Recent Development in the Vacuum Preloading Method and Its Application for Soft Soil Improvement

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On the 5th of January 2015, the Geotechnical Engineering Technical Division (GETD) conducted a talk on vacuum preloading on soft soil, a popular topic amongst civil engineers. The speaker, Professor Chu Jian, is James M. Hoover Chair in Geotechnical Engineering at Iowa State University, USA. He has more than 25 years' experience in geotechnical engineering in general and soil properties, in-situ and laboratory testing, soil improvement and land reclamation. The talk was attended by 49 participants.

The presentation started with an introduction on the principle and methodology of vacuum preloading. Conventionally, the vertical drains are used to consolidate soft cohesive soil by means of placing additional fill as surcharge loading. Vacuum preloading is different. Vacuum preloading creates a vacuum environment within drain areas by means of withdrawing air and water. When pore water pressure decreases, atmospheric pressure allows the overburden acting onto the soft cohesive soil. "The nominal vacuum pressure of 80kPa is generally achievable throughout the pumping process", said Prof Chu.

Figure 1 shows the typical cross-section of vacuum preloading. The process of vacuum preloading involves installation of vertical and horizontal drains, laying of 2 to 3 layers of membrane, installation of instrumentation and vacuum pumping.

In the event that sand layers are presence within the vacuum preloading area, a cut-off wall is required to ensure the workability of vacuum pumping process.

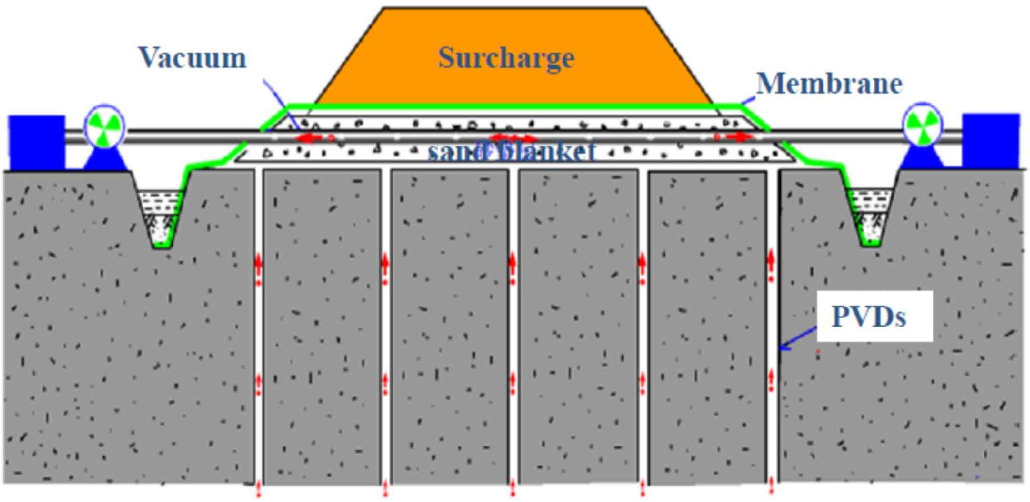

Figure 1: Vacuum Preloading

Case studies

Three case studies were presented by Prof Chu to demonstrate the effectiveness of vacuum preloading.

1. Case study 1: An oil storage station

   Here the land was reclaimed from dredged slurry with an undrained shear strength that varied from 10kPa to 30kPa. Through a series of instrumentations, i.e. pore water pressure transducer, inclinometer, multi-level settlement gauge, water standpipe and etc. were used to monitor the performance of vacuum consolidation. A total settlement of approximately 860mm and 920mm was recorded for Section 1 and 2 respectively. Based on the vane shear tests performed upon completion of vacuum consolidation, undrained shear strength increased by 20 to 45kPa.

2. Case study 2: A road on very soft clay (Chu, Yan and Yang, 2000)

   In the second case study involving soft ground in a roadwork construction the undrained shear strength was found to be 9 to 22Kpa. The total area of the soft ground was approximately 364m with an embankment width of 51m. In this case, close to 1m had consolidated due to vacuum consolidation.

3. Case study 3: A storage yard using combined vacuum and fill preloading method (Yan and Chu, 2005)

   Due to higher loading requirement, additional 3.5m of surcharge fill was placed over vacuum treatment area. Throughout the vacuum consolidation process, the ground settled approximately 1.4m with 80 degree of consolidation. The field vane shear strength increased two times of the original values. This case study had proven that the vacuum preloading had reduced lateral displacement, which could be problematic to the surrounding structure.

To assess the performance of vacuum consolidation, the analytical process is similar to consolidation using prefabricated vertical drain. The degree of consolidation can be performed either by using settlement readings or pore water pressures. In order to determine the degree of consolidation using settlement approach, the ultimate settlement parameter is required. Several methods, i.e. Asoaka, Hyperbolic and Zeng et al. can be used to determine the ultimate settlement. By taking the existing settlement reading over the predicted ultimate settlement, the degree of consolidation is calculated.

Since the effect of vacuum preloading is controlled mainly by variation of pore water pressure, it is essential to analyse the pore water pressure variation and to assess the degree of consolidation using pore water pressure. The pore water pressure approach is shown in the Figure 2, where the degree of consolidation is calculated by the integral in the numerator the area between curve $u_t(z)$ and the suction line $u_s(z)$ and the integral in the denominator the area between the curve $u_0(z)$ and the suction line $u_s(z)$.

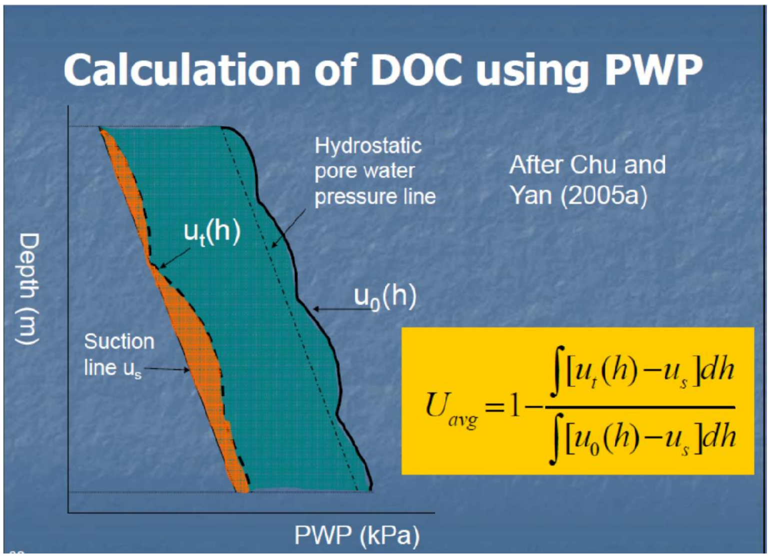

Figure 2: Degree of Consolidation using Pore Water Pressure Approach

Before the talk ended, Prof Chu presented many projects employing the application of vacuum preloading on clay slurry for land reclamation. Due to the nature of ultra-soft slurry, it had posted a major problem for the working platform construction. Several methods, i.e. sun drying, capping with sand, use of geotextile, lime or cement mixing, dewatering and etc. were discussed in relation to the working platform construction.

References

Chu, J., Yan, S. W., and Yang, H. (2000). "Soil improvement by the vacuum preloading method for an oil storage station", Geotechnique, 50(6), 625-632.

Yan, S. W., and Chu, J. (2005). "Estimation of Degree of Consolidation for Vacuum Preloading Projects", International Journal of Geomechanics @ ASCE, 158-165.