Project Title	Agmt./Task No.	Item No.	Agency Bgt. No.
Subsurface Drainage for Landslide and Slope Stabilization	T4120-10		
Research Agency	**Start Date**	**Estimated Completion**	**Revised Completion**
WSU/UBC	3/2007	12/2010	
Principal Investigator(s)	**Technical Contact**		
Balasingam Muhunthan (Washington State University) and Roger Beckie (University of British Columbia)	Tom Badger 360.709.5461		
WSDOT Program Manager	**FHWA or Other Technical Contact**		
Kim Willoughby 360.705.7978	Mike Adams		
Funding Source	**Schedule Status**		
CA, MD, MS, MT, NH, OH, PA, TX, WA, WY	☒ On schedule ☐ On revised schedule	☐ Ahead of schedule ☐ Behind schedule	

Research Area

☐ Bridges & Structures ☐ Environment ☒ Highway Design & Safety ☐ Mobility & Intermodal Planning
☒ Operations & Materials ☐ Traffic & Intelligent Transportation Systems Evaluation

Original Estimated Cost	Revised Cost	% Funds Expended	% Work Completed
$ 300,000		28%	30%

Objective

(1) Provide best practices and guidance for subsurface drainage applications for slope stabilization, including subsurface investigation and testing, groundwater-flow characterization, analysis, drain configurations and design, installation methods, monitoring, and maintenance. (2) Evaluate new applications of existing materials and technologies, such as trenchless technologies (horizontal directional drilling, micro tunneling, guided boring, etc.) and other innovative technologies and materials, for stabilizing slopes using subsurface drainage.

Project Progress:

The initial phase of this study was completed by Professor Muhunthan and his graduate student, Marie Pathmanathan during this period. It focused on collecting available literature and data from well instrumented subsurface drainage (predominantly horizontal drains) projects. The researchers also conducted numerical simulation of the performance of horizontal drains on slopes. They made use of the finite difference code TOUGH2 V2 to simulate the changes in ground water level pattern and pore pressure response as a result of horizontal drain installation. Detailed examination of the field performance of horizontal drains on some selected slopes in the states of WA and CA were made. This included the site location, details of the project, geotechnical and geologic records, drain location, instrumentation details, and performance data. The effectiveness of a drain installation was described in terms of the increase in slope factor of safety as compared to factor of safety without horizontal drains. The numerical results of the phreatic surface from TOUGH 2 were input into the slope stability program XSTABL to perform stability calculations. Based on the examination of the field records and the parametric study the following were drawn:

(1) The examination of the field records associated with case studies presented here showed that in all cases the installation of drains resulted in the lowering of the ground water level and increased stability. The level of the lowered ground water table remained relatively constant even with varying amount of rainfall. Thus, it can be concluded that the horizontal drains performed well on these sites regardless of the different nature of geological characteristics and soil profile.
(2) Anisotropic ratio was identified as the important soil parameter influencing the horizontal drain performance because it changes the profile of phreatic surfaces very much. Slopes with higher ratio of permeability (k_x/k_y) stabilized quicker than lower ratio of permeability (section 6.4).
(3) Drains installed along the toe of the slide gives more stability than those installed in higher elevations.
(4) The stability of the slope increased with increasing the length of drains but decreased when the drains are spaced at larger intervals.

(5) The length of drain extending further from its intersection with the critical failure surface does not provide any significant change in FOS.
(6) FOS calculated for various slope inclinations (1:2.5 to 1:3.5) confirmed that steeper slopes need more drains than shallower slopes to reach equal level of stability.

A progress meeting was held with the principal investigators and WSDOT (sponsoring agency) in Seattle, Washington. The purpose of the meeting was to share results from the initial phase of the study; to hand-off this information to Professor Beckie, who will be working on the second phase; and, to plan future research activity. The 3-D hydrogeologic models set up using TOUGH2 software in the initial phase of study will be provided to Roger for further and more detailed analysis and modeling.

New Period Proposed Activity:

The new proposed activity will be conducted at UBC beginning summer/fall of 2009 with input from WSU and WSDOT teams. It will consist of the following:

- Compile and examine the excellent data set for the Red Top landslide project in California presented by Tom Whitman at the 2007 TAC meeting. It will also include recent data compiled by CALTRANS.
- Evaluate sites where subsurface drainage has not been effective, to better characterize limiting conditions.
- Recognizing that more drain discharge data is needed, WSDOT instrumented some selected WA sites. These measurements will be analyzed.
- The various analyses methods and instrumented data will be used to develop a simplified design methodology for horizontal drains, and/or design tables that would be applicable for a variety of geologic conditions.
- The UBC team will also would investigate the use of stochastic analysis to evaluate sites with more uncertainty and to provide some method to evaluate costs and risks for complex/critical sites.