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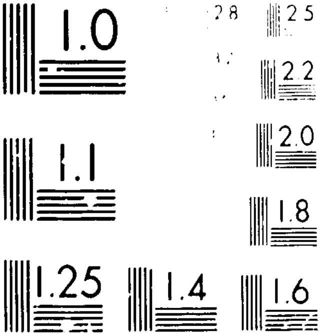
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CHINESE EXPERIENCES IN SMALL MINI HYDRO POWER GENERATION *

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002072

* This is an advance edition of a UNIDO pulication to appear in the Development and Transfer of Technology series. This document has been reproduced without formal editing.

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Preface

Decentralization of Hydro Power Generation is now being generally accepted as one of the potential and expedient ways of developing energy resources to meet the integrated rural requirements, as well as to support projects and programmes for rural industrialization and decentralization of industries in developing countries.

UNIDO organized "The Second Seminar-Workshop/Study Tour in the Development and Application of Technology for Mini Hydro Power Generation (MHG)", Hangzhou, China, 17 October 1980 and Manila, Philippines, 3-8 November 1980. One of the objectives of the Seminar-Workshop/Study Tour was to promote the exchange of experiences in the planning, construction and application of Mini Hydro Power Generation Units in the developing countries, particularly to learn the method of planning and programme implementation of the People's Republic of China.

At the meeting, the Chinese Delegates presented a number of papers on Mini-Small Hydro Power Generation based on their experiences. However, many participants requested UNIDO for more information on the Chinese experiences. Hence, UNIDO asked the Chinese Authorities to prepare this publication. It was decided that the first edition of the Manual should not be expected to be perfect but it would be subject to regular modifications and improvements based upon suggestions from the readers.

It is intended that this Manual would be complementaru, as well as supplementary to the previous UNIDO publication, entitled "Mini Hydro Power Stations - A Manual for Decision Makers" (Publication No. UNIDO/IS.225). Also the reader's attention is drawn to a number of other documents prepared in connection with the aforementioned Workshops in Hangzhou and Manila.

The preparation of this Manual was made possible by the contribution of the Chinese Government to UNIDO's Industrial Development Fund (UNIDF)

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UNIDO sincerely hopes that the Manual will serve as a practical and useful tool in planning Mini-Small Hydro Power Generation in the developing countries.

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CHAPTER 1: GENERAL ASPECTS

I. China's Hydro Power Resources and their Development

China has rich water resources with a total potential capacity of about 680,000 MW, of which 370,000 MW are feasibly exploitable. China's geographical features are characterized by high lands in the west and low lands in the east. Most of China's main rivers originate in the western plateaus. Furthermore, precipitation is abundant in southern China and therefore, hydro power resources are richer in this area in comparison to the northern area, where precipitation is quite low.

Since liberation in 1949, the Chinese government has attached great importance to the exploitation of hydro power resources and has had great success. The total installed capacity increased from 160 MW in 1949 to 19,450 MW at the end of 1979. However, the exploited hydro power only uses about 5% of the total water resources. The potential for future development is extremely large.

Based on statistical data, in 1979, coal-fired energy ranked first as a power energy in China, petroleum was listed as second and water power, which covers only 17%, came last.

The water power resources using medium and small rivers are also abundant (by rough estimation, about 150,000 MW).

As for the definition of a SHG/Mini HG/micro HG, it varies between the different countries and organizations, as shown in the following table.

Table 1-1 Definition of Small HG/Mini HG/Micro HG

Country of Organization		SHG (kW)	Mini HG (kW)	Micro HG (kW)
UNIDO	Kathmandu Seminar		100-1,000	up to 100
	Hangzhou-Manila Seminar	2,001-10,000	101-2,000	up to 100
China	by the unit	up to 6,000		
	by the installed capacity	up to 12,000		
Philippines		up to 5,000		
Peru		500-5,000	51-500	5-50
Romania		5-5,000		
Thailand*			up to 1,000	
Turkey*		1,001-5,000	101-1,000	0-100
USA		up to 15,000		
Sweden		100-1,500		
Preparatory committee for the UN Conference on New and Renewable Sources of Energy (Panel on Hydro-power)		1,001-10,000		up to 1,000

*) Classified not so clear

According to the development of the rural area in China, however, hydro power plants with a total installed capacity up to 12 MW, each unit below 6 MW as well as the small local grids which are mainly integrated in small hydro power plants are classified as small hydro power generation (SHG). In order to avoid confusion, it has been agreed upon to use mini-hydro power generation (MHG) instead of (SHG).

II. The Development and Construction of MHGs

Water power is a cheap, clean and renewable energy resource. Since the liberation, the Chinese government has attached great importance to the development of MHG. Up until the end of 1979, China constructed more than 89,000 MHG stations with a total capacity of 6,300 odd MW.

The annual power output by MHG in 1979 was 11,900 gWh, about 35% of agricultural electricity consumption (including irrigation and drainage, commune-run small factories, side-occupation industries, rural lighting, etc., excluding county-run industries). Based on statistics, by 1979, out of the total 2,000 odd counties, 1,500 had established their own MHG. About 700 counties relied mainly on MHG for supplying electricity to industry and agriculture. Thanks to the power supply both by the state-run grid and the scattered MHG, 87% of the people's rural communes, 62% of the production brigades and 50% of the production teams already are using electricity.

The construction of MHG in China was initiated on the basis of a nationwide movement in agricultural co-operation conducted in the early 1950s. Rural areas are comparatively backward in the econom[illegible] A huge amount of electrical energy is necessary for the developm[illegible] [illegible]ndustrial and agricultural production. It was difficult to match [illegible] [illegible]s needed in wide rural areas in a short time, and even impossible in the remote rural regions, by merely relying on large and medium scale power stations built by state investment.

Full utilization of the scattered small hydro power potential in combination with water utilization for other purposes is made by constructing stations and locally feeding electricity. There are numerous stations, each covering certain areas, scattered throughout the country. A local network was formed and then connected to the state-run grid. This should help meet the demands in rural areas for electricity and promote a quicker development of agriculture with less state investment.

In China, the developing tempo of MHG has been rather fast and can be roughly divided into three states: in the 1950s, the total annual capacity installed was only several thousand kW; in the 1960s, the total annual capacity installed was several dozen thousand kW; in the 1970s, the increased total annual capacity was several hundred thousand kW and by 1979, the increased installed capacity even approached one million kW. According to the present level of technology, the construction of a MHG plant with an installed capacity of several thousand kW takes about 2 years, from the beginning of construction to its first unit being put into commission. The installed capacity of all the constructing projects should be more than three times of the installed capacity which should be completed in the same year, i.e. if the total installed capacity in one year is 1,000 MW, the design capacity of the project under construction in the same year should be some 3,000 MW.

The production cost of MHG is rather low, approximately 2-3 Fen (Chinese currency) per kWh compared to either the small thermal coal or diesel fuel power stations where the production cost is about 10 Fen per kWh or more.

III. The Roles of MHG in the Social Economy

In recent years, as a result of the large scale construction of MHG, both staff and the masses have seen that although the scale of the MHG stations is small, the number is large. MHG has played a very important role. The advantages of MHG are as follows:

A. Promoting the water conservancy for farmland and thus creating conditions for rapid development in agriculture.

Wherever there is MHG, irrigation can be rapidly developed and the means of protection against floods and droughts can be improved. For example, at Enping County, Guangdong Province, the Jinjiang river cascades were exploited and 130 MHG stations with a total capacity of 36 MW were built. Drainage and irrigation improved rapidly by means of the power supplied by MHG. At present, all 280,000 mu of farmland along both banks of the Jinjiang river are irrigated and the 120,000 mu low-lying farmland previously threatened by water logging have been changed into stable and high yield farmlands, irrespective of flood and drought.

B. Developing the county-run or commune-run industries using economical MHG power supplies.

Previously, in many of the mountaineous regions there was no industry but after the establishment of MHG, various industries such as agricultural machinery, cement, fertilizer, paper, textile and food have been developed. For example, there is now an installed capacity available of 18,000 kW of MHG in Hendong County, Hunan Province. In 1979, the annual power output was 70 gWh. The total industrial output is several times higher than it was before implementing MHG.

On the other hand, the development of local industry speeds up the exploitation of MHG. Now, major MHG equipment is manufactured by local factories (usually run by the county). The maintenance and repair work for MHG is also done by local industry. Thus. the development of local MHG and the development of local Industry are interlocked.

C. Accumulating funds for the county, commune and production brigade.

The Red Guard MHG Station on the People's canal (irrigation canal) in Peng County, Sichuan Province, has an installed capacity of 6,400 kW and a yearly income of 1,940 thousand Yuan from the time it was put into commission. The Yellow Dragon MHG station in Wufeng County, Hubei Province, has an installed capacity of 2,400 kW. The return of investment took only four years. The Dafeishui MHG Station in Dayi County, Sichuan Province, has an installation of 5,000 kW. Its total income for the last nine years was 10,270 thousand Yuan, several times the original capital investment.

D. Promoting the development of rural electrification and mechanization.

Power supplied by MHG also enriches and promotes the cultural life of the people and speeds up the construction of new villages. The rural population applauds MHG by saying that "wherever a MHG plant is established, a big change will follow".

In short, the development of MHG has a broad future in China. Small hydro power is an important energy source for the modernization of agricultural industries. Wherever there is a rich water power resource, MHG can supply the main energy for the villages and towns in that region. This is due to the following conditions: (1) the power potential of MHG is widely scattered and easily accessable; (2) the technology of construction is popular.

The tempo of the increase in power supplies cannot match the electricity demands needed for social economy and for improvement in the living standard. Even though the consumption of electrical energy in the rural areas is rather low, it must be remembered that the operation and management of MHG is still at a backward level. The potential of the installed equipment has not yet been brought into full play in some places as the construction of transmission lines and substations lag behind the construction of the respective MHG station. Therefore, even after the starting-up of an MHG station, the power supply is still limited by the ability to transmit power. These problems have to be solved in the near future.

IV. The Organization, Programming, Implementation and Operations of MHG

A. The following is the organization chart of MHG in China on various levels.

Table 1-2 Organization Chart of MHG in China

Level	Organization in charge of water conservancy	Organization in charge of MHG
Central Government	Ministry of water conservancy	Department of Farmland water conservancy - Division of Hydropower
Provincial Government	Bureau of water conservancy	Division of Hydropower
Prefectural Authority	Department of water conservancy	Division of Hydropower
County Government	Division of water conservancy	Section of Hydropower - MHG Company

Remark: The county level section of hydropower usually is the grass root office dealing with the design, construction, operation and maintainance, and distribution of the MHG. Now, many countries have a total installed capacity of 10 - 20 MW and distribution line several hundred km in length.

B. The procedures are carried out as follows.

1. River planning

River planning should be carried out by the central government, province, prefecture or county, according to the scope of the river. If the river is the concern of more than one province, the planning works should be undertaken by the Ministry of Water Conservancy. If the river is located within one province but is related with more than one prefecture, the planning works should be by the provincial bureau of water conservancy. This same principle is applied to river planning for a small river which is located within a prefecture or county.

The contents of the planning report of a river should include plans for the development in the near future, distant future and for the project at the first stage of its implementation. The pre-feasibility study is also a part of this stage.

2. Design

After the river planning has been approved, the design work in the first stage of the project should be continued. For MHG projects, there are usually two steps.

a. Preliminary design: In a common case, the design work of a small unit MHG project is undertaken by the county. Approval of the design of the MHG project is given:

(i) at the provincial level when the unit capacity $>$ 500 kW (or the transmission line 35 kV or higher);

(ii) at the prefecture or county level when the unit capacity 500 $<$ kW.

The main considerations in approving the design are:

(i) social demands;

(ii) capability of state or province or the local authority;

(iii) economical benefits.

b. Detail drawing: This should be undertaken by the county if the unit capacity is less than 500 kW. MHG projects with rather large unit capacity should be undertaken by the prefecture or province design institute.

After approving the preliminary design, there will be a comprehensive balancing done by the planning committee to decide whether this project should be listed in the budget of the current year or the following one. Then construction of this project can be started.

3. Construction

a) A county MHG with a capacity 500>kW should be organized by the county and supported by a professional team from the prefecture or province.

b) A county MHG with a capacity 500<kW should be organized by the commune or brigade and also supported by a professional team from the prefecture or province.

c) Field organization is composed of two parts:

Professional team:	Engineering team)	from the
	Installation team)	province or
	Transmission line team)	prefecture
Common labour:	organized by the local authority	

4. Operation

Operational regulations and records are established in each MHG station.

5. Maintenance

Maintenance and minor repairs may be undertaken by the county. An overhaul repair should be occasionally done by the prefecture.

CHAPTER 2: POLICIES AND MEASURES

The Chinese government and the relevant leading authorities have established a series of policies for the development of MHG, as summarized below:

I. Dependence of MHG Development on People Masses

Stress should be put on the self-reliance of the masses in the development of MHG. Counties, people's communes and/or their subdivisions are encouraged to develop MHG. The principle of "whoever invests and builds a station will own, manage and benefit" must be implemented. If the MHG station is invested in and jointly built by several organizations, it will be owned by them. This policy has shown more than once to be a "greater, faster, better and more economical" way to expedite the development of MHG.

II. Sources of Finance

The sources of financing (including loans) will mainly be taken from local organizations at different levels and also subsidized by the central and provincial governments. The subsidy offered by the government is usually about 30% of the total investment.

In order to have loans play a greater role, the Sichuan Provincial People's Bank laid down five requirements for the application of a loan: (1) The project design and budget has to be made and approved by the relevant authority and listed in the construction items for the current year. (2) The supply of power units and main construction materials has to be confirmed by the departments concerned. (3) A possibility must exist of putting MHG into commission in the current year. (4) Power can be consumed and transmitted after the completion of MHG. (5) A certain portion of a self-financed fund has already been secured. If all the above-mentioned requirements are fulfilled, the loan will be given.

III. Overall Planning and Multi-Purpose Utilization

The construction of MHG must be in compliance with the natural objective law. The planning, geological exploration and design work must be carried out carefully; the supervision of the construction must be exact and strengthened to ensure quality and efficiency.

The planning of MHG will be made in accordance with a natural river system one by one, on the basis of the hydrological, geological conditions and load demands. During planning, the principle of overall planning and multi-purpose exploitation must be observed. Attention should be paid to the co-ordination between the departments concerned and to the solution of contradictions among power generation, flood protection, irrigation, navigation, fishery and log passing.

The MHG project's documents will be approved by the following: the feasibility study and design report of a MHG plant with a unit capacity greater than 500 kW (including the corresponding sub-station and transmission line) must be approved by the bureau or department of water conservancy at the provincial level; the design document of a MHG plant with a unit capacity less than 500 kW must be approved by the department of water conservancy at prefectural or county level. If the MHG project concerns two provinces, two counties, two communes or two brigades, an agreement between these two sides must be attached to the document.

The MHG cannot be listed among the construction items for the current year without the approval of the design document.

IV. Supply of Raw Materials for Power Units and Auxiliary Equipment

The mini-hydro power unit (capacity less than 500 kW) is usually manufactured by a local factory. A certain amount of the raw materials are supplied by the state but the remaining materials must be supplied by the province (or municipality). Power units (capacity larger than 500 kW) are manufactured and controlled by the state according to the plan. In China, in order to simplify the procedures of supply and to speed up the construction schedule, the equipment for MHG must be supplied by the relevant corporation in complete sets.

V. Policy of integrating MHG into the National Grid

Priority has been given to local consumption of MHG. In order to give full play to MHG and to improve the reliability of the power supply, the MHG plants may be gradually integrated to form a local grid and eventually even integrated to the national grid when the necessary conditions are satisfied.

An agreement of integration should be signed and implemented but the running and marketing of a MHG plant is still undertaken by itself in accordance with the agreement. The ownership and administrative power of the MHG remains unchanged after the integration. Both the national grid and the local grid have the responsibility to give active support to the integration of MHG. If the grid is interrupted, it is permitted to disintegrate the MHG and operate it independently.

CHAPTER 3: ECONOMIC CONSIDERATIONS FOR MHG

I. Economic Analysis of China's MHG

The special economic features of MHG in China are as follows:

(1) The construction period is short and the results are quick.

(2) Local materials and labour are fully utilized.

(3) Equipment is domestically manufactured and even locally when the unit capacity is less than 500 kW.

Due to the largeness of China where local conditions are quite different from region to region, the capital cost of MHG ranges widely from 500 odd Yuan per kW to more than 2,000 Yuan per kW. In general, the cost per kW installation ranges from 1,000 to 1,300 Yuan.

Tables 3-1, 3-2 and 3-3 show the technical and economical features of 25 MHG plants built in the 1960s and 1970s in Zhejiang, Guangdong, Hunan, Jiangxi, Sichuan Provinces and Guangxi Zhuang Autonomous Region (the range of the water head is 4.5-612 m and the range of the installed capacity is 150-12,000 kW).

As for a breakdown in cost, the differing lengths of the transmission lines in the various MHG stations effect the breakdown costs to a certain extent. The percentage of the breakdown cost to the total cost is summarized as: civil cost 42-65%, equipment cost 31-48%, transmission line cost 4-14%.

Tab. 3-1 Technical and Economical Analysis of MHG plant ("diversion type")

Plant Name	Location (Province)	Type of Plant	Design discharge CMS	Design Max. discharge CMS	Ave. head M	Total inst.cap. KW	Total cost (10^4 Yuan)	Annual ave. utilization hours	Cost per KW (Yuan)	Cost per KWH (Yuan)	Cost of generation Fen /KWH
Zhangwangmiao	Jiangxi	diversion	64	10	8.44	2 x 1250	478	4800	950	0.19	2.61
Yongan	Sichuan	diversion	63	11	10.0	3 x 1250 3 x 250	665.088	7989	1498	0.19	1.194
Tonglienyen	Jiangxi	diversion	8.88	22.9	22.4	1760	130	4215	730	0.28	2.5
Tongkouqi	Zhejiang	diversion	4.0	48.4	46.9	2 x 800	166.1	2000	1038	0.27	3.8
Yaqi	Zhejiang	diversion	11	51.6	50.4	4450	650	3120	1460	0.46	1.0
Tangshaoshui	Jiangxi	diversion	2.5	56	55	1 x 200 1 x 800	110.3	4716	1100	0.24	3
Minyangkuan	Jiangxi	diversion	4.2	76	75	2 x 1250	266	3670	1064	0.27	2
Tongyuan II	Jiangxi	diversion	3.6	80	80	2 x 630	109	2822	860	0.27	2.5
Kenghuang	Zhejiang	diversion	0.32	94.6	93.6	200	19.83	2500	992	0.4	3.8
Xixiankou	Guangxi Zhaung Auto.Reg.	diversion	3	132	130	2 x 1600	260	3150	813	0.26	2.5
Datian	Zhejiang	diversion	1	181	181	3 x 400	87.5	5000	729	0.146	2.5
Chongshan	Hunan	diversion	0.6	210	210	4 x 250	87.66	3360	876.6	0.26	3
Jiangkou	Hunan	diversion	0.28	612	612	2 x 500	84	1200	840	0.11	1.5

Tab. 3-2 Technical and Economical Analysis of MHG plant ("dam type")

<table>
<tr><th>Plant Name</th><th>Location (Province)</th><th>Type of Plant</th><th>Design discharge CMS</th><th>Design Max. discharge CMS</th><th>Ave. head M</th><th>Total inst.cap. KW</th><th>Total cost (10^4 Yuan)</th><th>Annual ave. utilization hours</th><th>Cost per KW (Yuan)</th><th>Cost per KWH (Yuan)</th><th>Cost of generation Fen /KWH</th></tr>
<tr><td>Yangtang</td><td>Hunan</td><td>*</td><td>6.8</td><td>5.5</td><td>4.5</td><td>6 x 1500
4 x 252</td><td>2090</td><td>4334</td><td>2090</td><td>0.484</td><td>1.2</td></tr>
<tr><td>Qingshan</td><td>Zhejiang</td><td>*</td><td>21.8</td><td>13</td><td>10.9</td><td>4 x 500</td><td>205</td><td>2500</td><td>1025</td><td>0.34</td><td>1</td></tr>
<tr><td>Dalongdong</td><td>Guangdong</td><td>*</td><td>12</td><td>25</td><td>20</td><td>2000</td><td>238.9</td><td>4380</td><td>1195</td><td>0.27</td><td>2</td></tr>
<tr><td>Maoqi</td><td>Hunan</td><td>*</td><td>20</td><td>45</td><td>36</td><td>4 x 1250</td><td>761</td><td>3920</td><td>842</td><td>0.2</td><td>1.2</td></tr>
<tr><td>Yangwotan</td><td>Hunan</td><td>*</td><td>12</td><td>50</td><td>43.75</td><td>1 x 3200
2 x 3000</td><td>80</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Kaofeng II</td><td>Hunan</td><td>*</td><td>4 x 0.48</td><td>136</td><td>136</td><td>4 x 500</td><td rowspan="2">321.9</td><td rowspan="2">5450</td><td rowspan="2">556</td><td rowspan="2">0.102</td><td rowspan="2">2.1</td></tr>
<tr><td>Kaofeng I</td><td>Hunan</td><td>*</td><td>3 x 0.77</td><td>219</td><td>202.5</td><td>3 x 1250</td></tr>
</table>

* Power house at the downstream side of dam

Tab. 3-3 Technical and Economical Analysis of MHG plant ("run-off and composite type")

Plant Name	Location (Province)	Type of Plant	Design discharge CMS	Design Max. discharge CMS	Ave. head M	Total inst.cap. KW	Total cost (10^4 Yuan)	Annual ave. utilization hours	Cost per KW (Yuan)	Cost per KWH (Yuan)	Cost of generation Fen /KWH
Chenjiang	Zhejiang	run-off-river	10.8	4.5	4.25	4 x 75	40.6	5500	135[illegible]	0.24	3
Xutang	Zhejiang	- do -	3.9	5.7	5.5	2 x 75	27.63	5225	1841.[illegible]	0.36	1.9
Chenguan	Hunan	- do -	13.68	5.125	4.125	8 x 500	551.47	6150	1400	0.207	2.5
Ganqi	Hunan	- do -	16.9	11.6	10.5	10 x 1250	2005.3	6150	1600	0.26	0.9
Tongkengqi	Zhejiang	composite	0.5	150	136	2 x 500	99	3500	990	0.33	4.83
Tongbai	Zhejiang	composite	3.4	310	300	2 x 4000	1250	4144	1563	0.3	2.5

11. Comparing MHG with other Energy Sources

China is very large and has many various kinds of energy sources. According to the planning load demand, the requirements of power for agro-technique must be met first. A comparison between the various alternatives of energy exploitation will be carried out. Priority is given to cheap and good quality energy sources which are available locally. It is preferable that the rural electricity supply is based on indigenous energy resources.

The economic comparison between different alternatives usually takes the total investment and annual operation cost as a whole. At present, the method of "years for compensation" is commonly adopted. When the total investment Z_1 of the alternative 1 is bigger than Z_2 of the alternative 2, and the annual operation cost F_1 of alternative 1 is lower than F_2 of the alternative 2, a comparison can be made by calculating N ("years of compensation").

$$N = \frac{Z_1 - Z_2}{F_2 - F_1} \qquad (1)$$

After N is obtained, other factors such as the availability of a local source, technical status and economic ability of the investor, etc., must also be taken into consideration. N usually takes about 10 years.

In China, the following alternatives to MHG for rural electrification are:

(1) a small thermal power station or diesel generation
(2) an extension from existing regional or state grid.

Biogas generation, geo-thermal generation and wind power generation for some specific places can also be considered according to the local characteristics.

A. Small thermal generation.

The capital cost and the operation expenses of a newly built small thermal power station (1960s statistic figures) are shown in Table 3-4 and Table 3-5, respectively.

Tab. 3-4 Cost of a Newly-Built Small Thermal Power Station

Capacity of power station (KW)	Cost					Cost (Yuan/KW)
	Total cost (10,000 Yuan)	Breakdown cost				
		Equipment %	Civil works %	Installation %	Miscellaneous	
2 x 750	150	65	17	10	8	1000
2 x 1500	270	60	24	8	8	900
2 x 3000	504	60	24	8	8	840
2 x 6000	876	58	26	8	8	730

Tab. 3-5 Operational Expenses of a Small Thermal Power Station

Capacity of power station (KW)	Depreciation, charge of material and spare parts (Yuan/KW)	Wages, overhead expenses (Yuan/KW)	Number of employees (men/MW)	Domestic power consumption (%)	Coal consumption (kg/KWH)	Cost (Yuan/KW)	Peakload utilization hours/year (hours)	Cost of generation (Yuan/KWH)
1 x 750	97.3	47.3	70	14-15	1.17	1200	1500-2000	0.144-0.120
1 x 1500	87.5	40.6	60	11-12	0.875	1080	2000-2500	0.099-0.086
1 x 3000	81.8	30.4	45	10-11	0.625	1010	2500-3000	0.069-0.062
1 x 6000	71.0	16.9	25	8- 9	0.578	876	3000-3500	0.051-0.047

Usually, the small rural thermal power stations are built near the town or region where fuel can easily be obtained and where no water resources are available or are far from the state grid.

A coal burning thermal power station should be built where indigenous coal is available or only a short distance from the coalmine and loading centre. Shortage of indigenous coal and long distance transportation of the coal will greatly raise the cost of generation.

In comparison to MHG, operation and management of a small thermal generation is rather complicated. The cost of generation is higher (8-15 Fen/kWh) and will also be effected by coal prices. The adaptability of the load change is poor. Pollution from a small thermal plant can also be rather serious. All these are unfavourable factors which must be taken into consideration before building a small thermal power station.

The exploitation of MHG can save coal fuel and supply cheap power as well. A hydro plant with a regulating capacity can play an important role in taking away some of the burden during peak load. The shortcoming of MHG is power deficiency in the dry season but the construction of small thermal plants can make up this deficiency. Therefore, constructing small thermal plants in the developing grid, which is mainly comprised of hydro plants, can make up the power deficiency in the dry season and thus raise the reliability of the power supply.

B. Small diesel generation.

In China, the capacity of diesel generation is usually smaller (below 100 kW). They have been primarily built in smaller towns and in small factories, mines and other enterprises. The capital cost of a diesel station (about 500-600 Yuan/kW) and its domestic consumption is low. The starting and shutting down operation of a diesel generation is rather simple and requires only a small number of operators. However, due to the diesel consumption, the cost of generation is rather high. A higher level of technology in operation and management is also required. As a result, only in cases where the load is not heavy, the load centre is far away from the coal mine or grid and where a hydraulic sources is not available in nearby regions, or is only a makeshift as an interim power source, should a diesel power station be adopted.

C. Extension from the grid.

Power supply from an existing regional or state grid may be more reliable and of better quality because grids have sufficient capacity to supply power to rural areas. This makes them more adaptable for regions where the load demand rapidly increases. In comparison to MHG and the necessary extension of transmission lines from the regional or state grid, in most cases, if the construction costs of the existing power plant in the grid is excluded, the cost of the power supply fed from the grid will be lower. Therefore, in rural areas, where demands are high, a grid is nearby but water power resources are not available, the power supply must depend upon the extention of this grid. At present, however, owing to the deficiency of power in the grid, it is difficult to meet these scattered rural load demands in the near future. Furthermore, long transmission lines are required to feed the distant rural villages and the construction of new medium or large scale power plants will need large investments by the state, as compared to MHG. The construction period of these medium or large scale power plants is also longer than for MHG. In short, MHG offers these special traits: full utilization of the scattered water potential, adaptability to the scattered distribution of rural villages, and it combines water uses for other purposes with MHG, which all should encourage local authorities at the different levels to develop MHG within their capabilities. There is also a reduction of investment by the state and a shorter construction period with quicker results. Hence, it is preferable to built MHG where water resources are available to provide electricity for local villages. This will not only reduce the burden on the grid but will also meet the rural load demand within a short period of time.

Connecting MHG plants into a network or an integration of MHG plants with the regional or national grid is recommended in order to fully utilize the water power. From the point of view of uninterupted power supply for the promotion of agricultural production, the integration of MHG is a viable measure.

D. Biogas generation.

Statistics have shown that the capital cost of biogas generation is lower than MHG, only 400-500 Yuan per kW of biogas generation. Equipment and technology for biogas generation is rather simple and can be done by most of the commune or brigade. However, biogas production is limited by conditions such as good sealing (the lowest temperature must be higher than 9°C) and the supply of raw materials. In some rural areas, biogas is presently used for cooking but is hardly ever used for power generation. Biogas generation with a small capacity, usually several kW to tens of kW, is only used in a few places.

Biogas is a sort of inflammable gas which contains mainly methane and is produced from organic waste materials through a process of fermentation by anaerobic bacteria under certain temperatures, acidity, alkality and airtight conditions. It is usually made up of 55-70% methane (CH_4) and is one type of good gas fuel.

An estimation of gas production from various materials is found in Table 3-6.

Table 3-6 The Production Rate of Biogas

Material used	Biogas yield per day (M^3)
a 40-50 kg pig's dung	0.2
a large buffalo's dung	1-1.4
0.5 kg fresh herring	0.3
0.5 kg hay	0.12

At present, the equipment for biogas generation uses a type of double burning. This equipment is usally refitted from diesel engines by simply putting a biogas-air mixer at the air inlet. It uses diesel oil as well as biogas. When biogas is the main fuel, only a little amount of oil is used at the beginning. Diesel consumption is increased when the biogas is not sufficient or the supply of biogas is interrupted.

E. Other energy sources for generation.

Aside from the above-mentioned energy sources for generation, there is geo-thermal generation, solar energy generation and wind power generation but all of these are still in the experimental stage.

In China, a group of experimental underground hot water power stations have been built. The temperature of water used in those stations is under 100°C. At present, two approaches are used for generation. They are (1) low boiling point actuating medium approach, and (2) pressure reducing - volume expanding approach.

Solar energy generation in China is still in the experimental stage. There are two types of solar energy generation; one converts solar energy into heat energy and then mechanical energy into electricity, and other one generates electricity directly from solar energy such as the solar battery.

Wind power generation is more suitable for grassland, pastoral areas, in-shore islands and remote mountainous districts where wind energy is plentiful. A wind power generator has been installed on an in-shore island and is being used to desalinate sea water.

The quality and quantity of solar energy and wind power generation is effected by natural conditions and thusly not very stable. To compensate, an energy storage device (such as a battery) should be provided but this adds a lot of expense.

CHAPTER 4: EXPLOITATION AND DESIGN

I. Design Criteria of MHG

The classification of hydro generation projects and their structures shall be in accordance with the norm (classification and design standards of water conservancy and hydro power projects) (in mountainous and hilly areas SDJ 12-78).

As for the design of hydraulic structures, aside from the above-mentioned norm, the specifications stipulated in the design norm of relevant hydraulic structures shall also be observed. In the seismic region, the norm (design norm of the earthquake effect on hydraulic structures SDJ-10-78) shall also be followed.

Tables 4-1, 4-2, 4-3 and 4-4 are given for reference.

Table 4-1 Classification of water conservancy and hydro power projects

Grade of Project	Scale of Project	Classification				
		Gross Reservoir capacity (10^6 M^3)	Flood protection		Irrigation Area (10^3 mu)	Installed capacity (MW)
			City and Industrial or mine area	Farmland (10^3 mu)		
I	Large (1)	> 1000	Very important city, industrial or mine area	> 5000	> 1500	> 750
II	Large (2)	1000-100	Important city. Industrial or mine area	5000-1000	1500-500	750-250
III	Medium	100-10	Medium size city, industrial or mine area	1000-300	500-50	250-25
IV	Small (1)	10-1	Town and common industrial or mine area	< 300	50-5	25-0.5
V	Small (2)	1-0.1			< 5	< 0.5

Table 4-2 Classification of hydraulic structure

Grade of Projects	Grade of permanent structures		Temporary structure
	Major structure	Minor structure	
I	1	3	4
II	2	3	4
III	3	4	5
IV	4	5	5
V	5	5	

Table 10-4-3 Design flood of permanent hydraulic structures in normal operation

Grade of structures	1	2	3	4	5
Period of recurrence of flood (yrs)	2000-500	500-100	100-50	50-30	30-20

Table 4-4 The lower limit of design flood of permanent hydraulic structure in abnormal condition

Type of Dams	Grade of structure				
	1	2	3	4	5
	Period of recurrence (years)				
Earth dam, rockfill dam, dry-laid rubble dam	10,000	2,000	1,000	500	300
Concrete dam, masonry dam and others	5,000	1,000	500	300	200

II. Planning

The main points in planning a MHG station are selecting the type of MHG, choosing the site and sequence of construction, deciding the scale of MHG, roughly selecting the type of structures and the layout, comparing the alternatives for transmission and distribution lines, and estimating construction costs.

The main considerations which must be studied during planning are:

A. Overall planning.

According to the principle of overall planning and comprehensive harnessing, a general investigation must be made of water resources in connexion with the development condition of the local industry and agriculture, and load demands. During planning, it is necessary to have a reasonable co-ordination among the various departments concerned and to assess the quantity of water available and the period of water consumption. It is also necessary to comprehensively consider various possible purposes for this water, including flood control, irrigation, power generation, navigation, water supply for industrial and domestic use, and fishery.

B. Feasibility of cascade development.

The "cascade development" is based upon the hydrological, topographical and geological conditions, distribution of farmland, mineral resources, losses of water impounding and other technical and economical factors. After comprehensive analysis and comparison, the top priority development project can be selected and the first stage of the project can be determined. In general, hydroplants with a storage dam are preferable for the upstream first cascade because the inflow regulated by the storage may improve power generation, irrigation, navigation and water supply.

C. Overall arrangement of MHG plants and major power plants and integration of MHG to the grid.

Small hydro power in rural areas mainly supplies electricity for agriculture by product processing, for irrigation and drainage, as well as for illumination. The major power plants provide electricity to industries run by the people's communes or counties and to big electrical pumping and drainage stations. In order to make the power supply more reliable, it is advisable to set up a local grid to integrate the MHG plants, or to integrate the local grid to the state grid to increase the electrical power and improve the capacity of the power supply. When a grid is formed, the power from various sources can complement one another.

If conditions permit, the MHG may be operated to supply reactive power to the grid and thus improve its quality of power supply.

D. Choosing the best alternative with favourable power-economical features.

Reliability and economy are the basic requirements for a project. In hydro plant planning, the power-economical features are used to measure the economic feasibility of a project.

The main power features of MHG are firm power Ng, installed capacity Ni, mean annual output Ea, etc.

The main economic features of MHG are investment, running costs, profit, etc.

Beyond the total cost, some unit costs are commonly adopted for investment comparison, such as unit cost per kW, unit cost per kWh, annual running cost which includes depreciation of structures and equipment, overhaul and repair costs, maintenance cost, overhead expenses and wages.

A water conservancy and hydro generation project with multiple purposes usually has comprehensive benefits such as flood control, irrigation, navigation, log passing, etc.. All these benefits should be considered comprehensively.

As for the net income of power generation, it can be formulated as:

$$I_N = \sum S_{Ni} \quad E_i \qquad \text{(Yuan/year)} \qquad 2)$$

Where S_{Ni} = net income per kWh (Yuan/kWh, obtained from selling price - operation cost per kWh).

Symbol i denotes different users (the selling price for agriculture and industry are different).

E_i = the power supply to the users during a mean year (kWh/year).

If a hydro generation project has the multiple uses of supplying water to industrial and domestic users as well as to the fishery, benefits in this case will be calculated according to concrete conditions.

The return period of the capital cost may be computed by

$$T_R = \frac{Te}{\Sigma N} \text{ (year)} \qquad 3)$$

where Te = the total investment

ΣN = net income per year.

At present, T_R = 5-7 years (usually adopted) and limited by 10 years.

T_R is an index shown in the general conception. It can not sho·r the feasibility when an increment of investment is applied. For example, in a hydro plant of high head and low discharge, an increment of discharge may sensitively increase the power output, so the feasibility of the alternatives to trans-drainage area water diversion is usually studied. In this case, the return period of increment investment for diversion of the ex-drainage area flows should be compared. The calculation is as follows:

$$\Delta T_R = \frac{\Delta Te}{\Delta XN} \quad \text{(year)} \qquad 4)$$

When ΔT_R = return period of increment investment (year)

Δ Te - increment investment (yuan)

Δ XN = net increment income per year (yuan/year)

ΔT_R - 10 years are usually adopted.

E. Selecting a site with favourable topographical, geological and hydraulic conditions.

During the planning of a hydro plant, the selection of site and layout of the dam, conveyance structure, power house and transmission and distribution yard are very important and very much depends upon the topographical, geological and hydraulical conditions.

Attention must be paid to the selection of a favourable site.

F. Saving construction materials and ensuring the availability of equipment.

During planning, in order to save steel, timber, oement, etc., it is better to make full use of the available local materials. For the selection of equipment, priority should also be given to the local manufacturers.

III. Hydrology

A. General description

At present, China has already established more than 17,000 hydrological stations of various kinds. Among them, 2,900 are standard stations mainly distributed on the big rivers and only 11% are located on the small rivers. MHG stations are mostly built on small rivers, therefore, shortage of hydrological data is a common condition. Generally, the hydrological work of a MHG is carried out by in situ investigation as well as by necessary calculation using hydrological handbooks. These hydrological handbooks have compiled relevant hydrological data and statistical parameters (expressed in isolines or graphs), formulas and worked examples. In case of a shortage of data, they are very helpful for the hydrological calculation of run-off and flood of the medium and small water projects.

In general, for MHG plants with a unit capacity larger than 500 kW, hydrological analysis should be presented in the design report; for MHG plants with a unit capacity less than 500 kW, no special hydrological analysis is necessary.

The main points of hydrology for the design of rural MHG are as follows:

1. to provide run-off data for water energy calculations;
2. to provide flood data for dam design;
3. to provide high and low stages for power house design;
4. to provide flood stage data for the design of cross structure for the conveyance canals.

B. Run-off calculation

If there is more than 15 years observatory data which reflects the rule and variation of the hydrological data of the high, medium and low water years of the design frequency at the project site, frequency calculation can be directly carried out. If there is approximately 10 years observatory data, the first step is to elongate the series and then calculate the frequency. If there is merely 6-7 years data, it still can be used as the basic data for extrapolation. If there is only 2-3 years data, or even no observatory data at all, the transposition method is proposed. It is then necessary to select a neighbour basin with rather long series data and where the natural geographical conditions are similar to the project basin. These long series data can be transposed to the design project. If there is no run-off data, but only precipitation data available, the run-off can be calculated from precipitation. In this case, attention must be paid to the following: when the mean annual average precipitation is about 1,500 MM and the mean annual average run-off co-efficient is over 0.5, there is a good relationship between precipitation and run-off; in an arid region, where evaporation is large, the variation of precipitation and run-off may lose their correspondence and relations may be inequal.

Hydrological data is usually lacking on medium or small streams. An isohyetal map or determined statistical parameter by data analysis of a similar neighbouring region can be utilized, from which the frequency characteristics of annual run-off may be obtained. Generally, the Cv value at the gravity of the project basin can be taken from the regional hydrology handbook and then take Cs in relation with Cv. Thus, where there is a lack of hydrological data, the determination of a mean annual average run-off $\bar{Q}aa$ is the key for establishing the annual run-off frequency curve.

1. Methods for $\bar{Q}aa$ calculation

a. Isohyetal method

The hydrological isohyetal map is derived from the rule of geographical distribution of the hydrological characteristics value (annual run-off, co-efficient of variation Cv, etc.). It is based upon the processing and analysis of numerous data. The isohyetal map is provided by plotting the hydrological characteristics value at various stations. Each hydrological characteristics value may be drawn in an isohyetal map for easier application.

(i) Application of an isohyetal map of annual average run-off depth ($\bar{y}$) or mean annual average run-off modulus ($\bar{M}$)

Based on the observatory data and the drainage area, which is controlled by the hydrological station by means of the principle of water balance, it is possible to establish an isohyetal map of the mean annual average run-off depth $\bar{y}$ If there is no hydrological station near the project site but the isohyetal map is available, the mean annual average run-off depth of the project can be determined by the isohyetal map. When the drainage area of the project is small and the isohyets are flat, it is possible to use the $\bar{y}$ at the gravity of the drainage area as the mean average annual run-off for the whole drainage basin. Otherwise, the whole basin must be divided into several sub-areas and the mean annual run-off depth of the whole basin computed by weight of area and isohyet.

$$\bar{y} = \frac{\bar{W}a}{F \times 10^6} \times 10^3 = \frac{\bar{W}a}{1{,}000\ F} \quad (MM) \qquad 5)$$

where F = basin area in km^2

$\bar{W}a$ = the mean annual average run-off volume in m^3

As $\bar{y}$ is obtained, the formula for calculating the mean annual average discharge of the project station is:

$$\bar{Q}aa = \frac{\bar{W}a}{31.5 \times 10^6} = \frac{1{,}000\ \bar{y} \cdot F}{31.5 \times 10^6} = \frac{\bar{y} \cdot F}{31.5 \times 10^3} \quad (CMS) \qquad 6)$$

Again, by means of the isohyetal map for the co-efficient of variation Cv of the annual run-off, one arrives at the Cv at the gravity of the catchment area, and can then obtain the co-efficient of skewness Cs by analysis. Through help of the table of the modulus ratio co-efficient Kp of the Pearson type III curve, the Kp value of the specific frequency can be found out for design purposes. The annual average discharge of the specific frequency can be calculated as:

$$Qaap = \bar{Q}aa \times Kp = Kp \times \frac{\bar{y} \cdot F}{31.5 \times 10^3} \quad (CMS) \qquad 7)$$

In the same way, the annual average discharge of various frequencies can be calculated. Finally, the theoretical frequency curve of the annual average discharge is established.

In China, the isohetal map of the mean annual average run-off modulus was given in the hydrological handbook computed by the relevant provinces. The mean annual average discharge yielded per km^2 of the catchment area is called the mean annual average run-off modulus $\bar{M}$:

$$\bar{M} = \frac{\bar{Q}aa}{F} \times 10^3 \quad (li/sec/km^2) \qquad 8)$$

where F in km^2

$\bar{Q}aa$ in 10^3 li/sec

$$\text{or } \bar{Q}aa = \frac{\bar{M}\ F}{1{,}000} \text{ (CMS)} \qquad 9)$$

When and if the isohyetal maps of $\bar{Y}p$ (annual run-off depth with frequency) and Mp (annual run-off modulus with frequency) are available, it is possible to find out directly the annual run-off volume of the specific frequency. For example, if the annual run-off of a design percent chance by means of a Yp or Mp isohyetal map is desired, the annual run-off depth Yg and annual run-off modulus Mg with specific frequency at the centre of gravity of catchment area can first be determined. The following formula is then used to calculate the annual average discharge of the design percent chance of the hydro plant:

$$Qaag = \frac{Yg \cdot F}{31.5 \times 10^3} \text{ (CMS)}$$

$$Qaag = \frac{Mg \cdot F}{1{,}000} \text{ (CMS)} \qquad (10)$$

(ii) Method for estimating annual run-off from a precipitation isohyetal map.

If there is no run-off isohyetal map, the mean annual average run-off volume of the hydro plant may be computed with the help of a precipitation isohyetal map. The formula is:

$$\bar{Q}aa = \frac{10^3 \alpha \bar{x}a\ F}{31.5 \times 10^3 \times 10^3} = \frac{\alpha\ \bar{x}a\ \ F}{31.5 \times 10^3} \text{ (CMS)} \qquad 11)$$

where $\bar{x}a$ = mean annual average precipitation (mm), examined from the precipitation isohyetal map

α = run-off co-efficient, related to rainfall volume and its intensity, topography of basin, evaporation, soil and water conservation, etc. α value varies on a large range, some smaller than 0.2 and some greater than 0.6.

In plain areas with good soil and water conservation as well as large evaporation and infiltration, a smaller α

value is proposed but, on the contrary, a larger value is taken. As it is not easy to get an exact value of the co-efficient α, formula 14 is used for a rough estimate.

The isohyetal maps are presented in the publications of the provincial or prefectural hydrological handbook in China. Attention should be paid to its applicable range and conditions. If the drainage area is very small, the influence of non-regional factors increase and thusly, the application of an isohyetal map may result in errors.

b. Estimating annual run-off from annual precipitation.

The above-mentioned isohyetal method is a simple method. It is, however, sometimes difficult to use the hydrological handbook or there is an increased amount of data since the publication of the handbook. In these cases, estimating the annual run-off series by means of the annual precipitation is proposed. This method is rather complex and if not done carefully, the accumulated errors will be many.

(i) Evaluating the annual precipitation series of the project's basin.

For ungaged areas, precipitation data from a nearby rainfall station to the design area should be transposed. The following points should be kept in mind during transposition:

(1) As rainfall varies from one area to the other, data of the nearest neighbouring area should be preferably used in transposition.

(2) The location of the raingages used for transposition and of the project's basin should be situated in the same climate belt.

(3) The effects of rainfall variation due to elevation must be taken into consideration, corrections being made if necessary.

(4) Select rainfall gages with long observatory data (over 15-20 years) as the transposed station.

When there is only short-period data (at least more than 5 years), it is better to first establish the correlation between the short-period data and the nearby gage with long-period rainfall data in order to elongate the short series to a long series of 15-20 years (using the correlation analysis method) and then transpose it to the project basin.

Correlation analysis has been widely used in hydrological calculation. It can be used for data interpolation and extrapolation, checking and correcting of data and deriving empirical formulas, etc.

(ii) Evaluating the annual run-off series of the project's basin.

1. Selecting the reference station and reference basin.

In order to exchange the annual precipitation for annual run-off, it is necessary to establish a correlation between annual precipitation and run-off. If there is no hydrological station in the project's basin, the correlation is not available for that basin. In this case, it is necessary to evaluate the correlation between precipitation and run-off in the basin where hydrological stations are established and then to transpose this correlation to the project's basin. This transposed hydrological station and the drainage basin are called the reference station and reference basin, respectively. In a normal case, the downstream nearby station with a catchment area closing at the project's basin area or to a neighbouring station and basin is preferable to a reference station and basin.

2. When a reference station has been selected, the correlation points of annual precipitation and annual run-off volume of the reference basin should be plotted.

If there are several rainfall stations in the reference basin, the average value of precipitation of those stations is used.

3. Analysis of the correlation curve and transposition for the project's basin.

During the selection of the reference basin, it is necessary to compare and analyse the factors which will influence the annual run-off of the two basins. With a small basin, the factors are: average height of the basin; relative direction of slope and air current; forest, farm land, soil and water conservation; average gradient of basin; forest, soil and geological conditions; supply of underground run-off, etc.

If the conditions of two basins are similar, it is possible to plot a smooth curve through the correlative points and also obtain the inner and outer run-off series as shown in Figure 4-1.

4. Calculation of the annual run-off series of the project's basin.

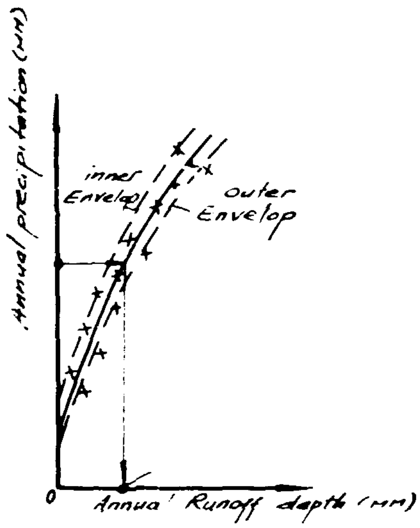


Fig. 4-1 Precipitation - Runoff Curve

By means of the correlation curve in Figure 4-1, the annual run-offs of the project's basin can be determined by the annual precipitation and the annual run-off series of the project's basin. A series of more than 15-20 years is desired.

c. Evaluating the annual run-off of the project station from annual run-off of the reference station (hydrological analogal method).

If there is a nearby hydrological station where the natural geological conditions are similar to the project area, it is reasonable to select this station as the reference station. Long-period hydrological data or prolonged data of the reference station is required.

If the difference between the two drainage areas is 3-5% only, the data of the reference station can be directly applied. If the difference is about 10-15%, it can be transposed according to the ratio of area:

$$Qa = \frac{F}{Fr} \; Qar \; (CMS) \qquad 12)$$

when the distribution of precipitation is unequal, correction of precipitation must be taken into consideration.

$$Qa = \frac{\chi a}{\chi ar} \cdot \frac{F}{Fr} \cdot Qar \; (CMS) \qquad 13)$$

where Qa, Qar = annual run-off volume of the project's site and of the reference station, respectively

F, Fr = drainage area of the project's site and of the reference station, respectively (km^2)

χa, χar = annual precipitation of the project site and of the reference station, respectively (MM)

2. Selecting a design sample year

To compute MHG, three specific years are usually taken as the design sample years:

- Low water year: The run-off of the low water year is used to predict the performance of MHG in dry years. 75-80% chance is used in the annual run-off series for this specific sample year.
- Medium water year: Usually a 50% frequency in the annual run-off series is selected as a medium water year.
- High water year: It is symmetrical to the low water year. A 20 or 25% chance is used in the annual run-off series for this specific sample year.

There are two main tasks in the selection of design sample years: to determine the annual run-off of the design sample year and to determine the distribution of the design annual run-off volume.

a. Design annual run-off volume.

According to the above-mentioned methods, the annual run-off volume frequency curve can be plotted first. From this curve, the annual run-off volume of the sample year (of specific frequency) can be evaluated.

b. Distribution of design annual run-off in a year.

The distribution of the stream or river run-off in a year is uneven. The distribution within a year is not only different from other years with different annual run-off volume, but also quite different even from years with equal annual flow. Since the flow distribution within a year has a large influence on the operation of the reservoir and hydro electrical station, a reasonable flow distribution within a year of the design annual run-off is required.

In practice, the selection of flow distribution within a year of the annual run-off is the determination of a hydrograph of the design annual run-off. For a yearly regulated hydro electrical station, the distribution can be shown in the monthly average discharge. For run-of-river or daily regulating hydro electrical stations, it is necessary to give the daily discharge of the design year.

(i) Hydrograph of a typical year.

The first approach is to select a typical year from the observatory annual run-off data. The annual run-off volume of the typical year must be equal or close to that of the design year. Then, the flow distribution within the typical year is used as the distribution of the design year.

The second approach is to select a flow distribution in a year in which observatory data has shown to be adverse to a typical year of the project. In this case, an adjustment must be applied according to the ratio of the annual run-off volume.

The co-efficient of correction K is:

$$K = \frac{\text{annual run-off of design year}}{\text{annual run-off of typical year}} \qquad 14)$$

The discharge of a typical year times K is the discharge of the design year. The flow distribution within the design year is thusly obtained.

(ii) Determining the flow hydrograph in the ungaged area.

- Approach 1: By means of observatory data from the nearby similar basin, using one of the above two methods, the flow distribution within a year of the design annual run-off is determined.

- Approach 2: By use of a regional hydrological handbook, the percentage of monthly inflow to the annual run-off volume of the nearby similar river is computed (this percentage is based on a lot of observatory data). The monthly flow of the problem site is then calculated.
- Approach 3: According to the typical annual precipitation distribution within a year of the design frequency (this precipitation is within the catchment area of the project's site), the discharge hydrograph of the design year of the same frequency is simulated.

3. Determining low discharge where hydrological data is unavailable.

If there is no hydrological data within the catchment area upstream of the project's site, hydrological data of the reference basin, where the drainage area, hydro-geological conditions, soil, vegetation are similar to the problem basin, can be used for estimation. It can be transposed directly or, if necessary, be corrected by using the drainage area's ratio. Field investigation and measuring are also used to determine the design low daily discharge.

The design percent chance of the MHG plant has a wide range (50-85%). For this low percent chance MHG plant with Pd=50% or a little higher, field observation works are emphasized. If the required reliability of power supply is high or the water resources are abundant but there are not many consumers, it is suggested that the average daily discharge in the mean dry season be observed and investigated and used as the firm discharge of the MHG plant.

For the selection of low discharge, attention must be paid to the discharge which will be extracted when planning or building a hydraulic project on the upstream reach of the river or tributaries. This discharge must be deducted from the design low discharge.

There are several approaches for investigating and measuring low discharge:

- investigating or estimating the low stage and then calculating the low discharge using the hydraulic formula.
- measurement by floating marks.

- measurement by weir.
- determining low discharge by means of a daily discharge isohyetal map or table.

For estimating annual run-off in those regions where there is a shortage of hydrological data, different approaches can be applied to make a comparison. The results of the evaluated run-off usually may be checked in the following ways:

- check the balance of the streamflow for downstream and upstream on the main stream (include main tributaries).
- check whether precipitation is larger than the run-off volume in the same period, check the of the run-off co-efficient.
- check whether the Cv of the run-off is greater than the Cv of precipitation in the same period.
- check whether the regional distribution of the mean value and Cv is equal in comparison with the nearby station.
- check the equalness of run-off distribution in each period from the flow hydrograph.

C. Floods

For the prefectural and county level backbone yearly-regulated hydro power station, attention must be paid to flood protection as it is of great concern to the lives and property of the people masses and will also determine success of failure of the project. If there are flood protection demands in the downstream, the reservoir must undertake the task of flood detention to reduce the flood peak. It is necessary that when a flood of certain specific frequency occurs, the downstream discharge can be lowered below the allowable one. This certain specific frequency is called the design standard of the flood protection. Generally, flood protection of agriculture is 2-20%, for industrial districts or urban areas it is 0.2-10%.

In a water conservancy project, when a flood of designed frequency has occured, destruction of the main hydraulic structures (dam, power house) must be prevented. As for the MHG project, the main task of the flood protection is to guarantee the safety of the hydraulic structures.

The design criteria of medium and small hydraulic structures is shown in Tables 4-3 and 4-4, for reference on pages 26 and 27.

1. Design discharge of the flood peak

a. Computation of design peak discharge by observatory data.

If there are hydrological stations upstream or downstream from the nearby project site, usually, a long-term flood series (over 20 years) is available; thus, frequency analysis can be carried out based upon the flood data. Investigation data of historical floods is also valuable in determining the design flood discharge. The calculation steps are as follows:

(i) calculate and plot the empirical frequency of the annual maximum discharge series;

(ii) determine the mean of flood peak value Qfav, co-efficient of variation Cvf and other statistical parameters;

(iii) take a skewness co-efficient Csf for small catchment, in common cases, Csf is 2-4 times Cvf;

(iv) analyze and verify the investigated data of the historical flood and estimate its frequency;

(v) use the principle of curve fitting to fit the points on the theoretical frequency curve as closely as possible to the points on the emperical frequency curve (the influence of the historical flood could also be taken into consideration) and eventually obtain the Csf in times of Cvf. The points on the upper part of the curve will be emphasized during the fitting of the curves;

(vi) the peak discharge of different frequency can be obtained from the flood frequency curve.

b. Computation of design peak discharge by other methods

The sites of MHG plants are usually located in the ungaged region. In these cases, the synthetic method of peak flood, flood volume modulus of the nearby gages basin and the storm idohyetal map, as well as the regional synthesis method of storm run-off calculating parameters, is recommended to determine the design flood. The other way is to determine the design flood by regional empirical formulas.

If there is reliable historical flood date and its chance of occurence can meet the requirements of engineering design, these historical floods can be used directly or by proper correction for the determination of design flood. Some approaches for the determination of design peak discharge are described as follows:

(i) **Estimating design peak discharge from the design storm - rational method.**

When the drainage area of the river is smaller than 500 km^2 in the mountainous region or semi-mountainous region, the basic formula estimating flood peak discharge from the intensity of storms is:

$$Qf = 0.278 \phi \, ip \, F = 0.278 \, \phi \frac{S}{\tau^n} \, F \quad (CMS) \qquad 15)$$

where 0.278 = co-efficient of unit exchange

ip = design storm intensity (mm/hr)

ϕ = co-efficient of the peak run-off; the ratio of the run-off volume to the storm volume during the flood peak period

S = rainfall density; the maximum one hour precipitation (mm/hr)

τ = time concentration of flow; also called the time of flood collection (hour). In a small basin, it may be assumed that the time concentration of the peak discharge equals the duration of the storm.

n = storm recession co-efficient

F = drainage area (km^2)

The following are ways of determining the main parameters and co-efficients of the rational method:

(i) Basin parameters:

F = drainage area of the control section of the project's site

L = distance from the remotest point of the watershed to the project's site along the river channel (km)

J = average gradient of the river channel

The above-mentioned three parameters may be measured from the $\frac{1}{50,000}$ topographical map.

2. Storm parameter S (rainfall density) can be formu-formulated as:

$$S = \frac{H_{24p}}{24^{1-n}} = \frac{K_p \bar{H}_{24}}{24^{1-n}} \quad (MM/hr) \qquad 16)$$

where H_{24p} = the 24 hours design storm volume in a given frequency (MM)

$\bar{H}_{24}$ = the mean annual meximum 24 hour storm volume (MM) (can usually be obtained from isohyetal storm parameter maps)

Kp = can be obtained from the Kp table (according to local data or take $Cs_{24} = 3.5\ Cv_{24}$) by frequency p and Cv, Cs of the maximum 24 hour storm

n = storm recession co-efficient (n varies with rainfall duration). When the duration of the rainfall is less than one hour, take $n = n_1$, if the duration is equal to one hour or longer, take $n = n_2$ (n is obtained from the handbook on hydrology).

3. Time concentration τ (hr) is the duration of the flood concentration in the basin. It is related to the length of river, channel gradient and velocity of flow concentration. It also varies with the size of the flood. There are empirical formula and nomograph of time concentration computation which are adaptable to the local conditions offered by relevant regions.

4. Flood peak run-off co-efficient ϕ is related to topographical conditions, water and soil conservation, flood frequency and its antecedent factors. If those factors are similar, the smaller the drainage area, the larger the ϕ value will be.

(ii) Empirical formula

On the basis of the observatory data, referring to flood investigation and taking natural geography into consideration, the empirical formula for determining flood peak discharge can be analyzed and derived in the various regions. One of the empirical formula is shown as:

$$Q_{fp} = C_p F^K \quad (CMS) \qquad 17)$$

where Q_{fp} = peak discharge of a certain frequency (CMS)

F = drainage area (km^2)

C_p = flood peak discharge modulus. Its empirical parameter which is concerned with the frequency, is presented in the regional hydrological handbook. Usually, at a fan shaped basin with steep channel gradient, the value of C_p becomes larger; while at a narrow shaped basin with a flat channel gradient, the value of C_p becomes smaller.

K = area co-efficient, which is an empirical co-efficient related to the regional natural geographical factors (also presented in the handbook on hydrology).

Another form of the empirical formula is:

$$Q_{fp} = qSF^{\frac{2}{3}} \quad (CMS) \qquad 18)$$

where S = rainfall density (MM/hr) (presented in the hydrological handbook of the relevant region, or calculated by formula (16)).

q = peak discharge parameter, as shown in Table 4-5

Table 4-5 Peak Discharge Parameter q

Item / Area of flood concentration	River channel gradient J (‰)	Run-off co-efficient ϕ	Velocity during concentration v (m/sec)	Peak discharge parameter q
Rocky mountainous region	> 15	0.80	2.2 - 2.0	0.60 - 0.55
Hilly region	> 5	0.75	2.0 - 1.5	0.50 - 0.40
Loess hilly region	> 5	0.70	2.0 - 1.5	0.47 - 0.37
Plain, flat slope region	> 1	0.65	1.5 - 1.0	0.40 - 0.30

where q is calculated by formula $q = 0.42\,\phi\, v^{0.7}$

(iii) Investigation and calculation of the "historical flood".

The historical flood occured much earlier in history but obviously was never measured. Due to lack of data, it is now necessary through the help of historical flood investigation to observe an elongated flood series in order to achieve a reliable calculation. This is the approach usually applied, especially in the ungaged area.

The main point for historical flood investigation is to discover reliable flood traces. From these, the corresponding peak discharge can be calculated. Generally, according to the surveyed longitudinal section and cross section of the river bed and the flood surface curve, the hydraulic factors of the design section can be calculated. Then, using the hydraulic formula, the flood peak discharge corresponding to the investigated flood stage can be calculated.

2. Design flood volume

For medium or small projects, the daily storm flood volume is generally used or, at times, a three day flood volume. For these gaged rivers, long time flood volume observation of one to three days is available through frequent analysis and calculation, the design flood volume can be determined according to the design frequency.

In medium or small drainage areas where there is a shortage of data, volume of one flood is usually taken into consideration. There are two approaches used for estimation:

(i) Volume of one flood is estimated from the approximate accumulated volume after a storm lasting a maximum of 24 hours.

$\overline{W}df = 1,000\ h24d\ F \quad m^3$..... (10)

where $\overline{W}df$ = design flood volume (m^3)

h24d = the maximum 24 hours excess rainfall depth (MM) of design flood frequency.

The steps for calculating h24d are as follows:

- obtain from the hydrological handbook the mean annual average for a maximum 24 hour storm volume $\overline{H}24$ and Cv24 of the annual maximum 24 hour storm;

- find out the design storm modulus factor Kpd from the hydrological handbook, according to its design flood frequency and Cv24.
- calculate the 24 hour design storm volume H24 from $\bar{H}24$ and Kpd, formulated in $H24d = Kpd \ \bar{H}24$. (20)
- according to H24d, consult the H24-h24 curve presented in the hydrological handbook and obtain the maximum 24 excess rainfall depth h24d.

(ii) Estimating flood volume by 24 hour design storm volume and the corresponding run-off co-efficient:

$$\bar{W}df = 1,000 \ H24d \cdot \phi \cdot \alpha \ 24 \cdot F \ (m^3) \qquad (21)$$

where H24d = 24 hour design storm volume, (MM) can be obtained from the hydrological handbook.

ϕ = storm point - area ratio , can be obtained from the hydrological handbook. The small catchment value is larger when $F < 300 \ km^2$, ϕ approaches 1.0.

α 24 = the run-off co-efficient of a 24 hour storm and can also be found in the handbook.

3. Design flood hydrograph.

There are two approaches used to calculate the hydrograph for flood routing.

(i) Enlarging the typical flood hydrograph.

If the annual maximum flood series is available, the design flood hydrograph can be derived from enlarging the typical flood hydrograph.

It is awared to select the flood hydrographs in high water years where the data is both rich of representativeness and comparatively reliable and where the ocurrence of flood peaks is adverse to the safety of engineering.

The discharge on the design flood hydrograph is the product of the discharge on the typical flood hydrograph and a co-efficient $Kf > 1$ (i.e. enlarged)

$$Kf = \frac{Qdf}{Qtf} \qquad (22)$$

where Qdf = design flood peak (CMS)

Qtf = the flood peak on the typical flood hydrograph (CMS)

(ii) Simplified designed flood hydrograph.

The establishment of the design flood hydrograph in the ungaged watershed is related to the approach used to compute the flood peak discharge. The flood hydrograph can be directly derived from both the unit hydrograph and isochrones. If the flood peak is calculated by rational formulas and regional empirical formulas, there will be only the peak discharge value but no flood hydrograph. Therefore, the simplified design flood hydrograph must be applied.

Mountain tributaries have small catchment areas, the basin slope and channel gradient are rather steep and the flood raises and falls fiercely. Here, the design flood hydrograph for small projects can be simplified as a triangle, as shown in Figure 4-2. Preferably, the simplified hydrograph should be selected with reference to the natural flood hydrograph data of nearby regions.

The volume peak relation of the simplified triangle of the design flood hydrograph is:

$$\bar{W}df = \frac{1}{2}\, Qdf \cdot T$$

$$T = \frac{2\bar{W}df}{Qdf} \qquad (23)$$

where $\bar{W}df$ = volume of design flood

Qdf = peak discharge of design flood

Taking a synthetic analysis based upon the investigatory and observatory data, the empirical relation between the duration of rising segment Ti, flood duration T and various catchment areas are provided for application.

To illustrate this, Table 4-6 shows the relationship between $\frac{Ti}{T}$ and catchments in a district in China. It is the result of analysis and synthesis of Ti and T of many flood hydrographs.

Table 4-6 $\frac{Ti}{T} \sim$ F table of a district.

F (KM^2)	1-3	4-10	11-20	21-40	41-100	101-200	201-500	501-1,000
$\frac{Ti}{T}$	0.374	0.352	0.337	0.325	0.312	0.300	0.289	0.277

Using formula 23, T can be obtained if the design flood peak discharge and design flood volume are given. Referring to the $\frac{Ti}{T}$-F of the problem basin or a nearby similar basin, the Ti can also be determined. After this, a simplified triangular design flood hydrograph can be plotted.

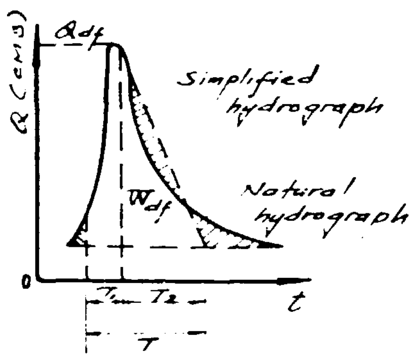


Fig 4-2 Simplified triangular flood hydrograph

D. Establishment of a stage-discharge relation

1. For the ungaged watershed, the stage-discharge relation can be derived from the results of hydraulic calculation used with the investigation data. The selection of roughness must be prudently done.

The transition of the river bed and the variations in the control conditions must be taken into consideration in advance.

2. If there is stage data but no discharge data, it is possible to transpose the upstream or downstream stage-discharge curve (with observatory data) to the problem site by means of determining the correlation between the up-

stream and downstream stages. Extrapolation through reasonable methods is necessary if the design condition is out of the range of the observed data.

3. The influence of backwater should be taken into consideration if necessary.

IV. Water Energy

Water energy design is used to determine the power features of the designed hydro plant. It consists of flow regulation, firm power, installed capacity and mean annual power output, etc. These indexes reflect the power benefit of the hydro plant and the extent of the utilization of the water resources of this developing creek or river. In this paragraph, the selection of the installed capacity of a run-of-river and daily regulated MHG plant will be covered in detail.

Technical data collected for water energy design is as follows:

- Hydrological data: includes characteristics of the drainage basin; flow series at the plant site; the stage-discharge curve at the plant site; and monthly precipitation and evaporation data.
- Reservoir's area curve and capacity curve.
- Demands of multiple-purpose utilization: water demands for irrigation, water supply, navigation and log transportation
- Load status: includes the range of the power supply for the project plant and the characteristics of load of the regional grid.

For the water energy design of rural MHG plants, both the data required and/or calculations can be simplified.

A. Electrical load

In China's rural area, the main users of electricity are irrigation and drainage, agro-based product processing, field operation, farm machinery repairing, fertilizer and pesticide, animal husbandry, paper, sugar industry and tile, etc. Their average power consumption is shown in Table 4-7.

Table 4-7 Norm of power consumption

Item	Power consumption	Item	Power consumption
Threshing	6~12 KW-hr/Ton	Brick and tile	50 KW-hr/1000yuan
Grinding	40 "	Pastecide	80 KW-hr/Ton
Husking	30 "	Sugar	12 KW-hr/Ton
Edible oil	60~90 "	Farm machinery	40-80 KW-hr/1000yuan
Mining	8 "	Fertilizer	30 KW-hr/Ton
Paper	500~600 "	Electrical pumping	$H=20^M$ 0.091 KW-hr/M^3
Illumination	15~25 Watt/household	Electrical pumping	$H=40^M$ 0.181 "/"

First, it is important to calculate the power consumption needed in the near and distant future in order to determine the scope of the power plant. If the power plant is over-installed and the demand load is low, a waste of capital cost incurs. On the other hand, if it is under-installed (when the water head and flow are fully utilized) and the demand load is high, this results in the need to construct a new plant or enlarge the existing one. As for the independently operated run-of-river station, only maximum load computation is carried out according to the demands of the reliable power supply. Necessary to collect is:

- Range of power supply, scope, type of production, number of shifts, load period, capacity of equipment, and rate of utilization for the various equipment.
- Annual and monthly power consumption and the working days of each month of the various consumers.
- Present and future population of the towns which are located within the range of power supply and their power consumption, including agro-based subsidiary lines and their quantity.

The range of power supply of a hydro power plant will be determined by the regional load status quo and its possibilities of development. The relation between the range, transmission voltage and transmission capacity is shown in Table 4-8.

Table 4-8 The capacity of power transmission and transmitting distance of different transmission voltage

Voltage of transmission line (kV)	Capacity of power transmission (kW)	Transmitting distance (km)
0.22	< 50	0.15 <
0.38	<100	0.6 <
10	200-2,000	6-20
35	1,000-10,000	20-70

Among these loads, the annual load for industrial purposes is rather even, but the daily load varies widely according to different working shifts and the kind of production. At present, in China, the electrical pumping and drainage is the main consumer in rural areas.

The property of agricultural electricity is seasonal. The load must be abruptly increased for pumping drainage and a consecutive day and night power supply is required for irrigation. The power supply for sideline occupations in rural areas is mostly concentrated in winter.

The load of illumination in towns and rural areas varies within a 24 hour period, and also in a year.

1. Daily load:

The summation of industrial, agricultural, and lighting loads provide the typical daily load on the power supply.

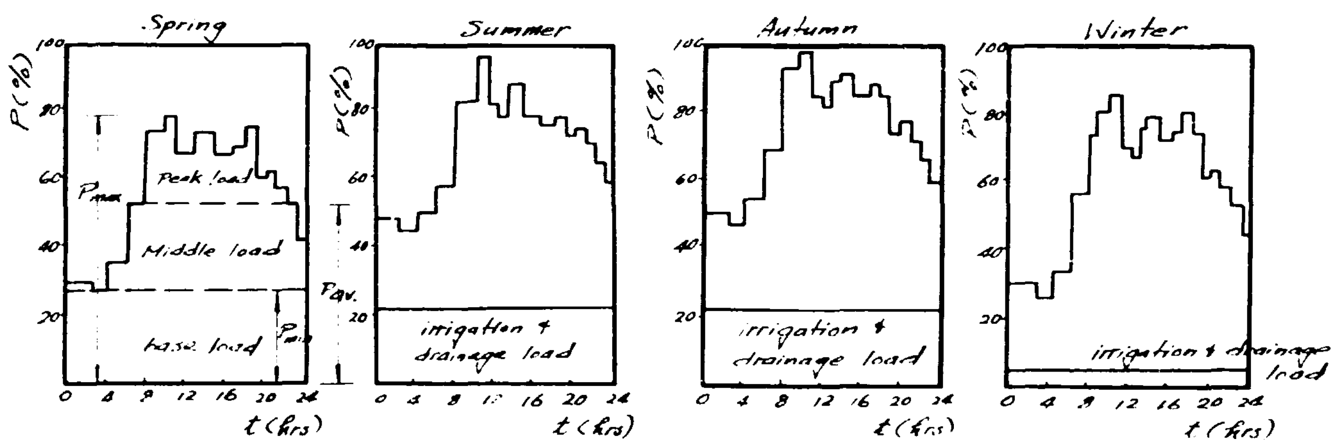


Fig. 4-3 Typical daily load diagram

There are three characteristic values (Pmax, Pav and Pmin) in the daily load diagram. Pmax indicates the maximum load in a day. In order to meet the power supply, the total installation capacity of the hydro plants must be larger than this value. Pav is the average load in a day: 24 x Pav is the daily power supply. Pmin is called the base load. Using these three characteristic values, the daily load diagram can be divided into three parts. Peak load (the load with large fluctuations) is above the Pav part. The middle load is between the peak and base load.

2. Annual load diagram:

The annual load diagram is used to express the load variations within a year; usually taking the load as the ordinate and time (month or day) as the abscissa.

If the agricultural power supply is large in this grid, due to its strong seasonal property, the peak load will not occur during the dry season. For example, if a hydro plant is designed mainly to supply power for pumping drainage, there will be no load demand in the dry season. Therefore, it is not important to determine the percent chance of discharge in the dry season, but it is very necessary to study the hydrologic characteristics in the drainage season, in accordance with the load demands of pumping drainage to determine the firm power and maximum working capacity of the hydro plant.

Usually, two typical daily load diagrams for both winter and summer are provided according to the year of the design load level. As for rural MHG, it is not necessary to set out the load diagram, only the load characteristics of the power supply will be taken into consideration.

B. Run-of-river hydro plant

1. Determination of firm power:

When hydrological data is available: First, the duration curve of the daily average discharge should be plotted. According to the design percent chance of the hydro plant, the firm discharge Q_G on this duration curve should be determined.

When hydrological data is not available: Determine the firm discharge corresponding to the design percent chance using the abovementioned method described in part III of this chapter.

The firm power of the hydro plant is formulated as:

$$N_G = AQ_GH \qquad (kW) \qquad (24)$$

where N_G = firm power

Q_G = firm discharge

2. Mean annual power output:

Due to the variation of power outputs in different hydrological years, the mean annual power output is adopted as an index to express the yield of power energy of a hydro power plant.

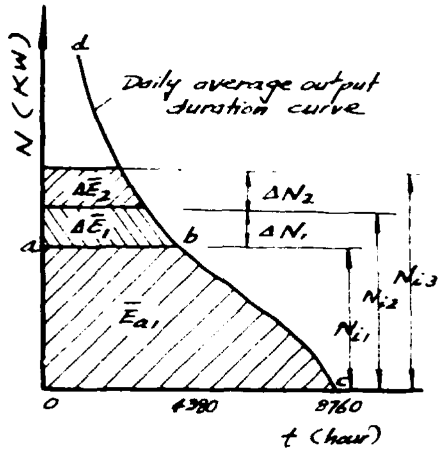


Fig. 4-4 Daily average output duration curve

Figure 4-4 shows the duration curve of the daily output in the medium year, taking Nil as the installed capacity of the said hydro plant. Ni and the duration curve intercept at point b. In Figure 4-4 the b d on the curve indicates that the natural flow output is larger than Ni . The output of the hydro plant, however, is limited by Ni . If the b c on the curve indicates that the natural flow output is less than Nil, then the output of the hydro plant is operated according to bc. Oabc is the working condition within a year; area oabc is the annual power output of a medium year ($\bar{E}$al in Figure 4-4). It is obvious that the mean annual output varies with the installed capacity of a hydro plant. When the installed capacity is increased from Ni to Ni2 (Ni2 = Ni +ΔN), the annual power output is increased from $\bar{E}$a to $\bar{E}$a +$\Delta\bar{E}$. In a normal case, the rate of $\overline{\Delta E}$ will be not sensitive when the installed capacity is too large, i.e. $\Delta N_1 = \Delta N_2$, $\Delta\bar{E}_2 < \Delta\bar{E}_1$. Several alternatives are proposed with different installed capacity to calculate their mean annual output and then to plot the Ni - $\bar{E}$a curve. The designed mean annual output will be checked from this curve when the installed capacity of the hydro plant has been selected.

3. Determining the installed capacity:

For a run-of-river hydro plant, the capacity is composed of the following:

a. Maximum working capacity: maximum working capacity is installed to meet the maximum load of the consumers. Usually, the maximum working capacity will not exceed the firm power.

$$N_W = N_G \qquad (kW) \qquad 25)$$

N_W = maximum working capacity
N_G = firm power

b. Spare capacity: there is no spare storage in the run-of-river hydro plant. It has no ability to undertake the emergency spare or load spare capacity in the grid.

The repair work of the units in a hydro plant can be done in the dry season or low load period. If the seasonal capacity is standstill in the dry season, his capacity can be used for inspection spare. If irrigation is the main function of a hydro plant, repairs can be planned for the non-irrigation period. If there are still difficulties, additional spare capacity for repair must be considered.

c. Seasonal capacity: the maximum working capacity of a run-of-river hydro plant is determined according to the firm discharge. In order to fully utilize the water energy in the high water season, some seasonal capacity may be installed when the following conditions are provided:

- there is a thermal power plant in the grid so that the seasonal power output in the high water period can save the fuel of the thermal power plant;
- there are seasonal power consumers inside the range of the power supply; aside from electrical pumping, also seasonal processing. If there are large consumers such as electrical furnaces for iron, aluminium and fertilizer,

calcium carbide, etc., the benefit of seasonal energy may be fully utilized.

- Integration of this plant into the big grid: seasonal power energy can be transmitted to the big grid.
- Annual regulating reservoir in the grid: during the generating of seasonal power by the run-of-river hydro plant, the hydro plant with an annual regulating reservoir will impound the water in the reservoir. This means that the water and the power are mutually compensated for.

There are three approaches for determining the seasonal capacity:

(i) Annual operating hours for the additional capacity:

In order to utilize the seasonal power energy, the seasonal capacity must be installed. The capital cost, overhead expenses, etc. will, however, increase. The rate of increase of the seasonal output will be reduced when installation is high. Generally, Δhc is used as an index for reference to verify the viability of the increment for the seasonal capacity.

$$\Delta h_c = \frac{\Delta E}{\Delta N} \geqslant h_s \qquad \text{(hrs)} \qquad 26)$$

where ΔN = an increment of installed capacity on the basis of a certain installed capacity (kW)

ΔE = an increment of annual power output corresponding to ΔN

Δh_c = the annual operating hours of the additional capacity according to the duration curve of the natural flow daily output (hrs)

Δh_s = the adopted annual operating hours of the additional capacity specified by the relevant department

(ii) The return years of the increment investment:

Examine the viability of the seasonal capacity by the annual benefit of the seasonal power energy. It is reasonable if the return is within 3-5 years.

(iii) The annual operating hours for seasonal capacity:

It is shown by the following formula:

$$h_c = \frac{\bar{E}_s}{N_s} \geqslant h_s \qquad \text{(hrs)} \qquad 27)$$

where $\bar{E}_s$ = seasonal energy
N_s = seasonal installed capacity
h_c = computed annual operating hours of seasonal capacity
h_s = specified value of the annual operating hours for seasonal capacity which is related to the regional energy and economical conditions and especially to the consumers of seasonal energy. In some regions in China, h_s = 1,800-2,500 hours are recommended ($2\frac{1}{2}$-3 months)

For those rural MHG or hydro plants with a rather large capacity but with deficient economic and load data, the following simplified methods are proposed for selecting the installed capacity:

a. Installed capacity is a multiple of the firm power:

The firm power of the hydro plant is first calculated and then an analysis is made of the composition of grid, load characteristics, water resources and multiple-purpose utilization, to determine the installed capacity as a multiple of the firm power

$$N_i = C\, N_G \qquad 28)$$

where C = ratio of N_i to N_G;
N_i = installed capacity;
N_G = firm power.

Table 4-9 shows the empirical statistical data of C in several regions for reference.

Table 4-9 Table of Value C (installed capacity/firm power)

The character of hydro plant			C
Rural MHG (< 500KW) operating independently			1.5-3.5
With high percentage of hydro power in the grid, and with regulating storage in the hydro plant	For power generation only		2.0-3.5
With high percentage of hydro power in the grid, and with regulating storage in the hydro plant	Mainly for power generation and secondarily for irrigation		2.5-4.0
With high percentage of hydro power in the grid, and with regulating storage in the hydro plant	Mainly for irrigation	Ordinary facilities	3.0-5.0
With high percentage of hydro power in the grid, and with regulating storage in the hydro plant	Mainly for irrigation	Good facilities	2.5-4.0
With low percentage hydro power in the grid	For power generation only		2.5-4.5
With low percentage hydro power in the grid	Mainly for power generation and secondarily for irrigation		3.0-4.5
With low percentage hydro power in the grid	Mainly for irrigation	Ordinary facilities	3.5-5.5
With low percentage hydro power in the grid	Mainly for irrigation	Good facilities	3.0-4.5

b. Installed capacity is based on annual utilized hours:

The mean annual power energy E_a divided by the total installed capacity N_i of the hydro plant is the annual utilization hours h_a of this hydro plant. Its formula is:

$$h_a = \frac{E_a}{N_i} \qquad 29)$$

h_a is equivalent to the annual operation hours under full load and indicates the extent of utilization of mechanical and electrical equipment.

Table 4-10 shows empirical statistical values of the design annual utilization hours used in some regions.

Table 4-10 Design annual utilization hours of the installed capacity (hr)

Character of hydro plant		ha (designed)		
		Kind of regulation		
		Run-of-river	Daily storage	Yearly storage
Rural hydro plant (< 500 KW)	Agricultural and sideline production and illumination	> 4,500	> 3,500	
	Small industry and illumination of the town	> 4,500	> 3,500	
Mainly for pumping and secondarily for other uses		5,000±	4,500±	2.500 - 4,000
With high percentage of hydro power in the grid	Rather large industrial users in continuous production	5,000 - 6,000	5,000 - 6,000	4,000 - 5,000
	Common consumer	5,000 - 6,000	4,000 - 5,000	3,500 - 4,000
With low percentage of hydropower in the grid		4,500 - 5,500	3,500 - 4,500	3,000 - 4,000

It must be mentioned that the above methods a and b have their adaptability. Adoption of these methods will depend upon concrete conditions. When Table 4-9 and Table 4-10 are used, the following points must be taken into consideration:

- In regions rich in water resources, the high value of the design annual utilization hours h_a and low value C (ratio between installed capacity and firm power) will be selected in comparison to the regions where water resources are poor.

- In the continental climate area where the flow distribution of creeks and/or rivers is uneven within a year, C may be used as the high value and h_a used as the low one.

- If there are several hydro plants (with large regulating storage) in the grid, the new designed hydro plant will undertake a rather uniform load. Therefore, high h_a value and low C value is proposed, and vice versa.

- In the grid, when there is large variation in the daily load diagram, if the base load and partial middle load are undertaken by the thermal plant and run-off hydro plant, the low h_a and high C value will be selected for the new designed hydro plant, and vice versa.

- In hydro plants which utilize the irrigation water (regulated by reservoir) as its water source, the firm power of this type of hydro plant will be rather low and the seasonal energy rather high. In this case, high C value will be taken.

- The h_a and C of the non-regulating hydro plant depend upon the extent of utilization of seasonal energy.

- If there is spare capacity in this designed hydro plant, low h_a and high C value are recommended.

c. Installed capacity is fitted by the standardized turbine-generator unit.

No matter what method is adopted to determine the installed capacity, manufacture and supply of the mechanical and electrical equipment must be taken into consideration. In some cases, the installation of a hydro plant is mainly determined by the availability of the units. If a standardized turbine-generator unit is selected, purchase is easy.

As for the number of units in a hydro plant, usually $Ni < 1{,}000$ kW, 2 units is preferable; when $Ni = 1{,}000$–$3{,}000$ kW, 2–3 units are selected. The number of units in most MHG plants is less than 4.

The capacity of each unit usually is equal or near to the firm power. If no suitable unit can be offered, the capacity of each unit should be at least 1.6 times of the firm power.

On the whole, there are three simplified approaches for determining the installed capacity of a hydro plant. The first approach is to take firm power as a prime factor. After calculating the maximum working capacity, selection of the installed capacity is worked out by analysis or is a multiple of the firm power. The second way is selecting the annual utilization hours which is related to the regional power resources load character and regulating ability of the hydro plant. The third approach is fitted by standardized turbine-generator units. In the practical design works, in those rural MHG (installed capacity less than 500 kW), the water energy design will be taken as simple as possible to avoid complex calculations.

C. Daily regulating hydro plant

The daily regulating hydro plant provides a regulating storage with the capacity to redistribute the natural flow within one day. The computation of the firm power and mean annual power output of the daily regulating hydro plant is basically the same as with a run-of-river plant. Their differences are: the up-stream normal high water level of the run-of-river plant is a constant while the up-stream water level of the daily-regulating plant fluctuates between the normal high water level and the dead water level. The average water level is used to calculate the power energy.

As for the installed capacity of daily regulating MHG plants, due to the ability of redistributing the natural flow within one day, the 24 hour power production is equal to the energy produced by the natural inflow of the same day. Therefore, the maximum load may be larger than the daily average output and the installed maximum working capacity (to meet the maximum load demands) can be larger than the natural flow firm power.

The following two cases are used for illustration.

1. Concentrated power generation: Figure 4-5 shows a daily regulating hydro plant. Its generation is concentrated in h hours. In this case, the designed low water natural inflow is concentrated at h hours for power generation. The maximum discharge in the time concentration is

$$Q_{max} = \frac{Q_G \times 24 \times 3600}{h \times 3600} = \frac{24}{h} \cdot Q_G \qquad 30)$$

Hence, the maximum working capacity of the daily regulating hydro plant is

$$N_W = AQ_{max} \; H = A \cdot \frac{24}{h} \; Q_G H \qquad 31)$$

$$= \frac{24}{h} N_G \; (kW)$$

where N_W = working capacity

N_G = inflow firm power

Obviously, with the same design percent chance, the maximum working capacity of the daily regulating hydro plant is $\frac{24}{h}$ times that of the non-regulating hydro plant.

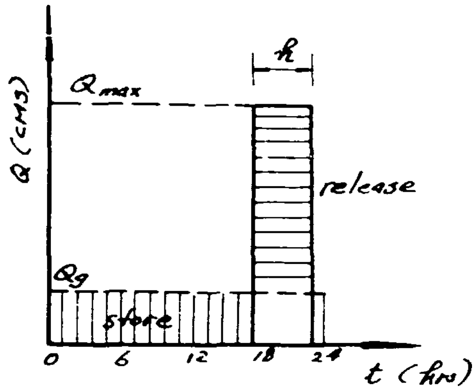


Fig 4-5 Daily regulation (a)

The vertical shadowed area in Figure 4-5 is the required daily regulation storage. The formula is

$$\bar{V}d = (1.10\text{-}1.15) \times Q_G(24-h) \times 3600 (m^3) \qquad (32)$$

where 1.10-1.15 is the safety co-efficient, considering insufficient and incorrect data, as well as computation error.

2. Interval power operation.

In considering the demands of both the power consumers and the water consumers, the water and power supply is divided into several time intervals according to the natural inflow. The first step is to determine the water and power supply of the time intervals other than the peak load period and to deduct them from the daily inflow volume. The remaining water is used for the peak load period. Therefore,

$$Q_{max} = \frac{Q_G \times 24 \times 3600 - (\bar{V}_1 + \bar{V}_2)}{h \times 3600} \text{ (CMS)} \qquad 33)$$

The maximum working capacity

$$N_W = A \cdot Q_{max} \quad H = A\left(\frac{Q_G \times 24 \times 3600 - (V_1 + V_2)}{h \times 3600}\right) \times H \qquad 34)$$

where H = head difference between the average up-stream water level and the downstream water level (varies with the corresponding discharge).

The required daily regulation storage is shown in the shadowed area of Figure 4-6.

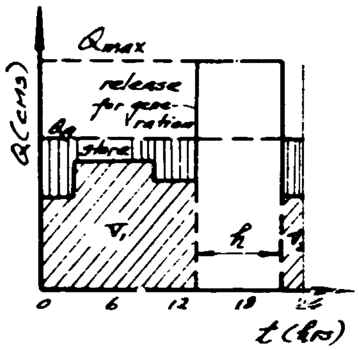


Fig 4-6 Daily regulation (b)

As for spare capacity and seasonal capacity, there is no substantial difference between the run-of-river plant and the daily regulating plant. The only different point is that: if there is a daily regulated hydro plant with rather large capacity, short distance to the load center and short water conduit, it is possible to consider this hydro plant for undertaking the extra load for frequency modulation.

When a major hydro plant of prefectural or county level is under planning, it is better to work out the typical design daily load curve of the grid, and then, by means of the daily energy mass curve, to determine the maximum working capacity of this hydro plant. The first step is to calculate the daily firm output E_G ($E_G = 24\ N_G$) according to the firm power N_G. The second step is to consider the load of the grid and the characteristics of the main power stations of the grid as well and then to decide the working position (the load to be taken by this hydro plant). Finally, by the balance of daily firm output on the daily load curve, the maximum working capacity would be determined.

D. Annual regulating hydro plant

Annual regulating storage must be provided for an annual regulating hydro plant. The natural inflow will be re-allocated within the year in order to meet the demands for power and other purposes.

The basic principle of flow regulation is the water balance at any time interval. The difference between outflow and inflow is the variation of storage of the reservoir at that interval. It is shown in the following formula

$$\Delta \overline{W}_N - \Delta \overline{W}_c - \Delta \overline{W}_\ell = \pm \Delta \overline{W} \quad (m^3) \qquad 35)$$

where $\Delta \overline{W}_N$ = the natural inflow emptied into the reservoir in certain time intervals (m^3)

$\Delta \overline{W}_c$ = the outflow of the reservoir in the same period for water supply to the relevant department (m^3) (including waste water in the flood season)

$\Delta \overline{W}_\ell$ = water losses in the reservoir in the same period (m^3)

$\pm \Delta \overline{W}$ = the variation of storage in the same period.

In computing storage regulation, as both the natural inflow and the water consumption are given, it is easy to find out the starting and ending time of the water supply by the reservoir and thus, the dry water season can be determined. By means of the water balance formula, computation is carried on in time intervals. Thus, the water deficiency of each time interval can be calculated. The summation of water deficiency in the total dry season is the total volume of water which will be supplied by the reservoir, i.e. the required volume of storage regulation.

As for the water energy design of the reservoir which main function is power generation or irrigation (power and irrigation are both independent and dependent) its design has been recommended in various literature and will not be repeated in this book.

V. Type of MHG and case study

The capacity of hydro generation is proportional to the water head and flow. Therefore, in order to obtain hydro power, the head difference between the upstream and downstream of the hydro plant must be determined.

According to the form of head concentration, the hydro plant is classified into three types.

A. "Dam type" plant - the head obtained by the dam

The construction of a dam or movable barrage impounds the flow of the river and forms a reservoir as well as raises the upstream water level. Therefore, a head difference between the upstream reservoir level and the downstream river level exists. In a so-called "Dam type" hydro plant, the reservoir water is diverted to the hydro plant by means of a tunnel or pipe and water turbine generator units generate the power. However, according to the layout of the hydro power houses, these hydro plants can be sub-classified into two types; hydro power houses acting as water retaining structures and hydro power houses located at the downstream side of the dam.

1. Hydro power houses acting as water-retaining structures:

Figures 4-7 and 4-8 show the Ganqi MHG plant, Hunan Province, a hydro power plant erected in the river bed. The stability of the structure is maintained by the combined weight of both the dam and the power house. The drainage area is 1,170 km^2, which is 96% of the Mi river basin. It is a multi-purpose water conservancy project for irrigation, power generation, and navigation. The maximum height of the dam is 20.5m and the length of the dam axis is 454 m. The hydraulic structure is composed of a pumping station, a hydro power station, a navigation lock, log passers and the dam. Ten DJ 510-LH-180 water turbine generator sets were installed in the power house with a total capacity of 12,500 kW. The design head is 10.5 m and design discharge is 160 CMS. Mean annual output is 76.8 million kWh. This MHG plant was integrated into the southern Hunan grid.

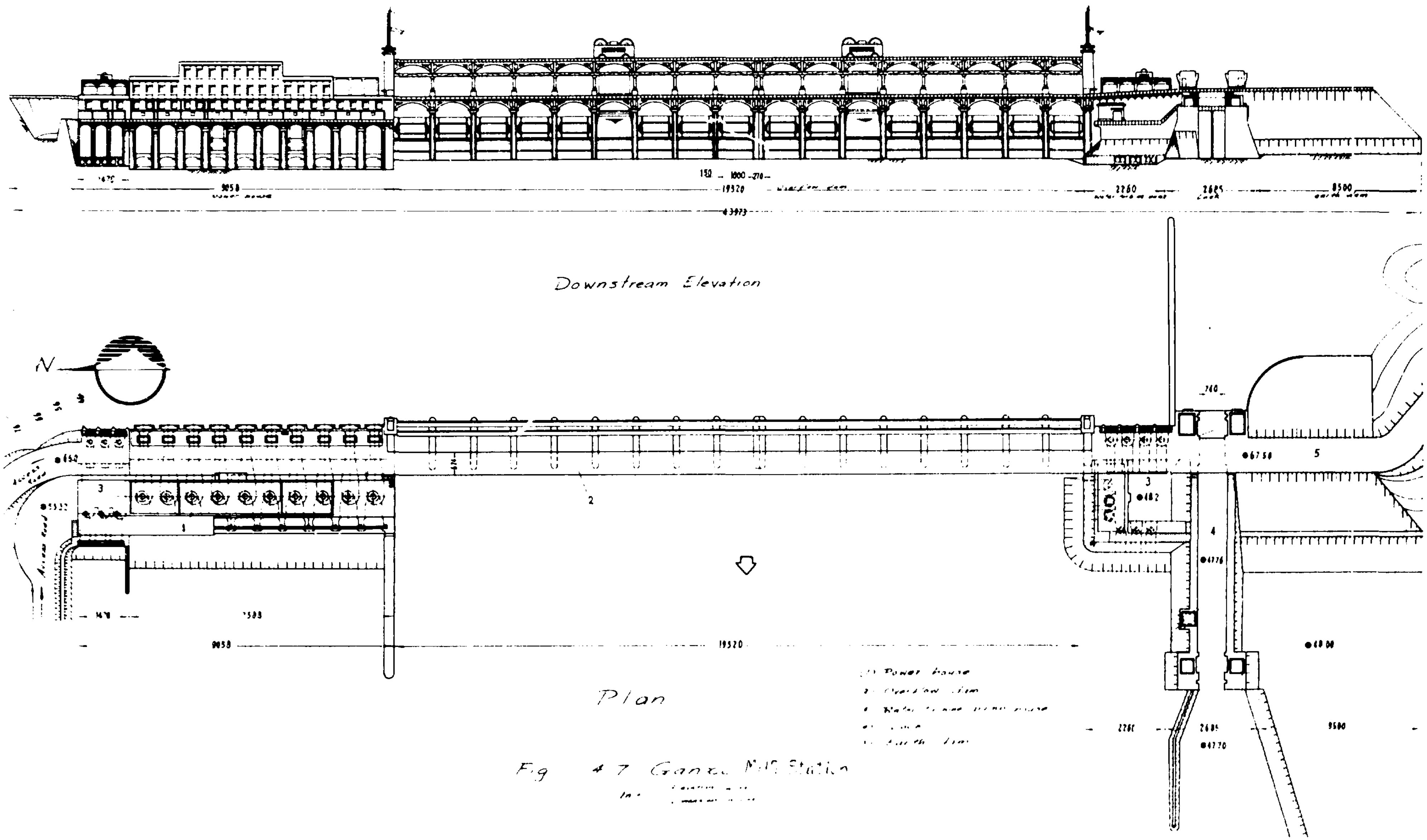


Fig 4 7 Ganzu N.º Station

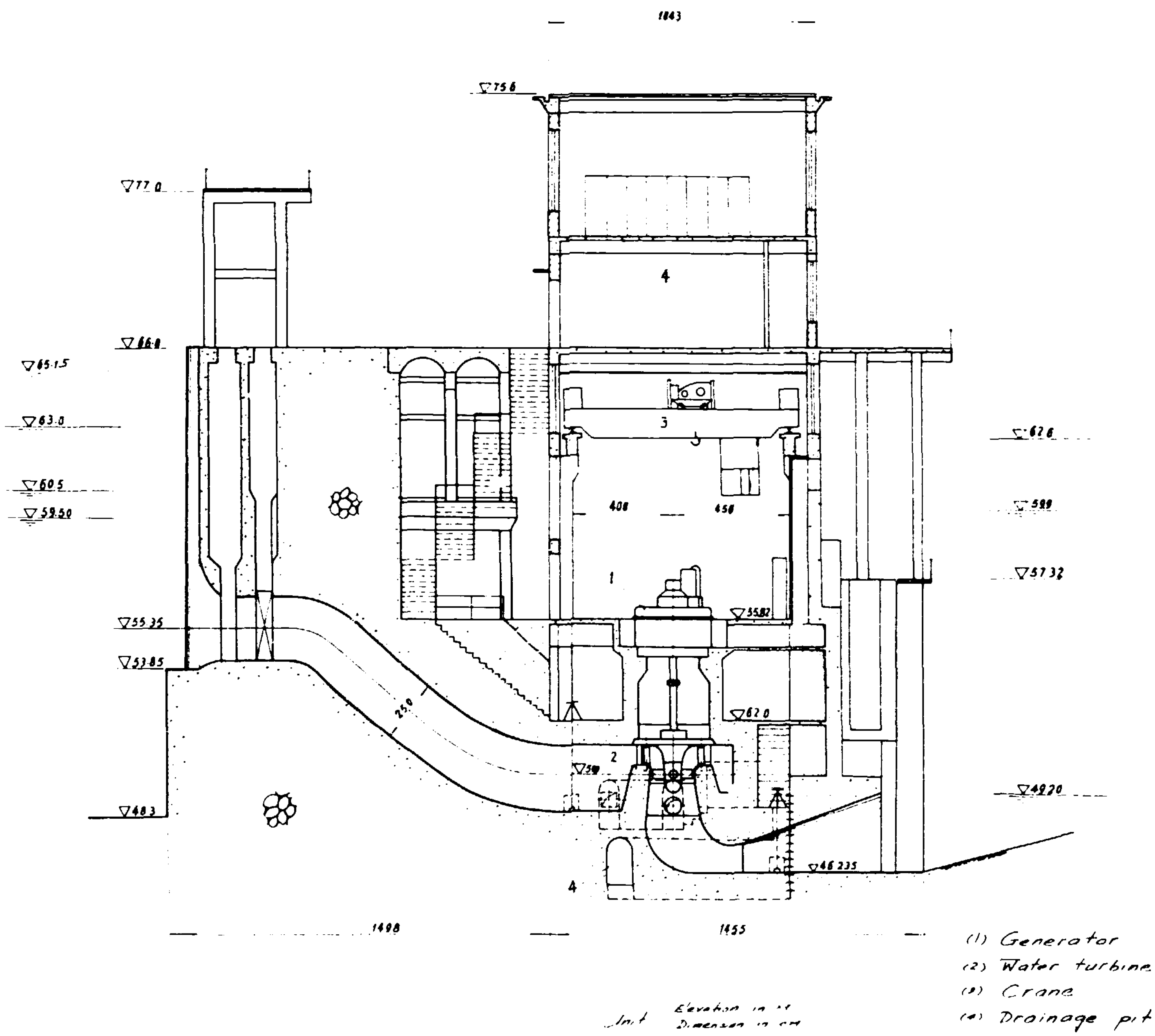


Fig 4-8 Ganzi MHG Station

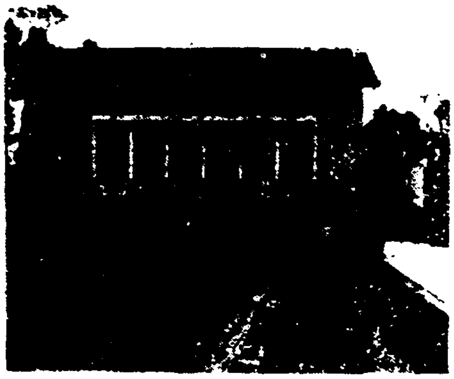


Fig 4-9 People's hydroplant

Figure 4-9 shows the small hydro power house erected on the main irrigation canal in the Tukiangyen Irrigation Area, Sichuan Province. H=7m, Q=16 CMS, 2x320 kW and 1x125 kW turbine generator units are installed. Fifty-five percent of the power generation supplied is used for agricultural purposes and 45% for industrial and family consumption in the nearby town. About 300,000 Mu of farmland is irrigated by the tailwater.

2. Hydro power houses located at the downstream side of the dam:

Figures 4-10, 4-11 and 4-12 show the Yanwotan hydro plant, Hunan Province. The power house is located on the right bank of the downstream river bend. The water is diverted by a ⌀ 3.5 m tunnel to the power house. The drainage area of the dam site is 457 km^2. The mean annual run-off volume is 407 million m^3 and the storage capacity is 87.6 million m^3 at the normal high water level. Thus, the reservoir has the capacity for yearly regulation.

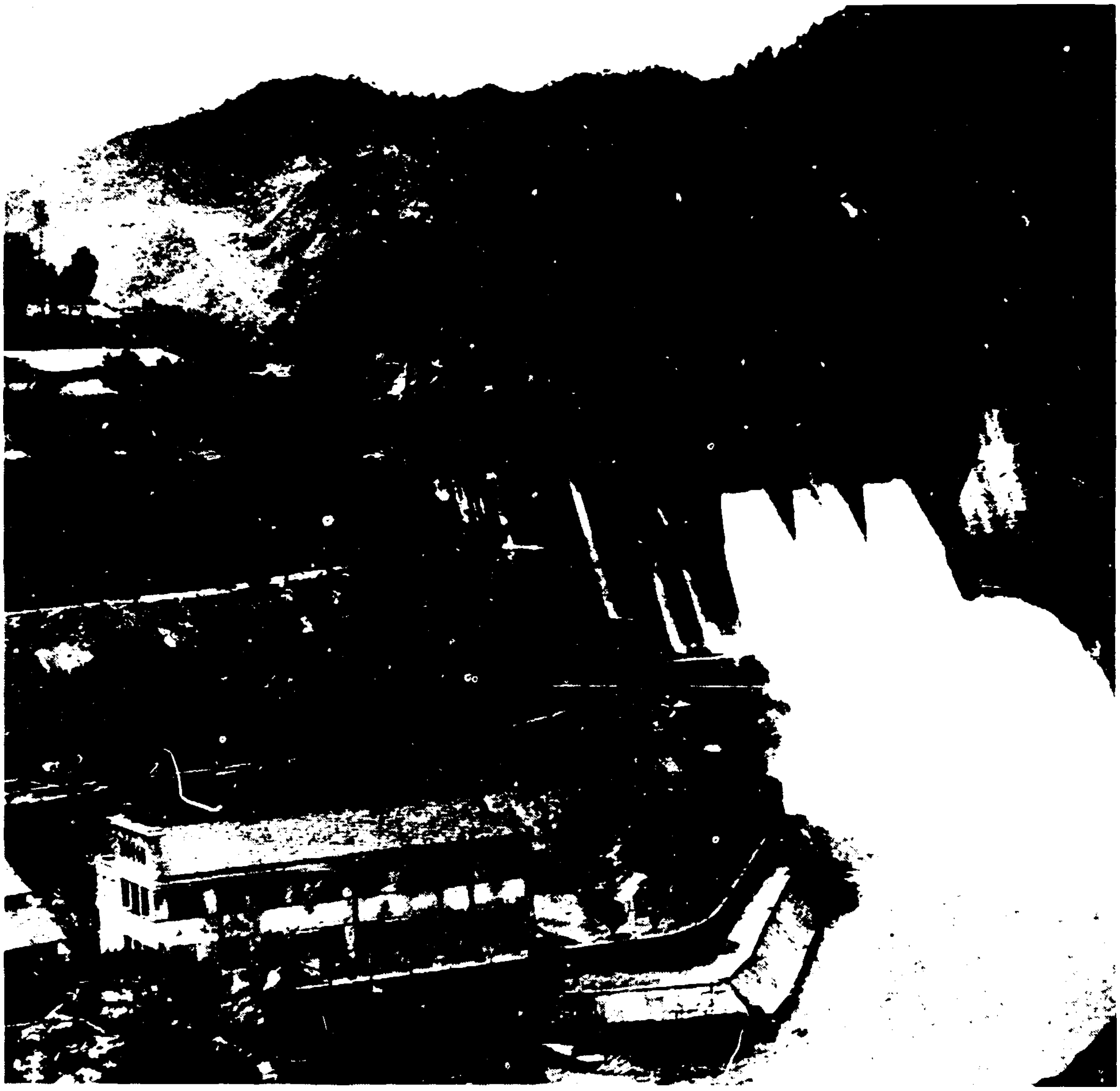
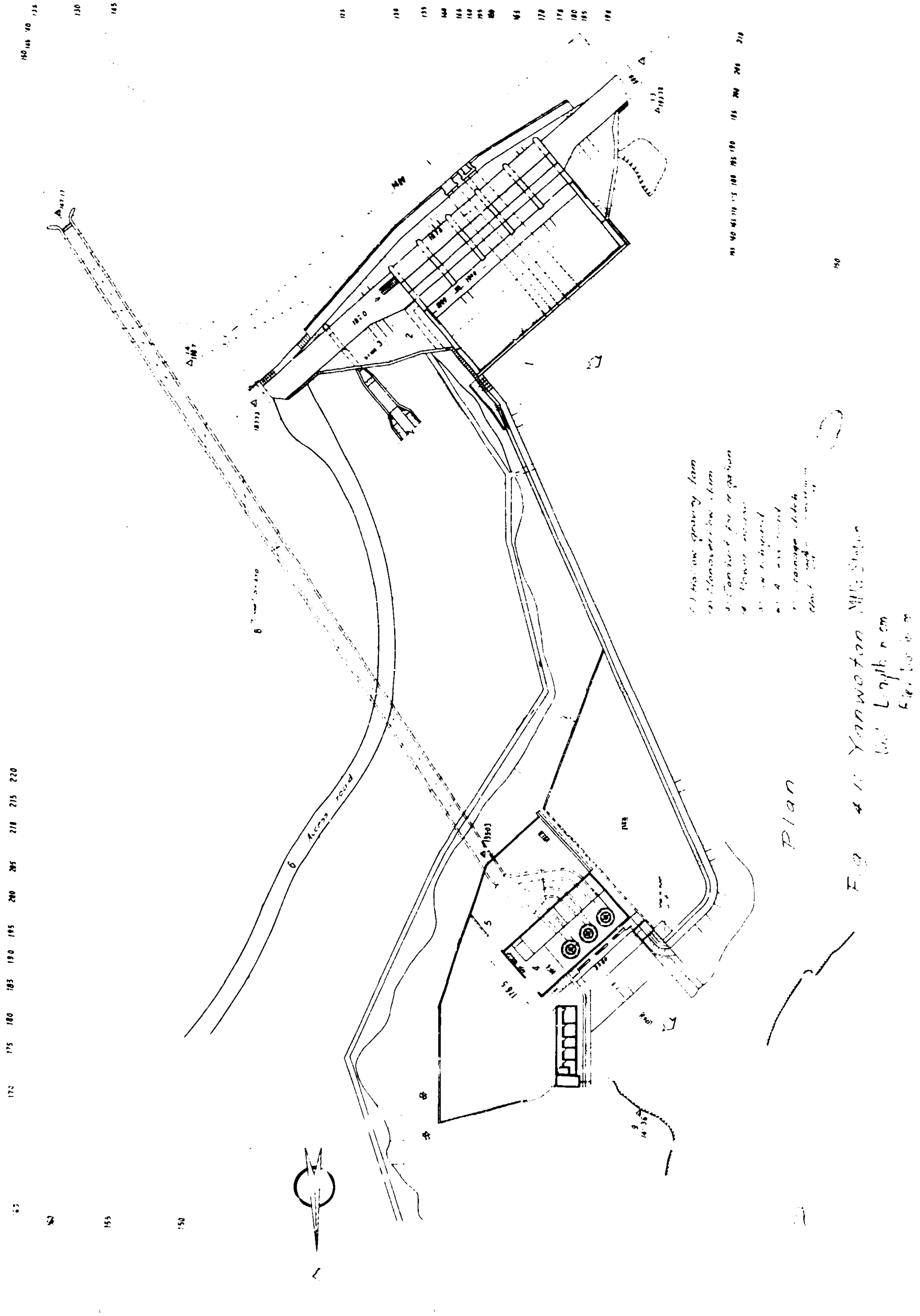
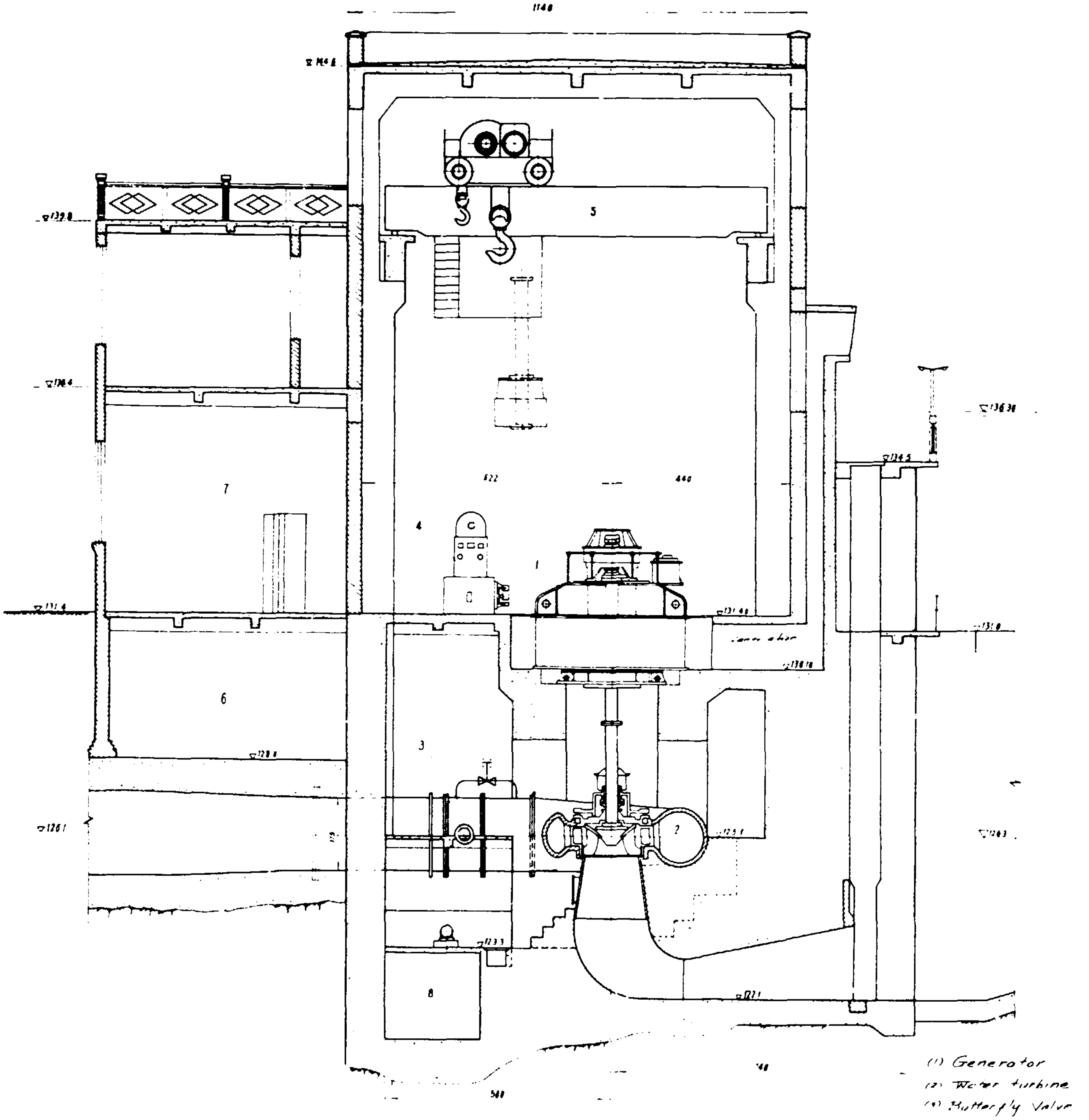


Fig. 4-10 Yanwotan MHG Station


Access road
Plan



Power house

Fig 4.12 Yanwotan MHG Station (2)

This project is mainly comprised of an overflow masor. hollow gravity dam, power house and tunnel. The crest length along the dam axis is 140 m and the maximum dam height is 66 m. There are two HL 230-LJ-134 units, 3,000 kW each, and one HL 123-LJ-140 unit installed in the power house with a total installed capacity of 9,200 kW. The design flow of the turbines are 12 and 12.6 CSM, respectively, and the maximum working head is 50 m. The annual output of this hydro plant is 33.9 million kWh. In consideration of the load characteristic of the county-run industry and full utilization of seasonal power, this hydro plant was put into parallel operation with a 3,750 kW county-run small thermal plant. During the highwater season, the hydro plant plays the main role while in the low water period, the thermal plant is used to supplement the power supply. This kind of county-run network including both a hydro and a thermal plant is quite reasonable. The Yanwotan hydro plant not only supplies the power to the county proper but also supplies the reactive power to the Central Hunan grid, thus improving the quality of power.

Figure 4-13 shows the Yunxiao hydro plant, Guangdong Province. The power house is located at the downstream side of the non-overflow rubble masonry gravity dam. The working head of this hydro plant is 31 m and the total installation is 2x 500 kW. The tailrace is used for irrigation.

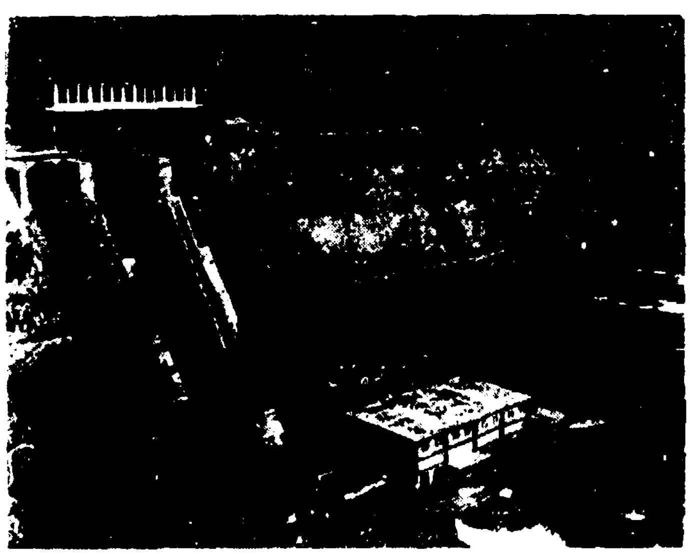


Fig. 4-13 Yunxiao MHG station

Figure 4-14 and 4-15 show the Mei stream stage I hydro plant. The height of the earth dam is 47 m with a storage capacity of 65.5 million m^3. The installed capacity of the power plant is 4x1,250 kW. The power plant was put into commission in 1962 and completed in 1967. The tailrace of the stage I plant can be utilized for the irrigation of 100 thousand farmlands and also used as the water source for the downstream cascade power plants.

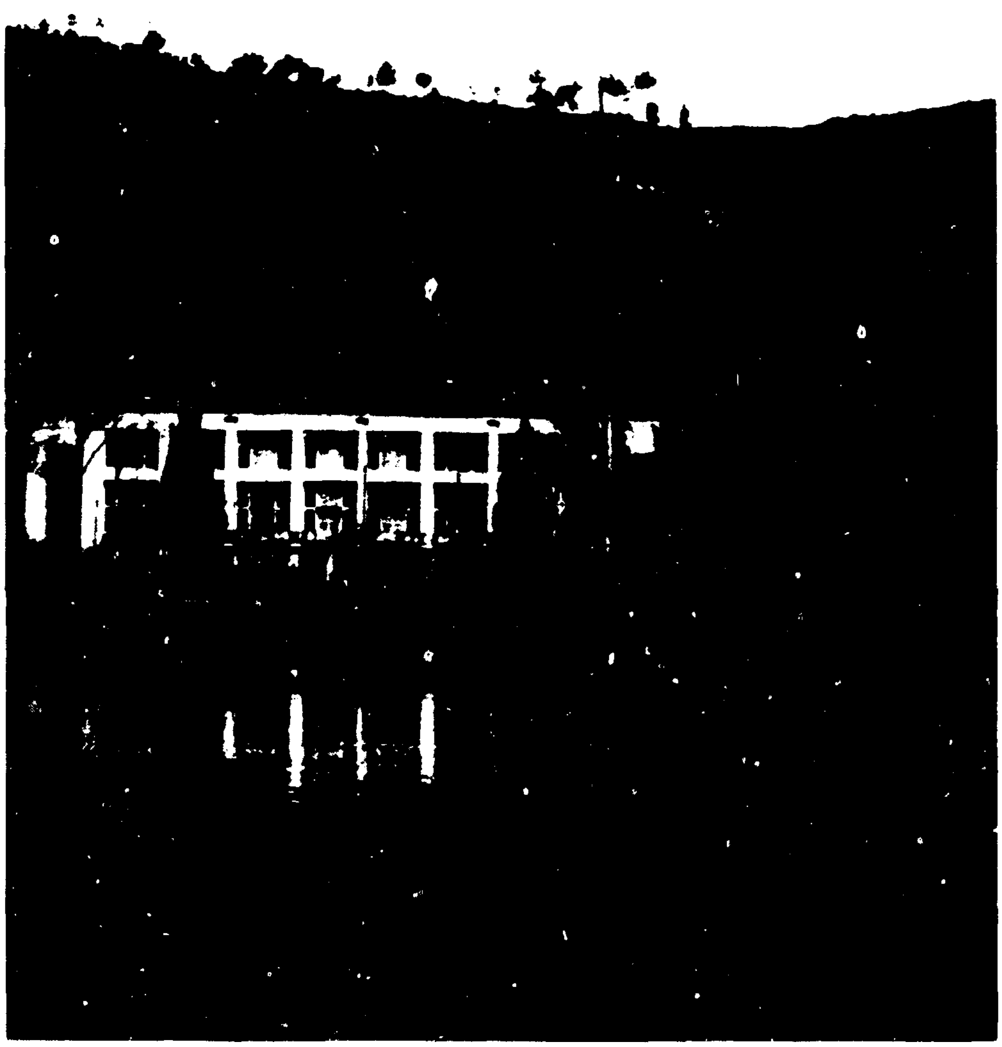


Fig. 4-14 Meixi I MHG station

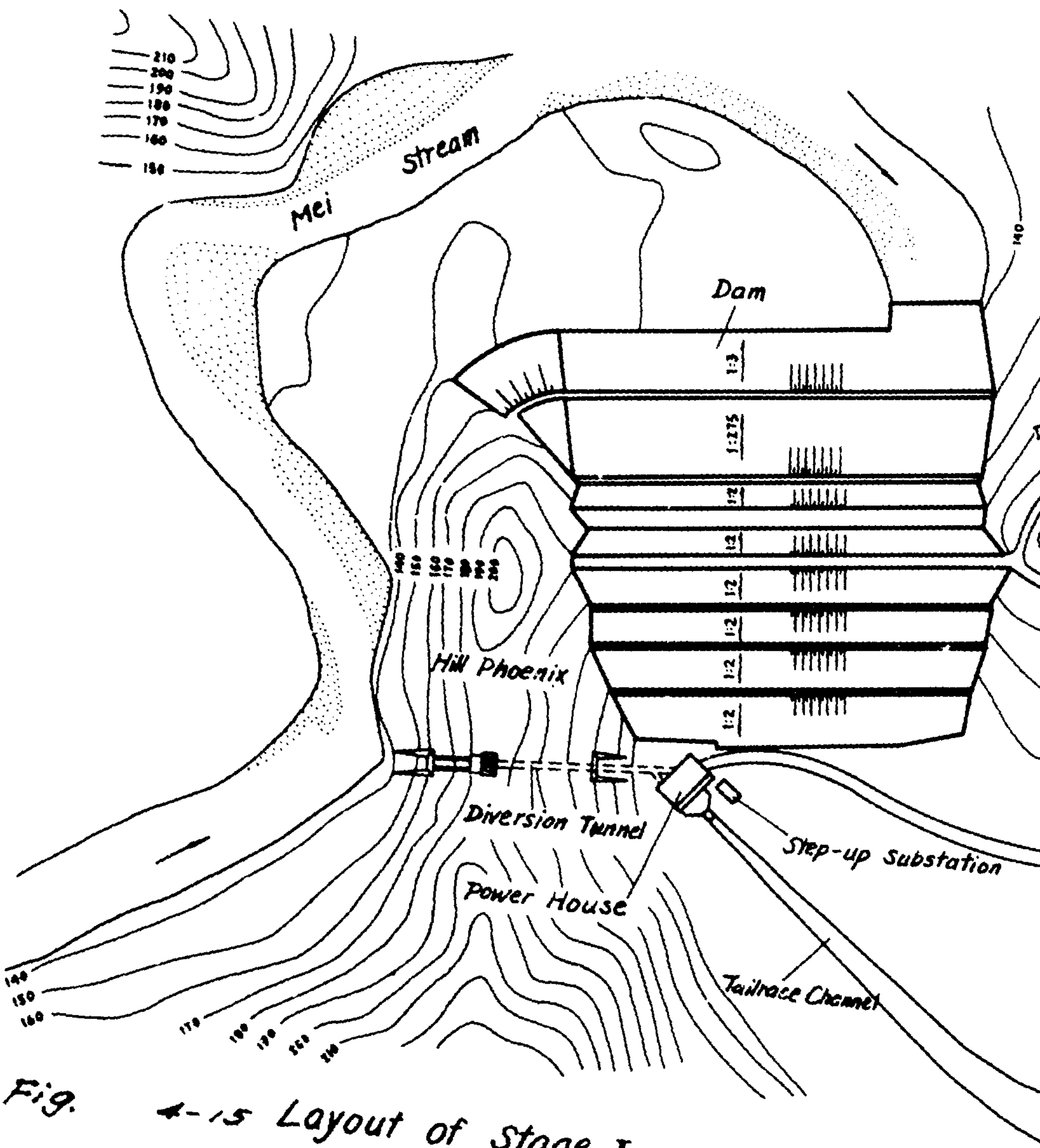
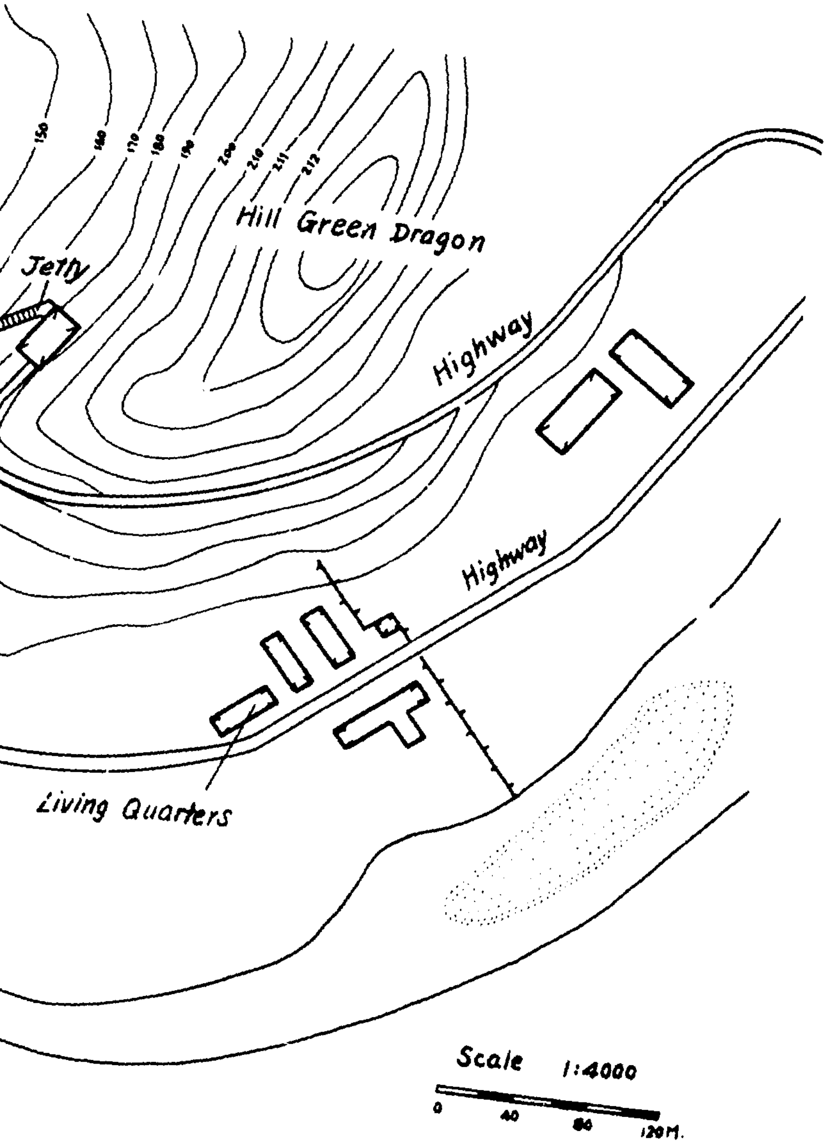


Fig. 4-15 Layout of Stage I
Meizi MHG Station


150
160
170
180
190
200
210
211
212
Hill Green Dragon
Jetty
Highway
Highway
Living Quarters
Scale 1:4000
0 40 80 120M.

In general, the special features of the "Dam type" hydro plant are as follows:

- Erects dam and movable barrage on the river to form the reservoir and to concentrate the head. The reservoir has a comprehensive profit. In the case of the MHG plant, the reservoir usually is used multi-purposely for irrigation, flood retention and navigation.
- The power house is located rather near the dam. The water conduit is rather short, therefore, hydro plants of this kind are adaptable to rather large design flow.
- If a high dam is constructed for water head concentration, then the geological conditions, the technology of dam construction and reinbursement of the reservoir must be taken into consideration.

B. "Diversion type" plant - the head obtained by the counduit structure.

The head of this type of hydro plant is formed mainly by a conduit structure. A low weir or sluice gate is erected on the river to divert the river flow to the conduit, such as a canal, tunnel, penstock, etc., and finally to the power house. This type of hydro plant is adaptable to the upper and middle reach of the river where the upstream land is not possible to impound and the downstream reach contains some rapids, falls or elbows.

Figure 4-16 shows the Double Dragons hydro plant. A 2,600 m canal was built to divert three water sources from the Double Dragon spring, the Lotien reservoir, and the Nine Dragon reservoir. The canal is connected by a ϕ 0.45 m penstock, 407 m in length, to the power plant. The head of the hydro plant is 196 m. The installed capacity is 512 kW and the design flow is 0.6 CMS.

Fig. 4-16 Double Dragon MHG station

Figure 4-17 shows the Baizhangtan stage III hydro plant, Hubei Province. The length of the diversion canal is 2,800 m. The available head is 66.5 m. The design flow is 2.7 CMS. One 800 kW and 1-500 kW set (same turbine model HL 702-WJ-50) are installed in the power plant. The annual output of this power plant is 3 million kWh.

Fig 4-17 Baizhang tan MHG Station

Figure 4-18 shows the Qingtong hydro plant, Guangdong province. This plant is a backbone power station of the county with an installed capacity of 3x1,600 kW. The design discharge is 1.6 CMS for each unit. The length of conveyance structures including tunnels, pre-stressed inverted syphon pipes and flumes, is 23 km. The available head is 142 m. The penstock of this hydro plant is ∅ 0.8 m pre-stressed concrete pipes.

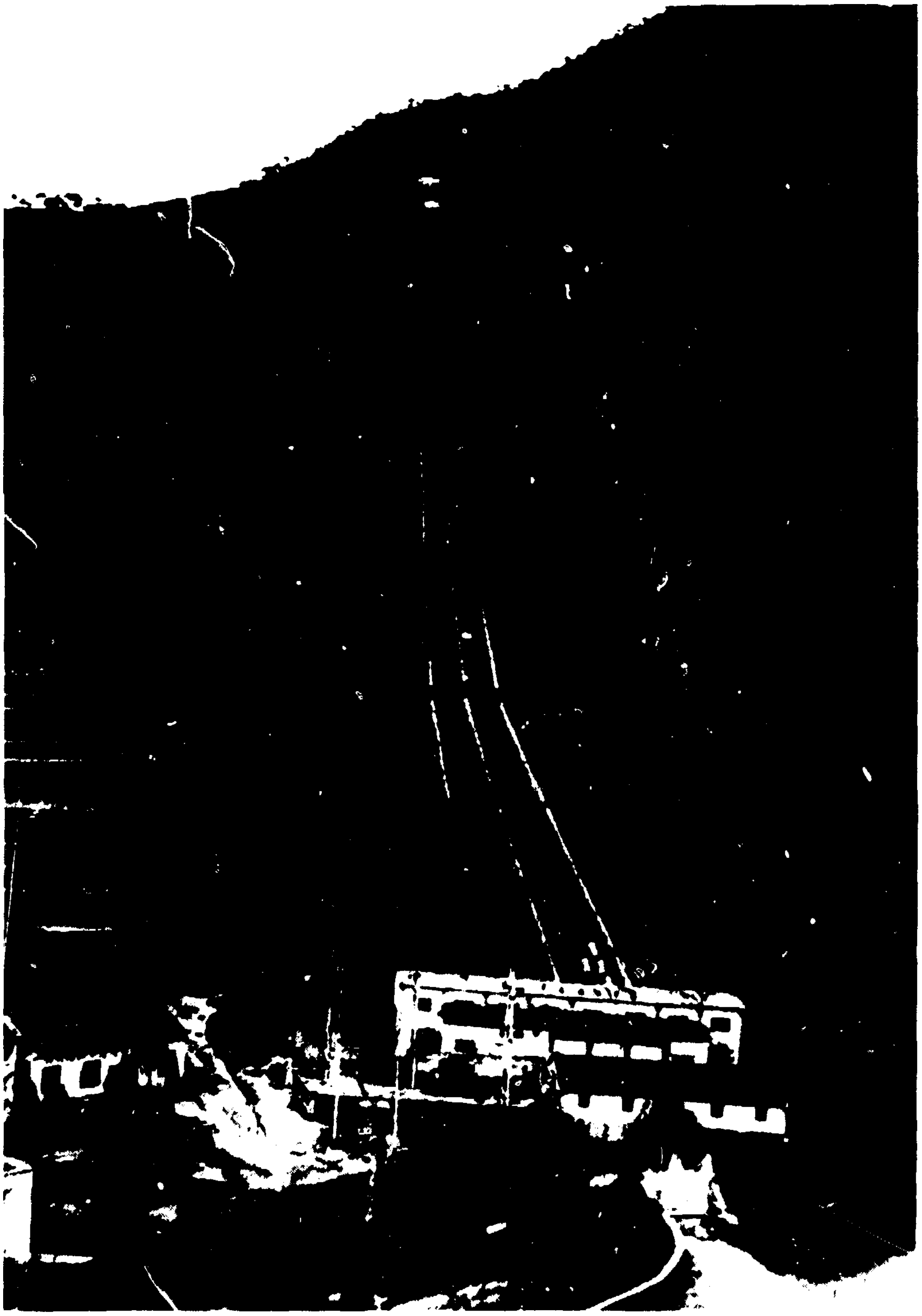
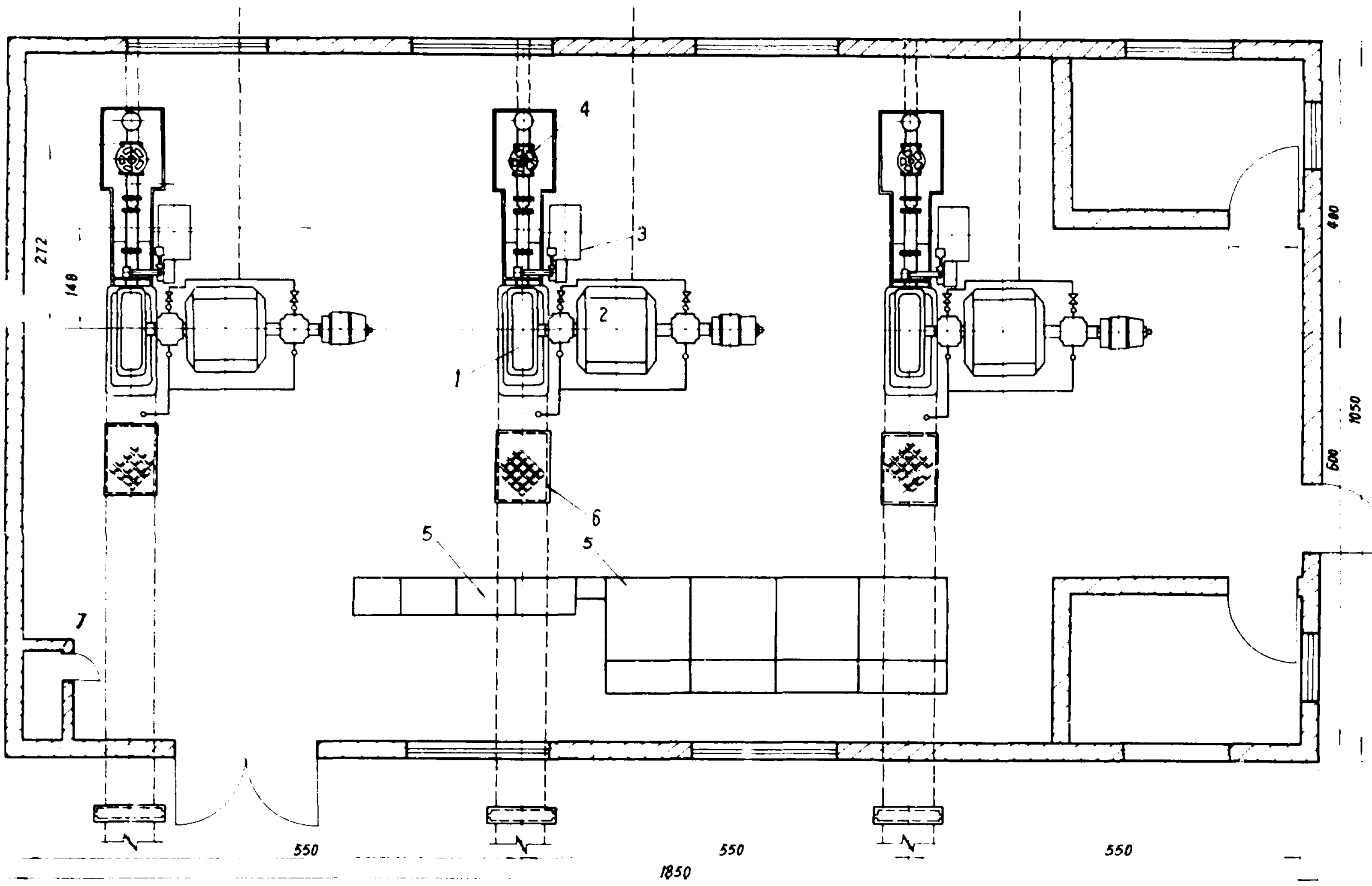


Fig 4-18 Qingtong MHG Station

There are also certain high head hydro plants with water heads more than 200 m in various provinces in China. For example, in the Huangtonjiang hydro plant, Guangdong Province, the water head is 218 m and the discharge is 1.5 CMS. The installed capacity is 3x800 kW. The penstocks are pre-stressed concrete pipes. In the Lantong hydro plant, Guangxi Zhuang Autonomous Region, the water head is about 430 m which is concentrated by a canal with a length of more than 2.8 km. The length of the penstock is 1,100 m and the design flow is 3 CMS. The total installed capacity is 3x3,200 kW.

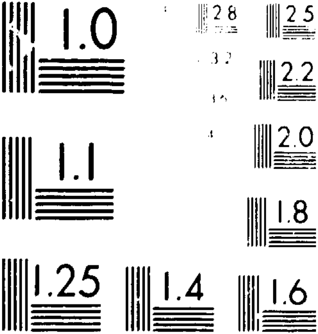
Figures 4-19 and 4-20 show the Chengshan hydro plant, Hunan Province. The design water head is 612 m, which is the highest among the MHG plants of the "diversion type" in China at present. The drainage area of the dam site is only 4.18 km^2 and the effective storage capacity of the reservoir is 2.5 million m^3. The length of the canal is 1,045 m and the length of the penstock (ϕ = 35 CM) is 1,446 m. There are 2 CD10-WJ-90/1 impulse water turbine generator units installed in the power house at present. Each unit capacity is 500 kW and the design flow is 0.12 CMS each. The mean annual output is 4.17 million kWh. From this, 69% is used for agricultural purposes and 31% for small industries and agro-sideline product processing.



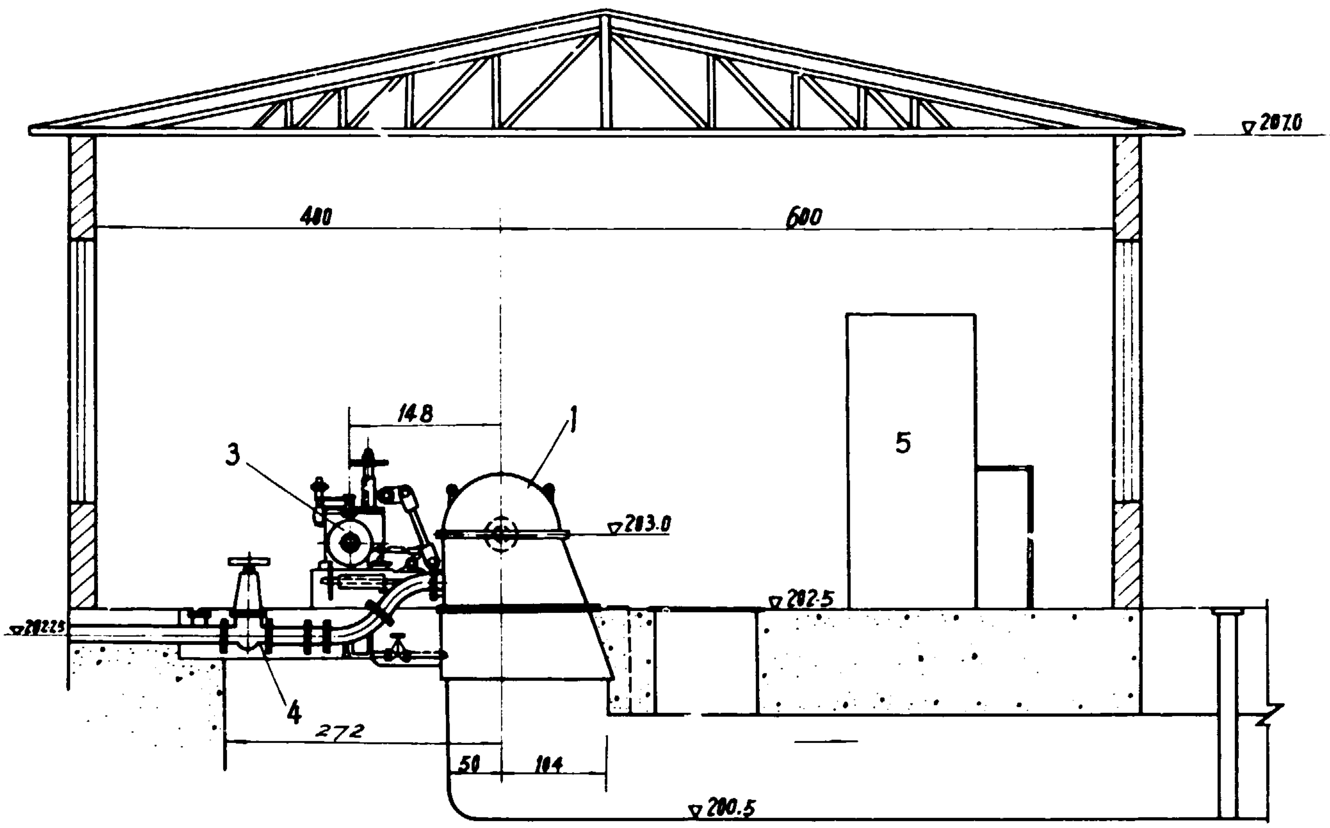
Plan

Fig 4-19 Chongshan MHG Station (1)

Unit: Elevation in M, Dimension in cm



1.0
2.8
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6



Cross Section   Unit: Elevation in M, Dimension in cm

Fig 4-20 Chongshan MHG Station (2)

Figure 4-21 shows a photo of the Qing Yuan MHG plant, Fujian Province. The length of the conveyance canal is 8 km. The head concentration is 46 m. The design flow of this plant is 2.6 CMS. Three 265 kW units are installed in this power house.

Fig. 4-21 Qing Yuan MHG Station

In general, special features of the "Diversion type" MHG plant are:

- In mountainous regions, if favourable topography is available, a big water head may be concentrated by conduit within a short distance. The low dam or sluice gate at the headwork of the canal intake causes the low reimbursement of reservoir impounding.
- No storage for regulation; the inflow from creeks between the dam and the hydro power house cannot be used for power generation.

C. "Composite type" plants: In some cases, the head of the hydro plant is obtained partially from the dam and partially from the counduit. This is the so-called 'composite type" plant. In mountainous areas, most of the "composite type" hydro plants serve both flood retention and irrigation, with the exception of a few hydro plants which are planned for power generation only. Figure 4-22 shows the Zaiqi hydro plant, Fujian Province. The hydro plant is located near the Wuyantou Fall. Upstream of the fall is a wide valley and a flat gradient which are both favourable for storage impounding, but downstream of the fall, the river has a steep gradient. This layout of this project is: At the upstream of the fall, an earth dam is constructed. The height of the dam is 17.2 m and the effective storage capacity is 3,000,000 m^3. The power house is located at the downstream of the fall. The conveyance structure is a 130 m long tunnel with bottom slope i=7.7% and a penstock 418 m in length. The total head of this "composite type" hydro station is 240 m. The design flow is 2.1 CMS and the total installation is 2x2,160 kW. The main purpose of this hydro plant is power generation. The tailwater may be utilized for irrigation and the flood attack may be reduced to some extent at the downstream.

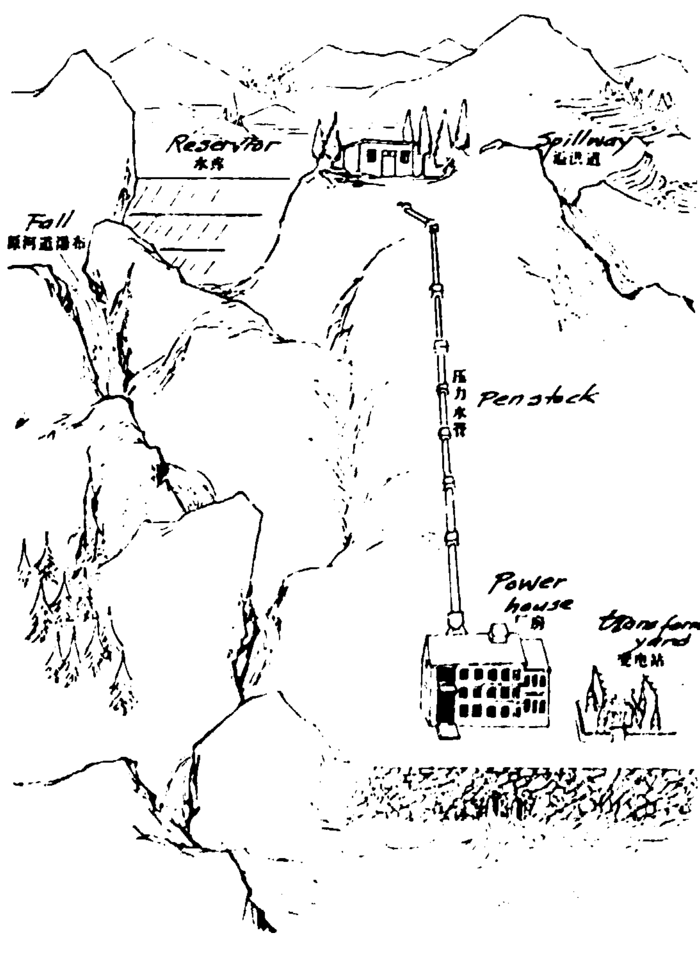


Fig 4-22

Zaixi MHG station

On the whole, from the point of view of head concentration, hydro plants with a dam or with a conduit make up the two basic categories. The "composite type" hydro plant is a combination of these two basic types. In cases where falls, rapids, drops in canal, river elbows, high land lakes or trans-river basin diversions exist, the hydro plant with a conduit or the "composite type" plant are usually preferable and will be described in D. of this paragraph.

D. Various lay-outs of water power exploitation

1. Utilization of falls:

Falls are a natural head concentration. Usually, falls have small flow variations within a year's period and are an ideal water potential for exploitation.

In the Yunnan Province, a 40 m fall was exploited for power generation. The Dishin hydro plant has a total installation of 3,250 kW.

In the Tongchen County, Hubei Province, there are several falls near the Paizhantan. After the construction of a 400–500 m conduit, the concentrated head is now about 140 m. Hydro plants which utilize falls are low in cost and less work, and thus present a preferable alternative.

2. The utilization of rapid and natural drops:

In mountainous regions, there are usually rapids (several meters or even more) or natural drops along the stream or river. These rapids or natural drops may be exploited for power generation. If the river flow is plentiful and there is a favourable topography, only a low diversion weir is required to divert the water without the use of a dam, as shown in Figure 4-23. Adequate measures should be taken to protect the power house and canal from flood attacks.

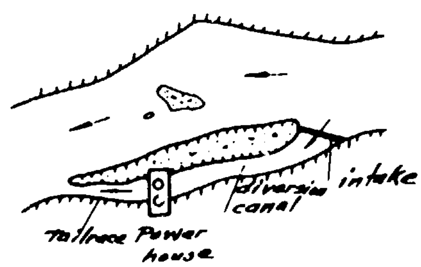


Fig. 4-23 Utilization of rapid

3. Utilization of drops on the canal:

Figure 4-24 shows the hydro plant in Guangdong Province, which irrigates by means of drops. The layout of the power house and canal drop are separate. This layout is of a hydro plant constructed at an existing irrigation scheme where the drops along the canal can be utilized. All existing structures can be utilized only a new power house will soon be built. This method of power exploitation reduces the cost considerably.

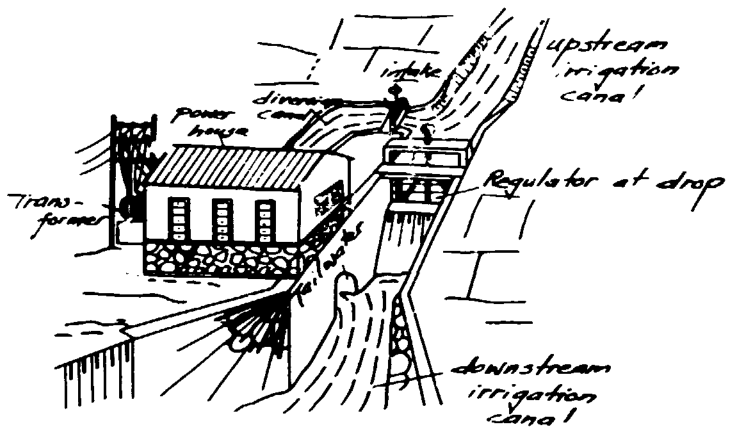


Fig 4-24 Separate layout of power house and drop

Figures 4-25 and 4-26 show hydro plants on the Mimyun-Beijing Canal. This canal conveys the water of the Mimyun Reservoir to Beijing. There are eight existing drops within 30 km. The total water potential is 35 m. The water potential of these eight drops are combined into five stages for exploitation, producing a total installed capacity of 11,400 kW.

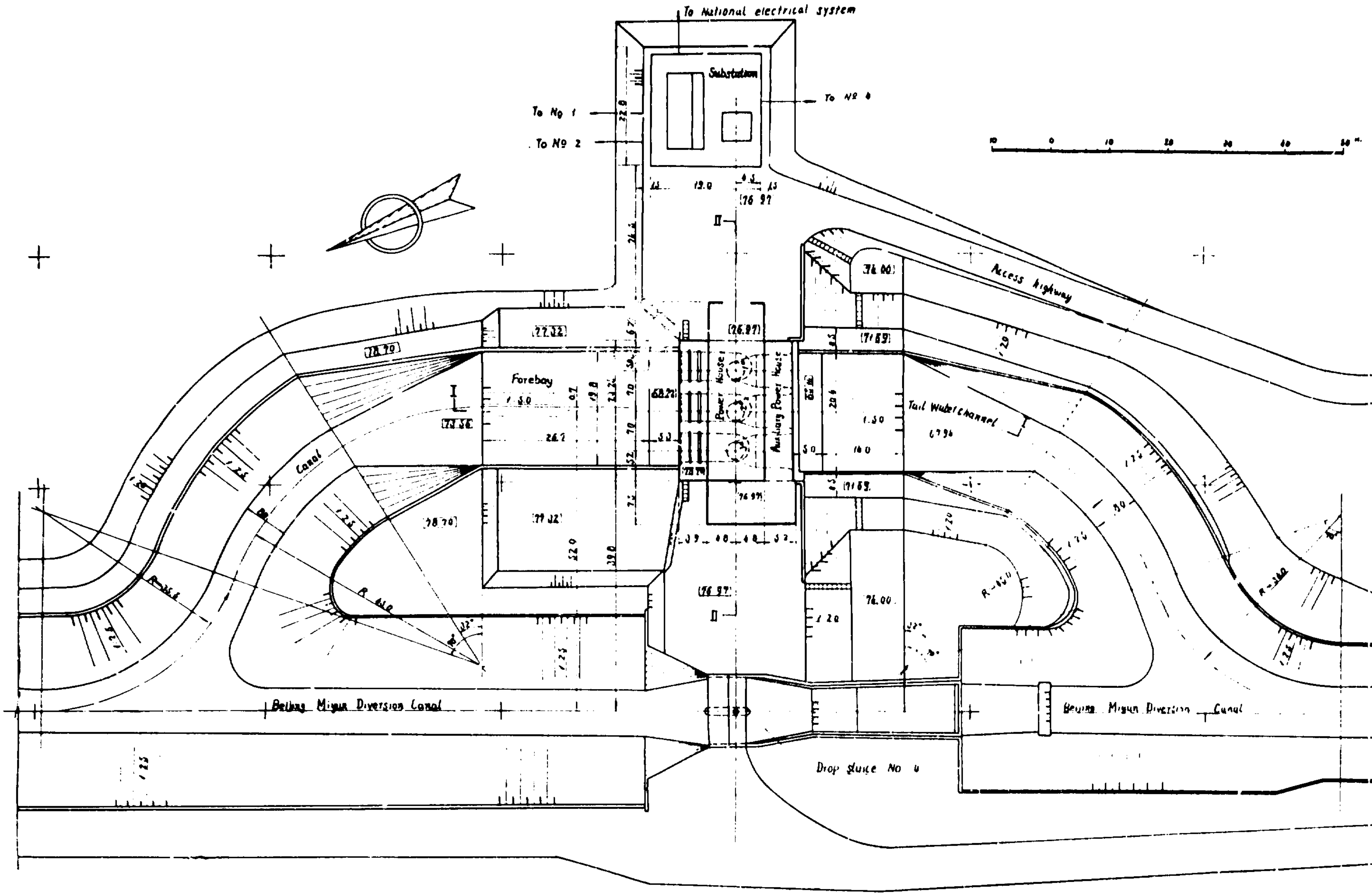
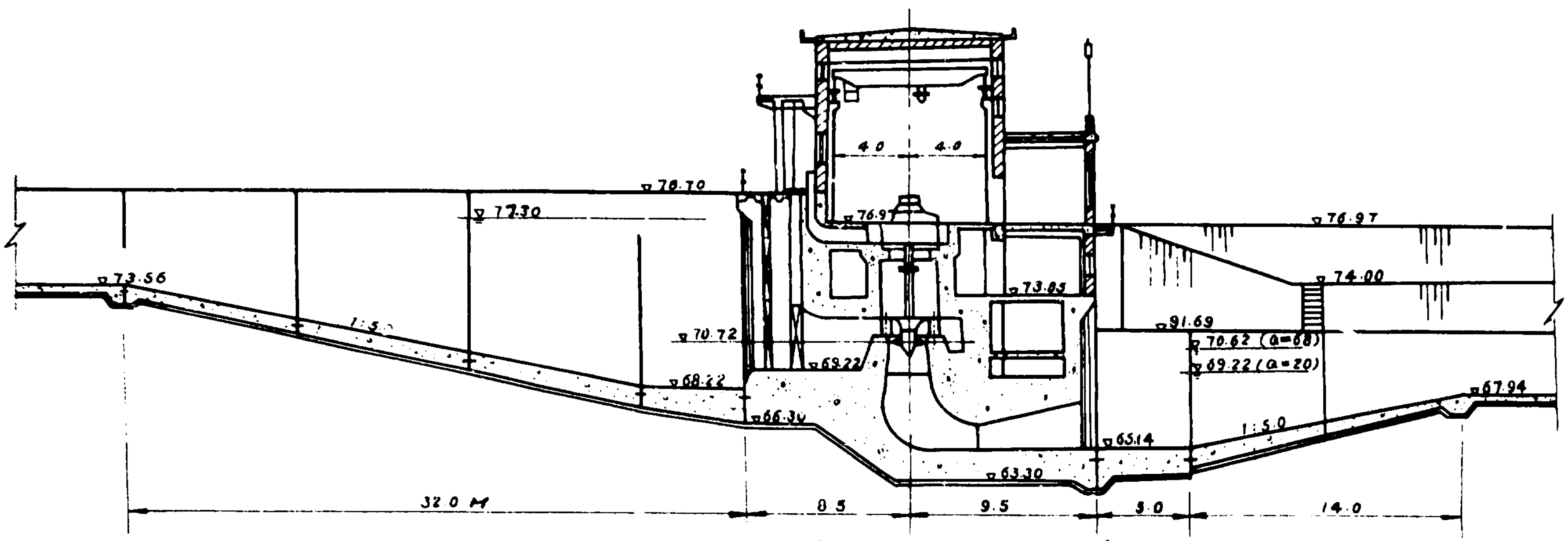


Fig. 4-25 PLAN OF WATER POWER STATION NO.3 ON BEIJING - MIMYUN CANAL



Cross Section I-I

Fig. 4-26 MHG Station on Beijing-Mimyun Canal

Table 4-11 shows the design water head and the installed capacity of these 5 MHG plants.

Table 4-11 The installed capacity of cascade stations on Beijing-Mimyun Canal

ITEM	Hydro plant				
	I	II	III	IV	V
Design net head (m)	6.5	4.7	6.5	4.7	4.5
Installed capacity (kW)	3x1,000	3x600	3x1,000	3x600	3x600

In order to minimize the types of water turbines needed and the number of sets and voltage levels for these 5 stations, water turbine model ZD 760-LH-200 has been adopted in all of these five stations: turbines with a working head 6.5 m coupled with a 1,000 kW generator (250 rpm) and turbines with working heads of 4.5 m coupled with 600 kW generators (214.3 rpm).

According to an annual flow volume of 500-700 million m^3, the annual output of these 5 stations is estimated at 28-39.4 million kWh.

4. Utilization of the river elbow:

In some mountainous areas, valley and river elbows are very developed. In some cases, the river elbow looks like a ring and the river gradient is rather steep. By a short cut conduit, a water head can be utilized for power generation.

Figure 4-27 shows a sketch of the Water Lane hydro plant in Green Dragon county, Hebei Province. The length of the exploited river elbow is 7 km and a short cut tunnel 1,580 m in length has been constructed. The head concentration is 85 m. The total installation is 1,375 kW. This is a backbone hydro plant in the Green Dragon county.

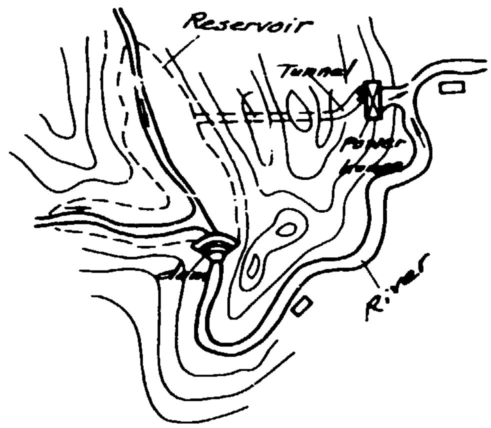


Fig 4-27 Water Lane MHG station

5. Water diversion in trans-river basins:

In some cases, particularly in hilly regions or river nets, the distance between the two rivers or two canals is not so far but a water head exists. The water diversion trans-river basins may be taken into consideration as a power generation source. Due to this, the tail-water flows downstream to the lower river. The water flow of the higher river will be reduced and that of the low river will increase. The sequence of flow-in and flow-out between the higher and lower river must be studied comprehensively regarding the requirements of irrigation, navigation, water supply, etc. on the downstream region. A technical-economic analysis is also a necessity.

The Datan hydro plant, Guangdong Province, is an example of such water diversion in trans-river basins. An 80 m tunnel and a 200 m canal have been constructed to divert the water of the Datan river to a lower small creek. The head available is 210 m. The total installed capacity is 640 kW, as shown in Figure 4-28.

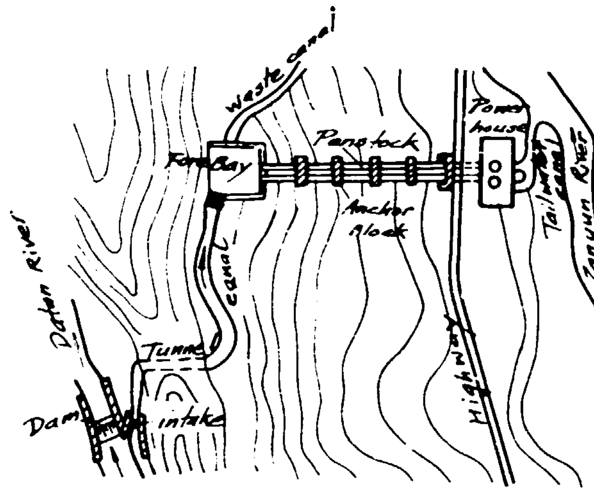


Fig 4-28 Datan MHG station

6. Utilization of high land lakes:

If there is a river or lake near the high land lake, potential energy may be exploited by diverting the higher water to the lower river or lake for power generation.

7. Utilization of tide potential:

China has a long seashore and many estuaries. There are many tes where tide potential utilization is feasible. This kind of hydro plant has special features; low head and large flow but is complex to construct, resulting in larger construction costs. At present, there are only a few such tide power plants in operation in China:

- Dalain hydro plant Shunde County, Guangdong Province: installed capacity of 144 kW.
- Kaotan hydro plant, Xiangshan County, Zhejiang Province: a tide head of about 4 m. The design flow is 8.5 CMS; installed capacity is 275 kW.
- Jing gong hydro plant, Rushan County, Shandong Province: installed capacity of 165 kW.
- Liuho hydro plant: power is generated by the tides of the Yantze estuary and has an installed capacity of 80 kW.

On the whole, these pilot tide power generations are small in scale.

The first pilot tidal power plant with two directional generation was recently put into commission (the No. 1 unit). This tidal power plant is located at the terminal of the Luoqi Bay, Wenling County, Zhejiang Province, where tide potential is abundant with a maximum tidal head of 8.93 m. The installation of a 6x500 kW turbine generator unit is planned.

8. Intercepting submerged water or collecting springs for hydro generation:

In Liyang County, Jiangsu Province, a production team dug water ponds in an area approximately 50 hectares in order to collect flows from creeks and brooks. The flow accumulated during the day time will be utilized for power generation in the evening. There is a 3.2 kW MHG plant. The head of power generation is 8 m.

In Nixing County, Jiangsu Province, a stone masonry cut-off wall was built to retain the submerged flows and raise the water level for power generation. A people's commune in Green Dragon County, Hebei Province, uses the same approach to retain the submerged flows. A hydro plant with an installation 2x40 kW was constructed with a design head of 9 m and flow of 2 CMS.

VI. Electrical Scheme and Step-Up Sub-Station

The electrical design of the MHG stations, differing in design from hydraulic engineering, is not very influenced by the variation of natural status. Hence, in spite of the respective special features in the electrical design of small stations in different places, they are fundamentally the same.

At present, the prevailing voltage level of MHG in China is as follows: The voltage of a generator set with a capacity of less than 500 kW is generally 400 V, which is transmitted at 10.5 kV through a 0.4/10.5 kV step-up transformer. The transmission radius of such a station is not greater than 15 km. The voltage of generator units at a capacity of 500-6,000 kW is generally 6.3 kV. Three levels of out-feeding voltage, i.e. 6.3, 10.5 and 38.5 kV, may occur in such stations. In a few places, 110 kV has appeared.

Transmission voltage of 6.3 kV has been adopted in previously constructed stations but have recently been replaced by 10.5 kV. The 3.15 kV voltage level used previously has been dismissed in the present.

There are numerous types of principal electrical schemes in China. The most often used ones are:

1. Single bus scheme at generator voltage, sectioned and not

sectioned (refer to Figures 4-29 and 4-30);

2. Block of generator - transformer (refer to Figure 4-31);
3. Step-up sub-station at voltage 38.5 or 10.5 kV:
   (a) "Bridge" connexion (refer to Figure 4-32)
   (b) Single bus (refer to Figure 4-33)
   (c) Block of transformer line (refer to Figure 4-29).

Various electric schemes may be designed by combining the above unit blocks.

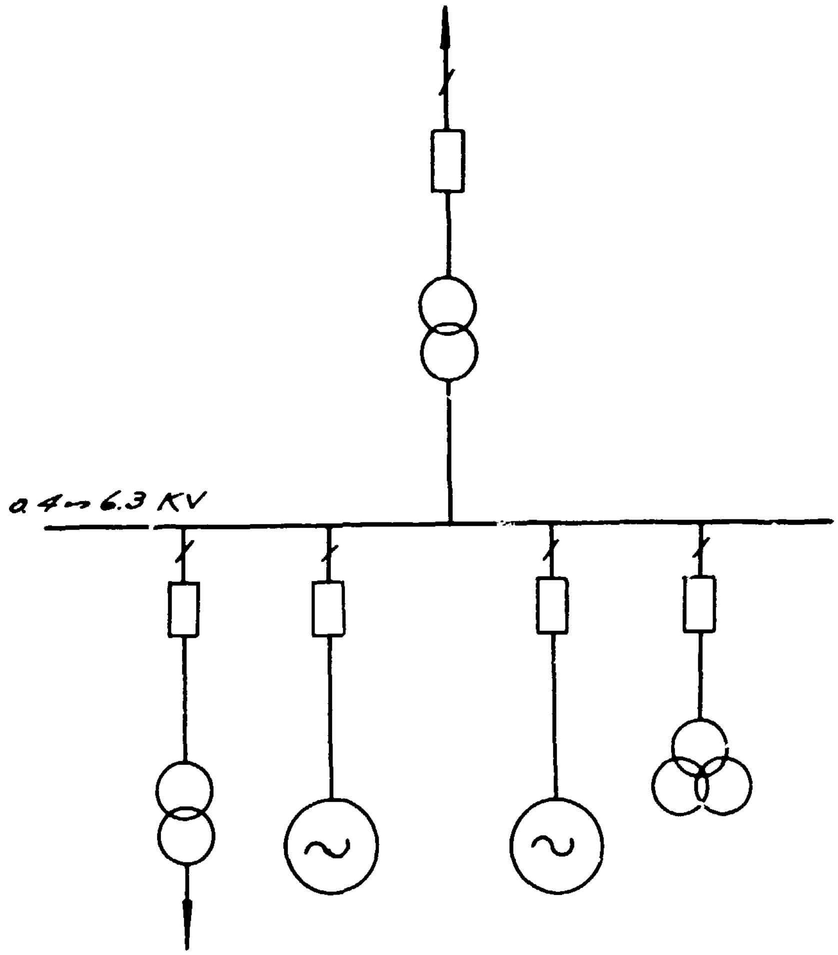


Fig 4-29 Single bus scheme (unsectioned)

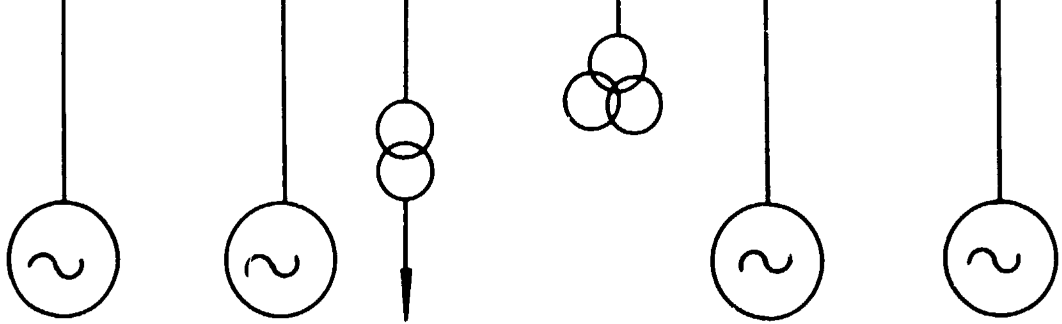
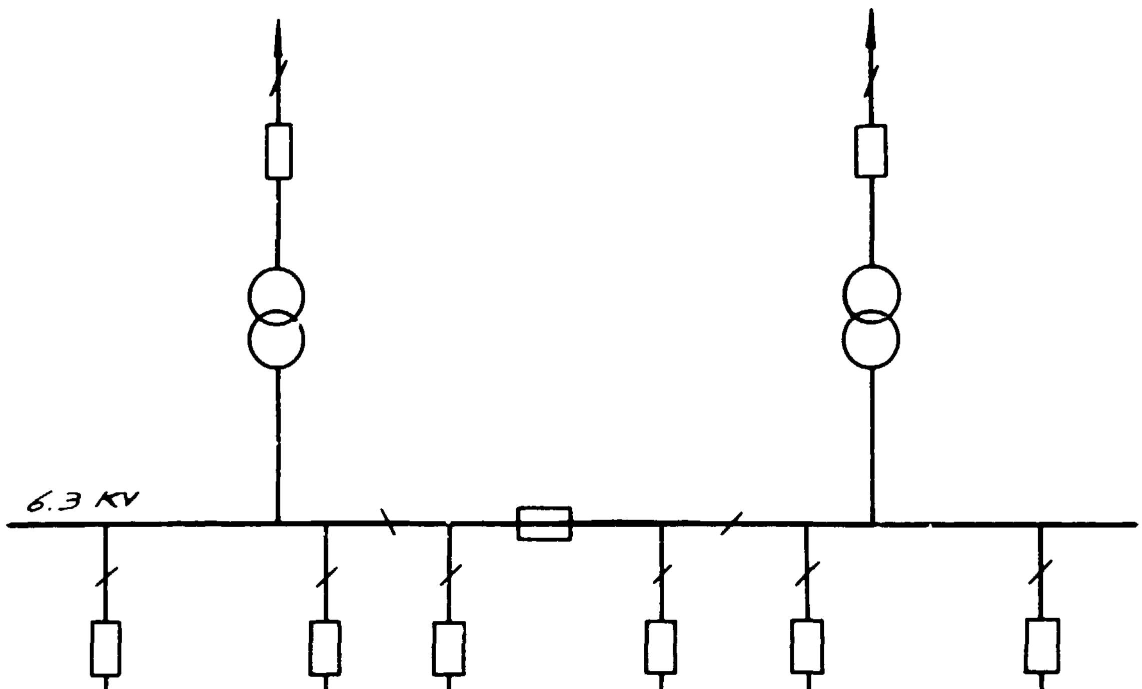


Fig 4-30 Single bus sche ιe 6.3KV
(sectioned)


6.3 KV

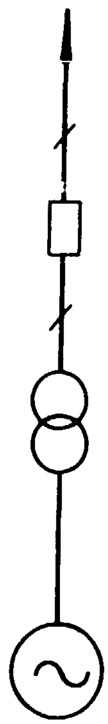


Fig. 4-31 Generator-Transformer block

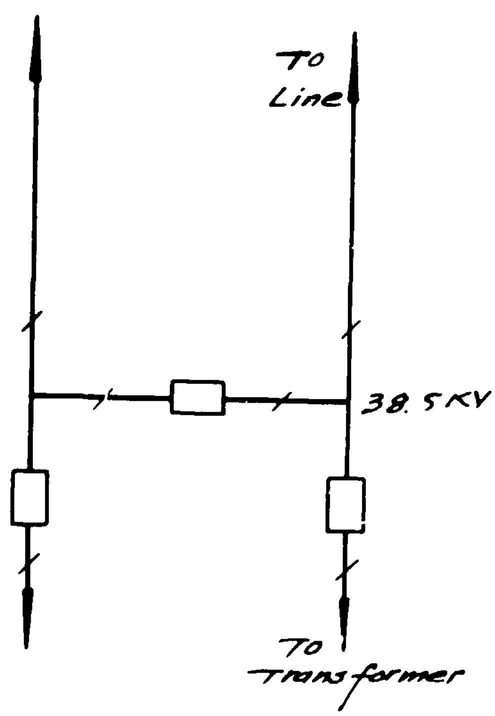


Fig 4-32 "Bridge" Scheme

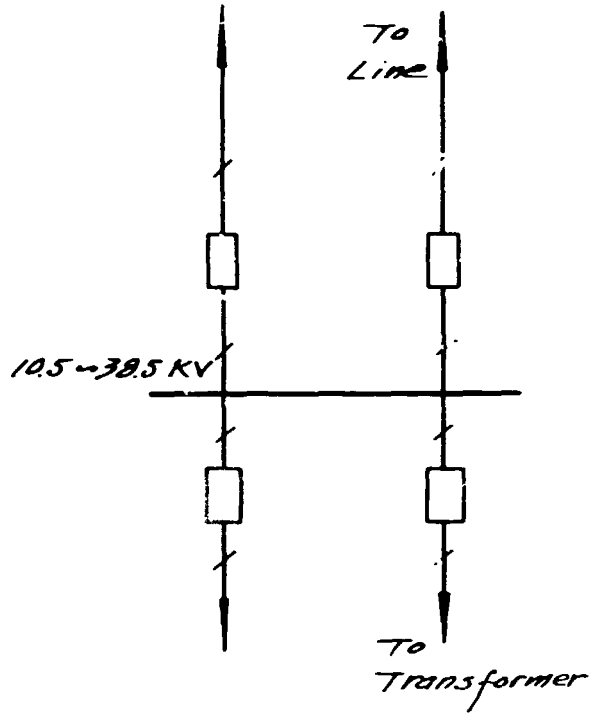


Fig. 4-33 Single bus scheme 10.5/38.5 KV

All high voltage equipment required for a power station in China can be produced in that country. Up to the present, all except very few provinces and autonomous regions have manufactured their own electrical equipment.

Complete switching sets are used for most 6.3 kV electrical facilities, in which circuit breakers, disconnection switches, instrument transformers, even metering and some relay protection and operating components are erected according to various composite schemes of primary and secondary wiring. These are provided to customers in complete sets. There are several tens or more varieties of seriation schemes of complete switching sets available for selection by the designing personnel of MHG stations.

Outdoor types are generally used for 38.5 kV electrical facilities, which are usually assembled in outdoor sub-stations.

The design standard of relay protection in an MHG station is similar for various places. The relay protection is usually composed of differential, over-current, over-voltage, overload, grounding fault, buchloch protection, etc. Up to the present, the relay protection components usually used in

China have been electromagnetic types. Transistor relay protection components are being used on probation at only a few stations.

There are also numerous ways of controlling MHG stations. The most adopted types are:

1. Centralized control in a central control room (generally used in comparatively large stations).
2. Controlling on site of a generator room with a special control and metering panel.
3. Controlling on site in a generator room using complete switch sets.

The latter two types are usually used in rather small stations. The d.c. operating voltages are usually of 220, 110 and 48 V.

The degree of automation in MHG stations in China is not very high. In stations with a capacity of 500-12,000 kW, the following automatic operations can generally be realized:

1. Automatic regulation of frequency and voltage.
2. Centralized operation for starting and stopping the generator sets and for regulation of loads.
3. Automatic warning on electrical and mechanical accidents and malfunctioning.
4. Automatic operation of some auxiliary devices in the stations.

The electrical scheme, wiring and components used in automat: generally still of the electromagnetic type. There are few places where trial operation of semi-conductor elements and logic circuits are taking place. The tele-mechanization of MHG has not yet been tried.

According to the specific status in China, the main objectives of automation of MHG are to ensure the quality of electricity, to raise the reliability of electric supply, to improve safety, to reduce labor intensity and to reasonably decrease the number of personnel needed for operation.

At present, most of the stations integrated in grids of different levels have been equipped with communication facilities in connexion with the local dispatching centre. Many stations with a 35 kV outline voltage have adopted carrier telephone on power lines.

CHAPTER 5: HYDROELECTRIC MACHINES AND EQUIPMENT FOR MHG

I. Hydro Turbine Generator Sets for MHG

The small hydroelectric machines and equipment manufactured by Chinese manufacturers are now quite complete. China has equipment not only for high head operations up to 612 meters which suits mountainous region development but also for large discharge and low head up to 2 m in the plain regions. Standard designs are presently available.

According to a new regulation, hydraulic turbines are classified into three main categories, including 27 series and 85 different types. They are of the axial flow type, the mixed flow type and the impulse type (refer to Table 5-1). Generator supports are 16 in number and 121 types (refer to Table 5-2). In order to fully utilize the widely dispersed water power resources and to furnish electricity to remote and mountainous regions, the manufacturers produce a special series of 0.25 to 75 kW mini-unit sets. Because the mini-unit sets are small in volume, light in weight, simple in construction and low in cost, they are very appreciated and welcomed by the people residing in the mountainous regions.

Since China has produced a large variety of small hydroelectric equipment, it is convenient for the consumers to select the equipment which suit them the best.

Owing to the shortage of reactive power in the rural grid, synchronous generators are used mostly in MHG.

The requirements of standardization, popularization and serialization are important for China which has so many diversified hydrological parameters.

The advantages of these products are that they are simple to manufacture, suitable for mass production, high in productivity, good in quality, low in cost and easy to operate and maintain.

Up to the present, China has produced over 200,000 sets of hydroelectric equipment. A portion of them have been exported and the rest were installed in more than 80,000 small hydroelectric stations scattered over a vast region. Some of them have been in operation for more than 20 years. Judging from their operating conditions, it has been proven that they are sound in quality and adapt very well to the varying operating conditions in different localities. For example, two 612 m head, 500 kW, CD10-WJ-90/1 impulse type units produced by Chongqing Hydroelectric Equipment Works, have been safely operating in Zhong Shan Hydroelectric Power Station, Dayong County, Hunan Province, for more than 10 years. The condition of cavitation is satisfactory. Jinghua No. 1 hydraulic turbine, through repeated operation and comparison, has proven to be of good quality and is now listed as a State standard (i.e. ZD 760). Recently, the Jinghua Manufacturing Works trial-produced a GZN 005-WP-250 type double-flow turbine generating unit which has already been installed in the tidal hydroelectric station in the Wenling County, Zhejiang Province. In recent years, many provincial manufacturers have produced a large number of equipment for the small hydroelectric stations.

Under the leadership of the Ministry of Water Conservancy, the manufacturers, being more self-reliant, have made many contributions in the construction of small hydroelectric stations. For example, the Machinery Co. of the Bureau of Water Power, Guangdong Province, has produced about 160,000 kW, 1,100 sets of hydroelectric generating units. Some of the units have already been installed in Tibet and the Hainan Island. This equipment has already withstood the most severe operating tests.

Investigations made on small hydroelectric machines and equipment after long periods of operation revealed that the equipment made in China is of simple but reasonable construction and of good quality. Table 5-3 shows a number of hydroelectric stations which have been operated for many years and still have satisfactory operating records.

In recent years, the production of small hydroelectric machines and equipment in China has been developing very rapidly. Now, the productive capability has exceeded a million kW. Besides main equipment, a whole set of equipment can be supplied upon request. Although the products are mainly for market at home, a certain amount is supplied to foreign countries.

Table 5-1 Serial Number of Various Types of Hydraulic Turbines

No.	Type	Operating Range		
		Head (m)	Flow (m^3/S)	Capacity (kw)
1	ZD760-LM-40,60,80,100, 120	3.5-7	0.45-6.8	12-400
2	ZD760-LMY-100,120	2.7-7	2.96-8.6	55-400
3	ZD560-LMY-40,60,80	4-14	0.568-3.45	12-400
4	HL260-WJ-25,30,35,42,50	9-29.7	0.235-2.45	12-500
5	HL220-WJ-42	24-50	0.95-1.375	200-500
6	HL110-WJ-30,35,42,50,60	20-70	0.159-1.07	20-600
7	CJ22-W-45/1x4.5, 55/1x7 55/1x5.5 70/1x9	50-330	0.055-0.401	20-630
8	XJ13-W-25/1x7,32/1x7 32/1x9,40/1x9 40/1x11,50/1x12	36-160	0.084-0.66	21.5-826
9	XJ02-W-63/1x16	75-220	0.761-1.262	400-2000
10	CJ22-W-110/1x12.5 110/2x12.5	220-340	0.781-0.970 1.446-1.942	1250-2500 2000-5000
11	CJ22-W-125/1x12.5	300-504	0.910-1.186	2000-5000

12	HL240-WJ-71	29.5	3.2	750
13	HL240-LH-120	18-23	7.23-9.13	1000-2000
14	HL240-LJ-120	20.1-37	8.06-10.85	1250-3200
15	HL240-LH-180	18.5-33.5	17-23.2	2500-6300
16	HL160-LJ-100	84-114	6.01-6.83	4000-6300
17	HL160-WJ-71	71.8-112.6	2.81-3.54	1600-3200
18	HL200-LH-100	67-90	7.81-8.97	4000-6300
19	HL260-WJ-71	21.3-28.7	3.32-3.86	500-800
20	HL260-LH-100	19-25	5.7-6.6	800-1250
21	HL220-WJ-50	30-70	1.48-2.3	400-1000
22	HL220-WJ-71	32-78	3.14-4.33	800-2000
23	HL220-WJ-84	30-55	4.33-5.91	1000-2500
24	HL110-WJ-60	100-145	1.4-1.52	1000-1600
25	HL110-WJ-100	120-200	4.1-5.6	4000-6000
26	HL100-WJ-71	222-315	1.58-2.4	3200-6000
27	ZD560-LM-180	9-16	15.8-23.02	1000-2500
28	ZD560-LM-250	10.6-15.5	31.4-44.00	2500-5000
29	ZD510-LH-180	6.5-14.5	13-18.8	600-2000
30	GD103-WP-275	4.5-8	39.2-57.6	1360-3600

Remark:

HL- Mixed flow reaction type

XL- Inclined tubular type

ZD- Axial-flow reaction fixed-blade propeller type

XJ- Cross flow type

CJ- Impulse type

GD- Tubular fixed-blade type

W- Horizontal shaft

L- Vertical shaft

J- Metal spiral casing

H- Concrete spiral casing

P- Bulb

M- Open flume

Z- Tubular type

Example 1 HL 110-WJ-35

HL 110 W J 35

- 35 — Nominal runner diameter 35 cm
- J — Metal spiral casing
- W — Horizontal Axis
- 110 — Runner Model 110 (specific speed)
- HL — Mixed flow reaction type

Table 5-2 Capacity of Hydroelectric Generators

Speed r.p.m.	1500	1000	750	600	500	428	375	300	250	214	187.5
NO.of poles / Support NO.	4	6	8	10	12	14	16	20	24	28	32
36.8	18 26	12 18									
42.3	40 55	26 40									
49.3		55 75	40 55								
59		100 125 160	75 100 125								
74		200 250	160 200	125 160							
85		320 400	250 320	200 250	160 200	125 160					
99		500 630 800 1000	400 500	320 400	250 320	200 250	160 200	125 160			

118		1000	630 800 1000	400 750 800	320 500						
143		1600	1250	800 1250	500 630 750 800						
145			1250 1600	1000 1250	630 1000		320 500 630				
148	3200 4000 5000 6000	2000 2500 3200									
173			1600 2000	1600 2000 2500	1250 2000 1600 2500				350		
215			6000	3200 4000 5000	3200 4000	800 2000	800 1000 1250		1250 1600	800	
260			6300	5000		3200	2500	1250 1600 2000	1000		
284											650
330									5000 6300	4000	2500 3200

Table 5-3. The Operating Conditions of a Portion of Hydroelectric Generating Units of Different Types

Station	Location	Installed Capacity (Units x KW)	Head (m)	Design Flow (m^3/s)	Turbine	Generator	Manufacturer	Operating Time (year)	Remarks
Baizhongtan Second stage	Tongcheng County Hubei Province	2 x 500	26-35	2.2	HL260-WJ-60	TSW-99/37-6	Shaoguan Hydraulic Turbin Works	5	Smooth operation
Xianggongdong	Dayong County Hunan Province	3 x 300	583	0.1	CD10-WJ-90/1	TSW-99/40-6	Chongqing Hydraulic Turbine Works Sichuan Province	13	Normal operation for a long time
Xiayuan	Chunan County Zhejiang Province	2 x 500	126	0.484	CJ-W-90/1x11	TSW-143/32-12	Hangzhou Generating Equipment Works Zhejiang Province	13	Normal operation. Good performance. Easy in Maintenance
Pangi Second stage	Jiayun County Zhejiang Province	2 x 800	220	0.5	"	TSW-143/43-10	"	6	"
Mabu	Longmen County Guangdong Province	2 x 3000	122.7	3	HL160-WT-71	TSW-146/60-6	Machinery Co. of the Bureau of Water Power Guangdong Province	6	Good performance
Biuwan River	Guanyang	2 x 320	50	0.77	HL110-WJ-60	TSWN-85/39-8	Kunming Electric Machinery Works Yunnan Province	11	Normal
Landong	Rongchen	3 x 3200	415	1	CJ-W-125/1x12	TSW-173/86-10	Liuzhou Hydraulic Turbine Works Guangxi Province	3 - 5	Normal
Ouanpi	Guangxi Province Tangshan Guangdong Province	6 x 800	184	0.6	CJ-W-92/1x11	TSW-143/44-10	Shaoguan Hydraulic Turbine Works Guangdong Province	15 Installed in stages	Normal
Mayang Second stage	Wuji County Zhejiang Province	2 x 1600	25.7	0.79	HL260-WJ-35	TSWN-59/41-6	Linhai Machinery and Electric Machinery Works Zhejiang Province	8	Normal operation. High output
Baishangji First stage	Wensheng County Zhejiang Province	2 x 12500	336-354	4.7	CJ-W-146/2-140	TSW-256/115-2	Chongqing Hydraulic Turbine Works Sichuan Province	20	Good performance continue to operate
Jiuguan	Pucheng County Fujiang Province	4 x 800	13	8.19	ZD560-LH-120	TSN-215/21-14	Nanping Electric Machinery Works Fujian Province	5	Normal
Majilong	Jinghua County Zhejlong Province	1 x 75	6	1.5	ZD760-LM-60	TSN-59/27-8	Jinghua Hydraulic Turbine Works Zhejiang Province	19	Normal
Feishuiyan	Huang County Zhejinag Province	2 x 160	78	0.44	XJ02-W-42/1x10	TSWN-74/29-8	Leqing Machinery Works Zhejiang Province	6	Normal
Dongguan Second stage	Yongchun County Fujian Province	2 x 1250	43	3.5	HL220-WJ-71	TSWN-143/61-10	Yongchun Hydraulic Turbine Works Fujian Province	10	Normal

II. Main Auxiliary Equipment

In China, the manufacturers of hydro power machinery are responsible for provision of main auxiliary equipment, including speed governors, excitation facilities and automatic components, in addition to the main generating sets.

According to the manner of operation, there are five types of governors used in the MHG, namely, hand manual, electrical, hydraulic-electrical, electronic-electrical and electronic-hydraulic. The number of serials comprised in the State set standard is eight.

Table 5-4 Type of Speed Governors

Model	Capacity (kg-m)	Type
TT-35	35	Single-regulation, direct flow.
TT-75	75	- do -
TT-150	100-220	- do -
TT-300	230-375	- do -
YT-300	230-375	Single-regulation, hydraulic-electrical
TT-600	450-760	- do -
YT-1000	760-1220	- do -
CT-40	2000-3720	- do -

The speed governor of YT-serials is an automatic governor designed in China specially fitting the MHG stations. This governor is equipped with an automatic flying pendulum and two servo-motors which are capable of automatically regulating the speed of the turbines and of controlling start-up and shut-down of the turbines from a distance, as well as regulating load. Besides, there is an electro-magnetic valve for emergency stops. This valve can be operated by a d.c. current which controls the hydraulic passage for prompt shutting-down of the generating set and prevents "flying accidency" in the case of an emergency of the station when the a.c. source is interrupted. If the hydraulic system of the speed governor happens to fail during normal operation, a manual operation can be undertaken through a specially equipped hand wheel or lifting rod. The fluid and air filling of the pressure tank of the YT-type governor can be automatically accomplished without the help of an outside air compressor which is required for ordinary governors. The features stated above are very suitable for mini hydro power stations which are often only equipped with simple facilities.

The YT-serial governors are mainly designed and produced by the Tianjin Manufacturer for Controlling Equipment of Hydropower Machinery. There are presently also many other manufacturers having the capability to produce these governors.

The types of excitation for generators are numerous. In the past, d.c. exciters with electro-magnetic regulators were mostly used. For generators less than 100 kW, only a resistor is equipped in the magnetic field to control the excitation.

Recently, many sorts of up-dated excitation facilities have been produced by many manufacturers in China. The fairly matured types are: a SCR excitation with a transformer at the outside terminal of the generator as a power source and a triple winding phase shift compound excitation and a silicon rectifier with a double winding generator shunted by a reactor. These products have been examined in different places under various modes of long-term operation and have been proven to be reliable and have advanced technological indicies. They have therefore been widely spread over the country.

In certain places, some old stations have been renovated with new electronic facilities, such as Laoding County of Guangdong Province, where 70% of the generators are equipped with or have been re-erected with a SCR excitation.

From the 1970's, 630-1,250 kW hydro generators with third harmonic voltage excitation through SCR have been successfully trial-produced and have been erected in several stations in Jiangxi, Gansu and Fujian Provinces. Several years of operation have proven the reliability of this excitation equipment, which, in comparison with electromagnetic excitation for generators of the same size, not only saves over 50% cost and 50% copper but also performs as a better self-forced excitation affected very little by variation of frequency.

In addition, brushless excitation, which is in common use abroad, has also been trial-manufactured and erected in some stations in the Sichuan, Zhejiang and Hunan Provinces.

A serial scheme of SCR excitation for generators with a capacity of 500-5,000 kW is under preparation by the Tianjin Research Institute of Electro-driving.

III. Complete Set Equipment Supply

For the sake of the customers convenience, provision of complete sets of main electro-mechanical equipment for MHG have been organized by the State and by some provinces. It includes the main equipment and its auxiliaries, transformers, high tension switchgears, various control and protecting panels, cables, cranes, air compressors, pumps, porcelains, etc. In the Sichuan Province, a "Manufacturing Corporation of Power Plant Equipments" has been set up to incorporate 90 or more manufacturers of power plant facilities under the principle of specialty co-ordination. Such corporations are also being established in the Zhejiang and Guangdong Provinces.

CHAPTER 6: RESEARCH, DEVELOPMENT, TRAINING COST REDUCTION OF MHG

China has trained many technical teams on the job in the implementation and management of MHG, in areas such as planning, exploration, design, construction, installation, operation and maintenance. Presently, efforts are being made to raise the level of technology, to carry out research and technical innovation, to improve the reliability of the power supply, and to reduce construction costs. The following are the main technical aspects.

I. Research

A. Application of pre-stressed concrete pipes in MHG plants

1. Advantages of pre-stressed concrete pipes - (hereinafter referred to as PSC pipes)

In the past, the high or medium pressure pipes used in MHG were usually made of steel. The supply of steel, however, was not adequate to meet the needs accompanying the development of the hydro power constructions. In 1964, utilizing gained foreign experience, the Gao-liang MHG station of De-qing County of Zhao-qing Prefecture, Guangdong Province, successfully used self-made spigot-and-socket type PSC pipes instead of steel pipes. Soon afterwards, all plants gradually began to do the same.

Up until this time, every county in this prefecture had run a cement pipe plant. These plants manufactured pressure pipes 76 km in total length for 2,700 hydro-electric units. Among these MHG plants, the highest water head is at the Huang-tongjiang MHG station of De- qing County which reaches 218 m. Three 800 kW generating units have been installed and 600 MM of PSC pipes have been used (Figure 6-1). At the Shiu-xia MHG station in Huai-ji County which has a water head of 168 m, four 3,000 kW generating units have been installed and PSC pipes 1,250-1,300 MM in diameter have been adopted (Figure 6-2).

Fig 6-1 Huongtongjiang MHG Station

Fig. 6-2 Shuixia MHG Station

PSC pipes possess the following advantages in comparison with steel pipes:

a. Low cost and low consumption of steel:

Generally, the consumption of steel can be lowered 70-90% and the cost reduced by 60% when PSC pipes are used instead of steel penstock (those with low head and large diameter may save even more steel and cost). For example, at the Shui-xia MHG station, about 175 tons of steel costing approximately 310 thousand yuan was required for the steel penstock design but only 53 tons of steel and 120 thousand yuan was needed to manufacture the PSC pipes. Thus, savings in steel and cost are approximately 70% and 61%, respectively.

All PSC pipes were tested using a water pressure test. After keeping the pipes under constant pressure for 24 hours, the tests revealed that a maximum water pressure of 34 kg/cm^2 was possible without danger of cracks and leakage. These PSC pipes have been in operation for four years now and are still in good condition.

b. Durability:

The first PSC pipes were put into operation 15 years ago in 1964. These pipes are still performing as well as they were at their installation. Another MHG station located in the suburb of Zhao-qing has a working head of 120 m. A steel penstock with a diameter of 0.4 m was installed in 1958. Owing to erosion as well as to the small diameter of the pipe which made maintenance an impossibility, the steel pipe ruptured under inner-water pressure. It was then replaced by a PSC pipe. The PSC pipe has worked without complications from its implementation in 1968 up until the present.

c. Convenience in installation and better water sealing of joints:

The spigot-and-socket type is easy to install. The important point is to lay a rubber seal in the spigot end and then put the spigot into the socket. This technology results in secure sealing and promotes high efficiency in installation.

For example, in one MHG station with a head of 200 m, in operation for over four years, the seal of the spigot-and-socket joint is still in excellent condition. This joint is also more capable of adapting to deformation.

d. Low maintenance cost:

Nevertheless, PSC pipes have shortcomings such as a larger dead-weight and that they break more easily during transportation and installation. These problems should be overcome by taking adequate measures.

2. Design of PSC pipes

PSC pipes consist of three parts; a concrete pipe core reinforced with longitudinal pre-stressed steel, a circumferential pre-stressed wire wound around the external surface of the pipe core wall, and a protective layer.

a. Design criteria:

(1) necessary strength and the avoidance of leakage;
(2) sufficient rigidity in the longitudinal direction to prevent cracks and breaking of pipes during pre-stressing, unshuttering, transportation and installation;
(3) The compressive stress of the core pipe σ_c must stand as follows:

Inner diameter DI $\leqslant$ 50 CM, σ_c 3-8 kg/cm^2
DI = 60-80 CM, σ_c 3-6 kg/cm^2
DI = 100-130 CM, σ_c 2-3 kg/cm^2

Experience has shown that when the diameter of a pipe is less than 30 CM, the thickness of the pipe will be 2-3 CM and the length 2-3 m. When the diameter is 30-130 CM, the thickness will be 4-8 CM and the pipe length 3.2-4.2 m.

b. Computation of pipe:

The strength of the pipe depends mainly upon the technology and workmanship during manufacture. Usually, the results of computation are merely used as a reference in the selection of the steel reinforcement bar. The actual strength of the pipe is measured by the water pressure test. The following data is used for computation: (see Figure 6-3)

DI = inner diameter of the pipe in CM

ri = inner radius of the pipe in CM

t = thickness of the core pipe in CM

L = length of the pipe in m

t_1 = thickness of outer protective layer in CM

H = design water head in m

P = equivalent inner-water pressure in kg/cm^2

R_g = ultimate strength of pre-stressed steel bar for low carbon cold extended steel bar A_3F, R_g is 7,000-8,000 kg/cm^2

R_a = compressive strength of concrete

R_ℓ = tensile strength of concrete

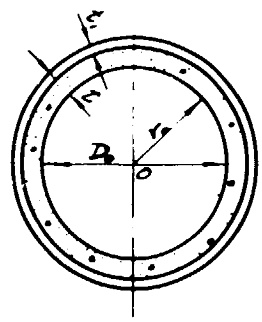


Fig. 6-3 Dimension of PSC pipe

In a circular direction, taking L=1 m for computation, the tensile force on the pipe wall is:

$$N = 100\ rip \quad (kg) \qquad 36)$$

The area of the reinforcement steel bars in the pipe wall is:

$$Ag = \frac{kN}{Rg} \quad (CM^2) \qquad 37)$$

(where k = the co-efficient of safety, use 2.0).

The following formula should be used in calculations for the prevention of cracking:

$$K_f N \leq \left[A_h \left(R_f + \mu \sigma_o \right) + 200\, A_g \right] \qquad 38)$$

where A_h = the cross section of pipe wall in linear length 1 m = 100 t (cM2)

σ_o = effective pre-stressed force (kg/CM^2)

K_f = safety co-efficient on cracking.

Precentage of steel $\mu = \frac{Ag}{t} \frac{1}{100}$,

Substitute μ, N, Ag to (38), to obtain σ_o

The loss of pre-stress will be σ_s and the total pre-stress will be $\sigma_k = (\sigma_o + \sigma_s) \leq 0.8$ Rg. It is mandatory that this condition must be met where 0.8 = the co-efficient of stress control.

In normal cases, when μ is not as high, the summation of loss in pre-stress lies between 1,000-2,000 kg/CM^2; for pre-stressed structures using pre-tensioned methods, σ_s greater than 1,000 kg/CM^2 is proposed.

3. Manufacture technology and quality examination of pre-stressed concrete pipes:

In order to satisfy the design requirements for optimal working capability, pre-stress concrete pipes should possess sufficient resistance to permeability and cracking as well as sufficient durability. These two qualities depend upon quality control during the manufacturing process. Resistance to permeability can be effected not only by material quality and mixing proportion but also by the pipe core moulding technology. The application and control of longitudinal and circumferential pre-stress on the pipe and the concrete strength of the pipe core are two factors affecting the crack-resistance of the pipes. Rusting of the circumferential pre-stressed wire will reduce the durability of pipes to a considerable degree. Hence, quality control and examination of pre-stressed concrete pipes in a three-stage technology using the centrifugal method has been emphatically presented and fully adopted in China.

a. Control of longitudinal pre-stress:

The longitudinal pre-stressing of pipes is achieved by pre-stretching the longitudinal steel. This is then temporarily anchored on the pipe mould before the pipe core is moulded in order to increase the level of possible pre-compressive stress after moulding. Both the electro-thermal stretching method and the screw-rod stretching method are commonly used to apply longitudinal pre-stress as shown in Figures 6-4 and 6-5. The pre-stress value of longitudinal steel is controlled by the elongation value of steel; namely, the steel is stretched up to the specified elongation value which can be calculated by the following equation:

$$\Delta \ell = \frac{\tilde{\sigma}_k + 300}{E_g} \ell \qquad 39)$$

in which $\Delta \ell$ = elongation value of longitudinal steel (CM);

$\tilde{\sigma}_k$ = controlled stretching stress of longitudinal steel (kg/CM^2);

E_g = modulus of elasticity of steel (kg/CM^2);

ℓ = distance between two anchorage points at the ends of longitudinal steel (CM);

300 = pre-stress loss caused by uneveness in the steel and plastic deformation of steel under high temperature and stress action (kg/CM^2).

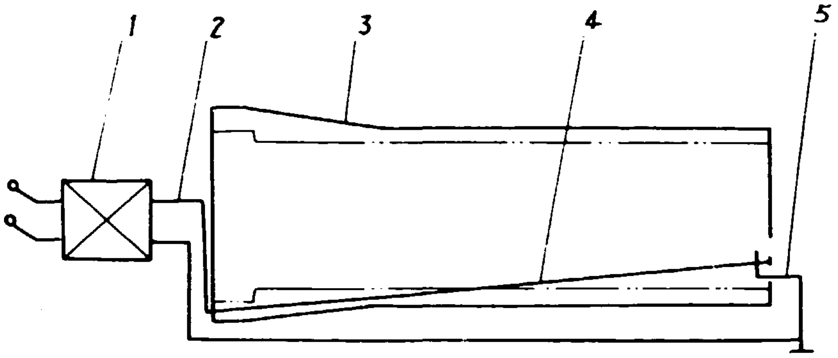


Fig. 6-4a Connection of electric wire and steel bar

Figure 6-4a - Sketch Showing Connexion of Three-Phase Transformer Cable with Steel

1____secondary coil lead;
2____pipe mould;
3____longitudinal steel;
4____electro-thermal support bracket.

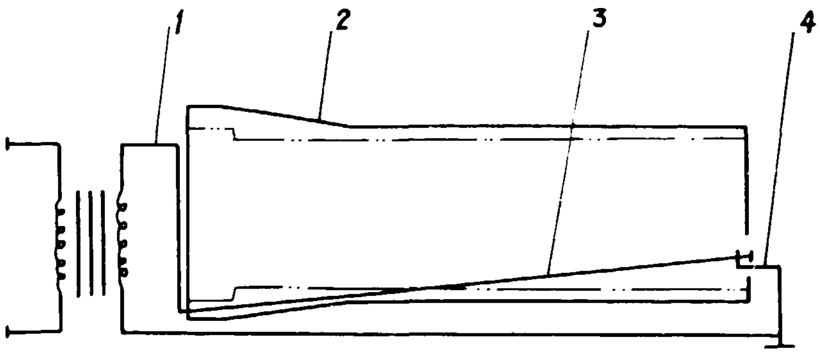


Fig. 6-4b Connection of arc welder and steel bar

Figure 6-4b - Sketch Showing Connexion of ARC Welding Machine with Electro-Thermal Steel

1____arc welding machine;
2____secondary coil lead;
3____pipe mould;
4____longitudinal steel;
5____electro-thermal support bracket.

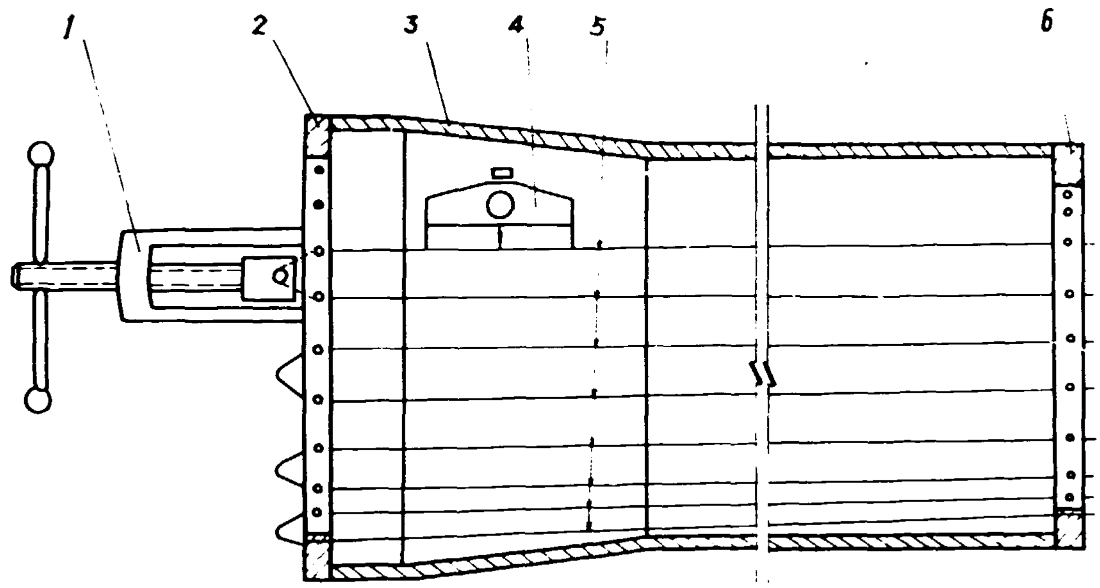


Fig 6-5 Lengthening of steel bar

Sketch Showing Longitudinal Steel Stretching with Screw-Rod Stretching Machine

1_____screw-rod stretching device; 2_____socket anchorage capstan;
3_____pipe mould; 4_____wire-tensometer;
5_____longitudinal pre-stressed steel; 6_____spigot anchorage capstan.

A wire-tensometer is used to measure the pre-stress value of the longitudinal steel.

b. Quality control of aggregates:

The quality requirements of sand and stone for pre-stressed concrete pipe are generally the same as those for high-grade concrete. However, clay impurities and stone powder in the sand must be completely eliminated for the concrete to possess sufficient resistance to permeability.

c. Control of concrete mixing proportion:

Before mixing, the proportion of concrete used for pipe manufacture should be determined by testing and should not be randomly changed or the permeability resistant property will fluctuate. The so-called "Control of Concrete Mixing Proportion" is primarily used to strictly control the water-cement ratio in concrete after using the centrifugal moulding method. The remaining water-cement ratio generally equals 0.66-0.68 times the water-cement ratio before this centrifugal moulding operation. In other words, the water-cement ratio in concrete before centrifugal processing is proportional to the remaining water-cement ratio in concrete after centrifugal moulding. Therefore, the arbitrary addition of more water must be forbidden.

d. Control of the centrifugal process in divided into three stages:

These stages are, namely, show speed, intermediate speed and high speed. Control of centrifugal technology means the adjustment in magnitude of speed and in duration of time of these three stages.

(i) Slow speed control:

Slow speed rotation is the first step in centrifugal technology, the aim of which is to provide facility for material feeding and to make concrete materials uniformly adhere more firmly to the pipe mould wall. For this purpose, the centrifugal force produced by the rotating speed should be larger than the deadweight of the concrete material, i.e.

$$m\,\omega^2 r > mg \qquad (40)$$

where m = mass of concrete (gm.sec/CM^2)

ω = rotation of angular velocity,

$\omega = \frac{2\pi n}{60}$ (1/sec),

r = rotating radius, namely, the external radius of the pipe core (CM),

g = gravity acceleration, $g = 981$ cm/sec^2,

n = rotating speed of pipe mould (rpm).

Consequently, the following expression for slow speed is obtained

$$n > \frac{300}{\sqrt{r}}$$

Through practice, the controlled slow speed is generally taken as 1.5∽1.6 times of the theoretical rotation speed, i.e. the applied slow speed

$$= (1.5\sim 1.6) \times \frac{300}{\sqrt{r}} \qquad (41)$$

The slow speed centrifuge depends upon the degree of uniformity of the material distribution on the pipe mould wall; it will be longer for pipes with a larger diameter and shorter for ones with a smaller diameter. In general, it takes between 5-15 minutes.

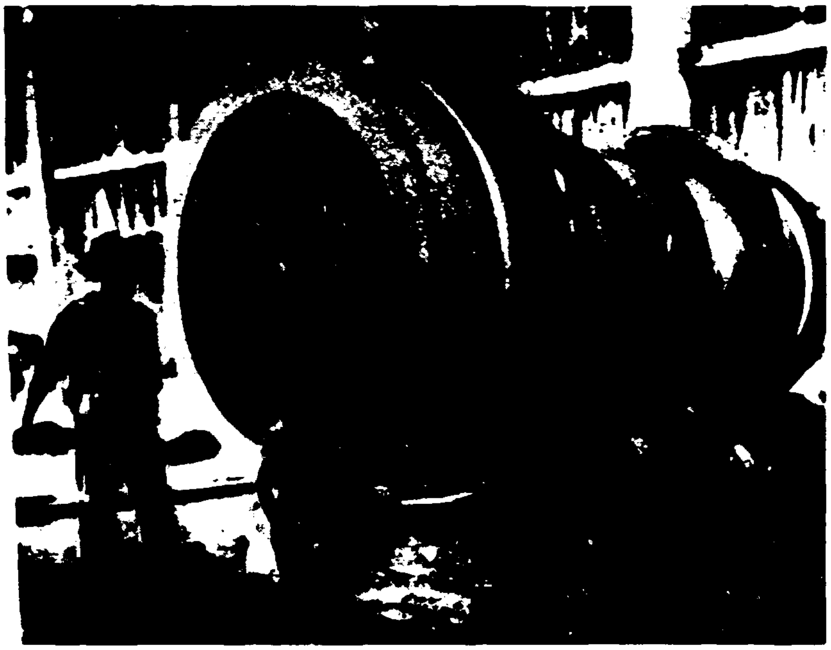


Fig. 6-6 Concrete placement of pipe core

Figure 6-6 shows the feeding process in pipe core centrifugal moulding.

(ii) Intermediate speed centrifuge:

Intermediate speed centrifuge is the transitional stage from low speed to high speed centrifuge. This transitional speed should be uniformly increased. Due to the relatively low water-cement ratio in concrete used in centrifugal technology, the flowability of the concrete mixture is relatively small. Abruptly raising the rotation speed to a high speed will result in displacement of material and consequently cause non-uniformity in the pipe wall thickness. Furthermore, an abrupt rise in speed will cause skipping in the pipe mould and thusly intensify the segregation of material. Therefore, the principle of intermediate speed control is to gently raise the speed from low to high. The revolutions per minute and the duration of time required should be determined by practical observation. In general, the duration of time is normally never more than 10 minutes. (see Figure 6-6).

(iii) High speed control:

High speed centrifuge is the final stage of centrifugal technology. Importantly, it is the stage at which the concrete will achieve its maximum density. According to the theoretical derivation, the expression for centrifugal pressure will be:

$$F = \frac{\gamma_h \pi^2 n^2}{2{,}700g} \left(r^2 - \frac{ro^3}{r}\right) \qquad 42)$$

where F = centrifugal pressure of core concrete acting on pipe mould (kg/CM^2);

γ_h = unit weight of concrete (kg/CM^3);

n = rotation speed of pipe mould (rpm);

r. r = internal and external radii of pipe, respectively (CM).

It is known from Eq. 42, when the dimensions of the pipes are constant that the larger the rotation speed is in high speed centrifuge, the larger the centrifugal compressive force will be. Hence, raising the centrifugal rotation speed is an important means to increasing the strength and permeability-resistance of the pipes.

To choose the rotation speed in high speed centrifuge, a rotation speed corresponding to a centrifugal compressive stress reaching 0.8-1.0 kg/CM^2 is considered the best. However, the best rotation speed is hardly ever attained due to the poor rigidity of the pipe mould which has usually been made by a hand manual with a steel plate 3-6 MM in thickness. The centrifugal pressure which the pipe mould can withstand does not always exceed 0.5 kg/CM^2. Based on production practice, when a pre-stressed concrete pipe with an internal diameter of 1,250 MM is manufactured, a centrifugal pressure between 0.73-0.75 kg/CM^2 is needed to enable permeability-resistance of the pipe to reach 34 kg/CM^2 or above. It can ther safely be used in a high-head hydro-electric plant with a design internal water pressure of 21.2 kg/CM^2. Consequently, control of high speed centrifuge should be determined according to the diameter of the pipe and the magnitude of the permeability-resistant pressure required. Generally speaking, centrifugal pressure acting upon the pipe mould should be in the range of 0.4–0.75 kg/CM^2. The highest limit is required for high permeability-resistant pressure and the lower limit for low.

The duration of time needed for high speed centrifuge is determined by the degree of drainage, the density of concrete and sometimes by the water pressure test.

(iv) Control of operation techniques:

Considering that segregation takes place due to the centrifugal process, the impermeability of the concrete pipe core mainly depends upon the mortar layer and the cement layer. The two together are called the permeability-preventive layer. The thickness of this layer is only one-fourth of the entire pipe thickness. If a method is used where both feed and centrifugal processes are done layer by layer so that multiple permeability preventive layers are formed on the pipe wall, the permeability resistance will be markedly increased. Generally, the feed-and-centrifuge process can be repeated two to four separate time, depending on the desired thickness of the pipe wall and the diameter of the pipe.

e. Control of the circumferential pre-stress:

The circumferential pre-stress wire is wound around the external surface of the pipe core wall. A weight-balanced tension-type wire-winding machine is extensively used to wind circumferential pre-stressed wire. The principle of wire-winding is shown in Figure 6-7 and 6-8. The wire is subjected to a tension equaling one-half the weight of the weight block. The pre-stress value of the circumferential wire can be controlled by adjusting the weight of the hung weight block and may be calculated by the following equation:

$$W = 2 \sigma_K f \gamma \qquad 43)$$

in which W = weight of the weight block (kg);

σ_k = controlled tensile stress of circumferential wire (kg/CM^2);

fy = cross-sectional area of a single circumferential wire (CM^2).

The circumferential pre-stressed wire is wound onto the pipe core through the guide pulling mounted on the gantry. This moves forward when the pipe core rotates. The pitch of the wire to be wound can be controlled by adjusting the moving velocity of the gantry.

Fig. 6-7 Prestressed steel bar Winded on the pipe core

Figure 6-8 illustrates the working principle of the weight-balanced tension-type wire-winding machine.

I____wire-winding system
II____balancing weight system
1____pipe core
2____gantry
3____steel wire capstan
4____wire-fastening and guide device
5____pre-stressed wire guide pulley
6____pre-stressed wire
7____tension transmitting device
8____steel cable guide pulley
9____steel cable
10____weight block
11____winch

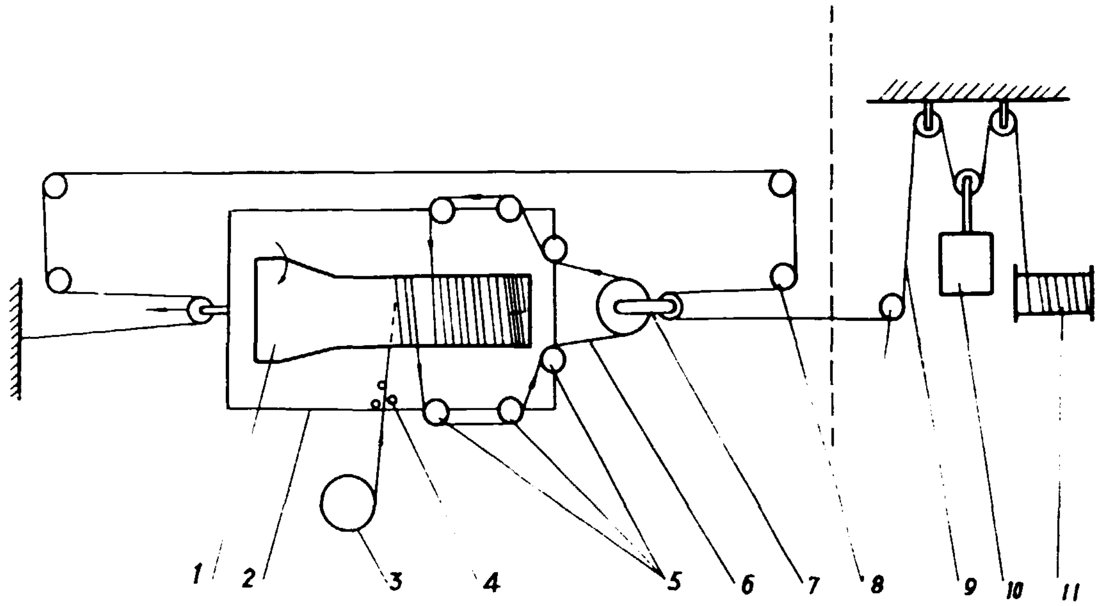


Fig. 6-8 Working principle of winding machine

Figure 6-8 - Winding pre-stressed wire onto pipe core.

If circumferential hair cracks appear on the internal surface of the pipe core wall after wire winding, it is necessary to examine whether the structural design of the pipe is reasonable, whether pre-stress on the longitudinal steel was sufficiently applied during the pipe manufacturing process and whether the pipe core reached its specified strength during the wire-winding operation. Then, corresponding measures should be taken for improvement. These types of circumferential hair cracks can be repaired with epoxy-resin.

f. Protection of circumferential pre-stressed wire:

The service life of pre-stressed concrete pipe is rather long but the circumferential pre-stressed wire can break due to rust erosion and cause failure of the pipe. In general, a cement mortar layer 15-20 MM in thickness is mechanically or manually made on the pipe surface as a protective coating. At present, a method employed to protect circumferential pre-stressed wire is to apply a rust-preventive coating on the wire. The most practical method is to install a container of rust-preventative material on one side of the gantry in the wire-winding machine as shown in Figure 6-9. When the wire passes through the container, a rust-preventive coating is automatically applied to its surface just before it winds on to the pipe core. Then, if the cement mortar protective coating fails, the rust-preventative coating will still remain on the steel wire itself.

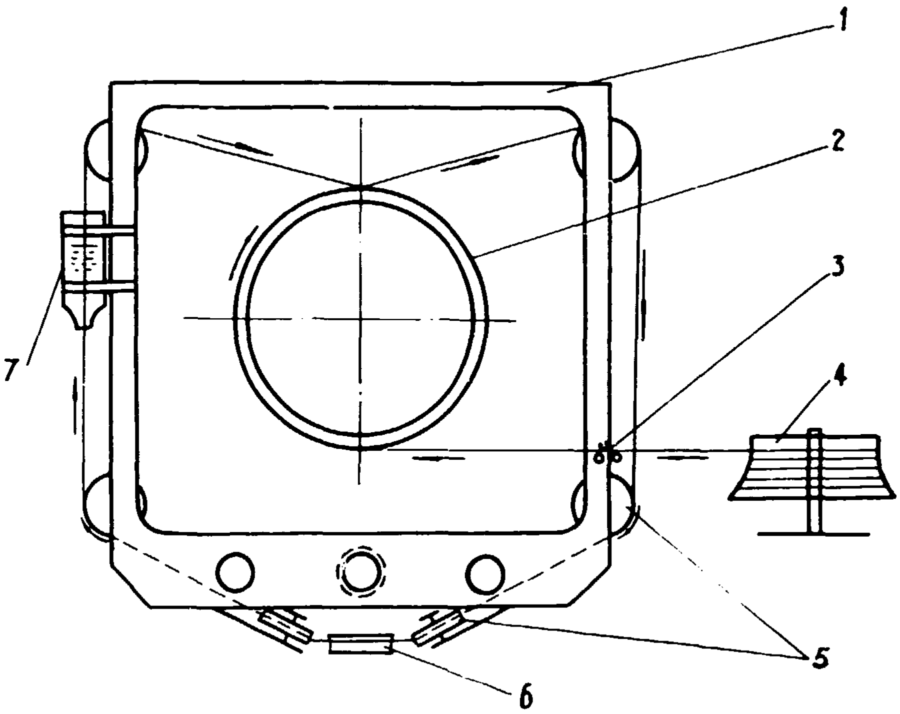


Fig. 6-9 Self coating of prestressing steel bar

Figure 6-9 illustrates the automatic application of a rust-preventative on pre-stressed wire.

1____gantry
2____pipe core
3____wire-fastening and guide device
4____steel wire capstan
5____steel wire guide pulley
6____tension transmitting device
7____rust-preventative container.

g. Hydraulic pressure test:

Permeability-resistance and crack-resistance can be determined by using a hydraulic pressure test. The equipment used in conducting hydraulic pressure tests is a water-filled type of hydraulic pressure testing machine. For pipes with larger diameters which will be subjected to higher pressure, an internal sleeve-type hydraulic pressure testing machine may be more convenient, as shown in Figure 6-10. The latter type can greatly reduce the total thrust of water pressure against the bulkhead at both pipe ends, making water sealing between the bulkhead and the pipe more easy.

Since pre-stressed concrete pipes used in hydro-electric stations are always laid along a hill slope in the open air and are not subjected to earth pressure and other live loads acting on the ground surface, the pressure used in hydraulic examinations is always taken as 1.3 times the sum of the hydrostatic pressure and water hammer pressure increment, i.e. 1.3 times the designed internal water pressure. If percolation and cracks do not appear in the pipe under such water pressure conditions, the pipes can be considered qualified. All pipes should be installed and employed only after passing both the permeability-resistance and the crack-resistance examination.

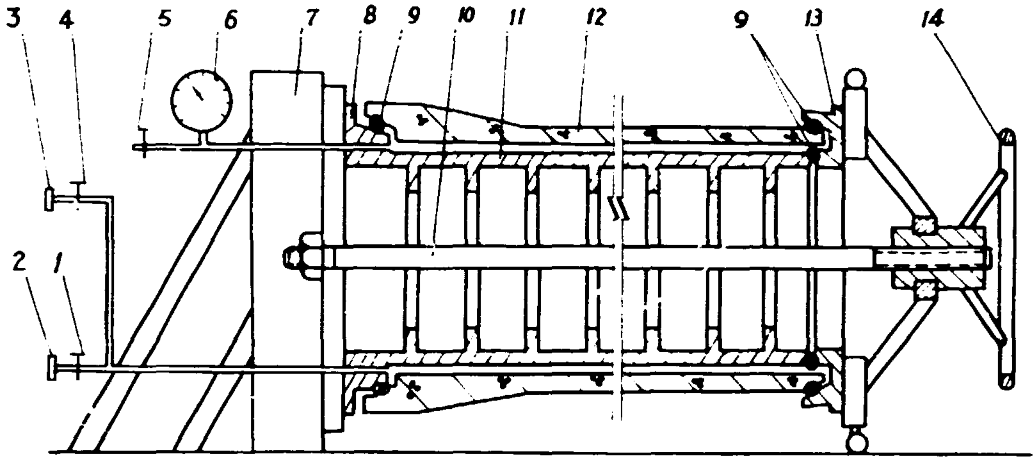


Fig. 6-10 Water pressure test machine

Figure 6-10 illustrates an internal-sleeve type hydraulic pressure testing machine.

1____water intake valve for pressure test

2____connected to electrical pressure test pump

3____connected to water pump

4____water filling valve

5____air release valve

6____pressure gauge

7____machine support

8____stationary bulkhead

9____water se. ling rubber ring

10____tension rod

11____steel sleeve

12____pre-stressed concrete

13____movable bulkhead

14____hand wheel

More than ten years of usage have shown that pre-stressed concrete pipes possess higher crack-resistance and better permeabiability-resistance. It has been verified that application of this sort of pipe in hydro-electric stations under 200 meters of water head is both feasible and safe. Pre-stressed concrete pipes with a diameter of less than 1,300 MM can be manufactured with comparatively simple equipment on site or in the plant.

B. Application of Relief Valves in MHG

If the load of a hydro-electric unit is rejected suddenly during operation, the governor will automatically cause the turbine to quickly close its guide vanes, consequently producing the penstock pressure rise ξ and the turbine speed rise β . ξ and β can be both expressed as functions of the principal variable Ts; the closing time of the guide vanes. It is known from the characteristics of the penstock and the turbine that ξ will vary contrary to β for a certain range of variation of Ts. That is, when Ts increases, ξ will decrease while β increases, and vice versa. For a hydro-electric station with short penstock (normally the starting time of penstock Tw is less than 2.5 seconds) reasonable value of ξ and β can be obtained if Ts is selected properly. For a hydro-electric station with long penstock, however, it is often impossible to select an appropriate value of Ts that will make both ξ maximum and β maximum fall within an allowable range. In such a case, a surge shaft (or surge tank) is usually installed to ease the contridiction between ξ maximum and β maximum, thereby ensuring stability of the regulation system. This arrangement actually shortens the effective length of the penstock and reduced the value of Tw within allowable limits. However, using surge shafts require larger amounts of building materials, higher construction costs and an increase in time needed for construction. Moreover, for some sites, surge shafts are difficult to construct owing to poor topographical and geological conditions. In order to cut down capital investment and speed up construction, a scheme of replacing the surge shaft with a relief valve employing a novel all-oil control system was developed. From the characteristic test for a single relief valve at Jingganshan hydro-electric station of Jiangxi Province and also from the industrial tests and four years of operating experiences at Longyuan Hydro-electric Station, Hunan Province, it has been shown that the application of type TFW-400 relief valves with all-oil control system can successfully replace a surge shaft.

The pertinent facts of the scheme are:

Total length of tunnel plus penstock 1,950 m, head 83 m.
Capacity unit = 1,600 kW.

In case of a rejection of the full load in all three units, the penstock pressure rise ξ is 14.5% and the turbine speed rise is 24.4%. These values are appreciably lower than those for a design employing surge shaft (ξ = 24%, β = 32%) and are very close to the values obtainable under optimum closing law, i.e. ξ = 11.2% and β = 25.5%. The stability and transient process quality under conditions of no-load and on-load disturbance for the turbine regulating system also meet requirements of the power station. A saving in cost of 90% of that of a surge shaft was realized in addition to the power station being put into commission one year ahead of schedule.

1. Type TFW-400 relief valve with all-oil control system:

The action of the relief valve must be sensitive, safe and reliable when it is used in place of a surge shaft in hydro-electric projects. Most relief valves used in the past were of the mechanical type. These have been proved by experience over the years to be unreliable, and the action of the relief valve also lags behind that of the guide vanes by up to 0.5 seconds. Consequently, even if a relief valve is installed in the hydro-electric station, the penstock pressure rise will still be very high. Special safety measures would have to be taken to protect the penstock in case of relief valve failure. Therefore, the mechanically controlled relief valve could not completely take over the function of reducing the water-hammer. Various designs of relief valves with hydraulic control systems were somewhat improved but shortcomings were still quite evident. For example, some valves still retained a time lag of 0.1-0.4 seconds; some valves required an increase of the capacity of turbine pressure oil systems; others had complicated systems comprising large numbers of control elements that were difficult to adjust on site, and so forth. The above-mentioned shortcomings have all been overcome in the type TFW-400 relief valve. The valve proper and control system are described separatly as follows.

a. The construction of the valve proper: (see Figure 6-11)

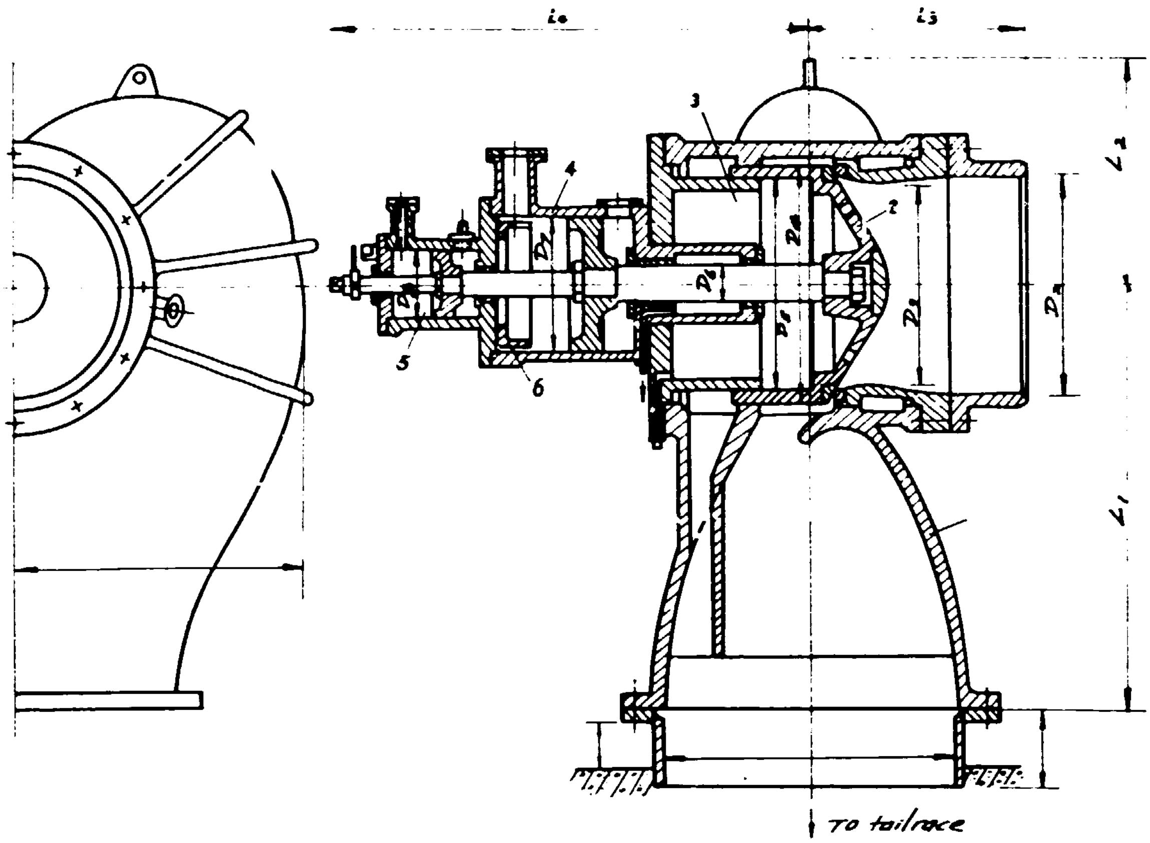


Fig. 6-11 Structure of pressure relief valve

The type TFW relief valve is of a horizontal arrangement and consists of valve casing (1), valve disc (2), balancing chamber (3), main servomotor (4), pilot oil chamber (5) and water inlet and drainpipe, and air supply valve, etc. The main servomotor and pilot oil chamber are connected integrally with the valve casing, meaning a small size, simple construction and a compact arrangement.

The cast steel valve casing is made up of two partially spiral-shaped ducting symmetrical to the vertical center line. Stay vanes in the valvo casing will turn the incoming water into vortex flow, thus achieving effective energy dissipation before the water is discharged into the tailrace. The valve is equipped with an air supply device to reduce vibration during operation.

The valve plug may be conical or round. They are made of cast steel with surfaces plated with chromium for rust prevention. Several balancing holes are provided on the valve plug to reduce operating pressure.

Sealing of the valve is accomplished by the close contact between the stainless steel overlaid seal ring on the valve plug and the removable phosphorous-bronze seal ring on the valve body. These two surfaces are precisely grinded and fitted to give satisfactory sealing.

b. The control system of the relief valve:

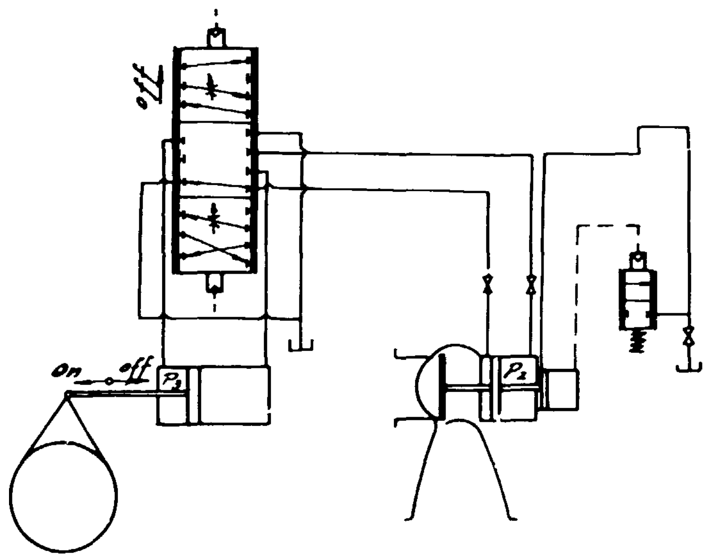


Fig. 6-12 Diagram of control system

The main feature of the relief valve control system is the employment of pressure oil for direct and complete control and operation. It also has a two-step closing device for the guide vanes.

The principle of the action of the control system is as follows:

- When the turbine load is constant, the piston of the main distributor is at middle position and the oil under pressure p, flows into the closing chamber of the relief valve via a throttle hole, while the opening chamber is connected to the drain. Because the oil pressure in the closing chamber of the main servomotor is higher than the water thrust on the valve disc, the relief valve remains in a closed position.

- When the turbine load is reduced by a small amount (within 15% of the rated output), the main distributor only moves upward a small distance, so that a limited amount of oil under pressure p, enters the closing chamber of the main servomotor to make the guide vanes close slowly, while the relief valve remains closed.

- When more load is rejected momentarily (greater than 15% of rated output), the upward motion of the main distributor piston is much larger and the relief valve opens quickly at the same time as the guide vanes close. The action of the two is synchronized with a zero time lag.

- As the turbine load increases, the oil under pressure p, flows directly into the opening chamber of the main servomotor. The relief valve remains at the closing position.

- "Stepped closure device": This device is thrown in when the relief valve starts to open fast. The relief valve accelerates to the position determined by the limiting ring and then proceeds at a lower speed, thus causing the guide vanes to close in two stages. The break point of the two step device can be easily adjusted on site.

Should the relief valve fail to work, the guide vanes have to be closed slowly to ensure that the penstock pressure rise will not exceed allowable limits.

2. Stability and transient process quality of the turbine regulating system employing relief valve.

When using the relief valve, the following problems are of great importance:

- Calculation of the maximum penstock pressure rise ξ maximum and the maximum turbine speed rise β maximum when the load is rejected.
- Calculation of the stability and the transient quality of the turbine regulating system when small disturbances occur.

For many years the practice has been to compute the two aspects of the same problem separately. That is, in the case of load rejection, methods such as Allievi formula was used for the calculation of the maximum penstock pressure rise ξ maximum and methods such as the S.M.S. formula for that of the maximum turbine speed rise β maximum. In the case of small load disturbances, the stability and transient quality calculations were carried out by simplifying the original high-order regulating system to a third-order system consisting of an ideal turbine, an ideal governor and rigid-column water hammer. Obviously, this method of calculation will not be suitable in cases of hydro-electric stations with a long penstock and a relief valve.

The present study treats the transient process of the regulating system on the basis of modern control theory and integrates the calculation for large perturbations and for small perturbations. It takes into account the non-linearity of the turbine elements and some important non-linear factors of the governor, such as the saturation characteristic of the frequency measurement device, stroke limit of daskpot, and dead band and stroke limit of the main distributor and main servomotor. Accurate results on both regulation guarantee and stability, as well as transient quality calculation, may be obtained simultaneously.

The computation has been presented in the paper "Application of relief valves in small hydro-electric stations" for UNIDO "The Second Seminar Workshop of Transfer of Technology on MHG", 1980.

Figure 6-13 shows the relative stability in a case using a relief valve as compared to that with a surge shaft for a unit equipped with Type XT-600 governor (mechanical type) when operating isolatedly.

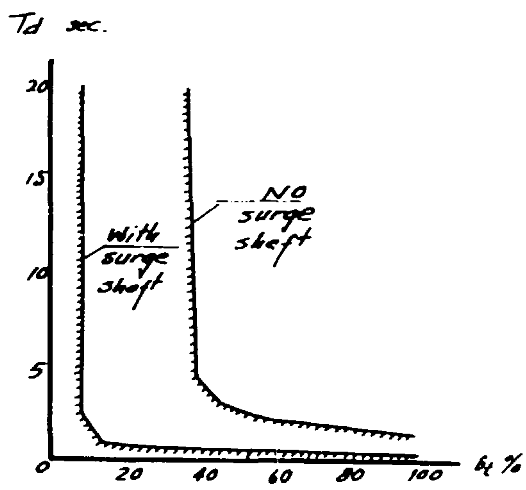


Fig. 6-13 Comparison of stability region of governor

The units run smoothly when they are connected to a large network but when each unit carries an isolated load, the stability under small perturbation mainly depends upon the performance of the governor; the larger the penstock, the higher the performance demand on the governor. Therefore, when making the choice to use relief valves instead of a surge shaft, emphasis should be put on the technical requirements of the governor according to the actual conditions of a given hydro-electrical station.

3. Serial design of the relief valve and its application.

The initial three sets of TFW-400 relief valves with all-oil control systems were successfully put into operation early in 1976 at Longyuan hydro station, Hunan Province.

Serial designing of the relief valve for different type turbines are underway. Seven models for various head ranges comprised of four diameters (ϕ 400, ϕ 600, ϕ 800, ϕ 1000 MM) were designed and manufactured. The main data is shown in Table 6-1.

Table 6-1 Main Features of TFW Relief Valves

Item \ Model	TFW 400/130	TFW 400/320	TFW 600/130	TFW 600/300	TFW 800/80	TFW 800/160	TFW 1000/100
Diameter Dx (MM)	400	400	600	600	800	800	1000
Max. stroke Yx (MM)	80	100	150	150	200	200	250
Nominal Hp (m)	130	320	130	300	80	160	100
Max. head Hmax = (1+ξ) Hp (m)	160	400	160	360	100	200	120
Max. discharge m^3/sec. Qx (corresponding to Hmax)	3.15	7.67	10.9	16.4	12.8	21.7	26.3
Weight of valve (ton)	1.2				5	8.5	

The range of application of the various relief valves are shown in Figure 6-14.

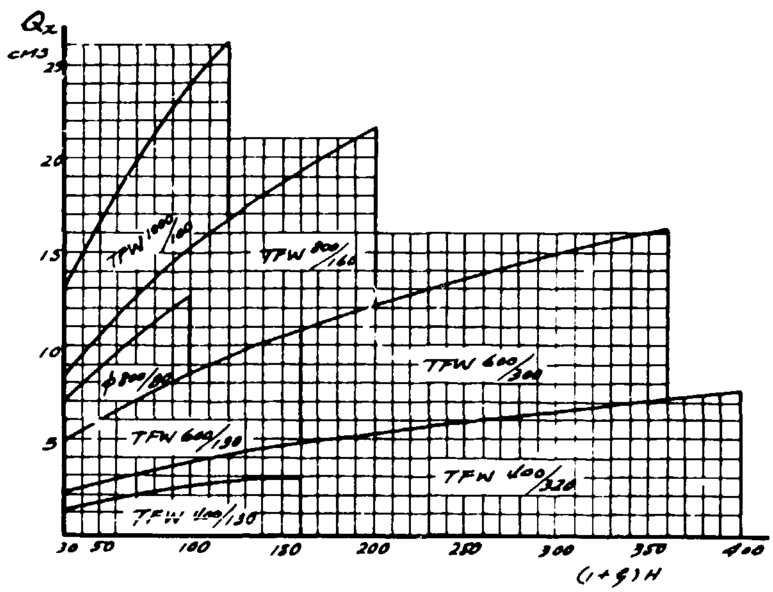


Fig. 6-14 Range of application of pressure relief valve

More and more projects came to use relief valves in place of surge shafts after the successful experiences at Longyuan. Up to the present, relief valves at a number of stations such as Jinggangshan (Jiangxi Province), Changtanhe (Guangxi Zhuang Autonomous Region) and Jixi (Fujien Province) have been put into normal operation successfully. Another 17 hydro-electric stations have been supplied with 33 relief valves.

A saving of investment of more than 5.4 million yuan has been achieved by adopting relief valves in place of surge shafts at these MHG units. The above savings do not include cases where topographical and geological conditions have not permitted the construction of a surge shaft. Investment savings in these cases are difficult to precisely evaluate.

In conclusion:

a. The relief valve with all-oil control systems exhibits advantages in sensitivity (no time lag), safety and reliability, simplicity in structure, convenience in adjustment and maintenance. A hydraulic interlock is built between the relief valve servomotor and the turbine servometer to allow accurate synchronization free from multi-functioning. Thus affording added safety to the penstock and the turbine, the "Stepped-Closure" device permits the selection of better parameters of regulation. Values of ξ and β can be determined from two independent time constants, i.e. the value of ξ from the turbine slow closing time TSS and value of β from the fast closing time Tm.

b. The relief valve of this control system will not act in cases of small perturbations. It is important to note that when selecting governors for a hydro-electric station equipped with relief valves, the governor temporary speed drop bt, time constant of the damping device Td and other related parameters should have the largest range of adjustment possible.

c. Because of the difference between the flow characteristic of the turbine and of the relief valve, a perfect match is difficult, with the result that a pressure depression often takes place at the initial interval of guide vane closing and at the end interval.

Uniform variation of flow in the whole penstock system can be attained by rational selection of opening-closing laws of the relief valve and guide vanes. Pressure depression can thusly be retarded or avoided.

II. Technical Innovation

A. Water resistor device.

Application of a water resistor device takes the place of a surge shaft. Successful results have been obtained by some hydro power stations using a pressure relief valve instead of a surge shaft but it has its limitations. It is only applicable to medium or small hydro power stations with a medium or high head. If the hydro plant has a low head and a big flow, this would cause over-dimension of the valve, complications in manufacture, high cost of outlet structure, etc. Besides, it is also unsuitable to use the pressure relief valve in stations where the water is high in silt content.

In 1962, a water resistor device was first used at the Wang Jia Chang Power Station (installed capacity 3 x 1,360 kW) of the Hunan Province to replace the surge shaft in order to overcome the difficulty of building a surge shaft at the foot of the dam. The total cost in building the water resistor device was 30,000 Yuan while the cost of building a surge shaft in the original design would have been 110,000 Yuan. Since then, the water resistor device has been recommended to some other power stations in China and certain improvements have been further carried out.

This device is similar in principle to the "load balance", which is studied abroad. Calculations should be made of the raise in pressure and speed if the load is suddenly rejected to see whether to use a water resistor device or not in a hydro power station. The water resistor device should be applied only when the calculating value exceeds the allowable value stipulated by technical regulations.

When the load is suddenly rejected and the active capacity in the generator's stator simultaneously disappears, the water resistor should be put into operation at that moment by the starting elements as a pretend load. Therefore, the speed governor is not shut down, the guide vane is only shut a little and only transition processes with little fluctuation are produced in the pressure penstock and the unit. When the unit is stabilized after loading up the water resistor, it can be unloaded gradually and the unit shut down normally. By this operation, the pressure and speed raise can be guaranteed within the permissible range stipulated by regulations.

If the loading up of the water resistor and the disappearance of he active capacity in the generator's stator happens at the same time, the value of pressure and turning speed will not be raised. In fact, due to the impossibility of synchronism in operation of the starting elements, the loading up of the water resistor always lags behind the disappearance of the active capacity in the generator. When the time lag between the loading up of the water resistor and the disappearance of the active capacity in the generator lengthens, the effectiveness of reducing the pressure and turning speed raise will be decreased. On the contrary, the sooner the water resistor is loaded up, the more obvious the effectiveness will be. Therefore, it is desirable that the starting elements for this device possess high sensitivity.

According to the analysis of operation in the hydro power stations, it is realized that accidents might have happened in the generator or in the water resistor when the water resistor is put into operation. Therefore, it is assumed in the design criteria, that one unit is suddenly unloading entirely and not loading up the water resistor. In this case, it should be guaranteed that the value of pressure and turning speed raise do not exceed the permitted value stipulated by the regulations.

It is rare that inner accidents happen to both units at the same time. In this emergency case, the pressure raise is permitted to exceed the allowable value stipulated by regulation but is limited by the pressure value at which the penstock will be destroyed. (The approach of prolonging the closing time Ts may be adopted).

In order to prevent the rejection of the water resistor, it is necessary that a spare water resistor device be installed but special attention must be paid to its maintenance and repair during the operation.

According to the result of experiments in three hydro power stations, the following points can be realized:

- The water resistor can take the place of a surge shaft in operation.
- The "time lag" of putting the water resistor into operation affects its effectiveness.

A further study is needed to improve and perfect this technical innovation.

B. Third harmonic voltage excitation system.

This is an updated type of excitation. The study, trial-manufacturing and probation was started in the 1960s in China. Fairly good results have been obtained.

At present, there are two categories of third harmonic voltage excitation in China: one for a unit less than 500 kW in capacity, which generally uses single phase harmonic winding in providing exciting current to the magnetic field of the generator through non-controlled silicon rectifiers. Though simple in structure and cheap in cost, its shortcoming is its instability in parallel operations and therefore has not been used often.

The other category is for generator sets greater than 500 kW, all of which use SCR as the rectifying component. Types of harmonic winding involve a three phase and a single phase integrated with a fundamental wave winding, etc. In China, there are three provinces where success has been achieved on probation with this type of excitation. Three kinds of generators with a capacity of 1,250, 630 and 800 kW, respectively, have been built and erected in 5-6 stations and operated for 5-8 years with good stability, not only in isolated operation but also in various forms of parallel operations. The 630 kW set of this type produced in Gansu Province has been used in over 5 sets.

According to a primary summary, the unique advantages of this excitation may be described as follows:

1. Economic viability:

Take a 630 kW generator for illustration, the type of which is TSW 143/39-12 (T indicates synchronous generator, S-hydro, W-horizontal, 143/39 - diameter and length of stator laminated sheet in CM, 12 - no. of poles). The excitation facility originally used for this generator is a d.c. exciter and an old compound excitation regulator. Later on, the magnetic poles of the motor were revised and a set of additional third harmonic winding was added to the slot of stator with the stator sheet diameter unchanged. A set of specially designed SCR and an automatic regulator was fitted to the generator. The cost of this new excitation system is much lower than the old one. The cost of the original set is 100%; the cost of the new set is 87%. If only the cost of the excitation system is accounted for (with generator proper excluded), the new type is only 58% of the old one in price. Besides, the harmonic voltage excitation saves about 50% on copper than the original one. Even in comparison with the generally used SCR excitation with a transformer at an outside terminal of the generator, the harmonic voltage excitation can save both cost and copper.

2. Good technological performance:

In addition to advantages of any kind of SCR excitation, there are still some marked features existing in harmonic voltage excitation such as the excellent ability of self-forced excitation and the very little influence on it of fluctuation of frequency, etc.

3. Less maintenance and repair work:

Another benefit to smaller stations, it requires less maintenance and repair work in comparison with the d.c. exciter which often requires mechanical processing in dealing with the erosion of commutator.

However, the design and calculation work of this type of excitation is rather large. The generator proper can be revised, if necessary. The theory of this type of excitation has not matured. China, at present, is still in the experimental stage.

C. Guaranteeing quality and raising the reliability of the power supply.

The quality demands of the power supply of local grids is specified as: fluctuation of cycle $< \pm 1$ Hz, fluctuation of voltage $< +5\%$ or -10%.

MHG stations with a unit capacity larger than 500 kW are usually equipped with an automatic governor control and a voltage regulator. Under normal conditions, both the voltage and the cycle would be kept in the allowable range. As for stations with a unit capacity less than 500 kW, the governor is controlled manually and the excitation system is either hand controlled or automatic. If the station operates isolatedly, the ranges of fluctuation of the cycle and voltage can be large.

Following the rapid development of MHG stations, small power networks have arisen in many places, helping to raise the reliability of the power supply. Usually, the installed capacity of a grid on a county level ranges from several thousand to ten or twenty thousand kW. Through practice, many countries have accumulated these rich experiences which may be summarized as follows:

1. In order to raise the reliability of power supply, the establish-

ment of a local small grid is necessary. Integration of a local small grid to the state grid is advisable if the necessary conditions are satisfied.

2. The local small grid must be equipped with several big units in order to bear the load impact and to stabilize the running of the grid.

3. The local small grid must have a sufficient installed capacity and also enough spare capacity.

4. The task of each power station in the grid must be reasonably allocated by strengthening the dispatch work.

5. The structure of the network should be improved to raise the quality of the transmission lines.

6. Relay protection may be improved by dividing the relay protection into three grades, i.e. county, commune and production brigade, in order to minimize the area possibly affected by accidents.

7. Improving communication: At present, all power stations without feeding line 35kV are equipped with communication equipment which connects with the county's dispatching room.

III. MHG personnel training

There are various channels for technical training of MHG personnel. They are:

1 School training:

- Institutes of higher learning: There are nearly ten colleges and departments in the universities which specialize in the field of water resources and hydro power. There are also many departments in the engineering faculties whose specialities are also concerned with the hydro power to some extent. Graduates (Bachelor Degree) from these schools usually become the high level technical forces in exploration, design, construction, installation and research of MHG development.
- Secondary technical schools: They are usually established by the province or municipality and are widely spread out in each province or prefecture (where water resources are abundant). The graduates from the secondary technical school are usually sent to

the Division of Water Conservancy in the province, prefecture, or county. They are the main force which work in the MHG stations on the county level.

- Technical school for workers: The students are trained to be skilled workers in the field of construction, installation, operation and maintenance.

2. Training course:

Training courses are on different levels. Usually, the state level training course is sponsored by the Ministry of Water Conservancy and the participants are nominated by the province. In most cases, they are the backbone personnel of the province.

The training courses sponsored by the province are attended by skilled technicians who take part in the county water conservancy section.

These training courses are run periodically according to the demand.

3. Training through practice:

The new MHG plants send new workers to old plants for training through practice. After training, the new workers are sent back to the new MHG and work as apprentices.

4. On-the-Job training.

IV. Reduction of cost of MHG

According to practices in China, there are many approaches to reduce the cost of MHG:

- reasonable planning and selection of site;
- reasonable selection of the type of exploitation and layout of the project;
- multi-purpose utilization
- serialization, standardization and popularization of machines and equipment;
- adoption of the results of research and development such as pre-stressed concrete pipes, pressure relief valves, etc.;
- good design of electrical schemes and network structures, as well as voltage selection.

All these approaches will result in reducing the cost of MHG. As for the civil works of the MHG project, the adoption of available local materials is also an effective measure to cut down MHG cost. The Chinese people have accumulated a lot of experience in constructing water conservancy projects as well as water power projects. Besides the earth dams, there are several other dam types of simple construction which are attractive in their savings of cost.

The dam is the main structure used to obtain the water head in the "dam type" hydro plant. However, there are also dams erected in the "diversion type" hydro plant but the function of those dams is mainly to improve the condition of intake.

The dams in MHG projects are usually of the overflow type used to discharge the flood in order to save the structures for flood releasing. These low dams are termed as weir with a height less than 5-6 m. The Chinese people have a long history in building dikes and dams in their struggle against disasters from floods and drought and have accumulated abundant experience. Besides the earth dam and stone masonry dam, they have also innovated some dams of simple construction. This is helpful in the study for reducing the cost of MHG. Some possible dams using local available material are described below.

A. Earth dams.

Earth dams are the most popular dam types in China. The earth dams permit the use of local available material and facilitate construction by the people's masses due to use of simple machinery. If the dam material is available, the earth dams are adaptable to almost all kinds of foundations anywhere, due to their low requirements.

In the construction of an earth dam, various embankment material has been used: loess, alluvial clay, gravelly cohesive soil, sand and gravel, fine sand, etc. Furthermore, in provinces with humid and rainy climates in Southern China, lateritic soil has been frequently used. This soil (fraction of clay particles is high) is usually used as the impervious core of the earth dam. Fig. 6-15 shows the type of earth dam.

In regions where sand and gravel is insufficient but cohesive soil is abundant, homogeneous dams have been built in an overwhelming majority. The homogenous earth dam, simpler in construction and able to be compacted by simple tamping equipment, has been popularly adopted in China, especially in the regions where there are deep deposits of gravelly cohesive soils and loess. Among the earth dams completed, 65% of them are homogeneous earth dams.

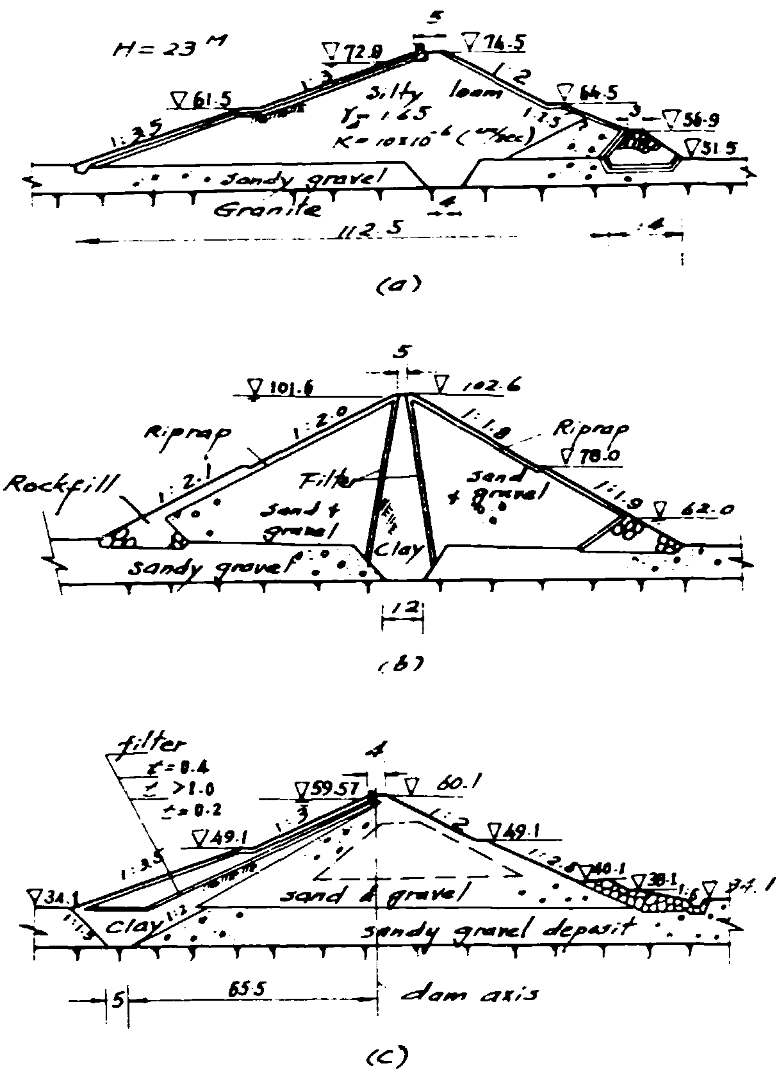


Fig. 6.15 Type of earth dam
(a) Homogeneous
(b) Central core
(c) Inclined core (upstream)

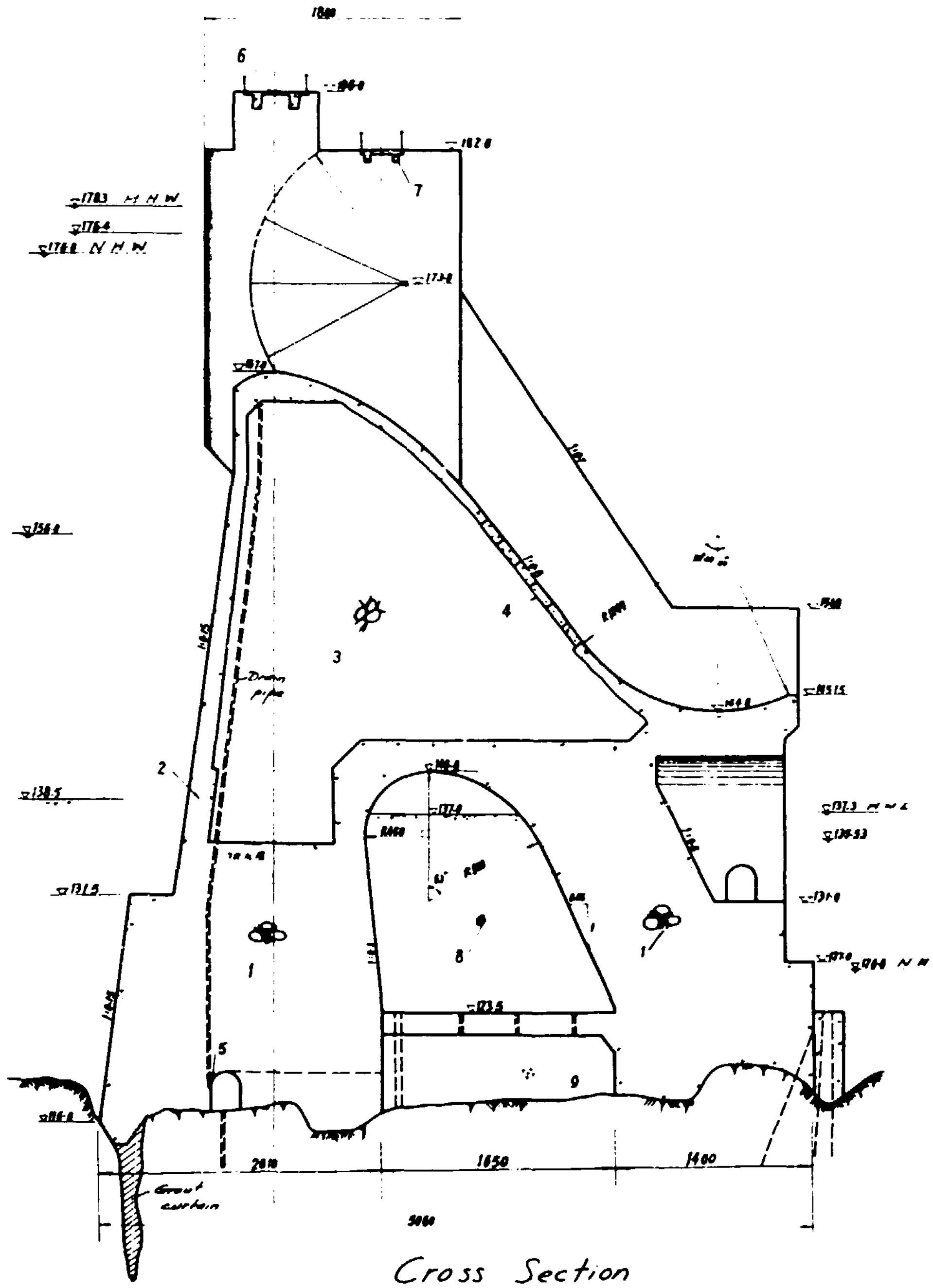
B. Stone masonry dam.

China has a long history in building stone masonry dams and has accumulated much experience. Stone masonry dams have less cement consumption than concrete dams by 40-50% and also consume less quantity of timber. The construction techniques of stone masonry dams are easy for the people's masses as construction can be carried out with fewer, simpler equipment which is easy to operate. In comparison with earth dams and composite dams, the stone masonry dam is more favourable for tackling the flood either during construction or when in operation. During flooding, a stone masonry dam can even be overflooded in the construction period. Generally, the effective working days per year of those dams are many.

By statistics, the number of stone masonry dams built in China is second to earth dams. For example, in Hunan Province there are seventy odd MHG plants with a total installed capacity of 413.5 mW (about 60% of the total installed capacity of MHG in Hunan Province) which adopted stone masonry dams. Among those stone masonry dams, 60% are gravity dams.

Figure 6-16 shows the cross section of the Yanwotan masonry hollow gravity dam, Hunan Province. The geological conditions are favourable; rock outcrops on both abutments. The depth of sand and gravel deposits is 8-10 m. The length of the overflow masonry hollow gravity dam is 59 m and the maximum height of the dam is 66 m. The width of the hollow cavity is 16.5 m at the bottom. The height of the cavity is 24 m. The cavity area is 15% of the dam cross section. The foundation of the cavity part is not necessarily stripped to speed up the construction and reduce the uplift pressure. The construction period of the Yanwotan masonry hollow gravity dam was rather short. The dam body was raised above the low water level in only one dry season. During high water season, the dam body has been overflowed seven times (total 99 hours) but only five working days have been interrupted. The maximum overflow depth is 9 m. The dam was safe. The construction period of this dam was 20 months which covered two dry seasons and one high water season.

In a narrow valley with favourable geological conditions, the stone masonry arch dam can be built with thinner dam cross sections and less volume (savings of 40-50% in stone masonry and about 40% in cement, in comparison with gravity dams). Besides, in the mountainous regions which have wide river valleys, some stone masonry multiple arch dams have been constructed. In comparison to the gravity dam, a 30-50% volume of stone masonry can be saved. The design and construction of the gravity dam, arch dam and multiple arch dam is available in various books on dam engineering and will not be described in this Chapter.



(1) 100# concrete
(2) 150# concrete facing
(3) 50# cement morter laid rubble
(4) 100# Precast concrete block
(5) Drainage gallery
(6) Working bridge
(7) Access bridge
(8) Backfill waste
(9) Unremoved sand and gravel deposit

Cross Section

Fig 6-16 Yanwotan hollow Gravity dam

Unit Elevation ; m
Dimension cm

C. Dams of simple construction.

1. Hard shell dams.

a. Construction of hard shell dams:

Such dams are composed of dry-laid rubble or dumped sand and gravel as its main part and wrapped by rubble laid in cement mortar or by concrete as the hard shell, in order to prevent seepage and erosion. In 1965, this type of dam was developed in Guangdong Province and still proves satisfactory. In 1967, the same type of dam with a dry-laid rubble hard shell was experiementally constucted in Zhejiang Province, see Figure 6-17. Hard shell dams are suitable as low weirs on rock foundations in places with abundant sand and stone but insufficient soil.

As the body of hard shell dams is loose material and uncemented, i.e. dry laid rubble, rockfill or sand gravel, whenever any part of the hard shell is cracked, it is easy for the entire dam body to collapse. Attention must be paid to both the structure design and the supervision of dam construction.

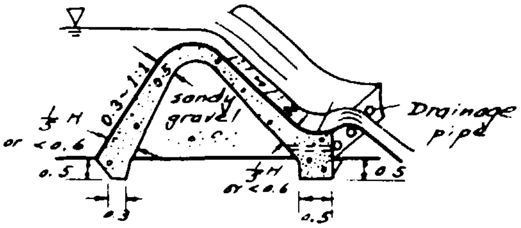


Fig. 6-17 Masonry hardshell dam (unit m)

The foundation of the cut-off wall which also supports the hard shell must be properly treated, extending 0.5 m deep into the sound rock. It is not necessary to treat the foundation of the other parts of the dam. For example, a dam of 17 m height in Guangdong Province has an overburden of 6 m deep. Only the sand and gravel at the cut-off wall have been removed. The overburden under the dam core is untreated. However, quality control of the dam core must be well supervised to avoid the unallowable settlement of the core which, as a result of separation between the core and shell, can cause damage to the dam.

b. Structural design:

In view of the convenience of construction and the reduction of the lateral pressure of the core, the slope of the upstream shell is selected as 1:0.3-1:1. The slope of the downstream shell is rather flat, usually taken as 1:1-1:2, in view of the overflow. It is preferable to form the arch action of the stone masonry hard shell. In this case, the shell will stand no matter what, - the settlement of the core is. The slope of the shell may be designed even more flat if it is necessary.

The stability calculation of this dam is basically the same as with the gravity dam. As the materials of shell and core are different, different specific weights of material must be taken into consideration and also different friction co-efficients in the foundation used, respectively. The core material is considered permeable. Uplift forces acting upon the core are neglected. The placement density of dry laid rubble is $\gamma_1 = 2.1 T/m^3$ (voids ratio $< 25\%$), of sand and gravel $\gamma_1 = 1.7-1.8 T/m^3$, of stone masonry shell $\gamma_2 = 2.1-2.2 T/m^3$.

The hard shell is supported by the dam core. The thickness of the shell is 0.6-1.5 m in most cases (sometimes 2.0-3.0 m is adopted for rather high dams). The outer shell is made of rubble laid in cement mortar plus the cement mortar facing, or rubble laid in cement mortar or concrete plus re-inforced concrete facing, see Figure 6-18. The thickness of the re-inforced concrete facing is at least 0.2-0.3 m and will be increased at the curvature parts. Both the longitudinal and transversal re-inforcement steel bars are 6-9MM. The spacing of contraction joints along the dam axis is not allowed to exceed 40 m.

At the downstream toe of the shell, there are drainage holes with inverted filters arranged beneath the bucket in order to reduce the seepage pressure on the shell. The holes are spaced 3-5 m apart with a diameter of 10-15 CM. The inverted filter has three grades to prevent taking out the core material or blocking of the holes.

In view of increasing the rigidity of hard shell, reducing the deformation and resisting the possible lateral pressure of the filling materials, it is preferable to build a stone masonry partition wall spaced at 10-15 m along the dam axis inside the hard shell. The thickness of the wall is 1-1.5 m (H≮10 m). It has the advantage that if some emergency happens in some segment of the dam, it will not effect the safety of the dam on the whole length.

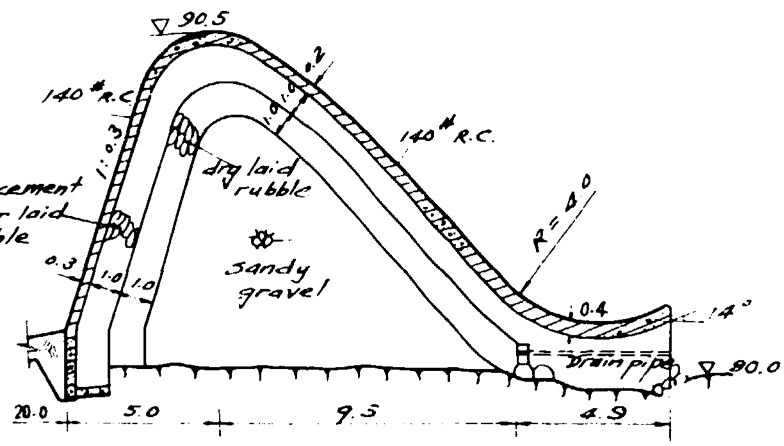


Fig. 6-18 Cross section of masonry hardshell dam (unit M)

c. Construction techniques:

After the foundation treatment is completed, the rubble laid in the cement mortar of the hard shell begins to lay up. There is a 10-30 CM concrete cushion on the rock foundation for a major dam in order to obtain good contact between the rock foundation and the masonry. The joint of rubble must be full with cement mortar. The lift of the shell must be done 3-4 days in advance of the core material in order to be strong enough to withstand the lateral pressure from the core material.

According to experience, the porosity of dry laid rubble or sand and gravel of the core material is more than 30%. Its placement density is only 1.6-1.8 T/m^3. River sand is usually used to fill the voids by sluicing and thus to increase the placement weight by 10-15%. The sluicing of sand should be carried out layer by layer. The stones are first laid in a layer 30-50 CM thick. Then, a layer of sand 5-7 CM thick is spread on top of it and sluiced to fill up the voids between the stones.

Table 6-2 The reference dimension of the dam with a stone masonry outer shell

Discharge per meter CMS/m	Height of weir (m)	Dimension of cross section		
		Top width (m)	Upstream Slope	Downstream Slope
< 3	< 3	1.5-2.0	1:0.75-1:1	1:1.3-1:1.5
	3-5	0	1:1	1:1.5-1:2.0
3-6	< 3	2.0	1:0.75-1:1	1:1.5-1:2.0
	3-5	2.0-2.5	1:1	1:2.0-1:2.5
6-10	< 3	2.0	1:0.75-1:1	1:2.0-1:2.5
	3-5	2.0-2.5	1:1	1:2.5-1:3.0

2. Dry laid stone dams.

The dry laid stone dam does not need cement materials. The dam is mainly composed of rockfill or gravel or sand and gravel, with dry stones at both the upstream and downstream slopes. This is a type of dam which makes full use of local available materials. It also allows the people's masses to construct the dam by themselves with a low investment. Fengshun county of Guangdong Province has a history of several hundred years in building this kind of dam. Some of them have been in good service up to now after experiencing many flood attacks during this long history. In Chongjiang County of Sichuan Province, the 2-3 m high overflow dam built of dry laid ashlar (named "straw raincoat dam") has a history of more than 500 years. In Yuanping county of Shanxi Province, the dam built of dry laid gravel has a history of more than 800 years.

At Guangdong, Zhejiang, Fukien, Sichuan, and Henan Provinces, there are various types of dry laid stone dams built using local available materials and adapting to the local conditions. These kinds of dams are more adaptable to larger deformation of foundation and can be built on sand and gravel foundations as well as on sand or earth foundations.

During construction, the demand on diversion of river water and drainage of foundation pits are relatively low. The laying of the stone can even proceed under water where the depth is less than 0.5 m. The foundation excavation is rather simple; only silty soil and sand and organic material will be removed. The shortcoming of this dam is its weakness in integration and seepage. To overcome these weak points, the selection of stone material and the workmanship of dry laying must be strictly supervised.

The trapezoidal cross section is usually adopted for this type of dam, see Figure 6-19. The dimension for reference is shown in Table 6-3. Figure 6-20 shows several types of dry laid stone masonry dams.

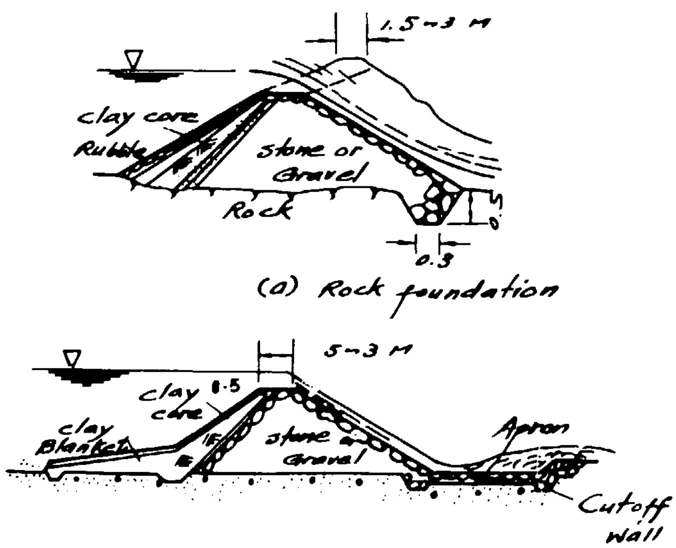


Fig. 6-19 Cross section of dry laid rubble dam

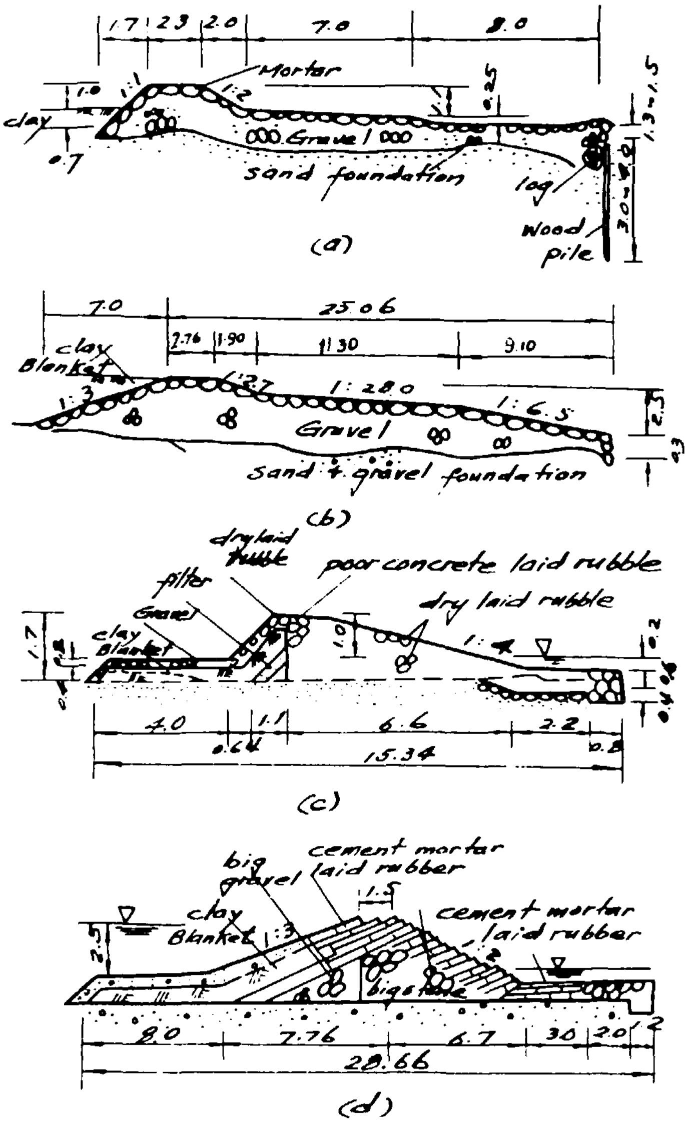


Fig. 6-20 Types of dry laid rubble dam

Table 6-3 Dimension of Dry Laid Stone Dam for reference

Foundation	Height of dam(m)	CMS/m	Width of top (m)	Slope	
				Upstream	Downstream
Rock Foundation	< 2	< 3	1.5-2.0	1:0.5-1:0.75	1:1.5-1:2
Rock Foundation	< 2	3-6	2.0	1:0.75-1:1	1:2-1:2.5
Rock Foundation	2-5	< 3	2.0	1:0.75-1:1	1:2.5-1:3
Rock Foundation	2-5	3-6	2.0-2.5	1:0.75-1:1	1:3-1:3.5
Sand and gravel foundation	< 2	< 3	2.0	1:0.75-1:1	1:3-1:3.5
	< 2	3-6	2.0	1:0.75-1:1	1:3.5-1:4
	2-4	< 3	2.0	1:0.75-1:1	1:4-1:4.5
	2-4	3-6	2.0-2.5	1:1	1:4.5-1:5

a. **The seepage barrier for dry laid stone dam:**

The main considerations in dam design of this type are: prevention of seepage from the dam embankment and foundation; stability of the dam slope; and prevention of scouring of the downstream face.

- Rock foundation: as seen in Figure 6-19A, page 151, an impervious sloping clay core is used with a slope of 1:1.5-1:2.0. The design of the thickness of the core is 1/4-1/6 head and not less than 1 m at the bottom and 0.5 m at the top. At the upstream side, the core is protected by a layer of 15-20 CM of gravel and then a layer of 20-40 CM dry laid rubble riprap. Between the clay core and the dam body are 2-3 filter layers. If the river is rich in silt and those low dry laid stone dams have no seepage - barrier, the dam is permitted to seep during the first and second years. The voids will fill up with the silt from floods and eventually, a natural impervious sloping core and blanket will be formed at the upstream face of the dam.

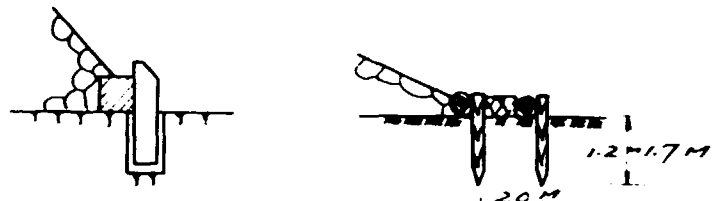
- Foundation with over-burden: On this kind of foundation, a clay blanket is also required in addition to the impervious sloping core, as shown in Figure 6-19(b). The length of the blanket is about 3-5 H and the thickness of the blanket at dam heel is 1-1.5 m, at the upstream end of the blanket is 0.5 m. There is a cut-off at the end of the blanket.

b. **Apron:**

On unrocky foundations, an apron must be provided at the downstream toe. The length of the apron is taken as 2-5 times the height of the dam or 1.5 times the upstream water depth. The thickness will be more than 0.5 m. If the apron is made of dry laid stone, the rubble must be tightly compacted and interlocked. Downstream of the apron, a protection must be made of dry laid boulders or timber cribs with a rockfill having a length 3-5 times the water head.

c. **Foundation treatment:**

The key to foundation treatment of this dam is the treatment of the downstream part which is very important to the stability of the dam. In general, on a rock foundation, a 0.5 m cut-off trench is excavated and backfilled with concrete masonry, as shown in Figure 6-19A. Another measure is to erect stone columns spaced every 3-4 m into the cut-off trench and also a row of cut stone just upstream of ten columns, as shown in Figure 6-12A. On soil foundations, after foundation stripping, a group of timber piles with a spacing of 1 m should be driven 1.5-2.0 m into the ground and a row of logs put horizontally just upstream of the piles as shown in Figures 6-20A and 6-21B. In addition, a downstream apron must be made to protect from scouring.



(a) Rock foundation

(b) Earth foundation

Fig. 6-21 Treatment of the toe of dry laid rubble dam

d. Quality control:

The construction must be carried on meticulously. Small sized stones are prohibited. Big sized stone blocks 0.6–1.0 m in length and with a weight exceeding 150 kg per block will be placed at the exterior slope, dam heel, toe, crest and - other parts suffered to erosion. Sound rocks will be selected which are durable to wearing and weathering. The stone blocks at the exterior slope must be very close together. Joints should be staggered in position in order to obtain a good integrity.

The construction schedule is usually to build the two abutments first and then build towards mid-stream. Upstream and downstream can be proceeded simultaneously. The upstream parts may be slightly higher than the downstream parts. They will be connected at the top of the dam and compacted rightly by sound stone blocks.

After the dam is put into operation, it is possible that settlement will occur, especially after the first flood. A large amound of seepage may also occur causing some stone blocks to settle or loosen and even be washed away. Therefore, inspection and maintenance must be reinforced. Careful inspection must be carried on before and after each flood. Loose and washed away stones must be repaired quickly.

Dry laid stone dams are widely used in small scale hydraulic schemes. Figure 6-20 shows four types of this dam. D is the "straw raincoat" dam. Its characteristics are that the cut stones are placed inclining upstream so that the cut stones are not easily washed away and can even be placed more compactly. The angle of inclination is 1:3-1:4. Figure 6-20C shows a trapezoidal cross section which is more convenient to build.

3. Overflow earth-rock dam.

The overflow earth-rock dam is composed of earth and stone. It is a popular type among those dams of simple construction. Since 1956, the people's masses in Wenling County, Zhejiang Province, have built many overflow earth-rock dams on rock foundations, called the Chaokuche type dam. It is adaptable to such local conditions as narrow valleys, insufficient soil materials, the need for large volumes of excavation for chute spillways, etc. For example, the 20 m high Chiaohsia dam of the Chaokuche type was completed in 1966, see Figure 6-22. Its downstream facing is a dry laid stone masonry with an exterior slope of only 1:0.2. Upstream to the dry laid stone is the rockfill. A sloping clay core is then laid on the upstream face of the rockfill. Filter layers are placed between the sloping clay core and the rockfill. The crest is protected by cut stone masonry laid in cement mortar so as to permit the overflow from floods, see Figure 6-23. Since the river bed is made of hard granite, there is no facility for energy dissipation at the downstream of the dam. After several years operation (the overflow depth was less than 1.0 m), the performance is still normal.

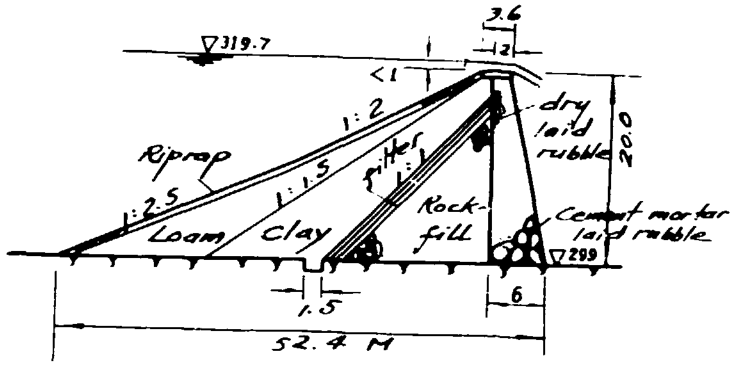


Fig. 6-22 Cross section of Laxia "Composite dam"

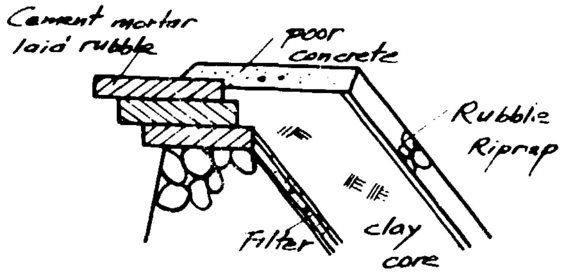


Fig. 6-23 Structure of the top of "Composite dam"

The "Chaokuche type dam" is adaptable to narrow valleys with rocky foundations. Its downstream facing is dry-laid stone blocks with an interior slope of 1:0.1-1:0.2, subject to a free fall. The volume of dry laid stone blocks and rock-fill is about 65-75% and 30% earth. During construction, the dam body may be utilized as the flood pass. Consequently, no diversion struction need be provided.

The downstream dry laid stone blocks sustain the lateral water and soil pressure from upstream. A fresh and sound rock foundation is advisable. The weight of each stone block must exceed 300 kg. Cut stone with a regular surface is preferable.

Table 6-4 The dimension of Chaokuche type dam for reference

Height of dams	Over-flow depth H	Top width of dams b	Top width of dry laid stones b_1	Bottom width of dry laid stones B_1	Bottom width of rock fill B_2	Total Bottom width B	Thick-ness of each filter layer	Total thick-ness of the filter layers	Height of upper upstream slope h_3	Up-stream slope: Upper slope	Up-stream slope: Lower slope
	(M)	(M)	(M)	(M)	(M)	(M)	(M)	(M)	(M)		
10	1	2.5	1.5	3.5	10.5	14.0	0.2	0.6		1:1.5	1:1.5
15	1	2.5	1.5	4.5	15.5	20.0	0.3	0.9	5	1:1.5	1:1.75
20	1	3.0	2.0	6.0	20.5	26.5	0.4	1.2	10	1:1.75	1:2.0

The joint of the stone blocks should be staggered. The porosity of the rockfill are specified less than 30-40%, with a placement density of 1.6-1.7 T/m^3. Filter layers are placed between the sloping clay core and the rockfill. The thickness of the filter layers should be greater than those of the earth dam in order to fit more deformations. The quality of craftmanship and dry laid stcne blocks of the downstream facing must be strictly supervised - and regularly inspected.

The dimensions of the cross section of a Chaokuche type dam are given in Figure 6-24 and Table 6-4 for reference. The height limitation of a Chaokuche dam is 20 m. Water head over the crest should not exceed 1.0 m. When the height of the dam exceeds 15 m, a variable upstream face with two slopes is recommended.

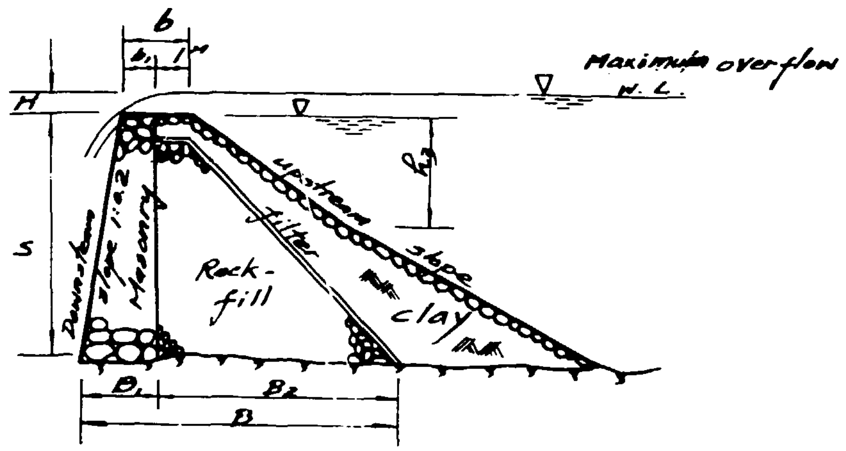


Fig. 6-24 Cross section of Chaokoushe "Composite dam"

4. Rockfill dam.

Rockfill dams are not generally designed as overflow types. The overflow rockfill dams without facing are only used as weirs below 3 m in height, as shown in Figure 6-25. The upstream slope of the weir is 1:2-1:3. The downstream slope is 1:8-1:12. This implies a rather large volume. It is, however, still easily destroyed by flood. Therefore, this low overflow rockfill weir should be built on sand and gravel riverbeds when rock material is abundant. Its building is rather simple and the cost is low.

Longitudinal partition walls with a thickness of 1 m made by rubble laid in 50# cement mortar are provided at 10-15 m apart in the direction of river flow (see Fig. 6-25). If the river deposit is shallow, the middle partition wall should extend into the rock.

If the river is rather wide, transverse partition walls are also added. The spaces between the longitudinal and transverse partitions are filled with rockfill, gravel, and coarse sand and then compacted layer by layer. The weir surface stone masonry must be smooth and sound. The weight of the individual blocks should not be less than 50 kg. In order to prevent the scouring of downstream, a dry laid stone block apron may be provided. The length of apron is 2 - 5 times the height of weir, the thickness of apron is 0.5 m.

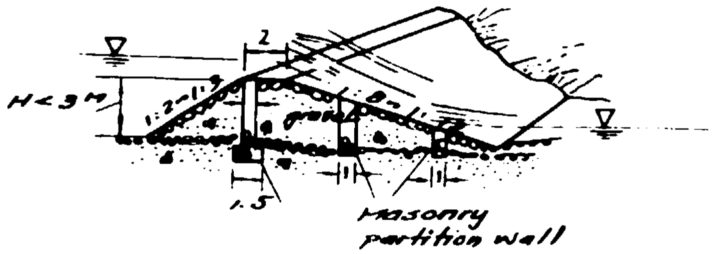


Fig. 6-25 Low overflow rockfill dam