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# Centrifuge Modeling of Seismically-Induced Uplift for the BART Transbay Tube

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## Supplemental Data

### Saturation Procedures

To saturate the sand, a vacuum lid was placed on the container, a vacuum of -90 kPa gauge pressure was first applied to the specimen. Next, the vacuum was relieved by flooding the container with carbon dioxide gas, and then the vacuum was re-applied. Then, de-aired viscous pore fluid supplied under vacuum was supplied by dripping fluid through the vacuum lid into a small trough above the sand. Saturation tubes ran from the bottom of the trough to the base of the trench where the viscous fluid was introduced to the sand. The saturation tubes are visible on the left side of Fig. S3.

### Container Window Pictures

Fig. S7 shows a photograph through the window of the container before and after testing of JCC01. The three large black dots (fixed to the Teflon sheet) attached to the tube and the black sand layers near points A and B in Fig. S7, clearly show that the tube moved up and soil around the tube settled down. The small black and white dots near each other in the photos (e.g., just to the left of point A) were attached to the window and can be used as an absolute reference for tube and soil movement. Also, on the right of Fig. S7 (b), an upside down W shape black colored sand layer was formed by the flow of the water along the side window during dissipation of pore water that collected at the nearby interface between the Gravel Fill and Sand Fill in the large TCU event.

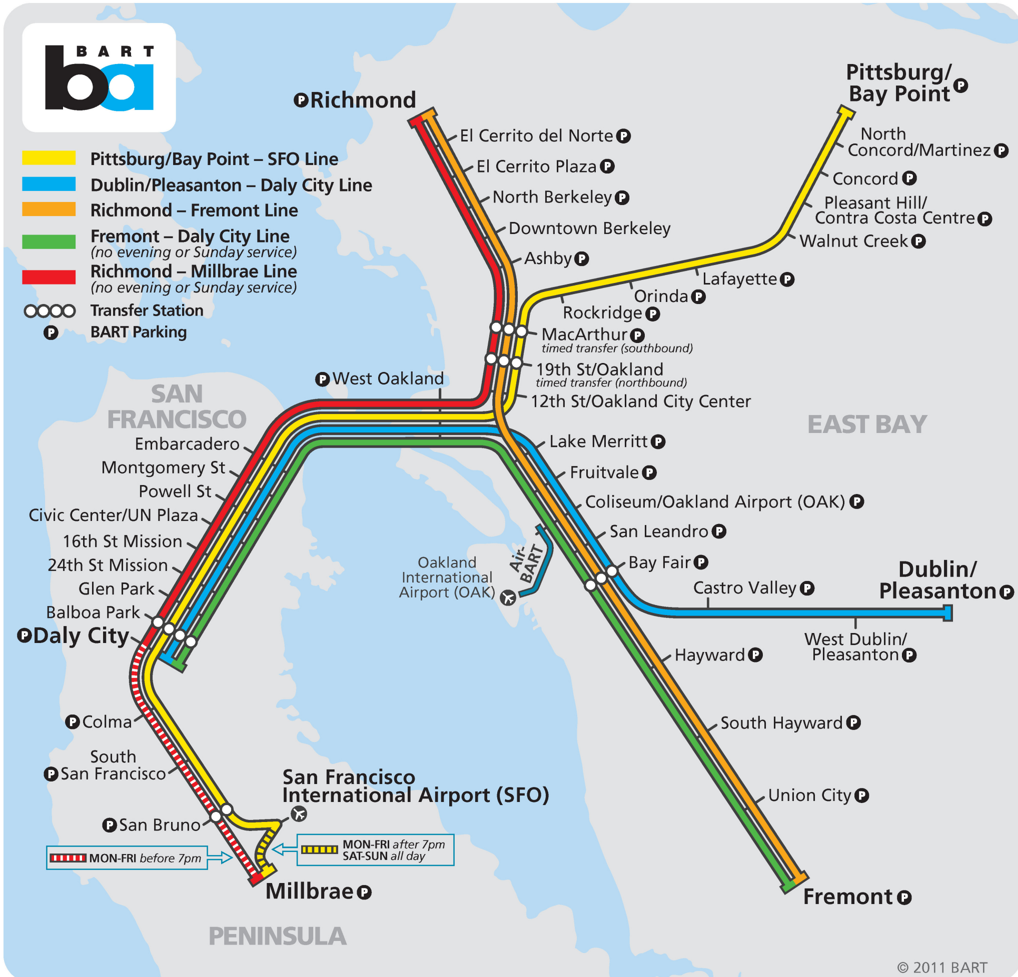



**FIG. S1.** The BART system. Four of the five lines pass through the Transbay Tube between the West Oakland and Embarcadero Stations (Source: http://www.bart.gov) (Reprinted with permission from the Bay Area Rapid Transit (BART))

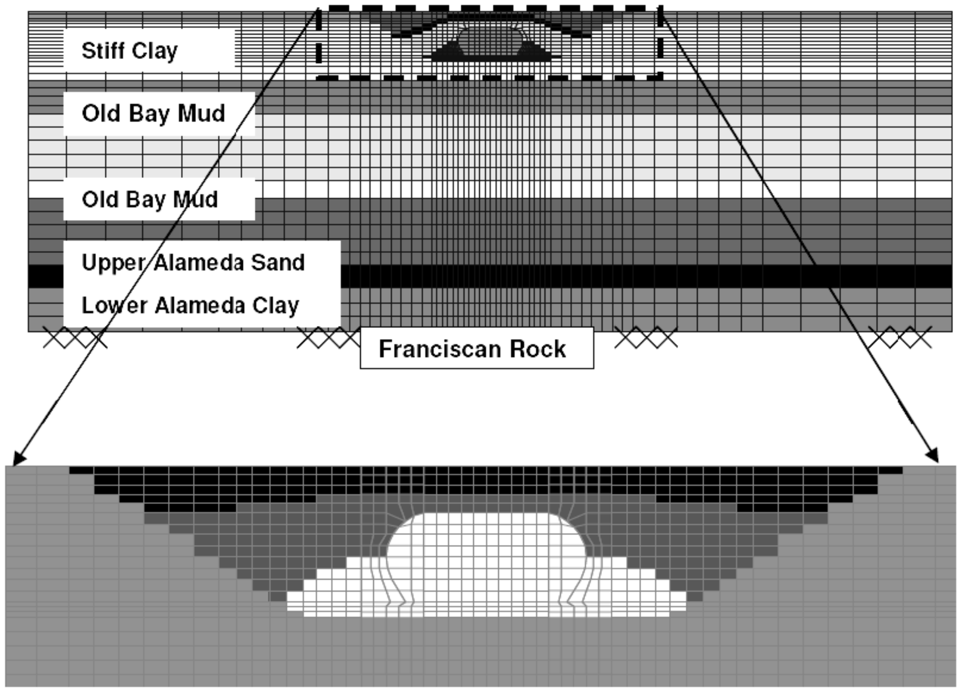



**FIG. S2.** Soil profiles showing the finite difference grid used to analyze the prototype (top) and the centrifuge model (bottom).

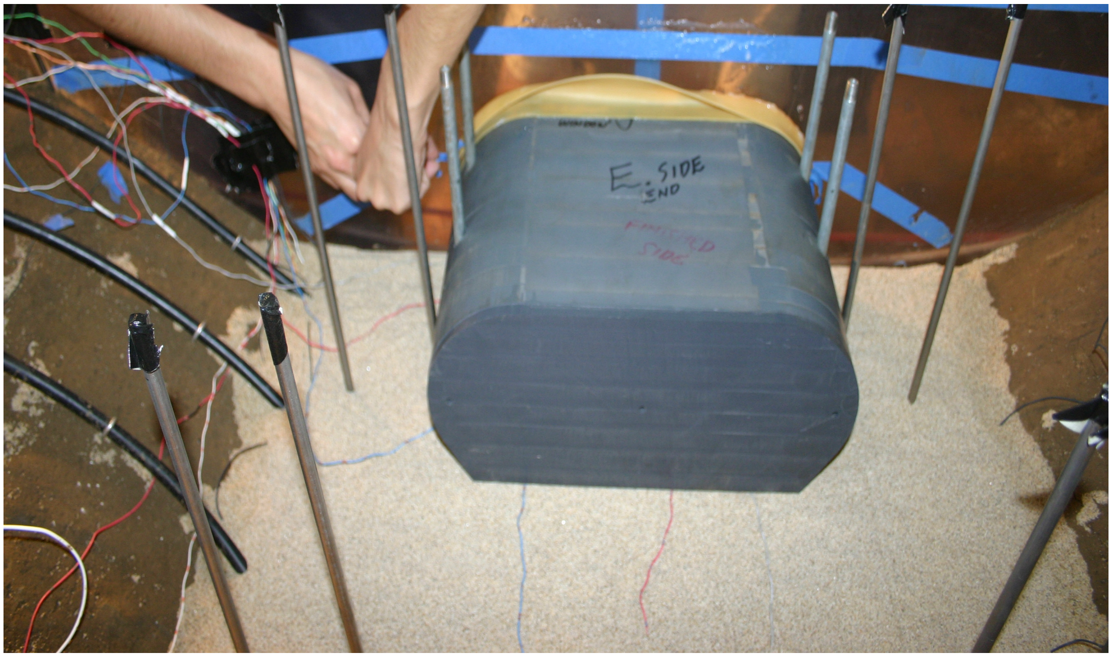



**FIG. S3.** Construction pictures from JCC01: East segment of Tube temporarily placed on Foundation Course; black saturation tubes on the left and vertical metal tubes for colored sand columns.

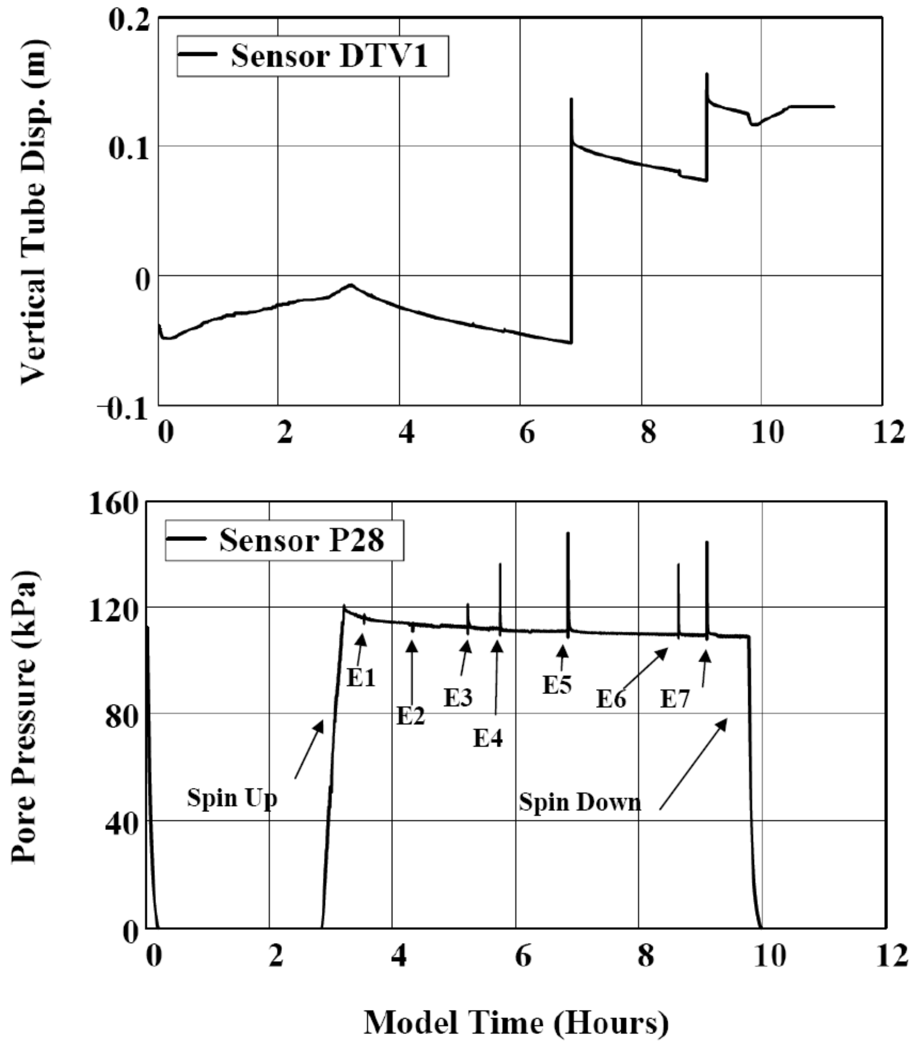



**FIG. S4.** Vertical tunnel displacement and pore pressures in the middle of the Foundation Course during JCC02.

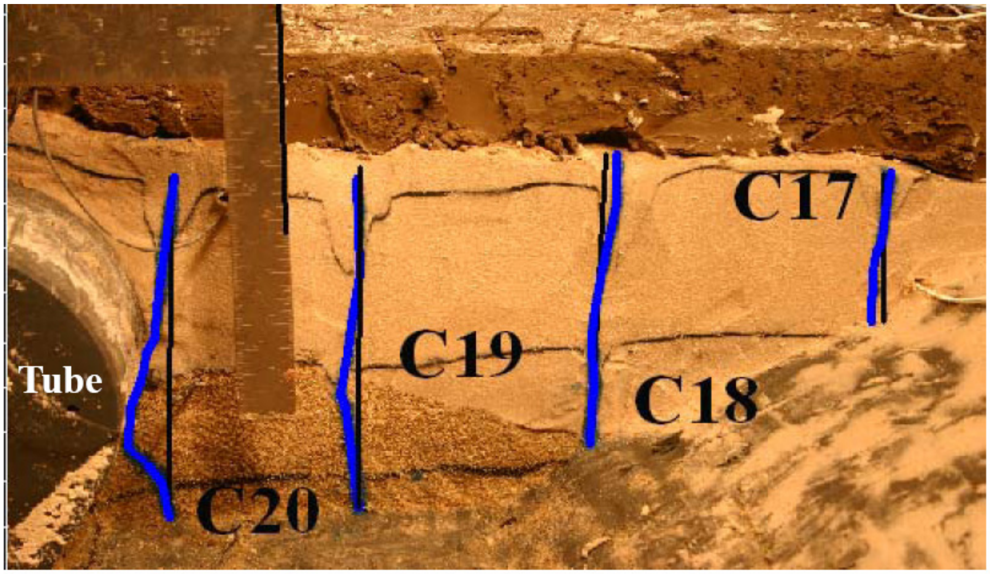
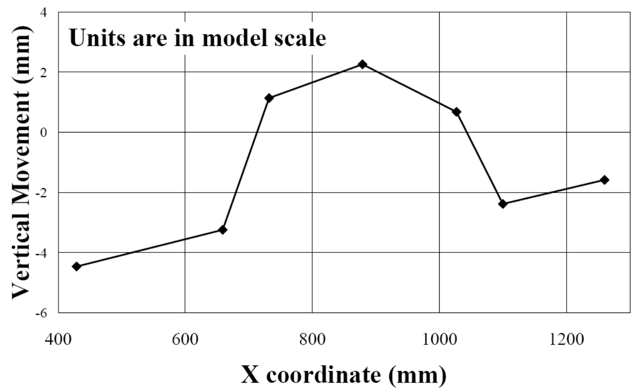
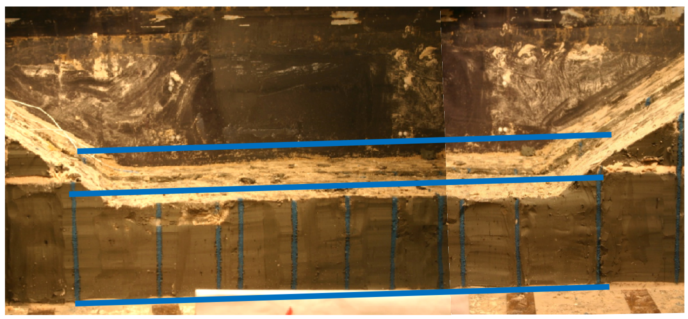



**FIG. S5.** Colored sand columns indicate the deformation pattern of sand in JCC02. (Vertical black lines indicate the initial locations of the colored sand columns.)

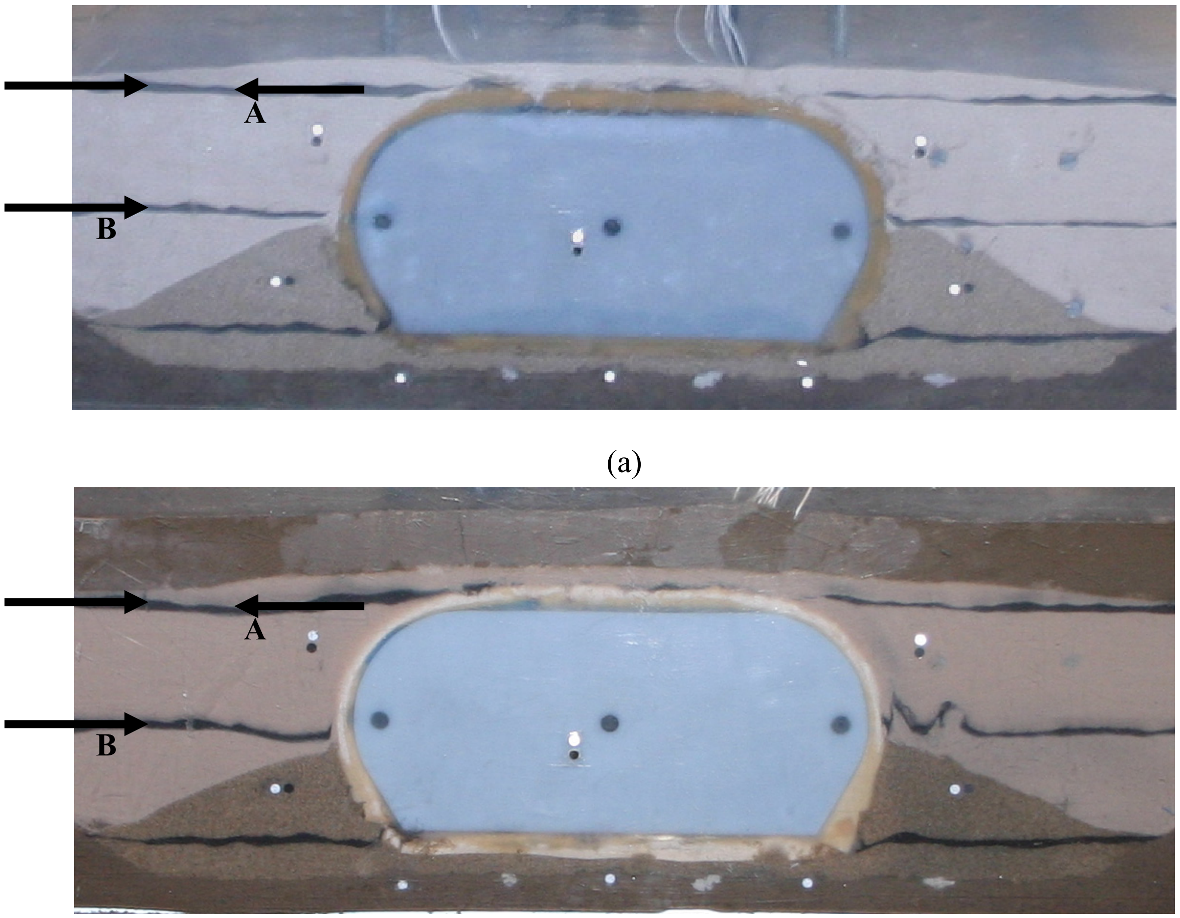



(a)



(b)

**FIG. S6.** Clay heave in JCC02 (a) Measured deformation shape (b) Annotated photograph.




(b)

**FIG. S7.** Views of west side of model through the window (a) before and (b) after the centrifuge test in JCC01. The small black and white dots are attached to the window. Movement of the soil layers relative to the small dots is apparent. The white Teflon sheet is bolted to the tunnel segment using countersunk bolts. Bolt heads are the three larger circles at mid-height of the tunnel. The latex rubber band sealing grease into and sand out of the interface between the window and the Teflon obstructs the view of the sand directly adjacent to the tunnel.

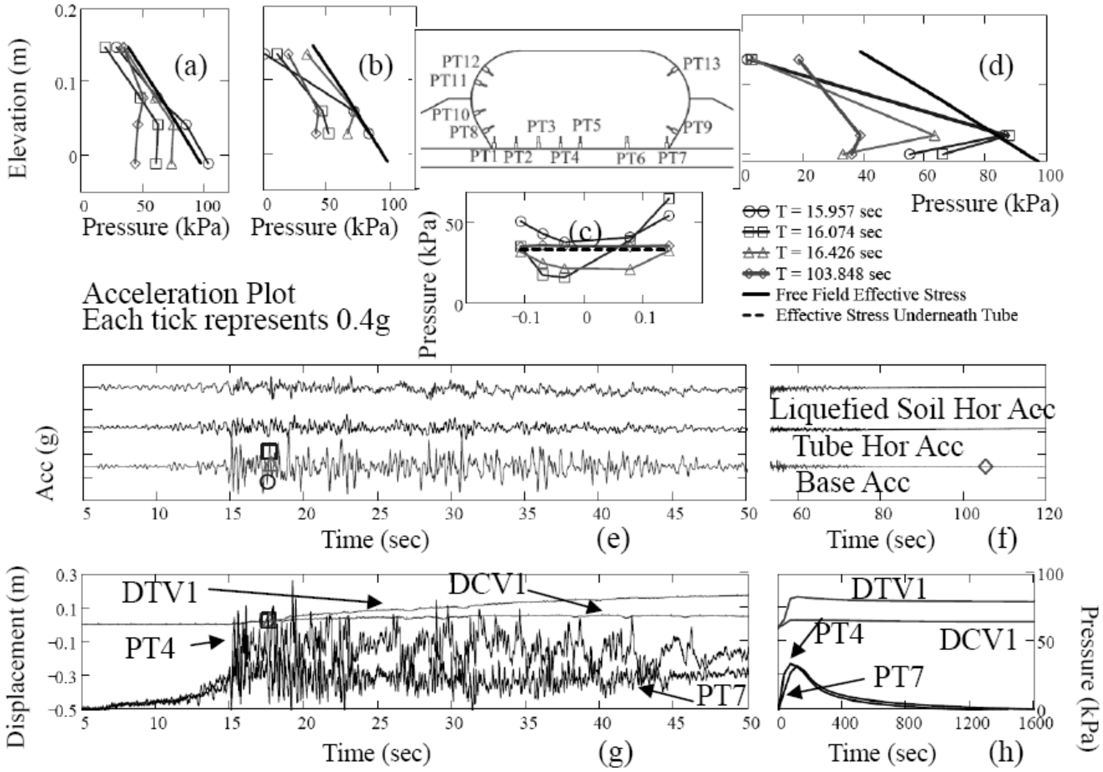
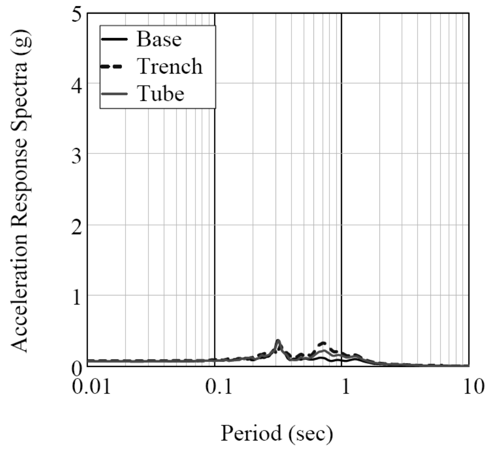
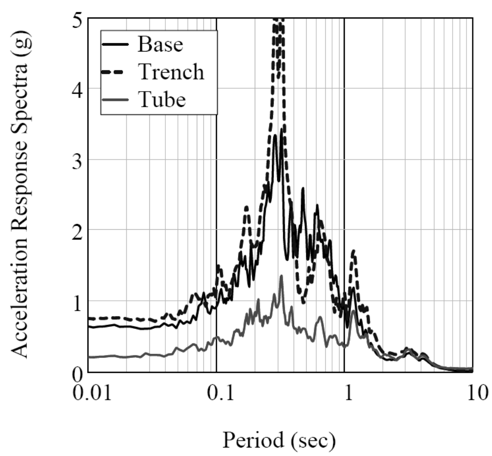


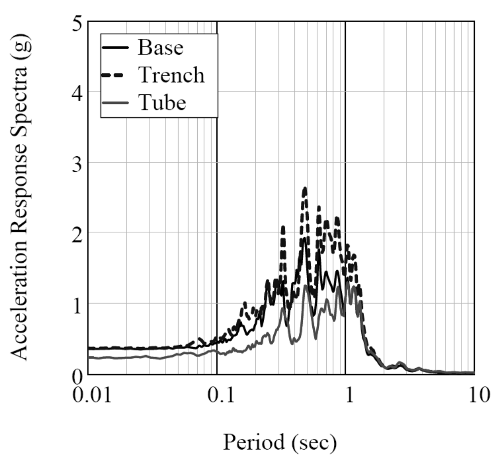

**FIG. S8.** JCC02 Plots of Disp. of Tube, Acc. of Tube and liquefied soil, pore pressure under Tube and in liquefied soil. (a) pore pressure in fill. (b) excess pore pressure at PT 8, 10 and 12 on north side of tunnel. (c) excess pore pressure along base of tunnel (PT2-PT7), (d) excess pore pressure at PT 7, 9 and 13 on south side of tunnel. (e-h) show short and long-term plots of acceleration (AH19, average of AH10 and AH13 and Base accelerometer), vertical tube displacement (DTV1), bottom heave of trench clay (DCV1) and pore pressure as a function of time.




(a)




(b)




(c)

**FIG. S9.** Acceleration response spectra (2% Damping Ratio) of the container base, trench (AH3) and tube (average of AH10 and AH13) for JCC02 in (a) Loma Prieta Motion (b) TCU Motion (c) Joshua Tree Motion.