Chapter 2
Planning and Design of Hydraulic Projects

2.1 Purposes of Hydraulic Projects

A hydraulic project may be small or large, simple or complex, and single or multiple purposed, and it should provide the functions to accomplish the optimum development of related water and hydropower resources.

In many cases, the project will be multi-purposed. For this reason, the investigations may comprise a large number of matters, and some or all of them will influence the selection of the project site and scale. Hence, the entire project must be investigated as a whole before the design requirements for each single structure, such as the dam, can be firmly established.

Main aspects of the river development using hydraulic projects, with particular emphasis upon the design requirements for dams and reservoirs, will be presented hereinafter.

2.1.1 Flood Control

Many river basins are frequently suffered from destructive floods and are, therefore, difficult to be used for farming and residence. A very effective way for flood defense is to build hydraulic projects with capacious reservoirs. Many projects (e.g., the Three Gorges Project) owe a good deal or majority of their social and economic benefits to flood control function. Sometimes, hydraulic projects are specially built to fight floods only.

In the design of flood control projects and structures, it should be taken into account that:

- The relation of the cost for flood control with the benefits to be derived through the reduction of cumulative damage should be favorable and in light of public interest, as compared to alternative means for obtaining similar benefits;

S.-H. Chen, *Hydraulic Structures*, DOI 10.1007/978-3-662-47331-3_2

- The temporary storage for design and check floods must be sufficient to cut the major peak inflows or to lower down the frequency of minor floods; and
- Flood control must be effective and reliable, and so far as it is predictable, the method of flood control should be automatic rather than manual.

2.1.2 Irrigation

Nowadays, about 230 million hectares of farmlands are irrigated all over the world—as much as 70 % of the water taken from rivers is used for irrigation, of which 75 % never returns back to the streams. In some regions, especially in the Middle East, the Central Asia and northern China, farming without irrigation would be unfeasible at all.

It is customary to distinguish between gravity irrigation and pumping irrigation. The former depends on the head created by dams over the elevation of the farmlands to which the water is delivered. The latter employs powered pumps, so the water can be lifted to any desired elevation, to be distributed later over the ramified system comprised of canals and conduits.

The desired amount of water is stored in reservoirs, and the power for pumps is furnished by hydropower plants that are generally components of multi-purposed hydraulic projects. Most modern China's irrigation systems are supported by multi-purposed hydraulic projects.

For successful irrigation, the supply of water must be adequate at an economically reasonable capital investment per unit of area and must be easy for operation and maintenance.

2.1.3 Power Generation

It is a sad fact that thermal power stations, especially those of coal-burned types, discharge a lot of ash and noxious gases into the atmosphere and foul up large territories. Of these, surplus dioxide is fraught with the gravest consequences. The thing is that it mixes well with water vapors and yields sulfuric acid, which, upon precipitation, poisons water bodies. In recent years, the toxic haze phenomenon frequently occurs in a wide territory across the northern and eastern China, which is mainly blamed for this coal-burned pollution, apart from another major pollution sources from steel and cement industries, city infrastructure construction, and vehicle exhaust.

Although they do not pollute the atmosphere, nuclear power plants present another danger since they produce radioactive wastes that are rather difficult to get rid of. The Fukushima Daiichi nuclear disaster caused by the Tohoku earthquake induced tsunami on March 11, 2011, gives a global warning for the potentiality due to uncontrolled consequences of nuclear power plant accident.

Hydropower stations are sufficiently "clean" enterprises that result in few soil, water, or air pollution. Therefore, they may considerably reduce the overall pollution compared to thermal or nuclear power stations. As far as the pollution problems are concerned, hydropower is extremely attractive.

On a global scale, the unlimited and uncontrolled development of power engineering (nuclear power plants being the most important cause for concern) may, in the long run, upset the thermal balance of the Earth—a fact its consequences to the mankind are very difficult to predict insofar. In this aspect, hydraulic power engineering, which ultimately depends on solar energy (in fact, it merely redistributes the energy released by the Sun) and therefore does not affect the thermal balance of the planet, appears to be an ideal choice.

Where the power generation is targeted in the development of a hydraulic project, the capacity of the power generating equipment and the load demand are closely related to the quantity of water available and the amount of storage provided, which in turn, dictate the height of the dam.

2.1.4 Navigation

River transportation plays an important role in water economy. As a rule, inland water transportation capacity will be raised considerably by building dams and barrages. The point is made that a chain of storage reservoirs improves navigation depths, straightens navigation channels, and ensures the pathway of large ships. Also, the regulated outflow from reservoirs improves navigation conditions in the downstream reaches. In China, most inland waterways depend on major hydraulic projects. Examples are the Yangtze River and the Yellow River waterways.

When a dam is constructed on a large river considering upstream and downstream navigation, it may be desirable to construct ship locks or lifts to provide pathway for vessels over the barrier. Depending upon topographic and geologic conditions, the locks may be the integral components of the dam or entirely separate structures. The functional design criteria are the dimensions of lock chamber or handling trough and the draft of vessels to be accommodated, and the estimated number of vessels passing upstream and downstream at peak periods without excessive delay.

2.1.5 Domestic and Municipal Purposes

Much water is consumed by metallurgical, chemical, wood pulp, and paper industries. Among major industry users are also thermal and nuclear power plants. In many industrially developed regions of China, the demand for water cannot be met by the local water resources solely. To deal with the problem, reservoirs are built to store the most of the local runoff, and large water developments are set up to divert water from other basins. Most of these water supply systems originate from the reservoirs of multi-purposed hydraulic projects.

Although it constitutes merely about one-tenth of the industrial water consumption, public water supply, which meets the immediate needs of the population, should be taken into account seriously. Consequently, it is hardly surprising that the primary function of quite a number of multi-purposed hydraulic projects is to supply water for domestic daily consumption.

Sometimes, there is a need for the hydraulic project in a region where stream flow either ceases entirely or is reduced to extremely low levels during seasons of the year, and where such natural stream flow is the principal source of water supply for one or more communities, water storage creation for stream flow regulation may be justified apparently.

The quality of the water must be such that it can be rendered portable and usable for domestic and most industrial purposes by economical treatment methods. It should meet state public health standards with regard to bacterial purity, taste, color, odor, and hardness. Control and protection of watershed areas are desirable for municipal water supply reservoirs.

2.1.6 Environment Protection

It might be a selfish but reasonable idea that the important environmental issues are those that the most direct concern to the livelihood and well-being of mankind, and the various other living things are of concern to human to whatever degree their existence is important to his living conditions, i.e., there is a close relation between the important environmental issues and the social needs of human beings.

Among the various beneficial environmental–social effects of hydraulic projects, they may be distinguished as farmland improvement by irrigation, higher standard in flood protection, enhanced water quality and supplying ability for domestic and municipal uses, clean power supply without consumption of fuel, and fishery and recreational development. These benefits, partially measurable in economic terms, are among the principal objectives of a hydraulic project. However, the negative impacts of the hydraulic project on the environment should be never overlooked in the design and construction.

2.1.7 Recreation and Other Purposes

A reservoir might significantly make an excellent site for various recreational facilities and health farms. Sometimes, small reservoirs are built specially for recreation purposes.

Occasionally, a hydraulic project is proposed to regulate the water level in shallow lakes and swamps other than those purposes heretofore enumerated. For example, the project for the detention or diversion of stream flow to conserve it by transforming surface water to groundwater through the process of infiltration could be planned and constructed. To justify the project economically, however, it must be determined that the soil characteristics will permit infiltration to occur in a desirable quantity.

2.2 Planning for Hydraulic Projects

2.2.1 Tasks and Requirements of Planning

Water resources planning is an important basis for their exploration, development, conservancy, and protection, which falls into river basin planning and regional planning. The former is further divided into river basin comprehensive planning and river basin specialized planning, while the latter is further divided into regional comprehensive planning and regional specialized planning (Jiao et al. 2004; Liu 2006).

Specialized planning means planning for the hydrographical test, flood control, hydropower development, logging control, irrigation, navigation, recreation and tourism, fishery, water and soil conservancy, water resources protection, environment protection, etc., of the river basin or region concerned.

Regional planning should be submitted to river basin planning, and specialized planning should be submitted to comprehensive planning. In China, the comprehensive planning of important rivers and lakes is accomplished by the related local governments under the leadership of the State Council. The approved planning must be executed to the letter; any revisions should be examined and approved by the State Council. Documents of the laws and regulations related to the water resources and hydropower planning in China are as follows: “Flood Control Law of the People’s Republic of China,” “Water Law of the People’s Republic of China,” “People’s Republic of China Land Law,” “Electricity Law of the People’s Republic of China,” “Environmental Protection Law of the People’s Republic of China,” “Law of the People’s Republic of China on Water and Soil Conservancy,” “Forestry Law of the People’s Republic of China,” “Environmental Impact Assessment Law of the People’s Republic of China,” “Regulations of Land Requisition Compensation and Resettlement of Large and Medium Hydropower Project Construction,” as well as the other administrative regulations.

Until 2010, there have been more than 70 years in the history of Chinese planning works for water resources and hydropower resources, and most of the basin comprehensive developments or main river cascade hydropower developments have been approved by the State Council and the related state ministries.

2.2.2 Principles of Planning

- Pay attention to the investigation of water resources and hydropower resources. The optimal development scheme should be completed after the comprehensive comparison resting on necessary topographic survey, hydrologic tests and analyses, geologic exploration and analyses, environmental impact evaluation, and engineering technology demonstration.
- Select mainstay projects of high regulation ability as leading reservoirs and to construct rational cascade development configuration. In this way, the head fall and water runoff may be fully exploited in both the short and long terms.
- Comprehensive utilization of water resources should be carried out in the whole planning process. On the one hand to aim main development purposes and on the other hand the comprehensive requirements such as electric power generation, flood control, sediment interception, navigation, irrigation, water supply, timber floating, fishery, and recreation are studied.
- Land acquisition and reservoir region immigration should be carefully handled and tackled. The comprehensive utilization of water resources should be restricted by the inundation loss, which is an important factor dominating the selection of the planning scheme.
- Care is taken over the protection and recovery of ecological environment system during the whole planning process. The water resources and hydropower development and ecological environment protection should be mutually promoted and coordinated.
- Market oriented in the water resources allocation should be persisted. The normal storage level and installed generator capacity are demonstrated and optimized with respect to the balance of exploitable and market demands, the relation of input and output, as well as the principle of maximum investment pay back.
- Engineering investment and benefits should be elucidated separately for multi-purposed water resources and hydropower projects. The feasibility and rationality of alternative schemes are to be studied. If there is no well-anticipated economic benefits in the near future, staged construction or obligate position for later construction should be considered.
- Very often, limited by the factors related to technology and finance status, basin water resources and hydropower planning cannot reach the goal in one step. As there are development in national economy and society and the progress in technology, the planning philosophy and method will be changed and innovated. Therefore, the approved planning scheme might be subject to revision and supplementation, if necessary.

2.2.3 State of the Art and Trends in the Planning

Exactly speaking, water resources and hydropower planning is related to three major systems including water resources system, energy system, and electric system. Each of them is large and complex with various influencing factors, featured as multi-purposes, multilayers, and indeterminate. Nowadays, the planning of water resources and hydropower development is directed to the techniques such as the multi-objective synthetic optimal selection criteria; solution of the distributed, multilayered, and multi-functioned system; group decision-making model based on process-oriented decision-making; and use of artificial intelligent system (e.g., artificial neural network) and expert system.

Today, hydropower development planning models are readily available in the form of tool kits whose various components are contributed by the scholars all over the world. At the end of the 1980s, by the application of the famous WASP-III (IAEA) (Hamilton and Bui 2001) and MARKAL (IEA) (Loulou et al. 2004; Seebregts et al. 2000) models, the Chinese planning model IRELP/I (Inter-Regional Electric Long-term Planning) was developed, which employed mixed-integer linear programming. With this model, the hydropower planning and the power source planning were for the first time combined in China. The SIRELP (Strengthened Inter-Regional Electric Long-term Planning) model is a strengthened version of the IRELP/I model, which uses several advanced optimization skills to overcome the shortcomings of its predecessor, for addressing hydropower projects with over-year regulation reservoir and huge calculation quantity. The above two models had been employed in the important domestic projects such as the Three Gorges. However, since the mixed-integer linear programming is not theoretically strict for solving nonlinear programming issues, and the dependent on 0–1 variables makes the calculation amount very huge, these models are not able to solve the planning problem for hydropower projects with over-year regulation reservoirs ideally.

To directly seek solutions for both the linear and nonlinear problems by successive approximation, the HELP (Hydropower and Electricity Long-term Planning) model (Dyner and Larsen 2001) developed on the basis of aforementioned predecessors in 1990s is now widely accepted in China due to its technique advantages such as the combination of dynamic programming and linear programming, the abandonment of integer variables, and the ability to make the investment decision and to handle discontinuous variable problems (e.g., numbers of generating units and transmission lines) as well as to optimize operation decisions (Yang and Pu 1993; Yu et al. 1994).

2.3 Ecology and Environment Protection

2.3.1 Ecological and Environmental Issues in Hydraulic Projects

The realization that human is an integral part of nature and that his interaction with the fragile ecological systems surrounding him is of paramount importance to his continued survival is prompting a re-evaluation of the functional relationships that exists between the environment, its ecology, and human (Dober 1969).

The needs to store water for use through the period of drought seasons, to supply industry and agriculture water for material goods and foodstuffs, to provide recreational water in ever-increasing amounts, and to meet the skyrocketing electric power demands, all require the construction of hydraulic projects. These projects help human beings, but meanwhile give rise to impacts on ecosystem and environment. Referring to the original environmental setting, hydraulic projects are a new component of the environment. Thus, care should be exercised to coordinate the old and new components of the environment, especially the new hydraulic projects constituting a new water resources system. An increasing concern is the effects of a hydraulic project integrated by several hydraulic structures upon the ecosystems, particularly on the fish, wildlife, and human inhabitants adjacent to the project (Brandon 1987; Golzé 1977; Graf 1999; ICOLD 1992; Oglesby et al. 1972; Thornton 1990; Wetzel 1990).

In the planning phase of any hydraulic projects, an environmental investigation must be implemented to evaluate environmental and ecological impacts of the hydraulic structures and to study proper countermeasures for avoiding or alleviating their adverse effects (United Nations 1990). In any events, the environmental impacts around the construction site areas are not to be overlooked in making a project plan. Philosophically, if well designed, a hydraulic project should reduce the natural hydrological disasters, utilize the water resources more effectively, and provide more harmonious circumstances for the survival and development of human beings and nature. However, it should be admitted that many of these are exceedingly complex and few answers concerning the total impacts of a hydraulic project on its environment are readily available.

1. Environmental benefits from hydraulic projects

(a) Reducing disaster and damage attributable to flood and drought control

A hydraulic project with dam may increase the resisting capability against natural disasters such as flood, water logging, drought, salinization, and alkalization, or reduce the frequency of their occurrences. As a result, it will provide more comfortable and stable circumstances for mankind.

(b) Providing hydropower as a clean energy

For a 2000 MW hydropower project built to replace the thermal power plant in the power system, 5 billion kg of raw coal may be saved annually. Furthermore, 44 million kg of emission of nitric oxides, 1.15 million kg of carbon monoxide, 24 billion kg of sulfur dioxide, and 1.4 billion kg of solid waste also will be cut each year. In addition, a large amount of water for cooling which is the pollution source of heat emission to local water body also will be eliminated.

(c) Improving inland transportation waterway

Water stream is a natural transportation route. Compared with land transportation, it has the advantages of low transportation cost, less or even no land occupation, less or no resettlement, low fuel consumption, less pollution, low noise, suitability for long distance transportation of heavy cargo, and enjoyable ship traveling for tourism.

(d) Protecting the ecological environment and bringing ecosystem in good circulation

The construction of a large reservoir, in general, would improve the local climate and make it turning to the beneficial direction. Through the regulation of water body, the annual average temperature and the extreme lowest temperature would be raised, while the extreme highest temperature would be lowered down. In addition, the relative humidity around the reservoir region and its surrounding areas would be enhanced, which is generally beneficial for crops.

The construction of a large reservoir may also prevent people from pests by controlling water level. As one of good examples, the Hongzehu Lake area in China was one of the historical bases of East Asia locusts. After the construction of the barrage located at the San He (River), 1.64 m of the mean water level of the Lake has been raised. Since 1960, the water level has been maintained at about 12.5 m, so that locusts living below 11.5 m were all submerged. As a result, the occurrence of plagues of locusts has been reduced. Another good example is the elimination of the schistosomiasis parasitized and reproduced through water snails. The situation in favor of the growth of water snails is that the region is submerged in summer and turned to dry land in winter. However, the fluctuation of the water level in the most reservoirs in China is in an opposite way: The reservoir water level in summer is always kept lower for storage of floods, while during winter, the level is commonly kept higher. It creates a situation unfavorable for the growth of water snails.

(e) Improving water quality and water supply capacity

Construction of hydraulic projects with reservoirs of regulating storage could enhance the dilution and self-purification capacities of water body, hence improve the water quality of river and reduce the possibility of saltwater intrusion in the estuary. In China, for example, the Fengman Project and Xin'anjiang Project have greatly improved the water quality of their riverside cities of Harbin and Hangzhou, respectively.

(f) Creating or improving recreational condition

All the large-scale hydraulic projects with reservoirs are able to be developed into recreation places, such as the Xin'anjiang Reservoir and the Three Gorges Reservoir.

Some reservoirs also may improve the downstream recreational sites through the augment of flow in dry season by their regulation. For instance, although the famous Lijiang River flows through the Guilin City lacks water in dry seasons, its recreational condition has been greatly improved by the upstream Qingshitan Project which supplies additional flow in the dry seasons for this beautiful river.

2. Adverse environmental effects caused by hydraulic projects

Human's understanding on the importance of environmental problems has been progressing from unconsciousness to overall concern since the 1970s. A hydraulic project may simultaneously have positive and negative effects on environment as any other kinds of man-made projects. The rational way out is that consideration should be given to all effects and efforts must be made to achieve the maximum positive effects and the minimum negative ones. If attention is called only at one effect either positive or negative, the overall potential benefits of the hydraulic project could not be fully exploited and sometime wrong decision might be made.

The pertinent aspects of the most concern with respect to adverse effects have been well recognized and summarized by scholars (Mattice 1991) such as:

- Over cultivation and reclamation, random deforestation, and other relevant environmental impacts caused by the improper arrangement of resettlement;
- Inundation or damage of historical and archeological sites, of forests and ecological environment for rare fauna or flora, as well as of mineral deposit;
- Loss of wildlife, fish, and aquatic habitats;
- Public health affected by waterborne diseases;
- Cold damage to irrigation and some migratory fish due to the released discharge through thermally stratified reservoirs; and
- Seismic activity, landslide, and other relevant environmental geology problems triggered or induced by reservoir impounding.

Nowadays, several heretofore enumerated detrimental effects may be either partially or nearly completely mitigated. However, it is noting worthy to indicate that the degree of importance of many these effects depends on the existing physical and environmental circumstances at the sites: Some may be so paramount as almost certainly to prohibit the use of the sites for reservoirs; at other sites, the effects may be quite minor and the amount of environmental loss may be easily acceptable, when the project needs are demonstrated.

3. Effects of environment on hydraulic projects

Environment also affects hydraulic projects in many aspects. Adverse effects include earthquake-induced dam failure and landslide, soil erosion in upper reaches bringing sedimentation into reservoir (Morris and Fan 1998), and scouring of riverbed. Therefore, before the construction of a hydraulic project, attention should be called at the study on the environmental settings around its up- and downstream areas as well as site area, which are considered as components of the system for planning and designing in order to ensure the long-term benefits of the project.

2.3.2 Environmental Protection Design for Hydraulic Projects

To improve environment is one of the main purposes of hydraulic projects. As for their adverse effects, if investigations have been done beforehand and the mitigation measures have been taken, generally they could be reduced to acceptable level (Pan et al. 2000a).

As a recently developed soft science, environmental hydroscience is the knowledge system in applying fundamental sciences for solving the environmental problems encountered in hydraulic engineering. It was introduced into China at the late 1970s (Dudgeon 1995; Zhong and Power 1996) and has been developing increasingly since then.

China has established a set of regulations and specifications for handling the environmental issues related to hydraulic engineering, covering respective phases of planning, feasibility study, project design, construction, operation, retrospective environmental assessment, monitoring network planning, and instrumentation.

1. Environmental impact alternatives

It is demanded to examine alternative dam and reservoir plans to take note of any possibilities for minimizing adverse environmental impacts while accomplishing the major project purposes. The eventual choice of a project plan is made in the consideration of relative accomplishments, expenditure, social effects, economic influences, and environmental impacts.

The following is the commonly employed methodology in China to select alternative plans having different amounts of environmental impacts, with each plan accomplishing the expected objectives.

The first step is to make an examination and inventory of the various important environmental qualities of the stream or stream system under consideration. Environmental factors might be ranked in sequence according to their importance. This inventory would be of the existing conditions, which may be natural conditions in some instances, but more likely may be conditions which have been influenced by human activities up to the present time.

In the second step, the future environmental condition without the project development is estimated: It may be the same as the existing one, or may be improved or degraded? The future environmental condition "without project," to the extent it can be foreseen, becomes the basis of the comparison of alternative project plans.

Next, an economically optimum project disregarding all environmental impacts except those that can be positively accepted is planned. The evaluation of this alternative plan will show the possibly maximum project accomplishments within the physical conditions and economic limitations. It might be designated as the "economically optimum planning alternative."

Another alternative plan would be devised wherein an attempt would be made to minimize all important adverse environmental impacts and still produce some portion of the intended project accomplishments. If this "environmentally optimum alternative" indicates greatly reduced accomplishments and/or much increased costs from the above "economically optimum planning alternative," it may be set aside in favor of a third alternative as described below.

A third alternative plan would be devised whereby a compromise would be made between the above two extreme alternatives, seeking to avoid or to minimize the most important adverse environmental impacts while achieving all or most of the potential project accomplishments of the economically optimum alternative. Since concessions must be made for environment, this plan will probably cost more per unit of accomplishment than the economically optimum plan.

The results of evaluation with respect to the alternative plans would be summarized to show relative amounts of environmental impacts, project accomplishments, expenditures, and the costs incurred. This summary will provide the basis for obtaining agreement and making decision on selecting a "better" plan.

2. Design targets

Design should be devoted to the accomplishment of the following goals:

- Keeping the natural beauty of the surrounding areas;
- Creating aesthetically satisfying structures and landscapes;
- Giving rise to minimum disturbance to the area ecology; and
- Preventing water from contaminants around the reservoir area.

Designer should try to accomplish these targets in the most economical way, through detailed structural considerations, landscape considerations, protective considerations, and construction considerations.

(a) Structural considerations

It goes without saying that the main purpose of any hydraulic structure is that it performs its function. Beyond this, thoughtful considerations should be given to blending the work with the environment and to provide pleasing surroundings. For example, if the work is an embankment dam, several actions can be taken which may prove beneficial to the project environment: A curved axis convex in the upstream direction could be used in lieu of a straight axis to make the reservoir more resemble to a natural lake; the downstream slope of the embankment could be covered with topsoil and seeded to present natural appearance; if it is not possible to reseed the downstream slope of the dam, cobbles and boulders which are indigenous to the area can provide a pleasing protective covering; the materials found in the reservoir area and from adjacent structure excavations are utilized to the maximum extent practically; and borrow areas located above the reservoir level should have their final slopes flattened to conform with the surrounding area and for easy reseeding.

If it is necessary to excavate rock abutments above the dam crest level, consideration should be given to the use of pre-splitting blast techniques since they leave clean, straight, and aesthetic surfaces.

The diversion schemes should be such that excessive siltation created during construction will not be released into downstream water body. Materials from excavations which are not used in the embankment compaction should be placed in the reservoir area and preferably along the upstream toe of the dam, which may provide additional stabilization of the upstream dam slope.

Buildings used at the work site should blend with their surroundings. Pipelines, power lines, and electrical apparatus would be better to be buried. Where this is not possible, they should be painted to blend with their background.

(b) Landscape considerations

As much as possible of natural vegetation should be left in place. If there exists significant areas of natural beauty near the project, every effort should be made to preserve them. Borrow areas and cut slopes near and above the reservoir area should be revegetated soon after the mission is completed; the topsoil removed from the slopes should always be stockpiled for reuse.

Access roads to the work site during construction should be kept to a rationally minimum, and those who not planned for permanent use after the completion of the work should be obliterated and reseeded. Road relocation near the work site provides an opportunity to eliminate deep cuts in hillsides, use scenic alignments, and provide reservoir viewing locations. Adequate road drainage should be installed and slopes should be so cut that reseeding operations will be convenient (Gray and Leiser 1982).

Erosion control should be started at the beginning of the construction. Roads, cut slopes, and borrow areas should be provided with terraces, berms, or other check structures if excessive erosion is anticipated likely. Exploratory trenches in borrow areas which are not used or are adjacent to the work site should be refilled and reseeded.

Quarry operations and rock excavations should be so performed that the minimum amount of material is removed, and final rock slopes for the completed excavation are shaped to be nice looking.

For projects where power transmission lines will be installed, suggestions from experts and institutions should be taken to alleviate their environmental impacts.

(c) Protective considerations

At locations where accidents or incidents can occur, protective devices and warning systems should be installed. The most dangerous locations at a dam site are near the spillway (especially if it is chute-type), the outlet works, intake tower, and the stilling basins. Siphons are extremely dangerous. In addition, canals often have steep side slopes which prevent climbing out. They should be all fenced off and marked by warning signs.

When the project encompasses the generation of electricity, the problems of providing adequate safety precautions are considerably important and the advice of corresponding experts should be sought.

(d) Construction considerations

The environmental and ecological design requirements provided in the specifications are converted from an document by the designer into a reality by the contractor. The owner should ensure compliance by having competent inspectors and specifications which clearly spell out the construction regulations. Excessive air, water, and dust pollution during construction should be prevented; specifications covering these items should provide a framework for the inclusion of other important environmental provisions. The contractor and his staff should be well informed that this is an important step in the planning, design and construction sequence. The contractor should also institute safety precautions during construction and be encouraged to bring forward any obvious defects in the environmental considerations encountered (Shields and Sanders 1986).

If not intended for permanent use, construction camp site would be better to be placed within the reservoir area below normal water level. All trees, shrubs, and grass land areas which are to be protected should be staked or roped off. Any operations which will affect a large wildlife population should be performed in periods of low wildlife occurrence. The used water going downstream should be muddied as little as possible and be pollution free. Siltation ponds may be needed in extreme cases.

A temporary viewing site showing the completed project and explaining its purposes is helpful in promoting good community relations, which may also be used for the tourism purpose after the completion of the project.

(e) Provisions of water contaminant around the reservoir area

A part of the water used for irrigation and almost all of the water used for industrial and public purposes goes back to rivers. Naturally, this water contains a vast amount of mineral, organic, chemical, and bacterial contaminants which may, unless appropriate measures are taken, kill the fish and waterfowls (Hocutt et al. 1980) and make the water unfit for drinking, recreation, or even for use in various industrial process (Serhal et al. 2009). Apart from contaminated sewage water, a great deal of pollution is caused by petroleum products getting into water from passing vessels and by the leachate of rotting sunken timber.

Nature has endowed the water body in rivers, lakes, and seas with an amazing ability to purify itself by the actions of oxygen, water plants, microorganisms, and solar radiation. In fact, not long ago when pollution was not as serious as it is nowadays, water body could manage its health successfully. Unfortunately, this self-purifying capacity is far from being limitless. To make the situation even worse, the natural purifying capacity may be further weakened due to the slow down of the water flow in reservoirs created by dams. Therefore, much should be done to fight the environmental pollution around the reservoir areas. For instance, the releasing of non-purified wastewater into reservoirs should be totally banned, and plants and factories are encouraged to adopt closed-cycle operation where the water would be reused after purification, and the hydraulic project should not be promoted without the advice of biologists.

2.3.3 Environmental Impact Monitoring and Reviewing for Hydraulic Projects

In order to build a function of environmental monitoring system, the issues need to be addressed are institutional arrangements within which such a system can be properly established; an effective network within which the components and parameters need to be monitored at different locations; position and frequency of monitoring for different elements in each location; indigenous expertise to carry out the necessary analysis; dissemination of information to potential users; and regular presentation of appropriate information to decision makers in time.

The role of the retrospective environmental impact assessment (EIA) for hydraulic projects is to justify the prediction of the change in the main environmental parameters and the effectiveness of the mitigation measures adopted. Moreover, the new mitigation measures and monitoring process to be adopted in the operation period are proposed. The EIA is accomplished by the identification, predication, and evaluation of the environmental impacts of the project on both the nature and society, and through the comprehensive assessment of the whole project. The public health issue in EIA becomes special concern recently. It is meant to assess the impacts on physical, biologic, and social sub-systems and their interaction with the project. The temporal scope of EIA covers construction stage and operation stage, whereas the spatial scope of EIA cover the project site and the surrounding areas.

Generally, the retrospective EIA of hydraulic projects consists in following aspects:

- To select the levels for assessment. Usually three levels are used, i.e., before construction, impounding stage, and operation stage.
- To determine the main environmental parameters to be investigated.
- Monitoring design and instrumentation.
- Statistics and analysis of data.
- Recommendation of the occurrence and development process as well as the mode of the main impacts on the important parameters.
- Feedback to the original EIA concerning the methods and conclusions.
- Put forward further mitigation measures, monitoring, and management methods.

For some important environmental parameters, the risk analysis and risk management should be carried out.

2.4 Engineering Hydrology

2.4.1 Engineering Hydrologic Issues in Hydraulic Projects

Engineering hydrology is an applied earth science which studies the movement, distribution, and quality of water on the earth, including the hydrologic cycle, its process, water balance, precipitation type, and estimation of precipitation.

Engineering hydrology uses hydrologic principles in the solution of engineering problems arising from human exploitation of the water resources. In its broadest sense, engineering hydrology seeks to establish relations defining the spatial (regional, geographic) and the temporal (seasonal, annual) variability of water, with the aim of ascertaining society risks involved in sizing hydraulic structures and projects (Golzé 1977; Pan et al. 2000b; Ponce 1989; Warren and Lewis 2003; Linsley et al. 1949; Zuo et al. 1984). Methods of stream flow measurement, stage discharge relation, unit hydrograph theory, transposition of hydrograph, synthesis of hydrograph from basin characteristics, stream flow routing, flood frequency analysis and attenuation of flood flows, sedimentation, etc., are the most important specified fields in the engineering hydrology.

Engineering hydrology finds one of its greatest applications in the design and operation of hydraulic projects. In the phase of river basin planning, the runoff and flood series of the main stream and tributaries are the basic data for the selection of the layout, the purposes and tasks, the scales and relationships, of the hydraulic projects. In the phase of feasibility study, to specify design parameters of a project, the magnitude of flood flow for safe disposal of excess flow, the minimum flow and quantity of flow available at various seasons, the capacity of reservoir storage, the interaction of the flood and hydraulic structures (e.g., levee, reservoir, barrage, and bridge) are studied based on the corresponding engineering hydrologic data. In the phase of construction, the design flood during the construction period, rating curve at the dam site and power plant site, etc., are necessary for the design of temporary diversion structures and for the arrangement of rational construction schedule, as well as for the rescue and emergency repair during flood seasons. In the phase of service life, the optimal safety operation of the project is also based on the high-quality hydrologic forecasting with regard to the runoff, flood, sediment, and ice conditions (Vide Chap. 18).

2.4.2 Collection of Hydrologic Messages and Data

Correct and reliable hydrologic messages and data establish solid base for engineering hydrologic computation and analysis. The main channels for obtaining the hydrologic messages and data are as follows:

- From the hydrology terminal, the distribution of hydrometric stations, gauging stations, and precipitation stations, which have long-term observation data concerning water level, flow discharge, flow rate, silt, precipitation, evaporation, may be found out.

- Short-term hydraulic survey may be carried out in several important river sections, for the collection of data concerning water level, flow discharge, and silt.
- During the phases of planning, designing, and construction, temporary water gauges are installed at the river sections near the dam site and power plant site, for the observation of water level, flow discharge, and sediment.
- Precipitation data are needed to evaluate factors for use in computing the probable maximum flood (PMF). The major storm over a project basin and its surrounding areas are analyzed with respect to orientation, isohyetal pattern, aerial coverage, total depth, duration, and short-term intensity.
- Through the verification of historical documents and inscriptions on tablets, the hydrologic messages such as historical flood or minimum water level in dry seasons may be obtained.
- By means of archeology, the messages of ancient flood may be collected.
- By means of aerial photographs and satellite remote sense, the messages and data concerning hydrology may be supplemented.

2.4.3 Hydrologic Computation

1. Computation of design runoff

The chronological record of flow is defined as the hydrograph, which is the base for all statistics analysis of the runoff for a river basin. It reveals many characteristics of the runoff of the basin, such as the seasonal distribution of high and low flows, the contribution of groundwater flow, etc. The time unit used in hydrograph is varied with different purposes: Annual discharge is usually used in comparing sequences of high and low years only; monthly flows are the most useful in the reservoir design of multi-purposes.

Arranging the flows for any unit of time in the descending order of magnitude, the percentage of time for which any magnitude is equaled or exceeded may be computed. The resulting array is called a flow-duration curve or cumulative frequency curve. Such curves are useful in determining the relative variability of flow between two points in or not in one basin, approximating the amount of storage, etc.

A mass curve is a plot of the cumulative of the runoff from the hydrograph against time. It is a useful device in the analysis of runoff records.

A storage-draft curve gives the specific storage needed to sustain various draft rates of regulated flow. If storage is unlimited, the curve will approach the available mean flow as an asymptote.

The frequency of occurrence of hydrologic events is a necessary part of the hydrologic studies for hydraulic project design, which may be expressed in either of the following two ways:

- Recurrence interval. It is an average interval expressed in years and does imply that events will be equally spaced in time;
- Probability or percent chance of occurrence in any year. It is computed as the reciprocal of the recurrence interval.

The key data to be analyzed are the annual maxims, or one flood peak event per year. The independent annual flood maxims should be first tabulated in chronological order and improved that each year is represented. Then, the relative magnitudes should be assigned an sequent number.

2. Computation of design flood

Flow is one of major environment conditions entail hydraulic projects—one of the dominant dam safety indices is the magnitude of flood that the dam can withstand. The flood peak, flood volume, and flood hydrograph corresponding to the design criteria for flood control are called the design flood. Determining design flood for a hydraulic project is to predict the flood that may occur during operating period in the future. However, since the flood in the future cannot be forecasted exactly due to the uncertainty of long-term changes in flood, the design flood often has to be determined by using frequency estimation, stochastic simulation, or probable maximum precipitation/flood (PMP/PMF), etc. (Davis 1952; ICOLD 2003; Morri and Wiggert 1972; Sokolov et al. 1976).

If the records of runoff are short and experience with known floods is limited, a design flood should be developed from storm record. As early as in the 1940s, the study on the PMP and PMF were initiated by American engineers (Hershfield 1961; US Weather Bureau 1947). The PMF may be obtained by the PMP via water yield and flow concentration computation. Later, the PMP and PMF are increasingly prevalent in the design of important hydraulic projects. The concepts of PMP and PMF were introduced to China in 1958, and the latter were employed to study the design flood for the Three Gorges Project. The study on the PMP and PMF was emphasized after a rare storm at the upper reaches of the Huaihe River in August, 1975, which resulted in huge losses of life and property. Nowadays, it is widely recognized that the PMP and PMF should be exercised for rechecking important hydraulic projects in the country.

The hydrologic analysis, economic analysis of cost, and benefit analysis, for different dam heights and reservoir capacities, will guide to the choice of the reservoir capacity and the corresponding dependable flow that can be justified. The selected design flow allows some degree of failure, and some deficiencies of water are also permitted.

In USA, the design flood may be selectively used as follows:

- The PMF is applied for extreme important projects, its failure should be absolutely prevented;
- The standard design flood is applied for important projects, huge losses could be resulted in, if failed;
- The flood by recurrence analysis is only used for the projects of minor disaster consequences after failure.

In China, depending on the magnitude of the project and the economic losses caused by overtopping of the dam and the damages to the permanent structures, the flood may have a wide range of recurrence intervals, varying between 10 and 10,000 years. The DL5180-2003 "Classification & design safety standard of hydropower projects" stipulates that, if the failure might result in extreme downstream disaster, grade 1 water retaining structures and spillway structures should use PMF, or recurrence intervals of 10,000 years, as check flood standard.

(a) Reservoir design flood

The volume of flood control storage should be sufficient to impound total or partial runoff from the greatest known flood that has occurred from the controlled area. Storage for flood control may be provided in a single purpose project in which all the capacity, except that for a small pool, is allocated to this purpose. Storage for flood control in a multi-purposed project may be allocated specifically, too, and this flood control storage is usually the top increment in the reservoir and is released as soon as practicably possible after the passing of a flood. Where there is a definite flood season, use of all or part of the flood control storage may be permitted in the dry seasons.

If the reservoir is one member of a reservoir series, it is needed to study the complete operation procedure and economics in selecting the capacity of the reservoir. Flood detention and releasing involve a change in timing of the natural flood hydrograph. With a system of reservoirs, the changes in timing may not necessarily benefit all downstream reaches with equal effectiveness. This is especially true if several floods occur in succession, and before the flood storage can be discharged without causing damage. Detailed operation studies are required to draw the "rule curves" for system coordination and the operation of gates for individual dam.

(b) Spillway design flood

The spillway for a dam project is intended to provide regulating outlet for flood control operation when reservoir levels are above the spillway crest, by which to prevent the dam from overtopping induced damages or failure.

The spillway design flood is the most important flood to be provided for in the design of a hydraulic project. The magnitude and probable recurrence interval of the flood is retailed to the importance of the project, its functional use, the economic value of the investment, and the potential losses to property and life that would result from total or partial failure of the project.

It does not exist a fixed criterion to establish the relation between the height of dam, the volume of storage, and the factor of safety, to be adopted in the spillway design flood. However, some general standards for the hydrologic design of spillways can be summarized as follows:

- Design the dam and spillway large enough to assure sufficient dam safe unless the coming flood is larger than the PMF.
- Design the dam and appurtenances in such a manner that the structure can be overtopped without failure and without suffering serious damages, if possible.

- Design the dam and appurtenances in such a manner that breaching of the structure from overtopping would only occur at a relative gradual rate, and in this way, the rate and magnitude of downstream flood would be within acceptable limits.
- Drawdown the reservoir level low enough and storage impoundment small enough in time, so that no serious flood hazard would occur to the downstream in the event of breaching.

3. Rate curve at dam site and power plant site

Rate curve at dam site and power plant site of several river sections is required for the project planning, design, construction, and operation. The rate curve before and after the construction is usually not the same; therefore, they should be studied for different cases, respectively. The rate curve also may be influenced by the construction slag deposit and the structural features and become very complicated, which should be studied specially.

4. Water balance computation of reservoir

It comprises the analysis of the inflow, outflow, and losses, which may be important for large- to medium-scale hydraulic projects. The losses including evaporation, leakage, and frozen and their estimation ordinarily make use of indirect methods based on different postulations due to the lack of observation data.

5. Hydrologic forecast

The technique of analysis and estimation, which can determine the hydrologic status in the future via the hydrologic status at earlier and present stages, is named as hydrologic forecast. The hydrologic forecast plays an important role in the safe construction and operation of dams and spillways, and electric power generation (Vide Chap. 18). Hydrologic forecast must have the predicted value and period with satisfied accuracy. The hydrologic forecast generally falls into short-term flood forecast and mid- and long-term hydrologic forecast, according to the forecast period. The theoretical base of short-term flood forecast is the theory of runoff yield and flow concentration. The mid- and long-term hydrologic forecast is generally developed by means of meteorology or statistics.

6. Sedimentation analysis

Rainfall and surface runoff are responsible for the detachment and movement of soil particles on the land surface. These soil particles are referred to as sediments. The study of sediment detachment and movement is an important subject in the engineering hydrology. The subject of sediment movement transcends engineering hydrology to encompass the related field of fluvial geomorphology, sediment transport and deposit, as well as river morphology (Garcia 2008).

Sedimentation is a key issue dominating the service life of reservoir and the benefits of hydropower projects. Sedimentation study comprises the estimation of sediment runoff, sediment particle gradation, position, shape, and speed of reservoir sedimentation, years of erosion and deposition of reservoir balance, and preventive countermeasures (Brandt 2000). The calculation of reservoir backwater is also an important task in the sedimentation study, which should be taken into account in the evaluation of the reservoir tail rise and its influencing on the reservoir inundation.

2.5 Engineering Geology

2.5.1 Engineering Geologic Issues in Hydraulic Projects

Investigations relating to geology and foundation conditions are essential for the design of hydraulic structures such as dams, spillways, and tunnels (Chen et al. 2000; Golzé 1977; ICOLD 2005; Price 2009; Zuo et al. 1984). Furthermore, various past events have emphasized the necessity for extending investigations to cover the reservoirs and even the areas beyond. In 1963, a landslide occurred at the Vajont Project, Italy, generated an immense surge wave overtopping the world's highest concrete arch dam of the day. This wave left its marks 238 m above the reservoir level and continued downstream into the town of Longarrone, resulting in an approximate 2500 fatalities. Within 60s, the Vajont Reservoir was choked with more than 239 million m^3 of earth and rock extending from the dam toe toward the reservoir tail for a distance of about 1.61 km. Remarkably, the dam withstood the overpressures to which it was subjected. In the same year, the failure of Baldwin Hills Project located in Los Angeles County, California, USA, provided a lesson of how the combined geologic factors and human activities outside the reservoir area might destroy a conservatively designed homogeneous earthfill dam of 47.2 m high (Scott 1987). The Baldwin Hills Dam is located in a seismically active and unstable region where the Inglewood fault lays 152 m to the west whose branches pass through the reservoir floor and dam abutment. The entire project is situated at the edge of Inglewood Oil Field, its extractions of oil, and gas from deep-seated formations had created a bowl of subsidence, the rim of which enclosed the project. Contemporaneously localized areas within this bowl were experiencing uplift as a result of secondary oil recovery operations which entailed high-pressure re-injection of water into the oil-bearing formations. The long-term effect of these conditions was to depress, tilt, and stretch the reservoir, which created offset and separation along one of the fault branches passing through the reservoir. As a result, a leakage pathway beneath the dam was developed and rapidly enlarged, leading to the complete failure of the dam, which in turn resulted in 5 fatalities and approximately $15 million of downstream property loss.

Every hydraulic project requires geologic investigation to detect and to evaluate conditions that will affect its design, construction, and operations. It is the responsibility of the engineering geologist to identify geologic conditions which could endanger the hydraulic structures due to significant geologic hazards including landslides, earthquakes, land subsidence, leakage, and the presence in critical locations of liquefiable strata.

Taken in sequence, the geologic investigation is generally accomplished by the following works (Acker 1974; Clayton et al. 1982; Lowe and Zaccheo 1975; Look 2007; Mathewson 1981):

- Canvass of the literatures of reports, maps, and photographs;
- Reconnaissance of the project area to detect geologic conditions which could affect project feasibility;
- Geologic mapping of the dam site, the reservoir site, and the location of the sources of construction materials;
- Subsurface exploration by means of geophysical surveys, drilling, exploratory pits, and/or trenches and/or adits; and
- Foundation evaluation entailing soil and/or rock mechanics studies.

2.5.2 Geologic Mapping

Geologic map for hydraulic projects is frequently the only "as built" drawing of the foundation conditions requiring detailed investigations and is useful in evaluating any stability, settlement, or seepage problems (Casagrande 1961). The map should convey as much information as possible to the designer and researcher so that they will be well informed of the site geology and utilize this knowledge in selecting the location and in the design.

Observation, interpretation, and recordation are the three elements of the geologic mapping. It should be performed under the close supervision of an experienced engineering geologist who is skillful in recognizing and interpreting those geologic features that are important with respect to project safety. The collection, study, and evaluation of foundation data form a continuing program from the time of the preliminary investigation to the design until the completion of the project. In a preliminary geologic mapping, assignment is targeted to provide data necessitated for the selection of the site and the type of dam. However, very often, the type of dam has not been determined in this phase; therefore, the geologic mapping should include information on availability and haul distances for construction materials for various types of dams. In the design stage, geologic mapping is supplemented by subsurface exploration and is, therefore, more accurate and detailed than that performed for the preliminary stage. Geologic features uncovered during construction period should be mapped as soon as possible since they will have an influence on any feedback analysis and redesign (e.g., resloping an excavation, and strengthening a reinforcement) that become necessary due to varied foundation conditions off anticipated. The final geologic maps may also be valuable in settling future claims and may prove to be important documents for the safety inspection and review, as well as for consulting boards of inquiry in the event of a future serious structural accident.

The quality of geologic maps largely depends upon the acuteness of the field observations. The geologist should examine as many outcrops and structural features as he can, which comprises identifying the rock type, determining discontinuity strike and dip, and structural trends as well as the other significant geologic features.

Gullies, canyons, and streambeds are the natural windows to the subsurface and should be "walked out" and examined. Man-made excavations or openings, such as mine shafts and connecting tunnels, should be observed since they provide important subsurface knowledge. Springs and wells within the reservoir area or in the areas affected by the reservoir should be investigated and pertinent information recorded, since they may contain useful clues concerning the thickness and characteristics of formations, and may also provide an opportunity to obtain hydrologic information such as groundwater level, rock formation permeability, and water samples for chemical analysis. Very often, faults perform as ground water barriers and cause a high phreatic zone along their trend. This wet area can be recognized by springs or strange vegetation.

For hydraulic projects, maps of greater than 1:5000 may be considered to be small scale which could be applied to the problems of general planning such as road and tunnel locations, locations of construction materials, and the description of geological conditions in a reservoir area; large-scale maps are those devoted to the depiction of relatively small surface in great detail and range from about 1:1000 (for a dam site) to about 1:50 (for a rock slope or tunnel). The following list presents the basic geologic documents provided by the geologist in charge of geological surveys: geology investigation reports, physical and mechanical testing reports, geophysical prospecting reports, topographic map (1:200–1:1000), engineering geologic plan (1:200–1:1000), longitudinal and cross sections (1:200–1:1000), adit geologic drawing (1:50–1:100), shaft geologic drawing (1:50–1:100), bare log (drill hole columnar section), stratigraphic column, hydrogeology experimental results and documents, long-term observations of groundwater level, ground water contour, and contour line map of rock roof (potential slip surface).

A new development in the production of engineering geologic documents is the use of computer-aided design/computer-aided manufacturing (CAD/CAM) systems and the geographic information system (GIS). CAD/CAM systems are mostly orientated toward handling vector type of data, whereas GIS systems can handle both the raster data and vector data. Vector data are those that may be described as points, lines, surfaces, and volumes that define an entity object in the CAD/CAM or GIS systems. Raster data have the form of a regular grid or cell structures that jointly define the object, but each cell is a separate entity in the systems. GIS systems normally combine or contain a (limited) CAD/CAM system, a database for the objects and entities with property values, a visualization unit, and a calculation unit able to manipulate the coordinates and properties and statistic routines. The combination of database and visualization makes a GIS system particular handy for engineering geology. For example, it should be possible, if the separate items of data necessary for rock mass classification exist, to ask the GIS system to produce a particular form of rock mass classification for a specified lithology within a given area.

2.5.3 Geologic Exploration and Investigation

Geologic exploration can be broadly distinguished as indirect or direct. The indirect method involves aerial photographic interpretation, geologic reconnaissance, seismic, and geophysical techniques including many electronic "down-the-hole" devices used to correlate physical drill-hole data. The direct method involves drilling holes into the ground and extracting samples for visual identification or laboratory analysis. Although there are many approaches to the problems of identifying soil and rock types and structural features, there is no singular method providing all of the information required for all of the soil and rock types associated with any particular project site. Depending upon the scale of a particular project, a combination of disciplines involving indirect methods in the preliminary phase followed by direct methods for correlation is generally utilized. The direct methods of exploration will be mainly discussed in further detail thereafter in this Chapter, while several typical indirect methods (e.g., non-destructive tests) will be presented in Chap. 18 of this book.

1. Exploration and investigation methods
(a) Boring

A boring is defined as a cylindrical hole drilled into the ground. The primary objective for a properly drilling exploratory program is to obtain information by sample extraction to determine the distribution, types, and properties of the subsurface soils and rock formations at the site. Borings can be excavated by hand (e.g., hand auger), although the usual procedure is to use mechanical equipments.

The required number and spacing of borings for a particular project must be based on judgment and experience. For rock slope engineering, three to five borings on a longitudinal section in the critical direction should be made to obtain main geological section for analysis. Number of other longitudinal geologic sections depends on the extent of stability problem, whose spacing is generally less than 30 m. For complex slopes, apart from longitudinal sections, at least two transverse sections perpendicular to the critical direction should be investigated. For the purpose of stabilization design, the borings should be layout in the area where reinforcement structures may be located.

The additional drill holes are incorporated into a drilling program which takes advantage of knowledge of special conditions revealed during the preliminary investigations. These drill holes become more specifically oriented and increased in number to better define the foundation conditions and determine the foundation treatment scheme.

(b) Geological excavation

In addition to borings, other methods for performing subsurface exploration are test shafts, tunnels (adits), pits, and trenches. Exploratory openings are usually oriented to cross particular geologic features or discontinuities. The number and depth of the openings depend on the soil and/or rock types and the trends of geologic discontinuities such as faults, shears, and prominent joint sets.

Geological excavation provides the best manner for examining the foundation by visual observation of subsurface conditions. They can also be used to obtain undisturbed samples of soil or rock. Backhoe pits and trenches are an economical means of performing subsurface exploration, while shafts and tunnels are more expensive. In many subsurface explorations, backhoe trenches are used to evaluate near surface geologic conditions, whereas shafts and tunnels are employed to investigate deeper subsurface geologic conditions. Geological excavations are also especially useful when performing fault studies, by which the width and elements of attitude (dip, strike, elevation) of the shear zone can be well determined. If there is uncertainty as to whether or not a fault is active, then dateable material must be present in the excavation in order to determine the date of the most recent fault movement. The excavation may also provide space for in situ tests.

(c) Geophysical detect

Geophysical detects are often exercised in the reconnaissance or preliminary phases of a site investigation program to provide information such as the depth of weathering, the bedrock profile, the location of major faults, the groundwater table, and the degree of rock fracturing. The results obtained from geophysical detects are usually not sufficiently accurate to be used in the final design and should preferably be calibrated by putting down a number of boring tests or excavation tests for spot-checking. Use of geophysical techniques involves considerable experience and judgment in the interpretation of results. Common types of geophysical techniques are the electrical methods, seismic methods, electromagnetic methods (geological radar), acoustic methods, gravity methods, borehole TV logger, etc., which will be presented in details in Chap. 18 of this book.

(d) Hydrogeological test

The investigation of groundwater plays an important role in geologic exploration. Hydrogeological tests (e.g., laboratory permeability tests and pumping or packer tests) and borehole hydrogeological observations (e.g., water table in borehole) are conducted to measure the permeability coefficients, groundwater table, flow direction and velocity, as well as the hydraulic relation of different strata, which provide the fundamental information on the site conditions needed for structural stability analysis and drainage design.

2. Reservoir investigation

Study on reservoir geology and environmental geology is attached relatively high importance in countries such as China due to the concentrated population and residences around reservoir areas and the relatively scarce farmland resources in the country. The contents of investigation are varied, depending on the natural and social conditions. The slope stability study on reservoir bank is focused on the large rockfalls, landslides, and unstable rock masses that are located near the proposed project site and may potentially endanger its safety, and on those large landslides that are located although far from the project site yet will potentially affect the local residence and navigation (ICOLD 2002). In the China's central to western mountainous areas, mudflow is a common natural disaster that will influence the reservoir's environment and needs to be carefully addressed. In some regions, mostly in northern China, bank caving and immersing resulted from reservoir impoundment also need to be controlled. The impact on mineral resources by direct reservoir inundation or by rising of groundwater table must be studied before the decision making. In limestone area, a clear conclusion must be reached before the dam construction on the possibility and amount, if any, of Karst seepage to adjacent valleys or downstream reaches. In some areas, assessment should be made on the variation of groundwater (water table, temperature, and quality) resulted from reservoir impoundment and its impacts (both positive and negative) on the local industrial and agricultural activities as well as people's life. Take the Three Gorges Project as an example. The number of resettled people from its reservoir area is tremendous. As a result, the secondary hazards induced by intensified human activities attributable to the resettlement of millions of people will be one of the most prominent environmental and geological issues for this project. So far, comprehensive and in-depth studies have been carried out covering the topics of reservoir bank stability, induced scouring by clear discharged flow to the downstream riverbed, the impact of intensified bank caving on the levee safety, the impact of water level variation on soil gleization in the Jianghan alluvial plain, the relationship between the Yangtzi River and the large lakes such as the Dongting Lake and Poyang Lake.

3. Dam foundation investigation

Generally speaking, the objective of engineering geological investigation for dam foundation comprises (ICOLD 1993):

- Define unstable rock masses and the limits for dam foundation.
- Identify various geological defects in terms of their locations, properties, and trends.
- Determine various boundaries for computation.
- Provide geotechnical parameters for competent numerical analyses, and propose principles and methods for the treatment of geological defects.

In the early days, the excavation depth for dam foundation was solely determined through the assessment of foundation rock mass quality based on geologists' experience. Along with the advancement of computational geomechanics (Chen 2006), as well as the testing and measuring techniques in the recent years, a quantitative classification methodology for foundation rock mass has been gradually replacing the traditional qualitative method of rock mass quality assessment systems: The location and top surface of available bedrock are determined with the consideration of the working conditions of hydraulic structures concerned.

(a) Cut slope

Study on the stability of deep cut slopes and on the respective supporting is one of the most arduous jobs in the engineering geological investigation for a work site (Hoek and Bray 1981), since statistics indicates that issues resulted from deep cut slopes are much more problematic than those caused by other hydraulic structures. The cut slopes may be the dam abutment slopes, the powerhouse slopes, the entrance and outlet slopes of underground caverns (tunnels), the slopes on both sides of stilling basin, the slopes on both sides of spillway, and the ship lock slopes.

The stability of deep cut slopes has attracted increasing attentions in China since the 1980s, and many engineering geology and geomechanical problems concerning cut slope engineering have been successfully solved in the construction of hydraulic projects. The Geheyan Project, for example, has a 110-m-high cut slope at the outlets of power tunnels, and the lower portion of the slope consists of soft shale containing numerous sheared zones, while the upper portion consists of massive and hard limestone. The Tianshengqiao II Project has a cut slope of 370 m high just behind the powerhouse, consisting of alternative layers of sandstone and shale with very complex tectonic structures. Rock mass slip occurred from time to time during the construction. Based on the geological conditions of the slope, comprehensive engineering countermeasures were adopted to stabilize the slope, including anti-slide piles, pre-stressed anchor cables, and unloading. The Three Gorges Project's navigation work comprises of double-lane and five-stage flight ship locks of 1607 m in length. It was totally excavated in a granite mountain with a maximum cut depth of 170 m. In order to guarantee the normal operation of the ship lock gates, it is demanded that the accumulated time-dependent deformation should not exceed 5 mm after the installation of the miter gates. Therefore, assessment of the slope stability and the long-term time-dependent deformation is a crucial technology challenge. Guided by the experts of various fields through extensive and in-depth study, this structure was completed and put into operation successfully in 2003.

(b) Embankment dam foundation

The foundation will limit the choice of embankment type to a certain extend, although such limitations will frequently be modified, considering the height of the proposed dam. The different foundations commonly encountered are as follows:

- Rock foundation. Attributable to relatively high bearing capacity and resistance to erosion and percolation, it offers few restrictions as to the type of embankment that can be built upon it. Economy of materials or overall cost will be the ruling factor. The removal of disintegrated rock together with the sealing of seams and fractures by grouting will frequently be undertaken.
- Gravel foundation. If well compacted, it is suitable for earth- and rockfill embankments in addition to barrages and low concrete gravity dams. As gravel foundations are frequently subject to water percolation at high rates, special precautions must be taken by providing effective water cutoffs or seals.
- Silt or fine foundation. It can be used for earthfill embankments in addition to barrages and low concrete gravity dams, if properly designed. But it is not suitable for rockfill embankments. The main problems are the settlement, the prevention of piping, the excessive percolation losses, and the protection of the foundation at downstream toe from erosion.

- Clay foundation. It can be used for earthfill embankments but require special treatments. Due to the considerable settlement if the clay is unconsolidated and the moisture content is high, clay foundations ordinarily are not suitable for concrete gravity dams and rockfill embankments. Tests of the foundation material in its natural state are normally required to determine the consolidation characteristics of the material and its ability to support the superimposed load.
- Non-uniform foundation. Occasionally, situations may occur where reasonably uniform foundations of any of the foregoing descriptions cannot be found and where a non-uniform foundation comprising rock and soft material must be used. Such conditions can often be overcome by special design and appropriate treatment.

(c) Concrete dam foundation

As the reservoir rises behind a concrete dam, it pushes the dam into the canyon walls and stream floor. To compute the stress and deflection of the dam as well as the abutment reactions, it is necessary to know how much the rock foundation deforms under the combined loads of gravity, water, temperature, and others.

The deformation characteristics of foundation rock for concrete dams are significantly influenced by the density, orientation, extension and aperture of joints and cracks near the loaded bedrock surfaces, and by the compressibility of gouge found within faults and shear zones (Farmer 1968). To evaluate the resistance of the foundation to the forces tending to push the dam downstream wards, it is necessary to know the shear strength along potential planes of weakness. Since the strength of discontinuities and the shearing forces are influenced by the magnitude and direction of the in situ stresses, their measuring is also demanded for determining the foundation deformation and the degree of rock slabbing or relaxation that may occur due to the removal of the overburden rock.

4. Spillway foundation investigation

Geologic exploration for a spillway foundation should begin with the preparation of a geologic map of the spillway and adjacent areas, followed by detailed subsurface exploration (e.g., exploratory drilling or trenching) along the spillway alignment, if necessary.

Although bearing capacity could be important, the weight of ground material removed is often greater than the weight of spillway, so the foundation generally is able to support the spillway structure. However, care must be exercised to ensure that in the foundation, there are no bedding planes, joint sets, fracture systems, or other discontinuities with adverse orientations.

Stability of both cut and natural slopes adjacent to the spillway should be studied with great care, which requires thorough geotechnical analyses taking into account of geologic structures, groundwater conditions, and the mechanical properties of the soil and/or rock. Where deep cuts are made for the spillway, particularly in shales and siltstones, or where there is high tectonic stress, considerable rebound may be anticipated. A good way to handle such rebound is to leave an interval of several months after excavation to allow the rock to finish rebounding before the concrete placement.

5. Underground work investigation

Underground works in hydraulic projects may be either the tunnels for river diversion, flood release, water conveyance and communication, or the underground caverns for accommodating hydropower plants. Since China's water resources and hydropower development is moving toward her Western territory, the underground works are much more frequently encountered and their types are much more widely varied than ever before. The Tianshengqiao II Project has a water conveyance tunnel of 9.8 km long located in a region with very complicated Karst and geological structure conditions. Various geological problems such as collapse, intrusion of groundwater, crushed zones of faults and rock burst were encountered during the tunneling. The Ertan Project is located in a canyon region of the Yalongjiang River with very high in situ stress. Its underground powerhouse cavern is one with the largest span in China—28.5 m wide and 71.5 m high. The Xiaolangdi Project has 16 tunnels (for diversion, flood releasing, silt releasing, water conveyance, and irrigation) and a giant underground powerhouse (containing six turbine generators). Those works have to be concentrated in the limited area of a mountain on the left bank, due to the constrains in the topography, geology, and hydraulic structure layout.

Since the mid-1980s, many pumped-storage power stations have been constructed in China, such as the Guangzhou Pumped-storage Power Station, the Shisanling Pumped-storage Power Station, and the Tianhuangping Pumped-storage Power Station. A lot of complicated geological problems were encountered during the excavation of their underground works. Similar to slope engineering works, the underground works in hydraulic project are varied in types, scales, and working conditions. Their geological conditions are very different with each other, varying from very hard and intact granites to strongly Karstified carbonate rocks, swelling plastic mudstones, gouge filled fault zones, and alternated rocks, from horizontal strata to strongly squeezed zones to high in situ stress and high geothermal areas. Insofar, a rich expertise has been accumulated concerning the geological and geotechnical investigation and research for long and giant underground works with complicated geological conditions.

(a) Tunnel

Basic questions with answers dependent on geologic conditions are as follows: Can the tunnel be built? Will the portal areas and tunnel body be stable? Will geologic hazards such as raveling or running ground be encountered during the tunneling? Will groundwater be a problem? Will it have to be lined? What kind of support?

The initial step should be the preparation of a geologic map in the vicinity and along the tunnel alignment to determine the physical and mechanical conditions of rock. During exploration drill, water pressure tests (pumping or packer) should be made to determine the permeability of rock. Temporary casing should be installed in drill holes, so water levels can be monitored. Springs in the area also should be canvassed and measured. These groundwater data are useful for determining how much water will be encountered during tunneling and how the tunneling adversely affects the groundwater environment as well.

(b) Powerhouse

Exploration program for an underground powerhouse should start with a detailed surface geology map and preliminary exploratory drill holes to evaluate the geologic conditions at the underground power plant. During this phase, geologic structures may become evident which would make reorienting or relocating of the underground chamber. To more accurately evaluate underground conditions, exploratory adits for observing the behavior of the rock during excavation, for performing additional rock mechanics tests, and for determining residual stress are necessary.

The kind of support is one of the most important concerns to be decided in light of geological exploration. The modern tendency is to use rock bolt reinforcement for the roof and walls. However, if the rock is closely fractured or too soft to be adequately reinforced by rock bolts, then other support systems such as concrete or steel arches must be installed to reinforce the roof of the powerhouse, which may either be supported on posts or on a rock hunch. If a haunch support is contemplated, the geologist should determine that the rock is suitable for excavation of a haunch and that there are no adverse rock structures which would cause the haunch to fail.

Because underground powerhouses are usually in the dam abutments, water impounding in the reservoir will change the groundwater conditions and can raise groundwater to envelope the powerhouse. Therefore, geologic investigations should indicate rock permeability around the powerhouse. In many instances, a grout curtain as an impermeable envelope around the powerhouse is conventionally employed to protect the powerhouse from groundwater, and a drainage system to collect any seeping water through the curtain is provided. Successful installation of such an anti-seepage system requires thorough knowledge of geologic conditions around the powerhouse.

Geologic problems with a surface powerhouse are considerably different from those of underground. The main geologic problems that generally arise are stability of both cut and natural slopes around the powerhouse, stability of the penstock foundation, adequacy of the foundation, and troubles that might arise from excavating rebound. Groundwater conditions that may affect either the construction or operation of the powerhouse should not be overlooked, too.

Where the groundwater is above the foundation level, particularly in alluvial strata, pumping tests should be made to evaluate the groundwater conditions, for dewatering system design of the foundation.

6. In situ stresses in surrounding rock mass

The virgin or undisturbed in situ stresses are the natural stresses that exist in the ground prior to any excavation, which is an important geologic setting of cut slope, tunnel, and dam foundation. They determine the boundary and initial conditions for deformation/stress analysis and affect the adjustments in stress that develop when an opening is created (Goodman 1989; Jaeger et al. 2007). The influence of in situ stress on the hydraulic structures should be assessed with the consideration on its magnitudes and attitudes and zoning features, the impacts of the in situ stress on fracturing of various rocks, and the working conditions of the structures concerned. The foundation of various hydraulic structures should fully use the stress transition zone, partially use the stress-release zone, and avoid as far as possible the stress concentration zone. The top of the structure's foundation bedrock should be adjusted appropriately so as to keep the ratio between the stress and the strength of the foundation rocks within a range in which the rocks could only be fractured slightly. The axis of the tunnel should be aligned as parallel as possible or oblique slightly to the maximum principal stress. The surrounding rock mass of underground caverns should be reinforced when it is situated within the stress concentration zone. Full attention should be paid to the stress concentration-induced damages such as rock burst, scaling, and fracturing.

The in situ stress existing in a formation can be decomposed into three principal compressive components, approximately one vertical and two horizontal, which are usually not equal. The vertical stress is attributable to the overburden weight exerting on the top of a formation. The horizontal stresses are the result of the deformation of the rocks plus externally applied tectonic actions. The parameters that affect the magnitude of the in situ stresses include overburden weight, fluid pore pressure, porosity, anomalies in the rock fabric (i.e., natural fractures), rock mechanical properties (such as Poisson' s ratio), tectonic activity, temperature changes, and chemical and physicochemical processes such as leaching, precipitation, and recrystallization of constituent minerals. Mechanical processes such as fracture generating and propagation, slip on fracture surfaces, and viscoplastic flow throughout the medium can be expected to produce both complex and heterogeneous states of the stress field.

Topographic conditions also significantly influence the in situ stress. In a deep cut river valley, the in situ stress field is commonly distributed in 4 zones:

- Stress-release zone. Situated in the superficial part of the valley slopes with small magnitudes;
- Stress transition zone. Situated in the shallow part of the valley, ranging in medium magnitude;
- Stable stress zone. Situated in the deep part of the valley slopes, ranging in high magnitude; and
- Stress concentration zone. Situated in the riverbed.

Although some of the simplest clues to stress orientation can be estimated from the knowledge of a region's structural geology and its recent geologic history, quantitative information from stress analysis requires that the boundary conditions are known, and field measurements of in situ stresses are the only true guide for critical structures. During the past 40 years, methods for measuring in situ stresses have been well developed (Goodman 1989). Based on a survey of published database, it may be confirmed that the vertical in situ stresses measured in the field reasonably agree with simple predictions using the overburden weight of rock. However, horizontal in situ stresses seldom show magnitudes as low as the limiting values predicted by elastic theory, but often vary considerably and depend on geologic history, denudation, tectonics, or surface topography. At shallow depths, there may be a wide variation in values since the strain changes being measured are often close to the accuracy limit of the measuring instruments.

To determine the magnitude and orientation of in situ stresses by the field test using several points, much manpower and material resources are requested. Basically, there are two types of in situ stress measuring methods: One is named as direct, represented by flat jack measurements and hydraulic fracturing, which determines a circumferential normal stress component at particular locations in the wall of a borehole. If sufficient boundary stress determinations are made in the borehole periphery, the local value of the field stress tensor can be determined directly. Another one is indirect, based on the determination of strain changes in the wall of a borehole, or other deformations of the borehole, induced by over coring that part of the hole containing the measuring device. If sufficient strain changes or deformation measurements are made during this stress relief operation, the six components of the field stress tensor can be obtained from the experimental observations using procedures developed from elastic theory. It should be pointed out that the in situ stresses measured in the same geology element commonly present different data by different methods. Even by a same measuring method, the data also display large dispersion. These are mainly attributable to the influence by the factors of faulting, topography, erosion, and denudation, apart from the errors resulted from measuring apparatus.

Based on these field readings, the stress regression method is designed to determine the initial stress field by means of regression method, least squares method, and other modern artificial intelligent methods, for example, artificial neural network (ANN) is a mathematical model often used as a nonlinear data modeling tool to fit the complex relationship between inputs and outputs. Recent research shows that the ANN and FEM can be combined to back analyze the initial stress field using measured in situ stresses before the excavation, whose basic procedure is illustrated as follows (Chen 2006).

(a) Establish 3D regional FE model with effort to reflect joints, fractures, and terrain;
(b) Define a set of boundary load combinations corresponding to the regional FE model;
(c) For each boundary load combination, implement FE analysis to obtain the stresses at the in situ test points;
(d) The computed stresses at the in situ test points and the corresponding boundary load combinations are grouped into samples for ANN, in which the stresses are inputs and the boundary load combinations are outputs;
(e) The ANN training is carried out using the samples defined in the step (d);

(f) Input the in situ test readings of the stresses into the trained ANN leads to the "best guess" of the boundary load combination;
(g) Apply the "best guess" of boundary load combination to the 3D regional FE model, the initial stress field is back analyzed, which may be used in the excavation calculation of dam foundations, cut slopes, and underground works.

Based on the 13 field test points in the Xiaowan Project, the initial stress field is back analyzed using the procedure described above. Figure 2.1 shows the distribution of the initial stresses whose characteristics coincides with which is well known with regard to the deeply cut valley.

2.5.4 Regional Tectonic Stability and Earthquake Hazard

The shaking of the ground surface during an earthquake is a consequence of seismic waves (stress waves), which are generated by the slip on and/or tip propagation at an exiting fault which causes the sudden release of stress (strain energy) in rock (Hyndman and Hyndman 2009). The motion due to a disturbance at the origin can be split into longitudinal, transverse, and surface waves, of which the latter are most destructive. Focus is the origin from which the earthquake tremor is supposed to start, or a point to which all the earthquake waves converge. Epicenter is the point on the surface above the focus. Earthquakes that produce destructive ground shaking usually are generated by faults in the upper 30 km of the earth's crust (Richter 1958).

The severity of an earthquake is gauged by the amount of energy released at the focus, is termed as the magnitude which is an index of the earthquake related to the size of the slipped fault area, and is described in a quantitative way in many countries inclusive China by the so-called Richter Magnitude of the earthquake for shallow shocks (GB17740-1999 "General Ruler for Earthquake Magnitude" 1999; ICOLD 2011). The maximum earthquake magnitude encountered is usually smaller than 9.

$$\begin{cases} M = \log_{10}\left(\dfrac{A}{T}\right)_{\max} + \sigma(\Delta) \\ \sigma(\Delta) = 1.66\log_{10}\Delta + 3.5 \end{cases} \qquad ((2.1))$$

where M = magnitude of earthquake; A = maximum amplitude of horizontal ground motion recorded by a standard seismograph, μm; T = wave period, second; σ = calibration function correcting for the angular distance Δ from seismometer to epicenter; and Δ = angular distance from seismometer to epicenter, (°).

The intensity is an identification of the effect severity of ground shaking at a definite point and is described in a short-hand way by the Modified Mercalli intensity number (from 1 to 12), which is correlated with certain classes of observed effects of ground shaking.

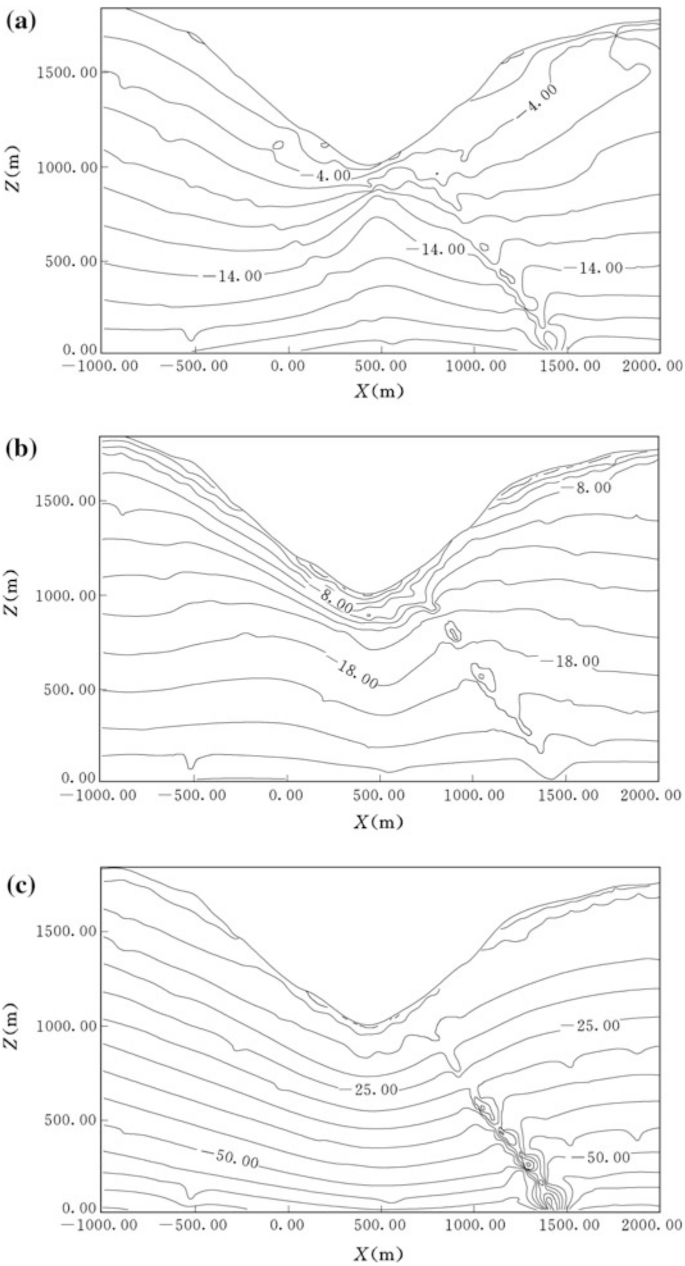

Fig. 2.1 Contours of initial stress of the vertical section along the dam axis (Unit: MPa)—The Xiaowan Project (China, H = 294.5 m). **a** Maximum principal stress; **b** medium principal stress; and **c** minimum principal stress

Many regions of the world are subject to potentially destructive earthquakes. The border of the Pacific Ocean is particularly prone to seismic activity where approximately 80 % of the world's earthquakes occur. A second seismic belt runs across northern India into Turkey, Greece, and Italy. In addition, destructive earthquakes also occur in other parts of the world, although much less frequently (ICOLD 1975; Poulos et al. 1985).

The potential hazard to a specific hydraulic project from an earthquake depends on how large the earthquake is and how near the project site to the epicenter. The occurrence of an earthquake in the vicinity of hydraulic structure can cause its damages, or even failure, if the earthquake actions have not been given adequate consideration in the design. Earthquakes of magnitude 5.0 or greater can generate severe ground shaking to potentially damage hydraulic structures. For earthquakes of magnitude lower than approximately 5.0, the ground motion is unlikely to be hazardous due to its very short duration, even though the peak acceleration may be large in the case of very shallow fault slip.

The following are two typical cases of earthquake damages to dams, which are often referred to as lessons in the community of dam engineering.

- Xinfengjiang Dam. This massive-head buttress dam in China was damaged by the magnitude 6.2 earthquake in March 19, 1962. The dam sustained a horizontal crack approximately 10 m below the crest.
- Koyna Dam. This concrete gravity dam was damaged by the south India earthquake in December 10, 1968. This magnitude 6.5 earthquake occurred close to the dam and an accelerograph within the dam recorded a peak acceleration of approximately 0.5 g. The dam sustained a horizontal crack near the upper third point and many of the appurtenances of the dam were also damaged.

It is not possible to predict when and where earthquakes will occur and how large they will be; therefore, considerable judgment is involved in assessing the seismic risk at a specific project site. Most seismic countries have prepared seismic zoning maps to assist designer and builder. These maps normally divide the country into a number of zones of different degrees of seismic hazard. Such zoning maps are employed for the first-level assessment of seismic hazard. In building codes for example, zoning maps are used to regulate the earthquake design of ordinary structures, or facilities.

As a complement to the published zoning maps, a seismic hazard analysis for a specific project site can be conducted by evaluating the magnitude of ground motions from all capable sources (focuses) with the potential for generating strong ground motions at the site. The value of such seismic analysis is the ability to incorporate the latest developments in local seismicity. The analysis is usually carried out in three steps: first, to establish the location and style of faulting of all potential sources and assign each a representative earthquake magnitude; second, an appropriate attenuation relationship is selected as a function of magnitude, faulting mechanism, site-to-source distance, and site conditions; and third, the capable sources are screened based on magnitude and ground motion intensity at the site, to determine the governing source.

1. Regional tectonic stability

Geology- or seismology-related elements often determine the feasibility of the project and strongly influence the planning, design, construction, and operational activities. Therefore, earthquake-related hazards should be identified early in the project investigation and be evaluated continuously in the subsequent stages of hydraulic work design.

Regional tectonic stability studies the presence of faults, active or inactive, and their influences on the design of the hydraulic structure. The study comprises regional tectonic setting analysis, regional tectonic stability analysis, as well as the geologic investigation for the hydraulic project.

Regional tectonic setting analysis is intended to collect the earthquake data and documents of 150–300 km in radius around the project. This may be carried out using "Chinese seismic intensity zoning map (1990)" or GB18306-2001 "Seismic ground motion parameter zonation map in China," from which the basic intensity at the reservoir and the dam site, as well as the level of seismic bedrock peak horizontal acceleration, may be obtained. DL5073—2000 "Specifications for seismic design of hydraulic structures" stipulates that if the basic intensity is 6 or greater, the special seismic risk analysis and aseismic design are to be carried out for the project with a dam higher than 200 m or a reservoir storage capacity over 10 billion m^3; these are carried out for the dam higher than 150 m and located on the area of basic intensity 7 or greater.

Study on the regional tectonic stability and seismic activities are customarily conducted in an area around the project approximately 20–40 km in radius. The study covers:

- Regional geological background, namely regional strata, geological structures, geomorphology, and geological evolution process;
- Features of deep geophysical field and characteristics and intensity of neotectonic movements;
- Distribution of faults and their activities;
- Historic earthquake records;
- Recent seismic observation data and seismic background analyses; and
- Seismic risk analysis and study on the dynamic parameters of earthquakes.

Studies are also made of geologic formations and soil deposits on the work site to assess their possible behavior during earthquake shaking and how they might affect the stability of the hydraulic structure.

The project site should avoid the epicentral region with earthquake magnitude over 6.5, or intensity over 10; the dam, spillways, and power plants should not locate on the active faults and related branching faults.

The Auburn Arch Dam (USA, H = 210 m), whose proposals and studies emerged in the late 1960s, and construction work commenced in 1968, involving the diversion of the North Fork American River through a tunnel and the construction of a massive earth cofferdam. Following a nearby earthquake and the discovery of a seismic fault that underlay the dam site, the project was suspended for fears that the dam's design would not allow it to survive a major earthquake.

China is a country with frequent earthquakes, which are mostly concentrated in the piedmont seismic zones of the Taihangshan and Yanshan mountains in east China, of the Qinhai, Ningxia, and Xinjiang Provinces in west China and of the most areas in southwest China (General Administration of Quality Supervision of the People's Republic of China 2001). Priorities thus should be given to the assessment of regional tectonic stability and seismicity risk when a dam is contemplated in these regions. Taking the Ertan Project as an example, it is located in a north–south trending tectonic zone in Sichuan and Yuannan regions that have very strong tectonic and seismic activities. After years of in-depth study and investigation, the Chinese engineers and researchers identified a relative stable massif (safe island) on which the dam would be located, by ascertaining the characteristics and activities of major faults surrounding the project area.

How the reservoir loading is related to the earthquake triggering is not well understood at present and is still the subject of research (Kerr and Stone 2009). Presumably, it is linked to the extra weight on the earth's crust and possibly also to additional water and water pressure diffused to considerable depth. It is thought that the reservoir loading is just the triggering mechanism to release an existing state of stress in the rock. It is now customary to install one or more seismographs in the vicinity of a new major dam to record shocks having magnitudes in the range of 1.5–3.5, to monitor any change in recurrence interval during and following the impounding of the reservoir.

2. Design criteria and aseismic analysis

The aforementioned studies provide information on the seismic hazard at a proposed project site by giving parameters as to the magnitudes and frequencies of occurrence of earthquakes that can be expected, the likely active faults identified, etc. Based on these, the judgment must then be made to establish appropriate earthquake design criteria for the project.

During earthquakes, a hydraulic structure is excited with vibrating motion due to the ground shaking. The procedure named as pseudo-static method that has commonly been employed for earthquake design is to include in the prescribed loads a constant percent (5, 10, etc.,) g of acceleration force and then to proceed with essentially an equivalent static analysis. When the pseudo-static method is used, the difficulties with correlating the equivalent static force to what actually happens during an earthquake, and with knowing what the factor of safety, make it desirable to develop a method of design that is based on dynamic analysis and that relates more closely to the actual behavior of a hydraulic structure during an earthquake (ICOLD 2013). The difficulties with this type of more advanced approach is that all the physical parameters are not known accurately and hence have to be estimated; furthermore, with the present state of the art, the subbase of the structure is commonly given an acceleration which is identical to the entire base, which is not realistic. More recordings of the earthquake motions of hydraulic structures and their bases are needed, and more research is required on how to model a real structure by means of dynamic analysis using numerical methods such as FEM that take into account the real dynamic properties of the material of which the structure is constructed.

2.6 Location and Exploration for the Sources of Construction Materials

2.6.1 Tasks of Construction Material Investigation

Investigation on natural construction materials is usually concerned with one or two questions, namely is there a sufficient quantity of specified construction material available within a reasonable haul distance, or the more comprehensive question of, what construction materials are available in the area (Golzé 1977). The importance of a thorough construction material investigation to the planning and design of hydraulic projects is apparent: The availability of construction materials often dictates the location and type of the dam which can economically be considered at a contemplated site.

Previously, investigation of natural construction materials was not so important in China, because the dams of that time were small, the dam sites had very favorable conditions, and the reserve of natural construction materials (e.g., sand and gravel, earth material and rock aggregate) is abundant. In the recent twenty years, more and more dams have been constructed in the western China, and the requirements on the environmental and ecological protection are getting higher and higher. As a result, the natural reserve of sand and gravel as well as earth materials in the project area finds itself being harder and harder to meet the demand. Therefore, new sources and types of construction materials, such as processed artificial aggregates, have to be explored.

In China, many types of hard rocks such as granites, basalts, carbonate rocks, metamorphic rocks, and sandstones have been used to process artificial aggregates. Among them, carbonate rocks are most widely employed. Study on the alkali-silica reaction of igneous rock aggregates and the alkali-dolomite reaction of carbonate rock aggregates is essential in the quality assessment of artificial aggregates even though it is expensive, time consuming, and difficult in techniques.

Gravelly soil, weathered residual soil, and their mixed soil have been widely used as impervious earth material. The requirements on the stone materials for high CFRD are quite different from those for traditional rockfill dams.

An efficient investigation can be realized only through proper planning, field, and laboratory works. Generally, the investigation contains several phases normally follows a “learn-as-you-go” procedure and becomes more detailed as the design work progresses and as the project moves from the planning phase to the construction phase.

2.6.2 Requirements in Planning Phase

A thorough search within 20 km distance around the project site should be made. The published geologic maps of the area are most useful in locating possible sources of construction materials, by showing the distribution of various geologic units and brief descriptions of them. Potential sources of construction materials may thus be identified and located, and further studies may be planned. Topographic maps are indispensable to the construction material investigation. Many surface soils are closely related to the type of rock from which they are derived. The agricultural soil survey maps and reports may be of value to the engineer in which items such as soil profile descriptions, ground surface conditions, natural vegetation, drainage, meteorological data, flood danger are included. Aerial photography may reveal material sources that may easily be overlooked by engineers who depend solely on visual ground investigations.

The potential construction materials in an specified area should be directed toward the estimation of the quantities of all types of construction materials available within the area, by which the geologic plan of 1/5000–1/10,000 and distribution plan of 1/50,000–1/100,000 for borrow are provided.

2.6.3 Requirements in Preliminary Phase

The objective of this phase for the material investigation is to locate suitable materials meeting the probable requirements from the type of dam or other work being considered.

This stage includes preliminary drilling, sampling, and testing of the most promising sources in order to verify that adequate quantities of suitable materials are available. A more complete and thorough investigation of existing geologic data, existing quarries and borrow areas, their test results, performance records, and production data is demanded at this phase.

Field studies, including geologic sectional mapping of 1/1000–1/2000, comprehensive geologic plan of 1/2000–1/5000, and borrow area distribution plan of 1/25,000–1/50,000 should be completed for the more promising areas. Limited sampling of selected areas and preliminary testing will provide more reliable data on the areas. New estimation of the volume of materials available should be based on the additional data collected, the volume of materials available should be at least three times of the design requirement, and whose estimation error should be lower than 40 %.

A joint review with planners, designers, and construction specialists is appropriate at this phase. This review brings out questions, new approaches, and suggestions for the final exploration of the construction materials. Frequently, this review provides the basis for narrowing the scope of the study and permits the investigator to concentrate his efforts on the more probable types of materials to be used for the project.

2.6.4 Requirements in Feasibility Phase

The objective of this phase is to confirm the location of adequate quantities of suitable materials for an evaluation of the specific sources of construction materials. It is also important to evaluate the excavation, process, transportation, and environmental impact of the material borrow.

The methods of exploration in this phase may vary locally. Large diameter drilling is probably the most efficient for exploring unconsolidated construction materials. Trenches and test pits excavated by backhoe are also very efficient for exploring unconsolidated deposits. All of these methods permit accurate and detailed logging, which should be accomplished by capable specialists. They should record the usual geologic and soils descriptions, and their observations are of great importance during drilling and sampling. Sufficient amount of material samples should be extracted in for reliable testing. The exploration also should be able to provide data on the issues such as the most suitable materials, methods of excavation, depth of overburden, thickness and uniformity of the materials, and depth to groundwater.

Geophysical methods such as seismic wave and electrical resistivity are not usually needed in exploring materials. However, in many areas, the geophysical methods may be exercised effectively to provide useful data on the borrow areas, such as the groundwater table, the depth to consolidated rock, the degree of fracturing, the density and the modulus of elasticity, etc. Although these may not be able to provide precise values, they are very accurate for a relative determination and are reliable in a qualitative sense.

At this stage, geologic sectional mapping of 1/500–1/1000, comprehensive geologic plan of 1/1000–1/2000, and borrow area distribution plan of 1/10,000–1/50,000 should be completed. The volume of materials available in the area should be at least two times of the design requirement, and whose estimation error should be lower than 15 %.

2.7 Economy Evaluation

2.7.1 Tasks of Economy Evaluation

The economy evaluation for a hydraulic project is to make analysis and demonstration of economic feasibility and rationality of the to-be constructed project, by providing integrated evaluation and suggestions. Aimed to avoid risks to the maximum extent and enhance optimal economic benefits, the economic evaluation is at the kernel in the feasibility study which provides an important basis for decision making (National Development and Reform Commission of the People's Republic of China, Ministry of Housing and Urban-Rural Development of the People's Republic of China 2006; Pan et al. 2000c).

The economy evaluation falls into process evaluation and final evaluation. The process evaluation is to make technoeconomic analysis and evaluation for available construction alternatives, after comprehensive comparison and screening, to find out an alternative with the best economic performance for inclusion in the feasibility report. The final evaluation is to make final integrated economic analysis and evaluation, which is the main component of feasibility study and the key to budget project investment (Zhou 2007).

From the 1950s to 1970s, China had been practicing a planned economy on the basis of whole public ownership. In the theories of investment effect, emphasis was put on that the social production and investment effect must follow the particular socialism laws of rigorously planned for proportional development. As a result, the payment period method for justifying alternatives and for selecting hydropower parameters was prevalent. In the early period after the founding of the P. R. China since 1949, goods prices remained stable which did not seriously deviate from their value, a rationally stipulated payment period was capable of reflecting the relative economy indices of hydropower and water resources projects. During this period, because the capital investment was provided gratis by the state in a unified way, time factor was usually not considered in the economic analysis.

From the end-1970s, the state commenced the policy of opening-up and economy reform step by step. The theories of socialist market economy have been established gradually, and the shift from the planned economy to a market economy has been realized. Hence, the theories and methodology for the economic analysis of project decision have entered a flourishing new phase. A series of codes for project economy evaluation have been issued, such as "Tentative Rules for Economic Analysis of Hydropower Project," "Economic Evaluation Methodology and Parameters of Construction Project," "Tentative Regulations for the Financial Evaluation of Hydropower Construction Project," and "Tentative Regulations for the Economic Evaluation of Pumped-storage Power Station."

The main tasks for economic evaluation may be accomplished through national economic evaluation, financial evaluation, and integrated economic evaluation (Yang and Pu 1993; Yu et al. 1994).

2.7.2 National Economy Evaluation

The national economy evaluation for hydraulic projects, particularly hydropower projects, is to analyze and calculate the net contribution of a hydropower project to the national economy from the point view of comprehensive national economy balancing, so as to allow for evaluating the economic rationality of the project (National Development and Reform Commission of the People's Republic of China, Ministry of Housing and Urban-Rural Development of the People's Republic of China 2006).

The national economy evaluation uses the shadow price for each year in the calculation period, follows the "with and without" comparison principle and emphasizes the overall benefits of electric power system. The costs may be direct or indirect, and the former is referred to the economic value of input calculated with shadow prices, whereas the latter is the cost paid by the society for the project, but not by the project itself. The internal rate of return is the main indicator in the evaluation, and the others may be selective according to the characteristics and actual needs of the project, for instance, the net present value, the net present value rate, etc., with respect to the economy.

2.7.3 Financial Evaluation

The financial evaluation is to analyze and calculate the direct financial benefits and cost of a project, to formulate financial statements, to calculate evaluation indicators, and to investigate profitability and payment capacity as well as foreign exchange balancing, so as to allow for evaluating the financial feasibility. The main indicators are the financial internal rate of return, the investment recovery period, the financial net present value, etc.

Similar to the national economy evaluation, the financial evaluation is mainly implemented by firstly dynamic analysis and secondly static analysis. "Tentative Regulations for the Financial Evaluation of Hydropower Construction Project" issued in 1994 clearly indicates that the calculation period should be ranged from construction to productive operation. The former is the total period of designed construction, including the initial operational period; the latter is usually counted as 20–30 years. For multi-purposed hydraulic projects, it is demanded that the financial evaluation should be made for the two cases of "with and without" investment allocation, the forecast prices based on current prices should be used in the evaluation, the financial basic rate of return is tentatively determined as 12 % for the total investment and 15 % for the capital fund, and the cost and benefits may be linked to the power generation where the special transmission and transformation engineering is tentatively included.

The financial evaluation also comprises sensitivity analysis aimed at investigating the impacts of the main elements on financial indicators (such as sale price to network), so as to forecast the capacity of the project against risks and to further determine whether the project is financially feasible.

2.7.4 Integrated Economy Evaluation

Many large- and medium-sized hydropower projects are of state infrastructure closely related with the social and economical development, and some of their economical factors are difficult to quantification. In order to comprehensively analyze their impacts on the development of society and economy, in addition to the national economy evaluation and financial evaluation, integrated economic analysis and study also have to be carried out from the macropoint of view, for evaluating the economic rationality and feasibility of the project. The indicators adopted in the evaluation are as follows:

- Total investment and unit functional investment (such as the investment per unit-installed capacity and the investment per unit energy). Comparison is customarily made between hydropower and thermal power projects of similar size.
- Main engineering amount.
- Quantities of reservoir inundation and land excavated or covered by construction, inundation and land occupation per unit function, and proportion of compensation cost for reservoir inundation in the total project investment.
- Quantity of saved fuel.
- Multi-purposed benefits in addition to power generation.
- Reliability and feasibility of power price checking and ratification.

For a particularly important hydropower project, analysis and evaluation should be made with regard to the role and impacts of the project on the national economy in the following aspects:

- The role and function of the project in the country, river basin, and regional economy;
- Adaptability to the state industry policies and productivity distribution;
- Amount of project investment and the financial capability of the state and the region. For a hydropower project requiring a large investment, consideration should be given to the national affordability, and the analysis should be made with regard to the finance, materials, technology, and manpower; and
- Impacts of reservoir inundation and land occupation by the project on the regional society and economy.

For a hydropower project of large scale and requiring long period of initial operation, one of the important economy evaluation supplementary indictors for studying its economic rationality is the proportion of investment before the beginning of benefit generation in the total investment. Usually, it is strongly demanded for a large-sized water resources or hydropower project to start creating benefits with less than the two-thirds of total investment be used up, and the lower, the better.

2.8 Phases of Investigation and Design of Hydraulic Projects

At present, there are two-phased (staged) systems of the investigation and design in China for water resources projects and hydropower projects, respectively. This situation is mainly due to the reshuffling history of the state central government:

One is mainly practiced by the institutes belong to the formal Water Resources Ministry, and another is mainly practiced by those who belong to formal Electric Power Ministry.

2.8.1 Phases of Investigation and Design for Water Resources Projects

The design for water resources projects is a five-phased process including proposal, feasibility study, preliminary design (conceptual design), design of bid, and construction documents design.

1. Proposal for the project

The proposal for the project is normally originated with the desire to satisfy the state's (or a region's) specific needs, objectives, or purposes. The main contents of the proposal for a project comprises the following: the background, aims, and tasks of the project; investigation and necessary exploration regarding the hydrology, geology, ecology, environment, society, and humanities; justification of the necessity of the project; preliminarily verification of the feasibility and rationality; preliminary consideration of the project scale, construction scheme, construction location and time, and layout of the main works; and investing estimation of the project.

Considerable basic data are usually available in the form of maps, aerial photographs, stream flow records, regional geological reports, census statistics, crop yields, market statistics, power loads, previous investigation reports, etc. The designer must evaluate these data, supplement them with rough additional data, and conceive a workable basic proposal that utilizes available resources to meet the needs. This basic proposal may then be compared roughly with alternatives to accomplish the desired purposes on progressively increased or diminished scope and scale. It will be possible, by judgment or cursory study, to eliminate many alternatives so that an approximate final proposal emerges which entails purposes, approximate locations and heights of dams, capacities of reservoirs, spillways, outlets, canals, power plants, and other features, and which minimizes the environmental impact of the project. All these will be refined in the successive design stages.

The proposed project should be consistent with any long-range planning program that may have been adopted for the vicinity. The entire area to be served by the proposed project should be studied to determine whether there will be conflicts with other projects of a similar nature for use of land or water resources, head drops, etc., or whether economies are possible by securing optimum development of resources through joint use (Zhou 2007).

2. Feasibility study

The objective of this phase is to determine the project's feasibility on the base of project proposal. This involves the studies that will permit a sound analysis and conclusion with respect to the specific engineering economic–environmental considerations. These are primarily:

- That the project is responsive to an urgent present or anticipated social or economic need;
- That the project will adequately accomplish the intended purposes;
- That the class, site, and layout of the project are clearly illustrated based on the major hydrologic and geologic parameters as well as the other major conditions which may be encountered;
- That the engineering construction quantities and period are properly rated and scheduled;
- That the land inundation and acquisition, as well as the indemnifying measures, are studied preliminarily;
- That the services performed through the project and the benefits produced will justify the investment; and
- That the project will cause minimal disturbance to the ecology and environment of the area.

The study should determine that the difficulties inherent in facility sites affecting economy, safety of construction, and quality of operation have been satisfactorily foreseen and that the designs are technically sound, and reasonably representative of the actual structures may be expected to be built after more detailed investigation.

3. Preliminary design (conceptual design)

The preliminary design bridges the gap between the design concept and the design of bid (detailed design). In this phase, the overall project configuration is defined. Schematics, diagrams, and layouts of the project will provide early project configuration, which could be changed or optimized in the following phases. The main features of the preliminary design are as follows:

- More detailed and accurate basic data are required concerning climate, hydrology, topography, geology, materials, economical, and comprehensive requirements;
- More detailed and thorough investigation, exploration, and experiment should be conducted;
- Decisions are made on the issues concerning comprehensive purposes, class of the project and grade of the structures, layout of the project, type and size of the main structures, and layout and type of main electromechanical devices; and
- Decisions on the quantities, methods, schedule, and preliminary budget of the project construction.

4. Design of bid (technical design)

As the extensively developing of bidding system in the engineering construction in China, the Water Resources Ministry stipulated in 1994 that for the projects demanding bidding but had not been commenced, design of bid should be supplemented after the completion of preliminary design, which is the basis of construction bidding documents and planning. The bidding design is similar to the former technical design intended to further improve the design for an optimal schemes, based on which the preliminary budget is revised, so as to meet the requirements for construction bidding.

5. Construction documentary design

This is a phase where the engineer should completely describe the designed product through solid modeling and drawings, including:

- Foundation excavations and treatments of the structures;
- Drawing of structural configuration and reinforcing steel bars;
- Metal structures and detail drawing;
- Layout and install drawing for electromechanical devices, embedded pieces, pipelines, and electric lines;
- Maintenance and testability provisions;
- Material requirements;
- Reliability requirements;
- External surface treatment and marking; and
- Design life.

In many countries, there is detailed design phase following the preliminary design, which is similar to the construction documentary design phase in China.

2.8.2 Phases of Investigation and Design for Hydropower Projects

The investigation and design of a hydropower project is divided into 4 phases including preliminary feasibility study, which is nearly identical to the feasibility study for water resources projects; feasibility study, which is nearly identical to the preliminary design (conceptual design) for water resources projects; design of bid; and construction documentary design.

2.9 Preparation and Compilation of Design Reports

2.9.1 General Requirements

There are various types of design reports. By rough classification, they are planning reports, research reports, investigation and design reports, consulting (evaluation) reports, safety appraisal reports, etc. By detailed classification, they are outlines of investigation and design, special engineering geology investigation reports, special test study reports, special demonstration reports of specialized fields, designing alternative comparison reports, consulting (evaluation) reports of specialized fields, appraisal reports of specialized fields, completed (water impounding) safety evaluation reports, summary reports of the survey and design works, staged design and study reports, etc., of which the staged design and study reports are the most important documents in the project demonstration and approval. In the following, the project feasibility report will be taken as an example to show how a technical report is prepared and compiled.

The project feasibility report is generally prepared on completion of the feasibility investigation as a basis for advising the sponsor or owner, the government department, and others who must approve or authorize the project of its merits. To ensure a complete description and record of all essential data, calculations, and conclusions entering into the design, a uniform procedure for the reporting is desirable (Golzé 1977). In China for example, the contents and depth of the project feasibility report are required officially in the design code or specification (e.g., DL/T5020-2007 "Specification for compiling feasibility study report of hydraulic and hydroelectric engineering").

The report should well describe the project investigations, plans, engineering features, environmental considerations, costs, benefits, and relationships to existing and further developments, problems, and financing. It should contain a general description of the design, including the various factors involved, a copy of the detailed estimate, and a drawing showing the general plan and sections. It also should present definite recommendations, based upon probable accomplishments, regarding feasibility and acceptability under possible means of financing the construction. The conclusions and recommendations should be adequately supported by the investigations, and in such form that, if necessary, the work may be readily reviewed by the responsible authorities.

2.9.2 *Contents and Outlines—Specifically for Feasibility Report*

In the following, we outline the items that a feasibility report should be generally covered. Although the information listed in the outline is not all necessary for small projects, the greater part of it will be necessitated for the medium to large projects.

1. Location and purposes
   - (a) River section, township, range, principal meridian, county, province, nearest city.
   - (b) Location in respect to the other features.
   - (c) Accessibility.
   - (d) Purposes such as amount of storage (live, dead), type of storage (irrigation, flood, power, domestic, etc.), water surface elevations, place where water will be transferred, etc.

2. Summary of project features
   (a) General plans and sections.
   (b) Capacities of storage, spillway, outlet, etc.
   (c) Installed generator capacity.
   (d) Levels of normal storage, maximum storage, minimum storage, etc.
   (e) Maximum height of dam above streambed.
   (f) Estimated expenditure of the whole project, dam, and reservoir.
3. Data for design
   (a) Comprehensive data. Topography; geology; logs of test pits and drill holes; hydraulic data including capacities and requirements, irrigation, flood, power, spillway, outlet, diversion, and area-storage capacity curves for various elevations of water surface; hydrologic data including hydrographs, maximum-recorded flood, inflow design flood, mean annual runoff of drainage basin, and tailwater rate curve; cross sections of streambed; climatic conditions; and borrow areas and aggregate deposits, location, and transportation facilities available.
   (b) Design data for the reservoir. Proposed capacities with corresponding water surface elevations; general dimensions; existing structures affected; nature of land inundation and clearing required; relocations including railroad, highway, telephone lines and optical fiber lines, oil lines, and power lines; and geology including general formations, factors relating to reservoir losses, contributory springs, deleterious mineral, and salt deposits;
   (c) Design data for the dam. Geological features, formations, nature of streambed, and abutments; interpretation of test pits and drill holes; percolation tests; and groundwater.
4. Dam design
   (a) Features entailing the design.
   (b) Water surface elevations, storage capacities, and freeboard.
   (c) Governing dimensions concerning crest width, sectional slopes, height, zoning, crest length, roadway, and base width at maximum section.
   (d) Safety standards (criteria) against percolation, sliding, cracking, etc.
   (e) Cutoff and drainage, including cutoff trench and cutoff wall, grouting requirements; toe drains; and draining holes.
   (f) Appurtenances, including galleries, parapet, and curbs.

5. Outlet works design

   (a) Factors affecting outlet location.
   (b) Requirements on discharges and corresponding water surface elevations; diversion capacities, and water surface elevations.
   (c) Dimensions, materials, linings, etc., of the tunnels and conduits, if any.
   (d) Gate chamber (inclusive dimension, location, accessibility), gates, values, and pipes (inclusive dimension and elevation).
   (e) Approaches, shafts, adits, plugs, and trash racks.
   (f) Stilling basin and plunge pool.

6. Spillway design

   (a) Requirements and other factors governing design and location.
   (b) Type and description of controlled or uncontrolled, lining, dimension, and elevation.
   (c) Gates (dimension and operation manner).
   (d) Stilling basin and plunge pool (inclusive general description and dimension).
   (e) Approach and discharge channels.

7. Appurtenant works design

   Navigation structures, fish ways, log ways, etc., if any.

8. Construction facilities

   (a) Construction layout (inclusive construction camp) and schedule.
   (b) Power available, construction railroad, shipping points, and hauls.

9. Materials and unit prices

   (a) Location of borrows and hauls of natural materials.
   (b) Cement (nearest mill, hauls).
   (c) Railroads, terminals.
   (d) Unit prices.

10. Environmental and ecological protection

   (a) Fish and wildlife protection.
   (b) Recreational development plan.
   (c) Area beautification plan.
   (d) Environmental protection measures during construction.

11. Appendices
    The feasibility report of a project should be accomplished by following documents, as parts of the report or as appendices:

    (a) Examination reports for the preliminary study and the corresponding researches of specialized fields, important meeting summaries and memories, and documents of seminars and discussions.
    (b) Certificates, agreements, or the main documents concerning the project comprehensive benefits, reservoir inundation, land occupation, submerge of mineral resources, and environmental evaluation.
    (c) Hydrologic analysis checks, or hydraulic calculation sheets.
    (d) Important reports of geologic investigation and rock and soil tests.
    (e) Reports of hydraulic model tests, structural model tests, and the other tests.
    (f) Reports of the specialized fields concerning construction techniques, layout, and schedule.
    (g) Reports of type selection for electromechanical devices and metal structure equipments.
    (h) Other important reports related to the design and research of the project, if any.

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Springer
http://www.springer.com/978-3-662-47330-6

Hydraulic Structures
Chen, S.-H.
2015, XXVII, 1029 p. 481 illus., Hardcover
ISBN: 978-3-662-47330-6