

Date of Submission	March 30, 2020
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IPL Project (IPL - 192) Annual Report Form 2019

1 January 2019 to 31 December 2019

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.

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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 focus in 2019 were to study the – a) influence of vegetation density on post-fire rainfall induced debris flows, and b) influence of soil density and slopes on suction and seepage velocity as well as slope stability. Soil samples were collected from a study area in southern California and compacted in a Plexiglas container, and installed with numerous tensiometers, soil moisture sensors as well as inclinometers, at various inclinations and different densities. The slopes were poured with different rainfall intensities. Tensiometer data as well as soil moisture and inclinometer data were recorded to evaluate seepage velocity and deformation during earthquake. In 2018, a massive post-wildfire rainfall induced debris flow event caused millions of dollars of property loss and dozens of death toll in Montecito city, Santa Barbara county, California. We visited the site, collected soil samples, measured geotechnical properties of the soil and evaluated the effect of vegetation cover on seepage velocity and slope stability by preparing the experimental slope models in a 3 m long and 1.4 m wide seepage tank, separately at different vegetation cover densities. Influence of vegetation density on seepage velocity and soil suction has been successfully studied.

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

Using the data we received in the past 5 years from our different experimental modeling works, we will perform comprehensive analysis on the influence of rainfall on seepage velocity, suction, and slope stability as well as deformation, specifically for soils having varying densities, geotechnical properties, compacted at different slope gradients, and varying vegetation cover density.

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. Cities in southern California could be benefitted through our research on the effect of vegetation cover on slope stability, specifically to manage slopes affected by recent wildfires. Moreover, several dozens of students were able to be involved in the research project. The project provided academic training to 22 graduate students, 32 undergraduate students, 19 international students, and 22 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 as well as post-wildfire rainfall induced landslides.

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

This project has resulted into 63 publications in various journals and conference proceedings including Landslides, Journal of geotechnical and geo-environmental Engineering, WLF4, and Landslides Interactive Teaching Tools in addition to dozens of keynote and regular presentation in various conferences pertinent to landslides and geotechnical engineering. It provided research opportunity for more than 95 students in the past 4 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., Gonzalez, A., and Sonbol, H. 2020. "Influence of Post-Wildfire Vegetation Cover Loss on Slope Stability - A Case Study of 2018 Montecito Debris Flow in California," Geotechnical Special Publication, 316, 40-49.
2. Tiwari, B., Ajmera, B., and Barnett, R. (2019). "impact of Low Shearing Resistance of Ash Deposit on Post-Fire Rainfall Induced Debris Flow," Proceedings of the 2019 IPL Symposium on Landslides, UNESCO Headquarters in Paris, France, 1, 57-60.
3. Gavela, S.N., Patron, T., and Tiwari, B. 2019. How Safety Margin of a Slope Changes With Duration of Rainfall, 27th Annual Southern California Conference on Undergraduate Research 2019.
4. Tiwari, B., Pradel, D., Ajmera, B., Yamashiro, B., and Diwakar, K. 2018 "Landslide Movement at Lokanthali during the 2015 Earthquake in Gorkha, Nepal," Journal of Geotechnical and Geoenvironmental Engineering, 144(3), 05018001 1-12, DOI: 10.1061/(ASCE)GT.1943-5606.0001842.
5. Tiwari, B., Ajmera, B., Yamashiro, B., and Phan, Q. 2018 "Effect of Overburden Pressure, Mineralogical Composition, and Plasticity on Post-Cyclic Shear Strength Degradation", Geotechnical Special Publication 295, 266-275, DOI: 10.1061/9780784481585.027.
6. Tiwari, B., Ajmera, B., Khalid, M., Donyanavard, S., and Chavez, R. 2018 "Influence of Slope Density on the Stability and Deformation of Clayey Slopes", Geotechnical Special Publication, 297, 293-301, DOI: 10.1061/9780784481608.028..
7. Tiwari, B., Pradel, D., and Ajmera, B. 2018 "Equations to calculate the undrained shear strength of lacustrine soil deposit with Swedish Cone Sounding", Geotechnical Special Publication, 295, 32-42, DOI: 10.1061/9780784481585.004.
8. Tiwari, B., Ajmera, B., Khalid, M., and Chavez, R. 2018. "Stability and Deformation in Clayey Slopes with Varying Slope Density and Inclinations Subjected to Rainfall," Proceedings of GeoShanghai 2018, 7, 90-98, DOI: 10.1007/978-981-13-0128-5_11.
9. Ajmera, B., Tiwari, B., Yamashiro, B., and Phan, Q.-H. (2018). "Influence of Consolidation

Pressure on Cyclic and Post-Cyclic Response of Fine-Grained Soils with Varying Mineralogical Compositions and Plasticity Characteristics,” Proceedings of GeoShanghai 2018, 6, 158-167, DOI: 10.1007/978-981-13-0131-5_18. (Best Paper Award)

10. Tiwari, B., and Ajmera, A. 2018. “Impact of Vegetation Loss Due to Wildfire on Debris Flow Volume.”, Proceedings of the 2018 IPL SYMPOSIUM ON LANDSLIDES, 1, 63-67.
11. 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, 1, 3533-3536.
12. Tiwari, B. and Pradel, D. 2017. "Importance of spectral acceleration in evaluating cyclic failure on soft clays – an experience from 2015 Gorkha Earthquake." Keynote Lecture, 15th International Symposium on Geo-disaster Reduction, Oki Island-Matsue-Kyoto, Japan, 1, 15.
13. Tiwari, B., and Ajmera, B. 2017. “Landslides Triggered by Earthquakes from 1920 to 2015,” Advancing Culture of Living with Landslides, Springer Nature, 2 (1), 5-15, (Keynote Lecture)
14. Tiwari, B. 2017. “Introduction: Advances in Landslide Science”, Advancing Culture of Living with Landslides, Springer Nature, 2 (1), 1-3.
15. Tiwari, B., Ajmera, B., Khalid, M., and Chavez, R. 2017. “Factors Influencing Rainfall Induced Slope Failures,” Advancing Culture of Living with Landslides, Springer Nature, 2 (1), 523-531.
16. Tiwari, B., Ajmera, B., Dhital, S., and Sitoula, N. R. 2017. “Landslides Induced by the 2015 Gorkha Earthquake,” Advancing Culture of Living with Landslides, Springer Nature, 2 (2), 819-827.
17. Tiwari, B., Ajmera, B., and Tran, D. 2017. “Influence of Post-Earthquake Rainfall on the Stability of Clay Slopes-IPL-192,” Advancing Culture of Living with Landslides, Springer Nature, 1 (1), 429-436.
18. Xue, K., Tiwari, B., Ajmera, B., and Hu, Y. 2017. “Stability of Red-Clay Slopes Subjected to Different Durations of Rainfall,” Advancing Culture of Living with Landslides, Springer Nature, 2 (1), 533-540.
19. Ajmera, B. and Tiwari, B. (2018) “TXT-tool 3.001-1.4 Using Excel Tools for Slope Stability Analysis,” Landslide Dynamics – ISDR-ICL Landslide Interactive Teaching Tools, 413-420, DOI: 10.1007/978-3-319-57777-7_23.
20. Tiwari, B. and Ajmera, B. (2018) “TXT-tool 3.001-1.3 Laboratory Measurement of Fully Softened Shear Strength and Its Application for Landslide Analysis,” Landslide Dynamics –

ISDR-ICL Landslide Interactive Teaching Tools, 393-402, DOI: 10.1007/978-3-319-57777-7_21.

21. Ajmera, B. and Tiwari, B. (2018) "TXT-tool 3.001-1.2 Physical Modelling of Earthquake-Induced Landslides," Landslide Dynamics – ISDR – ICL Landslide Interactive Teaching Tools, 287-295, DOI: 10.1007/978-3-319-57777-7_15.
22. Tiwari, B. and Ajmera, B. (2018) "TXT-tool 3.001-1.1 Physical Modelling of Rain-Induced Landslides," Landslide Dynamics – ISDR-ICL Landslide Interactive Teaching Tools, 277-285, DOI: 1007/978-3-319-57777-7_14.
23. Tiwari, B. 2019. "Slope Stabilization and Landslide Prevention." One day seminar provided to the professional engineers in California, Riverside, CA (Day-long Training Lecture), February 2019, Riverside, CA, USA.
24. Tiwari, B. 2018. "Earthquakes, Landslides & Mudslides", Invited Lecture, Future Earthquakes in Southern California & Preparedness Workshop, Chapman University, Chapman, CA, USA, November 2018.
25. Tiwari, B. 2018. Living with Natural Disasters, Keynote Lecture, Third International Symposium on Applied Research, Ensenada, Mexico.
26. Tiwari, B. 2018. "Causes and Effects of Landslides and Possible Mitigation Measures", Invited Key-note Lecture, Osher Lifelong Learning Institute lecture Series, October, 2018, Fullerton, CA, USA.
27. Tiwari, B. 2018. " Effect of Pore Pressure/ suction on Slope Stability." Invited Lecture, The METER Group, WA, USA, September 2018.
28. Tiwari, B. 2018. Slope Stabilization and Landslide Prevention, Webinar provided to the professional engineers in California, San Diego, CA (Day-long Training Lecture), September 2018.
29. Tiwari, B. 2018. "Similarities and Differences Between Earthquake and Rainfall Induced Landslides." Invited Lecture, The University of Florence, Italy, September 2018.
30. Tiwari, B. 2018. "Earthquake Induced Landslides - Analysis." Invited Lecture, Landslides Risk Assessment and Management (LARAM) School, The University of Salerno, Italy, September 2018.
31. Tiwari, B. 2018. Slope Stabilization and Landslide Prevention, Two-day webinar provided to the professional engineers, (HalfMoon Education), August 2018.
32. Tiwari, B. 2018. Slope Stabilization and Landslide Prevention, One day seminar provided to

the professional engineers in California, Sacramento, CA (Day-long Training Lecture), August 2018.

33. Tiwari, B. 2018. "Geotechnical properties of soft clays In Kathmandu and corresponding international building code based site class for seismic design of buildings." Invited Lecture, Department of Urban Development and Building Construction, Government of Nepal, Kathmandu, Nepal, June 2018.
34. Tiwari, B. 2018. "Similarities and Differences Between Rainfall and Earthquake Induced Landslides – Case Studies from Past Natural Disaster Events." Invited Lecture, Hong Kong University of Science and Technology, Hong Kong, May 2018.
35. Tiwari, B. 2018. "Global Trends of Landslide and Mudslide Disasters and Their Impacts on Community." Invited Lecture, Distinguished Voices program, National Academy of Sciences, Irvine, CA, May 2018.
36. Tiwari, B. 2018. " Retaining Wall Design and Slope Stabilization Techniques." One day seminar provided to the professional engineers in California, Santa Barbara, CA (Day-long Training Lecture), April 2018.
37. Tiwari, B. 2018. "Living with Natural Disasters." Outstanding Professor Lecture, California State University, Fullerton, CA, March 2018.
38. Tiwari, B. 2018. Slope Stabilization and Landslide Prevention, One day short-course provided to the professional engineers in California, San Diego, CA (Day-long Training Lecture), February 2018.
39. Tiwari, B. 2018. Slope Retaining Wall Design and Slope Stabilization, One day short-course provided to the professional engineers in California, Santa Barbara, CA (Day-long Training Lecture).
40. Tiwari, B. and Pradel, D. 2017. "Importance of spectral acceleration in evaluating cyclic failure on soft clays – an experience from 2015 Gorkha Earthquake." Keynote Lecture, 15th International Symposium on Geo-disaster Reduction, Oki Island-Matsue-Kyoto, Japan, 1, 15.
41. Tiwari, B., Ajmera, B., and Dhital, S. 2017. "Characteristics of Moderate to Large Scale Landslides Triggered by the Mw8 Gorkha Earthquake and Its Aftershocks," *Landslides*, Springer Nature, 14 (4), 1297-1318, DOI: 10.1007/s10346-016-0789-0.
42. 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.
43. Ghanei, S., Lee, C., Chang, K., Bernal, B., Ajmera, B., Tiwari, B., and Alexander, S.M. 2017.

Seepage Velocity in Partially Saturated Clayey Slopes with Different Relative Compactions, 25th Annual Southern California Conference on Undergraduate Research 2017.

44. Ahn, E., Bhattarai, P., Leimer, G., Dhital, S., Al-Behadili, M., Tiwari, B., Ajmera, B., and Chung, B., 2017. P and S Wave Velocities for Laboratory Prepared Soil Samples, 25th Annual Southern California Conference on Undergraduate Research 2017.
45. 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.
46. 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).
47. 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.
48. 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.
49. 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.
50. 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.
51. 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.
52. Chen, B., Chavez, R.V., Khalid, M., Reyna, J., Florentino, O., Aguiar, M. Bonfim, Y., Torreal, J., Siqueira, L., and, Tiwari, B. 2016. The Effect of Post-earthquake Rainfall on Triggering Landslides, 24th Annual Southern California Conference on Undergraduate Research 2016.
53. Yangsheng, C.X., Cortez, B., Matoszko, C., Batistoti, G., Turtera, I., Schulze, L., Alves, L., Hayashi, T., Dhital, S., Ostrovo, F., Al-Behadili, M., Ajmera, B., and

- Tiwari, B. 2016. Reduction in Shear Strength of Clayey Soils due to Leaching of Saline Water, 24th Annual Southern California Conference on Undergraduate Research 2016.
54. Chao, S.S., and Tiwari, B. 2016. Reducing the Impact of Earthquakes Ground Shaking on Infrastructure, 24th Annual Southern California Conference on Undergraduate Research 2016.
55. Martinez, J., and Tiwari, B. 2016. Reducing The Impact Of Earthquake On Soft Clay Sites, 24th Annual Southern California Conference on Undergraduate Research 2016.
56. Chavez, R.V., and Tiwari, B. 2016. Effect of Soil Density and Wetting and Drying Cycle on Slope Instability, 24th Annual Southern California Conference on Undergraduate Research 2016.
57. 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.
58. Tiwari, B. and Caballero, S., 2015. Experimental Model of Rainfall Induced Slope Failure in Compacted Clays, Geotechnical Special Publication, 256, 1217-1226.
59. 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.
60. 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., Upreti, S. 2015. Geotechnical Effects of the 2015 Magnitude 7.8 Gorkha, Nepal Earthquake and Aftershocks, Seismological Research Letters, 86, 1514-1523.
61. 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.
62. 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.
63. 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.