REVISITING TWO GROUND FAILURE SITES FROM THE 2010 CHILE EARTHQUAKE

R.E.S. Moss¹, T. Gebhart², J.D. Frost³, and C. Ledezma⁴

ABSTRACT

The 2010 M8.8 earthquake in Chile caused widespread damage due to strong ground shaking and tsunami. The GEER reconnaissance of this event was thorough, and for specific sites provided information on the geometry of ground failures (e.g., LIDAR) along with preliminary subsurface information (e.g., SASW). Two sites were recently revisited to collect further detailed subsurface information; the Las Palmas tailings dam failure, and the Retiro-Ruta 5 overpass embankment failure. What made these two sites particularly desirable for further study were the nature and scale of the ground failures and the LIDAR images of the failed geometry. We mobilized CPT and Vₜ equipment to better characterize the subsurface conditions, enabling these failures to be developed into detailed case histories. In this paper we discuss the recent field investigations and the preliminary results of the Las Palmas and Retiro-Ruta 5 case histories.

¹Professor, Dept. Civil & Environmental Engineering, Cal Poly, San Luis Obispo, CA 93407 (rmoss@calpoly.edu)
²Transportation Engineer, California Department of Transportation, District 5, San Luis Obispo, CA 93401
³Professor, Elizabeth and Bill Higginbotham Professor, School of Civil &Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332
⁴Associate Professor, Dept. of Structural & Geotechnical Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Macul, Santiago, Chile.

Moss, R.E.S., Gebhart, T., Frost, J.D., Ledezma, C. Revisiting two ground failure sites from the 2010 Chile Earthquake, Proceedings of the 11th National Conference in Earthquake Engineering, Earthquake Engineering Research Institute, Los Angeles, CA. 2018.
ABSTRACT

The 2010 M8.8 earthquake in Chile caused widespread damage due to strong ground shaking and tsunami. The GEER reconnaissance of this event was thorough, and for specific sites provided information on the geometry of ground failures (e.g., LIDAR) along with preliminary subsurface information (e.g., SASW). Two sites were recently revisited to collect further detailed subsurface information; the Las Palmas tailings dam failure, and the Retiro-Ruta 5 overpass embankment failure. What made these two sites particularly desirable for further study were the nature and scale of the ground failures and the LIDAR images of the failed geometry. We mobilized CPT and $V_s$ equipment to better characterize the subsurface conditions, enabling these failures to be developed into detailed case histories. In this paper we discuss the recent field investigations and the preliminary results of the Las Palmas and Retiro-Ruta 5 case histories.

Introduction

The strong ground shaking from the 2010 M8.8 event in central Chile resulted in two ground failures that were particularly interesting; the Las Palmas tailings dam failure and the Retiro-Ruta 5 embankment failure. LIDAR images of the post-failure geometry provide detailed measurements of the deformations. The Las Palmas site experienced a liquefaction flow-failure of tailings material. The Retiro site experienced a translational-slide of compacted embankment material with uncertainty in the controlling failure mechanism. To better learn from these failures, additional PEER-funded field investigations were recently performed, measuring penetration resistance with the CPT and stiffness with downhole and surface wave $V_s$ methods. In this brief paper we present the preliminary results of this investigation for future reference concerning similar failures.

Las Palmas site

This tailings dam failure was induced by liquefaction as evidenced by sand boils documented by the GEER reconnaissance report [3]. Figure 1 shows the LIDAR image of the failure which resulted in upwards of 350 meters of runout. Drilling with coincident SPT measurements were performed in 2011 by [5] to support ligation related to this failure.

1Professor, Dept. Civil & Environmental Engineering, Cal Poly, San Luis Obispo, CA 93407 (rmoss@calpoly.edu)
2Transportation Engineer, California Department of Transportation, District 5, San Luis Obispo, CA 93401
3Professor, Elizabeth and Bill Higginbotham Professor, School of Civil & Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332
4Associate Professor, Dept. of Structural & Geotechnical Engineering, Pontificia Universidad Católica de Chile, Vícuña Mackenna 4860, Macul, Santiago, Chile.

This subsurface information was used by [2] to back-analyze this case history and to provide estimates of the representative liquefied residual strength ($S_{ur}$), mean blow count corrected for energy and stress and fines ($N_{160CS}$), and mean effective stress ($\sigma'_v$) on the failure plane. To further characterize this case history we mobilized CPT and $V_S$ equipment in June of 2017 to measure the cone tip ($q_c$), sleeve ($f_s$), pore pressure ($u_2$), and stress-corrected shear wave velocity ($V_{S1}$).

Figure 2. Overburden-corrected cone tip resistance and shear wave velocity profiles. Red boxes indicate potentially liquefiable zones. Surface wave methods were not able to image soft materials below the stiff layer at 8 meters depth.
The Las Palmas site presented difficult field conditions requiring a portable (ram-set) CPT to measure at locations that a typical CPT rig could not access. Three CPT soundings that penetrated the tailings and into the underlying foundation soils were performed at the site in the unfailed tailings material with the goal of measuring in-place penetration resistance. CPT soundings were collocated with previously SPT borings where possible. V₅ measurements were made at six locations within both failed and unfailed tailings material using passive circular arrays which were post-processed using SPAC (spatial autocorrelation) [1] techniques. A complete summary of all the investigations from reconnaissance through this most recent field exploration can be found in [4]. Figure 2 shows representative CPT and V₅ measurements from this site. The summary results from this investigation and analysis will provide a new and fully characterized case history for use in forecasting liquefied residual strength.

Retiro-Ruta 5 site

The failed overpass embankment near Retiro, Chile, on Ruta 5 can be seen in the LIDAR image (Figure 3). There was no obvious evidence of liquefaction so the failure mechanism was uncertain at the time of the reconnaissance. This site was revisited in Fall of 2017 with a full-size CPT rig and four soundings were performed to depths of 6.6 meters in unfailed material along the edges of the embankment.

The subsurface conditions as seen in Figure 4 show a very weak material present at roughly 4 to 6 meters depth which would correspond to approximately the interface between the in-situ foundation soils and the embankment fill materials. Ongoing modeling of this failure is being conducted to determine the most likely failure mechanism, including liquefaction of sandy soil or cyclic failure of clayey soil. In similar cases, it is often the fines content and the plasticity of the fines that controls whether deformations are primarily due to co-seismic loading (cyclic failure of clayey soil) or due to strength loss from excess pore pressure generation (liquefaction of sandy soil). The results will be used to inform future embankment design to better avoid similar large deformation failures.

Figure 3. LIDAR of the Retiro-Ruta 5 embankment failure (from GEER, 2010).
Figure 4. Subsurface measurements to a depth of 6.6 meters at the Retiro Ruta 5 site showing (left to right) tip, sleeve, pore pressure, and shear wave velocity.

Acknowledgments

The recent field investigations were funded by CalTrans (California Department of Transportation) and the NRC (Nuclear Regulatory Commission) through the PEER (Pacific Earthquake Engineering Research) center’s NGL (Next Generation Liquefaction) program. The findings presented here are solely those of the authors and not necessarily that of the funding agencies.

References


5. DICTUC (2012). “Estudio Del Colapso Del Tranque De Relaves De La Mina Las Palmas.” Ingenieria DICTUC. Santiago, Chile.