maybe considered a dynamic loading when the pile is being driven into the soil by repeated blows or jacking, but once the depth has been reached, it now becomes a static loading to the soil. In the case of piling, when the piling is being done in a dilative soil, the soil exhibits volume increase and increase in effective stress that is, increase in strength which is a negative pore pressure response. The pore pressure in pile driving in a dilative soil responds by dissipating and once it dissipates, the soil decreases in strength and may result in the failure of the pile.

When piling is done in a contractive soil, the soil exhibits a positive pore pressure response which leads to decrease in effective stress that is decrease in strength and in this case now, piling becomes easy. After piling, the pore pressures dissipate and in the cause of the dissipation of the pore pressure, the strength of the soil increases.

4. CONCLUDING REMARKS

From the foregoing, we can conclude that pore pressure responses could be positive or negative. These responses also depend on the type of soil: contractive or dilative. Pore pressure response in dense sand (eg dilative soil) is negative while in contractive soil (normally and lightly over consolidated clay, loose sand), pore pressure response to loading is positive and could reach a magnitude such that the soil effective strength is completely lost, leading to liquefaction: complete loss of effective strength.

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