Date of Submission	Mar 29th, 2021

IPL Project (IPL - 230) Annual Report Form 2020

1 January 2020 to 31 December 2020

1. Project Number (approved year) and Title

   IPL-230 (2018) Title: Evolution-based key technology of landslide prevention in Three Gorges Reservoir region, China

2. Main Project Fields

   Hazard Mapping, Vulnerability and Risk Assessment; Catastrophic Landslides; Mitigation

3. Name of Project leader: Prof. Huiming Tang

   Affiliation: Vice President, China University of Geosciences (Wuhan), China.
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   Core members of the Project: Names/Affiliations: (4 individuals maximum)
   Prof. Changdong Li/ Faculty of Engineering, China University of Geosciences (Wuhan), China.
   Prof. Liangqing Wang/ Faculty of Engineering, China University of Geosciences (Wuhan), China.
   Prof. Wenping Gong/ Faculty of Engineering, China University of Geosciences (Wuhan), China.
   Dr. Miao Yu/ Faculty of Engineering, China University of Geosciences (Wuhan), China.

4. Objectives: (5 lines maximum)

   Based on the landslide geohazard research bases in the Three Gorges Reservoir region of China, this project aims to investigate the response characteristics of stabilizing pile embedded in landslide rock and soil masses, then the co-evolution characteristics of the landslide-stabilizing pile structure system will be further studied, afterwards key technologies of stabilizing pile design based on the evolution process will be summarized, finally the standardization of stabilizing pile design will be proposed.

5. Study Area: (2 lines maximum)

   Zigui Basin in Three Gorges Reservoir Region, China

6. Project Duration (1 line maximum)

   3 years, and this project has been completed in 2020.

7. **Report**

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

A physical model test system for typical landslide stabilized with anchored piles was developed independently, and a series of model tests aiming at investigating influences of different layout conditions and structural parameters on the deformation characteristics and failure mechanism of landslide-anchored pile system were completed. A novel flexible inclinometer was developed to measure the deep deformation of stabilizing piles. The designed physical model test system mainly includes three parts: thrust loading system, data acquisition system and landslide model reinforced by anchored anti-slide piles. Compared to the general landslide model test system, our developed physical model test system has the following advantages:1) The data acquisition system and thrust loading system can be effectively integrated and worked synchronously; 2) The loading system can realize automatic loading in a more realistic manner as it can simulate the whole failure process of reservoir landslides. In addition, corresponding numerical simulation works were also conducted to validate the physical model test results. The main results were reached:

① With the increase of anchor points, the displacement of pile top, shear force and bending moment of pile body decreased accordingly. The tension of anchor cable increased with increasing anchoring angle, whilst the displacement of pile top, shear force and bending moment of pile body decreased.

② Compared with the number of anchoring points, the influence degree of anchoring angle on the displacement of pile top, shear force and bending moment of pile body was not obvious. However, if the tension of a single anchor cable exceeded its bearing capacity, the anchor cable was easy to be damaged, so it is necessary to determine the optimal anchoring angle.

③ The displacement of pile top, shear force and bending moment of pile body and anchor tension of cables in landslide bedrocks containing soft interlayer were between those in landslide bedrocks composed of the whole soft rock and the whole hard rock. When the anchored anti-slide pile acted on the soft rock, the anchor tension was the largest. Therefore, it showed that different formation lithology can provide different sliding resistance, which emphasized the importance of considering formation lithology of landslide bedrock when designing stabilizing piles for landslide reinforcement.

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

This project was expected to be completed in the year of 2020. During the 3 years' implementation process of this project, comprehensive research approaches have been adopted to achieve the previous expected goals, which include the laboratory rock mass experiments, theoretical calculation methods, probabilistic design methods, data mining methods, physical and numerical model test methods. At the end of this project, evolution characteristics of the deformation of landslide-stabilizing pile system have been investigated, and the evolution mechanism and triggering factors of landslide-stabilizing pile system have been revealed and identified. Moreover, a novel and integrated framework considering the life-cycle of landslide-stabilizing pile system has been

proposed for the piles design in the reinforcement of landslides. In addition, a novel landslide mitigation measure called anchored stabilizing piles has been developed and studied via physical and numerical model test methods. Overall, this project has completed whole designed objectives well, and the produced results will play a significant important role in the prevention and mitigation of landslides.

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

The project related researches have expanded the understanding of evolution characteristics of the reservoir landslide-pile system in terms of the deformation response, and help to identify triggering factors of the deformation of reservoir landslide-pile system. Moreover, optimization method of stabilizing piles, which combines the system performance, life-cycle cost with the probabilistic characteristics of bedrock rock mass, were proposed and thus fills in gaps in the comprehensive design scheme for stabilizing piles used for reinforcing reservoir landslides. The above research results provide scientific references not only for the researchers in related research fields but also for the residents threatened by reservoir landslides and the companies working on the prevention and mitigation projects of landslides. Finally, the proposed approaches can be popularized and applied in the prevention and control of the engineering landslides in reservoir, mine, traffic and so on, and provide guarantee for the sustainable development of society and economy.

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

This project has led to the publication of 6 SCI papers and has cultivated 6 post-graduate students. The detailed information about the published papers is listed as follows:

① Haikuan Zhang, **Changdong Li***, Wenmin Yao, Jingjing Long. A novel approach for determining pile spacing considering interactions among multilayered sliding masses in colluvial landslides. KSCE Journal of Civil Engineering, 2019, 23(9): 3935-3950.

② Haikuan Zhang, **Changdong Li***, **Xinli Hu***, Zhiyong Fu, Wenqiang Chen, Wenmin Yao, Yunpeng Zhang, Xihui Jiang. Deformation response and triggering factors of the reservoir landslide–pile system based upon geographic detector technology and uncertainty of monitoring data. Stochastic Environmental Research and Risk Assessment, 2020, online. (DOI: 10.1007/s00477-020-01889-8)

③ Wenmin Yao, **Changdong Li***, Hongbin Zhan, Huawei Zhang, Wenqiang Chen. Probabilistic multi-objective optimization for landslide reinforcement with stabilizing piles in Zigui Basin of Three Gorges Reservoir region, China. Stochastic Environmental Research and Risk Assessment, 2020, 34(6):807-824.

④ **Changdong Li**, Wenqiang Chen, Yingjie Song, Wenping Gong, Qihua Zhao. Optimal Location of Piles in Stabilizing Slopes Based on a Simplified Double-Row Piles Model. KSCE Journal of Civil Engineering, 2020, 24(2):1-13.

⑤ Haikuan Zhang, **Changdong Li***, Yunpeng Zhang, Guihua Wang, Jingjing Long, Wenqiang

Chen. Optimisation on plane arrangement of stabilising piles subjected to spatial distributed lateral load in landslides with multilayer sliding masses. European journal of environmental and civil engineering, 2020, online. (DOI: 10.1080/19648189.2020.1824819)

⑥ Zhen Zhong, Rui Yong, Huiming Tang, **Changdong Li**, Shigui Du. Experimental studies on the interaction mechanism of landslide stabilizing piles and sandwich-type bedrock. Landslides, 2020, online. (DOI: 10.1007/s10346-020-01570-9)

Note:

1) If you will change items 1)-6) from the proposal, please write the revised content in Red.
2) Please fill and submit this form by 30 October 2020 to ICL Network <icl-network@iclhq.org>