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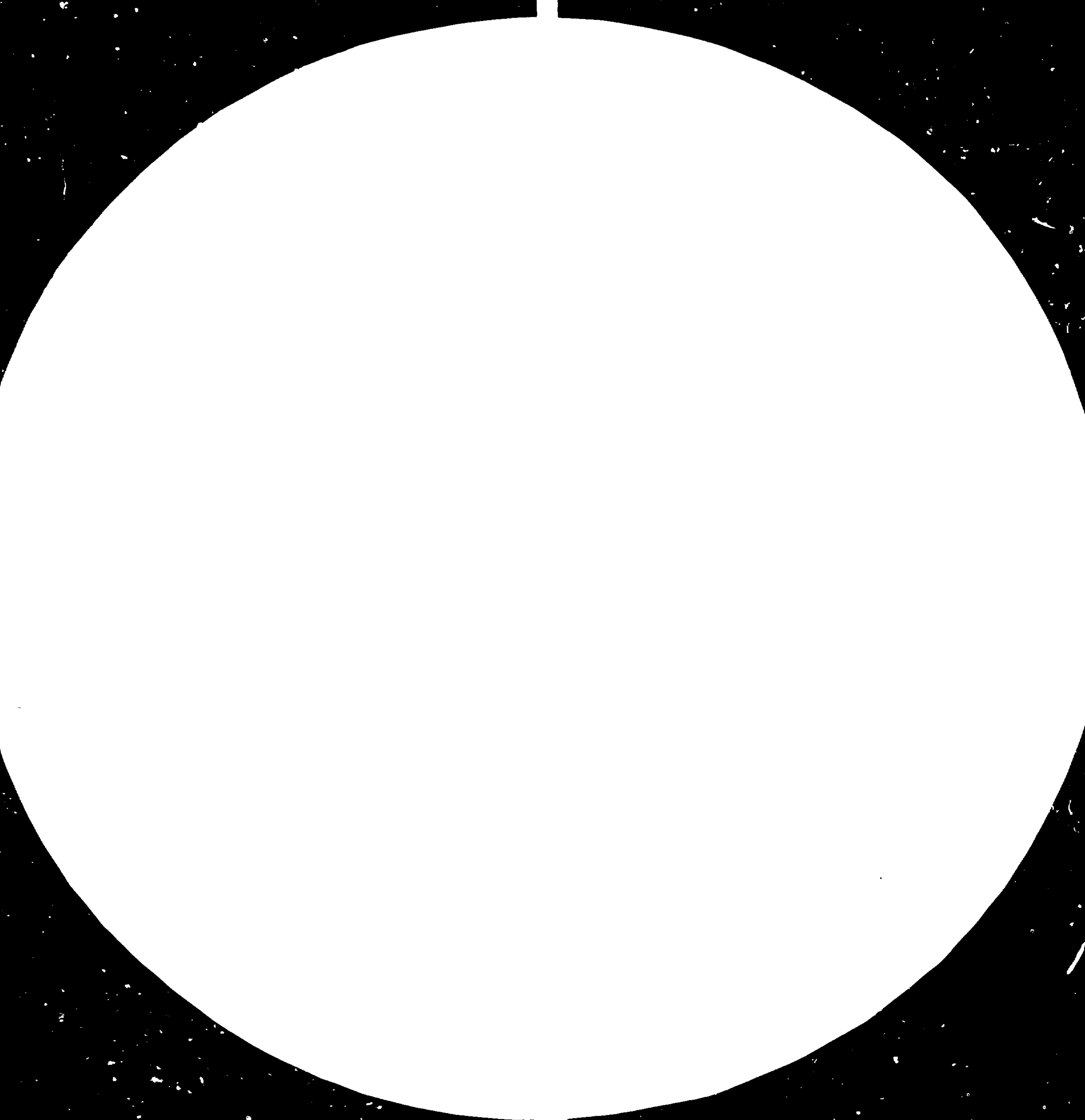

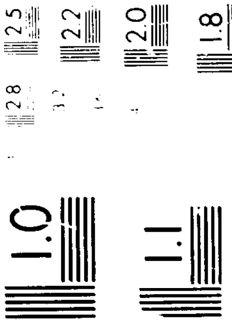

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EARTH DAM PROJECTS IN SMALL HYDRO-POWER CONSTRUCTION IN HUBEI PROVINCE*

by

Chen Yenlu**

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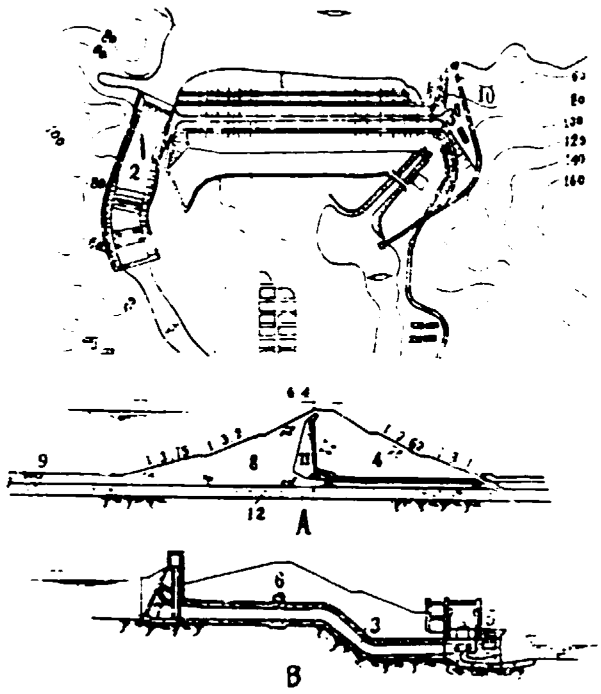
I. Preface

Hubei Province, situated in the middle reaches of the Chang Jiang River, has a total natural area of 187.500. square km in which there are 1.193 small and medium-sized rivers in addition to the Chang Jiang River and the Han River running through. A series of dams and reservoirs has been built since liberation (1949) on these small and medium sized rivers. According to the statistics, 6098 reservoirs had been, by the year of 1978, set up within the whole province. Among them 46 have a storage capacity above 100 million m^3 (Dan Jiang and Huang Long reservoirs and power stations excluded), 214 ranging from 10 million to 100 million m^3, 1041 ranging from 1 million to 10 million m^3 and 4797 ranging from 100.000 to 1 million m^3. Most of these dams were roiled-fill earth dams built with various types of local soils.

In accordance with the different features of each of the rivers and requirements for multiple-purpose development, site selection, geological exploration and layout were conducted in a serious manner before building the dams. After many years' operation, every reservoir has placed to various degrees its respective role in flood prevention, irrigation, power generation, navigation, aquatic breeding and so on. In the recent 10 years and more, especially in the past few years, rapid development of small hydro-power stations by building reservoirs upstream to regulate the river flow has enabled the province to acquire a total installed capacity of about 500.000 kw. this is a remarkable achievement in agricultural and industrial development at the commune and county levels within our province.

Figures 1 and 2 show the layouts for the earth dams of the Fushui and Bailian He Reservoirs respectively, with the cross-section views of the earth dams and that of the conduits for power generation. Both reservoirs are for flood prevention, irrigation, power generation, navigation and so on. In line with the characteristics of both geology and topography, spillways, slide ways or boat lifting facilities, power conduits or tunnels, irrigation canal, fish ponds, fish screens were well arranged in order to make the masures suitable to the local conditions.

Figure 3 shows the layout of the earth dam of Zhang Jia Zui Reservoir completed recently in our province. The purpose of building this reservoir is chiefly for irrigation and power generating. Both service and emergency spillways were arranged to guarantee the safety of the dam. All the conduits with the exception of irrigation conduits, were embedded underneath the dam that they can play the dual functions of river diversion and power generation. It took us quite a good while to study and handle the problem resulting from the complicated geological conditions of the dam site before the present normal operation.



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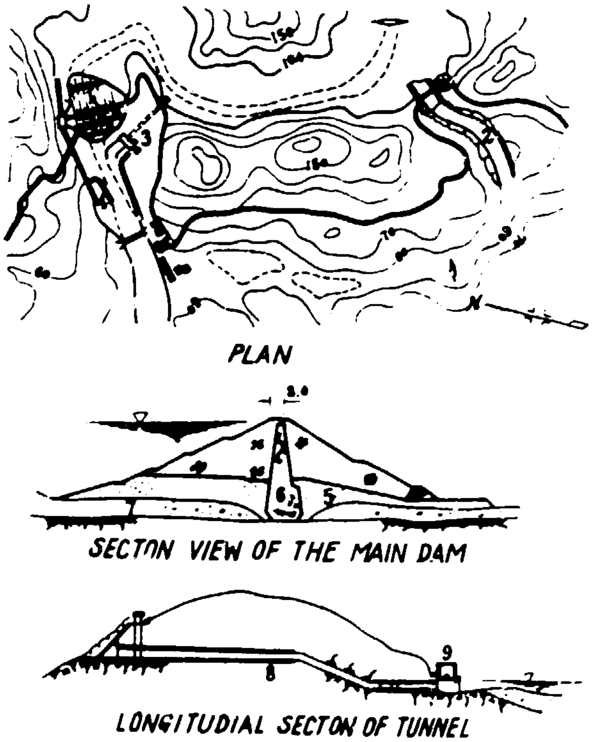

Fig. 2

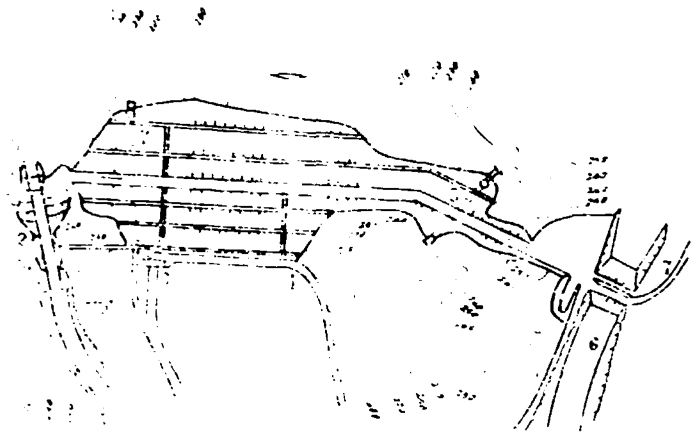

Fig. 3

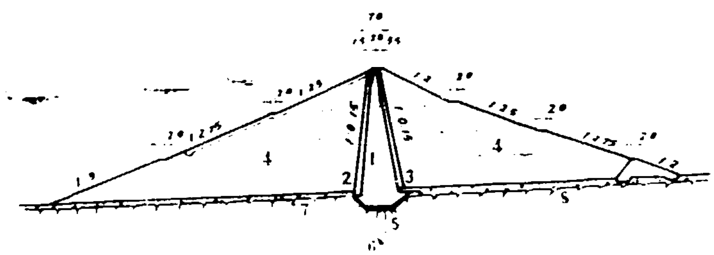

Fig. 3-2

The present article lays emphasis only on summarizing the basic experiences of rolled-fill earth dams in our province.

I'. Varieties of Dam Types and Selection of Soil Materials for Dam Building

Hubei is a place abundant in water resources and is also a hilly place which has seen several droughts since liberation. In early times, the masses pooled their experiences of repairing dykes and damming the gorges to carry out the construction of reservoirs in the mountain regions and hilly areas. The first earth dam in our province was Daao Dam, which was completed in 1953, the dam height is 32 m with a storage capacity of 17 million m^3 and the amount of stone and earth 410.000 m^3. The designed water head is 110 m. The installed capacity is 2 × 480 kw. A cross section is shown in Fig. 4.

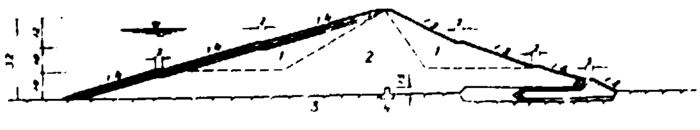

Fig. 4

In the 1950s, dam sites were, in most cases, selected at the outlets of brooks and streams. It was easy to select single soil material as the dams were not of a large size. Therefore, most of the completed earth dams were homogeneous dams, essentially homogeneous clay dams.

From the 60s forward, with the enlarging of the scale in the dam projects we gradually turned to choosing the dam locations at the middle or upper reaches of the large rivers according to the conditions for the exploitations of water resources. The varieties of the dam types increased as a result of many kinds of soil materials available. Besides homogeneous clay dams, central core dams and sloping core dams were also built. Above all things, the use of the weathered materials from the hill sides and mountain slopes as dam materials afterwards made the dam building techniques of our province somewhat special in the country.

Some typical earth dam sections in various regions in this province are illustrated as follows (Fig. 5~11).

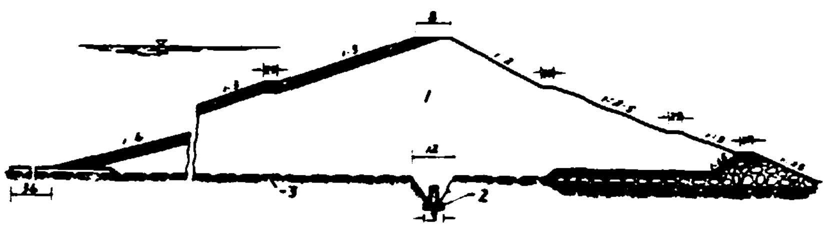

Fig. 5

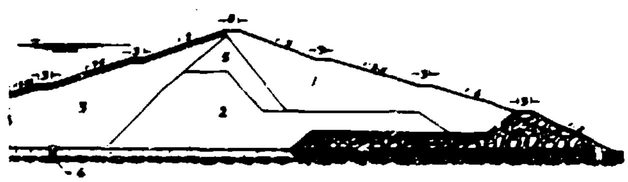

Fig. 6

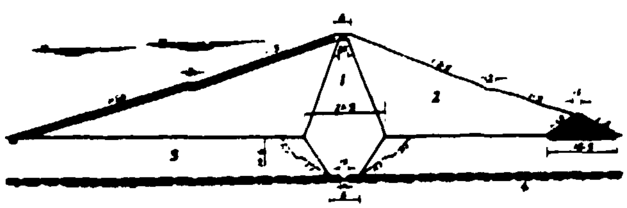

Fig. 7

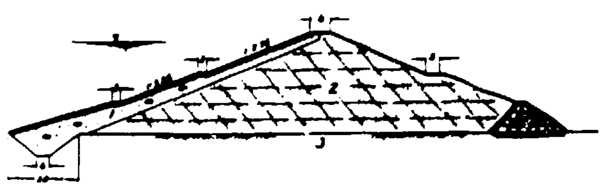

Fig. 8

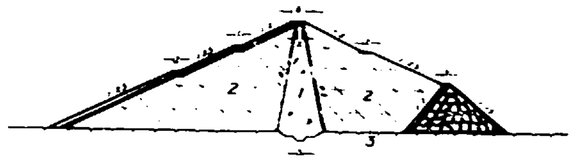

Fig. 9

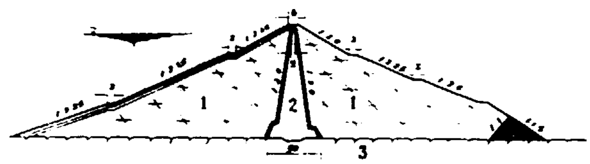

Fig. 10

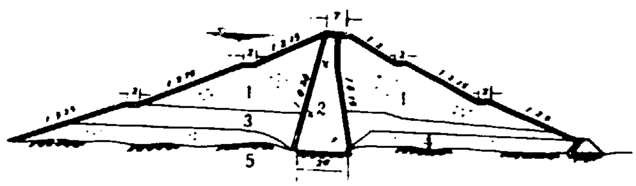

Fig. 11

The above mentioned selection of different dam types and earth materials will be further described respectively as follows:

1. The earth material selection and dry density design of homogeneous earth dams

The filling material of homogeneous earth dams is simple. Its construction technique can be easily mastered by the masses, and its impervious properties are more reliable. In accordance with the long years of experiences in constructing medium and small sized homogeneous earth dams in Hubei Province, these dams were, in general, considered successful, as long as the unit weight of the earth materials was well controlled and the soils were densely tamped in layers according to the construction control. The homogeneous earth dams designed in the past, however, were usually built of clay materials. Owing to the small shearing strength of the clay soils and the difficulties to control the unit weight, it was not so easy to control the compaction quality. In order to ensure a stable slope of the earth dam, gentle slopes were often used.

As shown in Fig. 5, the earth dam of Shi Long Reservoir is lower than those of the Heiwuwan and Xuijiahe Reservoirs built later. However, a slope sliding at the upstream face of Shi Long clay dam occurred and no slope sliding or crack occurred at the other two dams built of loam.

Based on the laboratory soil tests and the field measurements, the increase of the shearing strength for the same earth materials is, to a certain extent, related to that of the dry unit weight.

The arithmetic mean values of the angles of internal friction (∅) and cohesion (c, kg/cm²) are shown in Table 1:

Table 1

Dry density T/m³	1.50		1.55		1.60		1.65		1.70	
Strength parameter	∅	c	∅	c	∅	c	∅	c	∅	c
Clay	1.52°	0.35	18.5°	0.45	20°	0.5	23°	0.55	24°	0.63
Loam	19.1°	0.10	21°	0.15	23°	0.40	24.5°	0.44	26°	0.55

The permeability coefficients of clay and loam are between 10^{-7}~10^{-5} cm/sec.

In order to raise the shearing strength or soil materials, the dry density and control measures as stipulated in the design were high, but they could not be easily satisfied. For example, the designed dry densities of Shi Long, Heiwuwan and Shimen Reservoirs, etc. were once set as 1.60, 1.66, 1.72 T/m³ respectively, nevertheless, they could not be realized during construction.

The dry unit weights of the above mentioned three projects are shown in Table 2:

Table 2

Name of projects	Soil type	Designed dry unit weight	Dry unit weight during construction	Dry unit weight after completion
Shi Long Reservoir	Clay	1.60	1.47	
Heiwuwan Reservoir	Loam	1.66	1.62	1.56
Shimen Reservoir	Sandy loam	1.72	1.65	1.61

The three projects mentioned in Table 2 were built in the 1950s. They were compacted by 6-ton light sheepsfoot rollers. The placement layer was from 25 to 30 cm and the moisture content was controlled between 20-24%. Owing to the irrational and unrealistic requirements for high qualities, it was required to have 8 passes or even up to 20 passes.

The inspection on the dry densities and the shearing strength after completion of these projects showed that the safety factors of the stability of the dam slopes of the Heiwuwan and Shimen Reservoirs remained on the safe side, because the designed upstream slopes were so gentle that they could withstand the damage of shearing force. However, the slope of the Shi Long Dam had to be thickened and strengthened on account of slope sliding.

In selecting the soil materials, the physical and mechanical properties of the soils from the borrow pits should be taken into comprehensive consideration. Attention should not be directed to the mere increase of the dry unit weight. We hold that, under the concrete conditions of the soil qualities of different areas in Hubei Province, the optimum moisture content of the clayey soils (the clay content less than 30%) should be maintained within the range of 17~23% and the dry unit weight controlled above 1.55 T/m³. With these conditions fulfilled, the requirements of the stability and seepage control of the dams can be satisfied. This is also in conformity with the usual condition of compaction and the design reqirement. As to the loam materials, it is not difficult to control the optimum moisture content within the range of about 15~20% and to meet the requirement of the dry unit weight up to 1.6 T/m³ or even more.

2. Central clay core dams and wide applications of local materials

The area north of the Chang Jiang River in Hubei Province is mainly composed of Wudan schists, granite-gneiss, sandstone, and sandy shale, while the area south of the river mainly of limestone, argillaceous limestone, slate, shale, and tertiary conglomerate, etc. Rocks on the river slopes are seriously weathered, and the river beds are thick deposits of silt. In 1957, when the Mingshan Reservoir was under construction, (see Fig. 12), it was planned to use the river sand as the shell of the central clay core earth dams.

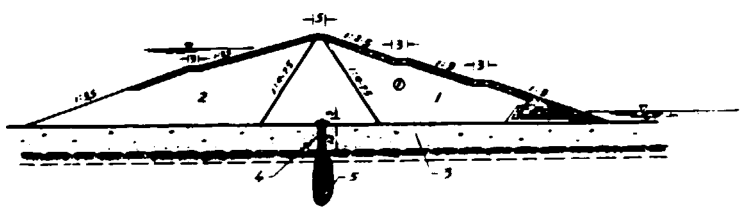

Fig. 12

But in reality, instead of using river bed sand materials for the dam shell filling, weathered soils on the hill slopes were utilized, because of the difficulties of excavating the sand from the riverbed under deep water and hauling great height to the construction surface of the dam and the difficulties of controlling the compaction quality.

The completed Mingshan earth dam is a central core dam built of soils of various types. The central core is of clay soil, the upstream shell is of sandy loam and the downstream shell was of weathered materials. Practice proves that no water leakage, slope sliding and fissures have ever occurred after completion.

Weathered materials have been widely used and preferred by the masses in the construction of earth dams as they are characterized by the following points: abundant amount, convenient transportation from high elevation to the site, less manpower and high labour productivity, high shearing strength, steeper slope and less amount of dam volume.

Statistics shows that in the past 30 years, 809 impervious core dams are of the height ranging from 15 to 30 m, 57 dams ranging from 30 to 50 m, and 20 dams are above 50 to 60 m. The materials of the dam shell are of weathered materials of diverse rocks. The quality of the dams is improved with time rolling by, and above all, becomes better than that of homogeneous dams.

The physical and mechanical properties of the weathered soils are, for the greater part, determined by the particle grading during construction and the quality of compaction. In the past, we could obtain a dry unit weight of 1.75~1.80 T/m^3 and a moisture content of 5~15% by means of smooth roller (5.5 T) or rib-typed roller (7.5 T), drawn by the Dung Fang Hung tractors for 8-10 passes.

The shearing strengths for different dry densities are listed in Table 3. The tests were performed in a large shear box (dimensions: 70 × 70 × 40 cm).

Whether or not the weathered soils used in rolledfill dams may be weathered into finer particles within a short period and reduced their strength considerably was once a problem of argument when the Fusui Dam was under construction. The following is the result of their simple experiment and investigation.

Table 3

Materials	Controlled dry density	Angle of internal friction	Cohesion	Natural angle of repose
Weathered gneiss	1.75-1.80	36-38°	0.15	36°
Weathered shale	1.8-2.0	37-39°	0.20	33-34° under water
Weathered sandstone	1.8-1.90	33-36°	0.20	31° under water
Pebble	1.89-2.0	33-39°		
River sand	1.58	32-38°		
Soil weathered from shale	1.68	16-20°	0.20	

Note: The coefficient of permeability varies between 10^{-2}~10^{-4} cm/sec.

Three groups of fresh shale fragments were respectively put into water, soil and air. After a time of one year, the shale under water and soil remained unchanged, but the shale in air had turned from 20-cm block into finer pieces. Shale gets weathered quicker in air. This is chiefly because that the influence by natural factors such as temperature, humidity, sunshine and rain will step up this changing process.

The actual conditions of the existing dams constructed of weathering materials are:

The weathering action is limited to an outer-surface layer of 40 to 50 cm deep and no significant changes took place in the interior of the dam. Provided that the materials are well graded and effective compactions are conducted, there will be no successive weathering and no influencing on the mechanical properties, and therefore no endangering on the safety of the dam.

As is shown in the previous table, the dry unit weight comes up to 1.8-2.0 T m³ or above, due to the high compressibility of the weathered materials. If little attention is paid to proper particle gradation, arching may appear and porosity becomes bigger even if a higher unit weight is obtained. What is more, this will lead to reduction of strength under water. The factors of underwater influence and the poor particle grading must be taken into account in designing a dam, by reducing an appropriate value its internal angle of friction in the analysis of dam stability.

By summarizing the test data of field compaction for Zhang He dam and others, the optimum gradation is such that the soil contains 50-60 per cent of fine particles within 5 cm and 50-40 percent of coarse materials with particle sizes-ranging from 5 to 15 cm.

Concerning the problem of the settlement, the weathered materials have a high rate and a large amount of settlement.

In the course of building a dam with weathered materials, settlement cracks may often occur as a consequence of differential settlements between the core and the shells. In coping with the fissures, cautions must be taken in controlling the grading and the construction quality. Successful experiences tell us that a sufficient transition zone between the central core and the weathered soil should be provided.

The preferable width of the transition zone on both sides of a central core ranges from 2 to 3 m. There is no need to choose soils according to the geometrical relations, since either sandy loam or fine sand can serve the purpose.

III. The Basic Principles for Earth Dam Design and Stability Analysis

In the past thirty years, about 200 earth dams were built in our province each year. All these dams were built mainly by relying on the masses, and using some simple rolling tools. However, little accidents have occurred for the reason of sticking to a number of basic principles which are as follows:

1. There should be a correct standard for flood and correct design of spillways. In case of extraordinary flood, spillways of sufficient discharge capacity schould be provided with a view of avoiding overtopping the crest.

2. Under the given operation conditions, there should be no possibility of slope sliding. That is: through stability analysis safety should be ensured for the upstream slope under the conditions of sudden drawdown of reservoir level, and for the downstream slope under the condition of full reservoir level.

3. With regard to the impervious core of the earth dam including the central core or the inclined core, ways and means should be devised to ensure close bond between the core and the foundation or the abutments. The backfill should be densely compacted with the aim of reducing seepage through the foundation or around the abutments.

4. The dam slopes on both the upstream and downstream must be protected. The upstream protection should withstand the washing and flushing of wave action and the downstream slope is designed to avoid furrowing due to rainfall and animals' burrowing and that the crest should also be provided with protective facilities.

5. Conduits embedded beneath the dam should be placed on solid foundation, preferably on rock foundations. Along the conduit, several cut-off collars should

be provided so as to reduce water seepage along the contact between the soil and the conduit.

6. On the river bed section, the dam should have sufficient drainage devices. And at the joints between the dam and abutments, there should also be provided with embedded drainage pipes and drainage ditches.

7. The dam crest should be tidy and uniform with a certain width so that emergency protective measures and reinforcements can be made in case of extraordinary flood during flood season.

8. In connection with the construction arrangement, roads leading to the crest of the dam should be made available, and traffics between the upstream and downstream as well as fishways and logways should be provided.

Based on the above-mentioned principles and, first and foremost, on the requirements of the river development programme and basic data, the location, type and height of the dam should be selected and decided upon under consideration of advanced techniques and economical feasibility.

To cut the matter short, the following will treat upon the problem of earth dam stability.

Those earth dams completed in the early days after liberation in our province are of gentle slopes. Innovations have been brought about with the use of weathered materials in the construction of earth dams. Since weathered materials have large angles of internal friction and strong perviousness, the dam slopes can be designed steeper. Many dams have steep slopes and thin central cores. Another characteristics of the weathered materials is that the strength will be reduced to some degree under the water or after a certain period of time. Therefore it is of great necessity to calculate and verify the stability of the dam slopes of this new type.

Examples of the dams of both small and large sizes are hereby cited for explanations.

Example 1: The earth dam of Zhengjiahe reservoir in Hungan County:

Dam height:	25.9 M
Reservoir capacity:	2.68 million M^3
Earth and stone volume:	0.26 million M^3
Average crest length:	117 M

Dam cross-section is shown in Fig. 13

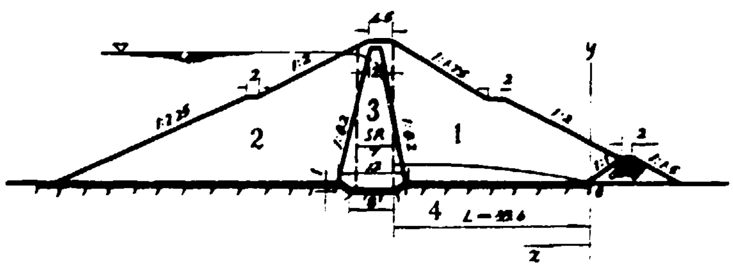

Fig. 13

Check the stability of the side slopes.

(1) Design data:

Clay materials for the central core:

Dry density: 1.6 T/m^3

Saturated density:	2 T/m^3
Angle of internal friction:	20°
Cohesion:	0.2 kg/cm^2
Permeability coefficient:	$K=1.5\times10^{-6}$ cm/sec.
Gneiss weathered materials:	
Dry density:	1.75 T/m^3
Saturated density:	2.06 T/m^3
Angle of internal friction:	34°
Permeability coefficient:	5×10^{-4} cm/sec.
Angle of internal friction: (under water)	28°

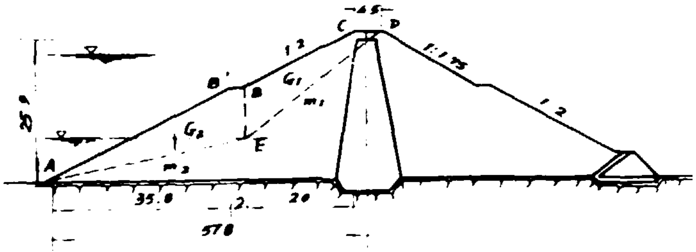

Fig. 14

(2) Calculations for phreatic lines

The coordinates of the phreatic line is illustrated in Fig. 13.

The seepage flow through the dam per meter length: $q = 5.66 \times 10^{-5}\ m^3/sec.$

Total seepage quantity through the whole dam length: $Q = 0.00664\ m^3/sec.$

(3) Calculation for the upstream slopes:

Analysis conditions:

After the reservoir filling, if the water level drawdowns suddenly from El. 96.3 meters to about one third of the dam height, that is, to El. 80 meters. part of the slope is above the water and part under the water. The sliding plane is assumed to be composed of broken lines and shall, first of all, be calculated by slip-line method.

The formulas of the slip-line method are as below:

(Earth Dam Design, first volume, by Gu Gang-chen)

$$Kc = tg\ \varnothing f \geq 1.2$$

$$\text{Where: } f = \frac{A+B}{2} \sqrt{\left(\frac{A+B}{22}\right)^2 - \left(\frac{BC}{m^2}\right)}$$

$$A = \frac{1+m_1^2}{m_2-m_1} \cdot \frac{m_2}{m_1}$$

(m_1, m_2 are the slope ratio of the broken slip lines, refer to Fig. 14.)

$$B = \frac{G_2}{G_1} \cdot A$$

(G_1 and G_2 are the weights of slights of sliding blocks. See Fig. 14)

$$C = \frac{1 + m_1 m_2}{m_1 (m_2 - m_1)}$$

Analysis procedures:

When water falls down to the elevation of 80 meters, a value for m_2 is first assumed, and three different values for m_1 are used to calculate a minimum safety factor for this water level and this value of m_2. Under the ~me water level, assume a second value and a third value for m_2, repeat the above calculation and select the least safety factor out of these groups of values.

The result of analysis: According to the three groups of m_2 values and nine different values of m_1, find out the minimum safety factor to be Kc = 1.19.

The result is shown in Fig. 14.

Draw a vertical line from point B to intersect the horizontal line of elevation 80 m at point E. Connect AE, ED and CD, and then obtain the results $m_2 = 5.48$, $m_1 = 1.21$, the weight of soil block AEBB' $G_2 = 205$ T, the weight of soil block EDCB $G_1 = 277$ T.

the above formulas, A = 2.62, B = 1.94, C = 1.47, f = 0.448

K_c = tg∅/f = tg28°/0.448 = .533/.448 = 1.19.

Moreover, the safety factor by the slip-circle method gives $K_c = 1.1$, i.e. this satisfies the design requirements.

(4) Analysis of downstream dam slope:

Since the phreatic line is low, the calculation can be conducted on the basis of no water conditions. The average value of the downstream dam slope is m = 1.95, and the angle of inclination with the horizontal line is 26.8°. The angle of internal friction of the weathered materials is ∅ = 32°. By straight line method, calculate:

K_c = tg32°/tg26.5° = 0.627/0.543 = 1.24>1.2

(5) The result of the analysis shows that the originally designed dam slopes of the upstream and downstream conform with the requirements.

Since this dam was built of a thin clay core, both the pore water pressure and the seismic force are not considered. This dam was completed in 1970. Measurements made on the dam indicates the total settlement was one per cent of the dam height, no horizontal movement and other deformations were observed. This proves that the dam is of good quality.

Example 2: Bailianhe earth dam in Xishui County.

Dam height:	69 m
Crest length:	259 m

The embankment of volume: 1.47 million m^3

This is also a thin core earth dam with dam shells of weathered materials, and both the upstream and downstream dam slopes are steep.

Design data of the clay core:

Dry unit weight:	1.65 T/m^3
Angle of internal friction:	∅ 20°
Cohesion C:	0.35 kg/cm^2
Permeability coefficient:	from 10^{-6} to 10^{-8} cm/sec.

The dam shells were mainly built of gravelly sand weathered from granite.

Design dry density:	1.7 T m^3
Angle of internal friction:	35°
Permeability coefficient:	10^{-4} cm sec.

This dam has steep slopes and thin core (refer to Fig. 15)

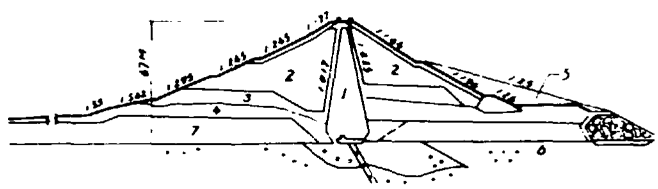

Fig. 15

The design department had used the slip-circle method to calculate the stability of dam slopes under different conditions of various water levels, and the result showed that the minimum safety factor could still be greater than 1.2. The dam withstood the test of the highest water level of 106.16 meters in 1969, and no slope sliding was found on the embankment.

One point for this dam is worth studying, that is, since the dam was completed and put into operation, the horizontal movement has increased with each passing year. The observed values are listed in the table (the vertical settlement is also recorded, but they can be neglected as the amount is very small). No observations has been made after 1974. The accumulated horizontal movement came up to the max. value 220 mm at the level of 50 - 60% of the dam's height.

The Management Department of Beilianhe Reservoir was much worried about the safety of the dam, which might be affected by the increase of the horizontal movement. With a approval of the leading organs concerned, the downstream slope of the dam was flattened in 1974. The present average slope of the downstream face ranges from 1 : 2.34 to 1 : 2.5. As is difficult to carry out construction under water at the upstream face, no alteration was made for the upstream slope.

From the foregoing two instances, it cannot be alleged that the stability of the two earth dams is not adequate. But they are closely associated with the problem of the relationship between safety and economy. As far as medium and small sized projects are concerned, data for both testing and observation are by far insufficient. At present no rigid rule can be followed as to what amount of horizontal movement is considered as being safe. From a long term point of view, it is not desirable to make the dam slope too steep because the excessive increase in horizontal movement will be detrimental to the structure of the earth tam.

Statistics of the annual accumulated values of the horizontal movement for the Beilianhe earth dam

Year	61	62	63	64	65	66	67	68	69	70	71	72	73
High water level	99.6	103.39	101.85	103.43	100.43	111.21	99.76	93.7	106.16	105.18	100.4	99.4	100.6
Observation points on the crest	30.1	52.5	70.6	88.8	105.8		124.5	119	148.5	152	144	145	149.3
No. 3 berm at the upstream	12.1	20.5	90.3	106.8	109.6	104	105	110		109	127	124	129
No 2 berm at the downstream	29	75.7		153	164	173	177	181	206	205	214	216	220
No. 1 berm at the downstream	26.6	73	76.1	118	128	133	134.5	140	153	156	161	171	169.5

Note: The unit is expressed in mm.

IV. Foundation treatment and seepage control

The foundation treatment of an earth dam is a problem or great importance. It deserves close attention and is a key problem in the process of construction. In building most of the earth dams in this provinc. measures suitable to the local conditions were taken. indigenous methods or simultaneous employment of indigenous and modern methods were followed. Reliable measures against foundation seepage were taken by integrating vertical cut-off walls with concrete key walls.

As the foundation conditions of different regions vary greatly. different measures should be taken in accordance with the concrete local conditions.

The following are descriptions of the afore-said points. Please refer to the foregoing cross sections of the earth dam

1. Treatment of impervious foundations

When the dam foundations consist of compact and impervious rock. clay deposit. or loam deposit. they can be remkoned as impervious layers. To erect dams on foundations of this kind. no matter what type of dams is adopted. it is of great necessity. to strip the superficial humus soil. grass rods. roots. fine sand layers and silt etc. which may give rise to seepage as well as sliding. The depth of stripping goes from 0.3 to 0.5 m. In building dams on impervious foundations. backfilling can be undertaken immediately after the foundation stripping when the design earthfill has the same soil type as the foundation soil. When the soils are different. one or two cut-off trenches should be dug in the dam foundation upstream of or along the dam axis with the aim of avoiding concentrated seepage along the contact of the dam foundation, and the backfilled clay should be similar to the foundation soil for reducing the seepage. The basic dimensions of the cutoff trench are:

depth: 1 — 1.5 m: width: 2 — 3 m

In case of rock foundations. cutoff trench should still be excavated. and should be coated with loess slurry on the rock surface before backfilling with compacted clay.

In case of building central core or sloping core dams. the central core or the sloping core should extend into the impervious soil foundation or rock foundation to a depth of 0.5 to 1.0 m.

2. Treatment of pervious foundations

When the dam foundation is composed of pervious sand. or sand and gravel and extends to a depth of within 15 m, the method of providing cut-off has been applied in all the cases in this province, i.e. trapezoidal cut-off trenc were excavated in the river deposit, extending to the impervious layer or the ... and then backfilled with soils similar to the impervious core of the dam. The bottom dimensions of the cut-off trenches should be determined according to the permissible seepage gradient of the impervious backfill and the compaction requirements. As the allowable seepage gradient of clay is 5 to 10. that means the bottom width of the cut-off trench may be 1/5 — 1/10 of the water head. The bottom widths of the cut-off trenches for small and medium-sized dams built in this province were usually 1/4 — 1/6 of the water head. when the compaction quality and other conditions had been taken into account.

The excavated slopes of the cut-off trenches should be stable during construction. Normally, it should not be steeper than 1 : 1.

In order to prevent piping or concentrated seepage along the contact between the bottom of the cut-off trenches and the rock, the past practice was to provide concrete key walls on the contact surfaces. In some places, this method has been discarded because it will interfere with the construction and elongate the back-filling time. The usual practice is to widen the bottom of the cut-off trench or another small cut-off trench is excavated and backfilled with compacted clay, as illustrated in Figs. 7~11. Practice has shown that this method is effective as well.

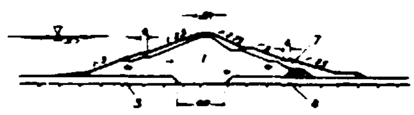

Fig. 16

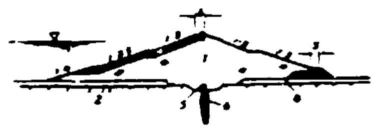

Fig. 17

Figs. 16-17 are the cross sections of the earth dams of the Heiwuwan Reservoir and the Xujiahe Reservoir. Both reservoirs fall within the category of large size, and the earth dams are homogeneous dams built of similar soil type. The depesits of the river beds as well as the hydro-geological conditions are in similarity. The former was provided with cut-off walls and grout curtain. The latter has no such facilities, but the seepage control effect is similarly satisfactory and no water leakage has occurred.

Concentrated seepage occurred during construction at several places in the cut-off trenches for the recently completed Zhang Jia Zui Reservoir, because the fissures in the foundation rocks were highly developed and that there was a fault parallel to the river flow. Through the water test the unit water acceptance was about 0.2 liters/min. the max. went up to 8.96 1 min. The treatment method is to extend the cut-off trenches as deep as possible, that is: the cut-off trenches should be excavated into the foundation rocks as deep as 3~8 m with a width of 7.5~15.8 m and concrete beds were cast on the bottom of the trenches to isolate the back-filled clay from the seepage through the foundation rocks and avoid the contact piping. It was originally planned to make curtain grouting under the concrete beds. However, after completion of the dam, little seepage was observed under both medium and lo wwater levels. The data of piezometers indicated that the losses of the water head through the cut-off trench had amounted to 63~80%. This demonstrated that the cut-off trench and the concrete bed proved effective. The management department has stopped preparations for grouting work but continues to strengthen observations.

When the river deposit has a depth greater than 15 m, excavation of cut-off trench may meet with difficulty. In this case, clay blanket may also be effective. This method was only adopted in a few projects in Hubei Province. Fu Shui earth dam is one among them, with pressure relief wells provided at the downstream.

Reinforced concrete interlocking pipe columns were used under the earth dam of Mingshan Reservoir for seepage control (see Fig. 12), but this measure does not have wide application, because of high cost and complicated construction, the cast in-situ concrete diaphragm can be used instead.

3. Treatment of karst foundation

In the limestone area in the northwest of Hubei Province, foundation excavation often meets with artesian water from the karst formation or water in fissured rock zones, which would affect the safety of the dam. Stopping and sealing all the crevices before backfilling are necessary. Treatment should proceed first from small, upstream ones at higher elevation and then to the large, downstream ones at lower elevation.

The concrete measurs are as follows: by rapidly filling with compacted clay; by sealing with cement or by sealing with thick slurry of cement and loess.

When the artesian water has a high head, the great amount of fountain water and the large number of fountains will be difficult to be sealed, small dykes around the well can be built to balance the water head and water is then pumped out of the well before blocking and sealing. Wooden piles, if necessary, can also be driven into the seepage holes for stopping the spring flow and then backfilling can be carried on.

If the above measures fail to stop the fountain completely, the method of water diversion can be applied. That is to lead the water out of the dam toe gradually through porous pipes.

4. Control of seepage around the dam.

The control of seepage around the dam is chiefly to cope with the problem of the connections between the dam and the abutments. The most effective method to guarantee good connection of the central core or the sloping core with the abutments is by removing the surface soil and excavating key trenches.

Geological exploration should, of course, also make clear whether there are pervious chanels or fault zones stretching along the dam axis to either bank. If necessary, curtain grouting can be conducted in a proper manner.

In our province, reservoirs such as the Shilong, Shimen, Heiwuwan, Mingshan built in the early period were provided on both abutments with curtain groutings along the dam axis. No curtain grouting was used for such kind of reservoirs later. Nevertheless, no seepage around the dam was observed. This may be due to low water head, well treatment of cutoff trench foundation, or less fissures in the rock foundation. There is no possibility for internal piping, even though the unit water acceptance is above 0.05 l min.

V. Pressure conduits under the earth dam.

Most of the reservoirs in Hubei are small size reservoirs mainly for irrigation, supplemented with power generation. The large and medium sized ones serve both for power generation and irrigation. Above all, there lies the great potentiality of cascade development downstream of the reservoirs. As for the outlet works of the reservoirs, in most cases the reinforced concrete pipes are embedded under the dams. Tunnels are used in few cases. So long as the outlets conform to the requirements of the design and the construction quality is good, the safety, in general, can be guaranteed.

According to the experiences gained from the operation of some hydro power stations in the early period, if the conduits under the dams are to be used for power generation, attention should be paid to the following points:

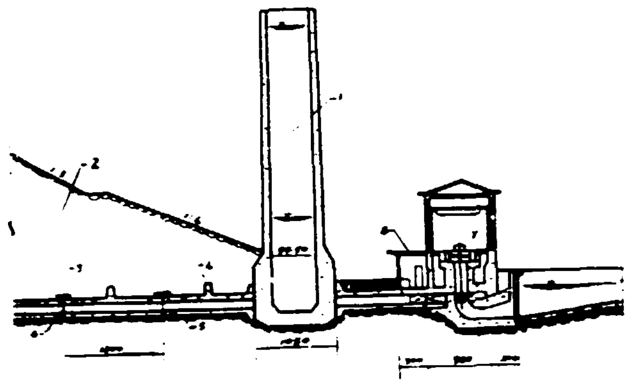

Fig. 18

1. The structural strength of the conduits and the effectiveness of water seals must be checked in line with the calculating requirements of the water hammer. The inner water pressure will not cause bending moment and will only exert influences on the axial force. When the water head becomes higher, the seepage control effect would become inadequate if the conduit wall is not thin enough. Meanwhile, careful check must be carried out by water pressure tests to see whether the original design is reliable and construction quality is good.

2. When pressure conduit is used for power generation, emergency gate must be provided. Besides meeting the requirements for flow regulation, the conduit diameter must be big enough to be accessible by maintenance personnel after the gate is closed. The suitability of using conduits with too small a diameter for power generation should deserve serious consideration.

3. The reinforced concrete conduits should have the characteristics of imperviousness, crack resistence, and anti-shock under the action of water hammer. Therefore, a proper thickness and strength are required for the conduit wall. For larger installed capacity, comparison must be made of the selection between the pressure conduit and the pressure tunnel.

The pressure conduit under Fushui dam has an internal diameter of 6.5 m. The thickness of the conduit wall is 2.04 m, and the total lengthh 180 m. This is the biggest conduit in diameter embedded under the dams in Hubei (see Fig. 1). Emergency gate is provided at the conduit intake. At the outlet section two bifurcations are led out from the conduit for power generation. The operation has been safe for 15 years because of the thick pipe wall and good construction quality.

V. Conclusion

1. Earth dams of rolled-filled type are water retaining earth structures, which are placed and compacted in layers according to the design requirements. Earth dams of this kind have developed in our province. The main reasons for this are:

(1) Local materials can be utilized;

(2) Measures which are suitable to local conditions can be taken;

(3) The masses can be easily mobilized;

(4) Construction can be conducted with the common and simple compaction equipments, and even simple tample tamping tools;

(5) Such projects are of less investment and quick effects, and are greatly preferred by the masses.

Although for years people have gained rich experiences of building dykes and dams. modern design method for earth dams has come into being only in the past fifty odd years. This is mainly due to the development of modern sciences in soil mechanics, hydraulics and engineering geology.

Earth dams are massive structures.Occasionally, a slight improvement will spare a good deal of manpower and investment. The masses in our province innovated the method of using weathered soils on hill-sides and mountain slopes for building earth dams during the early period after liberation. It developed on the basis of sand shell dams. It was devised by the masses to make full use of residual soils on the mountain slopes as substitute materials for the dam shells.

2. The technique of building dams is simple, but emphasis must be laid on the problems of quality and safety. A slogan in regard to the construction of earth dams in Hubei province goes: "The central core should go deep into the bottom of the dam foundation". That is: the adoption of cutting-off walls which is built of clay soil as foundation seepage control measures, has become popular. It is not advocated to construct an overflow earth dam in Hubei Province. Of course, overtopping of earth dams is strictly forbidden. From the very outset of building the first earth dam in this province, measures have been taken to heighten the dam in order to enlarge the reservoir volume for flood control. Moreover, one of the factors for selecting a dam site is whether there is a suitable site for a spillway. In so doing, the standard of storing and discharging flood water will be improved and the safety of the dam ensured.

In Hubei province, earth dams are constructed of greater height, and spillways are provided with greater discharge capacity. This is also one of the reasons that make earth dam projects successful in this province. As far as the development of small hydro-power is concerned, larger reservoir with good regulation of river flow is another favorable factor.

3. In the early period after liberation, we were in want of experiences for the construction of dams. Geological data were imcomplete. For instance, in the case of constructing a dam on the rock foundation, no matter how the geological conditions might be, concrete key walls were designed to prevent piping at the connection between the dam and the rock surfaces. It has been proved that these dams with concrete key walls are leakage proof. Since it will take a longer period of dry season to build the concrete key walls, this will consequently influence the construction of the main project ahead of schedule. In later period, the masses have, of their own accord, deleted the use of key walls wherever no seepage exists in the bedrock. Instead, they use cut-off trenches backfilled with compacted clay, and sometimes broadened the bottom width of the cut-off walls. Practice shows that no water leakage has been found.

4. Failures of earth dams due to poor construction quality are mainly in the form cracking, slope sliding, and leakage which has affected the position of the phreatic lines

Earth dams with central clay cores flanked by weathered materials may subject to cracking. Slope sliding or first cracking and then slope sliding may occur in homogeneous earth dams.

Slope sliding often occurs in the upstream face. Cracks due to sliding appear first. and followed by large displacement. Sliding takes the forms of arc or broken lines. In the downstream face, unstable slope may be caused by the raising of phreatic line.

Taking all the factors into consideration, the main cause of failure is due to poor construction quality and ineffectiveness of the drainage facilities.

Treatment measures may involve repairing, grouting, flatening the dam slopes or providing the filter toe weight.

Another measure which is of utter importance is that reservoirs must be provided with outlet facilities for emptying the reservoirs. In this province conduits embedded underneath the earth dams also function as river diversion, water conveyance and reservoir emptying. This is also one of the features typical of earth dams construction in Hubei.

5. Streses should be laid on the collection of basic data and the improvement on construction methods with the aim of lowering the cost for the earth dam building. According to investigations made on the medium and small rivers, the potential hydro power resource in the province is estimated to be 5~6 million kilowatts. The exploited power has amounted to only about one tenth of the total. We must, therefore, proceed to set up reservoirs and dams at the carefully selected locations and speed up the mechanization of the construction so that the construction of small hydro power stations can make more contributions to the "Four Modernizations".

The afore-mentioned are some experiences for the earth dam construction in this province, and they are confined to the conditions of one district It is necessary for us to undertake in-situ observations and experimental analysis in order to further perfect these pratical experiences.