RGC Ref. No.:
UGC/FDS25/E11/17
(please insert ref. above)

RESEARCH GRANTS COUNCIL
COMPETITIVE RESEARCH FUNDING SCHEMES FOR
THE LOCAL SELF-FINANCING DEGREE SECTOR

FACULTY DEVELOPMENT SCHEME (FDS)

Completion Report
(for completed projects only)

Submission Deadlines:
1. *Auditor's report with unspent balance, if any: within **six** months of the approved project completion date.*
2. *Completion report: within **12** months of the approved project completion date.*

Part A: The Project and Investigator(s)

1. Project Title

Development of a method to quantify risks posed by multi-landslide hazards triggered by extreme rainstorm events

2. Investigator(s) and Academic Department(s) / Unit(s) Involved

Research Team	Name / Post	Unit / Department / Institution
Principal Investigator	WONG Ho-Fai/ Associate Professor	Faculty of Science & Technology/ Technological and Higher Education Institute of Hong Kong
Co-Investigator(s)	Shuai Zhang/ Assistant Professor	College of Civil Engineering and Architecture/ Zhejiang University
Co-Investigator(s)	ZHANG Li-Min/ Professor	Department of Civil and Environmental Engineering/ The Hong Kong University of Science and Technology
Co-Investigator(s)	XU Qiang/ Professor	State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology
Co-Investigator(s)	Zhan Liangtong	College of Civil Engineering and Architecture/ Zhejiang University
Others	Peng Da-lei/ Senior Research Assistant	Faculty of Science & Technology/ Technological and Higher Education Institute of Hong Kong

3. Project Duration

	Original	Revised	Date of RGC / Institution Approval *(must be quoted)*
Project Start Date	01/01/2018	NA	NA
Project Completion Date	30/12/2020	30/06/2021	28/9/2020 By Institution
Duration *(in month)*	36 months	42 months	28/9/2020 by Institution
Deadline for Submission of Completion Report	31/12/2021	30/06/2022	28/9/2020 by Institution

Part B: The Final Report

5. Project Objectives

5.1 Objectives as per original application

1. To identify the possible cascading landslide scenarios and the interactions that could be generated in landslide-prone mountainous areas under extreme events;

2. To develop a multi-scale landslide processes modelling to simulate the complex mass movement of multiple landslide hazards and their interactions under extreme rainstorms;

3. To establish an improved framework to assess the human risks posed by the cascading landslide hazards considering the interactions among the multiple hazards and the vulnerabilities to these hazards.

5.2 Revised objectives

Date of approval from the RGC: NA

Reasons for the change: NA

1.

2.

3. ....

5.3 Realisation of the objectives

(Maximum 1 page; please state how and to what extent the project objectives have been achieved; give reasons for under-achievements and outline attempts to overcome problems, if any)

Objective 1:

- The interactions of the multi-landslide hazard in landslide-prone mountainous areas under extreme events has been analyzed based on the database of multiple landslide scenarios;
- The typical debris flow near the epicenter of the Wenchuan earthquake on 20 August 2019 was investigated based on remote sensing analysis and field investigation to analyse the formation condition and disaster characteristics of the rainfall-induced debris flows.

Objective 2:

- A typical well-documented debris flow and entrainment case is used as a benchmark to evaluate the performance of these entrainment models on an integrated debris flow simulation tool EDDA 2.0.
- The spatiotemporal coseismic sediments in hillslopes and different orders of channels were interpreted, and an integrated numerical model was applied to simulate the water runoff, channel entrainment, and sediment transport process.

Objective 3:

- A database of landslides induced by the Wenchuan earthquake was developed to propose a new model using Bayesian network for quantitatively estimating the vulnerability of people when exposed to catastrophic earthquake-induced landslides by considering comprehensive influence factors and their inter-relationships and to identify the control parameters influencing the loss of life due to earthquake-induced landslides.
- A self-adaptive data acquisition monitoring technique and automatically process the displacement data for rapid sliding slopes was developed, a real-time and practical LEWS using new artificial intelligence for loess landslides was established, and a multiple criteria warning model considering the deformation behaviors was proposed to solve the key problem of “when a landslide will occur” for loess slope sudden failure.

5.4 Summary of objectives addressed to date

Objectives *(as per 5.1/5.2 above)*	**Addressed** *(please tick)*	**Percentage Achieved** *(please estimate)*
1. To identify the possible cascading landslide scenarios and the interactions that could be generated in landslide-prone mountainous areas under extreme events.	✓	100%
2. To develop a multi-scale landslide processes modelling to simulate the complex mass movement of multiple landslide hazards and their interactions under extreme rainstorms.	✓	100%
3. To establish an improved framework to assess the human risks posed by the cascading landslide hazards considering the interactions among the multiple hazards and the vulnerabilities to these hazards.	✓	100%

6. Research Outcome

6.1 Major findings and research outcome
(Maximum 1 page; please make reference to Part C where necessary)
We have obtained the following major findings:

1.) Four debris flow events are investigated to study the long-term evolution mechanisms of debris flows in seismic areas. The evolution mechanisms were analyzed from four perspectives: rainfall threshold, initiation mechanism, runout characteristics and depositional property changes.
2.) The initial formation process and distribution pattern of the water pressure along the slipping surface of rock wedge failure can be summarized as the following two aspects: (1) Modelling of water pressure distribution along the sliding surface of the rock landslide. (2) The dynamic variation of the slope stability of the Chengkou landslide with the water pressure, i.e., hydrostatic pressure in the trailing edge, and the uplift pressure at the bottom slipping surface, have been analyzed. For details, please refer to Part C (**Zhang, et al, 2020**).
3.) The debris flows near the epicenter of the Wenchuan earthquake were initiated in four stages: (a) generation of a large amount of loose materials from the Wenchuan Earthquake; (b) run-off erosion from co-seismic landslide material on hilly slopes and repeated mobilizations; (c) development of high intensity localized rainfall events; (d) wash out of accumulated materials in gully by the flood
4.) All the three entrainment models perform reasonably well, giving satisfactory accuracy of the total entrainment magnitude, deposition volume, inundation area and runout distance compared with the field observations. In the Iverson-Ouyang model, the entrainment area is concentrated in the upper part of the track with steep slope angles. The Linear-Ex entrainment model provides satisfactory performance in predicting the entrainment, deposition and discharge processes, but predicts a much longer flow duration with high sediment concentrations. The Linear-MC entrainment model leads to simulation results similar to those from the Linear-Ex model, with a discharge process of about half an hour. The results serve as a reference for selecting models for hazard analysis and risk assessment. For details, please refer to Part C (**Shen, et al, 2020**).
5.) The sediment migration process contains four stages, i.e. coseismic landslides, debris flows mobilizing from landslides, sediments evacuating in channel networks, and debris flows generated from surface runoff. Approximately 89% of the supply of sediment flux volume originated from the channel networks and 58% originated from the third- and fourth-order channels
6.) The human vulnerability to earthquake-induced landslides is quantitatively estimated through constructing a systematic structure considering the uncertainties of the control factors and their inter-relationships. Comparison between the recorded fatality rate and predicted fatality is conducted to verify the proposed model.
7.) A quantitative human risk assessment model is employed to determine the landslide human risk referring an assessment criteria curve between frequency of number fatalities and number of fatalities (F-N curve). It is found that the societal risk at daytime was 0.078, 0.088, and 1.432 in 2002, 2014, and 2015, respectively. Meanwhile, the societal risk at night was 0.034, 0.037, and 0.611 in 2002, 2014, and 2015, respectively.

6.2 Potential for further development of the research and the proposed course of action *(Maximum half a page)*

6.3

1.) Identification of multi-landslide hazard scenarios and their interactions to assess the long-term evolution of landslide sediments;

Research activities (a): Based on the several debris flows triggered by heavy storms in the epicenter of the Wenchuan earthquake, the loose deposit volumes in the ravine before and after each of the four debris flows and the runout volumes can be evaluated. Triggering rainfall intensities, initiation mechanisms and runout characteristics of the debris flows can also be analyzed;
Research activities (b): Based on the databases of earthquake-induced landslide and rainfall-induced debris flows, the evolution process of coseismic sediments affected by 2008, 2010, 2011, 2013, 2016, and 2019 rainstorms can be analyzed.

2.) Numerical simulation of multi-hazard processes and their interactions in a relatively large area under dynamic extreme rainstorms;

Research activities: Based on the source materials investigation, UAVs images, 3D high precision point cloud data, and multi-Parameter Meteorological Radar, the complex mass movement of multiple landslide hazards and their interactions under dynamic extreme rainstorms can be simulated.

7. Layman's Summary

(Describe <u>in layman's language</u> the nature, significance and value of the research project, in no more than 200 words)

Multi-hazards prevail under the changing climate. Research on natural hazards has significantly improved our understanding of the mechanisms of the hazards themselves and their influences on human beings. The cascading landslide events have led to a large number of fatalities. Extreme cascading landslides occur frequently following an extreme rainstorm in the mountainous regions. Failure to anticipate the increased risks caused by the cascading landslides could lead to unexpected losses of human lives and property damages. Multiple hazard events do not usually occur at the same time. Rather, such events may evolve as a chain of disasters, with at times unexpected sequence of cascading events. Cascading landslide hazards are not independent and separate from each other but are highly correlated. Meanwhile, the assessment of human risks associated with multiple landslides is often conducted by considering individual processes, ignoring the possible interactions among the cascading hazards and among the vulnerabilities of the elements at risk to these hazards. The study developed a framework to simulate the complex mass movement of multiple landslide hazards and their interactions under extreme rainstorms event. The major findings serve as a reference for hazard analysis and risk assessment in Hong Kong and other areas.

Part C: Research Output

8. Peer-Reviewed Journal Publication(s) Arising Directly From This Research Project
(Please attach a copy of the publication and/or the letter of acceptance if not yet submitted in the previous progress report(s). All listed publications must acknowledge RGC's funding support by quoting the specific grant reference.)

The Latest Status of Publications				**Author(s)** *(denote the corresponding author with an asterisk*)*	**Title and Journal / Book** *(with the volume, pages and other necessary publishing details specified)*	**Submitted to RGC** *(indicate the year ending of the relevant progress report)*	**Attached to this Report** *(Yes or No)*	**Acknowledged the Support of RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
Year of Publication	**Year of Acceptance** *(For paper accepted but not yet published)*	**Under Review**	**Under Preparation** *(optional)*						
2020				Shuai Zhang, Qiang Xu, Dalei Peng, Zhanxiong Zhu, Wenhui Li, Hofai Wong, Shen Ping	Title: Stability analysis of rock wedge slide subjected to groundwater dynamic evolution Journal: **Engineering geology, Volume 270,** https://doi.org/10.1016/j.enggeo.2020.105528	No	Yes	*Yes*	*Yes*
2020				Ping Shen, Limin Zhang, Hofai Wong, Dalei Peng, Shengyang Zhou, Shuai Zhang, Chen, Chen	Title: Debris flow enlargement from entrainment: A case study for comparison of three entrainment models Journal: **Engineering geology, Volume 270,** https://doi.org/10.1016/j.enggeo.2020.105581	No	Yes	*Yes*	*Yes*
			✓	Shuai Zhang, Limin Zhang, Dalei Peng, Ho-Fai, Wong, Qiang Xu	Riverbed responses to landslide sedimentation in the epicenter of Wenchuan earthquake - the first ten	No	No	*Yes*	*No*

					years, **Geology**				

9. Recognized International Conference(s) In Which Paper(s) Related To This Research Project Was / Were Delivered
(Please attach a copy of each conference abstract)

Month / Year / Place	**Title**	**Conference Name**	**Submitted to RGC** *(indicate the year ending of the relevant progress report)*	**Attached to this Report** *(Yes or No)*	**Acknowledged the Support of RGC** *(Yes or No)*	**Accessible from the Institutional Repository** *(Yes or No)*
11 /2021/ Tokyo	Investigation of 20 August 2019 Catastrophic Debris Flows Triggered by Extreme Rainstorms near Epicentre of Wenchuan Earthquake	Fifth World Landslides Forum	No	Yes	*Yes*	*Yes*

10. Whether Research Experience And New Knowledge Has Been Transferred / Has Contributed To Teaching And Learning
(Please elaborate)

During the project period, part of the simulation work has been conducted by a Year four student in his Final Year Project. It can enhance students' ability in numerical simulation and provide him an opportunity to join RGC project which can strengthen their academic and research background for job hunting.

11. Student(s) Trained
(Please attach a copy of the title page of the thesis)

Name	**Degree Registered for**	**Date of Registration**	**Date of Thesis Submission / Graduation**
[redacted]	[redacted]	[redacted]	[redacted]

12. Other Impact

(e.g. award of patents or prizes, collaboration with other research institutions, technology transfer, teaching enhancement, etc.)

N/A

13. Statistics on Research Outputs

	Peer-reviewed Journal Publications	**Conference Papers**	**Scholarly Books, Monographs and Chapters**	**Patents Awarded**	**Other Research Outputs (please specify)**	
No. of outputs arising directly from this research project	2	1	NA	NA	Type	No.
					NA	NA

14. Public Access Of Completion Report

(Please specify the information, if any, that cannot be provided for public access and give the reasons.)

Information that Cannot Be Provided for Public Access	**Reasons**
N/A	