WG2: IPP Project Evaluation Methodology

Basic Points of evaluation for the civil structures related to LNG thermal power plant

The Chugoku Electric Power Co., Inc.

Contents

1. Introduction

- This lecture explains about civil structures related to LNG thermal power plant.
- Based on the questionnaire by the checklist, followings are set to understand the basic points of evaluation for the civil structure of LNG thermal power plant:
  - ✓ Outline of civil structure of LNG thermal power plant (e.g. name, function)
  - ✓ Objectives of evaluation for the civil structure related to LNG thermal power plant
  - ✓ Evaluation items for the civil structure related to LNG thermal power plant

Note: This lecture is based on the experiences in Japan. Please note that this lecture does not always correspond to the reviewing items based on the natural conditions, laws and regulations in Cambodia.

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2. Civil structures of LNG thermal power plant

- Main civil structures of LNG thermal power plant are explained by using Yanai LNG thermal power plant in CHUGOKU as an example.

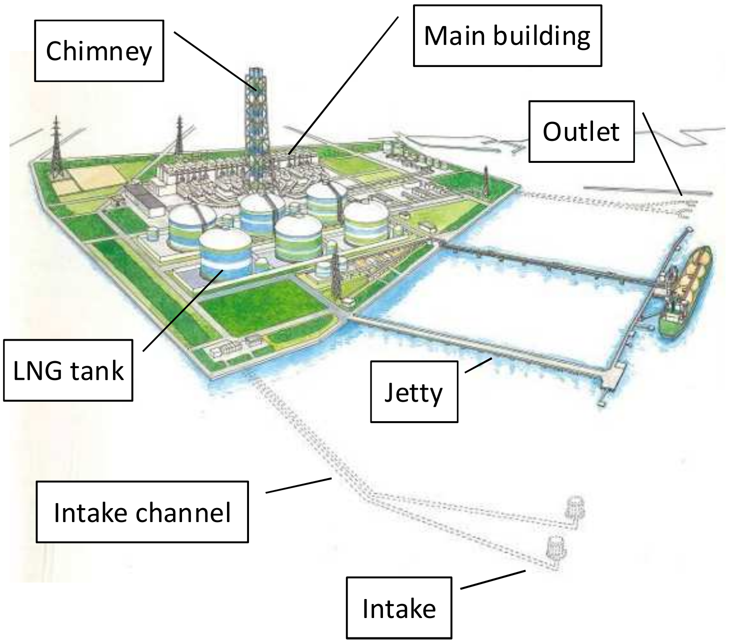

Fig. Overview of Yanai LNG thermal power plant

Tab. Specification of Yanai LNG thermal power plant

Location	Yanai city, Yamaguchi
Area	Approx. 50ha
Power Generation method	Combined cycle (gas turbine and steam turbine)
Max. output	1,400MW (700MW * 2units)
Fuel	LNG (Storage facility: aboveground tank 80,000kL * 6units)
Cooling water	Sea water (Volume: 21CMS * 2units)

2. Civil structures of LNG thermal power plant

2.1 Main site

- Area of Yanai power plant is approx. 50ha. This site was developed (landfilled) by dredging soil, sea sand and mountain soil.
- Since it is landfilled on ultra-soft viscous ground, foundation improvement works such as sand drains and sand compaction piles were carried out to prevent ground settlement during construction and after commercial operation.

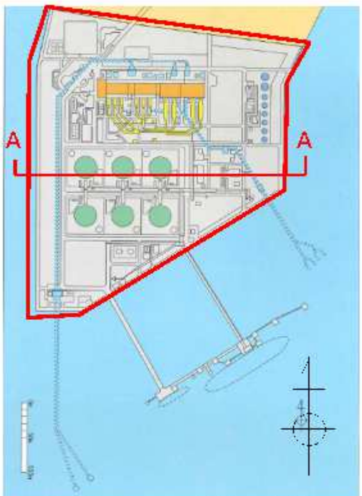

Fig. Plan map of Yanai TPP

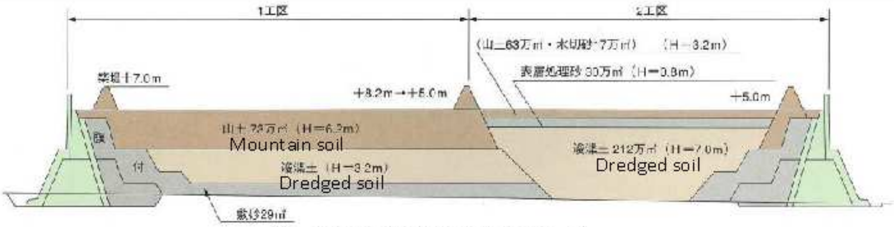

Fig. Cross sectional view (A-A)

Photo. Site preparation (view from west side)

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2. Civil structures of LNG thermal power plant

2.2 Shore protection

- Shore protection locates on south, east, and west sides of Yanai power plant.
- Total length: approx. 2km, Height: site level +1m
- It was installed to prevent damage caused by Tsunami and ocean wave, entering seawater and sediment outflow from main site. It also takes a role to support earth pressure from behind.

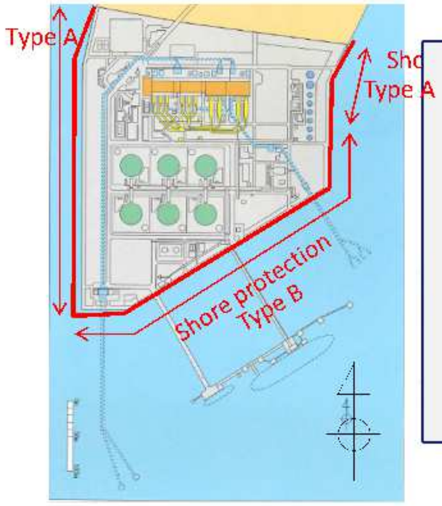

Fig. Plan map of Yanai TPP

Not disclosed due to containing confidential data

Fig. Cross sectional view (type A)

Fig. Cross sectional view (type B)

2. Civil structures of LNG thermal power plant

2.3 Port facilities

- Port facilities in Yanai power plant have LNG unloading jetty (L=300m), loading & unloading jetty (L=300m), berthing facilities (L=50m, W=20m) consist of working platform, dolphin and etc.
- At the working platform point, LNG, which is the fuel for the power plant, and materials and equipment for construction are unloaded, and that are transported through LNG unloading jetty and loading & unloading jetty.
- LNG unloading jetty and loading & unloading jetty were set to the specified length to protect the seaweed bed area.

Fig. Plan map of Yanai TPP

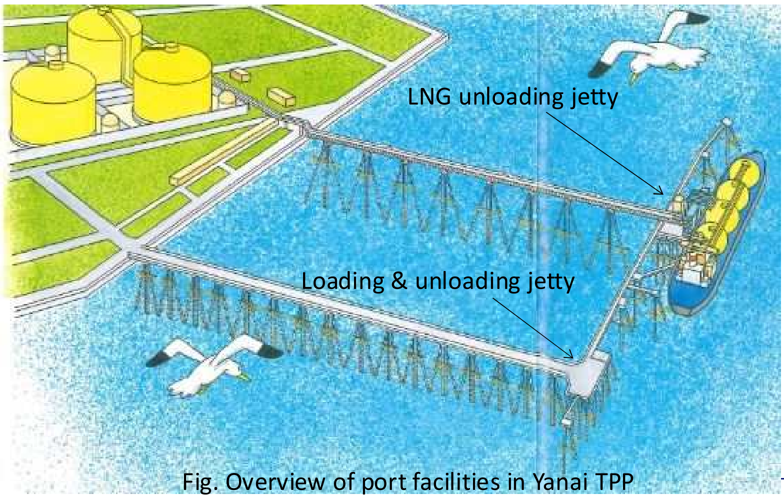

Fig. Overview of port facilities in Yanai TPP

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2. Civil structures of LNG thermal power plant

2.4 Intake and discharge facilities

- The water intake / discharge facilities are installed to stably supply lower temperature and clean seawater to the condenser and to discharge the seawater that temperature rose to the sea after passing through the condenser.
- At Yanai power plant, water is taken from about 500m south of the power plant by a pipeline and discharged about 300m southeast of the power plant.

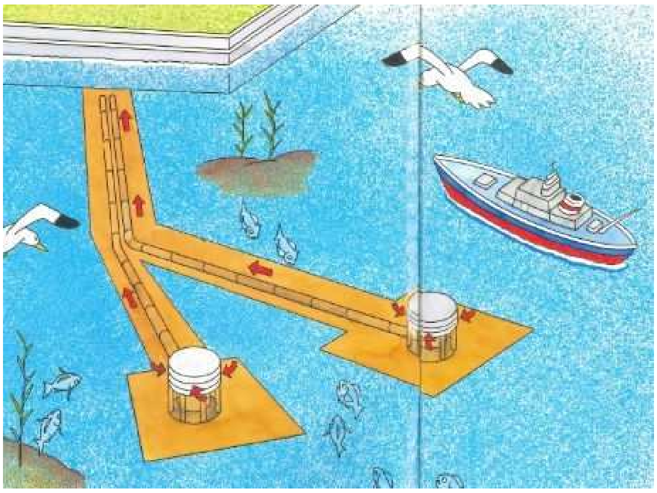

Fig. Overview of intake facility in Yanai TPP

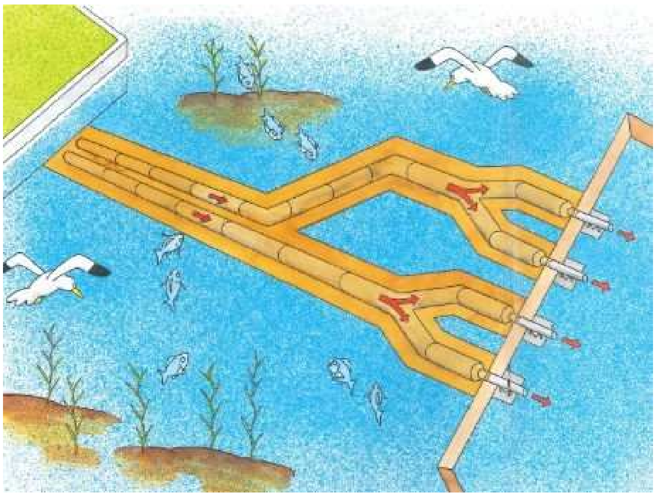

Fig. Overview of discharge facility in Yanai TPP

2. Civil structures of LNG thermal power plant

2.4 Intake and discharge facilities (continued)

- The intake chamber is a facility to be installed the pump that removes sand, wood chips, marine organisms, etc. from the seawater taken in from intake and send it to the condenser as cooling water.
- At Yanai power plant, 3 intake chambers with length of about 40 m are installed for No. 1, 2-1 and 2-2 systems.

Fig. Plan map of Yanai TPP

Not disclosed due to containing confidential data

Fig. Cross sectional map of intake chamber

Fig. Plan map of intake chamber

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2. Civil structures of LNG thermal power plant

2.4 Intake and discharge facilities (continued)

- Circulating water pipe is a pipe that delivers water from the condenser circulation pump installed in the intake chamber to the condenser and then to the discharge channel.
- Circulating water pipe of Yanai power plant consists of pipeline and reinforced concrete culvert. Total length of 2 system is about 1,000 m.

Fig. Plan map of Yanai TPP

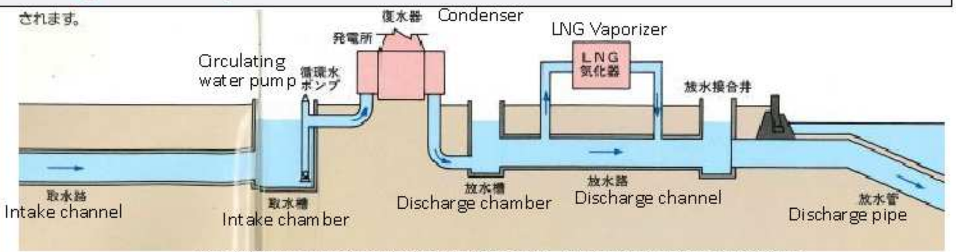

Fig. Cross sectional view of intake and discharge facilities

Photo. Discharge channel

2. Civil structures of LNG thermal power plant

2.5 Main building foundation (incl. boiler, turbine and etc.)

- Main building foundation of thermal power plant is an important structure that supports equipment such as turbines, boilers and building itself.
- Thermal power plants are often installed on the relatively soft ground, such as landfills and coastal dunes, so it is necessary to make strong foundation so that harmful subsidence does not occur.
- Yanai power plant is also designed pile foundation to support the load of superstructures including above equipment.

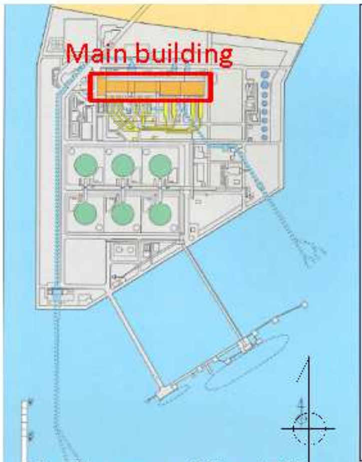

Fig. Plan map of Yanai TPP

Not disclosed due to containing confidential data

Fig. Cross sectional view of main building

Photo. Main building

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2. Civil structures of LNG thermal power plant

2.6 Foundation of environmental facilities

- With the rapid economic growth, environmental pollution such as air pollution, water pollution and noise has become apparent in various regions, and the social needs for environmental conservation are increasing.
- To meet these needs, environmental facilities for LNG thermal power plants includes flue gas denitration facility and wastewater treatment facility.
- The flue gas denitration facility is to decompose nitrogen oxides generated during combustion into harmless nitrogen and water by catalytic reduction.

Fig. Plan map of Yanai TPP

Not disclosed due to containing confidential data

Fig. Cross sectional view of environmental facility

2. Civil structures of LNG thermal power plant

2.6 Foundation of environmental facilities (continued)

- Wastewater treatment facility is to treat wastewater from fuel handling equipment and exhaust gas treatment equipment.
- That all structures are very important from the viewpoint of environmental conservation and, needless to say, that foundations are also important.

Fig. Plan map of Yanai TPP

Photo. Wastewater treatment facility

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2. Civil structures of LNG thermal power plant

2.7 Chimney

- The chimney of thermal power plant is installed to diffuse the burnt gas into the atmosphere.
- From the viewpoint of preventing air pollution, there are chimneys with a height of over 200 m. The height of Yanai's chimney is the same.

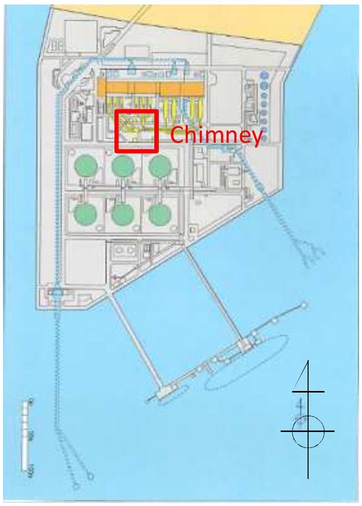

Fig. Plan map of Yanai TPP

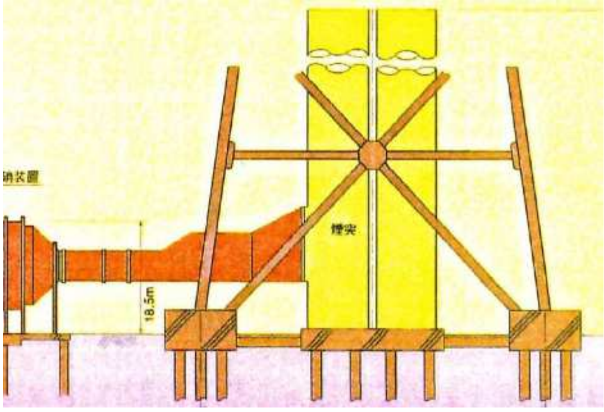

Fig. Cross sectional view of chimney

Photo. Chimney in Yanai TPP

2. Civil structures of LNG thermal power plant

2.8 Fuel facilities (incl. LNG tank, break water and etc.)

- Fuel facilities are roughly classified in transportation facility and storage facility.
- Fuel are usually transported by marine transportation or pipeline transportation.
- In Yanai, marine transportation are adopted. So, port facilities for fuel cargo handling are required. If LNG base or LNG pipeline locate near the site, it is common to install the pipeline for connecting to them directly.

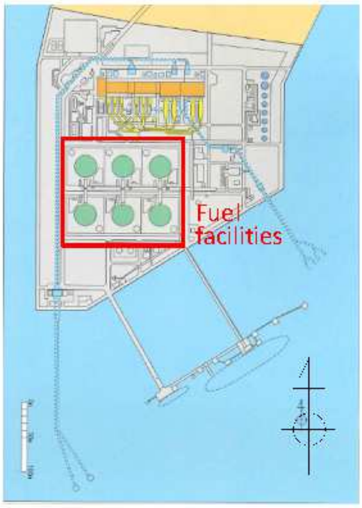

Fig. Plan map of Yanai TPP

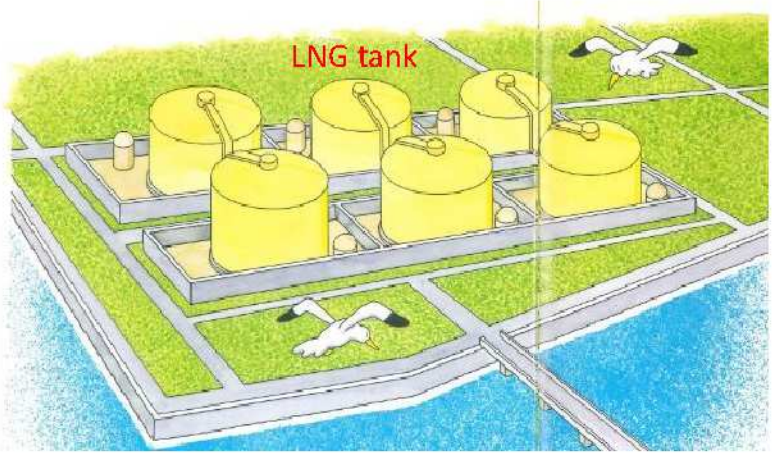

Fig. Overview of LNG tank in Yanai TPP

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2. Civil structures of LNG thermal power plant

2.8 Fuel facilities (continued)

- LNG fuel is stored in tank. The LNG tank stores ultra-low temperature liquids at -162° C, and must have a structure that can withstand low temperatures, such as preventing ground freezing.
- Yanai power plant uses a metal double-shell ground-based LNG tank (storage capacity of approximately 80,000 m^3), and the tank foundation is pile foundation.
- In addition, preparing for LNG leakage, a liquid barrier wall with a height of about 8m is installed on the outer circumference of the tank.

Not disclosed due to containing confidential data

Fig. Cross sectional view of LNG tank

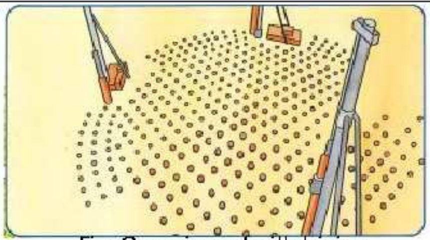

Fig. Overview of pill driving

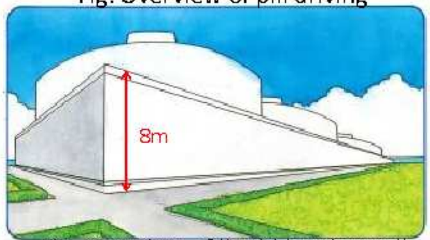

Fig. Overview of liquid barrier wall

2.9 Vaporizer

- A vaporizer is a facility that heats LNG by seawater to turn it into a gas for use as fuel.
- The seawater used for vaporization is discharged to the sea together with the cooling water of the power plant.

Fig. Plan map of Yanai TPP

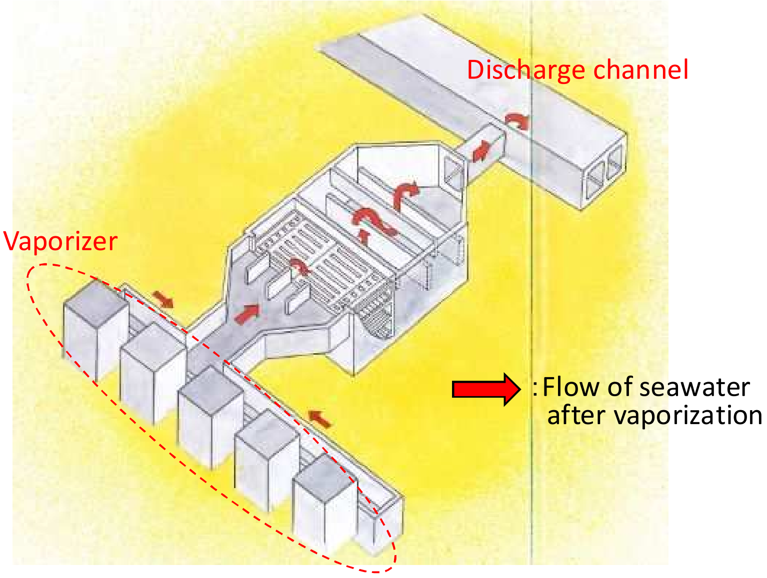

Fig. Overview of vaporize in Yanai TPP

2.10 Switchyard

- The switchyard in Yanai power plant locates on the north side of the power plant, and 110kV and 220kV GIS (gas insulation switchgear) are installed on the foundation slab with a length of about 50m and a width of about 30m.

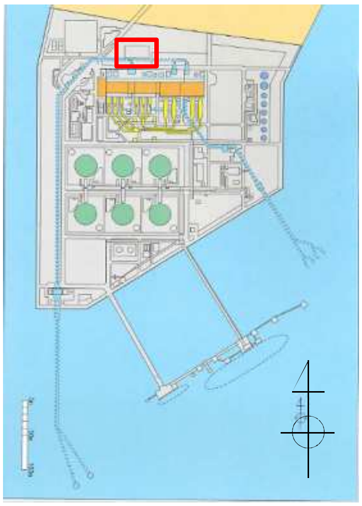

Fig. Plan map of Yanai TPP

Photo. Swichyard in Yanai TPP

3. Objectives of IPP project evaluation

- The purpose of evaluation for civil structure of thermal power plants is to confirm the following two points and objectively judge that the power plant can be constructed and operated safely.
  - ① The developer must be aware of various risks that affect power generation due to natural conditions and natural disasters unique to the project site.
  - ② The developer has taken appropriate measures against those risks.
- In order to achieve this goal, the following points need to be confirmed.
  - ① Does the developer collect the data necessary for planning and designing civil engineering equipment for thermal power plants?
  - ② Does the developer plan and design civil engineering equipment based on those data?
  - ③ Does the developer consider to avoid or reduce the risk of problems that may occur in civil engineering equipment (presentation of countermeasures, etc.)?
- The specific contents will be explained in the next chapter based on the checklist used by our company.

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4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Ground/ Soil condition	Not disclosed due to containing confidential data	

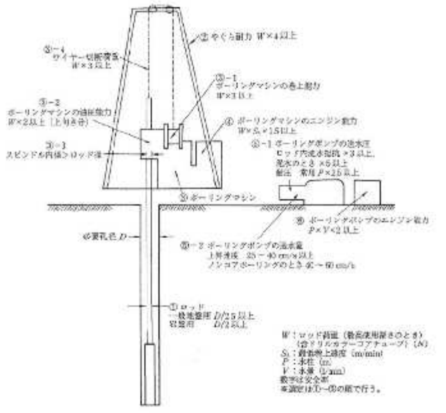


Fig. Image of boring survey

(Citation) 公益財団法人地盤工学会，地盤調査の方法と解説，p.194

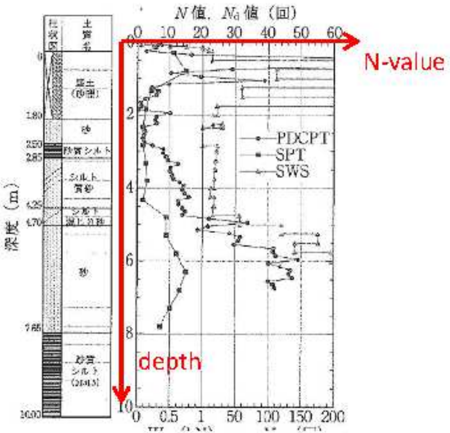


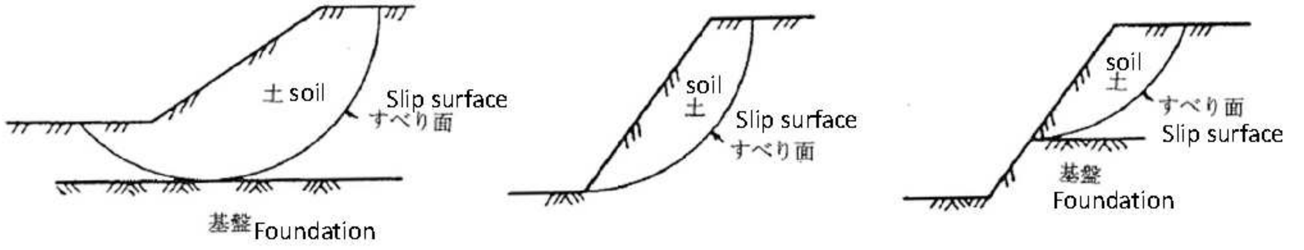
Fig. Boring log (N-value)

(Citation) 公益財団法人地盤工学会，地盤調査の方法と解説，p.320

4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Ground/ Soil condition (continued)	Not disclosed due to containing confidential data	



①底部破壊 Base failure ②斜面先破壊 Toe failure ③斜面内破壊 Slope failure

Fig. Type of circular slip

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4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Earthquake	Not disclosed due to containing confidential data	

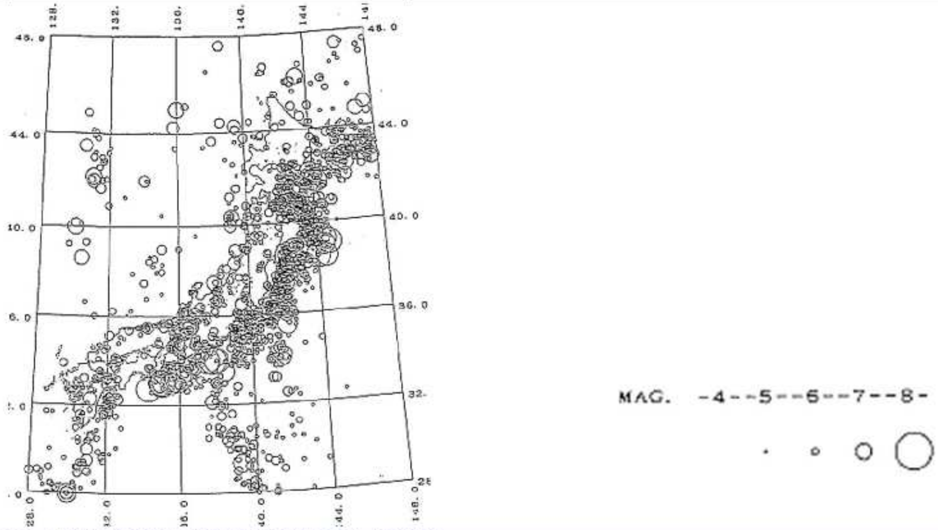
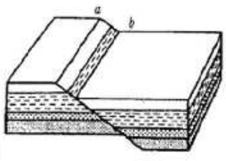


Fig. Earthquake hazard map in Japan

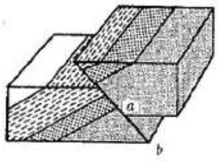
4. Check points of IPP project evaluation

<4.1 Survey and evaluation of natural conditions>

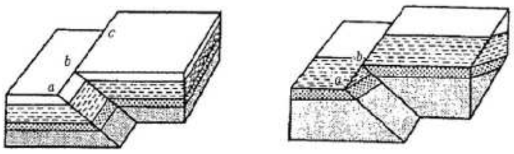
Evaluation item	Check point	Specific example
Earthquake (continued)	Not disclosed due to containing confidential data	



正 断 層
Normal fault



逆 断 層
reverse fault



水 平 断 層
Horizontal fault

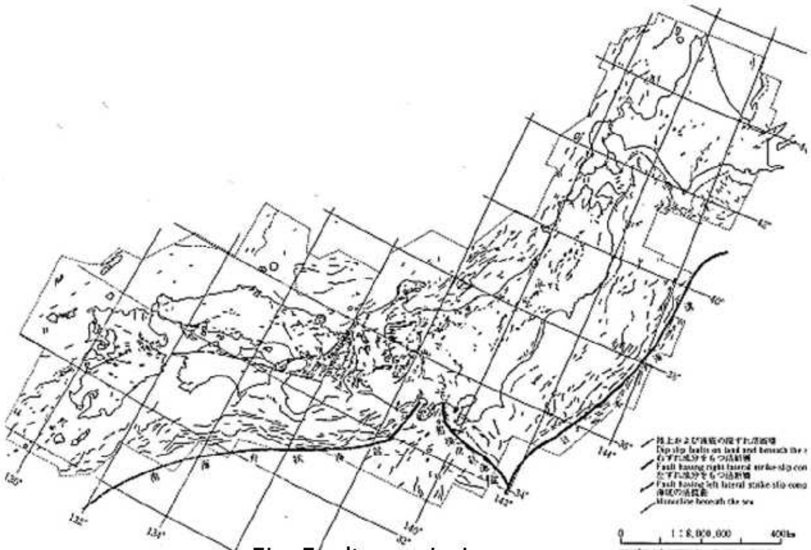


Fig. Fault map in Japan

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4. Check points of IPP project evaluation

<4.1 Survey and evaluation of natural conditions>

Evaluation item	Check point	Specific example
Tsunami	Not disclosed due to containing confidential data	

Wavelength: from several kilo meter to several hundred kilo meter

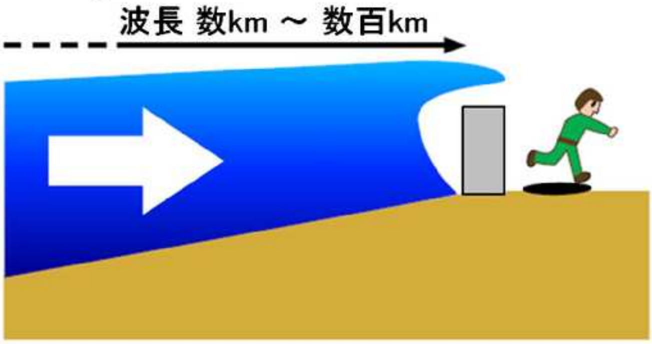

Fig. Image of Tsunami

(Citation)気象庁｜津波について, https://www.jma.go.jp/jma/kishou/know/faq/faq26.html

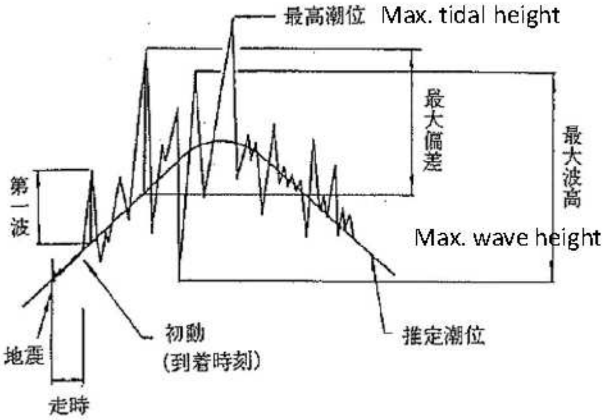

Fig. Time history date of Tsunami wave height (example)

4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Tidal wave	Not disclosed due to containing confidential data	

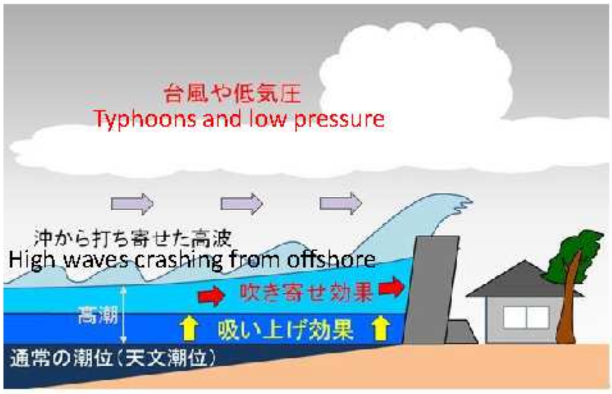

Fig. Image of tidal wave

Photo. Flood damage caused by Tidal wave

(Citation) 気象庁 | 潮汐･海面水位の知識 高潮, https://www.data.jma.go.jp/gmd/kaiyou/db/tide/knowledge/tide/takashio.html
気象庁 | 高潮による災害, https://www.jma.go.jp/jma/kishou/know/ame_chuui/ame_chuui_p6.html

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4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Rainfall	Not disclosed due to containing confidential data	

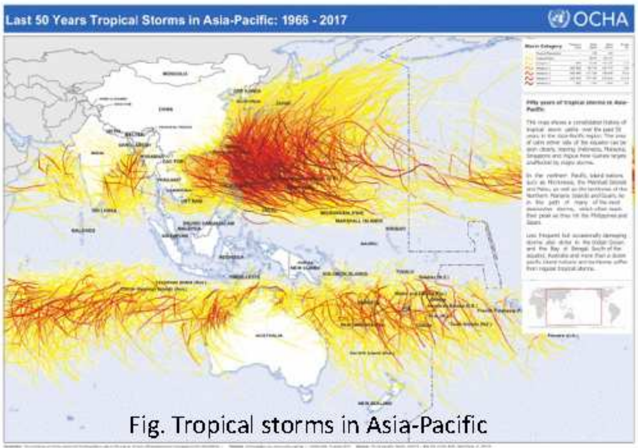
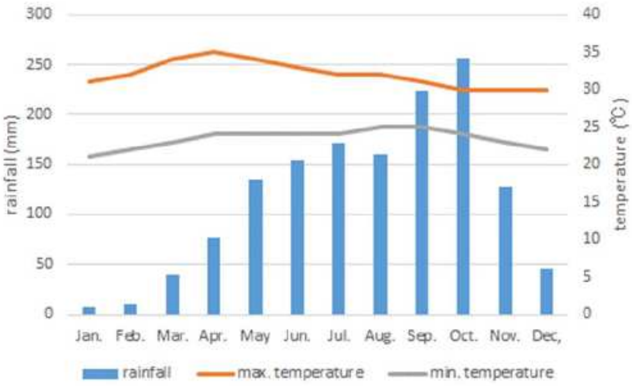


Fig. Tropical storms in Asia-Pacific



Graph. rainfall and temperature

(Citation) Last 50 Years Tropical Storms in Asia-Pacific: 1966 - 2017 - World | ReliefWeb,
https://reliefweb.int/sites/reliefweb.int/files/resources/OCHA_ROAP_StormTracks_v8_180118.pdf

4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Flood	Not disclosed due to containing confidential data	

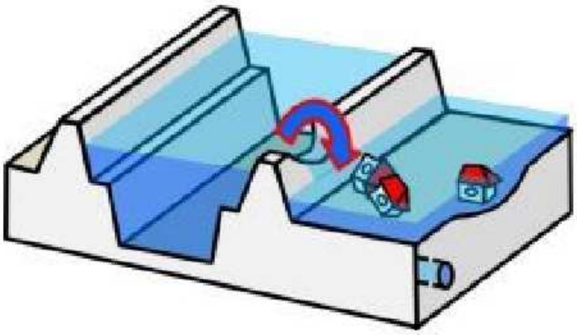


Fig. Image of flood

(Citation) 気象庁｜洪水災害，https://www.jma.go.jp/jma/kishou/know/ame_chuui/ame_chuui_p4.html

Photo. Flood in Kyushu (2012)

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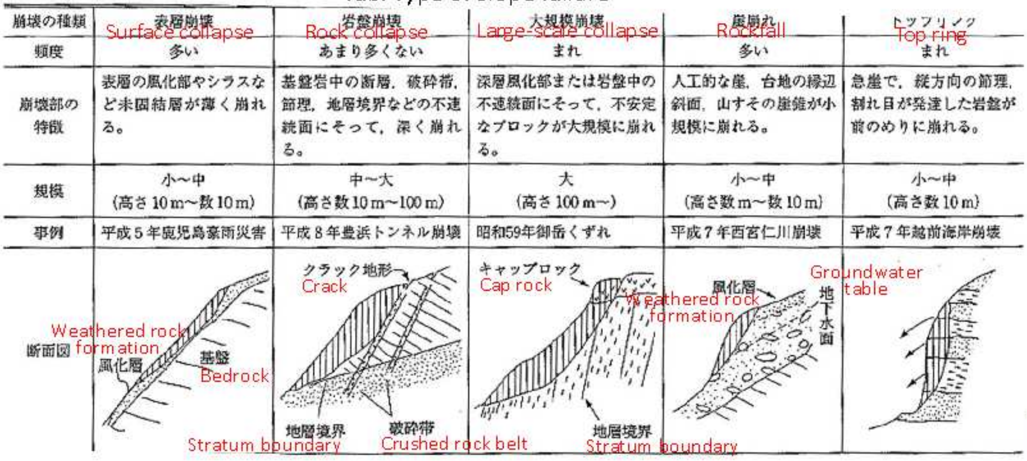
4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Erosion	Not disclosed due to containing confidential data	
Debris Flow		

Tab. Type of slope failure



崩壊の種類	表層崩壊 Surface collapse	岩盤崩壊 Rock collapse	大規模崩壊 Large-scale collapse	崖崩れ Rockfall	トップリング Top ring
頻度	多い	あまり多くない	まれ	多い	まれ
崩壊部の特徴	表層の風化部やシラスなど未固結層が薄く崩れる。	基盤岩中の断層，破砕帯，節理，地層境界などの不連続面にそって，深く崩れる。	深層風化部または岩盤中の不連続面にそって，不安定なブロックが大規模に崩れる。	人工的な崖，台地の縁辺斜面，山すその崖錐が小規模に崩れる。	急崖で，縦方向の節理，割れ目が発達した岩盤が前のめりに崩れる。
規模	小～中 （高さ 10 m～数 10 m）	中～大 （高さ数 10 m～100 m）	大 （高さ 100 m～）	小～中 （高さ数 m～数 10 m）	小～中 （高さ数 10 m）
事例	平成 5 年鹿児島豪雨災害	平成 8 年豊浜トンネル崩壊	昭和59年御岳くずれ	平成 7 年西宮仁川崩壊	平成 7 年越前海岸崩壊
断面図					

4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Tide level	Not disclosed due to containing confidential data	

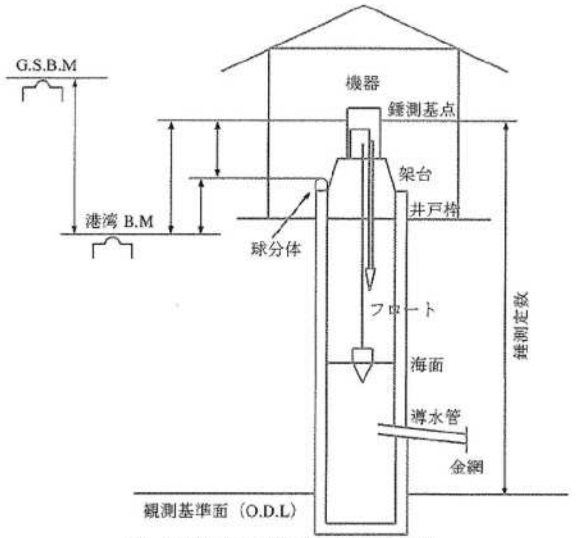


Fig. Image of tidal level gauge

(Citation) 日本港湾協会，港湾の施設の技術上の基準・同解説（下），p.1490

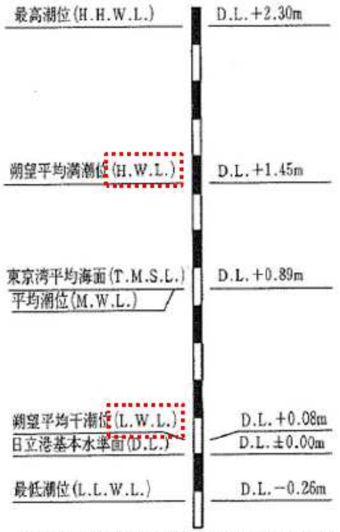


Fig. Tidal level in Pacific ocean

(a) 太平洋

日立港検潮所　昭和42年4月～58年12月

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4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Flow conditions	Not disclosed due to containing confidential data	

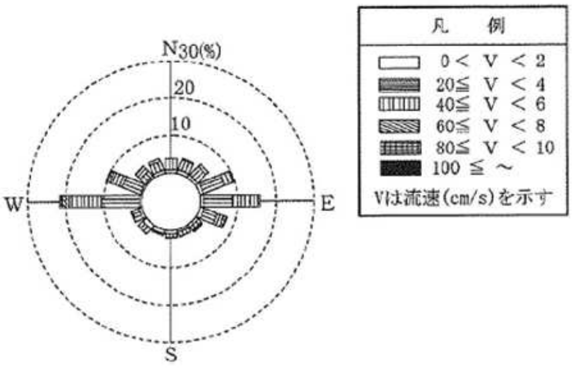

Fig. flow regime

(Citation) 日本港湾協会，港湾の施設の技術上の基準・同解説（下），p.1564，1567

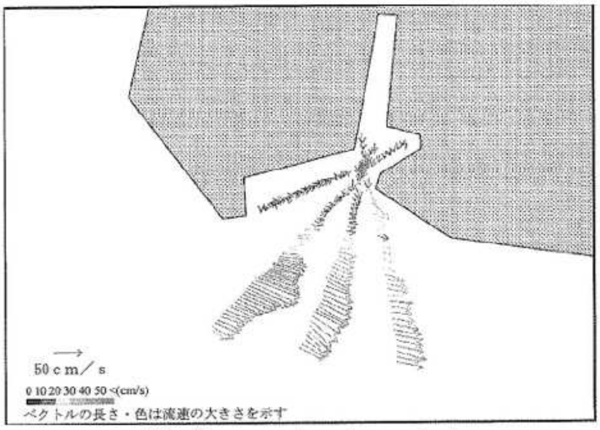

Fig. flow regime in project area

4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Seawater temperature	Not disclosed due to containing confidential data	

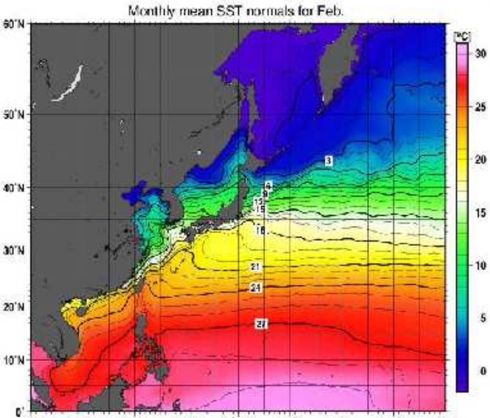

Fig. seawater temperature map

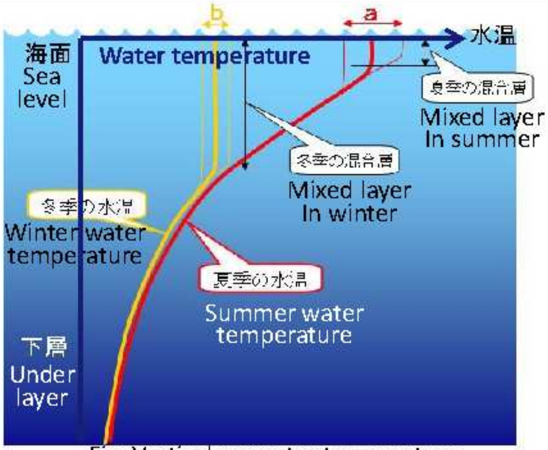

Fig. Vertical seawater temperature

(Citation) 気象庁｜海水温・海流の知識 海面水温, https://www.data.jma.go.jp/gmd/kaiyou/data/db/kaikyo/knowledge/sst.html
気象庁｜海水温・海流の知識 表層混合層, https://www.data.jma.go.jp/gmd/kaiyou/data/db/kaikyo/knowledge/mixedlayer.html

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4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Waves	Not disclosed due to containing confidential data	

Wavelength: A few meters ～ hundreds of meter

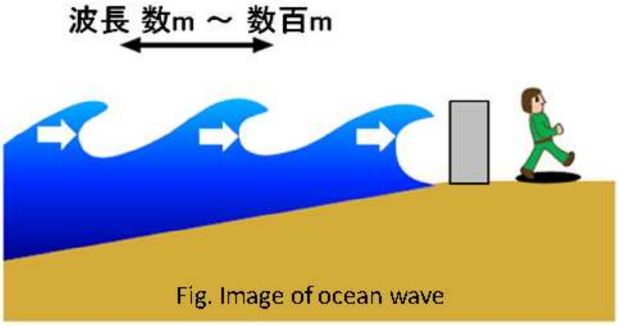

Fig. Image of ocean wave

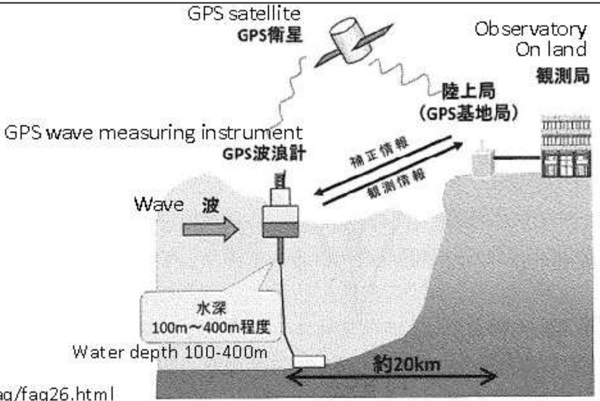

Fig. Ocean wave measuring system

(Citation) 気象庁｜津波について, https://www.jma.go.jp/jma/kishou/know/faq/faq26.html
日本港湾協会, 港湾の施設の技術上の基準・同解説(下), p.1517

4. Check points of IPP project evaluation

＜4.1 Survey and evaluation of natural conditions＞

Evaluation item	Check point	Specific example
Wind conditions	Not disclosed due to containing confidential data	

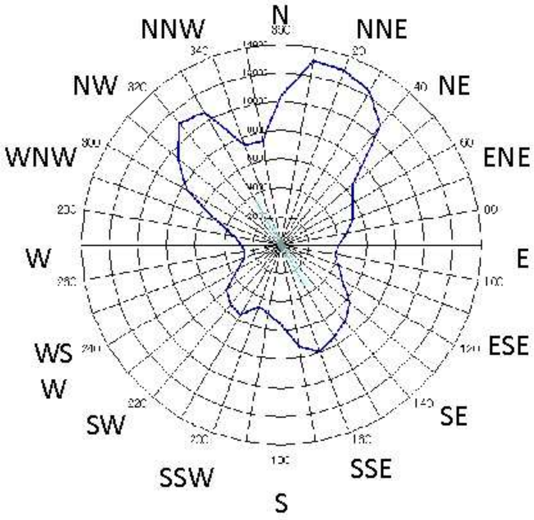

Fig. Image of wind condition

(Citation)成田航空地方気象台HP，https://www.jma-net.go.jp/narita-airport/kansoku/data/kaze2.htm#ue

There is a large proportion of northerly winds. The most wind direction is north-northeast, and the smallest wind direction is west.

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4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Equipment layout	Not disclosed due to containing confidential data	

Not disclosed due to containing confidential data

4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Equipment layout (continued)	Not disclosed due to containing confidential data	

Not disclosed due to containing confidential data

Fig. Plan map of Yanai TPP

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4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Equipment layout (continued)	Not disclosed due to containing confidential data	

Not disclosed due to containing confidential data

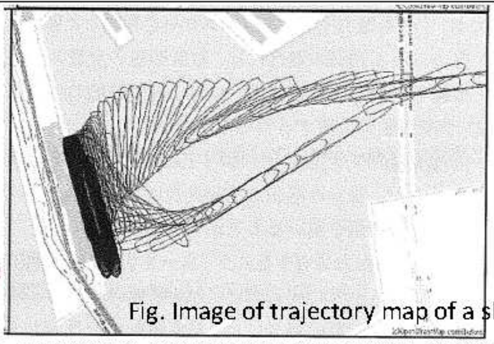

Fig. Image of trajectory map of a ship

(Citation)日本港湾協会，港湾の施設の技術上の基準・同解説(中)，p.903

4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Equipment layout (continued)	Not disclosed due to containing confidential data	

Not disclosed due to containing confidential data

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4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Specific example
Equipment layout (continued)	Not disclosed due to containing confidential data

Not disclosed due to containing confidential data

4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Shore protection	Not disclosed due to containing confidential data	

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4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Shore protection (continued)	Not disclosed due to containing confidential data	

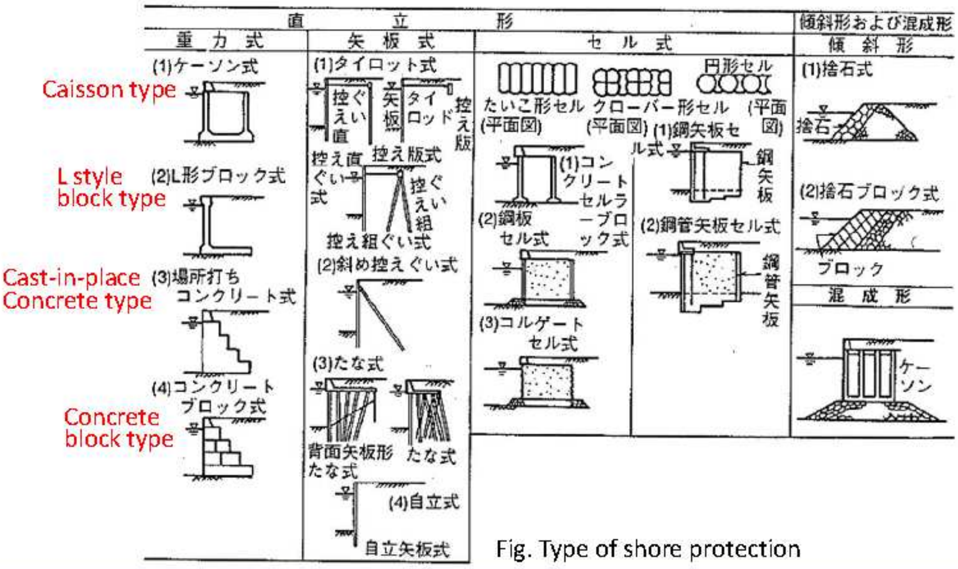
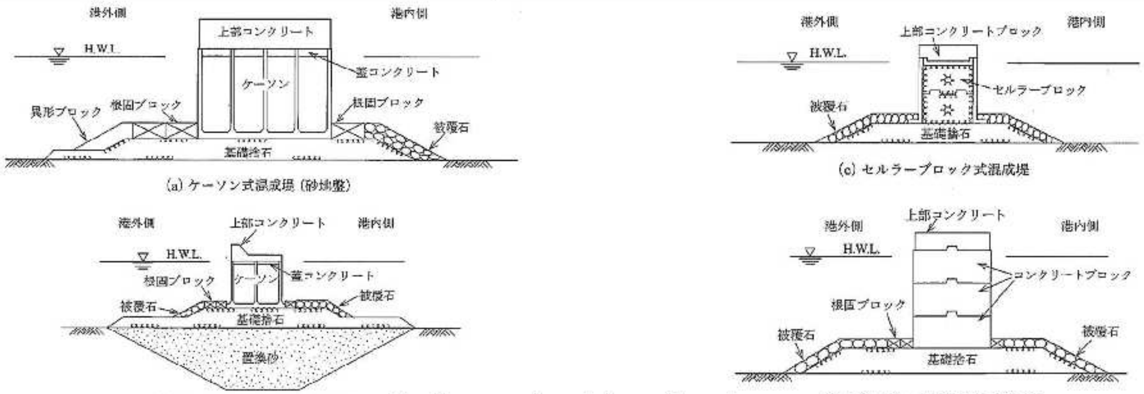


Fig. Type of shore protection

4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Breakwater	Not disclosed due to containing confidential data	



(a) ケーソン式混成堤（砂地盤）

(b) ケーソン式混成堤（軟弱地盤）

(c) セルラーブロック式混成堤

(d) コンクリートブロック式混成堤

Fig. Cross sectional view of break water

(Citation) 日本港湾協会，港湾の施設の技術上の基準・同解説（中），p.921

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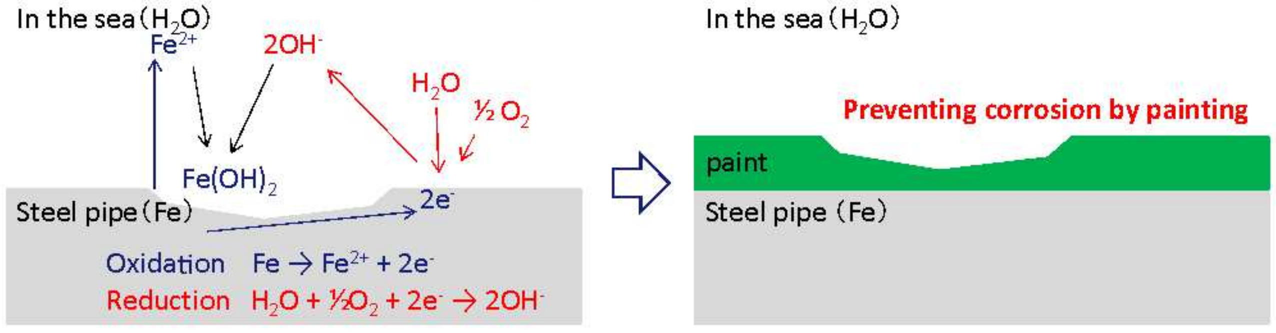
4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Water intake and discharge equipment (common)	Not disclosed due to containing confidential data	

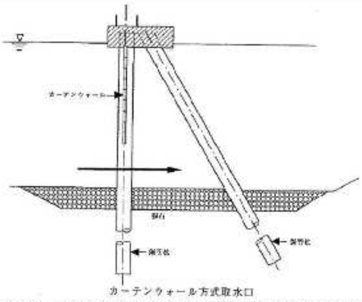


Corrosion of steel pipe by reduction
→reducing durability due to hole on the steel pipe

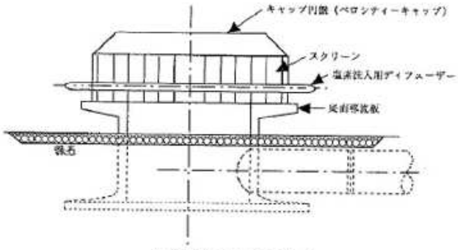
4. Check points of IPP project evaluation

<4.2 Planning and design of civil engineering equipment >

Evaluation item	Check point	Specific example
Water intake	Not disclosed due to containing confidential data	



カーテンウォール方式取水口
Fig. Cross sectional view of curtain wall type



標準型鉛直取水管方式
Fig. Cross sectional view of standard vertical intake pipe type

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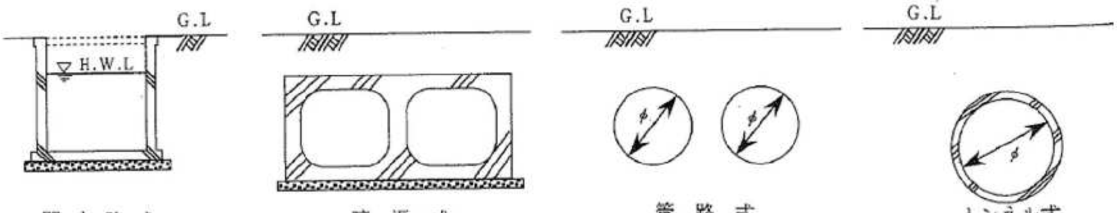
4. Check points of IPP project evaluation

<4.2 Planning and design of civil engineering equipment >

Evaluation item	Check point	Specific example
Intake channel	Not disclosed due to containing confidential data	



開水路式
Open channel

暗渠式
Culvert

管路式
pipeline

トンネル式
tunnel

図 17-3-1 取水路の構造形式例
Fig. Type of intake channel

4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Intake chamber	Not disclosed due to containing confidential data	

Not disclosed due to containing confidential data

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4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Discharge Channel	Not disclosed due to containing confidential data	

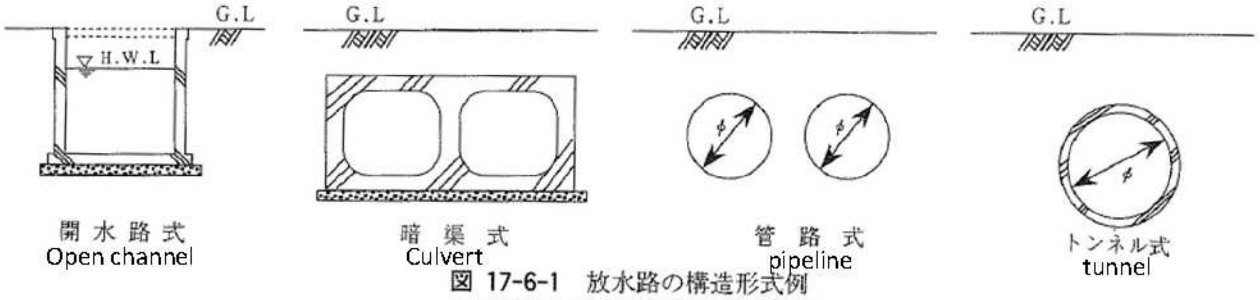


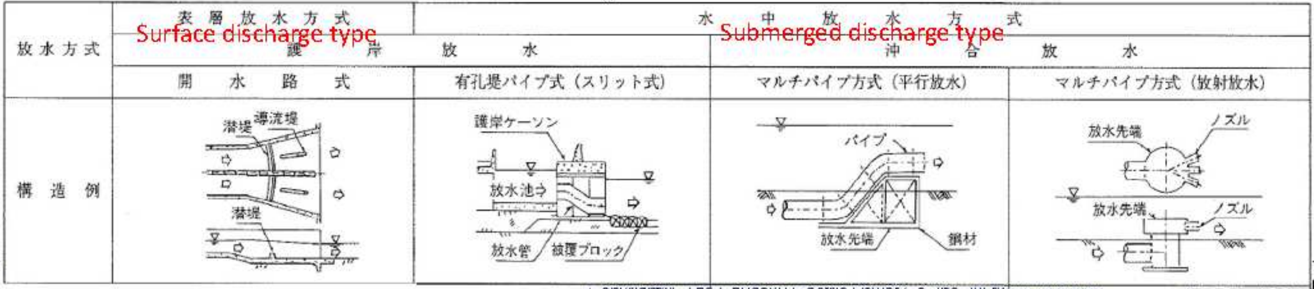
図 17-6-1 放水路の構造形式例
Fig. Type of discharge channel

4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
Outlet	Not disclosed due to containing confidential data	

Tab. Type of outlet



放水方式	表層放水方式 Surface discharge type	水中放水方式 Submerged discharge type		
	護岸放水		沖合放水	
	開水路式	有孔堤パイプ式（スリット式）	マルチパイプ方式（平行放水）	マルチパイプ方式（放射放水）
構造例				

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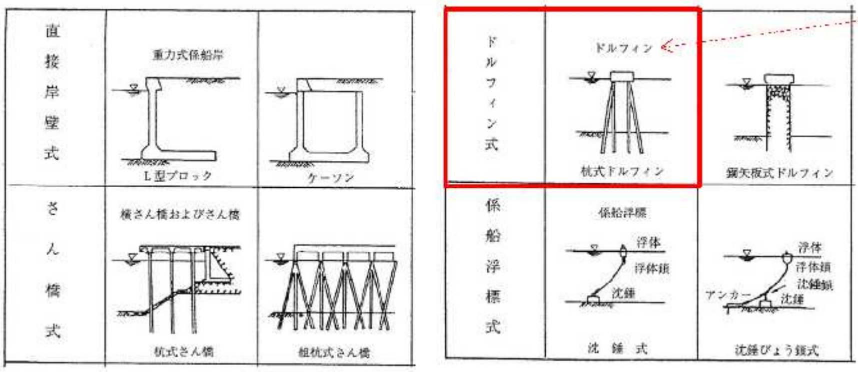
4. Check points of IPP project evaluation

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
LNG unloading jetty	Not disclosed due to containing confidential data	



Adopted at the jetty of Yanai LNG thermal power plant

Fig. Type of jetty

＜4.2 Planning and design of civil engineering equipment ＞

Evaluation item	Check point	Specific example
LNG unloading jetty (continued)	Not disclosed due to containing confidential data	

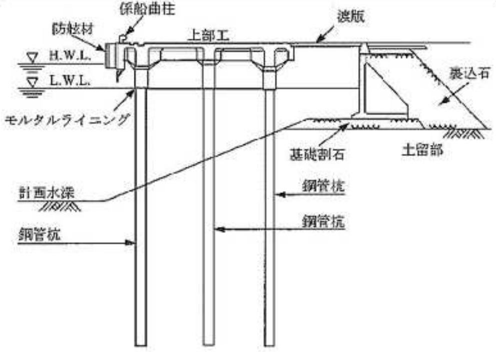


Fig. Cross sectional view of LNG unloading jetty

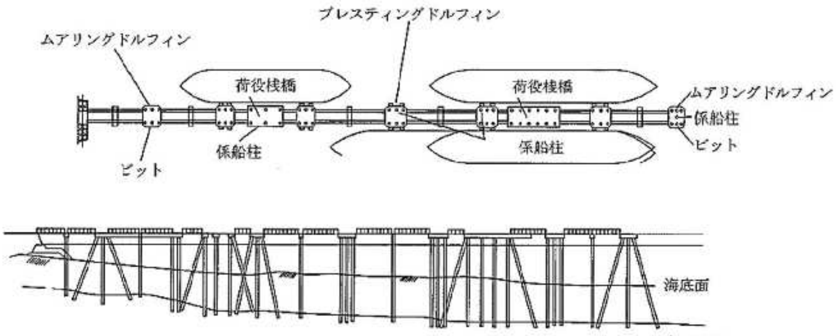


Fig. Overview of jetty

(Citation) 日本港湾協会, 港湾の施設の技術上の基準・同解説（中）, p.1199-1226

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5. Conclusion

- In this lecture, the outline of civil structures and basic points for evaluation were explained in order to improve the capacity of evaluation related to the civil structures of LNG thermal power plants by IPP.
- The points to be reviewed or evaluated intensively are different, project by project. However, I would appreciate you to work on future IPP evaluation based on today's contents.

Reference

- 社団法人電力土木技術協会編『火力・原子力発電所土木構造物の設計（増補改訂版）』
- 中国電力株式会社『柳井発電所Ⅰ・Ⅱ期工事　土木工事記録（計画・施工編）』
- 中国電力株式会社『柳井発電所Ⅰ・Ⅱ期工事　建築工事記録』
- 中国電力株式会社『火力発電所土木設備の概要』
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- 株式会社大本組　飛鳥建設株式会社　佐藤工業株式会社　洋林建設株式会社共同事業体『工事記録写真集　中国電力株式会社　柳井（発）1・2号取水路工事他』
- 清水建設株式会社　前田建設工業株式会社　大成建設株式会社　飛鳥建設株式会社　洋林建設株式会社　『工事記録写真集　中国電力株式会社　柳井（発）本館建物その他工事』
- 公益財団法人地盤工学会『地盤調査の方法と解説』
- 日本港湾協会『港湾の施設の技術上の基準・同解説（上・中・下）』

Thank you for your kind attention.

Energia
中国電力株式会社
THE CHUGOKU ELECTRIC POWER CO.,INC

WG2: IPP Project Evaluation Methodology

-Hydropower Plant-

1st Class : Basics

The Chugoku Electric Power Co., Inc.

● General View of the training to strengthen IPP review capacity (hydropower)

- The purpose of this training course (5 sessions including this lecture) is to deal with the technical matters necessary for the technical review of FS of hydropower plants, and to improve the ability of the participants.
- This training course consists of "lectures on basic knowledge" and "lectures on each specialized field such as civil engineering, electricity, and hydro-mechanical equipment", which are necessary for technical assessment of FS of hydropower project.

Flow of this training

STEP 1
(Nov, 2021)

- Confirmation of Cambodian IPP review capacity and requests for training through preliminary questionnaire

⇩

STEP 2
(Dec, 2020-Jan 2022)

- Review of training content based on results of preliminary questionnaire

⇩

Present
(Feb, 2022-Mar, 2022)

- Implementation of training to strengthen IPP review capability (hydropower, consist of 5 lectures)

1st Basic training, 2nd, 3rd and 4th training for civil engineering,
5th training for electrical engineering.

● Contents of this lecture

- In this 1st lecture, the basic knowledge required for the technical review of FS (including pre-FS) of hydropower plants will be explained.

〔Lecture Topic〕

Fundamentals required for technical review of FS of hydropower plants

〔Lecture Contents〕

Chapter 1: Place of FS in the investigation & study of hydropower plants

Chapter 2: Outline of each study and technical review item in the FS of a hydropower plant

Chapter 3: Major Check Points to be considered in the technical review of hydropower FS

Chapter 4: How to conduct the training on FS review of Hydropower

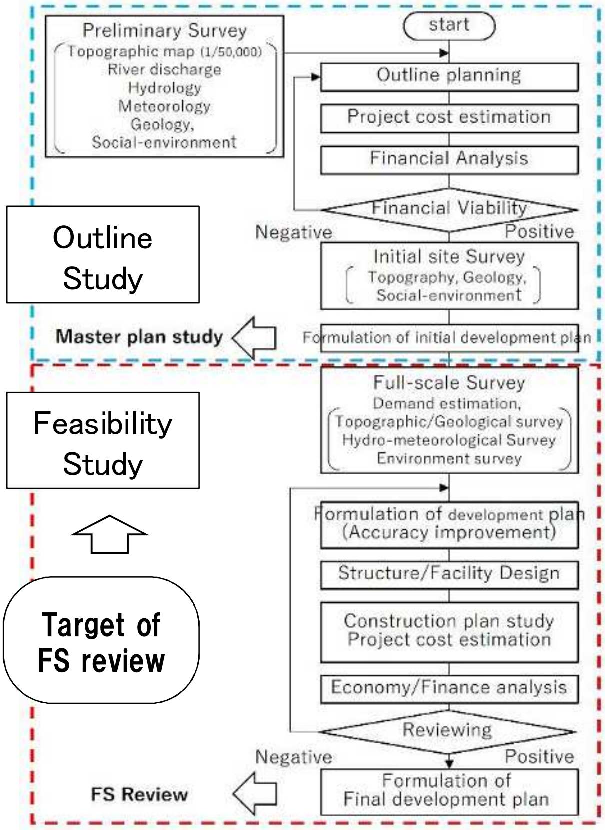
Chapter 1

Place of FS

in the planning study of hydropower plants

How to proceed with the Power Generation Plan Study

- Surveys and studies of hydropower can be divided into two types:
  - Outline study
  - Feasibility study (FS).
- The Outline study is an initial stage study that uses topographic maps at a scale of about 1/50,000 and is used to prepare a master plan.
- The FS is the final stage of project realization using topographic maps at a scale of about 1/1,000 to 1/5,000, and is used for the feasibility evaluation of individual projects. It is used to evaluate the feasibility of individual projects.
- The FS is the subject of this FS review training.



Source: 水力開発ガイドマニュアル, JICA(2011), p.5-2

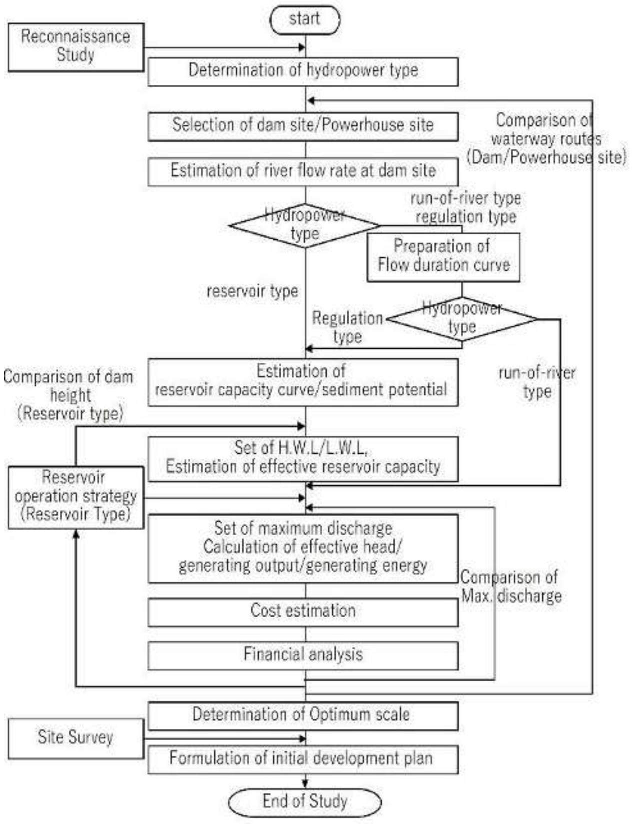
Procedure of Feasibility Study

Purpose of Outline Study

- Early stage surveys and studies of individual sites (to be conducted prior to FS)
- Potential Hydropower Study
- Master Plan Study

Procedure of Outline Study

- Select the dam and power plant (or discharge points) considering the river flow and topography.
- Determine the max. water discharge for power generation based on the flow rate at the dam.
- Calculate the power output and generated energy from the max. water discharge and the vertical gap between the dam and power plant.
- Calculate the construction cost of civil engineering facilities such as dams, waterways, and power plants, and electrical facilities such as water turbine generators, and calculate the construction cost of the entire project.
- Analyze and evaluate the project from the viewpoints of technology, economy, and environment, and formulate a draft



Source: 水力開発ガイドマニュアル, JICA(2011), p.5-4

Flow throughout FS

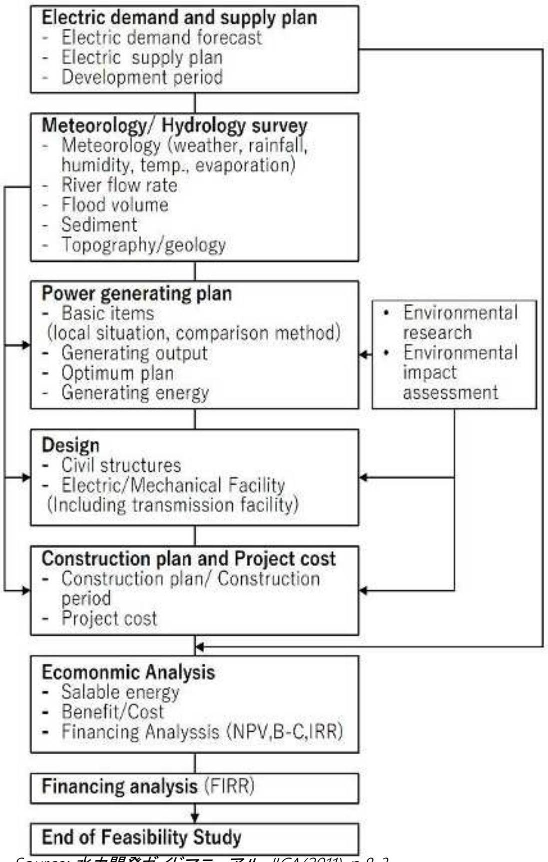
Purpose of FS

- An attempt to objectively prove that a project is feasible from the view of technology, economics, finance, and the social–natural environment. It serves as a document to judge the feasibility of a project.

- FS is classified into pre-FS and FS, and the difference between the two lies in the accuracy of the survey.
- Surveys that do not have the required accuracy are classified as pre-FS.

Procedure of FS

- Data related to meteorology, hydrology, topography and geology are collected and analyzed.
- Considering the topography and geology of the site, the power generation system and layout are determined. As a result, the basic specifications for facilities and power generation are determined.
- The design of civil engineering structures, electrical and power transmission equipment is carried out, and construction plans and costs are estimated.
- The impact of hydropower development on society and the natural environment is assessed, and countermeasures are discussed.
- Finally, economic/financial evaluations are conducted.



Source: 水力開発ガイドマニュアル, JICA(2011), p.8-3

Place of the FS in the Implementation of the IPP Project in Cambodia

Place of the FS in the Implementation of the IPP Project in Cambodia

- The pre-FS review is conducted to determine whether the project can proceed to the FS stage.
- The FS review is conducted prior to the Ministerial meeting to discuss whether the project can be implemented.
- In Cambodia, IPP review is conducted by a committee whenever necessary, and the main items and structure of the review are as follows

1. Formulation of the government's development plan for electron microscopes
2. Proposal by IPP developer
5. MOU conclusion, Pre-FS implementation, reporting

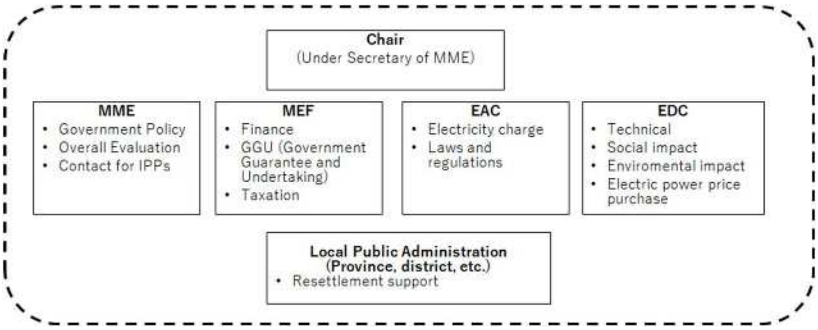
⇩ Review of Pre-FS

4. Approval of Pre-FS
5. MOU conclusion, FS implementation, reporting

⇩ Review of FS

6. Approval of FS
7. Report on FS to Council of Ministers
8. Application for PPA, LA, and IA
9. parliamentary debate
10.Conclusion of PPA, LA and IA
11.Start of construction

IPP Review Structure



Chapter 1: Place of FS in the planning study of hydropower plants

Summary

Place of FS in the planning study of hydropower plants

- The FS is the final stage of the project realization process and is used to evaluate the feasibility of individual projects.
- The pre-FS is a part of the FS, and the accuracy of the study is inferior to that of the FS.

Place of the FS in the Implementation of the IPP Project in Cambodia

- The pre-FS review is conducted to determine whether the project can proceed to the FS stage.
- The FS review is conducted prior to the Ministerial meeting to discuss whether the project can be implemented.

⇩

- Since the review of the Pre-FS and FS is conducted when important action or decisions are made within the Cambodian government, it is necessary to establish the review items, methods and criteria to ensure fairness and transparency.

Chapter 2

Outline of each study and technical review item in the FS of a hydropower plant

Introduction

- This section provides an overview of the FS conducted by IPPs in order to obtain the basic knowledge required for the technical review of the FS (including pre-FS) of hydropower plants.
- If the FS does not contain the necessary data for the review, if the necessary studies have not been conducted, or if the necessary actions have not been taken in case of social and natural environmental impacts, the IPP needs to be instructed to implement the necessary actions.
- First of all, we would like to be fully aware of what kind of data is required and what kind of studies are necessary in order to conduct the FS review.

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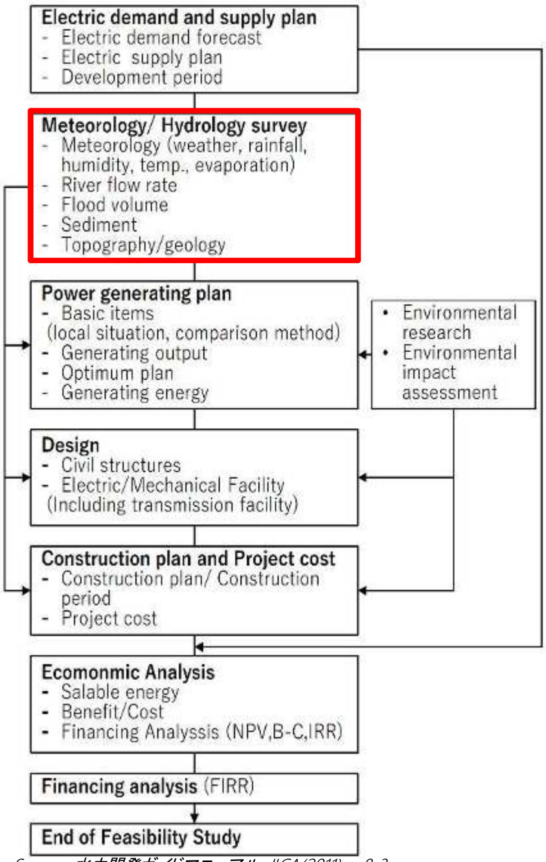
(1) Hydrological and Meteorological Survey, Topographical and Geological Survey

Overview of hydrological and meteorological surveys, topographical and geological survey

- The following data, etc., are required for power generating estimation, structural design and construction planning of hydropower plants.

Items	Data/Documents
Weather data	Rainfall, Evaporation
River Data	Water discharge, Flood volume, Amount of suspended sediment
Topographic data	Satellite images, Aerial photographs
Geology and Construction Materials*	Geological reconnaissance, Borehole survey, Geophysical prospecting
Seismic data	seismic load evaluation (horizontal /vertical seismic coefficient etc.)

- In the FS, above data will be collected, analyzed, and used in various studies to be conducted in the subsequent study.



Electric demand and supply plan
- Electric demand forecast
- Electric supply plan
- Development period

Meteorology/ Hydrology survey
- Meteorology (weather, rainfall, humidity, temp., evaporation)
- River flow rate
- Flood volume
- Sediment
- Topography/geology

Power generating plan
- Basic items (local situation, comparison method)
- Generating output
- Optimum plan
- Generating energy

- Environmental research
- Environmental impact assessment

Design
- Civil structures
- Electric/Mechanical Facility (Including transmission facility)

Construction plan and Project cost
- Construction plan/ Construction period
- Project cost

Ecomonmic Analysis
- Salable energy
- Benefit/Cost
- Financing Analyssis (NPV,B-C,IRR)

Financing analysis (FIRR)

End of Feasibility Study

Source: 水力開発ガイドマニュアル, JICA(2011), p.8-3

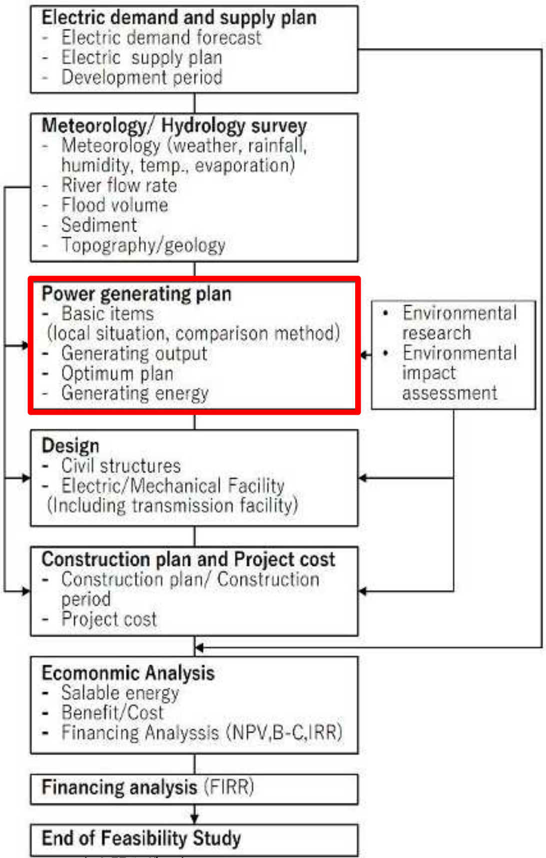
* concrete aggregate, fill material, core material, etc.

(2) Basic Study

Outline of Power Generating plan

- In consideration of the topography and geology of the project site, the power generation system (run-off-river, reservoir, or regulating reservoir) is determined, and the facility layout is selected accordingly.
- For the selected power generation system, an optimization plan with different power generation capacity and dam height, etc. is conducted by economic comparison, after confirming the environmental impact as appropriate.
- As a result, the optimal plan is selected, and the basic specifications as follows of the main structures and the power generation plan are determined.

Items	Data/Documents
Basic specifications of main structures	Dam height, Channel inner diameter, etc.
Basic specifications of power generation plan	Maximum water discharge, Gross head, force, Generating output, Generating Energy.



Electric demand and supply plan
- Electric demand forecast
- Electric supply plan
- Development period

Meteorology/ Hydrology survey
- Meteorology (weather, rainfall, humidity, temp., evaporation)
- River flow rate
- Flood volume
- Sediment
- Topography/geology

Power generating plan
- Basic items (local situation, comparison method)
- Generating output
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- Environmental research
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Design
- Civil structures
- Electric/Mechanical Facility (Including transmission facility)

Construction plan and Project cost
- Construction plan/ Construction period
- Project cost

Ecomonmic Analysis
- Salable energy
- Benefit/Cost
- Financing Analyssis (NPV,B-C,IRR)

Financing analysis (FIRR)

End of Feasibility Study

Source: *水力開発ガイドマニュアル, JICA(2011), p.8-3*

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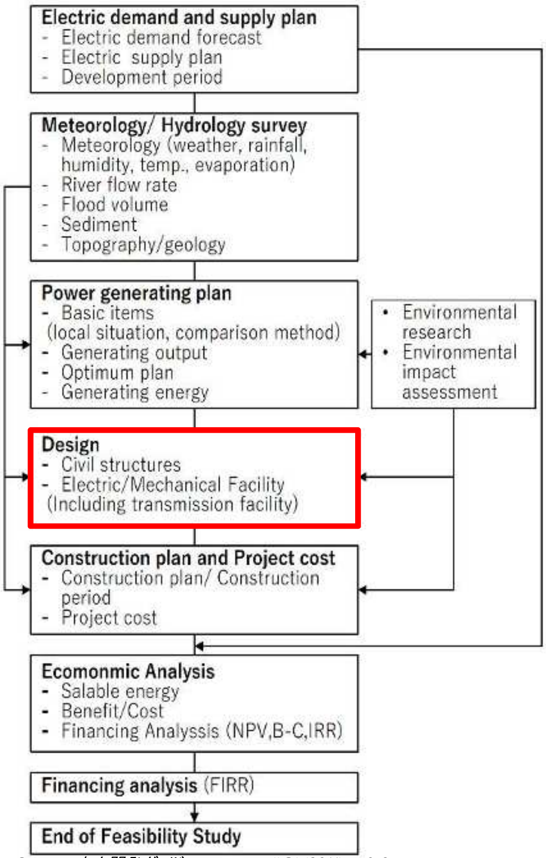
(3) Design of Civil Structures

Outline of Design of Civil Structures

- The basic design of each civil structures is implemented in the basic specification that were finalized in the "(2) Basic design".
- The basic design (including the structural design) of the following major civil structures is carried out in the meteorological and hydrological data, topographic and geological data, etc.

Location	Major Civil Structures
Dam/Weir	Dam/Weir, flood, Spillway
Headrace	Water Intake, Settling basin, Headrace (tunnel) , Head tank/Surge tank, Penstock
Powerhouse	Power house
Outlet	Tailrace, Outlet



Electric demand and supply plan
- Electric demand forecast
- Electric supply plan
- Development period

Meteorology/ Hydrology survey
- Meteorology (weather, rainfall, humidity, temp., evaporation)
- River flow rate
- Flood volume
- Sediment
- Topography/geology

Power generating plan
- Basic items (local situation, comparison method)
- Generating output
- Optimum plan
- Generating energy

- Environmental research
- Environmental impact assessment

Design
- Civil structures
- Electric/Mechanical Facility (Including transmission facility)

Construction plan and Project cost
- Construction plan/ Construction period
- Project cost

Ecomonmic Analysis
- Salable energy
- Benefit/Cost
- Financing Analyssis (NPV,B-C,IRR)

Financing analysis (FIRR)

End of Feasibility Study

Source: *水力開発ガイドマニュアル, JICA(2011), p.8-3*

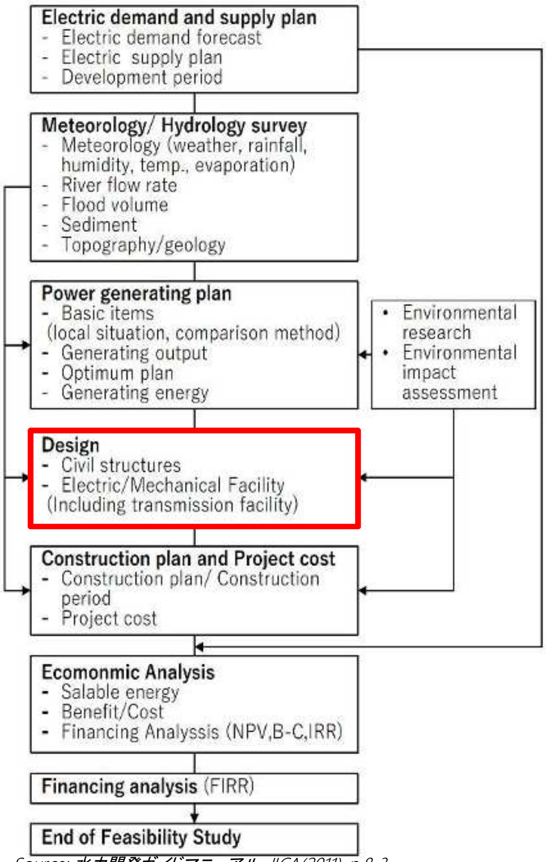
Chapter 2: Outline of each study and technical review item in the FS of a hydropower plant
(4) Design of Electrical and Mechanical facility (Including transmission facility)

Outline of Design of Electrical and Mechanical facility

- Taking into account the operation of the power plant and the fluctuating water consumption, the most suitable type of turbine and generator will be determined and the design with FS stage accuracy will be implemented.

Outline of Design of Transmission facility)

- Planning and design of transmission is carried out assuming the electric power supply destination of the hydropower project.
- Grid analysis is performed to study the stability of the grid when the project is put into the grid.



Electric demand and supply plan
- Electric demand forecast
- Electric supply plan
- Development period

Meteorology/ Hydrology survey
- Meteorology (weather, rainfall, humidity, temp., evaporation)
- River flow rate
- Flood volume
- Sediment
- Topography/geology

Power generating plan
- Basic items (local situation, comparison method)
- Generating output
- Optimum plan
- Generating energy

- Environmental research
- Environmental impact assessment

Design
- Civil structures
- Electric/Mechanical Facility (Including transmission facility)

Construction plan and Project cost
- Construction plan/ Construction period
- Project cost

Ecomonmic Analysis
- Salable energy
- Benefit/Cost
- Financing Analyssis (NPV,B-C,IRR)

Financing analysis (FIRR)

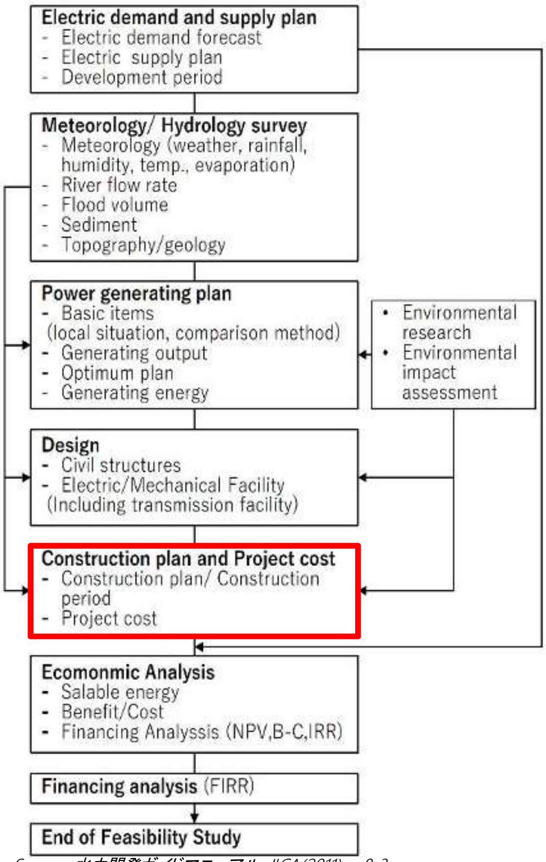
End of Feasibility Study

Source: *水力開発ガイドマニュアル, JICA(2011), p.8-3*

Chapter 2: Outline of each study and technical review item in the FS of a hydropower plant
(5) Construction plan and construction cost

Outline of Construction plan and construction cost

- Considering the site conditions of the project, the construction plan and the construction process are formulated based on the feasible construction method at the current technical level.
- In addition to meteorological and hydrological data, topographical and geological data, transportation conditions for materials and equipment, and construction conditions (labor, electric power, water, and land acquisition) are taken into consideration.
- Based on the design of each facility, the construction cost is estimated for each facilities, and then the total construction cost is estimated by summing them up.
- In addition to the construction cost directly related to the construction of civil and electrical facilities, the construction cost includes the cost for the management of the construction (engineering cost, reserve cost, and interest during construction).
- In order to make a financial plan, the required funds for each year are calculated for each item, in domestic and foreign currencies.



Electric demand and supply plan
- Electric demand forecast
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- Development period

Meteorology/ Hydrology survey
- Meteorology (weather, rainfall, humidity, temp., evaporation)
- River flow rate
- Flood volume
- Sediment
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Power generating plan
- Basic items (local situation, comparison method)
- Generating output
- Optimum plan
- Generating energy

- Environmental research
- Environmental impact assessment

Design
- Civil structures
- Electric/Mechanical Facility (Including transmission facility)

Construction plan and Project cost
- Construction plan/ Construction period
- Project cost

Ecomonmic Analysis
- Salable energy
- Benefit/Cost
- Financing Analyssis (NPV,B-C,IRR)

Financing analysis (FIRR)

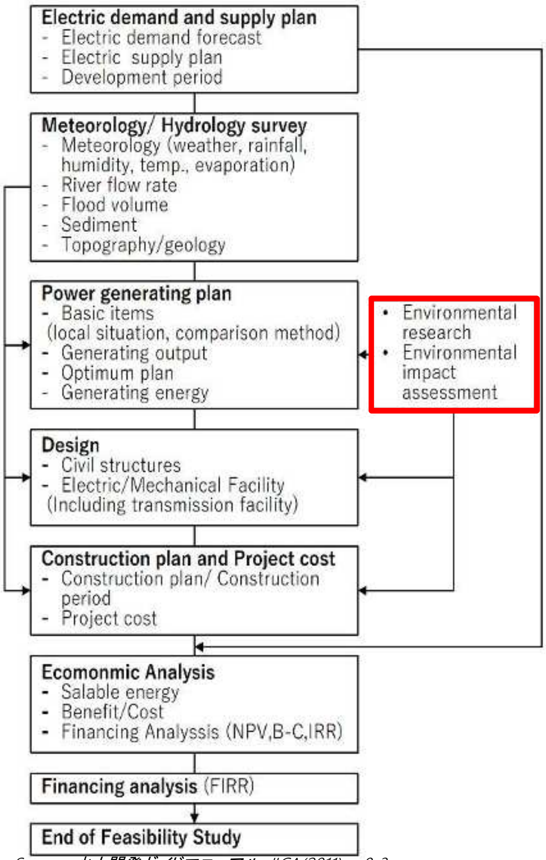
End of Feasibility Study

Source: *水力開発ガイドマニュアル, JICA(2011), p.8-3*

(6) Environmental Impact Assessment

Outline of Environmental Impact Assessment

- The development of a hydropower project that creating a reservoir may have serious impacts on the social and natural environment of the area surrounding the project.
- In the FS, the impact of the project on the social and natural environment will be assessed during the construction and operation periods, and the necessary measures to mitigate the impact will be defined.



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- Generating output
- Optimum plan
- Generating energy

- Environmental research
- Environmental impact assessment

Design
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- Electric/Mechanical Facility (Including transmission facility)

Construction plan and Project cost
- Construction plan/ Construction period
- Project cost

Ecomonmic Analysis
- Salable energy
- Benefit/Cost
- Financing Analyssis (NPV,B-C,IRR)

Financing analysis (FIRR)

End of Feasibility Study

Source: *水力開発ガイドマニュアル, JICA(2011), p.8-3*

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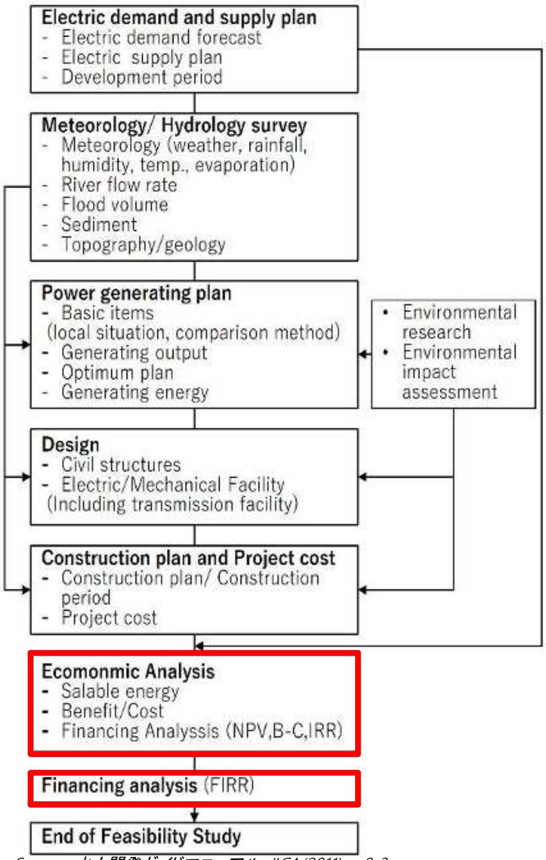
(7) Financing Evaluation

Outline of Economic/Financing Analysis

- The economic appropriateness of the project is analyzed in terms of benefits and costs.
- The benefits are determined in terms of the output and quantity of electricity calculated in "(2) Basic Study", while the costs are determined from the construction costs calculated in "(6) Construction plan and construction cost".
- IPPs are judged to implement the project by determining the internal rate of return (PIRR, EIRR) of the project and comparing it with their own hurdle rates, etc.



Electric demand and supply plan
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- Electric supply plan
- Development period

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- Meteorology (weather, rainfall, humidity, temp., evaporation)
- River flow rate
- Flood volume
- Sediment
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Power generating plan
- Basic items (local situation, comparison method)
- Generating output
- Optimum plan
- Generating energy

- Environmental research
- Environmental impact assessment

Design
- Civil structures
- Electric/Mechanical Facility (Including transmission facility)

Construction plan and Project cost
- Construction plan/ Construction period
- Project cost

Ecomonmic Analysis
- Salable energy
- Benefit/Cost
- Financing Analyssis (NPV,B-C,IRR)

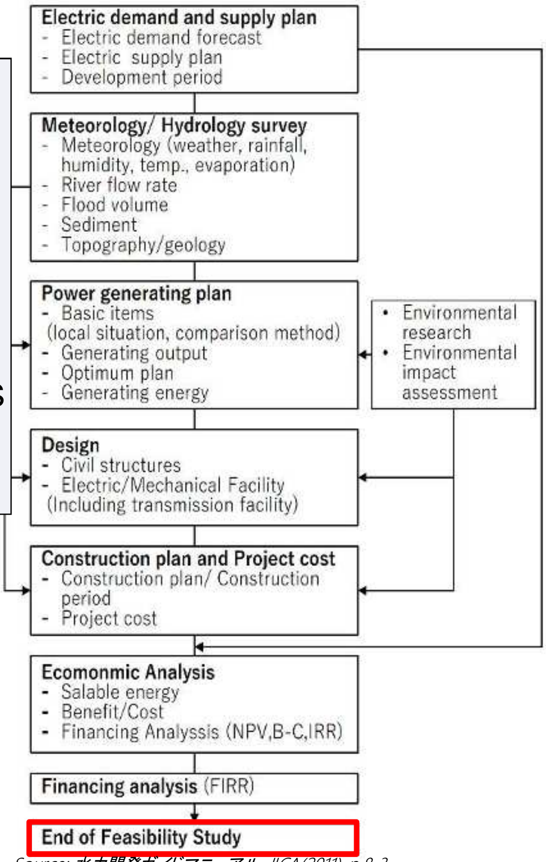
Financing analysis (FIRR)

End of Feasibility Study

Source: *水力開発ガイドマニュアル, JICA(2011), p.8-3*

Summary

- Feasibility Study (FS) is conducted to determine whether a project is technically, economically, socially, and environmentally viable or not.
- This chapter provides an overview of each of the studies and technical considerations conducted in the FS.
- In this chapter, I would like you to recognize what can be reviewed and what should be reviewed in FS review by joining the subsequent lectures.



Electric demand and supply plan
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Construction plan and Project cost
- Construction plan/ Construction period
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Financing analysis (FIRR)

End of Feasibility Study

Source: 水力開発ガイドマニュアル, JICA(2011), p.8-3

Chapter 3

Points to be considered in the technical review of hydropower FS

Introduction

Current status/concerns of FS review

- In Cambodia, the IPP Review Committee conducts the review from the prospective of ;
  - Consistency between the government plan and the power plant operation plan
  - Appropriateness of the proposed tariff
  - Appropriateness of the survey, the study and design from the technical view point
  - Appropriateness of the study on environmental and social considerations
- Since each organization consists of IPP Review Committee conducts a review while referring to precedents, examples from other countries, etc., there is a concern that problems may arise in the consistency and reliability of review results.

Measures to improve the current situation

- In this training course, we will explain from what point of view, what should be checked, and what criteria should be used to judge each technical item to be investigated and examined in the FS, including our own experiences or findings.

Technical aspects of FS review

Technical aspects of FS review

- Safety

  Hydropower facilities shall not harm the human or damage any object.

- Electrical or Magnetic interference

  Hydropower facilities shall be installed so as not to cause any electrical or magnetic interference that may affect other electrical facilities.

- Impact on power supply and other facilities

  There shall be no significant effect on power supply under any failure or damage of the hydropower facilities.

- Environmental Impact

  Hydropower facilities shall not have adverse effects on the surrounding environment.

- Stable Electric supply

  It is possible to generate a specified amount of electricity stably during the project period.

Technical aspects of FS review

- If the FS conducted by the IPPs is not carried out with proper procedures and with proper studies, the following failure may occur.
- If the failure occurs, it may cause some significant adverse impact for Cambodia.

Impact that may result from hydropower development

- ●Dam failure
- ●Flood
- ●Landslide
- ●Collapse of waterways
- ●Submerged power house
- ●Natural environment impacts
- ●Socio−economic impacts, etc.

⇨

Significant Adverse Impacts

- ● Disruption of power supply
- ● Adverse effects on human life, property, facilities, and the environment outside the power plant
- ● Acceleration of disaster occurrence during floods and earthquakes
- ● Secondary damage caused by damage to power generation facilities
- ● Decrease in rare plants and animals
- ● Loss of historical and cultural heritage , etc.

Technical aspects of FS review

Technical aspects of FS review

- When reviewing the power generation structures and facilities planned and designed by IPPs from a technical view point, it is essential to examine whether the facilities satisfy the basic requirements that the hydroelectric structures or facilities should be fulfilled as described in the following Cambodian standards.
  - General Requirements of Electric Power Technical Standards (GREPSTS)
  - Specific Requirement of Electric Power Technical Standards for Hydropower (SREPTS)

Chapter 4

How to conduct this training

Introduction

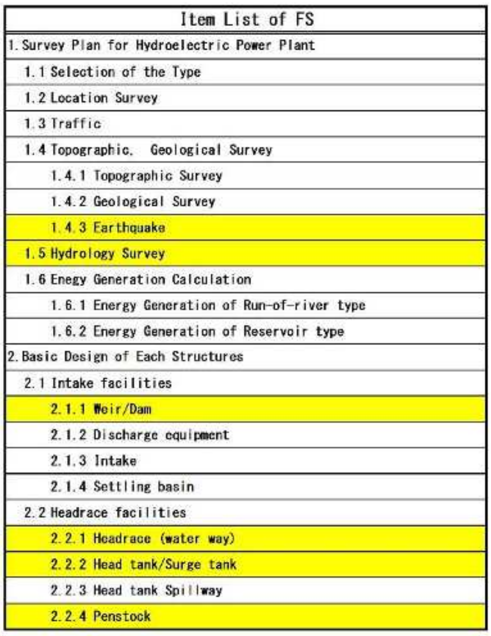
- The purpose of this training is to deal with the technical matters necessary for the technical review of FS of hydropower projects and to improve the competence of the trainees.
- This training consists of "lectures on basic knowledge (this lecture)" and "lectures on each specialized field such as civil engineering, electricity, and hydro-mechanical equipment" necessary for technical assessment of FS of hydropower plants.
- Based on the results of the questionnaire survey, the lectures on each specialized field will focus on the technical issues that require further improvement, in order to improve the competency efficiently.

Flow of this training

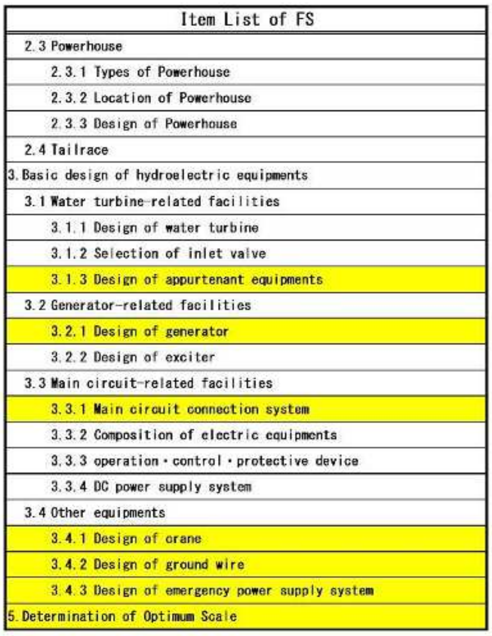
STEP 1 (Nov, 2021)	● Confirmation of Cambodian IPP screening capacity and requests for training through preliminary questionnaire
STEP 2 (Dec, 2020-Jan 2022)	● Review of training content based on results of preliminary questionnaire
Present (Feb, 2022-Mar, 2022)	● Implementation of training to strengthen IPP review capability (hydropower, consist of 5 lectures)

Result of the questionnaire

- A preliminary questionnaire was conducted to check the level of understanding of the MME and EAC for each item that constitutes the FS.
- As a result of the questionnaire, the following thirteen (13) items were identified as "items for which further improvement of ability is needed.



Item List of FS
1. Survey Plan for Hydroelectric Power Plant
1.1 Selection of the Type
1.2 Location Survey
1.3 Traffic
1.4 Topographic, Geological Survey
1.4.1 Topographic Survey
1.4.2 Geological Survey
1.4.3 Earthquake
1.5 Hydrology Survey
1.6 Enegy Generation Calculation
1.6.1 Energy Generation of Run-of-river type
1.6.2 Energy Generation of Reservoir type
2. Basic Design of Each Structures
2.1 Intake facilities
2.1.1 Weir/Dam
2.1.2 Discharge equipment
2.1.3 Intake
2.1.4 Settling basin
2.2 Headrace facilities
2.2.1 Headrace (water way)
2.2.2 Head tank/Surge tank
2.2.3 Head tank Spillway
2.2.4 Penstock



Item List of FS
2.3 Powerhouse
2.3.1 Types of Powerhouse
2.3.2 Location of Powerhouse
2.3.3 Design of Powerhouse
2.4 Tailrace
3. Basic design of hydroelectric equipments
3.1 Water turbine-related facilities
3.1.1 Design of water turbine
3.1.2 Selection of inlet valve
3.1.3 Design of appurtenant equipments
3.2 Generator-related facilities
3.2.1 Design of generator
3.2.2 Design of exciter
3.3 Main circuit-related facilities
3.3.1 Main circuit connection system
3.3.2 Composition of electric equipments
3.3.3 operation・control・protective device
3.3.4 DC power supply system
3.4 Other equipments
3.4.1 Design of orane
3.4.2 Design of ground wire
3.4.3 Design of emergency power supply system
5. Determination of Optimum Scale

Lecture theme

- Based on the results of the questionnaire, the importance of each technical item in FS review, and the relevance of each technical item, a total of four (4) lectures (Five (5) lectures if this lecture is included) on each technical area will be given as follows.

No.	Necessary item for Capacity-building		No.	Lecture
1	1.4.3	Earthquake	1	Earthquake/Hydrology Survey
2	1.5	Hydrology Survey		
3	2.1.1	Weir/Dam	2	Design of Weir/Dam
4	2.2.1	Headrace (Water Way)	3	Design of Headrace/Head tank/Surge tank/ Penstock/Tailrace
5	2.2.2	Head tank / Surge tank		
6	2.2.4	Penstock		
7	2.4	Tailrace		
8	3.1.3	Design of appurtenant equipment	4	Design of Turbine/Generator/ Auxiliary Equipment
9	3.2.1	Design of generator		
10	3.3.1	Main circuit connection system		
11	3.4.1	Design of Crane		
12	3.4.2	Design of ground wire		
13	5	Determination of Optimum Scale	Not implemented because optimal scale study may not be conducted in IPP's FS.	

Finally

- In the future, we would like to explain the key points in IPP review on the following five (5) themes.
- We would like to hear your opinions if there are any contents that are unclear at present, or if there are any contents that you would like us to focus on in the lecture.

No.	Lecture
1	Earthquake/Hydrology Survey
2	Design of Weir/Dam
3	Design of Headrace/Head tank/Surge tank/ Penstock/Tailrace
4	Design of Turbine/Generator/ Auxiliary Equipment

References

- SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES. （Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd., The Chugoku Electric Power Co., Inc. October 2009)
- EXPLANATION SHEET FOR SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd., The Chugoku Electric Power Co., Inc. October 2009)
- 水力開発ガイドマニュアル（独立行政法人　国際協力機構（JICA)、電源開発株式会社、株式会社開発設計コンサルタント　2011.3）

END

WG2: Technical Review on Hydropower Project

2nd Class : Hydrology Survey and Earthquake

The Chugoku Electric Power Co., Inc.

Topic１ : Hydrology Survey

Topic1 : Hydrology Survey

- In this lecture, we will explain the importance and purpose of hydrology survey, uses of hydrological data, method of hydrology survey and points to be checked in FS review.

〔Lecture Topic〕

Acquire the basics of hydrology survey and develop the points of view for FS review.

〔Lecture Contents〕

Chapter 1 : The importance and purpose of hydrology survey

Chapter 2 : Uses of hydrological data

Chapter 3 : Method of hydrology survey

Chapter 4 : 【Summary】Points to be checked in FS review

Chapter1

The importance and purpose of hydrology survey

Chapter1:The importance and purpose of hydrology survey

■ Purpose of hydrology survey

To investigate how much water is flowing in the river throughout the year, and to prepare materials necessary for power generation planning and design of facilities.

■ Importance of hydrology survey

【Plan】

- The river flow data is used to estimate the output of power plants and the amount of electricity generated. Therefore, it is essential for power generation planning.
- If the dam is constructed with insufficient river flow data, it will not be possible to obtain sufficient power generation and the project will not be completed.

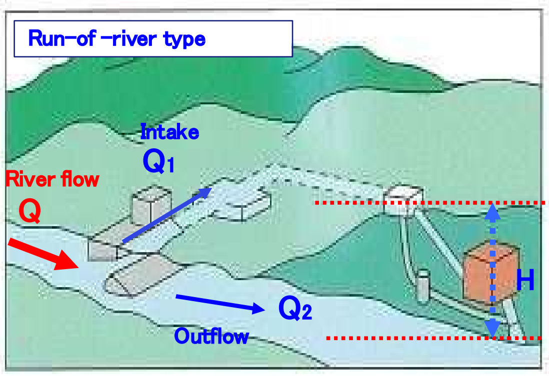
【Design and Safety】

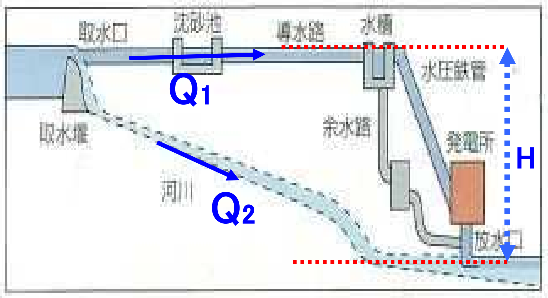
- The design flood is essential for the design of dams and spillway.
- If the design flood is not appropriate, it can lead to catastrophic disasters such as the destruction of dams due to overflow and the loss of power generation functions due to flooding of power plant.

Chapter1:The importance and purpose of hydrology survey

■ 【Plan】Importance of hydrology survey

The river flow data is essential for power generation planning.





River flow = Intake flow + Outflow

$$Q_{(\text{River flow})} = Q_{1(\text{Intake flow})} + Q_{2(\text{Outflow})}$$

Capacity :Energy output per unit time

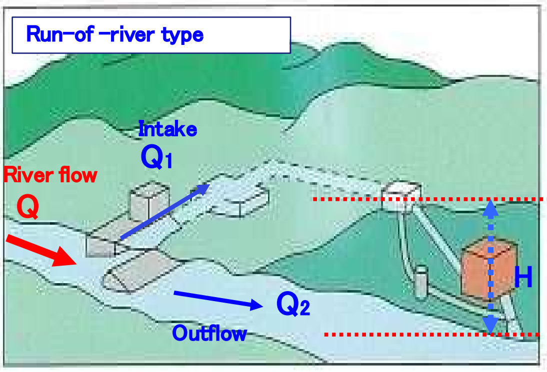
$$P(\text{kW}) = 9.8 \times \eta \times Q_1 \times He$$

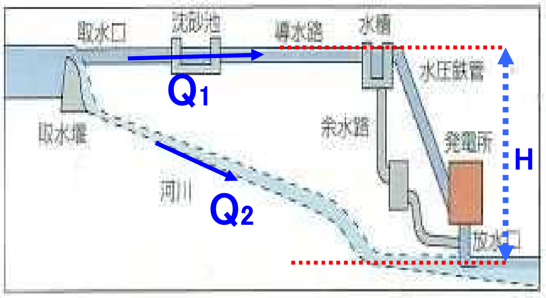
P : Capacity (kW)
9.8 : Gravitational acceleration (m/s^2)
η : Total efficiency $= \eta_{\text{water turbine}} \times \eta_{\text{generator}}$
Q : Maximum discharge (m^3/s)
He : Net head (m)

Chapter1:The importance and purpose of hydrology survey

【Plan】Importance of hydrology survey

The river flow data is essential for power generation planning.





Capacity :Energy output per unit time

$$P(kW)=9.8\times\eta\times Q_1\times He$$

- **Energy output per hour :** $E = P(kW) \times T(h)$
- **Total energy per year :**

$$E_{year}(kWh) = P(kW) \times 24(h) \times 365(d)$$
$$= P(kW) \times 8760(h\cdot d)$$

River flow data is one of the most important data for power generation planning.

Chapter1:The importance and purpose of hydrology survey

【Design】Importance of hydrology survey

The design flood is essential for the design of dams and spillway.

Q:What is a Design flood？

A:Design flood is the maximum flow that can possibly happen at the project site.

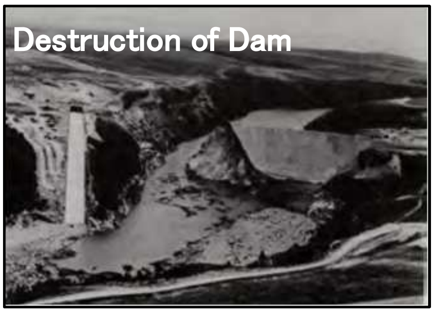
【Basics】

Dam	● Every dam shall be equipped with a spillway or spillways designed to be capable of sure and safe discharge of the design flood. ● The flood discharge is necessary for the design of Spillway.
Power plant	● Set up the power plant in the place that is not flooded.

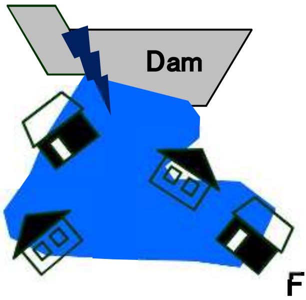
Chapter1:The importance and purpose of hydrology survey

■【Safety】Importance of hydrology survey

If the design flood is not appropriate, it can lead to catastrophic disasters such as the destruction of dam due to overflow and the loss of power generation functions due to flooding of power plant.



Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.13



HUMAN LOSS

Flooded resident in downstream

*2

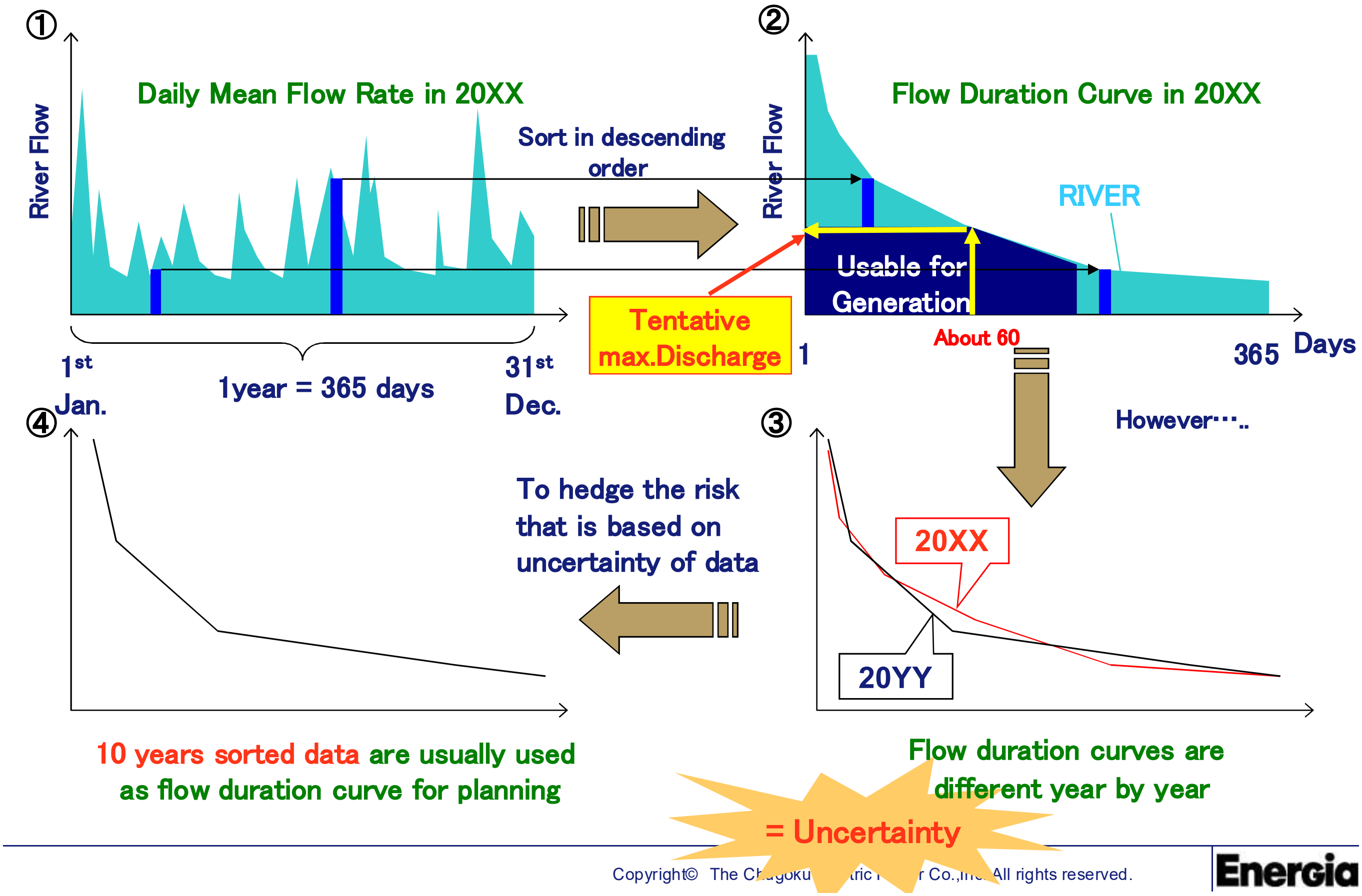
Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.16

POWER LOSS

Chapter2

Uses of hydrological data

Chapter2:Uses of hydrological data



10 years sorted data are usually used as flow duration curve for planning

Flow duration curves are different year by year

Chapter3

Method of hydrology survey

Chapter3:Method of hydrology survey

How can we collect a river flow data?

1. Gauging river flow directly.

- Direct gauging for long periods is the best way and most accurate.

2. Utilizing existing river flow data in gauging stations.

- In case there are NOT river flow data at the dam site, river flow data measured near the dam site can be converted into river flow data at the site.

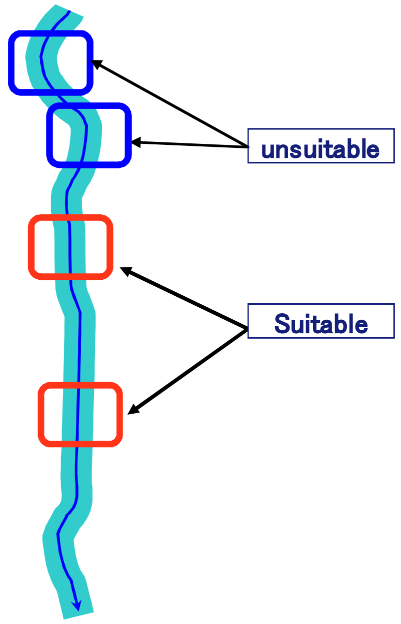
3. Converting rainfall data into river flow data.

- Conversion of rainfall data has a lot of uncertainty for calculating energy generation.
- But in case river flow data is not available, converting rainfall data into river flow data is usually used.

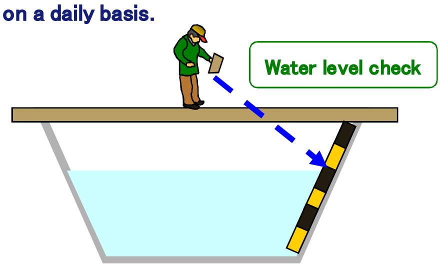
Chapter3:Method of hydrology survey

1. Gauging river flow directly.

How to survey the river flow



The water level is monitored at a stream gauging station on a full-time basis. In addition, the water level is visually checked on a daily basis.

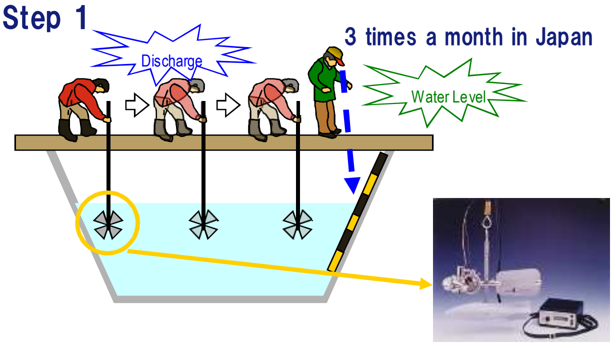


Overview of the measurement

Water level measurement

Step 1

3 times a month in Japan



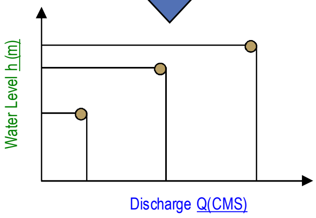
Step 3

One Time per everyday during a year

Fill the Table

Date	Site1			……
1st Oct	1.91m			……
2nd Oct	1.92m			……
3rd Oct	1.93m			……
:	:	:	:	:

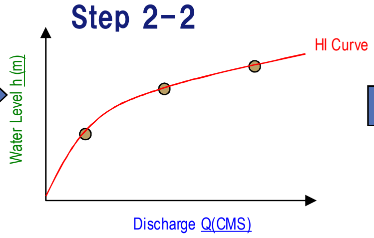
Step 2-1



Dot the points on the Q & h graph from the measured Q_i and h_i

River flow measurement with a current meter

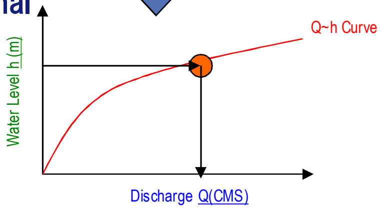
Step 2-2



Make the Q~h curve

Calculation of daily mean river flow

Final



Calculate the Q of everyday from the measured h.

Date	Site1			……
1st Oct	8.1CMS			……
2nd Oct	8.2CMS			……
3rd Oct	8.3CMS			……
:	:	:	:	:

Chapter3:Method of hydrology survey

1. Gauging river flow directly.

How to survey the river flow

· Measurement of the river flow

Propeller-type current meter

Chapter3:Method of hydrology survey

1. Gauging river flow directly.

How to survey the river flow

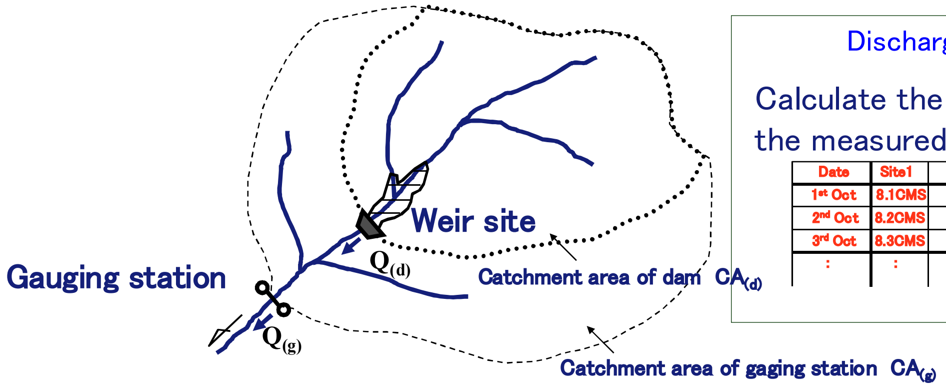
· River flow measurement

Chapter3:Method of hydrology survey

2. Utilizing existing river flow data in gauging stations.

Step1: Collecting existing gauging data of river flow

- We should look for existing gauging data .
- If you find gauging data near the development site, you should collect data.
- The longer period you get, the more accurate the data will be.
- The data is desirable if the existing gauging station is located in the same river basin as project site.



Discharge Q(CMS)

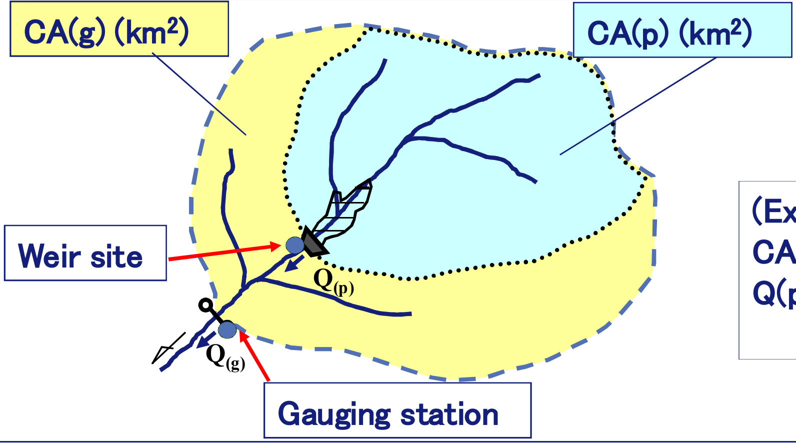
Calculate the Q of everyday from the measured h.

Date	Site1			……
1st Oct	8.1CMS			……
2nd Oct	8.2CMS			……
3rd Oct	8.3CMS			……
:	:	:	:	:

2. Utilizing existing river flow data in gauging stations.

Step2: Conversion gauging data into site data

- We should look for existing gauging data . (Please ask "Ministry of
- We should know the catchment area of existing gauging station (CA(g)).
- We should calculate the catchment area of the project site (CA(p)).
- River flow data at project site(Q(p)) can be calculated according to formula shown below according to data at gauging station (Q(g)).
- River flow data at project site has obtained.



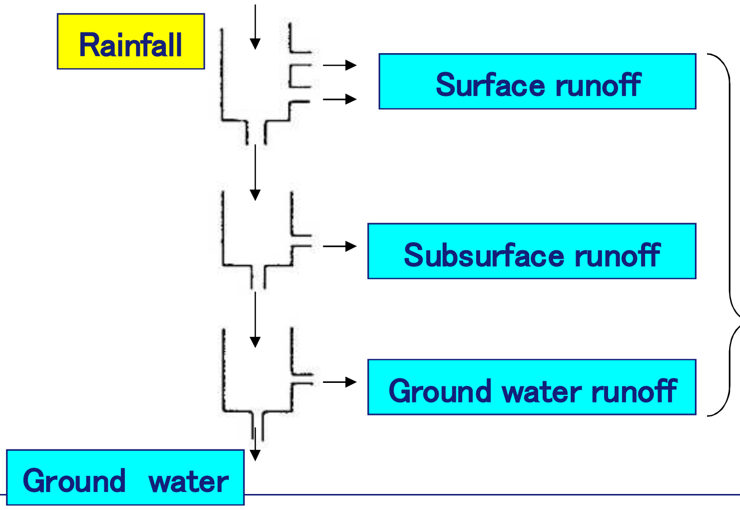
$$Q(p)=Q(g)\times \frac{CA(p)}{CA(g)}$$

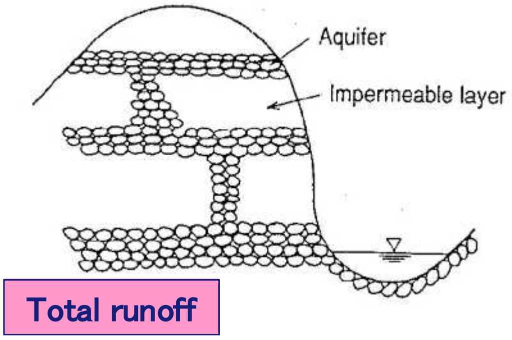
(Example)
CA(g) = 100km2, CA(p) = 50km2
Q(p) = Q(g) × 50/100
= 0.5·Q(g)

---

3. Converting rainfall data into river flow data.

- Many computer programs have been developed to calculate the flow from rainfall using a mathematical model. Here, **the tank model method** is explained briefly as one of such mathematical models.
- Because this model has much parameter, to raise the accuracy, daily river flow data is required.





Chapter3:Method of hydrology survey

How to estimate Design Flood?

1. Using probability density function by plotting recorded data.

- In case there are sufficient river flow data.
- There are several methods to estimate probable flood discharge such as Log, Gumbel, Pearson, Log Pearson typeⅢ distribution.

2. Utilizing existing rainfall data.

- In case there are NOT sufficient river flow data.
- Design flood can be calculated by Rational formula .

3. Using PMP/PMF method to estimate maximum theoretical flood volume.

- Maximum theoretical flood can be estimated by combining variety of meteorological data.

Chapter3:Method of hydrology survey

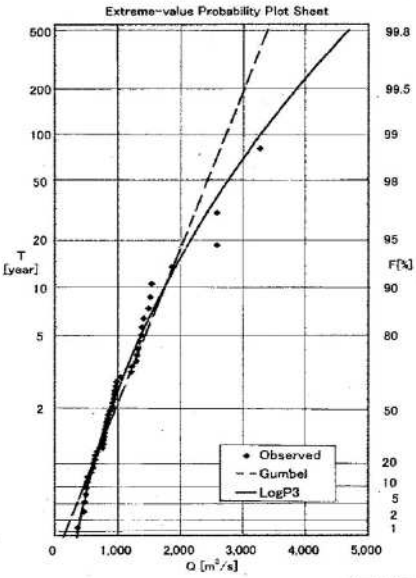
1. Using probability density function by plotting recorded data.

In case there are sufficient river flow data.

- Design flood is generally set by the **probable flood discharge.**

  For instance, 1,000 years return period should be applied to the dam classified into Medium in Cambodia.

- **The probable flood discharge** is calculated by plotting the flood data (maximum peak data in year of at least 20～30 years) on the log probability paper.



Source: *水力開発ガイドマニュアル, JICA(2011), Chapter 9 p.60*

2. Utilizing existing rainfall data.

In case there are NOT sufficient river flow data.

It is possible to estimate design flood with rainfall data.

Rational formula

- The flood data can be calculated roughly from rainfall intensity by using **Rational formula** in case that the catchment area is small (less than 200 square kilometers) and the basin storage need not to be considered.

【Rational formula】

$$Q = (1/3.6)\cdot f \cdot r \cdot A$$

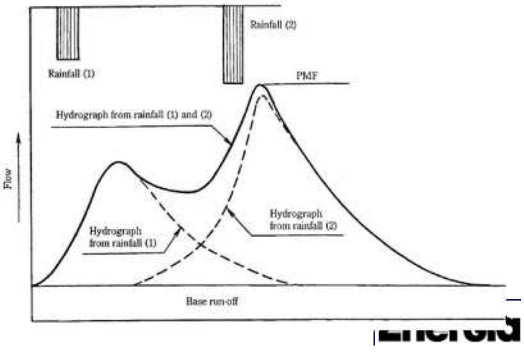
where,

Q : Design flood discharge (cms)
f : Discharge proportion (ex : f=0.7(mountains region))
r : Rainfall intensity (mm/hr)
A : Catchment area (square kilometers)

---

3. Using PMP/PMF method to estimate maximum theoretical flood volume.

- **PMP(Probable Maximum Precipitation)**
- The theoretical maximum amount of precipitation that is physically possible for a given season and region.
- Estimation of PMP
  ①:Meteorological method considering an amount of water vapor in the air.
  ②:Hershfield method : It is possible to estimate PMP even if meteorological data is not sufficient.
- **PMF(Probable Maximum Flood)**
- The maximum theoretical flood volume that can be expected when weather and hydrological phenomena are combined under the most severe conditions.
- Estimation procedure of PMF
  ①:PMP calculation
  ②:Production of Unit hydrograph
  ③:Production of hydrograph from PMP
  ④:Calculation of base runoff
  ⑤:Production of PMF hydrograph



Source: 水力開発ガイドマニュアル, JICA(2011), Chapter 9 p.61

Chapter4

【Summary】

Points to be checked in FS review

Chapter4:Points to be checked in FS review

River Discharge

Point to be Checked	Details
1. The river flow data should have a sufficient period of time data.	✓ It is desirable that the flow data, which is the basis for the estimation of the output and power generation, exist for as long as possible. ✓ The data period should be at least 10 years and preferably 30 years.
2. The type of river flow data should be appropriate.	【Basics】 ✓ Pondage type/Run-of-river type :Daily flow ✓ Reservoir type :Monthly flow
3. The river flow data should be reliable.	✓ The river flow at the intake should be directly measured. ✓ If river flow is not measured directly, obtain the flow data of the same river or nearby rivers and estimate the river flow at the intake based on the basin area ratio. ✓ If it is difficult to obtain river flow data, rainfall station data within the river basin shall be obtained, and the river flow model shall be estimated.

Design Flood

Point to be Checked	Details
4. The design flood discharge should be estimated using the appropriate method such as probable flood discharge or probable maximum flood (PMF).	✓ The design flood should be adopted as shown in the table below depending on the classification of the dam.
5. The design flood should be verified by comparing other planned sites.	✓ If the design flood is significantly lower than other planned sites, there might have a problem with the design flood adopted to the project.

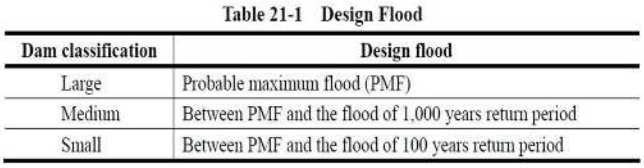


Table 21-1 Design Flood

Dam classification	Design flood
Large	Probable maximum flood (PMF)
Medium	Between PMF and the flood of 1,000 years return period
Small	Between PMF and the flood of 100 years return period

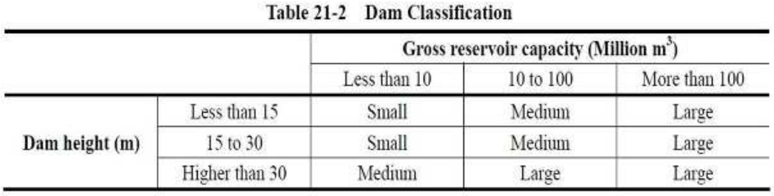


Table 21-2 Dam Classification

		Gross reservoir capacity (Million m^3)		
		Less than 10	10 to 100	More than 100
Dam height (m)	Less than 15	Small	Medium	Large
	15 to 30	Small	Medium	Large
	Higher than 30	Medium	Large	Large

Source: Draft SREPTS for Hydropower Facilities, JICA(2009), p.11

Topic2 : Earthquake

Topic 2：Earthquake

- In this lecture, we will explain the purpose of seismic survey, survey items, and points to be checked in FS review.

〔Lecture Topic〕

Acquire the basics of earthquake, seismic information that is necessary for safety evaluation of a dam and develop the points of view for FS review.

〔Lecture Contents 〕

Chapter 1： Basics of Earthquake

Chapter 2： Purpose of seismic survey

Chapter 3： Survey items

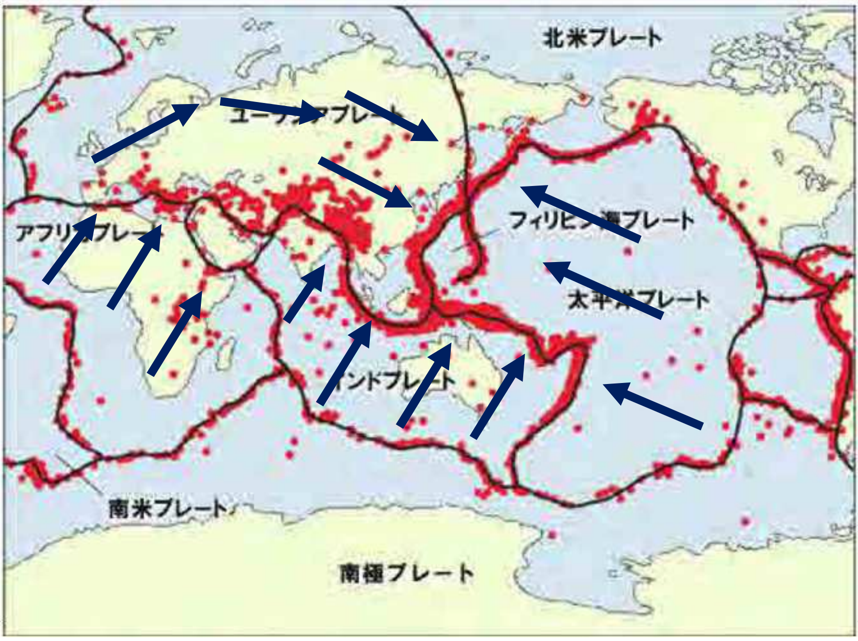
Chapter 4： 【Summary】Points to be checked in FS review

Chapter1

Basics of Earthquake

Chapter1: Basics of Earthquake

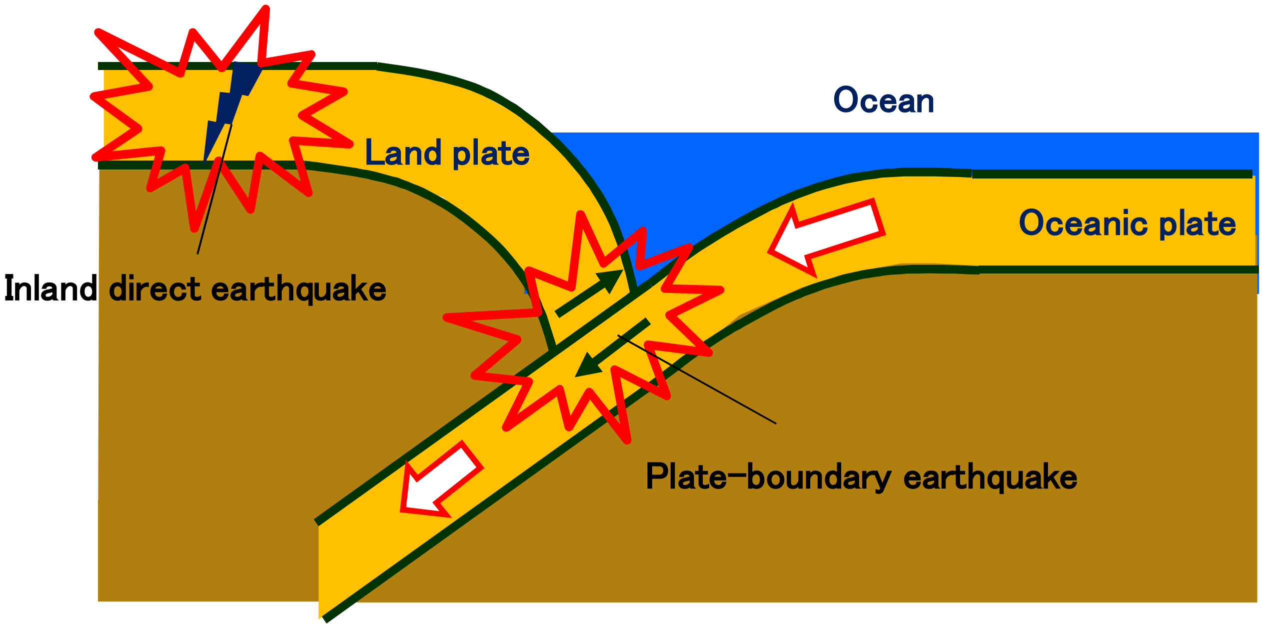
- **Plate Tectonics**: The basic idea of “plate tectonics” is that the earth’s outer shell (called the lithosphere) consists of several large and fairly stable slabs of solid rock called plates.
- **Earth’s 14 Tectonic Plates and their Movements**: Each arrow represents Tectonic plate movement.



Source: *水力開発ガイドマニュアル, JICA(2011), Chapter 9 p.25*

Chapter1: Basics of Earthquake

- **Causes of Earthquakes**: The subduction of oceanic plates and the resulting compression of land cause many earthquakes to occur around plate boundaries and inland.
- The most important earthquake for seismic design are the tectonic earthquake, “**Plate-boundary earthquake**” and “**Inland direct earthquake**”.

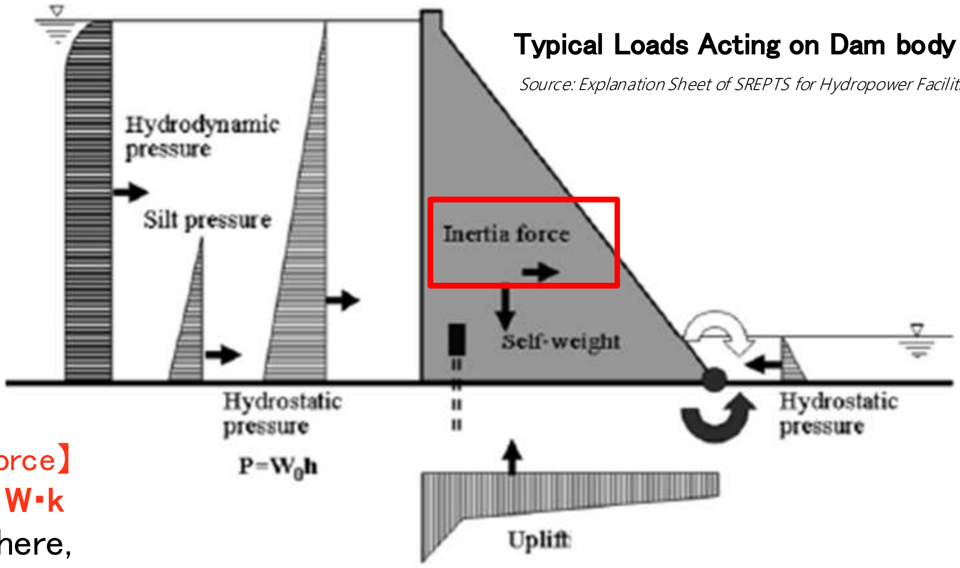


Chapter2

Purpose of seismic survey

Chapter2: Purpose of seismic survey

- In order to design a safe and economical structure, it is necessary to determine the seismic loads expected at the planned location. In order to evaluate the seismic loads, it is necessary to conduct seismic investigations.



Typical Loads Acting on Dam body

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.28

【Seismic force】

I = W･k

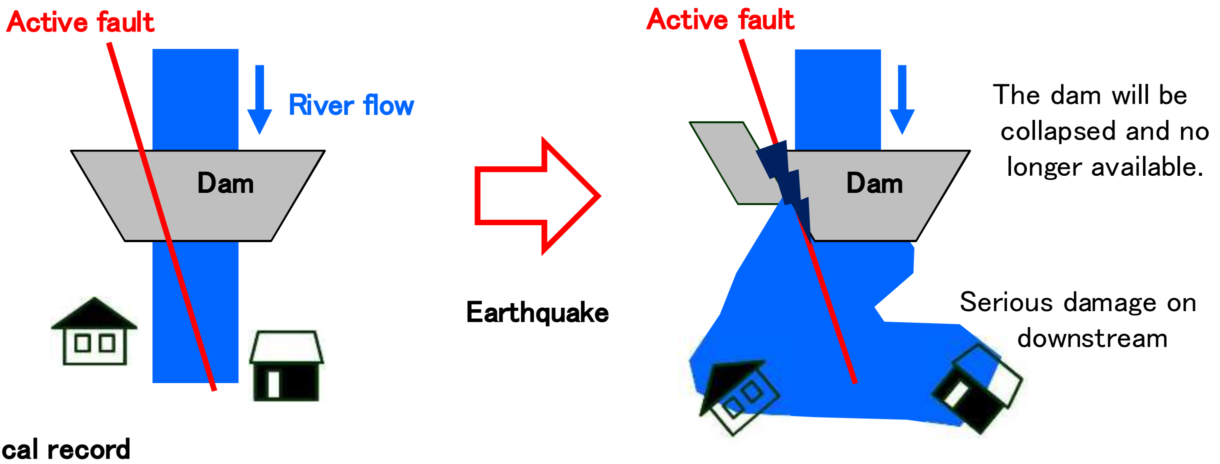
where,

I : Inertial force of the dam body during an earthquake
W : Self weight of a dam body
k : Design seismic coefficient

Chapter2: Purpose of seismic survey

- In order to design a safe and economical structure, it is also necessary to determine the active fault near the planned location. In order to evaluate the active fault, it is necessary to conduct sufficient seismic survey.

If the seismic survey is insufficient…



Historical record

- **The dam site located in Taiwan was collapsed** due to the 921 Earthquake that occurred on September 21, 1999.
- The dam was uplifted by about 7 meters because **there was the fault line directly underneath the dam.**

Chapter3

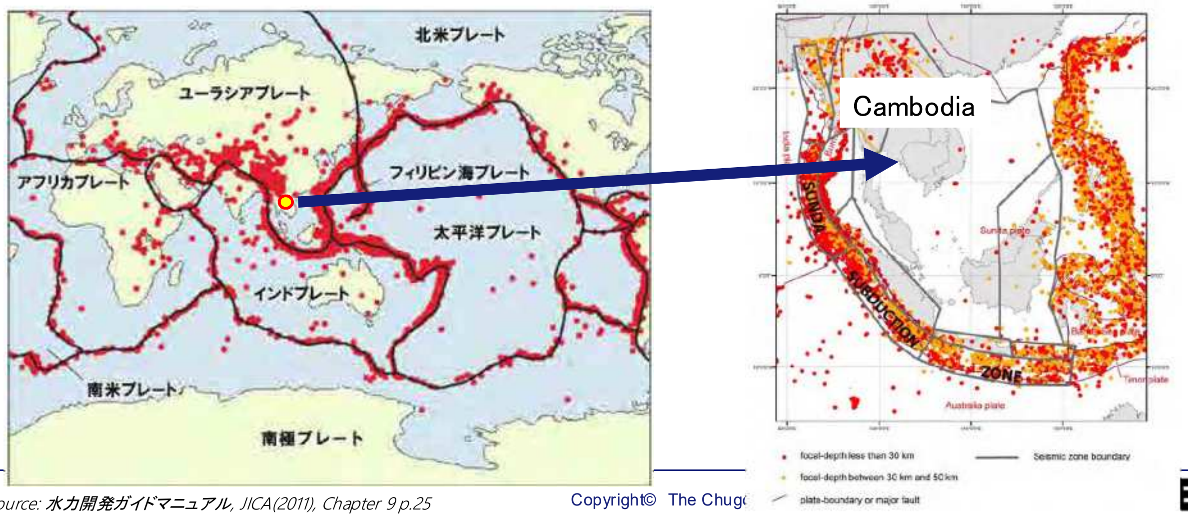
Survey items

Chapter3:Survey items

1. Comprehension of Seismotectonics

- As a first step in the investigation of earthquakes, an overview of the distribution of plates and the occurrence of earthquakes in the region surrounding the country should be obtained from a global perspective and based on existing literature.
- If the country is located in a plate boundary region or in an earthquake-prone area, the importance of seismic design increases, and it is necessary to conduct sufficient seismic surveys.

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.37



Source: 水力開発ガイドマニュアル, JICA(2011), Chapter 9 p.25

Chapter3:Survey items

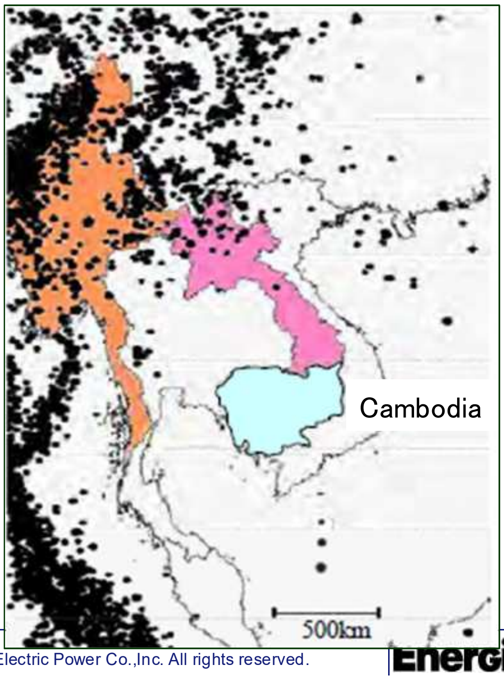
2. Historical Earthquake and Earthquake Damage History Survey

- If data on earthquakes in the country are available, collect them to understand the temporal and regional distribution of earthquakes, the relationship between the magnitude and number of earthquakes, and the damage caused by earthquakes.

- If there is no data on earthquakes in the country, it is effective to use earthquake catalogs, listed in next page, and databases available from research institutes around the world.

☐ Figure on the right shows major earthquakes occurred in South-East Asia (1904 – 1996)

☐ A severe earthquake zone exists in the northern part of Lao PDR and Myanmar. However, the entire area of the Kingdom of Cambodia is in the area with very small danger of gigantic earthquakes.



Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.35

Useful Earthquake Catalogs

- **Seismicity of Earth (Gutenberg & Richter, 1954)**

⇒List of major earthquakes that occurred in the world between 1904 and 1952.

- **Regional Catalogue of ISC (International Seismological Center, United Kingdom)**

⇒It publishes monthly reports of earthquake observations around the world and regional earthquake catalogs.

- **Preliminary Determination of Epicenter**

(USGS, 米国)

⇒ It publishes Earthquake Data Report, etc.

- **NOAA: National Oceanic and Atmospheric Administration**

⇒ It includes latest Earthquake records.

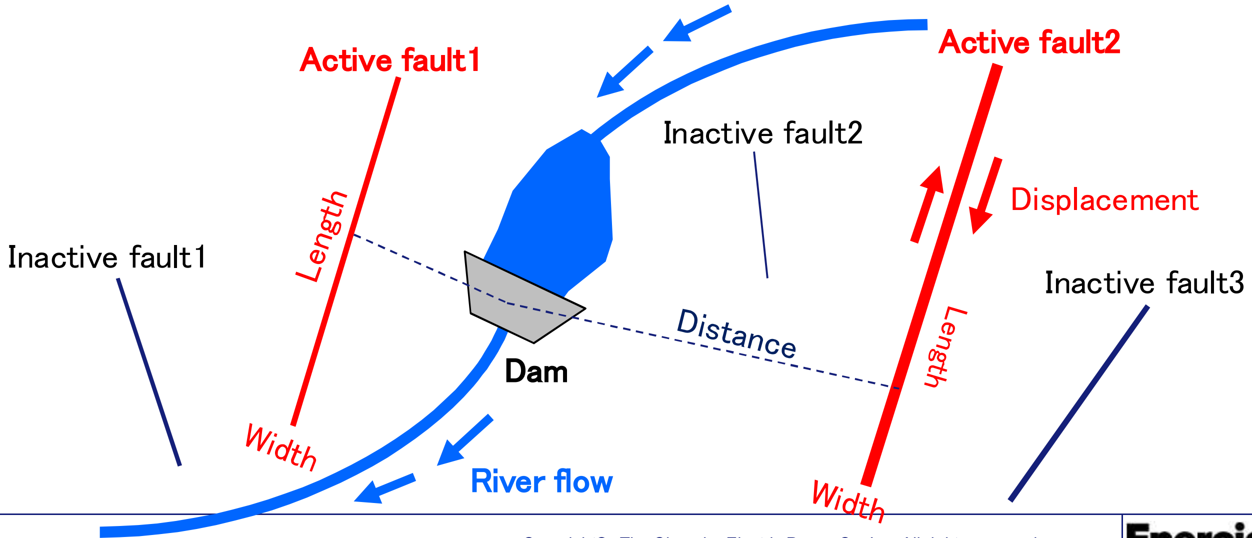
- **US Geological Survey (USGS)**

⇒It includes latest Earthquake records.

---

3. Comprehension of Active Faults

- In order to understand the active fault in the area around the planned site, the distribution of active fault in the area around the planned site will be investigated based on existing geological data, aerial photograph, topographic map.
- It is necessary to evaluate the characteristics of the fault, such as length, width and displacement of the fault, and distance between the planned site.



4. Seismic Coefficients (Cambodia)

- It is estimated that the Kingdom of Cambodia belongs to a minor seismic zone.
- The seismic coefficients shown below are proposed, based on the expected earthquake acceleration level in the Kingdom of Cambodia and also referring to the technical standards in the neighboring countries.

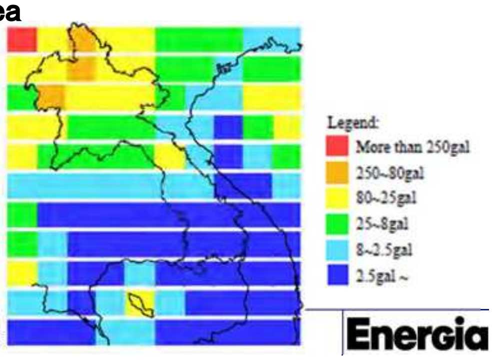
Seismic Coefficient in Cambodia

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.37

Zones of earthquake acceleration level	Concrete gravity dam	Arch dam	Fill dam	
			Homogeneous dam (Earth fill dam)	Rock fill dam
Minor (below 8gal)	0.06	0.12	0.07	0.06

Earthquake Acceleration Distribution Map Classified by Area

- ☐ The territory of the Kingdom of Cambodia is in a low maximum earthquake acceleration zone of less than 8 gal except one point in the range from 80 to 25 gal.



Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.36

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4. Seismic Coefficients (Neighboring Area)

- The estimated seismic coefficients for each zone of earthquake acceleration level and the examples in the neighboring area are shown below.

Estimated Seismic Coefficient by Zone of Earthquake Acceleration Level and Examples in Neighboring Area

Zones of earthquake acceleration level	Concrete gravity dam	Arch dam	Fill dam	
			Homogeneous dam (Earth fill dam)	Rock fill dam
Severe (250~80gal)	0.12	0.24	0.15	0.15
Middle (80~25gal)	0.12 (Theun Hinboune: 0.12)	0.24	0.15	0.12
Moderate (25~8gal)	0.10 (Nam Ngum:0.03)	0.20	0.12	0.10 (Nam Leuk: 0.10)
Minor (below 8gal)	0.06 (Xeset: 0.07)	0.12	0.07 (Houay Ho: 0.10)	0.06

( ) adopted coefficient

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.38

4. Seismic Coefficients (OBE and MCE)

- OBE and MCE must be considered for safety analysis of dam.

【Definition of OBE and MCE】

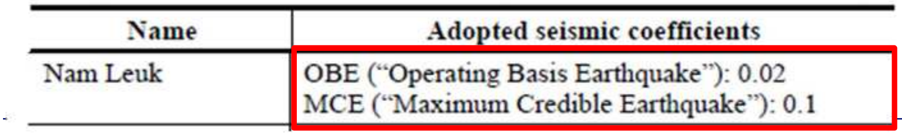
1. OBE (Operating Basis Earthquake)

- It represents the level of ground motion at a structure site at which only minor damage is acceptable. Engineering structures and equipment should remain functional and damages easily repairable, from the occurrence of earthquake shaking not exceeding the OBE.
- OBE is having a recurrence interval of 475 years (10 % probability of exceedance in 50 years)

2. MCE (Maximum Credible Earthquake)

- It represents the maximum level of ground motion for which an engineering structure should be designed or analyzed.
- MCE is having a very long return period, for instance 5,000–10,000 years.

Examples of OBE and MCE adopted to the dam in the neighboring country



Name	Adopted seismic coefficients
Nam Leuk	OBE ("Operating Basis Earthquake"): 0.02 MCE ("Maximum Credible Earthquake"): 0.1

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.38

Chapter4

【Summary】

Points to be checked in FS review

Chapter4:Points to be considered in FS review

Earthquake

Point to be Checked	Details
1. The seismic survey around the dam site should be sufficiently carried out.	✓ There should be an overview of the distribution of plates and the occurrence of earthquakes in the area surrounding the country where the dam is planned. ✓ The historical earthquakes that have occurred near the dam site and their damage histories should be sufficiently investigated using literature or another data source. ✓ The presence or absence of active fault near the dam site should be confirmed using geological data, topographic maps, aerial photographs, etc. ✓ Active fault that may affect the dam should be identified, and their characteristics (length, width, displacement) and distance to the dam site should be evaluated

---

Chapter4:Points to be considered in FS review

Earthquake

Point to be Checked	Details
2. The dam should be designed to be safe against earthquakes.	✓ The seismic force at the planned dam site should be estimated based on the results of seismic survey, and it should be satisfied the Cambodian technical standard. ✓ The seismic design of the dam should be carried out by setting the OBE and MCE.

References

- SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)

- EXPLANATION SHEET FOR SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
（Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)

- 水力開発ガイドマニュアル（第 **1** 分冊 一般水力・揚水式水力発電）
（独立行政法人　国際協力機構（JICA)、電源開発株式会社、株式会社開発設計コンサルタント　2011.3）

END

WG2: Technical Review on Hydropower Project

3rd Class : Weirs / Dams

The Chugoku Electric Power Co., Inc.

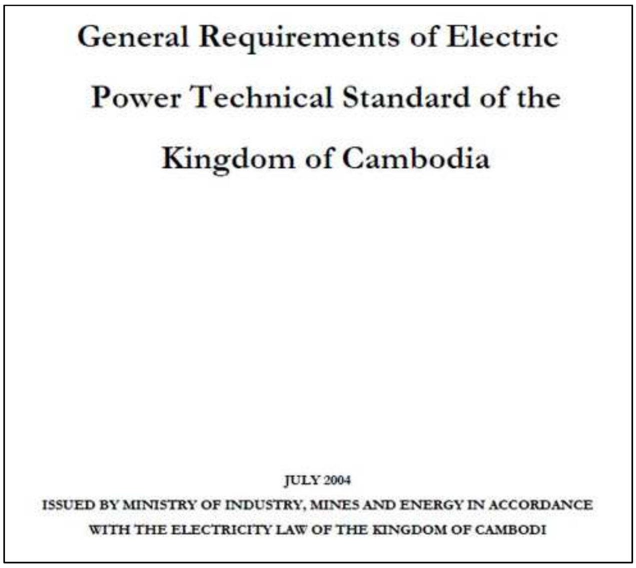
Energia
中国電力株式会社
THE CHUGOKU ELECTRIC POWER CO.,INC

Table of contents for training

Chapter1 : Clauses for Dams in GREPTS

1-1. What is the GREPTS?

- In this lecture, GREPTS is “General Requirements of Electric Power Technical Standard of the Kingdom of Cambodia”, referred by “ELECTRIC POWER TECHNICAL STANDARDS OF THE KINGDOM OF CAMBODIA” (July 2004)



General Requirements of Electric
Power Technical Standard of the
Kingdom of Cambodia

JULY 2004
ISSUED BY MINISTRY OF INDUSTRY, MINES AND ENERGY IN ACCORDANCE
WITH THE ELECTRICITY LAW OF THE KINGDOM OF CAMBODI

KINGDOM OF CAMBODIA
NATION RELIGION KING

ELECTRIC POWER TECHNICAL
STANDARDS OF
THE KINGDOM OF CAMBODIA.

https://rise.esmap.org/data/files/library/cambodia/Electricity%20Access/Cambodia_Electricity%20Power%20Technical%20Standards.pdf

1-2. Clauses about Dams in GREPTS

- Technical standards for Dams are found in clause 26 and 27.
- Clause 14 mentions about Environmental Issues.

Clause14: Compliance with the environment standards

Clause26: Dams, Waterways, Powerhouses and Other Facilities

26.1 Prevention of Overflow from Non-overflow Sections of Dams

26.2 Dam Stability

26.3 Prevention of Seepage Failure of Dams

26.4 Prevention of Serious Deformations and Cracks of Dams

26.5 Prevention of Failure of Waterways

26.6 Prevention of Failure and Damage of Powerhouses and Other Facilities

Clause27: Prevention of Damage caused by Hydroelectric Power Plant

27.1 Prevention of Damage to Reservoirs and Ground around Reservoirs

27.2 Prevention of Damage to Downstream Areas of Dams and those of Outlets

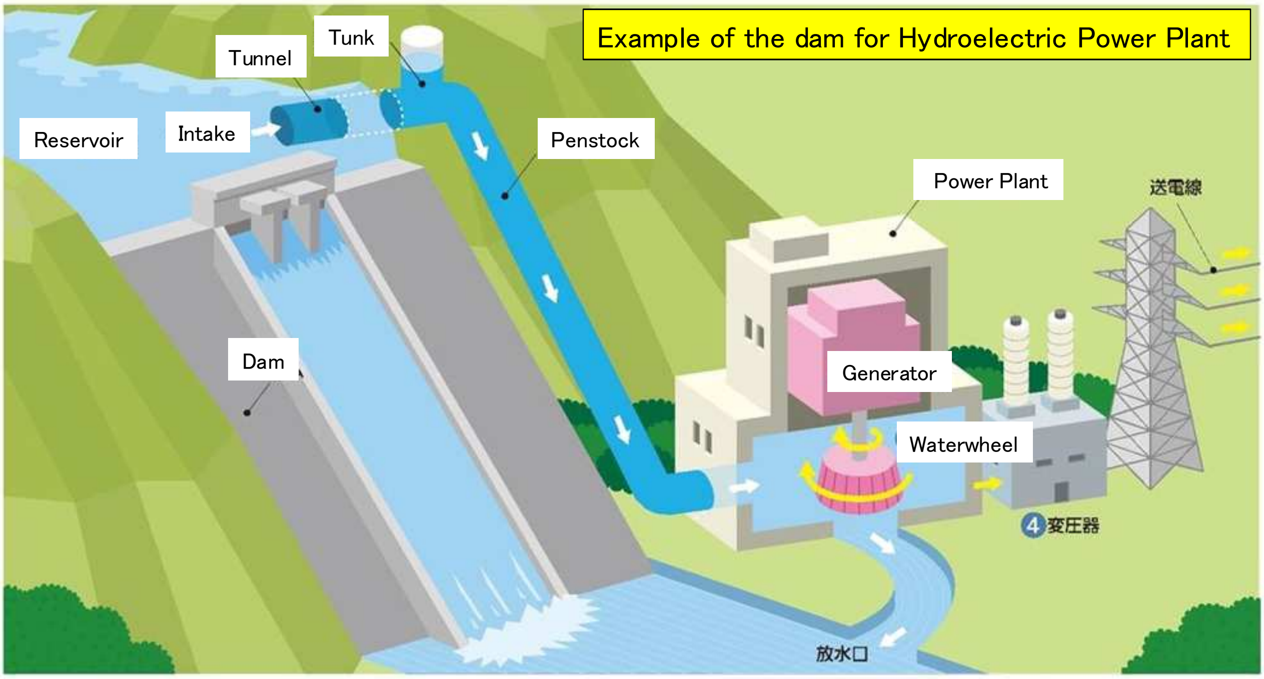
https://rise.esmap.org/data/files/library/cambodia/Electricity%20Access/Cambodia_Electricity%20Power%20Technical%20Standards.pdf

---

Chapter2 : Outline of Dams

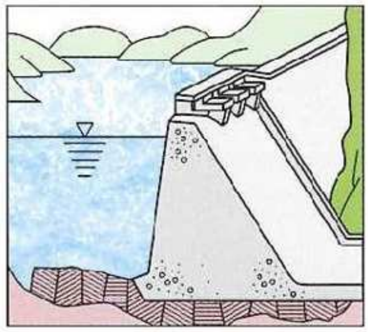
2-1. Role of Dams as facility in Hydroelectric Power Plant

- Dams are installed on rivers and play a role in holding back and reserve water.
- Dams can be given various roles, such as storing water for power plant, storing water during floods, or etc.


Example of the dam for Hydroelectric Power Plant

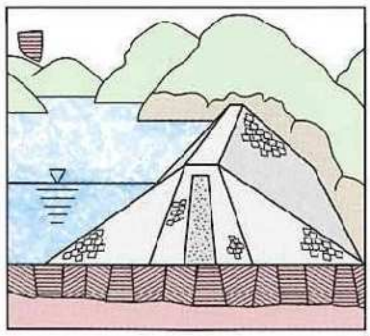
2-2. Types of dams

- Dams are classified some types by its materials and its structure.
- In this lecture, 2 types will be introduced.



Gravity dams

- ✓Constructed from concrete
- ✓Designed to hold back water by the self-weight
- ✓Most of weirs are classified this type.

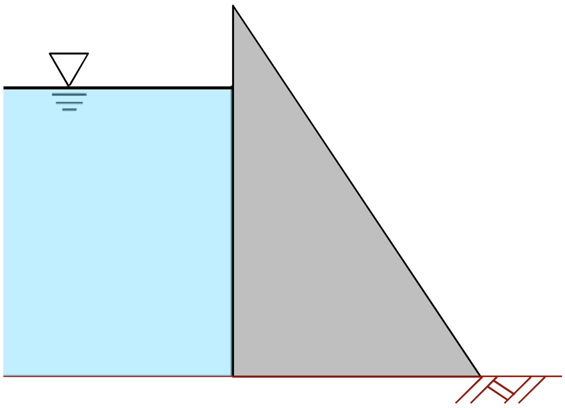


Fill dams

- ✓Made of rocks, sand, and etc.
- ✓This type can apply foundation that is not strong.

2-3. Gravity dams

- A gravity dam is generally constructed from concrete.
- This type resists the water pressure using the weight of the dam itself.

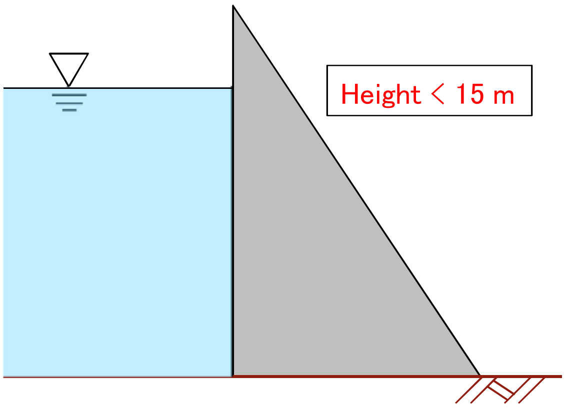


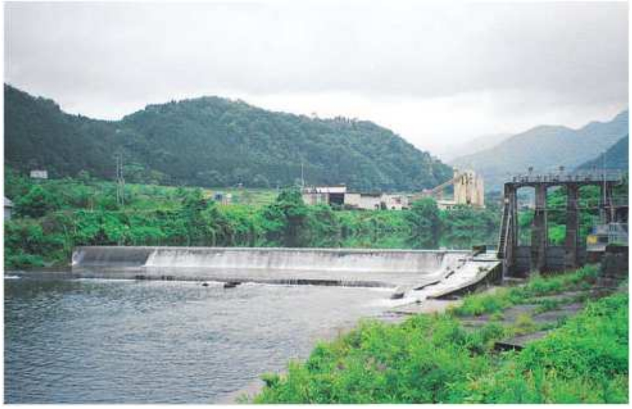
Dams ⇒ Height ≧ 15 m

Intake Weirs ⇒ Height < 15 m

2-4. Intake Weirs

- Intake weirs refer to a low dam with a height of less than 15 m.
- Most of weirs have free overflow spillway.
- Intake weirs saves labor in operation compared to dams (higher than 15 m).
- The structure is almost the same as gravity dams.



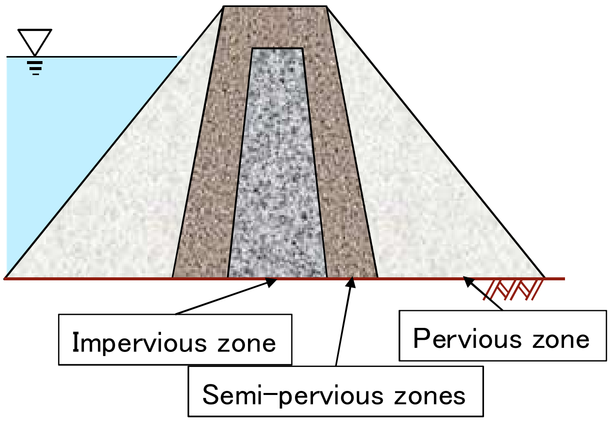


Dams ⇒ Height ≧ 15 m

Intake Weirs ⇒ Height < 15 m

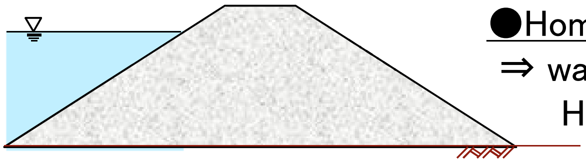
2-5. Fill dams

- A fill dam is made of earth, clay, or stone.
- This type can apply to relatively soft ground where gravity dams are difficult to installed.



2-6. Types of Fill dam

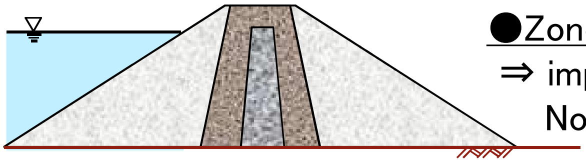
- Fill dams are generally classified 3 types.
- Each types need to take measures against seepage failure in dam bodies.



●Homogeneous Embankment Dam

⇒ water-impermeable materials

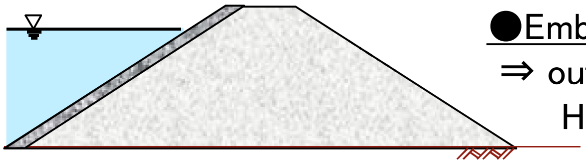
Height < 30 m in Japan



●Zoned Embankment Dam

⇒ impervious area in the center of dam

No limits of dam's height in Japan



●Embankment Dam with Membrane Facing

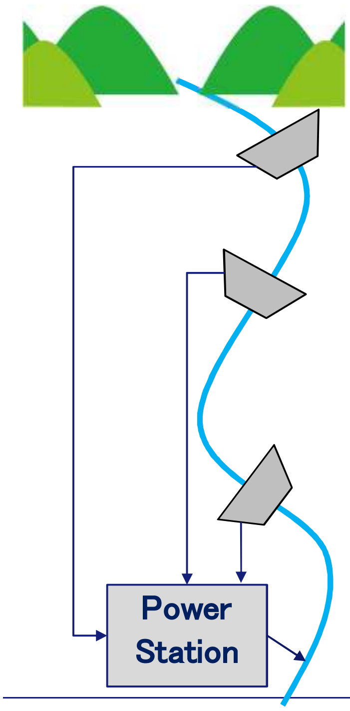
⇒ outside at upstream is covered with concrete

Height < 70 m in Japan

Chapter3 : Basic study about Dams design

3-1-1. Outline of Feasibility Studies (FS)

- In the FS, several proposals are compared in terms of economic efficiency and technical compatibility, and the best proposal is adopted.



Example of comparing proposals for FS

Proposal 1
・Gravity dam
・50 m

Economic efficiency : ○
Technical compatibility : △

NG

Proposal 2
・Fill dam
・40 m

Economic efficiency : △
Technical compatibility : △

NG

Proposal 3
・Intake weir
・8 m

Economic efficiency : ○
Technical compatibility : ○

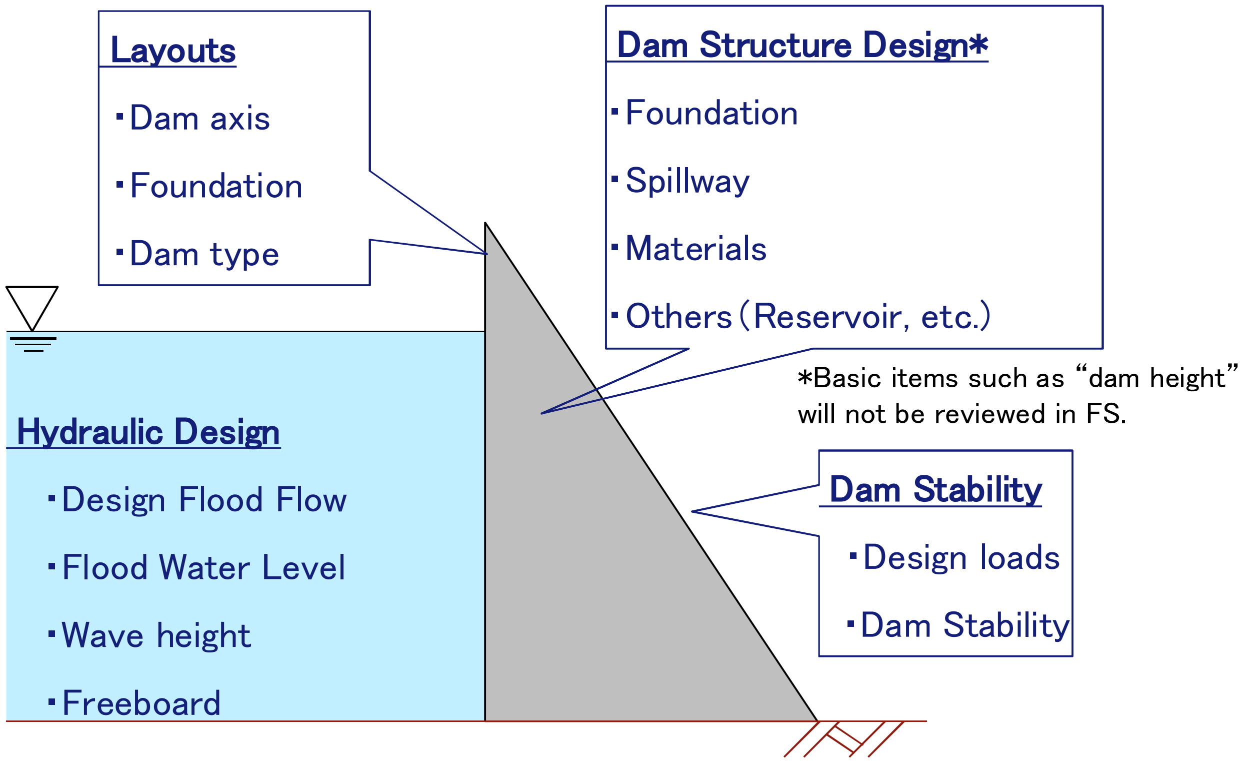
Good

Proposal 3 is adopted.

Reviewers check about proposal 3.

3-1-2. Basic factors for dam design

■ The review will focus on items below.



Layouts
- Dam axis
- Foundation
- Dam type

Dam Structure Design*
- Foundation
- Spillway
- Materials
- Others (Reservoir, etc.)

*Basic items such as "dam height" will not be reviewed in FS.

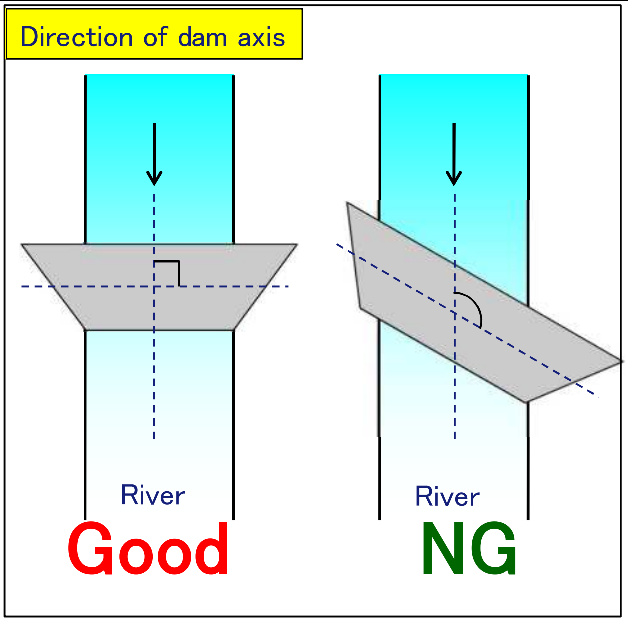
Hydraulic Design
- Design Flood Flow
- Flood Water Level
- Wave height
- Freeboard

Dam Stability
- Design loads
- Dam Stability

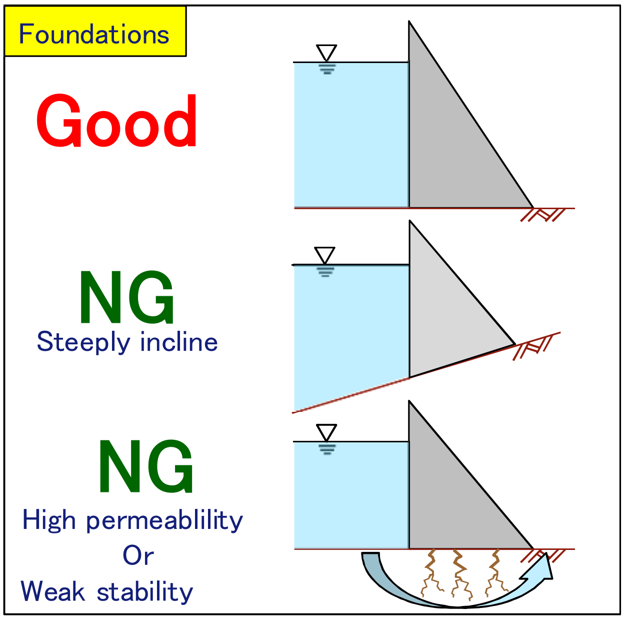
3-1-3. Basic condition for the dam layout

■ It is necessary for layout of dams that :
- ● The dam axis vertical position relative to river flow.
- ● Foundation has adequate strength and not steeply incline.

Direction of dam axis



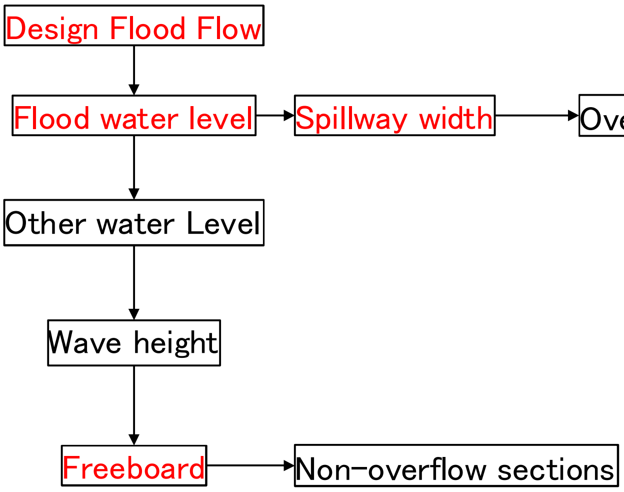
Foundations



Points : ①Dam axis and the river flow shall be vertical.
②Foundation shall have adequate strength and not be steeply.

3-2-1. Hydraulic design

- Hydraulic design is concerned with the following clauses in GREPTS.
  - Clause 26.1 Prevention of Overflow from Non-overflow Sections of Dams



Design Flood Flow

Flood water level

Spillway width

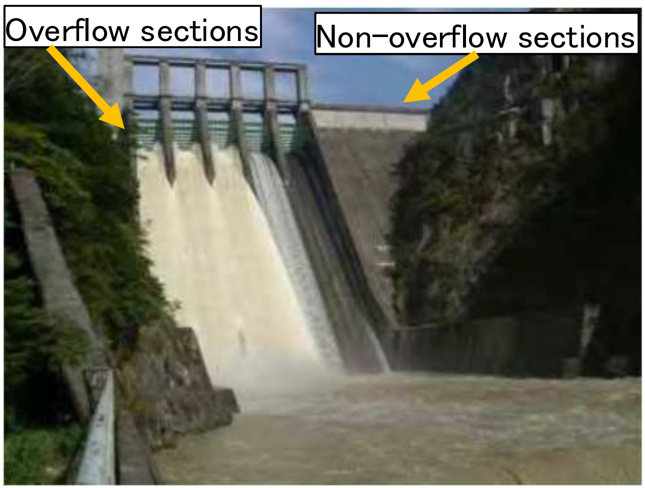
Overflow sections

Other water Level

Wave height

Freeboard

Non-overflow sections



Source: Glossary for SREPTS for Hydropower Facilities, JICA(2009), p.15

3-2-2. Design Flood Flow

- **Design flood flow** shall be established appropriately to prevent dam failure based on sufficient meteorological and hydrological research and review.
- Design flood flow shall be set tables based on the dam classification specified

Dam classification	**Design flood flow**
Large	Probable maximum flood(PMF)
Medium	Between PMF and the flood of 1,000 years return period
Small	Between PMF and the flood of 100 years return period

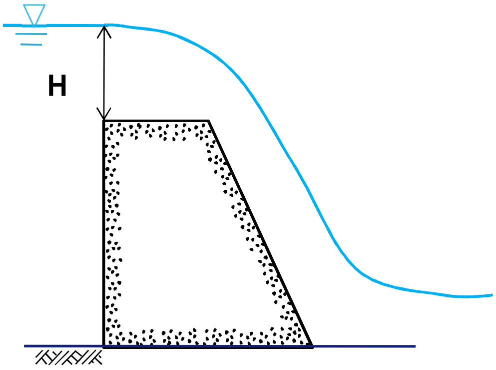
		Gross reservoir capacity (10^6 m^3)		
		Less than 10	10 to 100	More than 100
Dam height (m)	Less than 15	Small	Medium	Large
	15 to 30	Small	Medium	Large
	Higher than 30	Medium	Large	Large

Points : Design flood flow shall be set appropriately for the Dam’s scale.

Source: Draft SREPTS for Hydropower Facilities, JICA(2009), p.11

3-2-3. Flood water level and width of Spillway

- **Flood Water Level (FWL)** shall be the highest water level when the design flood flows over the spillway.
- For spillway width, it can be estimated from the this equation shown below.



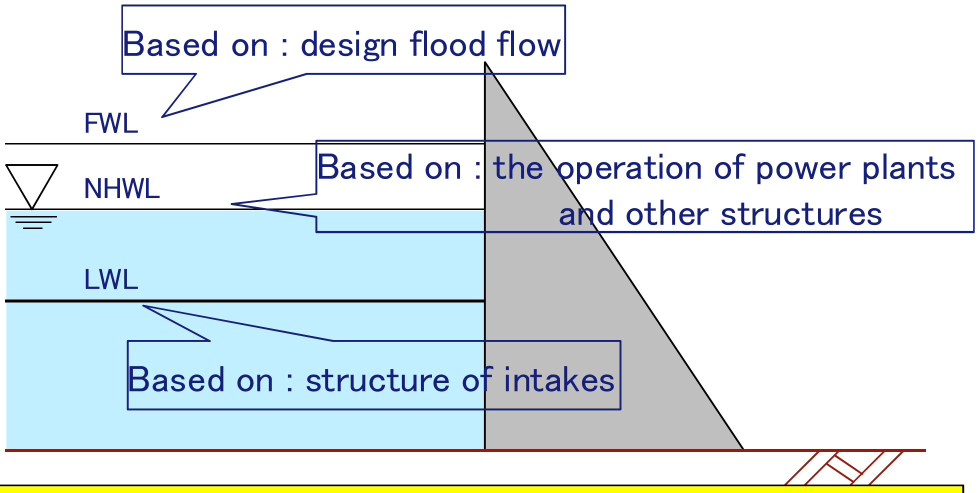
$$Q = CBH^{3/2}$$

Q : Design flood flows
C : Coefficient of overflow
In generally, C=1.8 ～ 2.0
B : Spillway width
H : Water depth above the spillway
(Flood water level)

Points : ①Spillway shall discharge design flood flow at FWL or lower.
②Spillway width shall be estimated Q = CBH $^{3/2}$.

3-2-4. Other water levels (NHWL, LWL)

- **NHWL (Normal high water level)** shall be the highest level of water stored in the reservoir of a dam during a non-flood period.
- **LWL (Low water level)** shall be the lowest level of water stored in the reservoir of a dam under normal reservoir operation.
- In generally, FWL ≧ NHWL ＞ LWL



Based on : design flood flow

FWL

NHWL

Based on : the operation of power plants and other structures

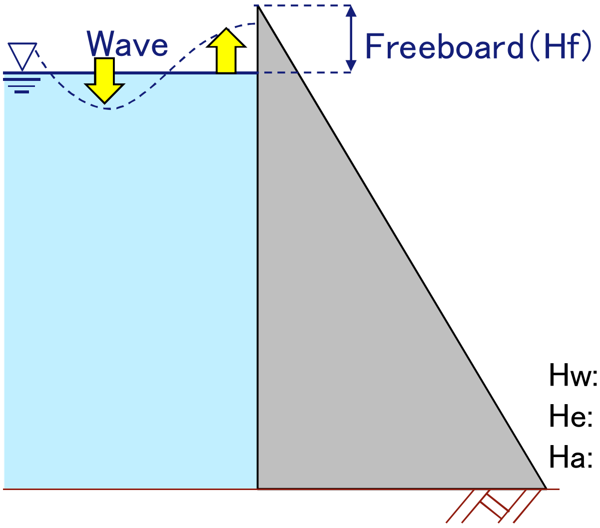
LWL

Based on : structure of intakes

Points : NHWL and LWL shall be set appropriately (FWL ≧NHWL ＞ LWL).

3-2-5. Wave height and Freeboard

- The non-overflow section shall be higher than either the normal high water level plus freeboard or the flood water level plus freeboard.
- **Freeboard** shall be set separately for the flood water level and the normal high water level by considering the type of a dam, wind-induced waves, earthquake-induced waves, and presence or non-presence of a spillway gate.



Criteria for Gravity dam

Water level	Freeboard
NHWL	Hf = Hw + He + Ha
FWL	Hf = Hw + Ha

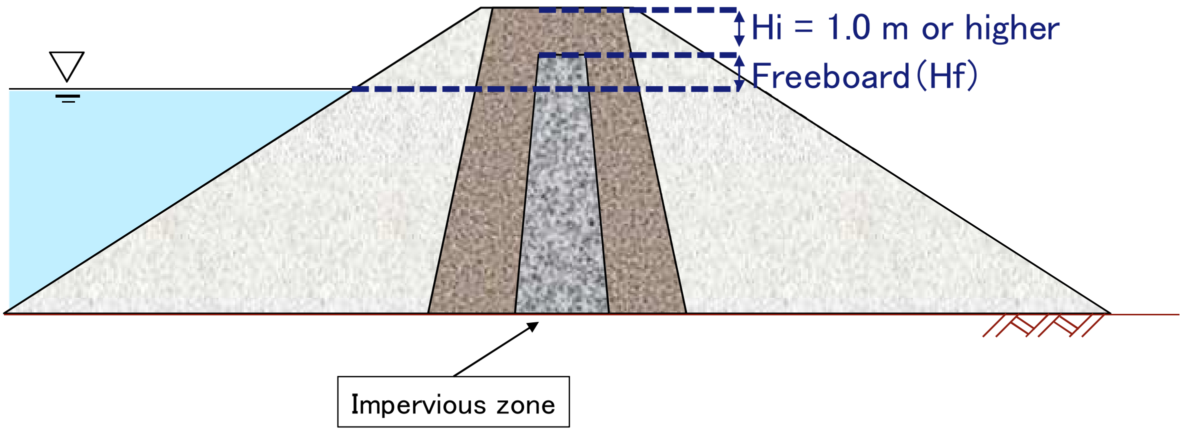
Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.26

Hw: the height waves caused by wind
He: the height waves caused by earthquake
Ha: the margin for a rise in a reservoir water level due to malfunction of spillway gates

Points : Freeboard applies the highest of values calculated for each water level.

3-2-6. Freeboard for Fill dams

- Freeboard shall be set to the top edge of the impervious zone as shown in the figure.
- In addition, a fill of 1.0 m or higher is planned to prevent settlement.



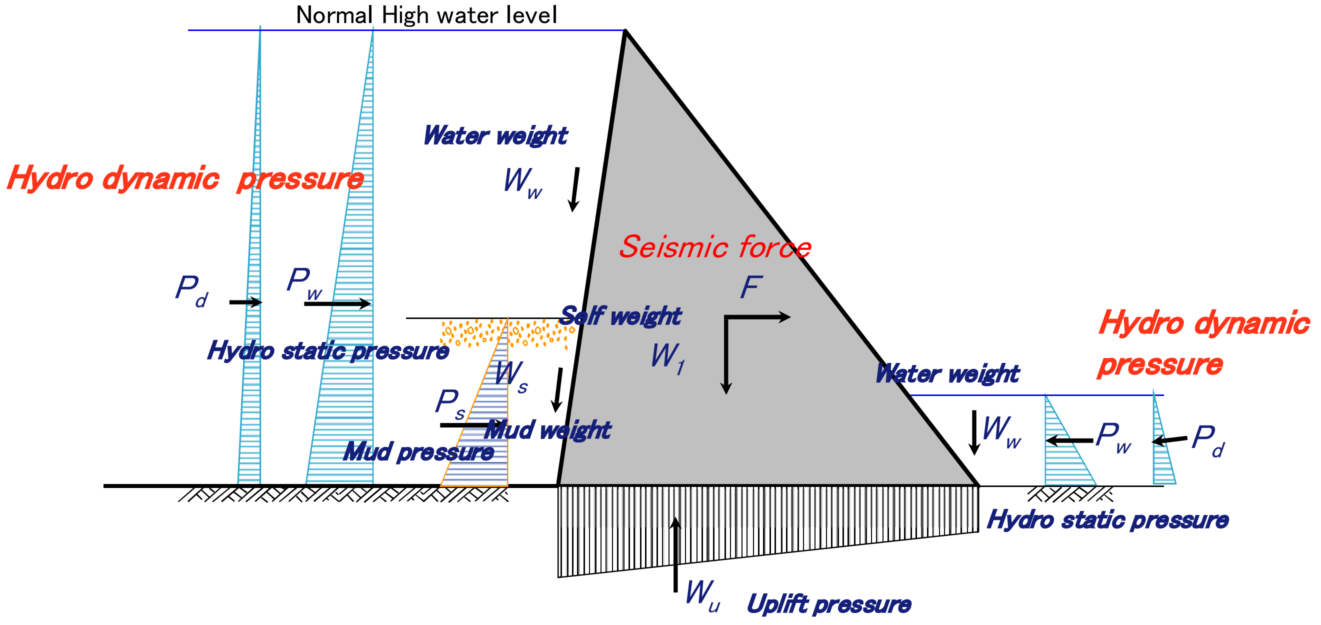
Points :①Freeboard shall be set to the top edge of the impervious zone
②In order to prevent settlement, a fill of 1.0m or higher shall be planned.

3-3-1. Dam structure design and stability

- Design of dam structures and dam stability are concerned with the following clauses in GREPTS.
  - 26.2 Dam Stability
  - 26.3 Prevention of Seepage Failure of Dams
  - 26.4 Prevention of Serious Deformations and Cracks of Dams

- **Stability**
  - Gravity Dams
  - Fill Dams
- **Foundation**
  - Gravity Dams
  - Fill Dams
- **Materials**
  - Fill Dams

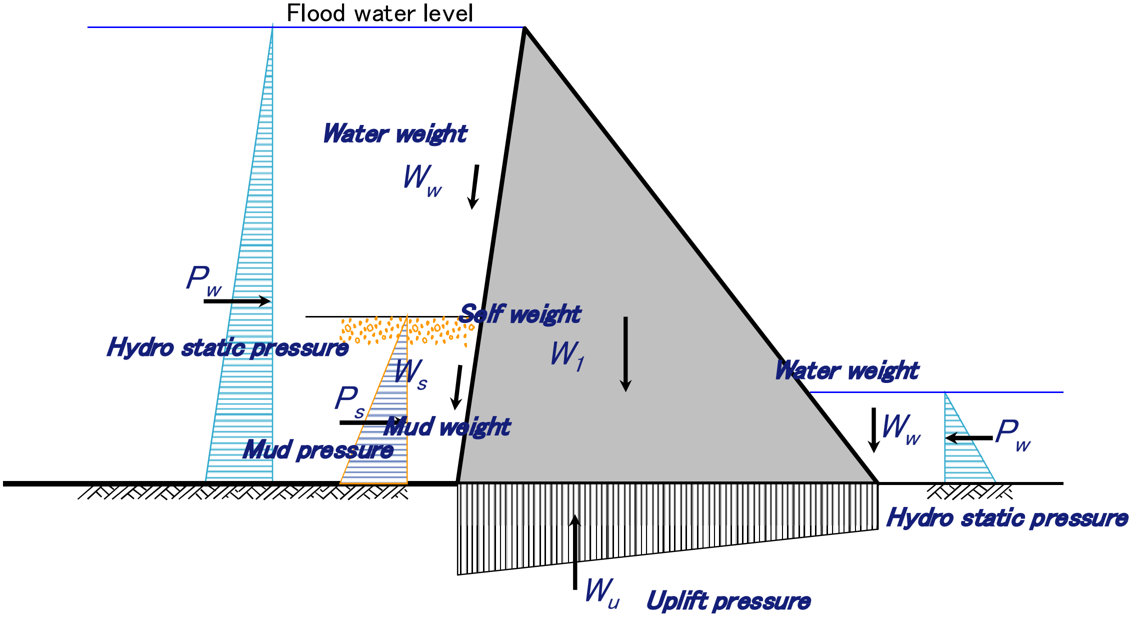
3-3-2. Example of setting loads for Gravity dams（NHWL）



Points : In order for dam stability, loads shall be set appropriately.

3-3-2. Example of setting loads for Gravity dams (FWL)

- In case of FWL condition, seismic force and hydro dynamic pressure are not considered because floods and earthquakes are not expected to occur at the same time.



Points : Loads shall be set according to the water level conditions.

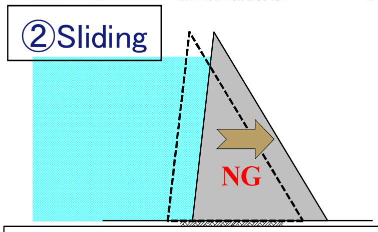
3-3-3. Confirmation about Stability for Gravity dams

- Three conditions shall be satisfied in order to confirm the stability of dams.

①Overturning

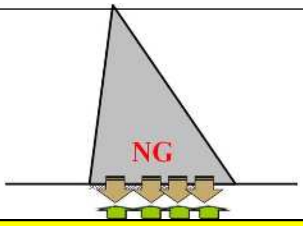
Tensile stress is not generated on the contact surface between a dam and foundation.

②Sliding



The contact face of concrete and foundation are stable against sliding by shear force.

③Strength and Durability

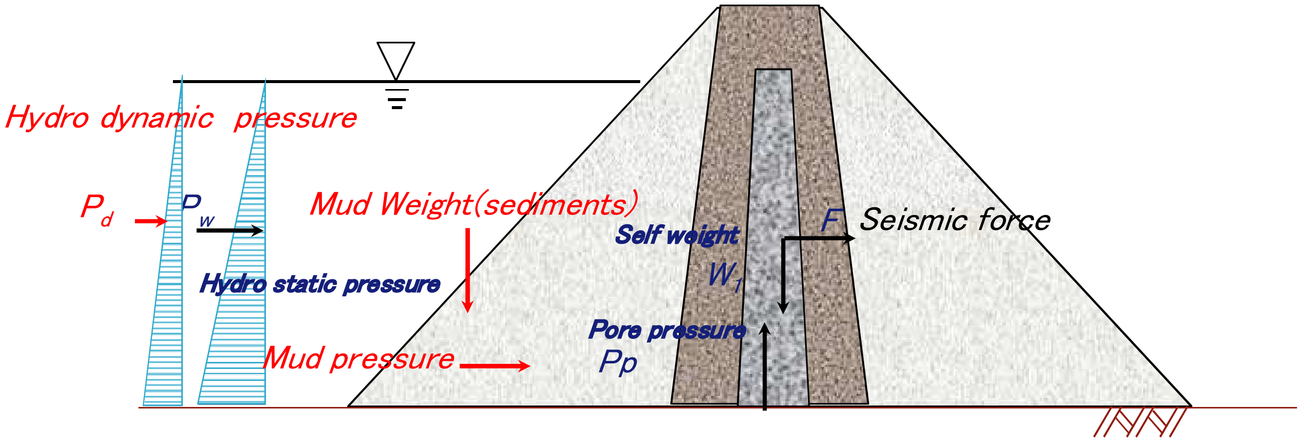


The stress on the foundation does not exceed the allowable value.

Points : Stability calculations shall be satisfied criteria.

3-3-4. Example of setting loads for Fill dams(NHWL)

- In the case of Fill dam, the following loads do not apply.
  - Hydro dynamic pressure
  - Mud pressure

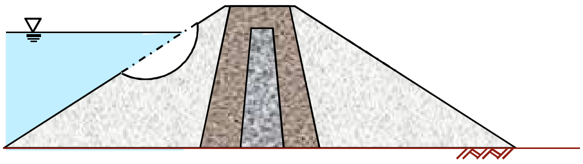


Points : In order for dam stability, loads shall be set appropriately.

3-3-5. Confirmation about Stability for Fill dams

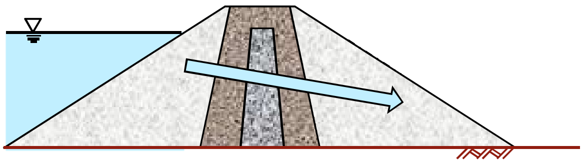
- Two conditions shall be satisfied in order to confirm the stability of Fill dams.
- ① and ② are important factors and complicated to calculate.

①Circular slip



Whether or not an circular slipping occurs on the dam embankment due to an earthquake.

②Seepage Failure



Confirm that the impervious zone will not be deformed or disintegrated by seepage water

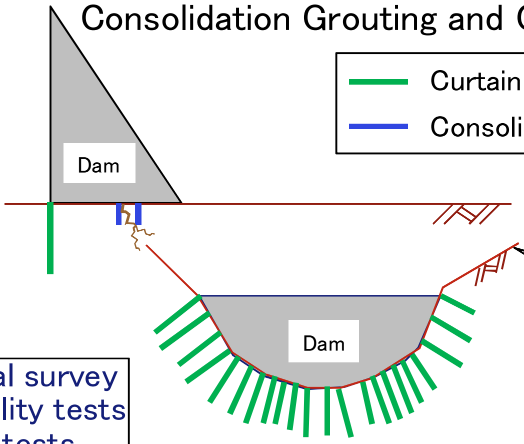
Points : Stability calculations shall be satisfied criteria.

3-4-1. Foundation (Gravity dams)

- Dam foundations shall have a required bearing capacity and shearing strength, and shall not have serious settlement, serious cracks, sliding failure and serious erosion.
- Grouting shall be designed such as hole spacing and Injection volume based on Other Construction Achievements.

Geological survey
Permeability tests
Strength tests

●Gravity Dam Applies :
Consolidation Grouting and Curtain Grouting



🟩 Curtain Grouting
🟦 Consolidation Grouting

Design in the FS :
･Grouting hole spacing
･Injection volume

Points : ①Surveys/tests shall be taken.
②Grouting shall be designed such as hole spacing and Injection volume.

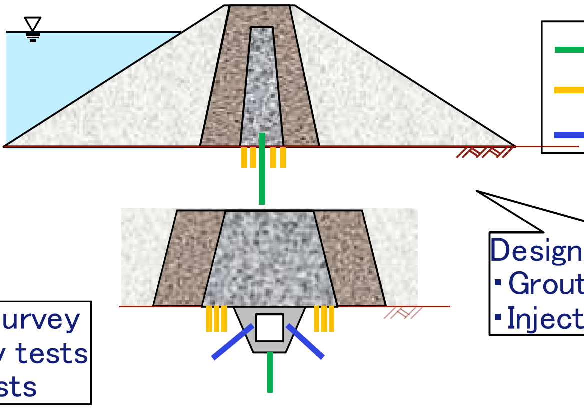
Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.39

3-4-2. Foundation (Fill dams)

- Dam foundations shall have a required bearing capacity and shearing strength, and shall not have serious settlement, serious cracks, sliding failure and serious erosion.
- Grouting shall be designed such as hole spacing and Injection volume based on Other Construction Achievements.

Geological survey
Permeability tests
Strength tests

●Fill dams :
Blanket Grouting, Curtain Grouting, Consolidation Grouting



🟩 Curtain Grouting
🟨 Blanket Grouting
🟦 Consolidation Grouting

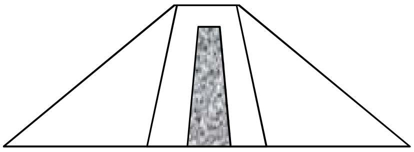
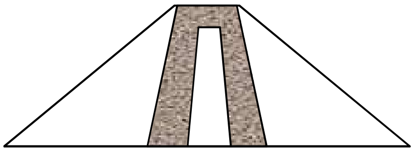
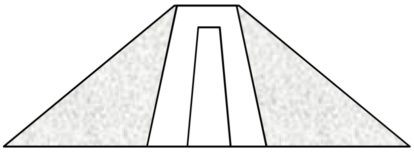
Design in the FS :
･Grouting hole spacing
･Injection volume

Points : ①Surveys/tests shall be taken.
②Grouting shall be designed such as hole spacing and Injection volume.

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.39

3-5-1. Materials (Fill dams)

- Materials conforming to the respective purposes in terms of mechanical properties shall be used for a dam body.
- All zones are consolidated and material properties are required to be known.

Zone	Image	Characteristic of materials
Impervious zone		Adequate strength and water-tightness Resistance to deformation Be free of expansion and shrinkage Not be prone to softening No organic materials Avoid water-soluble materials
Semi-pervious zone		Adequate strength and drainage capacity Having the required grain size distribution Resistance to deformation
Pervious zone		Adequate strength and drainage capacity Resistant to erosion (surface layer) Hard and durable firmly compacted

---

3-5-2. Example of Fill dam failure by seepage (Teton dam)

- Teton Dam was a fill dam that made of local Loess in Idaho, U.S.
- During a rainfall event in 1976, Seepage water caused the dam failure.
- It has been pointed out that the main causes of dam failure were below :
  - Faults were under the dam.
  - Design flaw of not having a filter zone to control seepage failure
  - Loess had higher permeability than assumed.

Name	Teton dam
Location	Idaho, U.S.
Purpose	Flood control Irrigation, etc.
Opening	1976
Height	93 m
Width (base)	520 m
Total capacity	355 × 10^6 m^3

Learn more ↓

Teton Dam History | Bureau of Reclamation (usbr.gov)
https://www.usbr.gov/pn/snakeriver/dams/uppersnake/teton/index.html

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.13

3-6-1. Reservoirs, Discharge facilities

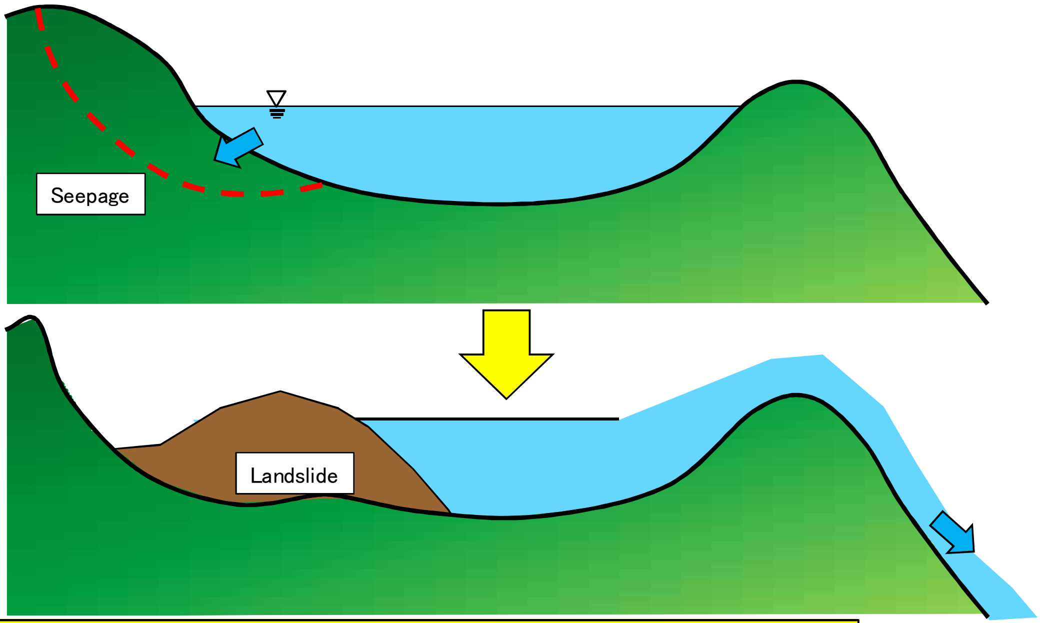
- Reservoirs and discharge facilities is concerned with the following clauses in GREPTS.
  - 27.1 Prevention of Damage to Reservoirs and around Reservoirs
  - 27.2 Privention of Damage to Downstream Areas of Dams and those of Outlets

- Reservoirs
  - Geological Survey
    - Measurement for sliding
  - Backwater effect study
    - Measurement for submersion

- Spillways
  - Energy dissipator
  - Other discharge facilities
  - Operation (No explanation)

3-6-2. Prevention of Damage to Reservoirs and around Reservoirs

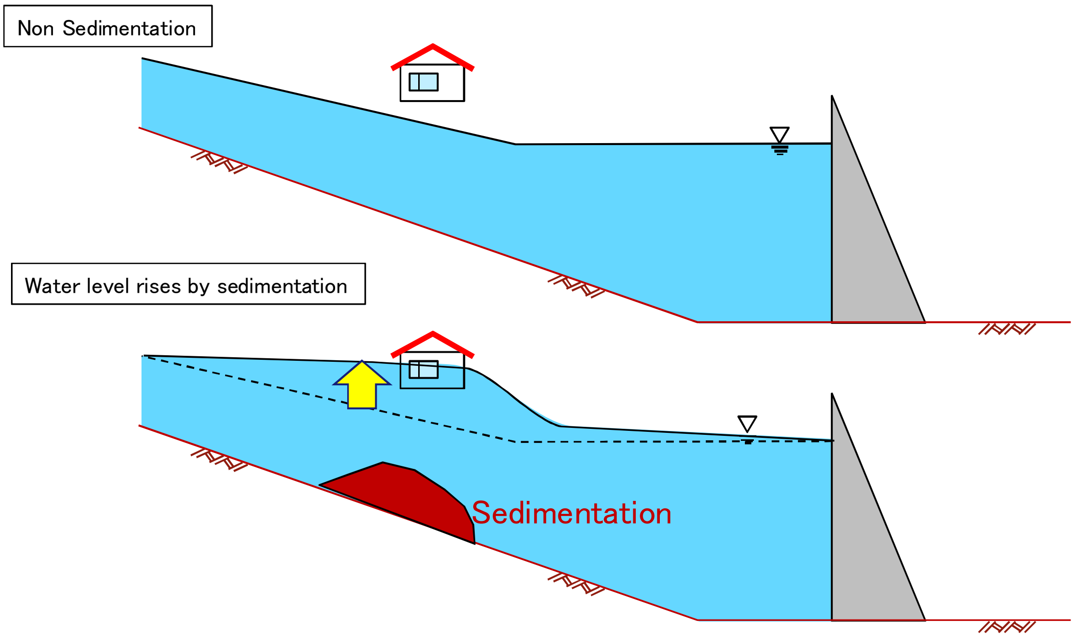
- Reservoirs shall not cause harmful water leakage to the surrounding ground, seepage failure of the ground, and large-scale landslides. (Clause 27.1)
- Vajont Dam (Italy, 1963) ⇒ https://damfailures.org/case-study/vajont-dam-italy-1963/



Points : Geological survey around reservoirs shall be done.

3-6-3. Backwater effects by sedimentation

- Proper measures shall be taken if submergences of properties such as houses and buildings may occur at upstream areas of a reservoir due to rises in water level caused by the reservoir sedimentation. (Clause 27.1)



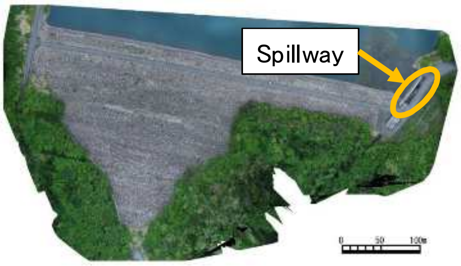
Points : Backwater impacts associated with dam installation shall be studied.

3-6-4. Spillway

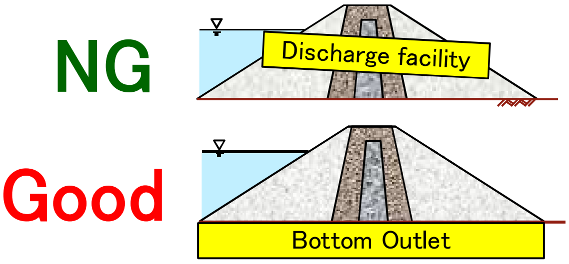
- All dams shall be equipped with spillways designed to safely discharge a volume of water equal to or smaller than the design flood.
- For a fill dam, no spillways shall be constructed on/in the dam body.

Spillways with gates

Free overflow spillway



Spillway installed near the dam body



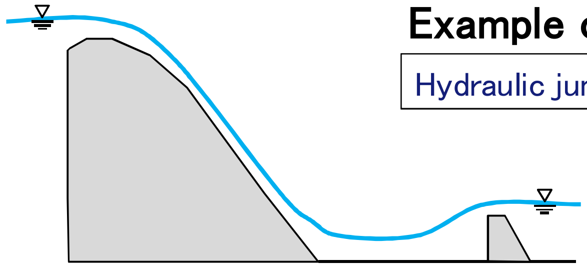
Points : Spillway shall be installed on/in/near dams.

Source: Glossary for SREPTS for SREPTS for Hydropower facilities, JICA(2009),p.15
Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.84

3-6-5. Energy Dissipator

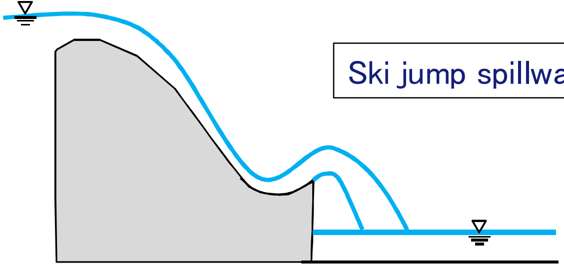
- The energy of water flowing down through spillways shall be dissipated to prevent negative impacts on the dam body and the downstream areas.
- Energy dissipator is generally placed to prevent the damage to dam body and downstream river course.

Example of Energy Dissipator



Hydraulic jump basin with impact blocks

There are impact blocks downstream of the dam in order to secure a certain amount of water, and to dissipate the energy of the discharged water.



Ski jump spillway

This is effective
- in reducing the force of the water by diffusing it
- in reducing souring directly below the dam by sending the water a little further.

Points : Energy dissipator shall be installed if necessary.

Chapter4 : Preservation of Environment when installing dams

4–1. Basics for EIA (Environmental Impact Assessment)

Compliance (Clause 14)

- To prevent the Environmental pollution, the electric power facilities shall be in accordance with the environmental laws and regulations in the Kingdom of Cambodia.

Pollution

- Comply with regulatory standards for pollutants.

Naturall Environment

- In principle, the project shall be conducted outside of a legally designated nature conservation area.
- Take necessary measures for the conservation of rare wildlife and biodiversity.

Resettlement

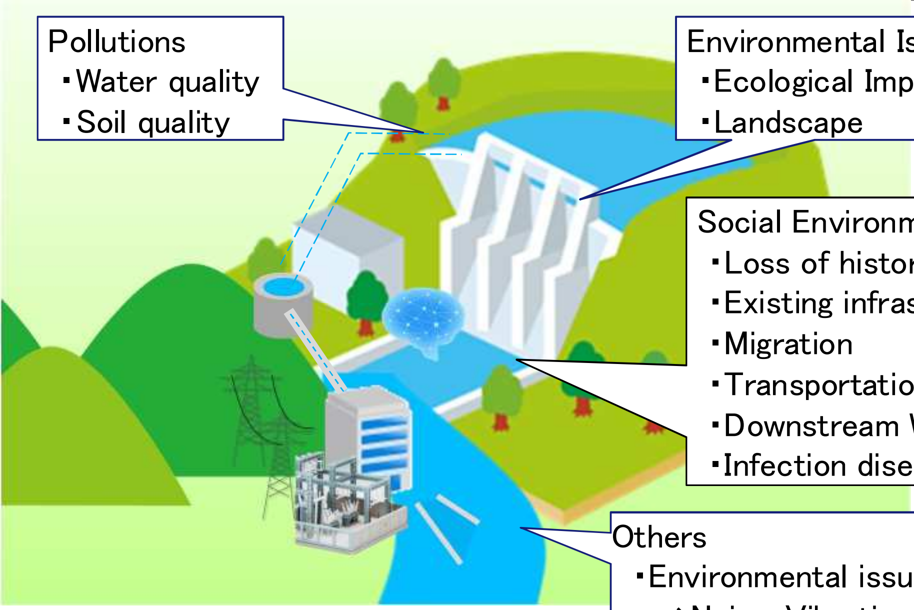
- Consideration for Migrants
- Consider keeping the number of migrants to a minimum.
- Develop a plan to mitigate the impact

Measurements for environmental protection

- The necessary costs must be included in the budget.

4–2. Environmental Impacts when installing dams

- JICA says that environmental considerations should be taken into account when installing hydropower plants.



Pollutions
- Water quality
- Soil quality

Environmental Issues
- Ecological Impacts
- Landscape

Social Environmental Issues
- Loss of historical/cultural legacy
- Existing infrastructure
- Migration
- Transportation(ships)
- Downstream Water Utilization
- Infection disease

Others
- Environmental issues while construction
  ⇒Noise, Vibration, Bad odor, Dusts

Points : Environmental impact factors associated with the installation of dams shall have been considered.

4-2-1. Measures (Fish path)

- Fish path is waterway which allow the passage of fish migrating upstream to spawn.
- The fish path should be minimum 1m wide with a 1:10 to 1:15 gradient.
- The velocity of flow should be approximately 1.2m/s to 1.5m/s.

4-2-2. Measures (River maintenance flow)

- River maintenance flow is also the measurements for Ecological Impacts and Landscape downstream dam.
- There are many factors that affect the setting of the flow rate.

Factors for flow rate

- ✓Fishing
- ✓Plants and animals
- ✓Groundwater level
- ✓Salt damage
- ✓Landscape
- ✓Boat traffic
- ✓etc.

Chapter5 : Summary

Points to be checked

5-1. Points to be checked in this lecture

Point to be Checked	Details

Basic design	✓ Basic conditions for dams layout shall be satisfied.
	  ✓ Dam axis and the river flow shall be vertical.
	  ✓ Foundation shall have adequate strength not be steeply.
	  ✓ Appropriate dam type shall be selected.

Clause26.1 (GREPTS)	✓ The following factors shall be set appropriately.
	  ✓ Design flood flow
	  ✓ FWL, NHWL, LWL
	  ✓ Spillway width
	  ✓ Wave height, Freeboard

Dams
Clause26.2
Clause26.3
Clause26.4
	✓ Loads acting on dams shall be set appropriately.
	✓ The criteria for dam stability shall be satisfied.
	  ✓ Gravity dams: Overturning, Sliding, Durability
	  ✓ Fill dams :Sliding, Seepage
	  ✓ Materials(Only for fill dams)

5-2. Points to be checked in this lecture

Point to be Checked	Details
Foundation Clause26.2 Clause26.3 Clause26.4	✓ Geological survey and proper tests shall be done. ✓ The grouting has been designed, and it shall be appropriate.
Clause27.1	✓ Geological survey around the reservoir shall be done. ✓ Proper measures are taken to control backwater impacts. Or are considering it.
Clause27.2	✓ Spillway shall be installed in proper location. ✓ Spillway can safely discharge design flood flow. ✓ Energy dissipator shall be set in order to prevent flood flow from harming area downstream dam.

5-3. Points to be checked in this lecture

Point to be Checked	Details
Clause 14 (when installing dams)	✓ Environmental impact factors associated with the installation of dams shall have been considered. ✓ Proper measures shall be considered.

REFERENCES

- ELECTRIC POWER TECHNICAL STANDARDS OF THE KINGDOM OF CAMBODIA.
  (Ministry of Industry, Mines and Energy in Accordance with the Electricity Law of the KINGDOM OF CAMBODIA, July 2004)
  https://rise.esmap.org/data/files/library/cambodia/Electricity%20Access/Cambodia_Electricity%20Power%20Technical%20Standards.pdf
- SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
  (Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc., October 2009)
- EXPLANATION SHEET FOR SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
  (Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc., October 2009)
- GLOSSARY FOR SPECIFIC SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
  (Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc., October 2009)
- The Teton Dam: rhyolite foundation + loess core = disaster
  (IAN SMALLEY, GEOLOGY TODAY, January 1992)
  https://onlinelibrary.wiley.com/doi/10.1111/j.1365-2451.1992.tb00347.x
- JAPAN INTERNATIONAL COOPERATION AGENCY (JICA) GUIDELINES FOR ENVIRONMENTAL AND SOCIAL CONSIDERATIONS
  (Japan International Cooperation Agency(JICA), October 2009)

Thank you for your attention

WG2: Technical Review on Hydropower Project

4th Class : Waterways

The Chugoku Electric Power Co., Inc.

Contents of this lecture (4th Class)

- In this 4th lecture, the basics of hydropower waterway design will be explained.

〔Lecture Topics〕

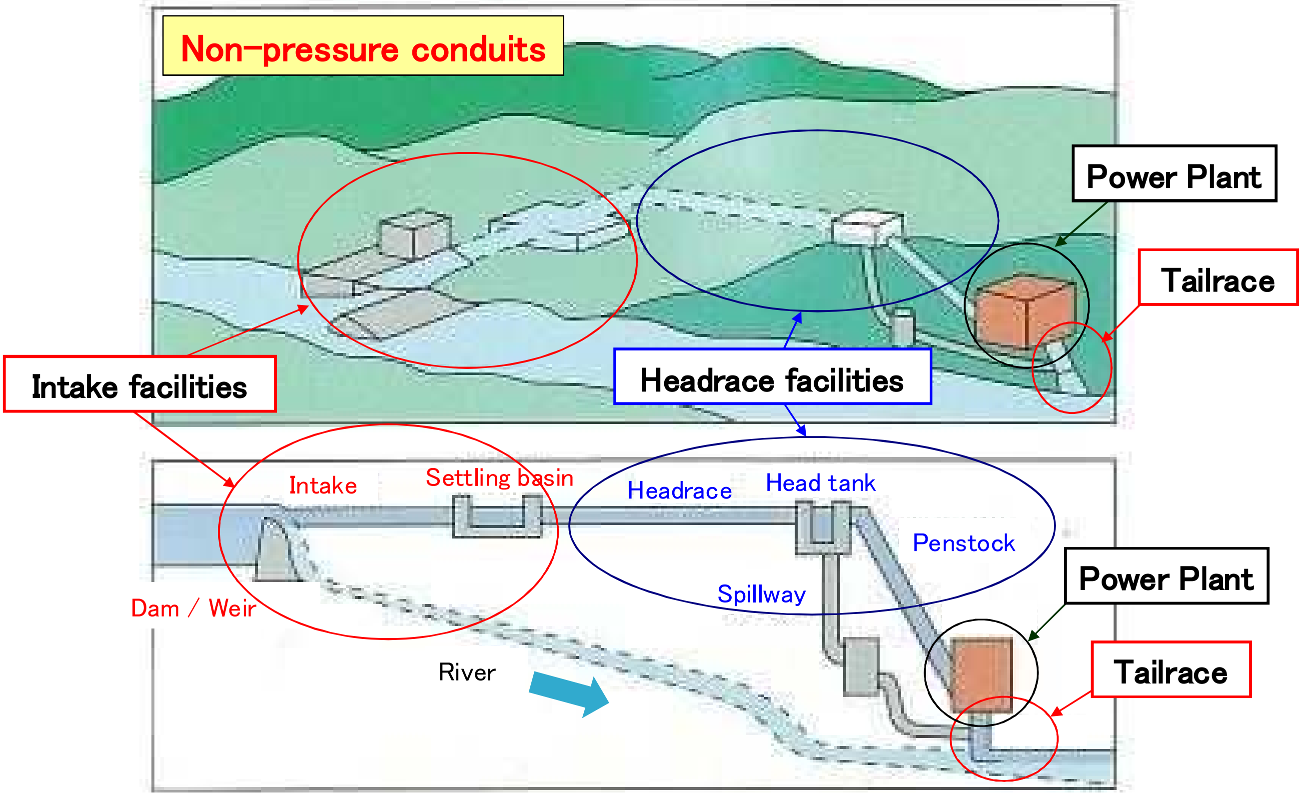
- ･Outline of the facility
- ･Outline of the basic study about waterways design
- ･Technical points to be checked in FS review

〔Lecture Contents〕

Chapter 1 : Outline
Chapter 2 : Intakes
Chapter 3 : Settling Basins
Chapter 4 : Headraces
Chapter 5 : Head Tanks
Chapter 6 : Surge Tanks
Chapter 7 : Penstocks
Chapter 8 : Tailraces
Chapter 9 : Summary
(Points to be checked in FS)

1. Outline

- Hydropower plants consist of the following facilities.



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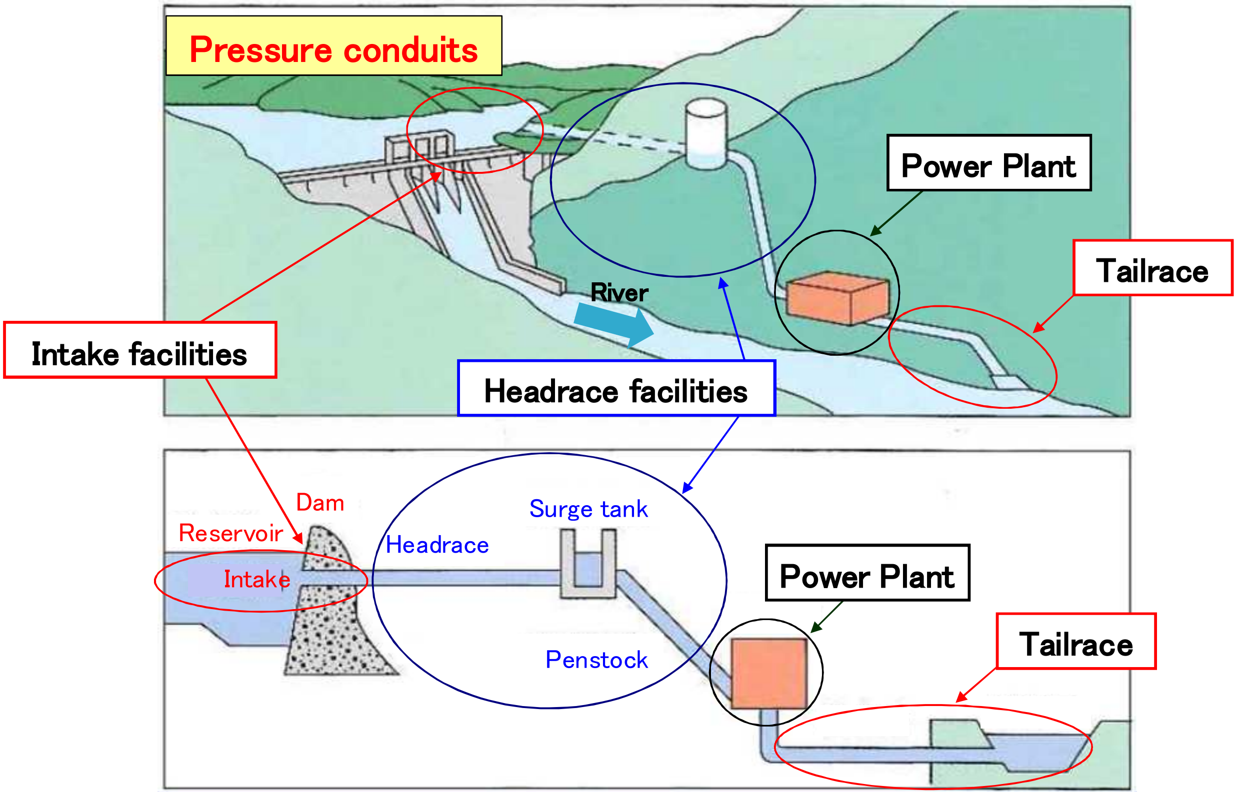
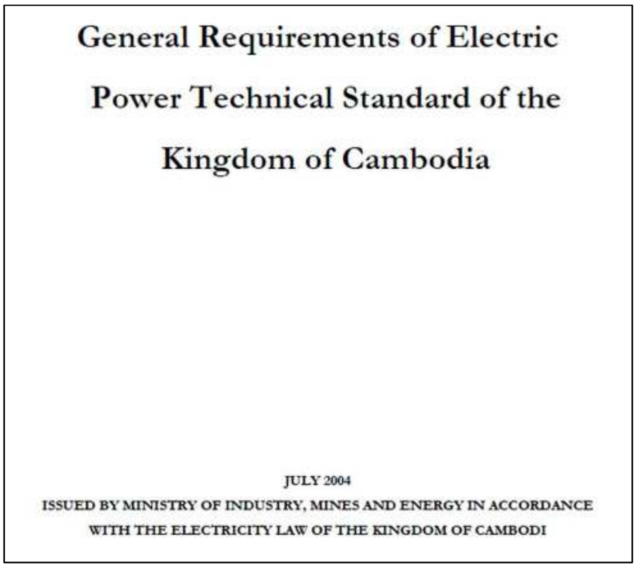
1. Outline

- Hydropower plants consist of the following facilities.



1. Outline

- In this lecture, GREPTS is “General Requirements of Electric Power Technical Standard of the Kingdom of Cambodia”, referred by “ELECTRIC POWER TECHNICAL STANDARDS OF THE KINGDOM OF CAMBODIA” (July 2004).



General Requirements of Electric
Power Technical Standard of the
Kingdom of Cambodia

JULY 2004
ISSUED BY MINISTRY OF INDUSTRY, MINES AND ENERGY IN ACCORDANCE
WITH THE ELECTRICITY LAW OF THE KINGDOM OF CAMBODI

KINGDOM OF CAMBODIA
NATION RELIGION KING

ELECTRIC POWER TECHNICAL
STANDARDS OF
THE KINGDOM OF CAMBODIA.

https://rise.esmap.org/data/files/library/cambodia/Electricity%20Access/Cambodia_Electricity%20Power%20Technical%20Standards.pdf

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1. Outline

- Technical standards for waterways are found in clause 26.5. (In GREPTS)

PART 3

GENERAL REQUIREMENTS FOR HYDRO POWER GENERATING FACILITIES

Clause 26: Dams, Waterways, Powerhouses and Other Facilities

26.1 Prevention of Overflow from Non-overflow Sections of Dams

26.2 Dam Stability

26.3 Prevention of Seepage Failure of Dams

26.4 Prevention of Serious Deformations and Cracks of Dams

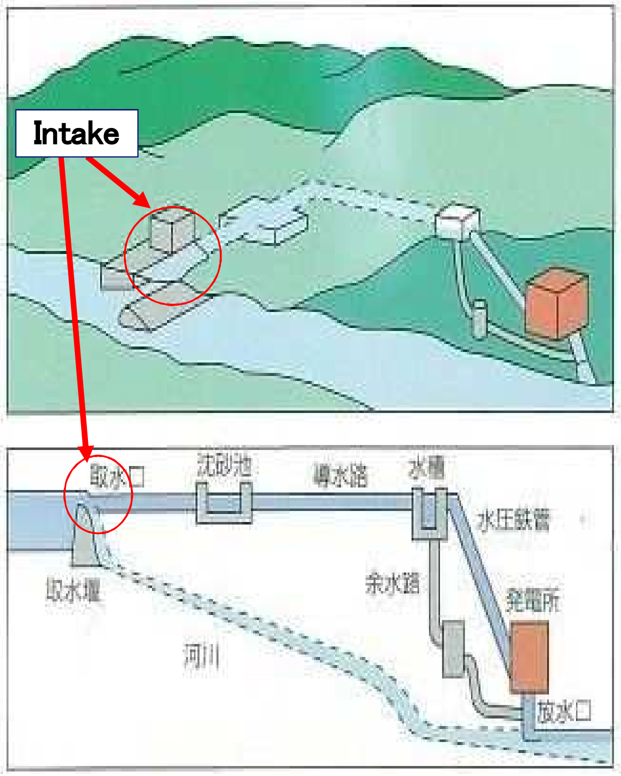
26.5 Prevention of Failure of Waterways

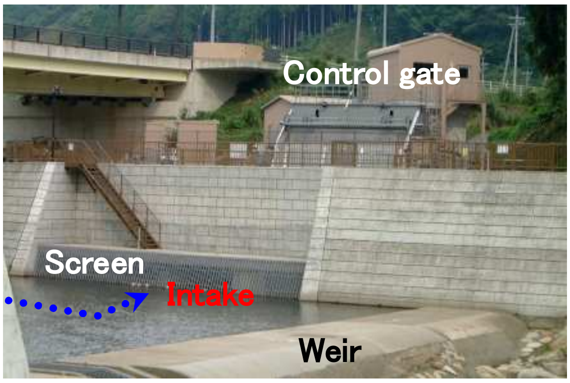
1. Waterways shall be structurally stable for anticipated loads, and not be damaged by disasters such as a landslide and a flood.
2. Waterways shall be able to safely and securely discharge and control a design plant discharge, and be hydraulically stable.

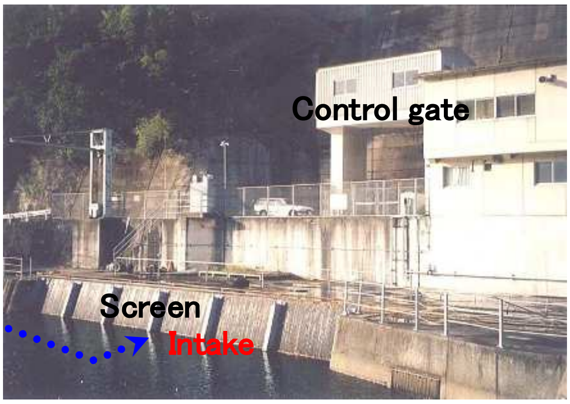
26.6 Prevention of Failure and Damage of Powerhouses and Other Facilities

2. Intakes

- Intakes are inlets that taking water from the river.







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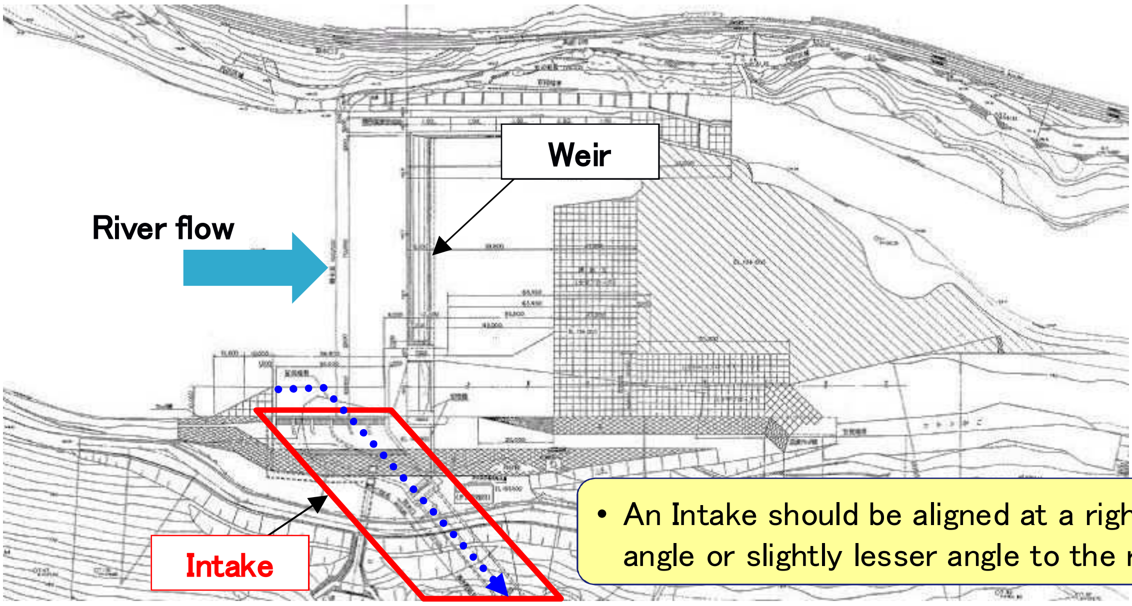
2. Intakes i) Location

- Intakes must be able to <u>properly</u> take river water into the waterway.
- Sediment and debris from the river should not flow into the waterway.
- The site shall be safe against a landslide and a flood.



- An Intake should be aligned at a right angle or slightly lesser angle to the river.

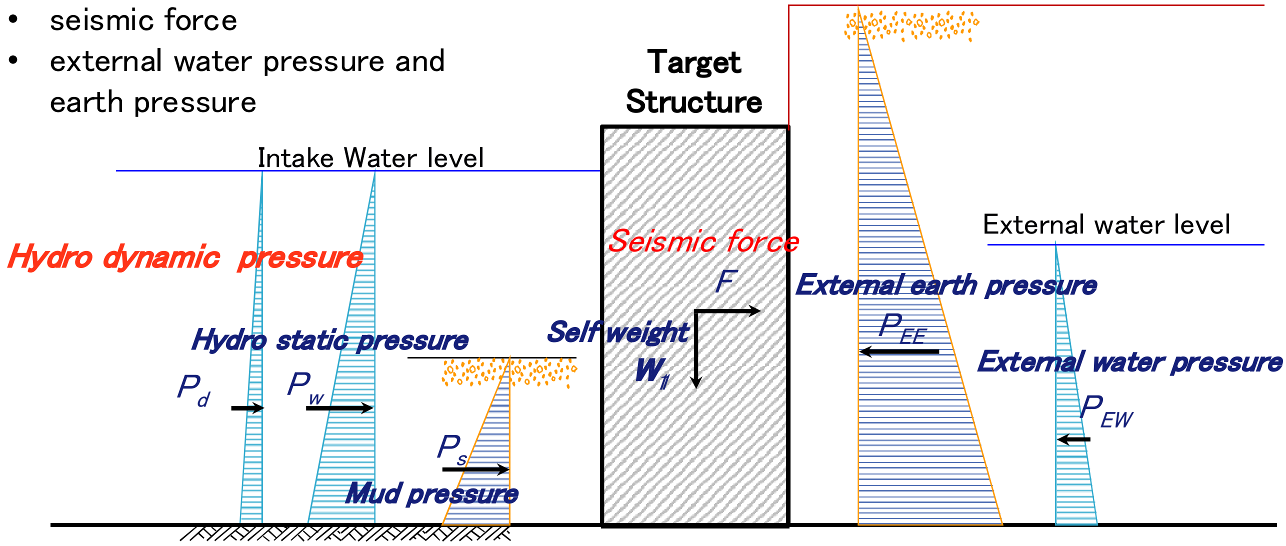
Plane view

2. Intakes ii) Design

Intakes shall be structurally stable for anticipated loads.

Anticipated loads

- self-weight
- hydrostatic pressure
- hydrodynamic pressure
- mud pressure
- seismic force
- external water pressure and earth pressure



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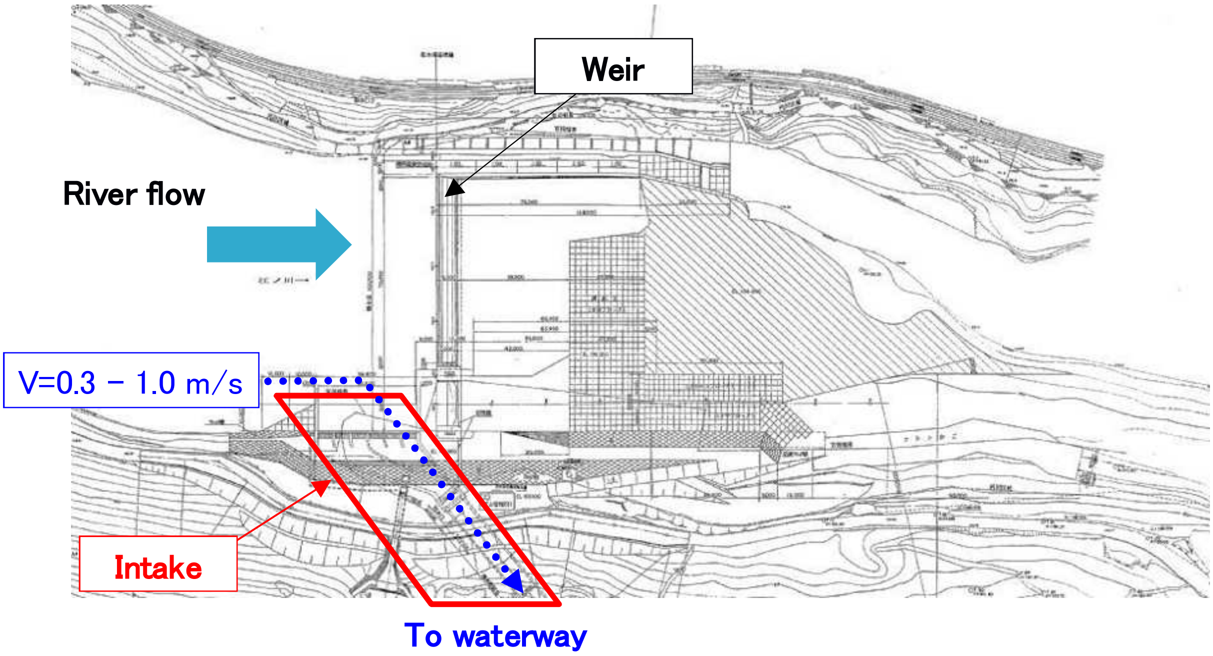
2. Intakes ii) Design

Intakes must be able to properly take river water into the waterway.

- Inflow velocity should be around 0.3m/s to 1.0 m/s.

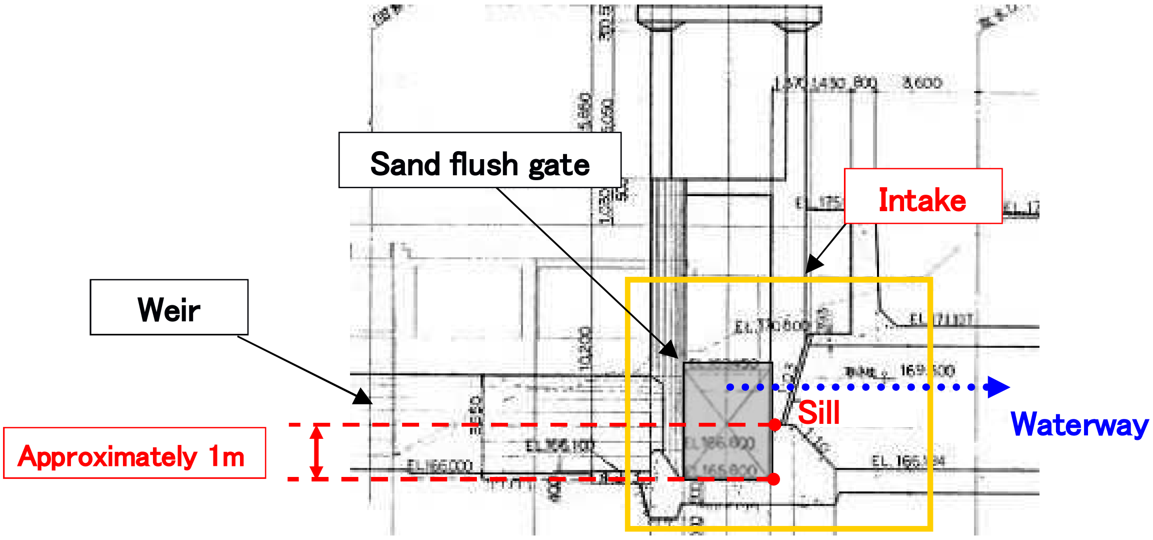


Plane view

2. Intakes ii) Design

■ Structurally, sediment and debris from the river should not flow into the waterway.

- The intake sill height should be set approximately 1 meter higher than the bottom of the sand flush gate to prevent the entry of debris into the waterway.



Cross-section view of intake

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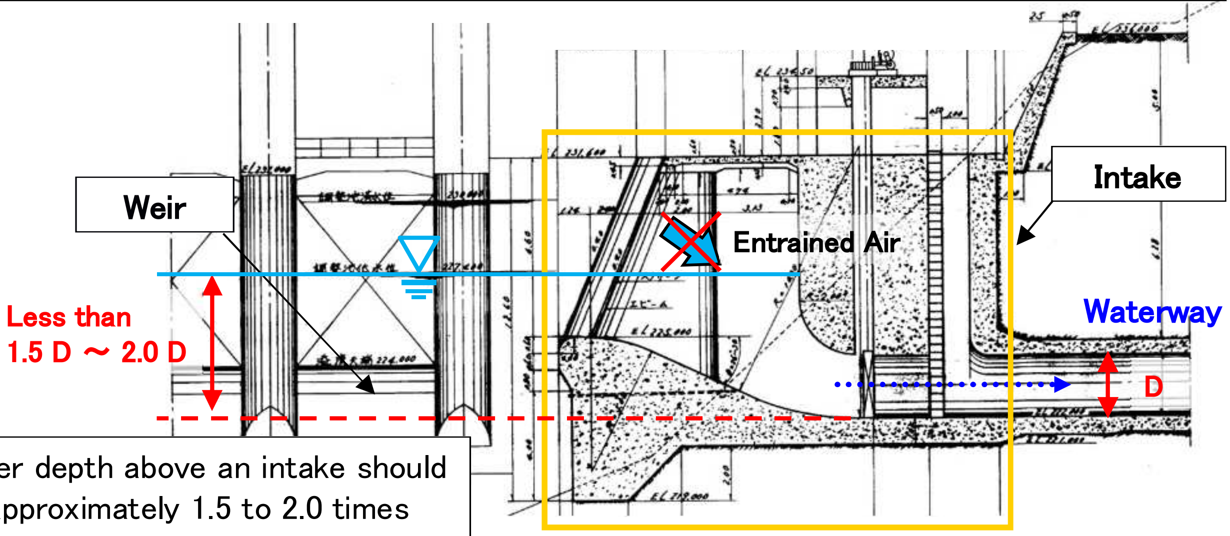
2. Intakes ii) Design

■ In the case that an intake is connected to pressure conduit, it must be located and structured <u>to prevent air from entering the waterway</u>, and must be capable of taking water at any water level within the range of use.



- Water depth above an intake should be approximately 1.5 to 2.0 times larger than the headrace diameter.

Cross-section view of intake

- If air is entrained into a pressure headrace, the turbines and other facilities may be damaged by an air hammer phenomenon.
- And the entrained air could cause the increase of head loss and the decrease of turbine efficiency.

2. Intakes iii) Ancillary facilities

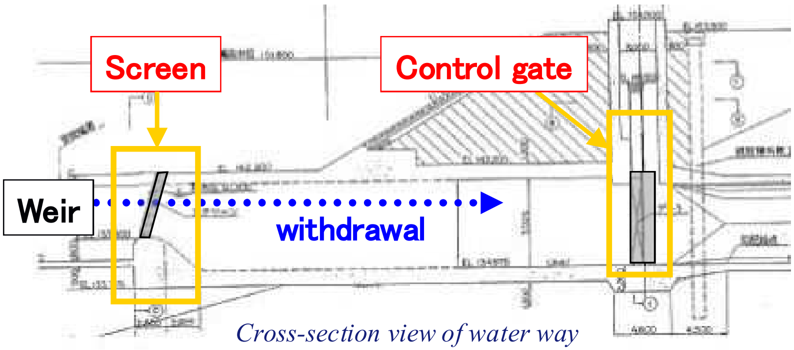
■ Screens and control gates should be installed.

Screens

- Screens are installed in front of the intake to prevent intrusion of driftwood and debris.
- For the small intake, debris that stay on the screen may be removed manually. However, for the large intake, mechanical rake is often used, that can remove debris efficiently and safely.

Control gates

- Control gates are installed to adjust the discharge corresponding to the intake water level and load fluctuation.
- It is also used for dewatering of the waterway for inspection and repair.



Cross-section view of water way

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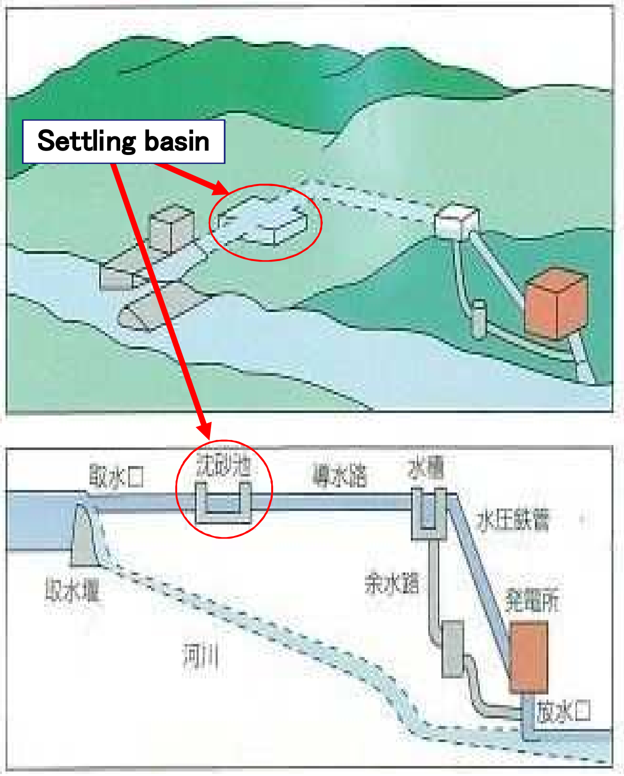
3. Settling Basins

Non-pressure conduits

■ Settling basins are water pools for making sand settle.



3. Settling Basins i) Design

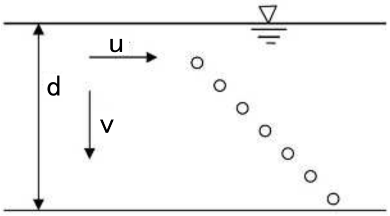
- Settling basins are constructed close to the intake to settle and flush sediment that may cause damage to downstream channels and turbines.

- A settling basin should be long enough to allow fine sand particles to gradually settle from the water surface and finally reach the bottom at the end of the basin.

$$L = \frac{d}{v} u$$

L : Minimum required length of settling basins (m)
d : Depth of settling basins (m)
v : Marginal settling velocity of sediment (m/s)
u : Mean velocity in settling basins (m/s)
(approximately 0.3 m/s)

- In practical design, it is common to set the length to 2 to 3 times the calculated length to ensure a margin.



Settling of Sand Particle

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.90

· If a settling basin isn't large enough and the river sand enter the headrace, it can cause serious damage to the headrace.

Sedimentation

Local scouring by sediment

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3. Settling Basins i) Design

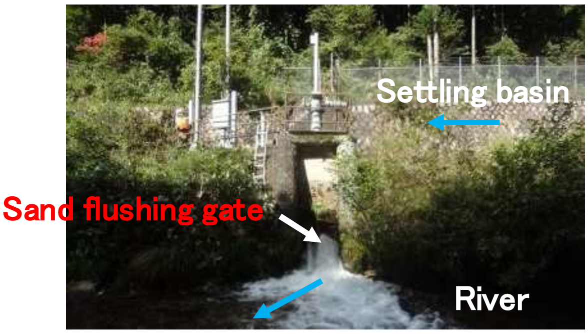
- The structure must be safe against a landslide and a flood.
- A settling basin shall be structurally stable for anticipated loads.
- The structure shall be capable of easily flushing sediment that has settled and accumulated.

Anticipated loads

- Self-weight, hydrostatic pressure, hydrodynamic pressure, seismic force, external water pressure and earth pressure

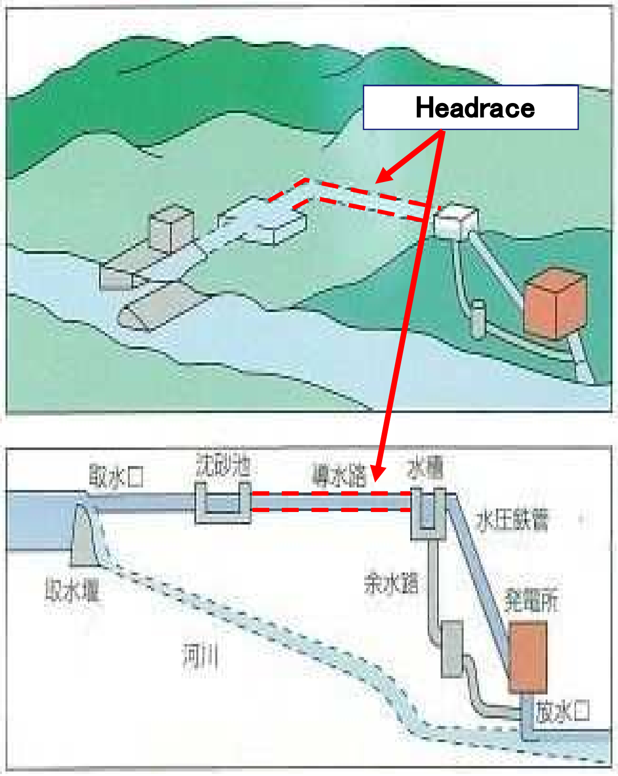
Flushing sediment

- Sand flushing gates should be installed to remove the sediment.



4. Headraces

- Headraces are waterways for leading water to the power plant.



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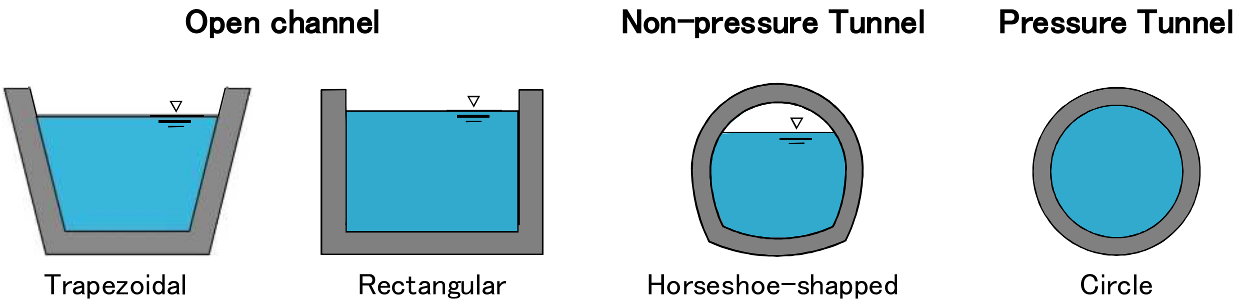
4. Headraces

i) Type of waterways

- Waterways are classified into pressure conduits and non-pressure conduits in terms of hydraulics.
- In terms of structure, waterways are classified into open channel, covered channel, culvert, tunnel, aqueduct, inverted siphon, etc.

Cross section

- In the case of non-pressure conduit, the trapezoidal cross section is generally used, but rectangular cross section may be used for small flow.
- A horseshoe-shaped cross section is generally used for culverts and tunnels due to the easiness of its construction, its strength against external forces and low cost.
- Where geological condition is unfavorable, a cross section close to a circle is used to resist external pressure.



4. Headraces ii) Design

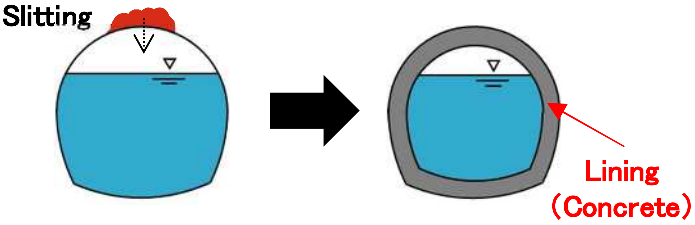
- A headrace shall be structurally stable for anticipated loads.
- Any leakage from a headrace inside shall not cause damages to the surrounding grounds or other structures.
- A headrace shall not significantly cause damage to the downstream waterways or a turbines due to slitting.
- Necessary countermeasures such as lining shall be taken when passing through areas with poor geological conditions.

Anticipated loads

- Self-weight
- Hydrostatic pressure
- Internal water pressure
- External water pressure
- Seismic force
- Earth pressure
- Surcharges etc.

Lining

- In Japan, the inner surface of the tunnel is usually lined with concrete.
- This prevents water leakage, protects the ground, and reduces friction loss in the channel.



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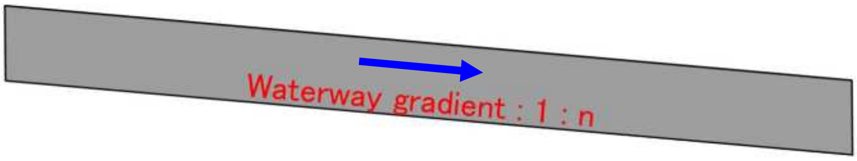
4. Headraces ii) Design

- It is necessary to determine the most economical waterway gradient and cross section in consideration of the balance of construction cost and energy output.



Non-pressure conduits

Steep gradient ⇒ Small cross section

- Smaller cross section decreases construction cost.
- But, energy output decreases due to increased friction loss by the waterway and lower water levels at the head tank.

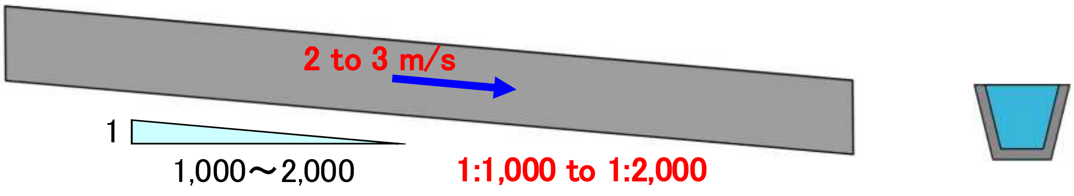
Gentle gradient ⇒ Large cross section

- Larger cross section increase the construction cost.
- But energy output increases due to reduced friction loss by the waterway and higher water levels at the head tank.

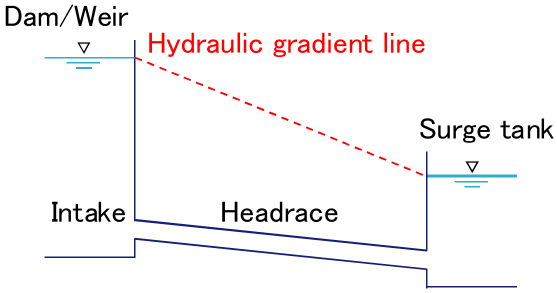
4. Headraces ii) Design

Non-pressure conduits

- In view of our experience and consideration for the balance of construction cost and energy output, optimum design of headrace is generally as follows,
  - The velocity of flow is generally 2 to 3 m/s.
  - The headrace gradient is generally 1:1,000 to 1:2,000 in the case of an open channel.



Pressure conduits



- A headrace shall be placed below the hydraulic gradient line connecting the lowest water level of an intake and a surge tank, to prevent negative pressure in the tunnel and damage.
- The gradient of pressure conduits shall be steeper than that of a non-pressure conduits.

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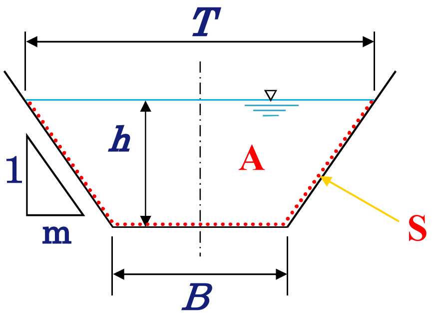
4. Headraces ii) Design

■ For the calculation of the discharge, Manning formula is used.

Manning formula

$$V = \frac{1}{n} R^{\frac{2}{3}} I^{\frac{1}{2}}$$

$$Q = VA$$



V : Mean velocity on waterway (m/s)
R : Hydraulic radius (m)
R=A/S
A : Cross sectional area of flow (m^2)
S : Length of wetted perimeter (m)
I : Hydraulic gradient
Q : Discharge (m^3/s)
n : Manning's roughness coefficient

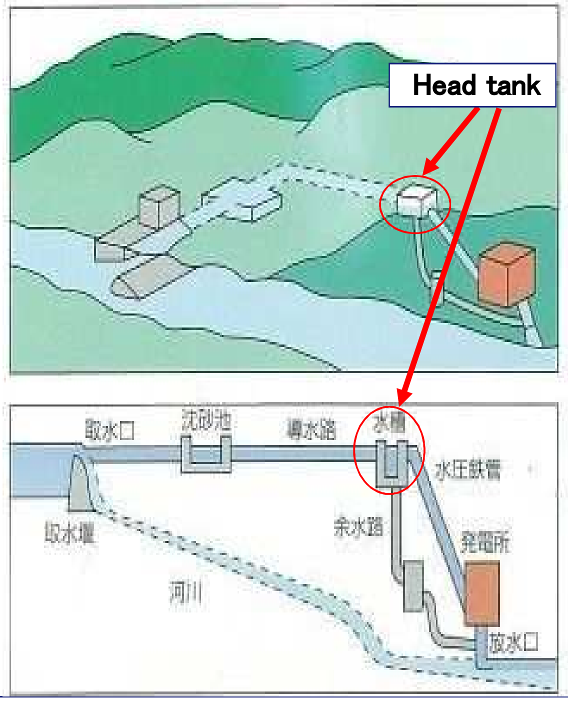
Manning's roughness coefficient

Lining Material	n
Conduit lined conventional concrete	0.013～0.016
Conduit constructed steel for forms and lined good quality concrete	0.011～0.014
Un-lined tunnel with only the bed placed with concrete	0.020～0.030
Totally un-lined tunnel	0.030～0.045
Welded steel pipe	0.010～0.013
Riveted steel pipe	0.011～0.018

5. Head Tanks

Non-pressure conduits

- Head tanks are the pondage located between the headrace and the penstock.
- It regulates the difference between headrace flow rate and penstock flow rate due to load fluctuations.



5. Head Tanks

i) Design

- A head tank shall have an adequate water capacity to prevent air intrusion to penstocks when the head tank is operating normally or even if loads increase rapidly.
- A head tank shall be structurally stable for anticipated loads.

Adequate water capacity

- Head tank capacity must be large enough to continue operation for 1 to 2 minutes at the maximum power discharge without any supply of water from a headrace.
- The water surface area of a head tank must satisfy the following against rapid changes in a water surface level or wave actions during steady operation.

$$A \geqq 50 \times Q$$

A : Water surface area (m^2)
Q : Maximum plant discharge (m^3/s)

- Water level fluctuations against load fluctuations must be within the permissible upper and lower limits.

Anticipated loads

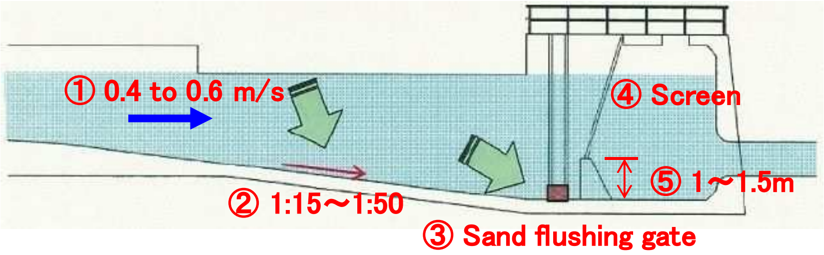
- Self-weight, internal water pressure, seismic force, external water pressure, earth pressure

5. Head Tanks　i) Design

- A head tank settles floating sand and debris from running water to prevent trouble to the penstock and turbine.
- It must be possible to easily remove accumulated sand from a head tank.

To settle and remove floating sand and debris

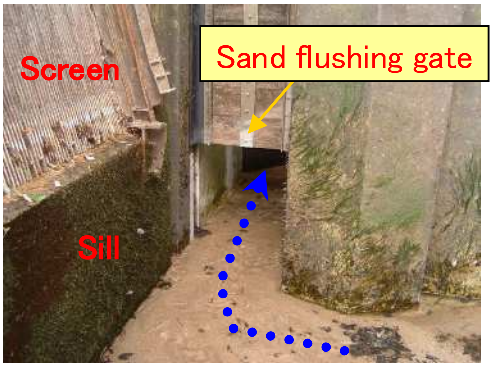
① The velocity is to be 0.4 to 0.6m/s.
② The bottom gradient is generally 1:15 to 1:50.
③ Sand flushing gates should be installed to remove sediment.

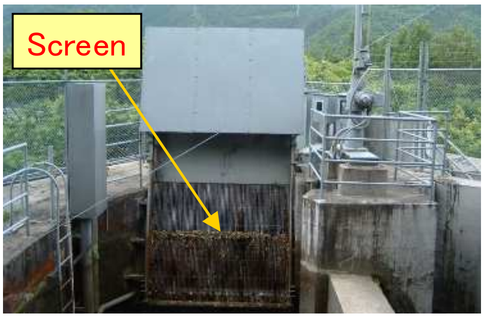


Longitudinal sectional view

To prevent sand and debris inflow to the penstock

④ A screen is provided in front of a penstock inlet section.
⑤ The elevation of the intake sill is 1.0 to 1.5m higher than the lowest part of the head tank





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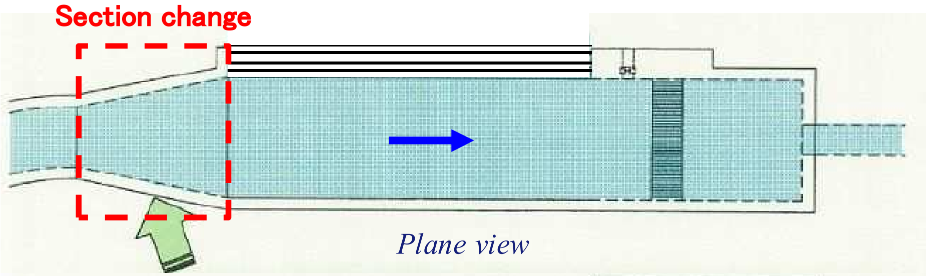
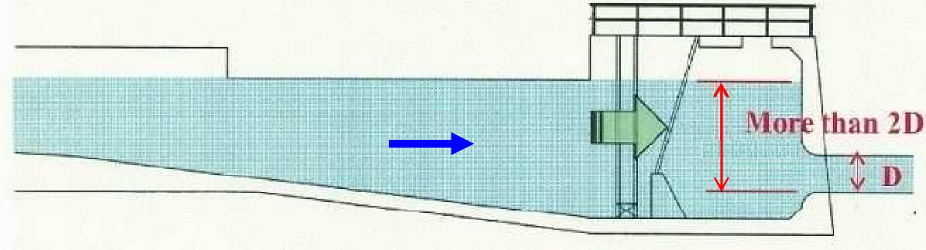
5. Head Tanks　i) Design

- Rapid Section change shall be avoided to prevent vortex of the river water flowing into the head tank.
- The water depth at the mouth of the penstock is twice or more than that of the inside diameter of the penstock pipe to prevent air entrainment into the penstock.



Plane view



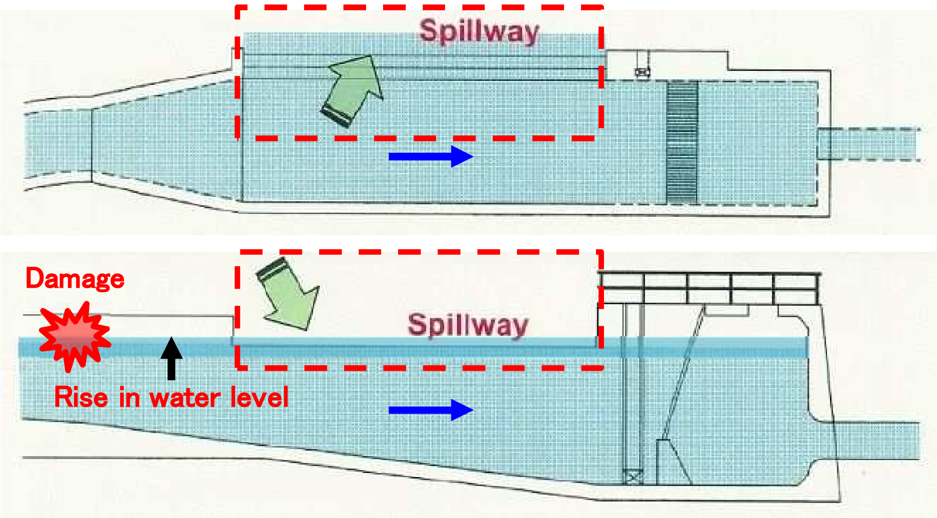
Longitudinal sectional view

5. Head Tanks

i) Design

- The rise of water level during overflow from the head tank shall not adversely affect the upstream headrace.

- A spillway is designed to safely discharge the maximum plant discharge at a water level that will not cause pressure on the top of the headrace during a full load shutdown.



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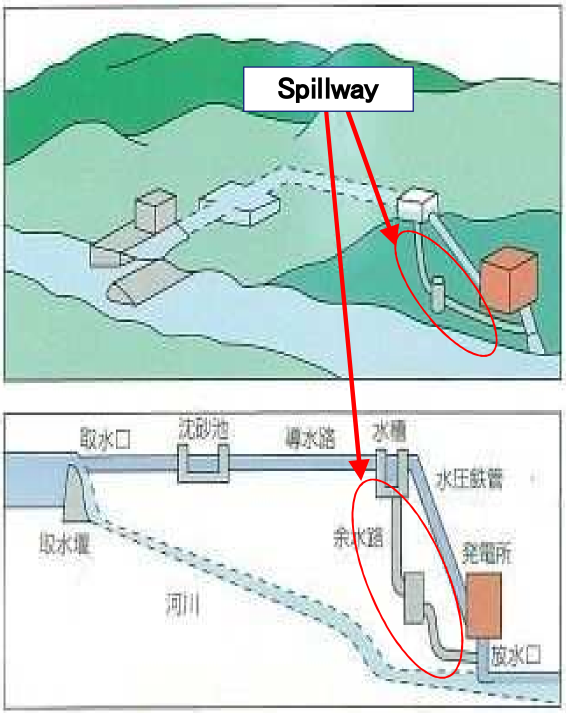
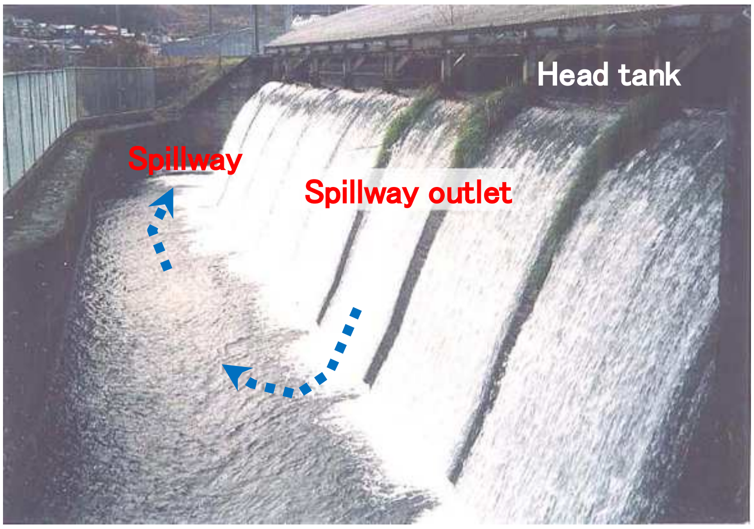
5. Head Tanks

ii) Spillway

- A spillway discharges the overflow from the spillway outlet of head tank into the river.
- A spillway controls the maximum designed discharge safely when the full load is shut down.

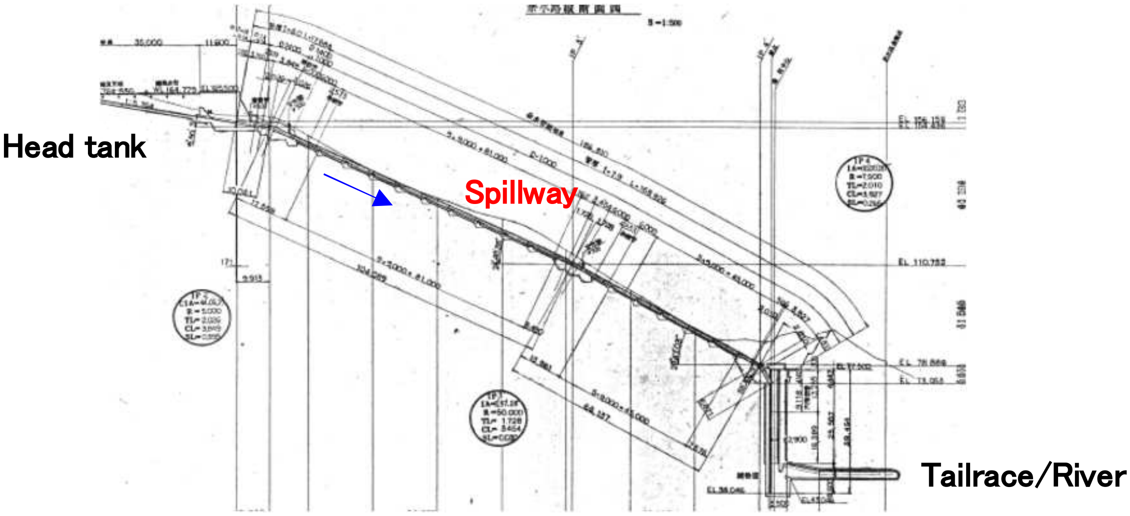




5. Head Tanks ii) Spillway

■ Discharges from the spillway don't cause damage to surrounding facilities or riverbeds.

1. The waterway should be as straight as possible.
   Because of rapid flow in steep spillway, impulse wave or cavitation can occur at bends and discontinuous part of spillway.
2. As the water surface may swell due to entrainment of air, the cross section of the spillway must be designed with attention to this phenomenon.



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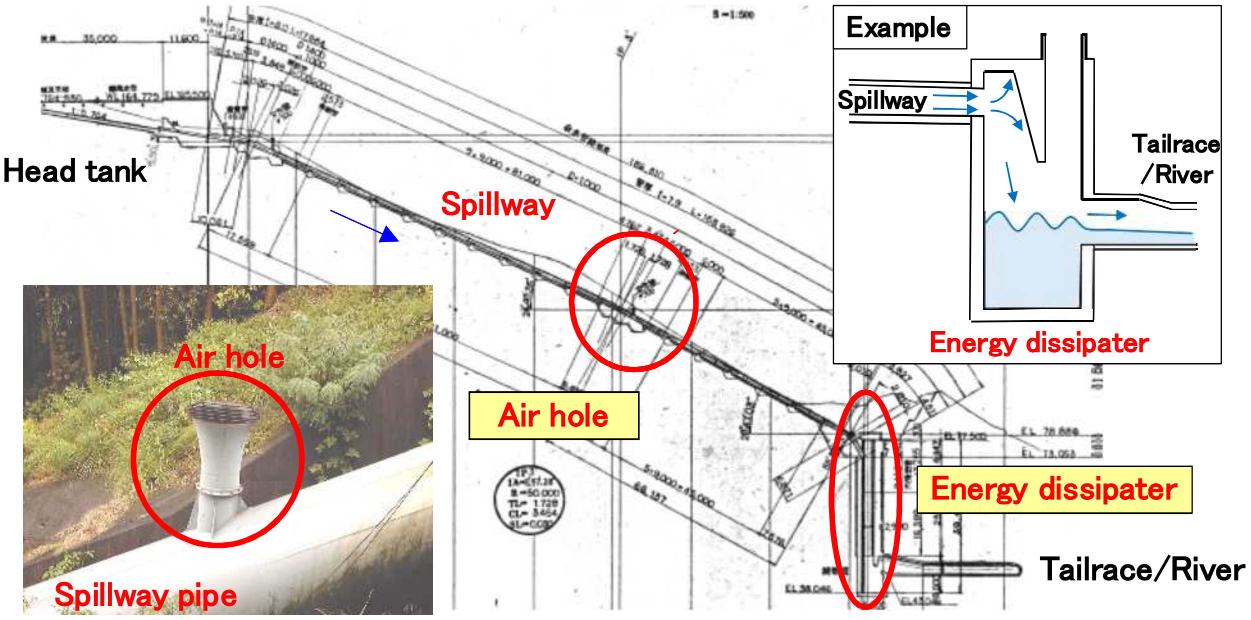
5. Head Tanks ii) Spillway

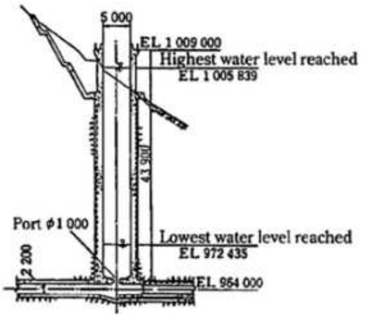
3. In the case of the pipe conduit, an air hole is provided at the bends to replenish the air carried away by high-speed water flow.
4. An energy dissipater is constructed at the end of the spillway to safely discharge water.
5. When water from a spillway is discharged directly to a river, it shall be located so as not to adversely affect the river, such as excessive scouring of the riverbed.



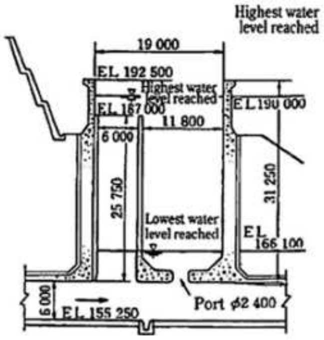
6. Surge Tanks

- Surge tanks are the pondage between the pressure conduits and the penstock.

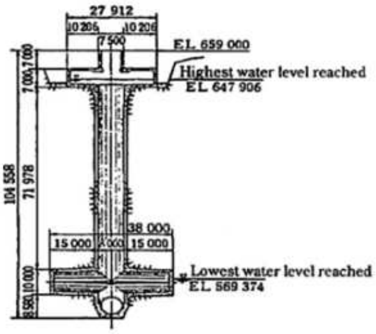
i) Simple type



ii) Restricted orifice type



iii) Differential type



iv) Chamber type

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.100

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6. Surge Tanks

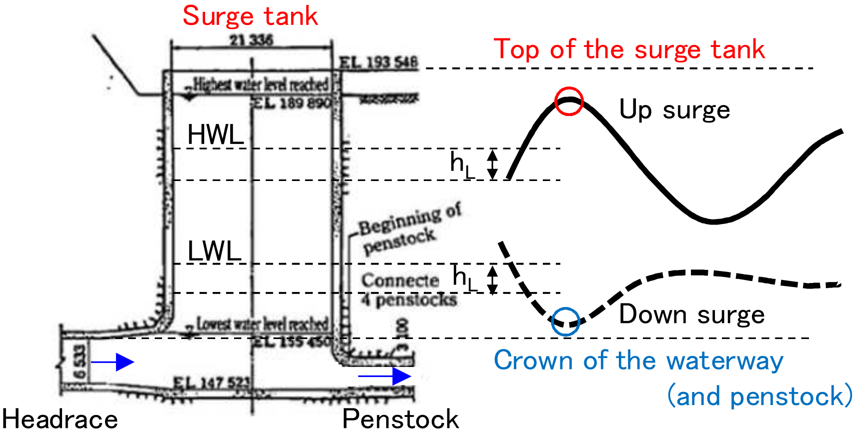
i) Design

- A surge tank shall be stable against anticipated loads.
- The fluctuation of the water level in the surge tank shall not accelerate and shall return to equilibrium in a short period.
- When the full load is shut down or the load increase from half to full at a power plant, (a) the fluctuation of the surge tank water level shall not lead to an overflow at the up surge and (b) the lowest down-surging shall be higher than the crown of the waterway and the penstock below a surge tank.

Anticipated loads

- Self-weight
- Internal water pressure
- Seismic force
- External water pressure
- Earth pressure
- Force caused by wind

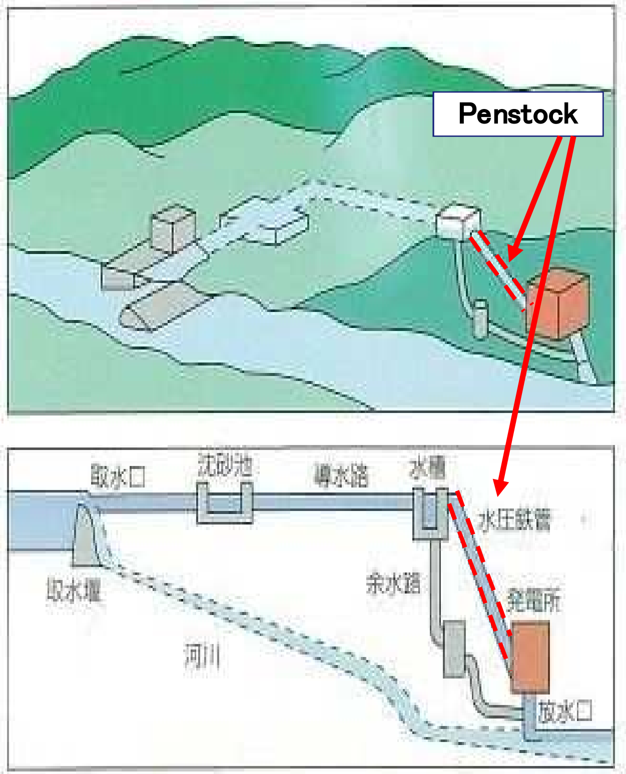
Up surge / Down surge



Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.100

7. Penstocks

- Penstocks are pressure lines to convey water from the head (surge) tank to the power plant.



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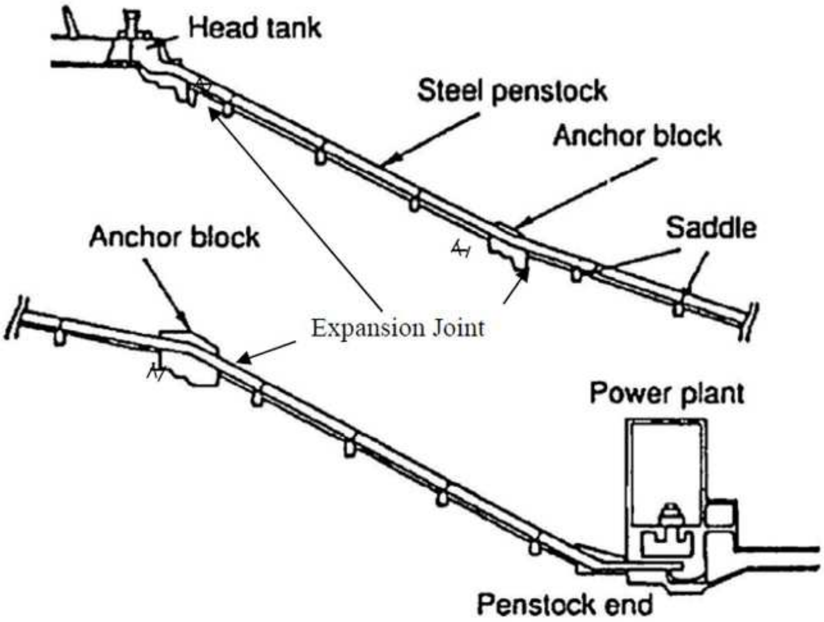
7. Penstocks i) Type of penstock

- Penstocks are generally made of steel.
- Penstocks are classified into exposed type penstock and embedded type penstock.

Materials of penstocks

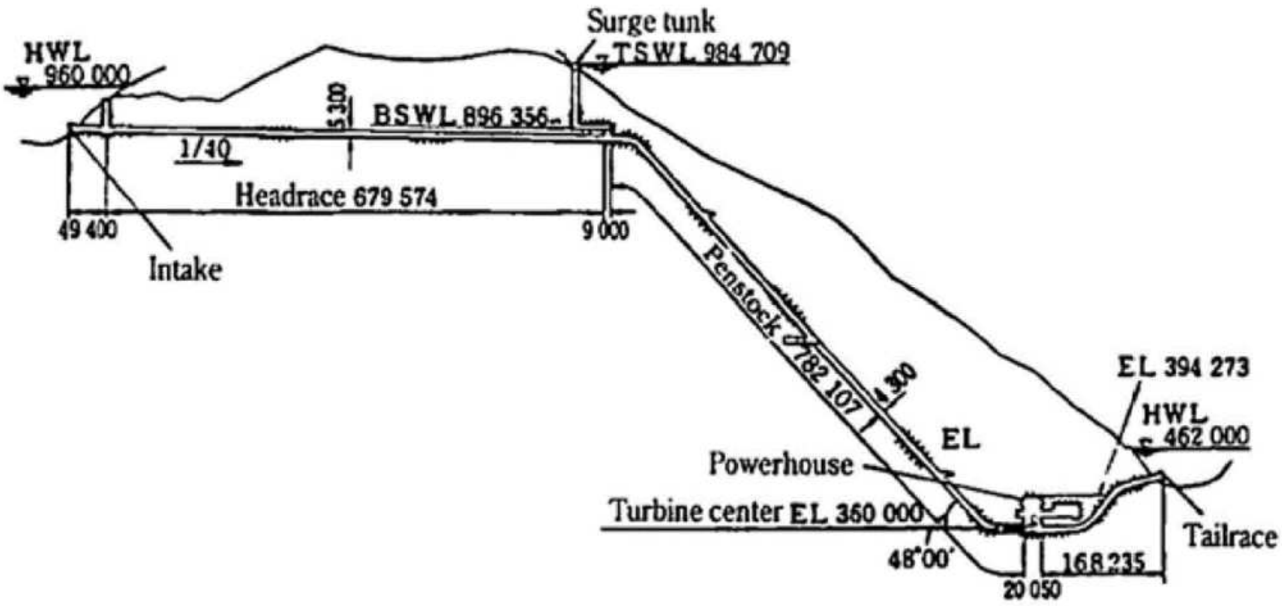
- Steel pipe are generally used.
- FRP (fiber reinforced plastic) pipe are used for small flow.



Exposed Type Penstock

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.109

7. Penstocks i) Type of penstock



Embedded Type Penstock
(Rock embedded, Earth-embedded)

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.109

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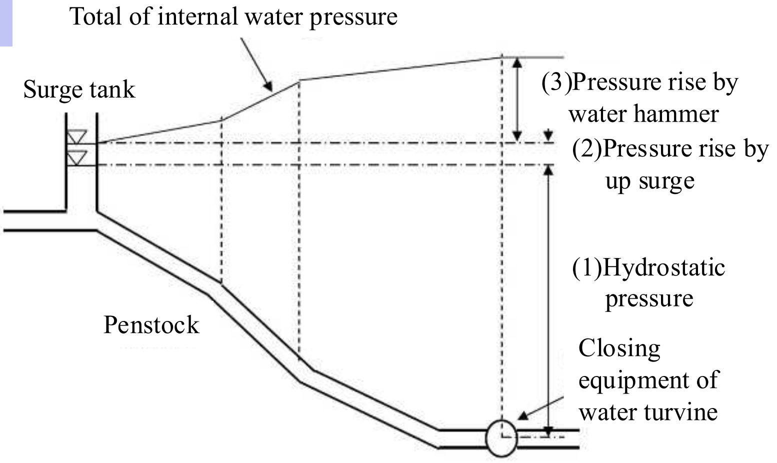
7. Penstocks ii) Design

- A penstock shall be stable against anticipated loads depending on the type of penstock (exposed, rock-embedded, earth-embedded).
- The crown of a penstock shall be placed below the lowest hydraulic gradient line which appears when the water level of the head tank or surge tank is at its lowest.
- A penstock shall not cause serious water leakage.

Anticipated loads (exposed type)

- <u>Composite maximum water pressure of hydrostatic pressure, water hammer pressure and pressure rise by surging</u>
- Pipe weight
- Thermal loads
- External pressure
- Water weight in pipe
- Seismic force
- Forces of flowing water inside the pipe



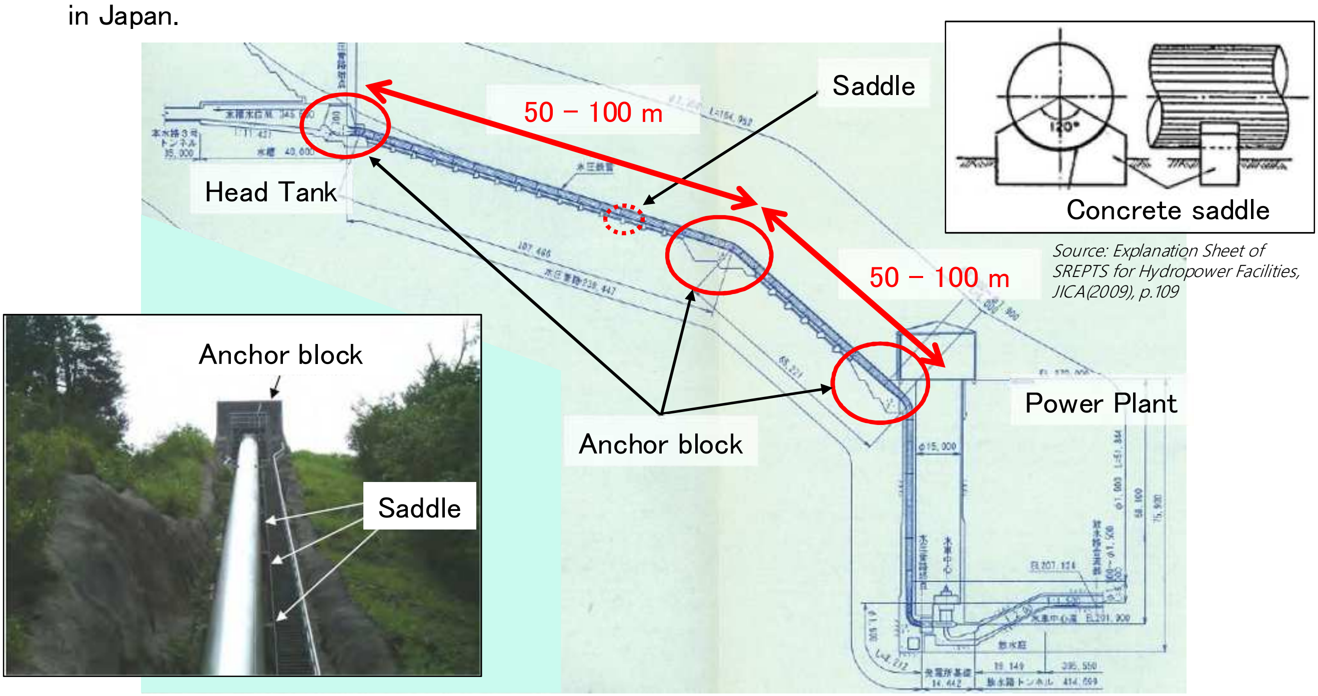
Cross section image of penstock and its internal water pressure

Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.104

7. Penstocks ii) Design

- In the case of exposed type penstocks, anchor blocks and saddles shall be constructed in order to support the penstock.

- Considering the topographical conditions, the anchor blocks are often spaced every 50–100 m in Japan.



Source: Explanation Sheet of SREPTS for Hydropower Facilities, JICA(2009), p.109

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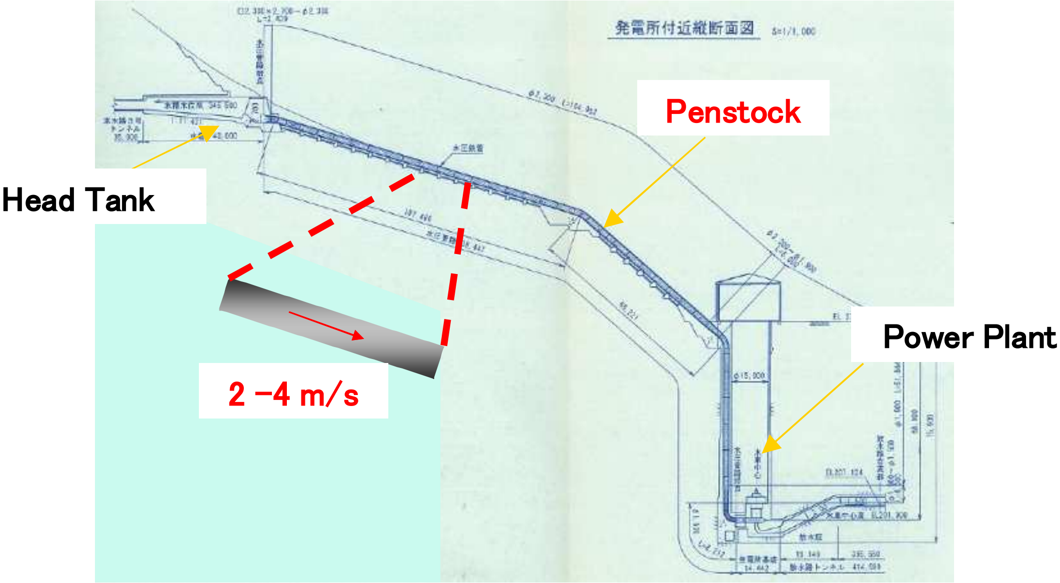
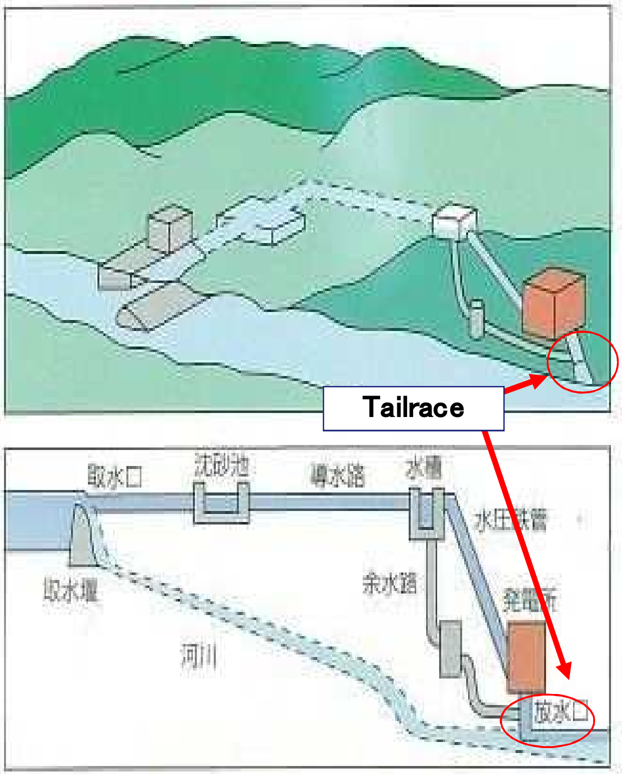
7. Penstocks ii) Design

- It is necessary that a penstock is planned to run straight over the shortest distance along a ridge with thin overburden and which is free from landslides.
- Based on previous experience and the balance between construction cost and energy output, flow velocity in the penstock is typically 2 to 4 m/s.



8. Tailraces

- Tailraces are part of waterways that guides water discharged from the turbine to the river.



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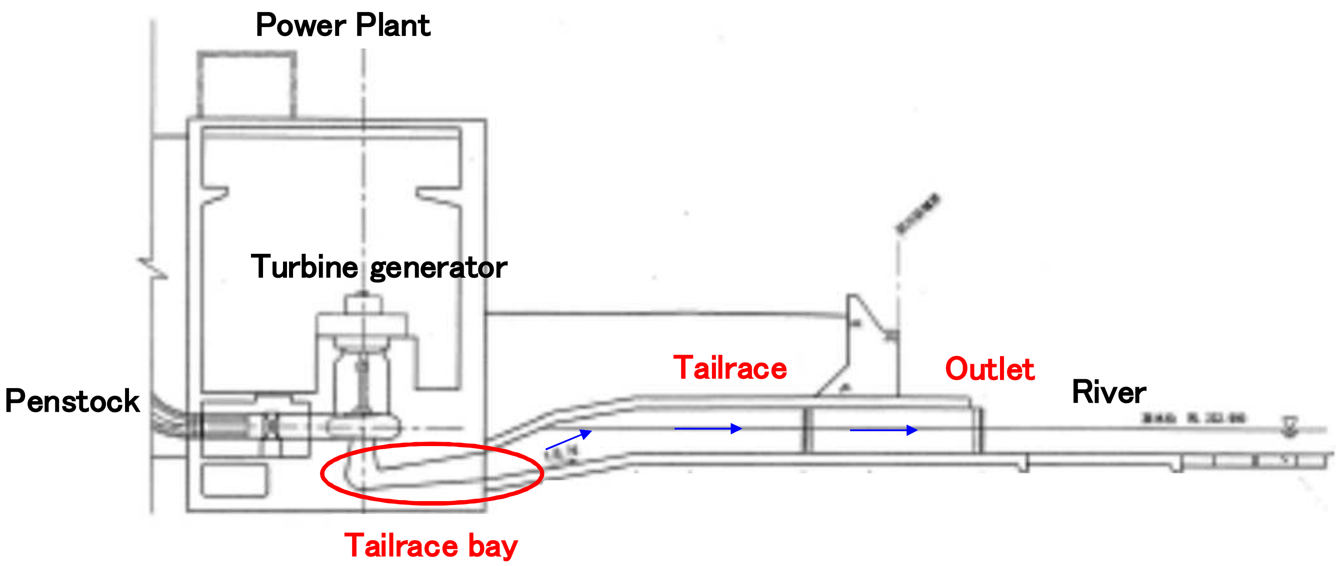
8. Tailraces

- Tailrace bays, which is a wide section of the tailrace, are constructed to reduce water level fluctuations in the tailrace due to power plant load fluctuations.
- Tunnels, covered channels, or open channels are used for tailraces.

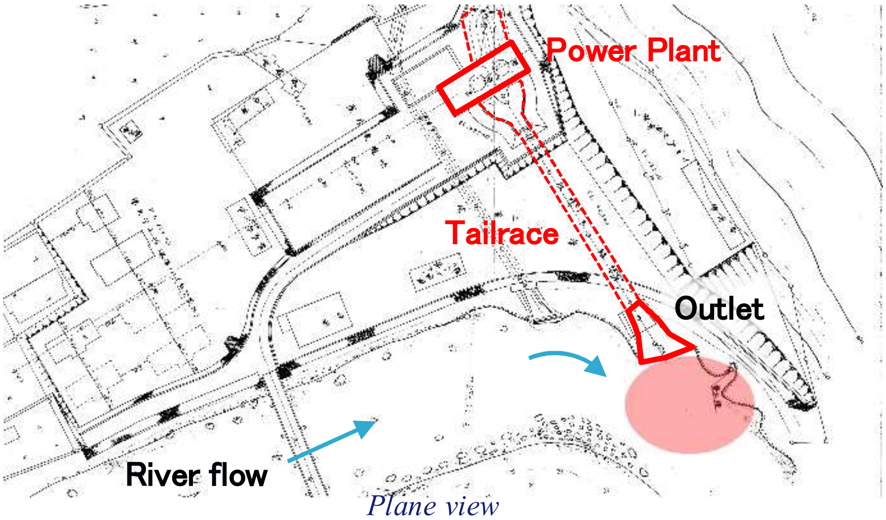


Longitudinal sectional view

8. Tailraces i) Location

- A tailrace shall have a layout that will not be damaged by river water or sand.

- There is no possibility of flood damage to the tailrace.
- The water level does not rise significantly and the riverbed does not fluctuate due to floods.
- There is no possibility of blockage of the tailrace due to sedimentation.
- The river flow does not directly strike the tailrace.
- The river width does not decrease near the downstream of the tailrace.



Plane view

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8. Tailraces ii) Design

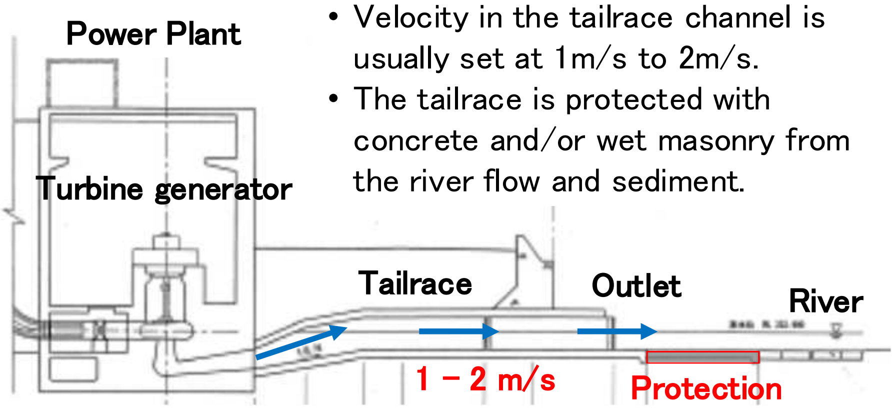
- A tailrace shall be structurally stable for anticipated loads.
- Any leakage from the tailrace inside shall not cause damages to the surrounding ground or other structures.
- A tailrace shall not significantly cause damage to the downstream waterways due to collapse of the waterways.
- In the case that cave-in of surrounding grand is anticipated (due to water leakage from the channel), countermeasures such as lining shall be taken.

Anticipated loads

- Self-weight
- Hydrostatic pressure
- Hydrodynamic pressure
- Mud pressure
- Seismic force
- External water pressure and earth pressure

Points of design

- Velocity in the tailrace channel is usually set at 1m/s to 2m/s.
- The tailrace is protected with concrete and/or wet masonry from the river flow and sediment.



9. Points to be checked in FS review

Point to be Checked	Details
Structural stability	■ Waterways shall be structurally stable for anticipated loads. ✓ Appropriate loads for each facility should be considered. (all) ✓ Waterways shall not cause slitting or serious water leakage. (Headraces, penstocks)
Disaster resilience	■ Waterways shall not be damaged by disasters such as landslides and floods. ✓ The site shall be located in a safe position against surrounding landslides and floods. ✓ In the case that cave-in of surrounding ground is expected, countermeasures such as lining shall be taken. ✓ The location and structure shall be such that driftwood, floating debris, and sediment do not enter waterways during floods. (Intake, tailrace)

Points to be checked in FS review

Point to be Checked	Details
Discharge and control	■ Waterways shall be able to safely and securely discharge and control a design plant discharge. ✓ Intake gates shall be installed to prevent over inflow. (Non-pressure conduits) ✓ Waterways shall have sufficient water capacity to function. (Settling basins, head tanks, surge tanks) ✓ A head tank shall have a spillway so that it can control the maximum designed discharge safely when the full load is shut off.
Hydraulic stability	■ Waterways shall be hydraulically stable. ✓ The location and structure shall be designed so as to prevent air intrusion. (Pressure conduits) ✓ Waterways shall be placed below the lowest hydraulic gradient line. (Headraces, penstocks) ✓ The spillway of a head tank shall be designed so that discharge from the spillway does not cause damage to surrounding facilities or rivers.

Points to be checked in FS review

Point to be Checked	Details
Equipment	■ The necessary equipment shall be installed. ✓ Intake gates shall be installed to allow inspections and repairs of waterways. (Intakes) ✓ Screens shall be installed to prevent intrusion of driftwood and debris. (Intakes, head tanks) ✓ Sand flushing gates shall be installed to flush the sediment easily. (Settling basins, head tanks)

References

- SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
  (Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)

- EXPLANATION SHEET FOR SPECIFIC REQUIREMENTS OF ELECTRIC POWER TECHNICAL STANDARD FOR HYDROPOWER FACILITIES.
  (Japan International Cooperation Agency(JICA), Electric Power Development Co., Ltd. , The Chugoku Electric Power Co., Inc. October 2009)

- 水力開発ガイドマニュアル（第 1 分冊 一般水力・揚水式水力発電）
  （独立行政法人 国際協力機構（JICA）、電源開発株式会社、株式会社開発設計コンサルタント 2011.3）

Thank you for your attention