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PRELIMINARY DISCUSS ON LIFE RISK STANDARD CAUSED BY HYDROPOWER DAM-FAILURE IN CHINA

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1 . RISK PROBLEM ON HYDROPOWER PROJECTS

From the incomplete statistics, more than 85,000 water dams have been constructed by the end of 2008 in China. These dams are playing an important role in the flood control, electricity generation, irrigation, water supply and promoting the entironment protection etc., make up of indispensable aspects on flood control and public security engineering system and infrastructure of guaranteeing sustaining development of national economy. It must be pointed out clearly that some water dams constructed during 50~70's in 20th centuries, more than 30'000 dams have different deficiency because of low construction standard and inferior construction quality[0]. These ill and precarious dams bring out failure disaster easily to threaten seriously downstream people's life, property, infrastructure and the ecosystem safety, except that cannot exert engineering design benefit. Such as Banqiao dam and Shimantang dam in Henan province broke out in August 1975, Gouhou dam in Qinghai province wrecked in August 1993 that all resulted in the huge loss of life and property.

According to the influence degree and scope, the risk caused by hydropower projects are classified into three grades: influencing on normal operation, causing main building ruined, and resulting in serious secondary disaster. The most serious risk is dam failure. Risk losses include loss of life, economic damage and social and environmental influence.

Up to present, there have been more than 3’400 dam failures accidents that caused miserable life losses and enormous economic damage [0], such magnitude of dam-break accident cannot be endured under the condition of current social and economy development in China. The loss of life is a social hot point of problem concerned by public. Systematically research on loss of life had been carried out among many nations by the end of 20th century, obtaining a lot of primary achievements, but standard on loss of life become the consistent understanding have not established. Currently, research on loss of life is still placed in the entry-level stage and the standard of life loss is a hypersensitive subject in China. By considering the situation of China and influence factors on establishment of hydropower dam risk standard, some preliminary suggestions of risk standard on individual and social life are put forward in this paper.

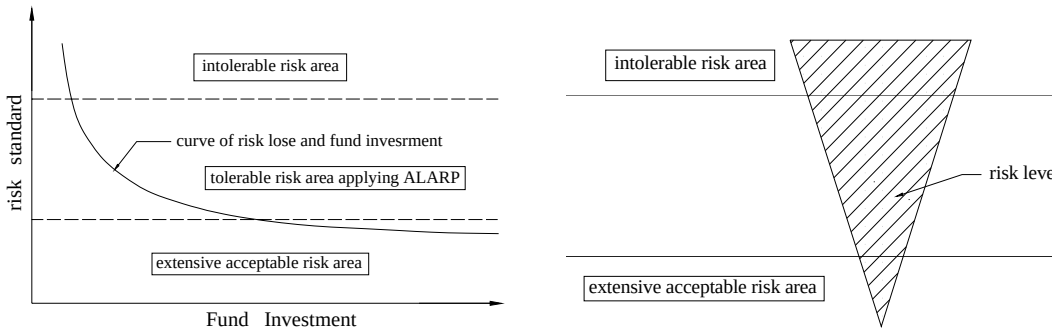
2. LIFE RISK STANDARD ON HYDROPOWER DAM AND ITS INFLUENCE FACTORS

Life risk caused by hydropower dam is probable hazardous to downstream life after dam failure, is defined as product of failure probability multiplied by possible life loses. Standard on large dam life risk includes individual life standard which is the risk that individual lives and works within particular environment can accept or tolerate, and social life standard which is the extreme limit value of life that the social public expect.

The establishment of the life risk standard, is not only affected by the technique means, but also subjected to risk level the society could accept, involves politics, culture, public psychology, technique development, health and environment etc., and building risk standards also need to consider both acceptable risk standard and tolerable risk standard. The British healthy and safty committee(HSE) define acceptable risk as any person who is subjected to the risk influence, for the sake of the purpose of the life or work, if the risk control mechanism is constant, the risk that prepare to accept, tolerable risk as society can suffer for the sake of obtaining a certain profits. Tolerable risk don't mean can be accepted. It needs a periodical check, and should be reduced as lower as possible. Risk can be tolerated only when lowering the risk is not feasible or investing funds and decreasing risks are very dissymmetry, seeing the Fig. 1(a). Decreasing risk as low as reasonable practical (ALARP) level is the risk management and decision guide line. As showed in Fig 1(b), the frame of risk standard is built up from ALARP.

Two horizontal lines are showed in diagram; top horizontal line is acceptable risk and bottom line is neglectable risk. Whole risk area is divided into three sub area by two horizons according to risk degree. Area above top horizontal line the risk is too high to be accepted that the compulsive measure should be adopted to decrease the risk. This area is called as unacceptable risk area. Area under the bottom horizontal line the risk is very low level and need not adopt any measure to decrease the risk. This area is called as extensive acceptable risk

area. Between the unacceptable risk area and extensive acceptable risk area is the ALARP. In this area, measure for decreasing the risk should be applied as far as possible according to actual condition. For various risk processing project, what measure is adopted according to cost and benefit analysis.



(a) Relationship between economy Investment and risk reduction

(b) Risk grade and ALARP principle

Fig. 1

Frame of risk standard and guideline for ALARP

Because social economy development level, traditional cultural background, social value, management and insurance system are diversity, different countries, regions and owners differ in understanding of risk standard. The life risk standard drawn up is difference. In China, risk research on large dam is still placed in the start stage, lack of system and integrity, especially research on risk standard is few. Therefore, according to international experience and combined with the actual situation of China, research on life risk of large dam need to be carried out thoroughly, the focus topic is how to understand adaptability between life risk standard and the economic development level in different region.

2.1. THE INDIVIDUAL RISK STANDARD OF LIFE

Tolerable individual risk standard of life. For risk, it is certain that people would like to accept more the low risk than the high. In general, it would be thought as low as reasonable level what people don't worry about when the risk is below 10^{-6}/a. When the risk is above 10^{-6}/a, whether people live or work herein would like to accept depends on his own will.

Technical Advisory Committee on Water Defense of Netherlands (TAW) has drawn up individual risk standard combined with personal will of $10^{-4}\beta.\beta$, which is will factor, reflects personal will degree ranged from 0.01 to 10. It is lack of measurement basis because of large scope of β selection. In addition, to be the basis value of 10^{-4}, corresponding β is 1 also cannot reflect personal will

degree.

Australian National Committee on Large Dams (ANCOLD) has drawn up life risk standard based on the lowest population death rate of year. The lowest death rate of year of Australia population is 10^{-4}/a (10~14 years old), therefore, 《Guidelines on Risk Assessment》 [0] constituted in 2003 suggests that, for current service dam, individual risk is not tolerable when it causes individual and group risk above 10^{-4}/a. Individual risk exceeding 10^{-5}/a is not tolerable for new-built or rebuilt dam. The British HSE define tolerable individual risk standard of the worker and the public as 10^{-3}/a and10^{-4}/a respectively.

Some scholars [0Error! Reference source not found.] in China consider accidental death rate of transportation that the pubic can tolerate as the foundation of individual risk standard establishment caused by dam failure. According to statistical date in 2003, unexpected death probability is about 3.3×10^{-4} when taking mobile vehicles. Therefore, it is suggested that tolerable individual risk standard of life caused by hydropower dam is 3.0×10^{-4}/a, and acceptable individual risk standard of life is 10^{-5}/a currently. Applying the way of raising the standard gradually, the standard of tolerable individual life risk and acceptable individual life risk are improved up to international level finally, 10^{-4} and 10^{-5} respectively. Some scholars also suggest taking annual average apobiosis rate for multiple years of 0.66% as the basis of standard establishment. According to current economy and social development level, tolerable individual life risk standard caused by dam failure is suggested as 5×10^{-4}/a~1.0×10^{-3}/a, acceptable individual life risk standard improved one order of magnitude corresponding to tolerable standard, is 5×10^{-5}/a~1.0×10^{-4}/a.

The authors think that hydropower project is different from other infrastructures because loss of life and social influence caused by dam failure are disaster. For example, two large-sized reservoirs of Banqiao and Shimantang, and two medium-sized reservoirs of Zhugou and Tiangang broke in “75.8” , flood made more than 10 millions people the victims of the disaster, put more than 2.6 thousands people into a tragic death. Gouhou concrete faced rockfill dam located in Qinghai province broke in August 1993, the county city of the downstream 13 km away from the dam site was flooded by more than 2000m^3/s of peak flood discharge of the dam-break which is 8 times of design flood discharge. Dam-failure caused several hundred of people death and thousand of families homeless [Error! Reference source not found.]. In addition to the innocent life loses, dam failure will also result in survivals mental disease and confused fear, even social turbulence. With the rapid development of society and economy and sudden population growth of the downstream, it will be larger that loses of life, economy damages and society influence caused by dam failure. For large and medium-sized hydropower project, dam-break is intolerable risk. To be the most important pivotal building, difficulty and prices that expect to reinforce the dam will be larger during operation period. Therefore, hydropower project, especially new-built dam, which establishment of life risk standard should consider not only current economy development level, but also the

characteristics of high-speed of economic and social development. Raising life risk standard gradually is not suitable for the state of China.

In addition, the life risk standard is also in accordance with the reliability level of the hydropower project in China. Reliability indexes specified in《Unified design standard for reliability of hydraulic engineering structures》are 4.2, 3.7 and 3.2 for the first, second and third grade building[Error! Reference source not found.], corresponding failure probability are $3.0\sim10\times10^{-5}$. Taking into account the shortest design reference period for hydropower structures is 50 years, the highest annual mean failure probability is 0.2×10^{-5}. Even considering variability of some partial factor, reliability of hydropower dam could be guaranteed by strengthening design for dam weakness and safety monitor, scientific reservoir operation and effective forecast [0]. Therefore, it is suggested that the tolerable individual risk standard of life for hydropower dam doesn't lower than 10^{-4}, and the acceptable individual risk standard doesn't lower than 10^{-5} in China.

2.2. SOCIAL RISK STANDARD OF LIFE

Social risk standard of life is constituted with combining F-N curve with ALARP rule. Curve of F-N is the relationship between life loss number N and probability of exceedance, the general formula could be expressed as following [3].

$$1-F_N(x)<\frac{C}{x^n} \qquad (1)$$

Where: n is the inclined rate of the line, C is a constant, which decide the restrictive position of the standard line.

The curve of F-N adopted, n and C taken in some countries and regions are showed in Fig. 2. It could be concluded that the n is higher, require failure probability lower. The adoption of F-N rule for large scale engineering with high social life risk, require high safety. Engineering reliability analysis is accordance with risk evaluation in essence. Because of concerning object is dissimilarity, risk standard not only reflect engineering technique level, but also consider social public request. Vrijling [Error! Reference source not found.] put forward modified method of acceptable risk based on F-N rule. In method, n equals 2, and C involves quantity of certain specialized types of infrastructure in nation, reduced risk factor and policy factors. Song Jingxian etc [Error! Reference source not found.] bring forward different social risk standard of life for risk elimination and reinforcement of the ill and precarious reservoir dams in different regions using above method.

For current reservoir dams in commission, repair and rehabilitation funds

need local government appropriated funds in addition to central public finance. Economy development levels in eastern region, central region and western region of China are of great diversity, local appropriate funs exist of great difference. Reservoirs play an important role in developing local economy. If unified risk standard of economy is adopted in the whole country, it is undoubted that some reservoirs were put into end or altered operation mode, thus worsen economy development again. Literature **Error! Reference source not found.** presents suggestion of diversity risk standard for current service dam in different region, contraposing present condition of reservoir dams, to meet the economy development requirement, hereafter unify the standard gradually. If consideration is from single economy development, such suggestion is doubtless. But it is not proper that debasing life risk standard exchanges developing economy. In contrast, because of frangible economy foundation and weak economy withstand in undeveloped region, it should raise the reliability of reservoir dam in these region, that is, lower social risk of life. For built and new built reservoir dams, adoption of unified social risk standard of life is not only supporting current economy development, but also guaranteeing sustainable development, meeting safety production requirement, bodying the industrial idea of people oriented and law impartiality.

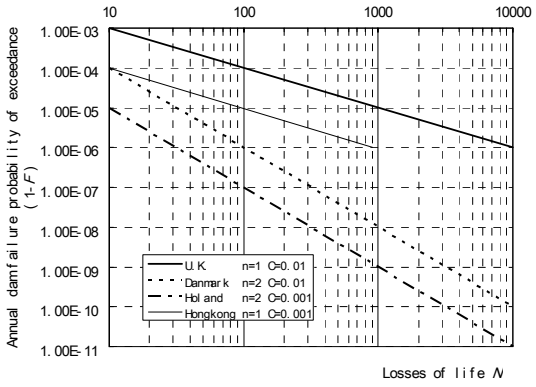


Fig. 2
Social risk standards of life defined by the F-N curve in some countries and regions

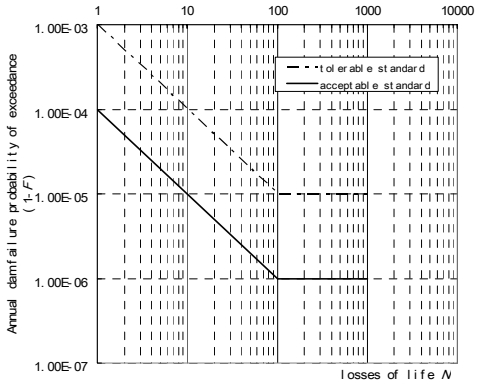


Fig. 3
Recommended standards for large and medium-sized hydropower engineering project in China

According to dam failure dates, annual dam-break probability for medium-sized reservoirs is 7.257×10^{-3} before 1980, and 1.107×10^{-4} after 1980. There is no large-sized reservoir dam failure.

From several to hundreds of people are lost each dam failure. Supposed that loss number of life is 10~100, annual loss of life probability is 1.11×10^{-3}~1.11×10^{-2} for large and medium sized reservoirs. Upper limit of life loss is intolerable, and lower limit may be taken as tolerable risk standard. Jumping-off point of F-N curve for large and medium-sized reservoirs is

suggested as 10^{-3} with reference to above tolerable risk. According to ANCOLD suggestion, 10% of annual dam failure probability is regarded as horizontal limit line of tolerable social risk of life and 1% of dam failure as limit value of acceptable risk. Level limit of tolerable social risk of life for large and medium-sized reservoirs may be taken as 10^{-5}, and acceptable risk is 10^{-6}. Meanwhile, considering disaster accident for large and medium-sized reservoirs and current construction and management level of hydropower engineering project, for new-build dam, loss of life over 1000 of people is also added as restricted condition of intolerable risk. Comprehensive suggestion social risk of life curves are showed as in Fig.3.

3. CONCLUSION AND SUGGESTION

As one of the most important infrastructures in China, because of its scale and importance, dam failure of large and medium size hydropower project is not an acceptable risk, so life risk standard need be built up strictly. Owing to population density is high, it is necessary to draw up life standard no lower than developed countries in China. It is also feasible on the basis of current technique level. Adoption of strict dam failure risk standard is suitable for mutually high speed of economy and society development, requirements of safety production.

It is not proper that establish different life standard on the consideration of region economy discrepancy. High or low economy development level in different region can be a reference when the economy risk standard is set down. Adopting the unified life risk standard in whole country is a concrete reflection of people oriented and life is equal in the eyes of the law in hydropower projection construction.

The research on life loss caused by dam failure is still placed in the entry-level stage in China. Although primary research results have been achieved, the life risk standard has not yet become consistent understanding. Influence factors of life risk standard caused by large dam failure are discussed primarily. A suggestion on hydropower dam failure in China is put forward that tolerable individual risk standard of life is not lower than 10^{-4} and acceptable risk standard is not lower than 10^{-5}. According to dam failure dates in nearly 20 years, departure point of tolerable social risk of life is 10^{-3}, horizontal limit line with 10% and 1% of the dam failure rate of the year are taken as tolerable and acceptable social risk of life, correspond to be 10^{-5} and 10^{-6}. For new-built dam, the lose of 1000 people is added as an intolerable restrict condition.

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SUMMARY

Life risk is a hypersensitive topic for discussion. The standard establishment of life loss needs to comprehensively consider the influences of national politics, economy, culture, public psychology and technical development level. Risk caused by hydropower dam-break is unacceptable owing to its large scale and severe result, so high standards and strict requirements are needed to establish the criterion for life loss caused by hydropower dam. Based on each infrastructure industry life loss standard, influences on standard establishment of life loss are discussed and uniform individual life risk standards and social life risk standards are put forward.

KEY WORDS

Hydropower project, dam failure, risk analysis, life risk standard