Human Factor Analysis in Dam Safety

Wang Huiwen¹,², Li Dandan² and Pan Shijia¹
¹Hohai University College of Water Conservancy and Hydropower Engineering, Jiangsu, Nanjing 210098, China
²Hydraulic Engineering Department, Nanjing Hydraulic Research Institute, Jiangsu, Nanjing 210029, China
²ddli@nhri.cn

Abstract. Since introduced in the 1950s, human factor reliability analysis technology has been widely used in many important fields. However, as an area that also depends on people, dam safety management has not been specifically studied on it. This article focuses on the analysis of human factors in dam safety, puts forward its research significance and focus, and combines human factor research in other fields at home and abroad to propose relevant prospects.

1. Introduction
Since human error was proposed by the US National Laboratory in the 1950s, human reliability analysis has been applied in various fields after decades of development. Accidents in the water industry have serious consequences and depend on the normal operation of man-machine systems. Human errors account for the majority of accidents. This paper introduces the application of human factor reliability analysis in dam safety, analyses its development prospects in our country, and conducts a systematic overview.

2. Human factors analysis in dam safety

2.1 Research significance
Dams, while exerting their own flood control and water storage benefits, also pose a certain risk to downstream life and property [1-3]. Once a dam failure occurs, it is likely to cause a huge social disaster, which is a typical sudden public security incident, having painful lessons at home and abroad. Our country's dam breaks mainly occurred before the 1980s. These historical dam breaks were mainly caused by environmental factors such as floods and engineering factors such as insufficient construction [4]. After entering the new century, with the continuous improvement of construction level and science technology, the proportion of dam breaks caused by over-standard flooding, inadequate flood storage capacity design, construction defects and other engineering factors decreased significantly. Meanwhile, during non-flood seasons, the proportion of dam failure accidents caused by human factors has increased relatively [5], and the role of human factors in dam safety has become more prominent.

In modern life, many accidents and disasters are caused directly or indirectly by human errors, and the reliability of human-machine systems depends largely on the reliability of human factors. On one hand, the systems need people to control operations and make decisions. On the other, due to psychology, spirit, emotion and other factors, people have certain weakness, great plasticity and are difficult to control [6]. Human play an increasingly important role in system security. According to statistics, in
different industries such as nuclear power, aerospace, petrochemical, nautical ships, mining, and power, the proportion of accidents triggered by human errors \[^7\] is above 70\%, and the water industry is no exception.

2.2 The operation management stage of dams in our country

Since the founding of New China, the construction of dams in our country has developed from disorder to order, the level of dam management has also been continuously improved. The dam failure accidents have gradually decreased. At the same time, it has also been a process of continuously strengthening the constraints on human errors \[^8\]:

The first stage was between the 1950s and 1970s. Limited by economic and technological constraints, there was no strict supervision on dam construction and management. Human errors were difficult to control, and dam-break accidents occurred frequently. From the 1980s to 2000 as the second phase, dam construction and management rules were gradually established. Human errors in design, construction and operation were restrained to a certain extent, so the dam failure rate decreased significantly. However, due to the strong administrative colours at that time, human errors still occurred from time to time. The third stage since the 21st century, driven by the concept of dam risk, dam safety management has been further modernized and institutionalized, and the rate of dam failure have been greatly reduced. But in recent years, some dam-break accidents have shown that human factors such as illegal over-storage and inadequate inspections are also one of the main reasons for dam-break. Therefore, it is very necessary to scientifically express the human error in dam-break accident, find out the key impact factors, refine the mode of human mistakes and establish a quantitative method for human error which is based on domestic historical dam break data and combined with dam management practice.

3. Research status and development trends at home and abroad

3.1 Human error data

Human factor data acquisition is the basis of human error research, generally from accident analysis reports, simulator test data, expert judgment data, etc \[^9-10\]. China has established its own applicable databases in different fields: in the field of nuclear power, a human factors database based on data reports has been established \[^11\]; in the power system, Wen Dongshan et al. \[^12\] established the human factor database of the Chinese power system; in the transportation field, Wan Ping \[^13\] comprehensively uses EEG equipment, NIRS technology, etc. to measure driver duty data, as an effective means to study the cause of human errors. The above-mentioned databases generally have the problems of single data structure and incomplete data management and sharing mechanism, and most of them are obtained through simulator test and monitoring operators. Since human errors in the dam project come not only from first-line managers and operators, but also from supervisors and decision makers, the human factors data in the former fields can only be used for reference and cannot be directly applied. For the research of dam safety, we should set up our own human factors database based on the information of dam failure in our country.

3.2 Factors affecting human errors

The influencing factors and patterns of human error are its external representation, which is also the foundation of the research on quantitative methods, and the influencing factors are the basis of its external representation. There are different stages of understanding at home and abroad on the study of the causes of human errors: Embrey’s \[^14\] early research on the causes of human errors only focused on the perception-driven model, ignoring the impact of cognitive behaviour; Hollnagel \[^15-16\] proposed a cognitive reliability and error analysis method (CREAM) based on a complex social system, which divides the causes of human errors into individuals, technology, organization and environment, and proposed 9 common performance conditions such as procedures and plans (CPC); Chang \[^17\] analysed the human response in nuclear power plant accident scenes, and defined 50 performance impact factors based on the human cognitive models; Li Pengcheng \[^18\] and others analysed the organizational factors
in human errors and identified the influence of organizational factors. The above research is mainly focused on theoretical research, especially nuclear industry, aviation and other fields, and there is very little research on dam safety management. Unlike the causes of human error in the nuclear industry, human error in reservoir management are contained in the vastness of space, the long-term time, and between different personnel, so the causes are more complicated and cannot be directly applied.

3.3. Human error mode
The human error mode is a form that describes the human error before the dam break occurs, expressing the relationship between human error influence factors, and is the key link to quantitatively determine the contribution of the interaction between human error and dam system to the risk of dam failure. A lot of research has also been carried out at home and abroad on the human error mode: Swain [19] used human behaviour as a guiding ideology, divided human error paths into three stages of detection, diagnosis, and operation, and divided human error patterns into omission error patterns and execution error patterns; Li et al. [20] transplanted and modified the failure mode, effects and criticality analysis (FMECA) used in the hardware to obtain human error mode, effects and criticality analysis (HU MECA); Reason [21] believes that the human error mode includes the manifest type and the latent type, and describes them from the human cognitive process in detail. Although the above human error analysis methods have certain reference significance, they cannot be directly applied due to different fields. Special research should be carried out on human error in dam-break accidents.

3.4. Human error probability calculation model
In the nuclear industry, the most representative human error probability calculation method is Technique for Human Error Rate Prediction [22] (THERP), which uses the event tree model to obtain the failure probability of the entire response action sequence by calculating the three stages of awareness, diagnosis, and operation. The American Electric Power Research Institute (EPRI) proposed the Human Cognitive Reliability Model (HCR) [10], which is based on Rasmussend’s SRK Cognitive Model [23], that divides people into regular, skill, and knowledge-based, and uses the Weibull distribution formula to calculates the probability of human error. Xi Yongtao et al. [24] based on cognitive reliability and error analysis method (CREAM), predicting the probability of human pilot error due to the relationship between the control mode and the probability of error when the person completes the task. The probability calculation of dam failure accidents mainly includes event tree method and reliability method [25]. However, there is no specific and feasible calculation method for the probability of accidents related to human factors. It almost entirely depends on expert experience to make judgments, which is subjective and the conclusions between different experts may be very different.

4. Outlook
In summary, although after decades of research, the theory of human reliability analysis has been greatly developed, and has been used in many major fields with different databases and suitable models. However, it mainly focuses on the nuclear industry, aerospace industry, transportation and other fields, insufficiently used in the water conservancy industry, especially in the field of dam safety analysis.

In China, Li Dandan et al. [26] suggested that human reliability theory should be introduced into dam risk analysis. Based on the information of 14 historical dam failure accidents, they found that the main factors of human errors are professional quality, responsibility, experience, organization management. But the influencing factors concluded are not systematic and comprehensive. Sheng Jinbao et al. [27] qualitatively analysed the human factors in the dam break of removal and reinforcement project on the dangerous reservoir. In the future, it is necessary to collect a large amount of dam-break information in the history of our country, as the information source of human factors database. We should combine with cognitive psychology, management and other disciplines, digging deeper into the influencing factors from the perspective of human perception, memory, observation, etc. It is important to combine the existing human reliability research with the actual operation of dam safety operation, scientifically
characterize the human influencing factors and failure modes, and form an index of human influencing factors suitable for dam safety management System and calculation model.

Acknowledgments
This work was supported by National Key R&D Program of China (2018YFC0407105), National Natural Science Foundation (51909172) and Fundamental Research Funds of Nanjing Hydraulic Research Institute (Y720006).

References:
[1] Zhou Xingbo, Zhou Jianping, Du Xiaohu, et al. Research on the risk standard of dams in our country [J]. Journal of Hydroelectric Engineering, 2015, 34(1): 63-72
[2] Gu Chongshi, Su Huaizhi, Liu Hezhi. Review of Dam Service Risk Analysis and Management Research, Journal of Water Resources, 2017, 49(1): 26-35
[3] Li Zongkun, Ge Wei, Wang Juan, et al. Strategic thinking of dam safety and risk management in China [J]. Advances in Water Science, 2015, 26(4): 589-595
[4] Xie Jiabi, Sun Dongya. Statistics of national reservoir dam failure and analysis of failure reasons [J]. Water Resources and Hydropower Technology, 2009, 40(12): 124-128
[5] Li Dandan, Liu Zhiguo, Li Lei. Human error analysis in the dam-break incidents [J]. Journal of Water Resources and Water Transport Engineering, 2013, 6(6): 92-95
[6] Zhang Li, Wang Yiqun. Human Factor Analysis: Needs, Problems and Development Trends [J]. System Engineering Theory and Practice, 2001(06): 13-19
[7] Wu Yibo, Wang Guochang. Advances in research on the cognitive mechanism of human factor reliability [J]. Applied Science and Technology. 2013, 40(5): 66-69
[8] Zhang Jianyun, Yang Zhenghua, Jiang Jinping, et al. Research and warning of dam disease and failure [M]. Beijing: Science Press, 2014: 46-51
[9] Liang Zheng, Zhang Di, Zhang Jinfen. Dynamic prospective development of probabilistic safety assessment from the 13th PSAM International Conference. Communications and Security, 2017, 35:10-18
[10] Chauvin C, Lardjane S, Morel G. Human and organizational factors in maritime accidents: Analysis of collisions at sea using the HFACS [J]. Accident, Analysis and Prevention. 2013, 59(5):26-37
[11] Liu P, Li Z. Human error data collection and comparison with predictions by SPAR-H[J]. Risk Analysis,2014,34(9):1706-1719
[12] Wen Dongshan, Bao Yingkai, Zhang Yu, et al. Human factor reliability Analysis of power system operators and its database system [J]. Power System Protection and Control, 2017, 45(11): 35-42
[13] Wan Ping, Wu Chaozhong, Lin Yingzi, et al. Driver anger emotion recognition model based on confidence rule base [J]. Transportation System Engineering and Information, 2015, 15(5): 96-10
[14] Evans A W. Fatal train accidents on Europe railways:1980-2009[J]. Accident Analysis & Prevention, 2011,43(1):391-401
[15] Chai Song, Yu Jianxing, Ma Weilin, et al. Human Factor Reliability Analysis Method Based on CREAM and Uncertain Reasoning [J]. Journal of Tianjin University, 2012,45(11):958-962
[16] Dong Xiaolu, Ding Chao, Liu Peng, et al. Overview and development trend of reliability analysis methods for nuclear power personnel[J]. Nuclear Safety, 2017, 16(1): 48-55
[17] Chang Y H J,Mosleh A. Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents[J].Reliability Engineering & System Safety,2007:92:997-1101
[18] Li Pengcheng, Chen Guohua, Zhang Li, et al. A Human Factor Reliability Analysis Method that integrates organizational factors [J]. Nuclear Power Engineering, 2010, 31(4): 82-86
[19] Bao Y, Tang J, Wang Y, et al. Quantification of human error probability in power system based on SLIM[C]. 2014 IEEE PES Asia-Pacific. IEEE, 2014:1-5
[20] Li J, Xu H. Reliability analysis of aircraft equipment based on FMECA method [J]. Physics Procedia, 2012, 3:1816-1822
[21] Kim M C, Seong P H, Hollnagel E. A probabilistic approach for determining the control mode in CREAM[J]. Reliability Engineering and System Safety, 2006, 91 (2): 191-199
[22] Zhang Li, Dai Licao, Zhao Ming, et al. Human Factor Reliability Analysis of Qinshan Nuclear Power Plant[J]. Atomic Energy Science and Technology, 2012, 46(4):416-421
[23] Sun Z Q, Xie H W, Shi X J, et al. Engineering approach for human error probability quantification [J]. Journal of Systems Engineering and Electronics, 2009, 20(5): 1144-1152.
[24] Xi Yongtao, Hu Shiping, Chen Weijiong, et al. Improved CREAM model for quantifying the operational reliability of ship pilots [J]. Chinese Journal of Safety Science, 2015, 25(11): 3-9
[25] Peng Xuehui, Sheng Jinhao, Li Lei, et al. Research on the formulation of risk standards for reservoir dams in our country [J]. Journal of Water Resources and Hydropower Engineering, 2014(04):7-13
[26] Dandan L, Lei L. Suggestion of Introducing the Human Reliability into Dam Risk Analysis[J]. Advanced Materials Research, 2010, 225: 395-398
[27] Sheng Jinhao, Liu Jiaxin, Zhang Shichen, et al. Investigation and analysis of dam break mechanism of the reinforcement project for dangerous reservoirs[J]. Geotechnical Engineering Journal, 2008, 30(11): 1620-1625