APPENDIX C

GOUHOU DAM PAPER

BREACHING OF THE GOUHOU CONCRETE FACE SAND AND GRAVEL DAM

BY

ZUYU CHEN

Institute of Water Conservancy and Hydroelectric Power Research

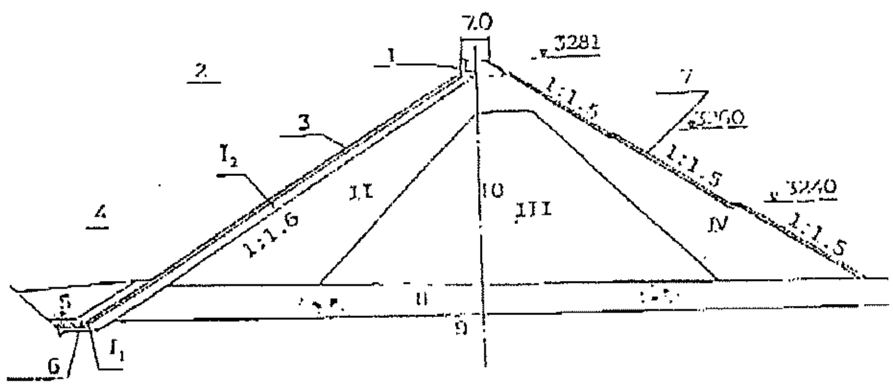
P.O. Box 366, Beijing, China

ABSTRACT

This paper gives a briefing of the failure of the Gouhou dam which happened on August 27, 1993 in Gongho County, Qinghai Province, China. Main aspects of design and construction are outlined, followed by a description of the failure process. Investigations both on the fill material and concrete structures were given after failure. Comments are given regarding the causes of the failure.

1.INTRODUCTION

On August 27, 1993, a catastrophic dam failure happened at the Guohou Reservoir, located near the town of Qiapoqia, capital of the Gongho County, Qinghai Province. Breaching of this concrete face sand and gravel dam (CFGD) created an estimated 1,500 m^3/s peak discharge of water, sweeping away half of the embankment material and bringing about great losses in human lives and properties.



1. Crest wall; 2. Normal water level; 3. Face slab; 4. Dead water level; 5. Random fill; 6. Clay. 7.Dry packed rock; 8.Alluvium; 9.Bed rock; 10.Dam axis

Fig. 1 Cross section of the dam

2. MAIN FEATURES OF THE DAM

2.1 General

The dam was 71 meter high measured from the alluvium river bed or 84 meter, from the bed rock where the plinths were placed. Normal and maximum water levels are both at the elevation 3278m, which is 3 meter lower than the crest of the dam. It was 265m long and 7 m wide at the crest. The upstream and downstream slopes were 1.6 on 1 and 1.5 on 1 respectively. Total water storage at normal water level was 3.3 million m^3 (Fig.1).

Average runoff of the Qiapoqia River is $0.4 m^3/s$. The only discharge facility of the project was a 390 meter long tunnel located at the left abutment (Chu., et. al., 1992).

2.2 Foundation of the Dam

The Gouhou dam was founded on a 13 meter thick sand and gravel alluvium, underlain by highly fractured granite bedrock. The river alluvium, having a unit weight of 2.40 KN/m^3, coefficient of permeability of 20.9-94.5 m/d and coefficient of uniformity of 391, was believed to be dense, permeable and well graded. Consequently, it was decided that the alluvium would not be removed except where the plinth was to be placed. Excavation of the alluvium was undertaken there until the lightly weathered granite was exposed for placing the plinth. Grouting under the plinth was required until the value of ω, water intake per water head per unit length, went below 0.03 l/s-m-m.

2.3 The Fill Material and Zoning

The embankment sand and gravel material was taken from two borrow pits 3 kilometres downstream of the dam site. The gravels are hard, un-weathered, fairly granular and made of granite and sandstone. The report of the field geotechnical tests indicated that the content of fines (particle size less than 5mm) was 33%, that of silt (particle size less 0.1mm) was 4% and the coefficient of uniformity was 78 in average. It also gave an evaluation of coefficient of permeability being 1.48×10^{-1} cm/s.

The dam was divided into fours zones as shown in Fig. 1. Main features of the four parts are indicated in Table 1 from which one may find that no serious restrictions to the gradings of difference zones were given. Since large pebbles were rare, the dam was essentially a uniform sand and gravel one (Hong, 1990).

2.4 The Concrete Face Slabs

Concrete slabs were placed with vertical joints spaced at 14m in the middle part and 7m near abutments of the dam. A horizontal joint was provided at the elevation 3255m for early water storage during construction. The thickness of the slab is 30cm at the top and 60cm at the bottom of the dam. Reinforcement was provided for the face slabs. For the vertical joints in the middle part of the dam, where compressive stresses were believed to prevail, the joints were connected with copper W-type water stop and filled with mastic. For those near the abutments, where tensile stresses dominated, an additional rubber water stop was provided.

2.5 The Crest Wall

Following the common practice of CFRDs, an L-type crest wall was provided to save the volume of rockfill and facilitate concrete placement of slabs by the slip form.

The horizontal slabs of the crest wall were 35 cm thick reinforced by single layer of steel bars and

Table 1 Specifications for the fills of the various zones

Zone Number	Fills	Layer Thickness cm	Maximum Size 4mm	Relative Density	Dry Density KN/m^3
I1	Transition	20	20	0.8	2.30
I2	Transition	30	100	0.8	2.30
II	Old Borrow Pit	60	400	0.75	2.30
III	New Borrow Pit	90	600	0.70	2.26
IV	New Borrow Pit and Tunnel Rock Fragments	130	800	0.70	2.26

were connected with the face slab by rubber water stop. The elevation of the horizontal slab was 3277.35m. To accommodate possible settlement of the dam, transverse joints are provided at 6m spacing.

3. PERFORMANCE OF THE DAM

3.1 Behaviour of the dam before 1993

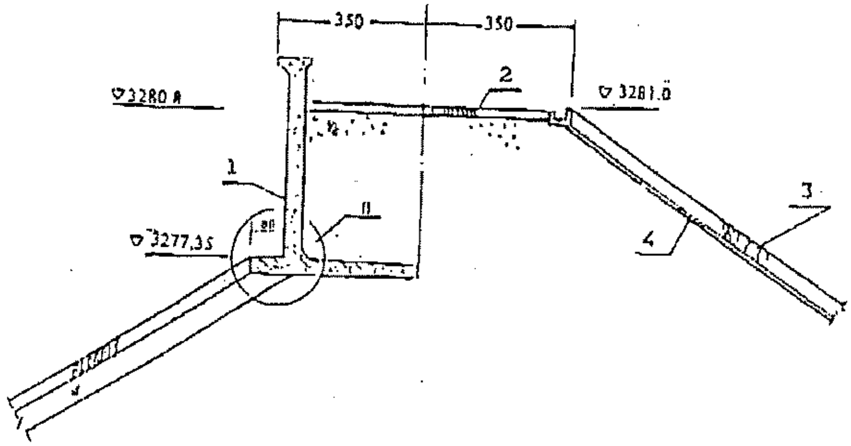
The Gouhou dam started water impoundment on September 28, 1989. On October of the same year, corresponding to a reservoir water level of 3258m, a concentrated flow appeared at the downstream slope somewhere 1.5m higher than the toe(ele. 3223m). Local remedial work included replacement of the scoured fill material, after which the flow seemed to disappear.

October, 1990 saw the first high reservoir water level of 3274m. The concentrated water flow re-appeared at the same location seen in 1989. The inflow measured at the weir near the toe of the dam was 18 l/m^3. No concentrated seepage was visualized during 1991-1992, a period whose reservoir water level was relatively low, not exceeding 3262m (Yu. 1993).

As a small project, limited instrumentation was available. It was measured that the settlement at the dam crest was 7cm. The water levels of the four open stand type piezometers of the abutment indicated that ground water level of the bed rock was lower than 3225m, which is reasonably low. An earthquake of the magnitude 6.9 on the Richter scale hit the area on April 26, 1990 with its epicentre 40 km from the dam. The dam was found to be intact.

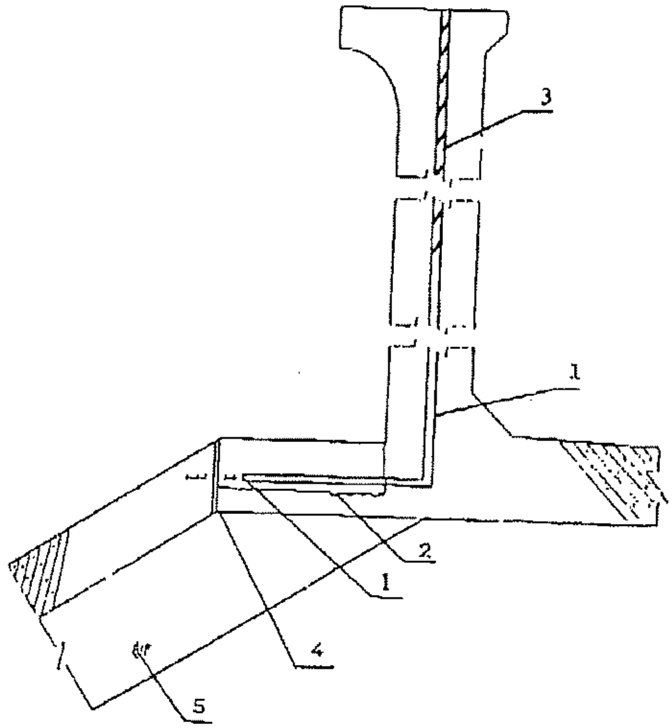
3.2 Failure Process.

Starting from July 14, the water level of the reservoir kept rising from 3261m. On August 26 the reservoir level reached 3277m which meant that it had been close to or sometimes higher than the horizontal slab of the crest wall for about 24 hours before the dam failure. It must be emphasized that this statement, which is significant in explaining the causes of the dam failure as will be seen later,



1. Reinforced concrete; 2. Pavement; 3. Masonry; 4. Transition.

a. Layout



b. Details

1. Rubber water stop; 2. Top of the intact concrete; 3. Timber soaked by oil; 4. Timber Fill; 5. Transition.

Fig. 2 The crest wall

图 3.失事后的大坝全景
Fig. 3. The breached dam

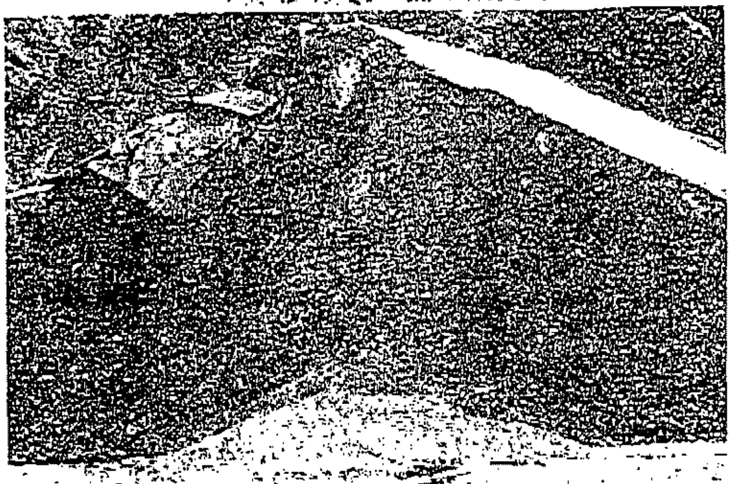


图 4.大坝缺口左侧面上涌水形成的冲沟
Fig. 4 The gullies cut by the flowing water

图 5.防浪墙底板碎裂情况
Fig. 5 The horizontal slab of the crest wall

was based on the memory of the administrative staff since the written records of water levels were destroyed by the flood during the dam failure. However, field survey of the water prints on the remaining parts of the wall gave a universally admitted water level at failure which was around 3277.3m.

At about 8:30 pm of August 27, Ms Sun Guilian, a villager, climbed on the dam slope with her sister She found water gushing out at the second berm (elevation 3260m) like 'tap water'. Since it started raining, they went back.

Hang Guo, the maintenance worker of the reservoir was probably the first one who witnessed the failure. He narrated:

'I heard a thunder-like noise. I went out of my office immediately and saw water splash and stones rolling on the dam slope. I also saw some fire flash probably created by the bumping stones. Then I managed a motorcycle, rushed to the town and reported to the leaders'

People were urged to leave their home immediately. However it was too late to evacuate all the residents when the flood reached the town of Qiapoqia, which is 13km downstream of the dam, at about 11:50 pm, a time which was confirmed by most survivors. The exact time when Mr. Hang discovered the incident was not clear. Tracing his activities, it was estimated to be around 9:15 am. The breaching of the dam developed very rapidly.

3.3 Destructions of the Dam

The breaching of the dam created a triangle weir on the concrete face slab, which is 137 meter wide at the dam crest. The elevation of the lower point was 3250m. Part of the slot went along the horizontal joint of the face slab. The flood cut through the dam body and created a 61m wide chute with almost vertical side walls. Total amount of water released was estimated to be 2.61 million m^3. The remaining part of the dam body lower than 3250m kept retaining water which overtopped the crest and created a water fall as shown in Fig. 3.

4. INVESTIGATIONS

4.1 Geotechnical Investigations

4.1.1 Visual Inspections

It has been found that the remaining part of the dam body was fully saturated from the top to the bottom of the dam. Apart from the all wet side walls that dipped for at least two days, evidence also includes:

- A number of concentrated flow which appeared on the side walls, creating more than ten gullies on both sides. The water flow lasted for at least two days (Fig. 4).
- Two concentrated flows identified on the downstream slope masonry of the remaining right part of the dam at elevation 2765m.
- Three typical piping holes seen on the left vertical wall, at the elevation 3226m.

The stability of the surviving left and right parts of the dam seemed to have been affected. Some longitudinal cracks and slightly bulging were seen on the right embankment. Cracks of the crest walls developed on both parts.

4.1.2 Grading of the Gravel Material

The lack of adequate drainage of the dam has aroused common concern about the grading of the fill material. All available field gradation test results have been collected. They include the 55 gradings obtained from the borrow pit and the dam body. The tests were carried out by the contractor for quality inspection purpose. The smallest, average and greatest contents of fines (particles less than 5mm) are 23.5%, 41.7%, 66.8%; and those of silt (particles less than 0.1mm) are 0.3%, 4.3%, 8.3% respectively. Fig. 6 gives three curves that represent the finest, coarsest and average gradations of the samples.

Very limited permeability tests were carried out during dam construction. Two shallow well permeameter tests were carried out in the surviving dam bodies by the case inspectors after failure, which gave the coefficients of permeability of 1.0×10^{-2} cm/s and 1.83×10^{-2} cm/s respectively.

4.2 Investigations of the Concrete Structures

4.2.1 The Face Slabs and Joints

There are eleven concrete debris on the river channel, which enabled us to check the quality of the joints and water stops. It has been found that some of the contacts between copper water stops and the concrete slab have not been fully filled. A two meter long clean un-scratched rubber stop found in one of the debris indicated that this rubber stop, having no contact with the surrounding concrete, had not suffered from shearing during dam failure. Some concrete exhibits 'honey holes', indicating poor quality during construction.

4.2.2 The Crest Wall

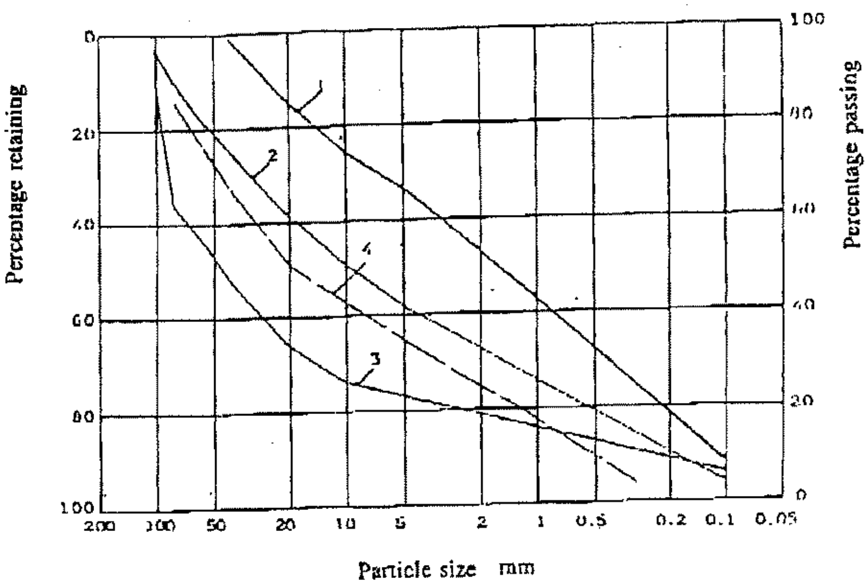
It was surprising to find that all the remaining horizontal slabs of the crest wall were highly fractured. The investigators were told that not long after the placement of the concrete, cracks developed on the slabs. They were then corrected by pasting cement mortar which again cracked. As a result of the concrete crumbling on top of the horizontal slabs, the existing intact slabs were invariably lower than the rubber water stop (Fig.2). There is no doubt that water would come into the dam through the unsealed gaps between the face slab and crest wall as soon as it exceeds the horizonal slab The investigators did find a number of holes and digged out some weed powder, indicating the path of seeping water (Fig. 5). As discussed above, the water level had been close or higher than the horizontal slab for about 24 hours before the failure.

5. DISCUSSIONS AND CONCLUDING REMARKS

It is clear that the failure of the Gouhou dam was caused by the unexpected high phreatic line of the dam. Water came into the dam through damaged concrete slabs and their joints especially when it exceeds the slab of the crest wall. The fill material seemed to be not permeable enough to allow free draining. Detailed study on the deficiencies both on design and construction phases are much demanded. The author hopes the following points might be of help in clarifying some issues.

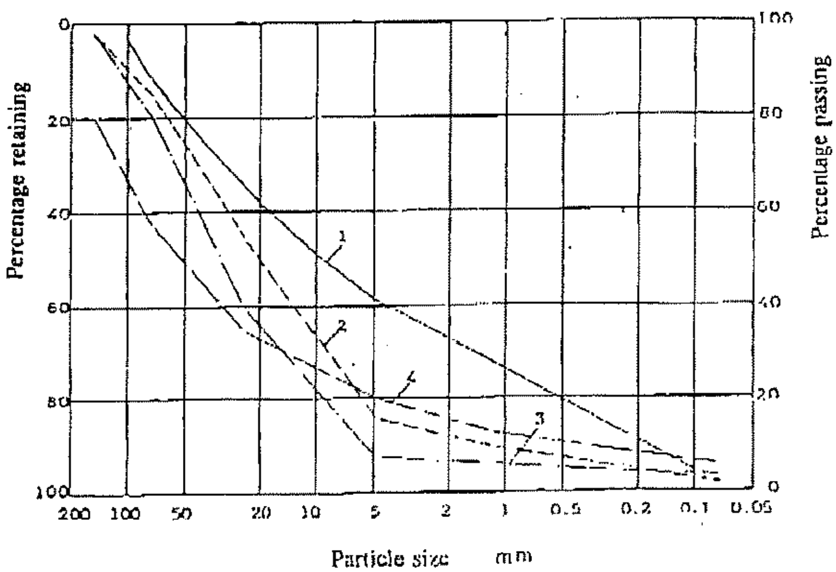
(1) All witnesses confirmed that failure started from the upper part of the dam. The remaining dam body still works satisfactorily in retaining water with an overflow through its crest (Fig.1). No seepage through foundation has been visualised. It is therefore confirmed that the foundation of the dam works perfectly and does not contribute to the failure.

(2) The Qiapoqia River is a small creek with a natural runoff not more than 0.8 m^3/s at the time of failure and it was found that the reservoir water level kept rising instead of lowering before failure. This means the maximum seepage into the dam body would not exceed 0.8 m^3/s, an order of magnitude several CFRDs have also experienced without failure. Compared with the gradings of the then existing three CFGDs in the world (Fell, R. et. al., 1992, Fig.7), the Gouhou fill material was



1,2,3: Selected gradings of 55 samples. 1, finest; 2. average; 3. coarsest. 4. Average of 8 samples taken from exploratory pit of borrow area.

Fig. 6 Gradations of the fills



1. Gouhou (based on 55 gradings; 2. Crotty; 3. Salvagina; 4. Golillas

Fig. 7. Comparisons of gradings.

relatively fine. However, unlike the three dams, special free drainage zone was absent. The designers have given similar discussions (Chu, 1992).

(3) The permeability of the fill material is a problem of common concern. The design of the dam was based on the test data taken from the borrow pit, which gave a value of 1.48×10^{-4} cm/s. The available 56 gradings of the fill material exhibit big variance as can be seen in Fig. 6. The average of the 55 samples taken from the dam was finer than that of the 8 samples taken from the borrow pit during design stage. Some risk analysis might be desirable in assessing the reliability of the field test data if the number of tests is not large enough and the locations of the samples are not reasonably representative.

(4) This dam has an important feature that the normal water level is above the horizontal slab of the crest wall. The reason of the cracking of the crest wall slab is still a question of much needed study. However, correcting the cracking by cement mortar is by all means wrong. As an important part of the dam structure, the crest wall is subjected to very complicated working conditions including settling of the foundation, rotating due to earth pressure, etc. Details of the crest wall must be carefully studied to assure safe performance of the wall.

The failure of the dam is unfortunate, but the lessons learned from this case are enlightening: *a leaking embankment with inadequate drainage can be dangerous.*

ACKNOWLEDGEMENTS

Part of the information of this paper is adopted from the design and construction documents prepared by the Water Resources Design Institute of Shanxi Province and the No. 20 Railway Construction Bureau to which the author is indebted.

REFERENCE

Chu, L. and Yang, Z., 1992. Some probless in the design of the Gouhou concrete face sand and gravel dam. *Water Power*, pp.29-31, in Chinese.

Hong, C., 1990. Main features of the Gouhou concrete face rockfill dam. *Proceedings of CFRDs*. pp 167-173. Hohai University Press, in Chinese.

Yu, Y., 1993. Investigations on the seepage of the Gouhou concrete face sand and gravel dams. *Water Resources of Qinghai*, pp. 23-24, in Chinese.

Fell, R., MacCregor, P. and Stapledon, D., 1992. Geotechnical Engineering of Embankment Dams ,A A. Balkema, pp. 526-628.