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Centrifuge Modeling of Embankments Built on Saturated Fly Ash Deposits

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ABSTRACT: An experimental setup used to study the performance of soil embankments built on saturated fly ash deposits is presented. Three scale models were constructed, instrumented, and tested in a centrifuge. The centrifuge tests were effective for measuring the behavior of fly ash foundations for conditions leading to failure. This study was a collaborative effort between the US Army Corps of Engineers Centrifuge Research Center, Stantec Consulting Services Inc., and the Electric Power Research Institute (EPRI).

1 INTRODUCTION

In the United States, over 100 million tons of coal combustion residuals (CCR) are produced annually in the production of electric power. A large percentage of CCRs is coal fly ash, which is captured to prevent atmospheric release. Only about half of this material is beneficially used in construction materials or as engineered fill. Coal fly ash is often stored in wet impoundments adjacent to power plants. Closure of these facilities requires the construction of earthen embankments and engineered caps over the top of older, saturated ash deposits.

Fly ash is a particulate material that exhibits behaviors and properties that vary with confining pressure. Saturated ash can be vulnerable to the rapid loss of strength as surface loads generate high excess pore water pressures. Under the right conditions, saturated ash can liquefy under static loads, leading to sudden embankment collapse and flow failures of the underlying ash (i.e. static liquefaction).

This research was conducted to evaluate the performance of a sand embankment overlying a saturated fly ash deposit. Three tests were conducted on models with fly ash from three different sources. The tests were planned to induce slope failures passing through the fly ash foundation.

2 MATERIALS

Fly ash was collected from the dry handling systems at three coal-fired power plants. The measured index properties for the ash from the various sources ranged as follows:

- Initial pH in water = 8.79 to 10.67
- Specific Gravity = 2.32 to 2.69
- Fraction Passing No. 200 Sieve = 88.7 to 91.5%

The embankment material used in all models was a dry, clean, uniform, #90 Silver Sand with density properties as follows:

- $\gamma_{dry} = 1542.59 \text{ Kg/m}^3$
- $e = 0.716$
- $G_s = 2.60$

3 CENTRIFUGE TEST FACILITY

The centrifuge tests were conducted at the U.S. Army Corps of Engineers, Engineering Research and Development Center in Vicksburg, Mississippi. The centrifuge is capable of carrying a maximum payload of 8000 kg on a testing platform that measures 1300 mm by 1300 mm. Accelerations of 350 g can be achieved, with the machine spinning at 230 rpm.

4 MODEL CONSTRUCTIONS

4.1 Test Box

A 13 mm thick aluminum box, measuring $635 \times 127 \times 356 \text{ mm}^3$, was used for the centrifuge tests. The three models were formed within this box. A transparent Plexiglas panel on the front face allowed for visual observations of the model throughout the test. Additional bracing was added pre-flight to minimize potential bulging of the Plexiglas panel.

4.2 Test bed formation

The fly ash foundation was constructed by slurry placement to mimic field conditions in a CCR impoundment. Fly ash was mixed to a water content (40%) where the slurry would readily flow. Batches of the material were then placed in lifts (Figure 1). Once the desired thickness (152 mm) was achieved, the test bed deposit was allowed to consolidate under self-weight. Excess water displaced by the consolidation process was removed prior to constructing the sand embankment.



Figure 1. Placing fly ash slurry to form test bed deposit.

4.3 Embankment Formation

Using a hopper, sand was pluviated across the surface at a moderate flow rate to build up the embankment in relatively uniform lifts. The drop height was kept about 25 mm above the surface.

Figure 2 shows a completed model. The sand embankment was 165 mm high, with a sloping face (1.5 horizontal to 1 vertical). A fine mesh was placed over a portion of each lift to act as reinforcement, to prevent shallow sliding within the sloping face of the sand.

After the embankment was completed, a portion of the ash foundation remained exposed. A damp cloth was laid over this portion and sprayed with water daily to ensure the ash foundation remained saturated while test preparations continued. The model was also covered with a plastic tarp overnight.

4.4 Surcharge Load

A rapidly applied, additional surcharge load was needed to cause undrained failures in the ash during the centrifuge tests. This was accomplished by pneumatically loading the top of the sand embankment while the model was in flight.

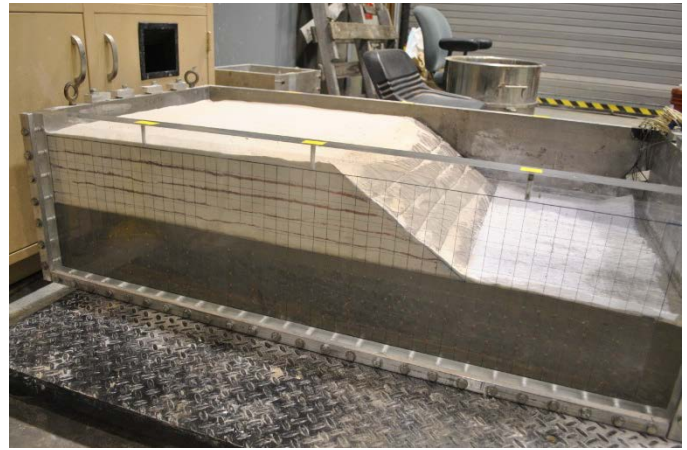


Figure 2. Completed fly ash deposit and sand embankment.

For the first test, an approximately 25 mm thick pneumatic lifting bag was used to surcharge the top of the sand embankment. A reaction plate secured to the test box was used to contain the air bladder. Due to the rigidity of the lifting bag, the surcharge pressure applied to the sand embankment was less than the measured air pressure. A post-test calibration was necessary to correct the data. Additionally, the bag expanded minimally when pressurized; therefore, surcharge pressures could not be sustained once significant vertical deformations of the model occurred.

In the final two tests, an expandable, accordion-style airbladder was used to generate the surcharge pressure. A flexible, nylon-reinforced, urethane fabric air bladder (Figure 3) was custom made for the tests. This bladder had a collapsed height of 25 mm and could expand to a height of 102 mm. The construction of the custom made air bladder allowed for uniform surcharge pressures, even after 76 mm of downward deformation of the model embankment.



Figure 3. Custom-made air bladder on sand embankment.

4.5 Reaction Frame

Figure 4 shows the reaction frame for the air bladder. The frame consisted of two brackets, a flat aluminum plate and threaded rods. The flat plate has the same surface dimensions as the air bladder and was used to restrain the bladder and to ensure even pressure distribution over the sand embankment. The two brackets, one placed over the flat plate and the other under the bottom of the model container box. The brackets were then connected with threaded rods on each side of the container box. Small footings were used on the opposite end of the box to level the model container.

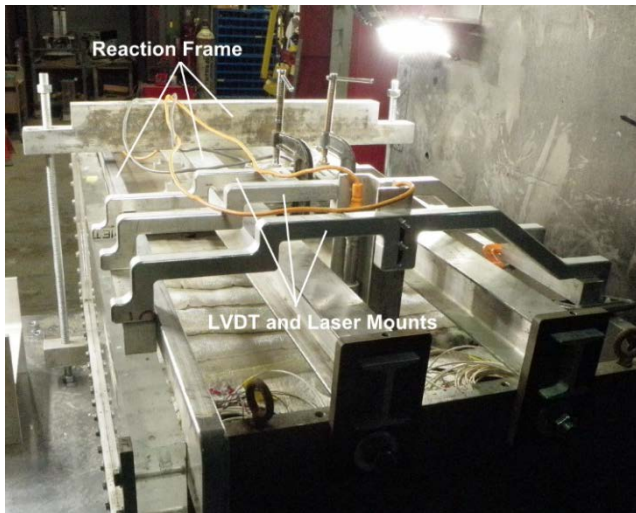


Figure 4. Reaction frame and instrument mounts on top of the test box.

INSTRUMENTATION

Figure 5 shows the general test instrumentation layout. While conducting the centrifuge tests, several instruments were used to monitor the conditions in the fly ash and sand embankment.

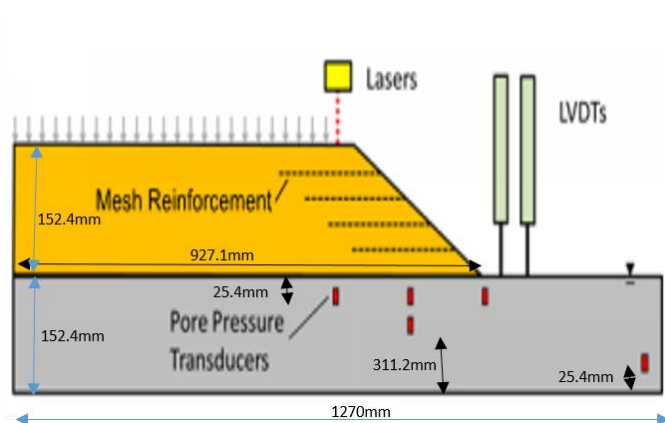


Figure 5. Instrumentation layout.

4.6 Pore Pressure Measurements

Eight to ten submersible Druck pore pressure transducers (PPTs) with a porous stone filter, thin wire, model PDCR-81-3478, were employed in the ash during the tests. PPTs were located in four or five locations on two cross sections spaced 165 mm apart. Four PPTs were mounted on aluminum rods, protruding from the base of the test box. The remaining PPTs not mounted on fixtures and were inserted into the fly ash from the completed ash surface. Mounting PPTs from below allowed for more accurate placement; however, the supporting rods could influence the stability of the model, so their use was minimized.

4.7 Deformation Measurements

Two laser range, Banner Q50AVU 50-150 mm, finders were mounted to measure settlements at the crest of the embankment. Near the toe of the slope, two RDP Electronics Ltd. Type ACW 1000A, linear variable differential transformer (LVDTs) were mounted to measure vertical deformations of the ash surface. Lightweight, plastic bearing discs were placed on the ash surface to prevent penetration of the LVDT tips.

In the first two tests, these instruments were mounted to the reaction frame. This configuration caused errant readings when the reaction frame deflected upward as the air bladder was inflated. For the third test, fixtures were manufactured to independently mount the lasers and LVDTs (Figure 5).

Figure 6 shows deformation markers used to track model movements during testing. Prior to model construction, a clear plastic sheet with 25 mm gridlines was taped to the transparent face of test box. Small, multi-colored, plastic tabs were then temporarily attached at the grid points, using a small amount of vacuum grease. Care was taken to prevent disturbance of the markers during model construction.

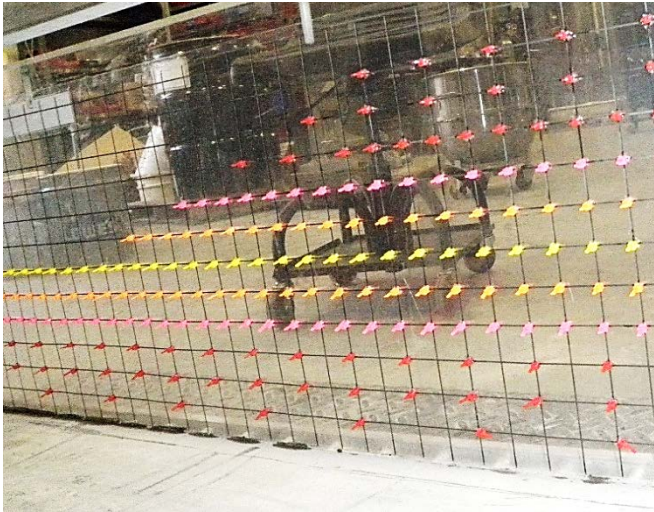


Figure 6. Deformation markers on the interior face of experimental box.

Finally, pre-flight and post-flight model geometry were scanned using a handheld color laser scanner, ZScanner 800. This provided a three dimensional model of the surface before (Figure 7) and after testing.

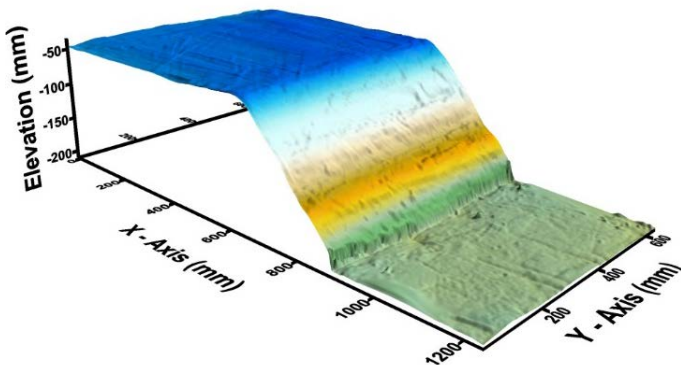


Figure 7. Scanned geometry of embankment model prior to testing.

4.8 Other

Six cameras allowed for real time observations of the model during in-flight testing. The video was recorded and analyzed after test completion. A pressure transducer on the air bladder measured the applied surcharge load during testing. Finally, an accelerometer mounted on the centrifuge platform provided an acceleration time history of the flight.

5 CENTRIFUGE TEST AND RESULTS

Once the tests were initiated, acceleration was increased to a predetermined level of 100g's. Pore water pressures were observed and allowed to equalize before pressurizing the air bladder. This rapid loading produced slope failures in two of three

models. Example data collected during the test is plotted in Figure 8.

The PPTs were prone to malfunction. During the three tests, 19 out of 27 PPTs produced unusable data. Additionally, most PPT measurements drifted during testing, as evidenced by non-zero readings at 1 g after the test ended. However, relative readings of pore water pressure over similar time frames were still useful.

The LVDTs and lasers functioned properly throughout all three tests. The deformation markers were especially helpful in visualizing movements of the model during and after testing. Movements throughout the ash and sand could be clearly tracked as illustrated in Figure 9.

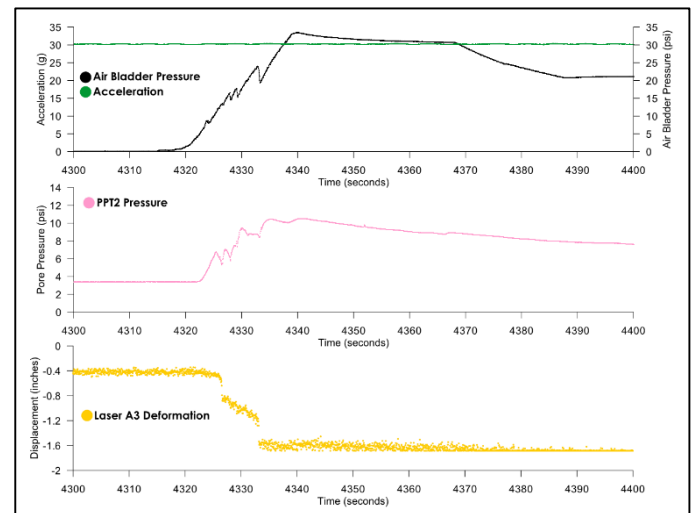


Figure 8. Example instrumentation measurements gathered during testing.

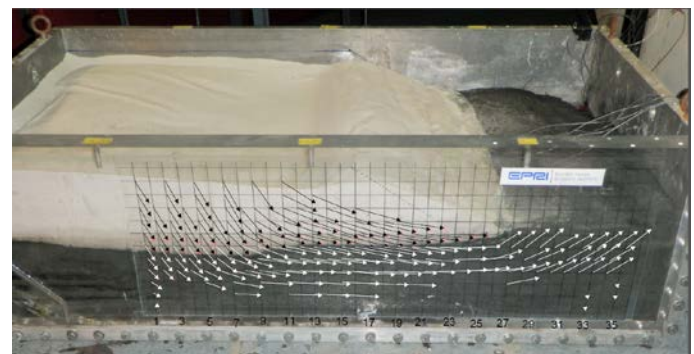


Figure 9. Post test results with displacement vectors plotted using deformation markers.

6 CONCLUSIONS

An effective methodology was developed to test fly ash foundations under embankment loads in a centrifuge. The scale model was constructed in a

repeatable manner to the desired dimensions. Instrumentation was used to capture pertinent measurements during centrifuge testing. Pore pressure measurements were not as reliable as deformation measurements during the test; however, all instruments provided information that was useful to the engineering analyses that followed the model tests. The desired slope failure was achieved in two of three model tests.

REFERENCES

- Bowman, E.T, Laue, J., Imre, B., and Springman, S.M. 2010. Experimental modelling of debris flow behavior using geotechnical centrifuge. *Can. Geotech. J.* 47: 742-762.
- Ram, L.C., Masto, R.E. 2009. An appraisal of the potential use of fly ash for reclaiming coal mine spoil. *Journal of Environmental Management* 91 603-617.
- Bournonville, B., Nzihou, A. 2002. Rheology of non-Newtonian suspensions of fly ash: effect of concentration, field stress and hydrodynamic interactions. *Powder Technology* 128 148-158.
- America Coal Ash Association website <https://www.aaa-usa.org/Portals/9/Files/PDFs/2014ReportFinal.pdf>.