# Some Experiences from Damages of Embankments During Strong Earthquakes China

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# Some Experiences from Damages of Embankments During Strong Earthquakes in China

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SYNOPSIS: This paper gives a series of case histories of earth dams which have been damaged by strong earthquakes in the past 25 years in China. These damages include slides, cracks, settlements leakages and also some appurtenant structure failures. Experiences show it is necessary to stringently control the design and construction to resist earthquakes.

## INTRODUCTION

The practice of construction of embankment dams and their behavior during strong earthquakes are most important factors for understanding the nature force acting on these dams especially the dynamic forces. The understanding of the response of embankments will give some idea to build dams more reasonably. This is why engineers are paying attention and collecting them as good references.

## STRONG EARTHQUAKES IN THE LAST 7 YEARS IN CHINA

Since 1980 there were 2 earthquakes stronger than magnitude 7 and 36 earthquakes stronger than magnitude 6 in China.

There were 13 earthquakes with magnitude 6 in 1986. It was a rather active year even no earthquake stronger than 7 happened. During these earthquakes no damages were discovered except during two strong earthquakes, one in Yunnan Province and another in Xinjiang Uygur Autonomous Region in 1985.

## DAMAGE OF CHANGMAIDI EARTH DAM DURING 1985 LUQIEN AND QUENDIAN EARTHQUAKE IN YUNNAN PROVINCE

In April 18, 1985 the earthquake with magnitude 6.3 had a depth of epicenter only 5 km. The intensity of epicenter was 8 degree. Changmaidi earth dam is of homogenieous type with height 18m, crest length 105m. The nearest rim of reservoir is 6 km from epicenter, the local intensity was 6 degree. The reservoir storage capacity is 314000 $m^3$. The upstream slope of this dam is 1:2.5, downstream slope is 1:1.9 without protection. No filter was provided in the downstream drainage. A culvert pipe was embedded in the dam body with an inclined gate (Fig. 1 and 2).

The reservoir was nearly full during earthquake. Water level was just 0.8 m below the crest of dam.

16 cracks were found on this dam after earthquake, mainly (12 cracks) along the abutments of dam (Fig. 1 , 2 and 3). The width of cracks was generally 1-3 cm, with maximum width of 18 cm. On the downstream slope the depth of cracks reached 2.5 m. 3 of 4 longitudinal cracks were on the crest, the longest one was 38 m. The fourth crack was on the downstream slope, the width of crack near the spillway channel was 10 cm, its depth was more than 1.2 m. Muddy water flowed through the culvert pipe about two hours after the earthquake.

## DAMAGES OF KASHI EARTH DAM DURING SEVERAL EARTHQUAKES IN XINJIANG UYGUR AUTONOMOUS REGION IN 1985

In 1985 from August 23 to September 12 there were a large number earthquakes in Uqia County of Xinjiang Uygur Autonomous Region. The magnitudes of two strong earthquakes were 7.4 with epicenter 21 km from the dam site, and 6.8 with epicenter 16 km from the dam site respectively. The intensity at the dam site was both 7 degree. This region is of high seismicity by records. There were 7 earthquakes with magnitude greater than 6, and 5 greater than 7 historically. After earthquakes there were rather serious damages on the earth dam.

The Kashi Hydroelectric Power Station has 3 sets generators each with 6500 kw capacity. The dam is with inclined core and sand gravel shells (Fig. 5 and 6); the height is 16 m and crest length is 480 m. The grain size distribution curves of shells and core are shown in Fig. 7.

There were some damages as sliding of upstream slope and settlements of dam during the first earthquake, but the power station was still in operation. While the repair work was going on, the second strong earthquake destroyed it and damaged it very seriously.

There were 6 longitudinal cracks, 2 of them were on the crest, 4 on the upstream slope (Fig.8, 9). The horizontal dispalcements were 20-30 cm, the vertical displacements were 10-40 cm. 11 transverse cracks were discovered near abutments. The maximum width was 5 cm.

The slide of upstream slope 0+250 section show in Fig. 10, 11.

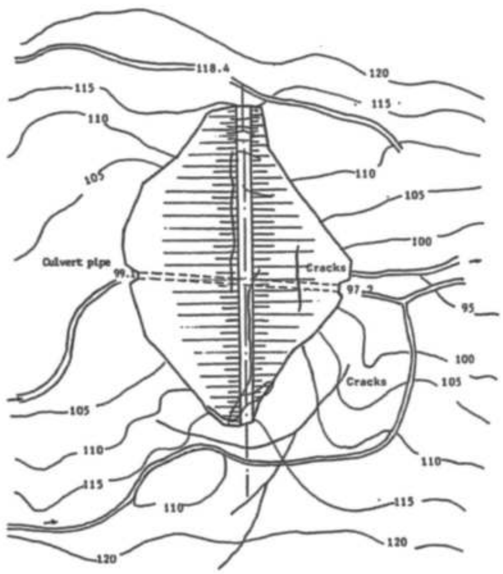


Fig. 1 Plan of Changmaidi earth dam

Fig. 2 Photogragh of Changmaidi dam, transverse cracks on the dam

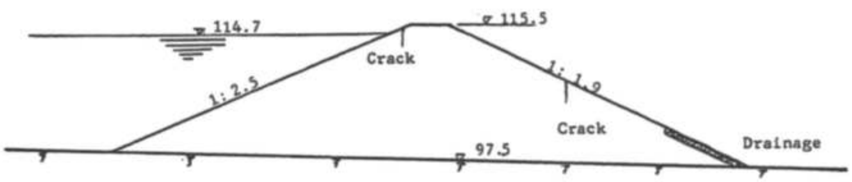


Fig. 3 Cross section of Changmaidi earth dam

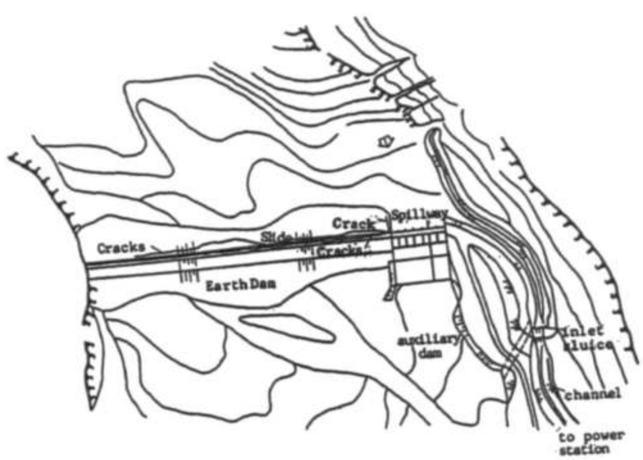


Fig. 4 Plan of Kashi hydroelectric power station

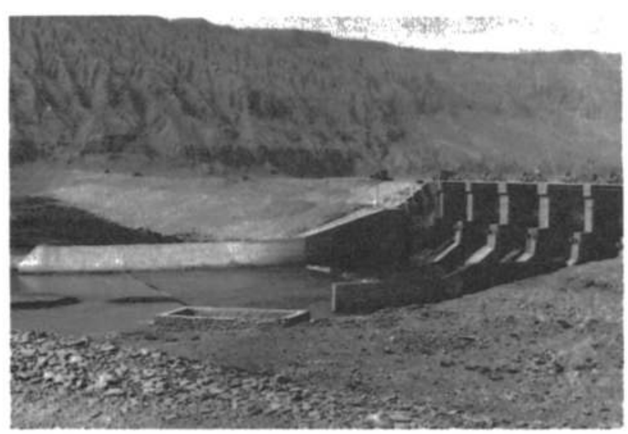

Fig. 5 Photogragh of Kashi dam and spillway

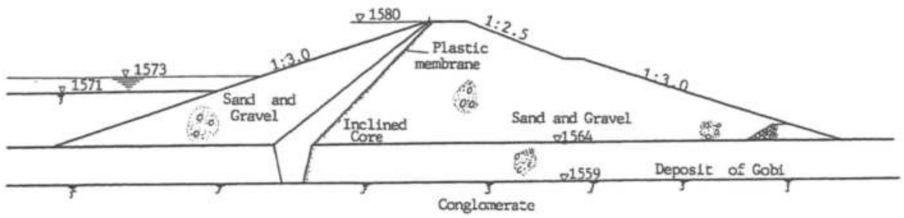


Fig. 6 Cross section of Kashi earth dam

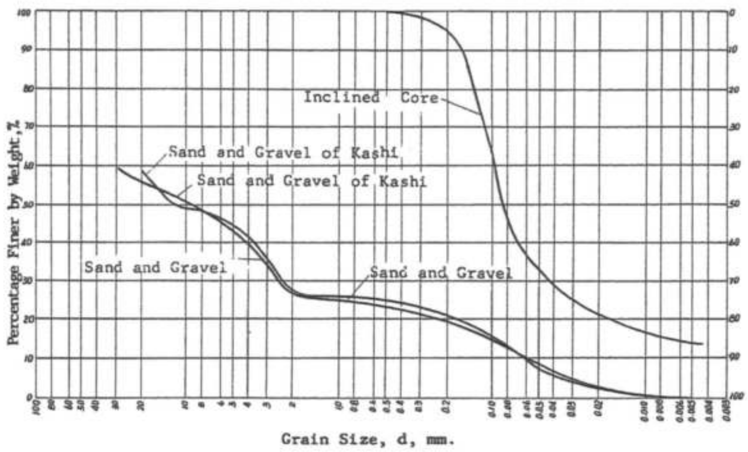


Fig. 7 Grain size distribution curves of Kashi earth dam

Fig. 8 Photogragh of longitudinal cracks on the upstream slope of Kashi earth dam

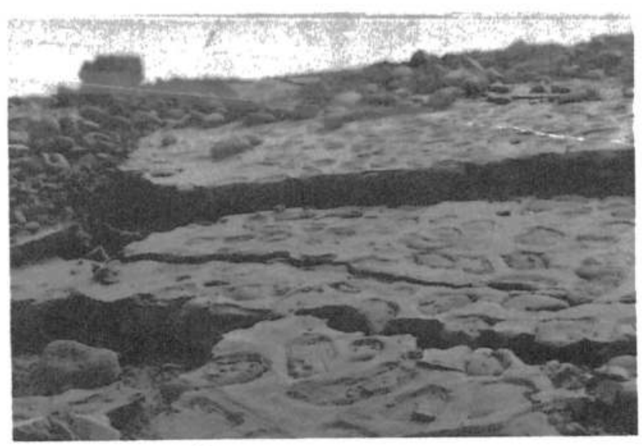

Fig. 9 Photogragh of longitudinal cracks on the upstream slope of Kashi earth dam

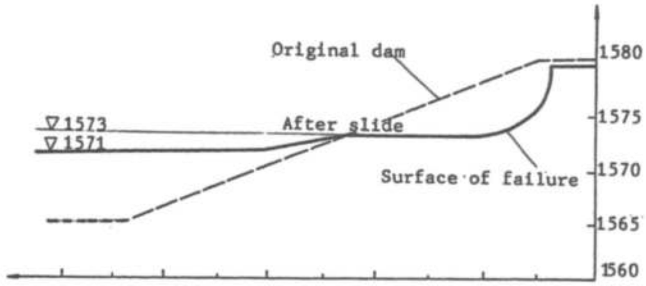


Fig. 10 Cross section of slide on the upstream slope of Kashi earth dam at 0+250 after earthquakes

Fig. 11 Photogragh of the slide on the upstream slope of Kashi earth dam at 0+250

The settlement of dam crest was generally 20 cm during the first earthquake, and 60 cm after the second earthquake. The maximum settlement was 1.5 m near the middle of dam axis.

The masonry parapet on the crest of dam collapsed and fell onto the upstream slope mostly (Fig.12).

There is an auxiliary earth dam to the left of the spillway, 10 m high and 200 m long. This dam was protected by concrete face slabs. Longitudinal and trasverse cracks were found with widths generally 10 cm.

Also the appurtenant structures had different damages. The power station had to stop operation.

RESULTS OF DIFFERENT DAMAGES DUE TO STRONG EARTHQUAKES AND THEIR ANALYSIS

Collection of different damages by earthquakes on earth dams in China from 1961 to 1986 is shown in the following table:

(See next page)

Fig. 12 Photogragh of the failure of Parapet Wall on the crest of Kashi earth dam

From this table it is easy to find out:

1) In these strong earthquakes some damages of earth dams were very serious causing stoppages of normal operation but no one was collapsed.
2) In these 216 earth dams only 25 dams higher than 30 m, 4 dams higher than 40 m. The highest earth dam was Baihe dam in Miyun reservoir (H=66.2 m) and rockfill dam was Nangoudong in Henan Province (H=78 m).
3) The most common aspects of damage of earth dams were cracks. They took place about 78% of different types of damages in high and low intensities of earthquakes:
a) Transverse cracks appeared mostly along the abutments of dams by unequal settlements. Sometimes they were due to settlements of foundation overburdens.
b) Longitudinal cracks appeared on both slopes of dams. Some of them were curved in plan and may be the result of potential slides. Sometimes they may be due to the serious settlements of foundation, liquefaction of saturated silty soil or poor compaction during construction.
4) The slide of slope was more dangerous aspect of damages. Most slides appeared not only in high intensity of earthquakes like Douhe in Tangshan (degree 9) but in lower intensities (degree 5-6). The dominant factors are the types of embankments and the angle of friction of dam shells. For homogeneous earth dams filled by sluiced siltation method it is most critical. This type of damages is most typical for the downstream slope of many dams in the Heligeer Earthquake, even the intensity on the dam site was degree 6 only. Most upstream slope of saturated silty clay or fine sand and gravel during earthquake, as the slide of surface protection on the upstream slope of Baihe dam, which were investigated by many authors ten years ago.
5) Settlements appeared in many dams with accompanying cracks. Of course, earth dams always settle during earthquake, but sometimes the induced unequal settlement produced different types of cracks, as mentioned before. This problem was not so serious, because most of these earth dams were not so high.
6) The increase of leakage was a general aspect after earthquakes. Three different kinds of

Different Types of Damages of Earth Dams by Strong Earthquakes from 1961 to 1986

(by Incomplete Statistics)

| Earthquakes | | | Types of Damage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Place | year, month | Magnitudes M | Slide of Foundation | Slide of slope | Cracks | Cracks with Leakage | Settlements | Leakage | Others | Total |
| Bachu (Xinjiang) | 1961 Apr. | 6.8 | 1 | | 1 | | 1 | | | 1 |
| Urumqi (Xinjiang) | 1965 Nov. | 6.6 | | | 1 | | | | | 1 |
| Xingtai (Hebei) | 1966 Mar. | 6.8<br>7.2 | | | 4 | | 1 | | | 4 |
| Bohaiwan | 1969 Jul. | 7.2 | | 3 | | | | | | 3 |
| Yangjiang (Guangdong) | 1969 Jul. | 6.4 | | | 5 | | | | | 5 |
| Tonhai (Yunnan) | 1970 Jan. | 7.7 | | 1 | 41 | | | | | 41 |
| Liyang (Jiangsu) | 1974 Apr. | 5.5 | | | 6 | | | | | 6 |
| Zhaotong (Yunnan) | 1974 May | 7.1 | | | 1 | | | 1 | | 2 |
| Haicheng (Liaoning) | 1975 Feb. | 7.3 | | 1 | 26 | | | 11 | | 35** |
| Helingeer (Inner Mongo.) | 1976 Apr. | 6.3 | | 9 | 17 | | 1 | 18 | | 44 |
| Longling (Yunnan) | 1976 May | 7.5<br>7.6 | | 5 | 19 | 1 | | | | 21 |
| Tangshan (Hebei) | 1976 Jul. | 7.8<br>7.1 | 1 | 2 | 35 | 2 | 2 | 9 | 1 | 39** |
| Liyang (Jiangsu) | 1979 Jul. | 6.0 | | | 8 | | | | | 8 |
| Luqien Quendian (Yunnan) | 1985 Apr. | 6.3 | | | 5 | 2 | | | | 5 |
| Kashi (Xinjiang) | 1985 Aug.<br>Sept. | 7.4<br>6.8 | | 1 | 1 | | 1 | | | 1 |
| Total | 15 | | 2 | 17 | 170 | 5 | 69 | 39 | 1 | 216 |
| Percentage % * | | | 0.9 | 7 | 78 | 2 | 2.7 | 18 | 0.4 | 100 |

* The percentage will be higher than this figure, because some dams have two or three of damages.

** Only dams with reservoir storage capacity greater than 1,000,000 $m^3$ are included.

leakage were discovered: The first was temporary increase after earthquake, sometimes with muddy water, and after a few hours stopped by self relief. The second was increase of leakage through the abutments or foundations due to damage of grout curtain. The third was openning new channels of leakage after earthquake mostly in karst regions.
7) Many parapet walls were destroyed during earthquake, because they stood on the crest of earth dams and there existed large horizontal acceleration force acting on them. Besides, the masonry structure had not enough tensile strength.

Another weak point of earth dam to resist earthquake was the interface between the embankment and concrete or masonry structures. The retaining walls of spillway and the culverts or pipes embedded in the dam body were always sources of trouble.

## SOME EXPERIENCES

More than 200 examples of damages and 30 years of research works gave us some experiences, although some of them were well known already for many years.

### 1) Improvement of Design

For some small earth dams located in the counties, their design had obvious defects without proper control. For instance, the Kashi earth dam is of inclined core (silty clay loam) with sand gravel shells, the designers wanted to have an impermeable barrier and they put on two layers of plastic membrane with thickness 0.2 mm not on the surface but on the bed (Fig. 2). It made the whole core under water saturated and decreased the friction angle from $34^{o}$ to $23^{o}$. It undoubtedly was the reason of the surface slide (Fig. 6). This is also an example of liquefaction of the core and shell.

Some earth dams had too high phreatic lines and without drainage. Therefore the strength of soil decreased due to the increase of pore pressure during earthquakes. The correct design of drainage and filters are very important too. Some damages of earth dams were due to the defect of drainage.

### 2) Improvements of Construction

Most of the damages like cracks, settlements and slides were caused by poor compaction. The low density of soil gives low strength and is vulnerable to liquefaction. For some small dams proper compaction equipments were not available. The self-consolidation needed a long time, so the dam was damaged even during minor earthquakes.

Damages also occured due to bad foundation conditions.In some medium and small sized reservoirs the foundation treatment works of dams were too much simplified. Sometimes the grout curtain were not deep enough. Sometimes the saturated silt in the loose alluvium was not cleared away, causing liquefaction like in Kashi, mentioned above.

The quality control of materials (soil, rockfill etc.) was not strict, causing damages as excessive settlements, leakage and displacements after completion of the dams.

### 3) Adoption of Reasonable Safe Measures Against Earthquakes

For design of high earth dams the prediction of seismicity and research works were well done, the designers generally paid more attention to the careful choice of materials, therefore there were no problems during earthquakes of intensity less than degree 6. But for small dams it will be questionable to prove their safety at reasonable cost. The right approach is to make risk analysis and allow some damages but without failure. Some cracks may be considered allowable. In any case the possibility of immediate drawdown of reservoir water level with emergency spillway or bottom outlets was very necessary.

### 4) Avoidance of High Structures of Parapet Wall on the Crest of Dams

High structures are always weak points during strong earthquakes, experience proved that, the masonry parapet walls on the crest of dams were quite often damaged due to whipping effect.

## CONCLUSION

From the case histories of Chinese embankments damages by 15 strong earthquakes in the last 25 years, it can be concluded that:

1) Even 216 embankments were damaged, and some of them were very serious, but no one was collapsed.

2) Many serious damages of earth dams were caused by the defects of investigation and design, especially the inadequate drainage and the improper use of materials.

3) The poor compaction of earth dams in construction and unreasonable treatments of foundation were another main cause of damages, which must be avoided.

4) High structures or wave walls on the crest of dams should be avoided in any case.

Understanding the nature of sismic response of dams through practice is a direct and essential way. The analysis and research of data collected becomes the source of our knowledge. It is regretted that not sufficient data are available, because for many small dams there are almost no records. Therefore our research is a time consuming job. This paper is an attempt to solve this complex problem.

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