

Recent Advances in Modelling of Liquefaction and Lateral Spreading

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Use of geotechnical centrifuges to investigate the behaviour of geotechnical structures under earthquake loading has become very popular in recent years. There are already many established research centres worldwide with more joining this fraternity. In this paper we describe the development of a Stored Angular Momentum (SAM) based earthquake actuator at Cambridge for use on geotechnical centrifuges. An overview of the SAM earthquake actuator and model container is presented in Figs.1 and 2. While the SAM actuator has been working since 1995, certain key developments have been achieved which enhanced both the operational ease of this actuator and the quality of the earthquake loading. These developments will be highlighted in this paper.



Fig.1 An overview of the Stored Angular Momentum (SAM) Earthquake Actuator



Fig.2 Self-contained swinging platform carries both the SAM actuator and the ESB soil model container

One of the challenging aspects of dynamic centrifuge modelling is the simulation of the semi-infinite extent of the prototype ground. Many concepts are in use to minimise the boundary effects for example a Duxseal layer at the end to form an absorbing boundary or the use of laminar boxes with very low horizontal stiffness or Equivalent Shear Beam (ESB) model containers which aim to mimic the dynamic stiffness of the soil during earthquake loading. The concept of ESB model containers proposed by Zeng and Schofield (1996) has been adopted for container design at Cambridge. A new deep ESB model container has been recently been developed at Cambridge that can simulate soil layers with a depth of 40m. An overview of this model container is presented in Fig.3. Recent work by Steedman (1999) has raised interesting issues about liquefaction of soil at the high confining pressures that can be encountered below very high dams. It is anticipated that this new model container will be able to address this topic of liquefaction of soil under high confining pressures.



Fig.3 A view of the new large Equivalent Shear Beam (ESB) model container

Extensive work has been carried out to study the performance of the ESB model containers during dynamic centrifuge tests. Special in-flight cone penetrometers have been developed to compare the penetration resistance before and after earthquake loading and to quantify the boundary effects. A view of the in-flight CPT's is presented in Fig.4 and a view of the penetrometer probe is presented in Fig.5. The development of these cone penetrometers will be presented in this paper along with salient results.

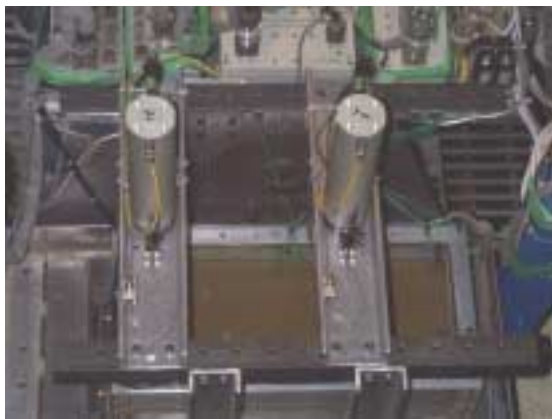


Fig.4 A view of two cone penetrometers assembled on the ESB model container



Fig.5 A view of the cone penetrometer probe

Three examples of the use of the SAM earthquake actuator and the ESB model container will be presented in this paper. The first example will be on modelling of liquefaction induced lateral flow of soils. The experimental results will be used to understand the development of excess pore pressures during the earthquake loading including the large suctions that will be generated during part of the acceleration cycle. The generation of the positive excess pore pressures and the suction 'spikes' will cause the soil slope to suffer a stick-slip type motion during the earthquake. Once the earthquake stops the soil will flow freely until it regains the necessary shear strength owing to the dissipation of excess pore water pressures.

The second example will be on the modelling of pile foundations in slopes of laterally flowing soils. Flexible and rigid piles were tested. With the flexible piles both the bending moments and the earth pressures on the upstream and downstream faces of the piles were measured. These results have given rise to a unique understanding on the transient forces acting on the piles during the earthquake and the residual forces following the lateral spread. With rigid piles, the earth pressures acting on both faces of the piles were measured. Also two cross-sections namely square and circular piles were employed in these tests to investigate the ease with which liquefied soil can flow past the two shapes. The flow patterns indicated that for the circular piles the flow lines are streamlined, a wider area around the pile was affected. For square piles the area of influence was shorter but a distinct line of shear was visible between the soil stopped by the pile and the freely spreading soil. In this paper we will show that while the current design codes estimate the residual force on the piles reasonably well, they under predict the peak transient forces by 200% to 300%.

The last example will consider liquefaction remediation using gravel drains. While design codes based on Seed and Booker's charts (1977) are currently in use, the efficacy of the gravel drains in relieving the excess pore pressures following liquefaction remains to be established. A series of centrifuge tests were carried out to understand the mechanism by which this dissipation was invoked following the earthquake loading. The results of this research indicate that flow capacity of drains is an important parameter for the gravel drains employed in liquefaction remediation. Deeper layers were able to discharge more fluid into the drain while the shallow layers remain liquefied for longer, as the drain is filled up with fluid from the deeper layers. Also the zone of influence of a drain and its temporal variation was investigated based on the centrifuge test data. In addition multiple drains were also tested to see the interaction effects among the drains, and to examine the validity of the unit cell assumption.

The paper will summarise the philosophy of dynamic centrifuge modelling and its use in various earthquake related problems. The progress of this research is closely linked with developments in instrumentation and the need to develop both MEMS based instrumentation and better data logging and handling will be highlighted. The use of novel analysis techniques such as Wavelets to improve understanding complex centrifuge test data sets will also be emphasised.

References:

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