# Effect of soil particle size on seismic response of gentle slope by centrifuge shaking table test

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## INTRODUCTION

Earthquake induced soil liquefaction continues to be an active topic of research, primarily driven by the continued observations of liquefaction induced failures in recent earthquakes such as the Tōhoku earthquake in Japan in 2011 and the Christchurch earthquakes of 2010 and 2011. The widespread liquefaction caused by the latter event and the damage it caused to important infrastructure such as bridges was considered by many researchers.

Dynamic centrifuge modelling has been established as a useful way to recreate liquefaction under laboratory conditions since the early 1980 s. The original VELACS project in the early 1990 s funded by the National Science Foundation, USA was the first effort to use centrifuge modelling test data to compare with and validate the numerical procedures available at that time. Since that time, the experimental techniques used in centrifuge modelling and the instrumentation employed have improved significantly. Similarly, the numerical procedures that are currently available to carry out fully coupled analysis and the computational power to perform such analyses have vastly improved.

There is a renewed interest amongst researchers and geotechnical engineering practitioners in many countries in developing a new database of centrifuge test data on liquefaction problems. Accordingly, a project named Liquefaction Experiment and Analysis Project (LEAP) was organized, involving researchers from the US, Japan, China, Taiwan and the UK. As an exemplar problem, the case of fully saturated, sloping ground with a slope angle of 5° was modelled at universities in Cambridge, Kyoto, Davis, RPI, Taiwan and China all of whom used the same Ottawa F-65 sand in their centrifuge tests. Numerical analyses of the same problem were also attempted elsewhere.

## TEST SETUP

A centrifuge shaking table test was conducted by geotechnical centrifuge and shaking table (GCST) in National Central University (NCU) to investigate the effect of soil particle size on seismic response of gentle slope. The NCU Centrifuge has a nominal radius of 3 m and a 1-D servo-hydraulic shaker integrated into a swing basket. The shaker provides a maximum nominal shaking force of 53.4 kN with a maximum table displacement of ± 6.4 mm and accelerations up to 80 g with a maximum payload of 400 kg. The nominal operating shaking frequency range is 0–250 Hz. The payload mounting area has the dimensions 1000 mm × 546 mm × 500 mm.

The model NCU2 in LEAP-UCD-2017 is adopted to be the control group model, and the material of NCU2 model is Ottawa sand F65 which is shipped from USA in LEAP-UCD-2017. The model (LPS, which means larger particle size) conducted in this study is made of a larger particle size sand, and the dimensions and the arrangement (shown as Figure 1) are same with the LEAP model. The soil properties of 2 kinds of sand are listed in Table 1.

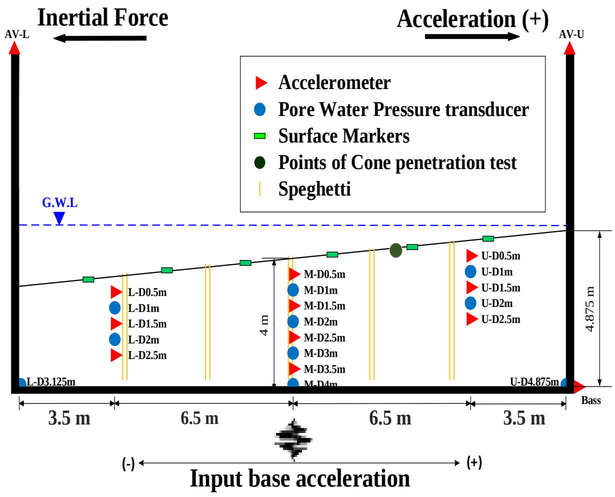


Figure 1. Model arrangement in LEAP-UCD-2017

The preparation procedure of LPS model is following the specification established in LEAP-UCD-2017. The sandy slope was made by air-pluviation method with constant drop height and flow rate, and the sensors were installed at the specific location. Finally, the achieved dry unit weight of model LEAP and LPS are 1612 kg/m3 ($D_r$ = 69%) and 1519 kg/m3 ($D_r$ = 68%), respectively. Afterward, the model was saturated by viscosity fluid with specific viscosity. The test was carried out under 26 g acceleration centrifuge field. When the centrifuge spins up to 26 g-level, the shaking events and CPTs were implemented in the order listed as follow: (1) pre-shaking [s1], (2) CPT 1, (3) main shaking [s2], (4) CPT 2 and (5) pre-shaking [s3]. The dry density of models and properties of shaking events are listed in Table 2.

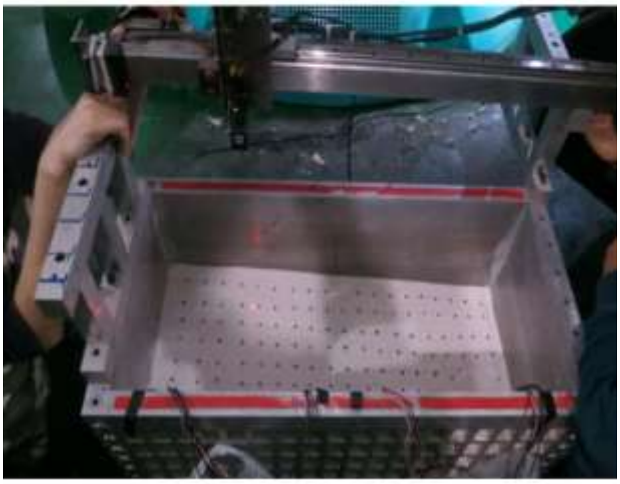

Figure 2. Ground surface profile before test.

## RESULTS

The acceleration response of models shows the LPS model has smaller spike acceleration than LEAP model. It indicates that the dilation behavior of LPS is not significant as compared with the Ottawa sand. From excess pore water pressure (EPWP) response, the depth of liquefaction at the middle part is 4 m in LPS model and 3 m in LEAP model. The dissipation time at 4 m depth is 100 seconds in model LEAP, but less than 100 seconds in model LPS. It is because the LPS has larger permeability so that the water can dissipate faster.

The shear velocity and predominant frequency are determined via analyzing the acceleration time series data from pre-shaking events. The shear velocity and the predominant frequency of soil strata is 113 m/s, 5.4 Hz and 164 m/s, 5.0 Hz in model LEAP and LPS, respectively. The $q_c$ at depth 2 m measured by CPTs is about 2.5 MPa and 2.3 MPa in models LEAP and LPS, respectively. It would result from the same relative density but different dry unit weight. Only two kinds of soil particle size are discussed in this study. More tests conducted with more kinds of soil particle size are necessary to conclude the precise response.

Table 1. Properties of soil

| Soil name | Unit | Ottawa sand F65 | LPS sand |
|---|---|---|---|
| Particle size | (mm) | 0.15 - 0.25 | 0.25 - 0.45 |
| USCS | | SP | SP |
| $\gamma_{d,max}$ | (kN/m$^3$) | 17.3 | 15.8 |
| $\gamma_{d,min}$ | (kN/m$^3$) | 14.5 | 13.2 |
| φ | deg. | 32.5 | 29.9 |
| k | (cm/s) | 2.2x10$^{-2}$ | 1.1x10$^{-2}$ |

Table 2. Test conditions

| Event no. | s1 | s2 | s3 |
|---|---|---|---|
| Frequency | 3 Hz | 1 Hz | 3Hz |
| Cycle | 1 | 16 | 1 |
| PBA (LEAP / LPS) | 0.09 g / 0.09 g | 0.22 g / 0.23 g | 0.09 g / 0.07 g |
| Waveform | Sine wave | Tapered sine wave | Sine wave |

## CONCLUSIONS

Two centrifuge model tests of models were performed to determine the effects of soil particle size on the slope model on soil liquefaction. From the test results, we conclude that:

1. The surface deformation of models is represented by tracking the displacement of surface markers, and the results show the LPS model has larger horizontal displacement toward downslope after soil liquefied.
2. The test results show the seismic response including acceleration response, EPWP behavior, and displacement induced by liquefaction of model is affected by different soil particle size. However, the other properties like shear velocity, predominant frequency and $q_c$ of soil strata are not strongly related to soil particle size.

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