Design and construction of liquefaction tank

Chapter 3. Methodology

As mentioned in previous chapters, the objective of the project is to design and construct a " liquefaction tank" to be used during geotechnical engineering lectures and laboratory sessions to demonstrate the liquefaction phenomenon fundamental concept.

Existing liquefaction models

The liquefaction demonstration tank is not anything new. In fact, it is a classic in a geotechnical engineering program. This demonstration experiment tends to leave a lasting impression on the students mind. It is easy to find numerous figures and pictures of a basic quicksand model. For example, Holtz and Kovacs (1981) demonstrate a conceptual design diagram of a liquefaction tank, as shown in figure 3. 1. The model consists of two tanks. The water tank is at the bottom and the top tank contains sand. A pump is used to pump the water from the bottom tank into the sand tank, creates the upward flow in the quicksand tank. Flowing through the porous stone layer at the bottom of the sand tank, the upward water pressure is distributed evenly over the entire base of the sand layer, keeping the porewater pressure constant throughout. Number of piezometers is installed directly onto the sand tank at different level, which enables water heads within the quicksand tank during the experiment to be observed and readings to be taken.

From the literature research, there are two existing quicksand models built at other universities, pictures of which are obtained. Essentially, the concept is similar in both tanks. There are two separate containers, one on the top contains sand specimen and a tank with water at the bottom that will be used to fill and drain the sand tank into. Figure 3. 2 shows the model at the University of Illinois which is very similar to the diagram in figure 3. 1. The other liquefaction tank shown in figure 3. 3 is built at the Nanyang Technological University, Singapore. Instead of using pump, a standpipe is used to create and control the upwards flows in the sand tank. Also the piezometers in this model are installed on a separated board. Using flexible tubes, they are connected to valves installed at the side of the tank. A dial-gauge used to measure the vertical settlement of the object on top of the sand mass when it liquefies.

Design of the model

After evaluating all of the existing liquefaction models, an outline drawing including all dimensions and key features was drawn as shown in figure 3. 4. The main concept of the model is kept the same as those existing models. Utilising a hydraulic bench to contain water and support the sand tank, pump and water tank is not be needed. As for the liquefaction tank, there are numerous requirements that its design has to meet. First all of the tank, measured 500x500x700mm, must be make strong enough to support the pressure created by the sand and water mass (about 200kg) in side. It also needs to be made water proof to prevent water from leaking out. One of the important requirements is that the tank must be transparent enough to enable a clear visual of the sand and the phenomenon happens in site to be observed.

Taking all consideration into account, the sand tank is made out of fabricated Perspex panels glued together using impermeable glue. Similar to the model at the Nanyang Technological University, Singapore, five piezometers are installed on a separated board and connected to the tank using flexible tubes. This enables the model to be moved around safer and easier compared with rigid piezometers installed on the tank due to the significant height required. The tank also has two valves one on side acting as the inlet and out let, which helps to control the upward flow inside the tank. An overflow tube also is incorporated at the top. At each tube and valves connections, filter is used to prevent the sand particles from leaking out.

Inside the tank, there nine plastic cylinders placed at the bottom of the tank to support the mass. The sand will sit on a layer porous stone of 40mm thick which contained by 2 layers of metal meshes with drilled holes. This allows the upward water flow to be distributed evenly over area of the sand mass base. Layers of geotextile are placed between the stone layer and the sand layer, which effectively stops the fine particles from leaking down to the porous stone layer. The sand was filled up to the height of the fifth piezometer which made up a total thickness of 430mm from the metal mesh base. The sand tank is placed on top of the hydraulic bench. There is also a steel frame support to be made in the future to secure the tank to the bench, enables it to be moved around safely.

Based on these drawings, with the assistance of our departmental senior technicians, the tank was constructed as shown in figure 3. 5. There is a small modification to the design, which the valves are not connected directly onto the side panel but through a thick layer of Perspex prevents any crack to occurs at the connections. Similar to the model at the Nanyang Technological University, Singapore, a dial gauge attached to a steel bar place over the top of the tank, is used to measure the vertical settlement of the model. A metal string helps to secure the structure model to the steel bar, which enable the model to be taken out of the tank easily after completely sinking into the sand mass.

Testing materials

Porous stone layer

As described in the final design of the model, there is a porous stone layer with a thickness of 40mm placed between the sand and the mesh support. For this project, 10mm concrete aggregate was used to make up this stone layer. A sieve analysis was carried out on a 1 kg of sample to determine the grain size redistribution of this type of aggregate.

Leighton Buzzard sand

Once constructed, the model was used for testing liquefaction resisting performance of number of different type of structures. For these tests, Leighton Buzzard Sand fraction C was used. This was supplied by the David Ball Group, Cambridge, UK, confirming to BS 1881-131: 1998. After performing number of classification tests namely maximum and minimum density and sieve analysis on the 0. 5kg sample, properties of the sand were determined as follows. Specific gravity of the Leighton Buzzard Sand fraction C was 2. 65. Minimum and maximum dry densities were 1. 40 g/cm3 and 1. 68 g/cm3, respectively. These are value corresponding to the maximum and minimum void ratios which were calculated as 0. 89 and 0. 58, respectively. More than 80% of the coarse sand particles, which are rounded and mainly quartz, are between (around) 300 μm and 600 μm which meets the BS 1881-131: 1998 standard.

Resisting structure models

For this project, three small models with similar weight were made, representing three different foundation designs as shown in figure 3. 6. All three models have same shape, weight and made of the same materials. Table 3. 1 shows the dimension and weight of the models. Models A represents pile foundation for high raise buildings and large infrastructures. Model B represents a typical mat foundation which is a shallow foundation for small and medium houses and apartment buildings. Model C acts as the control which is just a standard block structure without foundation.

Testing procedures

To enable a comparison of the performance of the different types of foundations, the liquefaction tank was used to create the quicksand condition, in which the model placed on top of the sand surface, starts to sink down when the top sand layer liquefied. As mentioned in the literature review, there are various factors that can influent the liquefaction susceptibility namely soil particle grain size, upwards seepage and level of compaction. For this experiment to be accurate, all of the above parameters were kept approximately constant from one test to the other. The same sand, Leighton Buzzard (fraction C) was used in all three tests. Initial water level within the tanks as well as the flow rate controlled by the inlet valve with also was kept the same.

All nine supports were placed at the bottom of the liquefaction tank, followed by the metal mesh and the qeotextile layer. A 40mm thick layer of cleaned concrete aggregate was put on top of the geotextile and slightly compacted. Another layer of geotextile and metal mesh were put in before pouring the sand in. The sand were poured into the tank and compacted evenly in three layers. Once the model and the dial gauge were installed on top of the tank, the experiment was ready to run. While the outlet was completely closed, the inlet valve was opened to allow the water is pumped in the tank creating an upward flow, hence the change in pore water pressure between the sand particles and the increase in the water level in the piezometers. Hydraulic heads reading from the piezometers at different levels were recorded periodically and later on used to determine pore water pressure inside the tank. As predicted by the theory, as the inlet, valve 1, is opened to let the water to flow in, the head at the bottom of the sand layer will gradually increase and eventually to a sufficient value which can cause the sand to liquefy. The upward seepage forces will balance the downwards gravitational forces created by the sand mass. Hence rendering the shear strength of the sand to zero, any structure/object placed on top of the sand surface will sink in gradually sink into the sand mass. The whole procedure of the test will be recorded using a digital camera for reference when analyzing the data.

As can be noticed form the figure 3. 5, a small amount of blue dye was added to all five piezometers, to enhance the visibility of the water level inside the tube, especially when taking pictures and video. This can cause the non unity density of the liquid inside the whole length of the tube and result in the inaccurate measurements of the heads in the tank. However, since the amount of dye is minimal and taking the non unity of the water inside the tank, it is assumed that the head represented by the piezometers is approximately same as the head inside the tanks. In fact, this can be shown in figure 3. 7, where inlet and outlet valves are closed, the water level inside the tank is stationary. The different in heads caused by the non unity of the fluid can hardly be seen in all five piezometer.

Data collection

Liquefaction is a phenomenon that tends to occur very quickly. Therefore manual readings taking from all five piezometers are difficult and not very accurate. For this project, a digital camera was used to capture pictures at interval and record a video of the whole experiment.

From the reading of the piezometers, porewater pressures at different level inside the tank will be calculated during the whole experiments. From these data, graph of settlement against porewater pressure will be plotted for each experiment. Since all other parameters were kept constant from one test to the other, excepts for the type of foundation used, therefore difference between graphs will enable a comparison between the different type of foundation to be drawn.