Soil Stabilization Techniques for Roads on Expansive Soils and Loose Sand

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Abstract. There are various techniques to stabilize soil which changes in volume due to vibration. Structural foundation in regions with expansive soil or loosely filled soil have to be laid after stabilizing such soils or by adopting the depth of foundation below the zone of movement. The tunneling induced vibration or alternative swelling and shrinking of soil due to seasonal change or change in ground water table level, causes movement of soil. This movement of soil result in additional stresses on the foundation, if the foundation depth is within this zone of movement. Normally, this zone of movement will be 1.5 to 2m below ground level. In some cases, this zone of movement may extend up to 5 to 6m. In this paper we have reviewed the various methods of stabilizing the expansive soil and loosely filled soil, especially the soil subgrade below the roads. Moreover, tunneling induced vibration due to underground metro rail construction also affects the soil behavior which in turn affects roads and nearby structures. Hence we have studied the effect of vibration on sandy soil by conducting laboratory experiments in the vibration table. The experimental result showed that the sandy soil settled more due to vibration when compared to the soil stabilized with gravel column. Addition of geomaterials such as gravel/stone in the form of column reduced the settlement level of loosely packed sand. Hence installing stone columns in soil is a better method to reduce settlement due to vibration that are produced during tunneling operations. Stone columns also prevents pore water pressure that builds up during earthquake vibration.

1. Introduction
Tunneling for road and rail networks is inevitable as it saves space in urban cities in developing countries and cities are developed rapidly for the purpose of modernization. Increasing population and technology advancement demands improvement of road and rail network in major cities. Construction of road and railway lines requires vast area of land including its future expansion work. Due to non-availability of lands, we need to construct tunnels. There are two major problems encountered during the process of tunneling, they are vibration and settlement. Tunneling creates vibration, in turn
nuisance to surrounding population, disturbance of working condition of sensitive devices, destroy the serviceability and durability of nearby buildings and structures.

The frequency level of ground and structural vibration depends on the source, soil-structure interaction, distance from the source and the condition of existing structures surrounding the construction site. Tunneling causes vibration and settlement of ground, hence it affects the stability of nearby buildings and structures. Mitigating the effect of vibration and settlement on nearby buildings, is the need of the hour. Granular wall or gravel drain has been effective in reducing the liquefaction effect and settlement.

Experimental comparative study have been carried out to understand the vibrational effect and resulting settlement. The settlement of soil before and after the implementation of mitigation technique is compared in this project. The main objectives of the project to measure the settlement of the natural river sand before and after stabilizing with geomaterial in the vibration testing machine. Then to compare both the settlement and to adopt suitable technique to reduce vibration induced settlement in sandy soil.

2. Literature review

Boominathan et al. (2019) studied the installation of gravel drains around the tunnel accelerates the pore pressure dissipation from the vicinity of the structure and there was a considerable reduction in the pore pressure accumulated at the invert of the structure. So we are using this process in our experimental study. Xie et al. (2018) discussed that the process of blasting operation, the shock waves, and earth quack waves subsequently developed. Due to the existence of these waves, the internal structures of the rock mass are inevitably influenced. Deckner (2017) developed a simpler and accurate method for estimating vibration dissipation as the distance from pile driving increase and predicting where ground settlement will occur.

Huang and Shi (2015)-The main design restriction for tunnel excavation in urban area is the induced ground deformation when the tunnel line passes near an existing building. In this paper, a numerical study was carried out to evaluate the possibility of reducing ground movements involved by tunnelling by pre-installing a passive protective barrier between the tunnel and the building exposed to potential damages. Liu et al. (2018) performed parametrical analyses using the Plaxis 2D and 3D Finite Element to define the soil-structure interaction mechanism that allow the reduction of ground movements induced by tunnel excavation. Diaphragm walls pre-installed between the tunnel and the buildings show to be effective in mitigation the effects induced by tunnelling.

3. Materials used for this study

The construction of geomaterial column in loose sand deposit is simulated in laboratory by installing cylindrical gravel column in the middle of mould filled with river sand.

3.1. Natural River Sand

Natural river sand is the most preferred choice as a fine aggregate material. River sand is the product of natural weathering of rocks over a period of millions of years It is mined from the river beds. The natural river sand are deposited in loose condition with more air voids. Construction of buildings near the river or in river basin pose serious threat as the loose soil tends to densify and cause settlement under mechanical vibrations or liquefy during earthquake vibrations. Pile driving in river sand vibrates the surrounding soil and stresses the nearby building. In this study, natural river sand is used to simulate loose soil condition.

Properties of Natural river sand

- Coarse sand (4.75-2.00mm) - 6.6 % by weight
- Medium coarse sand (2.00-0.475mm) - 73.5% by weight
- Fine sand (0.475—0.075mm) - 19.8% by weight
- Specific gravity - 2.67
3.2. Geomaterial

Geomaterial can be used as a part of mix in concrete. They are also used in the slab and vapour barrier. They are used in the construction of driveways and roadways. In this study, aggregate of size 4.75mm passing is considered as geomaterial.

Properties Of Geomaterial

- Size of the aggregate: 4.75mm
- Fine modulus (%): 2.864
- Grading zone: 2
- Bulk density (kN/m$^3$): 17.42
- Percentage of voids (%): 56.169
- Maximum percentage of bulking (%): 18.3
- Corresponding moisture content (%): 2
- Water absorption (%): 2.14

4. Experimental Procedure

The experiment was carried out in the Cushioned Steel Vibration table 75 * 75cm, 3600 r.p.m., 440V. Empty weight of the cylindrical mould was noted.

Mould Dimension

Height of the mould: 170mm
Diameter of the mould: 150mm

Natural river sand was filled over the entire mould, and then the mould with sand weight was noted. The sand filled mould was fixed on the vibrating table. The table vibration was rapidly increased within 8 minutes. The effect of the settlement was noted using scale. Then the geomaterial (aggregate) was filled in the centre of the mould using a PVC pipe. Geomaterial was placed in three layers and each layer was compacted well with 24 blows. The mould with the sample was taken to the vibratory table and the same procedure is repeated which was carried before. Settlement was noted at the end. As a result, the settlement of sand stabilized using a geomaterial column will be less than before without the geomaterial. The pictures of experimental setup, mould filled with natural river sand and mould filled with natural river sand and geomaterial are shown in figure 1 through figure 4.

5. Results and discussions

Two tests were carried out i.e, only natural river sand and river sand stabilized with geomaterial. The diameter ratio was calculated (ratio of diameter of the geomaterial column to the diameter of the mould) as 1/5, 1/3, 7/15. For every diameter ratio value, the above mentioned two tests were done. Four trials have been done for each tests. From these tests the diameter ratio value of 7/15 was found to have less settlement when compared with the other two values.
In each trial, the settlement of material was noted after vibration. The value of settlement without geomaterial after vibration and the average value of settlement is given in Table.4.1. For this average settlement value, relative density was calculated which is also given in Table.4.1. The value of settlement with geomaterial after vibration and the average value of settlement is given in Table.4.2. For this average settlement value relative density was calculated which is also given in Table.4.2.
Table 1. Settlement of only river sand after vibration

| Test no | Settlement after the vibration (mm) | Average settlement after the vibration (mm) | Relative density value          |
|---------|-------------------------------------|--------------------------------------------|----------------------------------|
| 1.      | 32, 34, 31, 32                      | 32.25                                      | γ min=1.549g/cc γ max=1.911g/cc  |
| 2.      | 30, 29, 30, 31                      | 30                                         | γ min=1.583g/cc γ max=1.922g/cc  |

Table 2. Settlement of river sand stabilized with geomaterial after vibration

| Test no | Settlement after the vibration (mm) | Average settlement after the vibration (mm) | Relative density value          |
|---------|-------------------------------------|--------------------------------------------|----------------------------------|
| 1.      | 31,30,32,30                         | 30.75                                      | γ min=1.549g/cc γ max=1.891g/cc  |
| 2       | 28,27,25,27                         | 26.75                                      | γ min=1.583g/cc γ max=1.879g/cc  |

The loose sand condition is maintained at the start of the test by first making the aggregate column at the center of the mould by filling the PVC pipe with aggregate. Then the sand is filled in loose condition surrounding the pipe and pipe is removed. This prevents the densification before the start of the experiment. The settlement value after stabilization is only 26.75mm when compared to 30mm before stabilization. The results shows that the use of aggregate column within the river sand has reduced the settlement of loose sand in the mould. Thus the aggregate column due to its coarser nature and particle arrangement, tends to dissipate the vibrational effect being passed on to the surrounding soil. Hence the construction of aggregate/geomaterial column reduces vibration induced settlement.

6. Conclusions
Hereby we conclude that the better way to reduce settlement in loose sandy soil during and after tunnel construction is to stabilize with geomaterial column or wall. This will reduce settlement to greater extent as compared to tunnel provided only in loose sand deposit. We suggest to use of aggregate to soil area ratio of 7/15 to get better reduction of settlement during and after tunneling. Thus, stabilizing the loose sand deposit with aggregate columns along the length of the tunnel or stabilizing the area between the tunnelling path and the building line will reduces the vibrational effect of the tunnelling operation and safeguards the buildings.

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