Date of Submission	March 25, 2017

IPL Project (IPL - 192) Annual Report Form 2017

1 January 2016 to 31 December 2016

1. Project Number (approved year) and Title,

   IPL-192 (2015) Title -Development of post-earthquake rainfall induced landslide (PERIL) hazard mitigation framework

2. Main Project Fields

   (1) Technology Development

   A. Monitoring and Early Warning

   (3) Capacity Building

   B. Collating and Disseminating Information/ Knowledge

3. Name of Project leader: Binod Tiwari, Ph.D., P.E.

   Affiliation: Professor, Civil & Environmental Engineering Dept, California St. University Contact: 800 N State College Blvd., E-419, Fullerton, CA, 92831, USA; Ph: 1(657)278-3968; Fax: 1(657)278-3916; email: btiwari@fullerton.edu

   Core members of the Project: Names/Affiliations: (4 individuals maximum)

   Nagendra Raj Sitoula/ Tribhuvan University; John Faller/ California State University Fullerton (CSUF); Salvador Mayoral/ CSUF; Phoolendra Kumar Mishra/ CSUF

4. Objectives: (5 lines maximum)

   Create a deterministic model from globally gathered data and available practice deterministic models; Predict outcomes and compare data collected from small and large scale experimental modeling; Develop a robust and high performance computer-based program with parallel computing technologies that can utilize machine learning, international data mining, rainfall forecasting, and soil parameters to predict post-earthquake stability/hazard of slopes

5. Study Area: (2 lines maximum)

The model scale study and validation of developed machine learning enhanced numerical modeling will be done at CSU Fullerton USA; Field scale study and capacity building will be done in Nepal.

6. Project Duration (1 line maximum)

   4 years

7. Report

1) Progress in the project: (30 lines maximum)

   The team has compiled a database of over 15,000 post-earthquake landslides that were triggered after the 2015 Nepal Earthquake that resulted into a post-Gorkha earthquake landslide inventory report. Moreover, a database of historical earthquake induced landslides has been prepared and published. A number of journal and conference proceedings articles were prepared based on the current research findings. The team visited, multiple times, various post-earthquake landslide sites in Nepal and collected field information. Moreover, soil samples from a study area in southern California were compacted in a Plexiglas container and prepared slopes at various inclinations and different densities. The slopes were poured with different rainfall intensities and shaken on the shake table after rainfall. Tensiometer data as well as accelerometer data were recorded to evaluate seepage velocity and deformation during earthquake. The work is going on. Moreover, the project will be expanded into other parts of the world in Americas, Europe, and Asia.

2) Planned future activities or Statement of completion of the Project (15 lines maximum)

   The GIS based landslide identification for post-earthquake condition in Nepal and post-earthquake rainfall in Nepal will be continued. Moreover, based on the experimental modeling, slope stability analysis will be performed to evaluate real time safety of slope during rainfall and earthquake. Few more field verifications and experimental investigations will be conducted in coming years.

3) Beneficiaries of Project for Science, Education and/or Society (15 lines maximum)

   The government agencies of Nepal and other implementing agencies who are involved in landslide hazard mitigation were benefitted from the research finding. Moreover, students were able to be involved in the research project. The project provided academic training to 12 graduate students, 18 undergraduate students, 17 international students, and 7 high school students. In addition, the professional societies pertinent to landslide science and engineering got some research results pertinent to post-earthquake rainfall induced landslides.

4) Results: (15 line maximum, e.g. publications)

   This project has resulted into 23 publications in various journals and conference proceedings including landslides, WLF4, and Interactive Teaching Tools in addition to over 15 keynote

and regular presentation in various conferences pertinent to landslides and geotechnical engineering. It provided research opportunity for more than 40 students in the past 2 years. The article recently published in Landslides has been downloaded for more than 210 times by date. Citations of the published articles are presented below.

1. Tiwari, B., Ajmera, B., Tran, D., and Caballero, S. 2017. "Effect of Post-Earthquake Rainfall in Triggering Landslides," Proceedings of 19th International Conference on Soil Mechanics and Geotechnical Engineering (in press).

2. Tiwari, B., Ajmera, B., Khalid, M., and Chavez, R. 2017. "Factors Influencing Rainfall-Induced Slope Failures," Proceedings of World Landslide Forum 4 (in press).

3. Tiwari, B., Ajmera, B., and Dhital, S. 2017. "Landslides Induced by the 2015 Gorkha Earthquake," Proceedings of World Landslide Forum 4 (in press).

4. Tiwari, B., Ajmera, B., and Tran, D. 2017. "Influence of Post-Earthquake Rainfall on the Stability of Clay Slopes-IPL-192," Proceedings of World Landslide Forum 4 (in press).

5. Xue, K., Tiwari, B., Ajmera, B., and Hu, Y. 2017. "Stability of Red-Clay Slopes Subjected to Different Durations of Rainfall," Proceedings of World Landslide Forum 4 (in press).

6. Ajmera, B. and Tiwari, B. 2017. "Physical Modelling of Earthquake-Induced Landslides," Landslide Dynamics – ISDR – ICL Landslide Interactive Teaching Tools (In Press).

7. Tiwari, B. and Ajmera, B. 2017. "Physical Modelling of Rain-Induced Landslides," Landslide Dynamics – ISDR-ICL Landslide Interactive Teaching Tools (In Press).

8. Tiwari, B., Ajmera, B., and Dhital, S. 2017. Characteristics of Moderate to Large Scale Landslides Triggered by the Mw 7.8 2015 Gorkha Earthquake and its Aftershocks, Landslides, 1-22.

9. Ajmera, B., and Dhital, S. 2017. "Geological, Topographical and Seismological Control on the Co-Seismic Landslides Triggered by the 2015 Gorkha Earthquake," Geotechnical Special Publication 2017, 278, 234-243.

10. Tiwari, B., Ajmera, B., Yamashiro, B., Sitoula, N. 2016, Post-cyclic Strength Degradation of Black Cotton Soil in Kathmandu and Its Effect on Landslide at Lokanthali of Araniko Highway During Mw7.8 2015 Gorkha Earthquake, Proceedings of 2016 IPL Symposium, UNESCO, Paris, 1, 52-57.

11. Tiwari, B., Ajmera, B., and Yamashiro, B. 2016. Causes of Cyclic Shear Failure at Lokanthali of Araniko Highway after Mw7.8 2015 Gorkha Earthquake, Proceedings of Fifth International Conference on Forensic Geotechnical Engineering, 78-91 (Keynote Lecture).

12. Xue, K., Ajmera, B., Tiwari, B., and Hu, Y. 2016. Effect of Long Duration Rainstorm on Stability of Red-clay Slopes, International Journal of Geo-environmental Disasters, 3:12, 1-13.

13. Tiwari, B., Tran, D., Ajmera, B., Carrillo, Y., Stapleton, J., Khan, M., and Mohiuddin, S. 2016. "Effect of Slope Steepness, Void Ratio and Intensity of Rainfall on Seepage Velocity and Stability of Slopes," Proceedings of the Geotechnical and Structural Engineering Congress 2016.

14. Tiwari, B., Tran, D., Ajmera, B., Woli, H. & Stapleton, J. 2016. Effect of Pre and Post Earthquake Rainfall Events on Deformation and Stability of Slopes. Proc. Geotechnical and Structural Engineering Congress 2016, Phoenix, AZ.

15. Carrillo, Y., Ajmera, B., Tiwari, B., Stapleton, J., and Tran, D. 2016, Influence of Void Ratio on the Stability of Compacted Clay Slopes Subjected to Rainfall, Proceedings of International Symposium on Engineering Research, Sorocaba, Brazil, 1, 9.

16. Stapleton, J., Ajmera, B., Tiwari, B., Carrillo, Y., and Tran, D. 2016, Influence of Void Ratio, Slope Inclination, and Rainfall Intensity on Slope Stability of Compacted Clay Slopes, Proceedings of International Symposium on Engineering Research, Sorocaba, Brazil, 1, 20.

17. Hashash, Y. M.A., Tiwari, B., Moss, R. E. S., Asimaki, D., Clahan, K. B., Kieffer, D. S., Dreger, D. S., Macdonald, A., Madugo, C. M., Mason, H. B., Pehlivan, M., Rayamajhi, D., Acharya, I., and Adhikari, B. 2015. Geotechnical Field Reconnaissance: Gorkha (Nepal) Earthquake of April 25 2015 and Related Shaking Sequence, Geotechnical Extreme Event Reconnaissance GEER Association Report No. GEER-040. Version 1.1 August 7, 2015.

18. Tiwari, B. and Caballero, S., 2015. Experimental Model of Rainfall Induced Slope Failure in Compacted Clays, Geotechnical Special Publication, 256, 1217-1226.

19. Kawakatsu, T., Kawai, K., Tiwari, B., and Iizuka, A. 2015. PORE AIR BEHAVIOR WITHIN A SLOPING EARTH STRUCTURE. Journal of Japan Society of Civil Engineers, 71 (2), 171-180.

20. Moss, R., Thompson, E. M., Kieffer, D. S., Tiwari, B., Hashash, Y. M. A., Acharya, I., Adhikari, B., Asimaki, D., Clahan, K. B., Collins, B. D., Dahal, S., Jibson, R. W., Khadka, D., Macdonald, A., Madugo, C. L. M., Mason, H. B., Pehlivan, M., Rayamajhi, D., Uprety, S. 2015. Geotechnical Effects of the 2015 Magnitude 7.8 Gorkha, Nepal Earthquake and Aftershocks, Seismological Research Letters, 86, 1514-1523.

21. Lowe, J., Carrillo, Y., Tran, D., Reyna, J., Stapleton, J., Ajmera, B., and Tiwari, B. 2015. "The Influence of Void Ratio on Slope Stability," 23rd Annual Southern California Conference on Undergraduate Research 2015.

22. Carrillo, Y., Stapleton, J., Ajmera, B., and Tiwari, B. 2015. “Influence of Void Ratio on the Stability of Compacted Clay Slopes Subjected to Rainfall,” 23rd Annual Southern California Conference on Undergraduate Research 2015.

23. Stapleton, J., Carrillo, Y., Reyna, J., Lowe, J., Tiwari, B., and Ajmera, B. 2015. “Influence of Slope Inclination and Rainfall Intensity on Slope Stability of Compacted Clay Slopes,” 23rd Annual Southern California Conference on Undergraduate Research 2015.