Study on engineering-hydrogeological problems of hydroelectric project

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Abstract: Engineering-hydrogeological problems arise from the interaction between engineering activities and geological environment, in which rock-soil mass and groundwater are especially important constituents. However, up-to-date research on them is relatively dispersive and simple due to their complexity and lack of comprehensive and systematic study methods. Starting from geological analysis of mechanism to geological model based on geological regularities, the paper predicts the tendency of geological evolvement and puts forward proper measures to solve problems. In this paper, elevated water-sensitive structure in rock-soil mass, which mainly causes engineering hydrogeological problems, and problems in hydropower is discussed based on unique construction in Chinese Western hydropower projects. Engineering hydrogeological problems are reservoir induced earthquakes leakage from reservoir bottom in karst, stability of high slope at reservoir banks, sliding of dam foundation and dam abutment, and confined water at key positions which are introduced and determined by using water-sensitive factors (or structure) according to special hydrogeological conditions.

Keywords: Engineering-hydrogeological problems; Geological analysis of mechanism; Geological model; Rock mass seepage; Hydroelectric project

Introduction

Hydrogeology and engineering geology are vital branches of applied geology in the 20th century. Research from the different views and field of groundwater can greatly enrich the connotation and extension of hydrogeology, and then some new interdisciplinary will be formed. For example, there are positive and negative aspects to research groundwater by using the view of geological forces. The positive effects are such as groundwater mineralization, and the negative effect is that groundwater mainly as a kind of directly or indirectly force can cause various geological disasters. These disasters can cause a series of engineering and environmental geological problems which directly restrict the engineering design, construction as well as operation and seriously influence human survival environment under natural conditions or the human engineering activities. “Engineering-hydrogeology” was proposed between hydrogeology and engineering geology by ZHANG Xian-gong (1993) who both considers water and rock-soil mass from the view of engineering geology, and comprehensively researches their interaction and influence on engineering and environment.

Engineering-hydrogeology problems relate to the water, which arise from interaction between rock-soil mass and groundwater in the human engineering activities and geological environment (XU Mo and WANG Shi-tian, 2003).

With social progress, engineering-hydrogeological problems, in fact, gradually draw the attention of academia and engineering circle.
Human engineering activities expanded both in scale and scope. Especially since the 1960s, there has been a series of major engineering accidents in the world (e.g., Malpasset Arch Dam in French), which indicates that groundwater plays an important role in damaging interaction between engineering and geological environment.

Hydropower project is the human engineering activity that develops and utilizes hydropower resources. China owns abundant hydropower resource, the highest in the world. The reserve is 6.8×10^8 kW in theory, and the exploitation is 3.8×10^8 kW. However, at present, the exploitable degree is low. Predictably, the development of hydropower construction will face newer and bigger challenge. It is not hard to imagine that in large-scale hydropower construction, the interaction between human engineering activities and geological environment will be more complex and intense. As a result, it is required to research and solve more complex and difficult engineering geology and engineering hydrogeological problems in time.

Engineering-hydrogeological problems arise from interaction between rock-soil mass and groundwater of geological environment during the human engineering activities. Water as an active factor of geological environment plays an important role in the interaction relationship between hydropower construction activities and geological environment will be more complex and intense. As a result, it is required to research and solve more complex and difficult engineering geology and engineering hydrogeological problems in time.

1 Analysis on occurrence condition of engineering-hydrogeological problems in hydropower project

1.1 Overview of the main function of water in the hydropower project

The biggest difference between the hydropower project construction and others is water. Water is both the project goal (damming impoundment) and an important factor of geological environment in hydropower engineering, and it plays an important role in the mutual restriction and interaction of geological body and engineering building. Generally speaking, the role of water (or function) is embodied in the following three aspects:

1.1.1 Mechanical effect of water

Interstitial hydraulic pressure: the self-weight stress of groundwater in various gap (pore, fracture and fissures) with hydrostatic transmission applied to rock-soil mass. According to the status of groundwater, interstitial hydraulic pressure has two kinds of forms: (1) Hydrostatic pressure, which is the interstitial hydraulic pressure under the hydrostatic condition; (2) osmotic pressure, which is the interstitial hydraulic pressure under stable seepage condition. The interstitial hydraulic pressure in the fractured rock-soil mass points to the direction of fracture surface normals. Intertitial hydraulic pressure plays a very important role in rock-soil mass deformation and failures, and it is usually expressed by the following effective stress principle:

\[ \sigma = \sigma_s + p_w \text{ or } \sigma_s = \sigma - p_w \]

\[ s = (\sigma - p_w) \tan \phi + c \]

where, \( \sigma \) is the total stress, \( \sigma_s \) is the effective stress, \( s \) is the shearing strength of potential failure surface in rock mass, \( \tan \phi \) is friction coefficient, and \( c \) is the cohesion. Under the constant condition of total stress, effective stress will decrease and rock-soil mass will rebound deformation with increased water pressure. For fractured rock mass, with the increased water pressure, on one hand, it means that the water under along the fracture of rock mass enhances “wedge splitting”; on the other hand, stability against sliding will decrease along this potential failure surface, and it is due to the overall damage of rock mass.

Dynamic water pressure: the force on the rock-soil mass from frustration of groundwater seepage by rock particles or pore wall. It is a kind of volume force, a vector function of the position space and time, and its direction is consistent with groundwater flow, and the head size depends on groundwater head difference. The dynamic water pressure is that water seepage applying a certain thrust effect on rock-soil mass, and it is easy to
cause shear deformation or displacement of the structural surface; if there is a lot of fillings in structural surface, the dynamic water pressure may cause mechanical pipe seepage.

1.1.2 Physical chemistry of water

Water is the active factor in geological environment, and water-rock reaction plays an important role in almost all geological process. Currently, this research is more concentrated in low-medium temperature geological environment especially in the weather process, and its product research is the most widespread.

In the geological environment, hydroelectric project will accelerate weathering of high slope of new excavation. In some cases, the water-rock reaction can often significantly affect the progress and characteristics of interaction between engineering activities and geological environment. Of particular note is: (1) Water-rock reaction will change the chemical composition and physical mechanical properties of rock-soil mass and weak structure surface, and may affect the project; (2) water-rock will change chemical composition of groundwater, and pose potential hazards to engineering building.

1.1.3 Value of water function

Hydroelectric power projects benefit from impounding water to generate power, irrigate, cultivate and improve shipping conditions. Its fundamental point is to effectively accumulate water in the dam within the reservoir. However, in some special geological conditions, the elevation of water level may drive water through underground passage to adjacent regions or downstream leakage regions, thus giving full play to benefits.

The reservoir leakage has corresponding geological and hydrogeological condition, which is the hydrodynamic condition and channel condition. So in practical work, identifying two aspects are is crucial

1.2 Geological conditions of hydropower project’s engineering-hydrogeological problems

Hydropower project’s engineering-hydrogeological problems are geological problems, and have their specific geological conditions, different geological environment, different regions, and different engineering rock mass. Due to different lithology, structural conditions and stress state, the different reactions on water effect sensitivity show vast difference.

A large number of real data shows that water in the reservoir-induced earthquake plays an important role. Currently, there were 33 770 reservoir dams above 15 meters, and just 116 induced the earthquake whose recurrence rate was only 0.34%, and the recurrence rate was 0.09% in China (XIA Qi-fa, 1993). From the view of reservoir-induced earthquake, reservoir’s sensitivity to water effect has large difference in different areas.

Water’s erosion on the concrete mainly happens on the continental sedimentary strata that are rich in gypsum, for example, Bapanxia of the Yellow River, Yanguoxia, Chaoyang hydropower station in Qinghai Province encountered problems of different degrees herein (ZHOU Cheng-jie, 1994).

A regional geological environment’s sensitive degree to function of water will be divided into:

\[
\begin{align*}
\text{water stability} & \quad \begin{cases} \text{Area} \\ \text{Rock mass} \end{cases} \\
\text{water sensitive} & \quad \begin{cases} \text{Light sensitive type} \\ \text{Extremely sensitive type} \end{cases} \begin{cases} \text{Area} \\ \text{Rock mass} \end{cases}
\end{align*}
\]

Water sensitive areas or rock mass have some special hydrogeological conditions or some kind of water sensitive factors, which are called water-sensitive factors, and if the factors are rock-soil mass structure, it is called water-sensitive structure. Central South survey Design Institute of Ministry of Power Industry of the People’s Republic of China has reviewed research on Huanglongtan reservoir bank stability, since impoundment of reservoir below the dam from 1974 to 1985, there were 73 landslides, mainly happening in a kind of typical structure of the low angle slope and water-sensitive structure, composed of quartz schist and mica chlorite schist. The lithology is soft, and easy to soften; the schistosity is well developed, and the inclination is slow.

Water-sensitive factors (structure) can be
classified as follows: (1) According to its developmental area, it can be divided into two categories—superficially and deeply (Table 1). (2) According to mode of water function, it can be divided into mechanics, chemistry and leakage. As you can see in Table 1, different types of water-sensitive structure (or factors) will cause different types of engineering hydrogeological problems.

Thus, for any specific hydropower projects, we should initially find out the general engineering geological conditions, and analyze them to determine which water-sensitive factor or structure plays the role, as well as what kind of possible engineering hydrogeological problems the projects have.

### Table 1 Characteristic list of deep buried and shallow surface water-sensitive structure in hydroelectric projects

<table>
<thead>
<tr>
<th>Type</th>
<th>Action location</th>
<th>Composition of water-sensitive structure</th>
<th>Mode of water function</th>
<th>Function characteristic</th>
<th>Main engineering-hydrogeological problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inside of slope</td>
<td>Combination of rock mass discontinuity that controls the stability of side slope, especially the weak structural plane</td>
<td>Interstitial hydraulic pressure; Hydrodynamic pressure; Softening and mudding effect</td>
<td>Happening mainly at rainy seasons and the time when reservoir water level fluctuates rapidly</td>
<td>Stability of bank and slide disaster</td>
<td></td>
</tr>
<tr>
<td>Dam foundation and abutment</td>
<td>Combination of rock mass discontinuity that controls stability of dam foundation and abutment</td>
<td>Interstitial hydraulic pressure; Hydrodynamic pressure; Softening and mudding effect</td>
<td>Happening mainly at the time when reservoir begins impounding</td>
<td>Anti-sliding stability of dam foundation and abutment</td>
<td></td>
</tr>
<tr>
<td>Superficially</td>
<td>Carbonatite stratum and spatial distribution</td>
<td>Groundwater flows out of the reservoir along karst underground watercourse</td>
<td>occurring immediately after impounding under proper hydrodynamic condition</td>
<td>Reservoir karst seepage</td>
<td></td>
</tr>
<tr>
<td>Reservoir</td>
<td>Continental stratum rich in soluble constituents like gypsum etc.</td>
<td>Groundwater erodes concrete by dissolving ion, like SO$_4^{2-}$ etc.</td>
<td>Site of exposure Groundwater erosion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dam</td>
<td>Confined groundwater structure</td>
<td>Uplift pressure of high head</td>
<td>Occurring within the range of confined water area</td>
<td>Anti-sliding stability of dam position</td>
<td></td>
</tr>
<tr>
<td>Deeply</td>
<td>Reservoir</td>
<td>There is fracture plane close to critical stress state in the rock mass allowing water to infiltrate</td>
<td>Interstitial hydraulic pressure effect Load effect Stress corrosion effect</td>
<td>Water function acts within a wide range because of its flowing characteristic Reservoir-induced earthquake</td>
<td></td>
</tr>
</tbody>
</table>

### 2 Main engineering-hydrogeological problems in hydroelectric project

A built reservoir with high dam will greatly change the hydrogeological conditions and form a new groundwater seepage field. Under a certain geological environment condition, engineering structures and interactions between groundwater and rock-soil mass (Table 2 and Table 3) will produce a series of engineering hydrogeological problems in different places (Table 4).
### Table 2 Types and characteristics of the interaction between groundwater and rock and soil mass in hydroelectric project

<table>
<thead>
<tr>
<th>Location of the reservoir</th>
<th>Type of interaction between groundwater and rock mass</th>
<th>Interaction characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shallow rock mass of reservoir bank and pivot</td>
<td>Softening and mudding effect</td>
<td>By improving aquosity of earth-rock to reduce its strength</td>
</tr>
<tr>
<td></td>
<td>shrinkage, swelling and disintegration</td>
<td>By improving aquosity of earth-rock to deteriorate its quality</td>
</tr>
<tr>
<td></td>
<td>Seepage deformation</td>
<td>By flowing away fine particle in earth-rock to reduce its carrying capacity</td>
</tr>
<tr>
<td></td>
<td>Freezing-swelling effect</td>
<td>By freezing water leading to volume expansion to split fracture</td>
</tr>
<tr>
<td></td>
<td>Chemical suffosion and corrosion</td>
<td>By flowing away soluble component in earth-rock to deteriorate its engineering qualities</td>
</tr>
<tr>
<td></td>
<td>Hydrodynamic pressure effect</td>
<td>By water seepage to exert trust on earth-rock</td>
</tr>
<tr>
<td></td>
<td>Interstitial hydraulic pressure</td>
<td>By reducing effective normal stress on failure surface of rock and earth mass to lower its strength</td>
</tr>
<tr>
<td>Slope and riverbed at downstream of the dam</td>
<td>Hydraulic scouring effect</td>
<td>By intensive water flow impacting to destroy rock and earth mass</td>
</tr>
<tr>
<td></td>
<td>Softening, mudding and Interstitial hydraulic pressure effect caused by rain and fog infiltration</td>
<td>-</td>
</tr>
<tr>
<td>Deep rock mass of reservoir</td>
<td>Load effect</td>
<td>A mechanical effect that reservoir water acts on the reservoir base in form of surface load</td>
</tr>
<tr>
<td></td>
<td>Interstitial hydraulic pressure effect</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Hydrothermal and vaporization-swelling effect</td>
<td>Water infiltrates into deep underground, then it contacts high-temperature rock mass generating endothermic and vaporizing expansion</td>
</tr>
<tr>
<td></td>
<td>Stress corrosion effect</td>
<td>Load-bearing silicate rock meets water and then tensile stress concentrates at rock mass’ original fracture end accelerating hydration of Si-O bond and lowering its strength</td>
</tr>
</tbody>
</table>

### Table 3 Types and characteristics of the interaction between groundwater and engineering construction in hydroelectric project

<table>
<thead>
<tr>
<th>Part of reservoir</th>
<th>Function type</th>
<th>Action feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir and project zone</td>
<td>leakage</td>
<td>Under the condition of high water head drive, the reservoir water flow along the rock melting channel, the fault rupture zone, the fracture zone and so on, to the adjacent area and downstream of the dam. It is the main form of karst leakage.</td>
</tr>
<tr>
<td>Project zone</td>
<td>Erosion effect</td>
<td>Complex chemical composition in the natural environment, the interaction of groundwater and reservoir water and the complex components of the dam, the erosion of the dam and other concrete structures.</td>
</tr>
</tbody>
</table>
Table 4 Main engineering-hydrogeological problems in hydroelectric project

<table>
<thead>
<tr>
<th>Type</th>
<th>Mode of Groundwater action</th>
<th>Action characteristic</th>
<th>Action location</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep confined water in pivot area</td>
<td>Hydrodynamic pressure</td>
<td>Anti-sliding stability of dam foundation</td>
<td>Pivot area</td>
<td>Guandi Power station</td>
</tr>
<tr>
<td></td>
<td>Interstitial hydraulic pressure</td>
<td>Dam foundation seepage erosion on construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Chemical action</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seepage stability of dam foundation</td>
<td>iffual deformation</td>
<td>Lowering dam foundation strength, increasing its permeability even leading to the engineering accident</td>
<td>Pivot area</td>
<td>Guan Yingyan power station</td>
</tr>
<tr>
<td></td>
<td>Chemical subsurface erosion and corrosion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability of reservoir bank and high slope</td>
<td>Hydrodynamic pressure</td>
<td>Direct thrust from water flow and decrease of structural plane strength lead to reservoir silt, even to surge that further threatens dam security</td>
<td>Bank slope of reservoir</td>
<td>Vajont reservoir landslide; Jinlongshan landslide; Qian-jiangping landslide</td>
</tr>
<tr>
<td></td>
<td>Interstitial hydraulic pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reservoir-induced earthquake</td>
<td>Load effect</td>
<td>Influencing dam security, being the main geological disaster caused by interaction between groundwater and rock mass in hydroelectric project</td>
<td>Whole reservoir bed and deep rock mass around it</td>
<td>Tongjiezi power station</td>
</tr>
<tr>
<td></td>
<td>Interstitial hydraulic pressure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karst seepage</td>
<td>Seepage toward adjacent region and downstream</td>
<td>Influencing reservoir impounding efficiency</td>
<td>Reservoir area and adjacent region where carbonatite is distributed</td>
<td>Guandi power station</td>
</tr>
</tbody>
</table>

Conclusion from the table: (1) In a large hydroelectric project, interaction between engineering structure and groundwater as well as rock-soil mass is a multifactorial mechanism process, so it is possible to generate multiply complex engineering hydrogeological problem; (2) interstitial hydraulic effect is a key factor for the existence of water-rock interaction in different parts of the hydroelectric project; (3) studying groundwater seepage in rock-soil mass under project condition is the basis for solving engineering hydrogeological problem.

3 Examples of engineering hydrogeological problems

3.1 Deep confined water in pivot area

Confined water is formed in the proper hydrogeological structure under the specific geological environment. The confined water is circulated in the geological environment with its own hydrogeological feature, and is in harmony with the natural environment. When human engineering activities are related to the geological environment of the confined water, this change will also reverse the role of the engineering building.

The Guandi Hydropower Station dam on the Yalong River is located in Permian basalts, and there is confined water with deep and high water head as well as special water chemical composition at dam axis line IX exploration right of river bed and the right bank. The buried distribution points to the confined water system in the upper and bottom reach: the confined water system in the upper reach is shallow, exposed at low water head, non-smell of H$_2$S and water types is HCO$_3$-Ca-Na-K; lower confined water system buried deeply and expose high head, large flow, with a thick smell of H$_2$S, the type of water is Cl-Na-K. The chemical composition of water and its formation process can be deduced from the confined water formed in the local slope, lower system due to sound closed conditions, which will not produce the effect of practical significance to the project; there is head difference in the upper region.
part of the confined water of the earth, which makes the dam after reservoir water supplies into the upper aquifer. This effect cannot be ignored, the dam design should be combined with grouting and drainage, and attention should be paid to solving the problems’ harm (XU Mo et al. 2004).

The Yellow River Tianqiao Hydropower Station is located in Baode and Fugu County of Shanxi Province. Middle Ordovician limestone is distributed in dam-site, of which O\textsuperscript{11}\textsubscript{2} formed karst aquifer blocked by the overlying O\textsuperscript{11}\textsubscript{2} with undeveloped crack. The confined water mainly comes from the left bank of the river with a large area of exposed limestone O\textsuperscript{11}\textsubscript{2} accepting precipitation infiltration, which shows rich and stable level. Due to the specific geological conditions, O\textsuperscript{11}\textsubscript{2}’s only excretion area is the dam site, so after the impoundment of the reservoir, drainage area is blocked, and the confined water level will rise, and then uplift pressure of the dam base will increase, which poses a threat to the dam safety. According to the calculation of groundwater observation data, when the reservoir reached the normal water level of 834.0 m, O\textsuperscript{11}\textsubscript{2} confined water level will be increased to 835-840 m, the resulting pressure will account for 60 to 70% of the vertical load, and this is the main factor affecting the safety of the project (WANG Fa-xi, 1989).

The Nanhe dam on the Han River tributaries is wide-seam gravity dam of 50 m, and dam foundation is the Upper Sinian Dengying dolomite. It has complicated fault structure, and is karst developed. In the Baiyun karst gap, a deep karst confined water system exists, whose valley slope accepts recharge and runoff to the bottom. The dam changed cycle conditions of confined water, rainfall intensity of 139 mm/6h occurred in August 1, 1980 when the water level was 68.49 m higher than the deep confined water, and it directly threatened dam safety (ZHOU Yuan-xin and ZHOU Chuang-bing, 1994).

Qinghai Chaoyang hydropower station dam foundation features red rock with rich gypsum, and the hydrochemical type of groundwater is SO\textsubscript{4}-Cl-Na. During four years’ station operation, concrete experienced several times of cracking and loose structure, as well as other problems. Above the drainage and skirting boards of 20 m occurred thickness of 0.3 to 0.5 m of the loose layer on the surface of the concrete, and there are a lot of white floc and acicular crystallization, forcing engineering multiple repair. This is obviously due to crystallization erosion to the concrete from SO\textsubscript{4}\textsuperscript{2-} in groundwater (ZHOU Cheng-jie, 1994).

As can be seen from the above examples, influence on the hydropower project of confined water is mainly manifested in two aspects: one is high head uplift pressure of confined water which has certain influence on the dam foundation stability against sliding; on the other hand, the confined water formation and movement formed complex chemical constituents by leaching and ion exchange, undoing and undermining the concrete. Therefore, in hydropower engineering investigation, if the project areas are confined water, formation conditions and development features must be found out, the correct evaluation of its impact on the project is necessary, and proposals on the prevention and control measures should be taken.

### 3.2 Seepage stability of dam foundation

Unlike other buildings, in the construction of dam, not only the strength and deformation of the general problem, but also water leakage problems should be taken into considerations. The seepage of the dam foundation brings not only economic loss, but also safety concern of the dam. It has been found that the destruction of many dams is often not because of the weak strength of the dam or foundation, but because of the ground rock-soil mass being not enough to resist the pressure of water.

The water flow in rock-soil mass gap is affected adversely in two ways of physics and chemistry on foundation bearing capacity. The size of hydrodynamic pressure on the medium of flow water is proportional to the hydraulic gradient, and significant erosion and soil erosion occurs here. At the same time, water has also caused hydrostatic pressure, reduces the effective stress between soil particles, and decreases the shear strength of rock-soil mass. When the dam foundation rock or soil has some soluble salt minerals, seepage water may gradually dissolve and take away them, and forms voids or reduce the internal cohesion and shear strength of the rock-soil mass.

From the crash, two main modes can be summarized: (1) Too much seepage caused erosion;
(2) too high pore-water pressure caused the sliding collapse.

For the concrete dam construction in rock foundation, the dam experienced crash or accident which showed small seepage volume and high pressure. Such as France’s Malpasset Arch Dam, China Meishan Arch Dam and so on.

3.3 Stability of reservoir bank and high slope

The development of deformation and destruction as well as stability of the slope depend on the geological environment condition. When the geological environment conditions change, the development and the stable state of the slope will change correspondingly. Ground water is often the most important triggering deformation factor of the slope in the geological environment.

For the reservoir bank and the high slope, its particularity is that in addition to changing the slope seepage field of groundwater by rainfall similar to the general slope, reservoir impoundment and operation further complicate the groundwater flow field. Mainly the following several aspects: (1) Reservoir impoundment softens rock-soil mass strength and weight of suspension, and may change the landslide stability state; (2) sudden change of the reservoir water level generates dynamic water pressure, and may induce landslide deformation and failure; (3) reservoir water storage may induce earthquake, and the earthquake could trigger landslide deformation and failure.

Reservoir accidents, including Italy Vajont giant reservoir landslide in October 1963, the Jipazi landslide in Yungyang County of Sichuan Province in July 1982, the Qianjiangpings landslide in Zigui County of Hubei Province in July 2003, etc. were all directly related to rising ground water level of slope. Vajont landslide and Qianjiangpings landslide were caused by reservoir impoundment, and the Jipazi landslide was caused by rapid rise water level during the storm drain and blocked slope.

3.4 Reservoir induced earthquake

Reservoir induced earthquake is the earthquake caused by hydropower project activities. It may pose a threat to project safety, and cause grave environmental disasters.

At present, the world has built more than 100 thousand reservoirs. According to statistics, only 132 of the reservoirs (controversial reservoir) are related to reservoir induced earthquake, which spread 31 countries on five continents, of which 22 cases are in China which is the largest country in the world with reservoir induced earthquake.

At present, although people have different views on formation mechanism of reservoir induced earthquake, there is a consensus that water plays an important role in inducing earthquake. There are three effects of storage water on the bottom rock mass (ZHANG Zhuo-yuan et al. 1994): The physical and chemical effects of water, the load effect of water and the mechanical effect of water.

The effect of interstitial hydraulic pressure is caused by water penetration and diffusion. As long as the rock permeable channels exist, such as fault zone, karst and so on, the reservoir water infiltration increases pore water pressure, which reduces the shear strength of structural plane, and weakens rock strength. With the increased accumulation of earthquake materials, more and more scholars have accepted the view of interstitial hydraulic pressure as a main factor inducing earthquake.

Tongjiezi reservoir on the Dadu River has two hydrogeological structures to conduct interstitial hydraulic pressure: (1) Consequent bedding confined water conduction structure showed no hysteresis energy conduction mode. Interstitial hydraulic pressure increment is synchronized with the reservoir water level, and the development process of interstitial hydraulic pressure coincides with the characteristics of induced earthquake in downstream (XU Mo et al. 2002); (2) the fault-type transmission structure, which is based on two-phase (solid and liquid) interstitial hydraulic pressure diffusion theory of porous media, is conducted relatively homogeneously, and the conduction process coincides with the development of frequent seismic events in southeast region.

3.5 Karst leakage of reservoir

Hydroelectric power projects benefit from
impounding water to generate power, irrigate, cultivate and improve shipping conditions. Its fundamental point is to effectively accumulate water in the dam within the reservoir. However, in some special geological conditions, the elevation of water level may drive water through the underground passage to adjacent regions or downstream leakage regions, thus giving full play to benefits.

The reservoir leakage must have corresponding geological and hydrogeological conditions, which are hydrodynamic condition and channel condition. In the practice of the leakage problem, the karst leakage problem is the most complicated and universal.

In 1845, the first dam was built in the karst area in France and now it is over 100 years. Yugoslavia, the United States, the former Soviet Union, Italy, Turkey and other countries in the karst area built more than 130 large-scale hydropower engineering projects. According to incomplete statistics, there are 18 dams that are higher than 100 m, and the highest is the Inguri arch dam of the former Soviet Union whose maximum dam height is 271.5 m; the maximum reservoir is Turkish Keban reservoir, with a total capacity of 340 million m$^3$. With the development of technology and impervious treatment experience, from 1950s to 1960s, Spain, Switzerland and other countries built 100-150 m high dams. Since 1970s, the former Soviet Union, Yugoslavia, Turkey, Mexico and other countries built 5 dams more than 200 m high.

Guanting reservoir built in 1954 and Yunnan Liulangdong hydropower station built in 1955 opened the prologue of building hydropower projects in karst area of China. At the end of 1950s, a large number of small and medium-sized projects were built. From 1960s to 1970s, the Maotiao River ladder rung hydropower stations and a number of medium-sized reservoirs above 50 m or the capacity is more than one billion cubic meters were built. This has accumulated rich experience of dam construction in karst area for China. At the beginning of 1980s, Wujiangdu power plant marked a new level. According to incomplete statistics, there are 20 dans above 70 m or the capacity is more than one billion cubic meters, and they are basically successful.

In the survey and design stage, due to complex karst problems, how to use the limited human resource, material and data for effective research and evaluation of the reservoir karst leakage problems is the key to the benefits of building reservoir.

4 Conclusions

Engineering-hydrogeology problems arise from interaction between rock mass and groundwater in human engineering activities and geological environment. In the hydropower projects, the function between the building and groundwater as well as rock-soil mass is different under different conditions and parts of project, and the combination of factors and the main control factors are also different.

During discussing hydro geological problems of hydropower project, reasonable working procedure is to identify the geological prototype, analyze the mechanism of pore water pressure effect, simulate the interaction of water-rock-engineering based on complex rock groundwater seepage problems, and forecast the development trend and the whole process of governance measures.

References


