Behaviors of Dams in Mexico Earthquake September 19,1985

by

Choshiro Tamura

1. Introduction

Cases of large dams built with modern design and construction methods being subjected to strong earthquake motion have begun to increase in number. Particularly, these cases are important in judging the earthquake-resisting capabilities that fill dams actually possess.

Rockfill dams are said to be very earthquake-resistant and high dams of this type are being built even in regions of great seismicity. Since the earthquake resistance are prominently affected by the foundation ground, materials, and construction method, these factors must be considered in evaluating earthquake-resisting strength, which is not a simple matter. That is why actual cases of earthquakes having been experienced are valuable. From such a point of view, Miboro Dam (H = 132 m, construction completed 1961, Japan) in the Kita-mino Earthquake (M = 7.0, 1961) and Makio Dam (H = 104.5 m, construction completed 1963, Japan) in the Nagano-ken Seibu Earthquake of 1984 (M = 6.8) are actual cases of high rockfill dams, the former with an epicentral distance of about 17 or 18 km, and the latter about 4 to 5 km.

At the time of the earthquake of M = 8.1 that occurred in September last year (1985) at the Pacific Ocean coast of Mexico, there were two rockfill dams, La Villita and El Infiernillo in the epicentral area or its surroundings. The author made a field reconnaissance in October, the following month, and the information obtained is hastily reported below.

2. Outline of Earthquake

The particulars of the earthquake are given below.
Time of occurrence: 0718, September 19, 1985 (local time)
Epicenter: 18.266°N, 102.748°W
Magnitude: Ms 8.1
Focal depth: said to be 15 to 30 km

As for the maximum aftershock, it occurred at a location approximately 100 km distant and was as follows:
Time of occurrence: 1938, September 20, 1985 (local time)
Epicenter: 17.801°N, 101.651°W
Magnitude: Ms 7.5

The epicenters and focal areas are shown in Fig. 1. The main shock was a multiple shock consisting of a first subevent, and after approximately 30 sec, a second subevent which occurred at a point about 100 km distant, the focal area being within the broken line. The maximum aftershock occurred close to the second subevent, its focal area being indicated by the solid line. Consequently, an area close to the two was subjected to strong earthquake motions three times. The point depicted as La Villita within the focal area of the main shock is the earthquake observation point on bedrock at the La Villita dam site.

3. Intensities of Earthquake Motions in Focal Areas and Surroundings

Maximum acceleration will be considered here as the scale of earthquake motion intensity. Earthuake observations are being carried out on rock bodies with the Guerrero Allay Observation System installed from the focal area of this earthquake eastward along the seacoast. Records were obtained at more than 17 sites including four in the focal area. Hypocentral distances correlated with maximum accelerations in the horizontal direction based on data furnished by UNAM are as shown in Fig. 2. This was under the presumption that focal depth had been 20 km. The two subevents were 100 km apart, while there was a time differential of approximately 30 sec between the two so that it is possible to find maximum accelerations corresponding with the respective subevents in the accelerograms of the epicentral areas. The maximum acceleration values of observation points to the east of the epicentral area were correlated to the second subevent. Marks, ◎, ⦿ in Fig. 2 are records of Zacatula obtained on ground consisting of sand-gravel and the values are approximately double compared with others. According to this figure the maximum accelerations within a radius of roughly 100 km from the epicenter were about 120 to 170 gal and more or less constant, but beyond that there was damping according to distance. The maximum aftershock, similarly treated, is shown in Fig. 3.

It may be seen from these figures that the maximum acceleration in the focal area of the main shock was at a comparatively low level. On making a reconnaissance it was thought that the condition of earthquake damage in this area is in agreement with the intensity of the earthquake motion.

4. Behaviors of Dams

La Villita Dam is located approximately 15 km to the north upstream from the mouth of the Balsa River, while approximately 40 km farther to the northeast is El Infiernillo Dam. The former was completed in 1968 and the latter in 1963 so that both had already experienced a number of strong earthquake motions. Earthquakes which had occurred recently were the one offshore of Lazaro Cardenas on October 10, 1975, M = (5.5), the one with its epicenter between the two dams on November 15, 1975, M = (6.5), the one with its epicenter in the vicinity of Zihuatanejo in March 1979, Ms = 7.6 (6.5), and further, another one immediately offshore of Lazaro Cardenas on October 25, 1981, M = 7.3 (6.2). The magnitudes in parentheses for the above cases are Mb values indicated from P waves.

According to the records (J. A. Aramburu, G. M. Gomez) of the earthquakes experienced by the two dams, accelerations of roughly the same degrees have been sustained between October 1975 and October 1981. These are respectively 85 gal or more and 105 gal in the direction orthogonal to the dam axis, and respectively 83 gal or more and 120 gal in the direction of the dam axis.

Since Lazaro Cardenas at the mouth of the Balsa River was approximately at the center of the focal area of the recent earthquake, La Villita of the two dams, accordingly, was located in the focal area.

The maximum accelerations recorded on bedrock (andesite) at the site of La Villita Dam were 125 gal N-S, 122 gal E-W, and 58 gal vertical, the accelerograms being as shown in Fig. 5.

The two dams will next be individually described.

(1) La Villita Dam

La Villita Dam is a center-core type rockfill dam of the following specifications:

Dam height	60 m
Crest length	420 m
Dam volume	3,510 x 10^3 m^3
Storage capacity	710 x 10^6 m^3
Year completed	1968

The standard cross section is as shown in Fig. 6. The upstream and downstream slopes are 1:2.5 and the dam axis is curved toward the upstream side. The foundation has river-bed deposits about 25 m in thickness at the deepest spots, but because the river is rapid the the river bed load at the site consists of gravel and coarse sand.

Disturbances brought about by the recent earthquake, as shown in Photo. 1, were small longitudinal cracks formed over lengths of approximately 150 m along the dam axis at the crest of the dam about 1.5 m on the inside from the tops of the upstream and downstream slopes. The width of the crest, which is being used as a roadway, is 14 m, and 1.5 m of extra banking is provided at the middle portion of the dam. Surveying was being done at the time of the reconnaissance so the amounts of settlement and displacement will be known. In light visual inspection, no remarkable change other then the abovementioned longitudinal cracks was found.

Parapet walls (height 70 cm, thickness 15 cm) are provided at the tops of the upstream and downstream slopes, and 9 panels of the downstream wall had toppled over to the downstream side, but these walls were of simple structure with only steel bars about 20 cm in length inserted as anchors.

The two longitudinal cracks were formed at locations which were both on extensions of the upstream and downstream slope lines of the core. From the fact that the depths were about 50 cm they can be considered as being disturbances of the kind frequently seen in areas of severe earthquakes.

The maximum accelerations at the dam crest are still unknown, but in the previously-mentioned records, the ratios between maximum accelerations at bedrock and dam crest were 4 to 4.7 in the axial direction of the dam. Analogized from this it should be permissible to consider that maximum acceleration at the dam crest in this earthquake had been 450 to 500 gal.

The dam has a spillway (tainter gates) provided at its right-bank side, and no disturbance was seen. Power transmitting and transforming facilities (power transmission at 230,000 V) were located on the right-bank bedrock (andesite), but there was no damage at all. There was partial cracking produced at walls and ceilings of the one-story administration building, but the damage was extremely light.

A powerhouse exists at the right-bank side downstream of the dam, built excavating bedrock. The building is of structural steel construction. Plastic had been used for window panes in consideration of earthquakes, and it was surmised that the construction was sound. This building vibrated severely during the earthqauke, but practically no damage was suffered. There was only partial damage to the ceiling of an office room on the fourth story inside the building. Generators stopped temporarily, but returned to normal operation on inspection and confirmation that an abnormal situation did not exist.

(2) El Infiernillo Dam

El Infiernillo is a center-core type rockfill dam built approximately 40 km northeast from La Villita Dam.

The specifications are

Dam height	148 m
Crest length	350 m
Dam volume	5,500 x 10^3 m^3
Storage capacity	9,340 x 10^6 m^3
Year completed	1963

The standard cross section is as shown in Fig. 7 with the construction on bedrock (andesite), and with the upstream and downstream slopes fairly steep at 1: 1.75. In the recent earthquake longitudinal cracks of depth about 60 cm were formed respectively on the insides of the tops of upstream and downstream slopes. Settlement of approximately 10 cm occurred at the middle, while conversely there were rises of about 10 cm at the two ends.

Raising of the core was being done when the author visited the site and it was not possible to observe the longitudinal cracks formed as a result of the earthquake. Nothing that appeared like a disturbance could be seen at the downstream slope surface. There was no damage to the power transmitting and transforming facilities on the bedrock at the downstream side of the dam, while it was said that rockfalls did not occur either.

The maximum accelerations at the dam and dam site have not yet been obtained by the author, but it is thought about 100 gal was reached on the bedrock. Incidentally, the ratio of maximum acceleration at the crest to the maximum acceleration at the bedrock in case of this dam is 2.5 to 3.4 in the direction orthogonal to the dam axis. That this ratio is small compared with La Villita Dam is probably because the dam body is constructed directly on bedrock.

The powerhouse is located underground at the left-bank side and six generators are installed there (output approximately 1 million kW). Relays were activated for the No. 2, No. 3, and No. 4 units at the time of the earthquake to stop the generators. Power generation was resumed on confirming that nothing was wrong. It might be added that in the earthquake of M = 7.6 in 1979 with the hypocenter offshore of Zihuatanejo there had been earthquake motions stronger than this time. A maximum acceleration of 120 gal at the bedrock was recorded then, and it is said the dam crest settled several tens of centimeters.

It is said that rollers were used at the time the dam was constructed.

Hardly any damage was seen at the administrative office building located downstream from the dam.

5. Conclusion

At the time of the investigation the configuration of the dam was being surveyed at La Villita Dam, while core raising work was under way at El Infiernillo Dam, and it was not possible to obtain accurate quantitative data on behaviors during the recent earthquake.

However, it can be said that actual examples of great earthquake resistance of high rockfill dams have been provided to add to the information available on the behaviors of Miboro and Makio Dams previously mentioned.

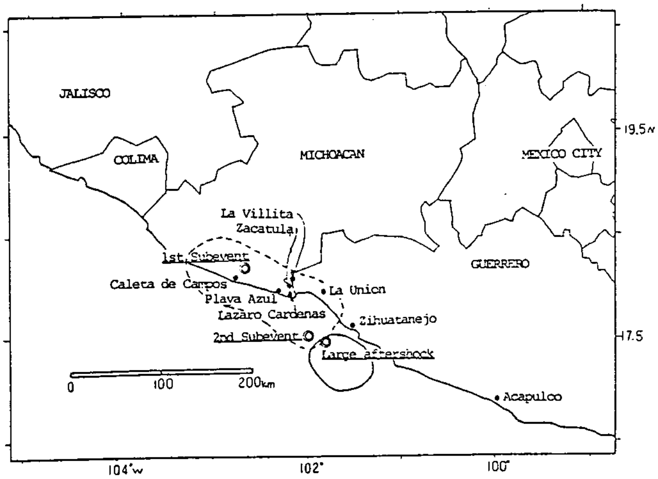


Fig. 1 Aftershock areas of main shock and maximum aftershock.

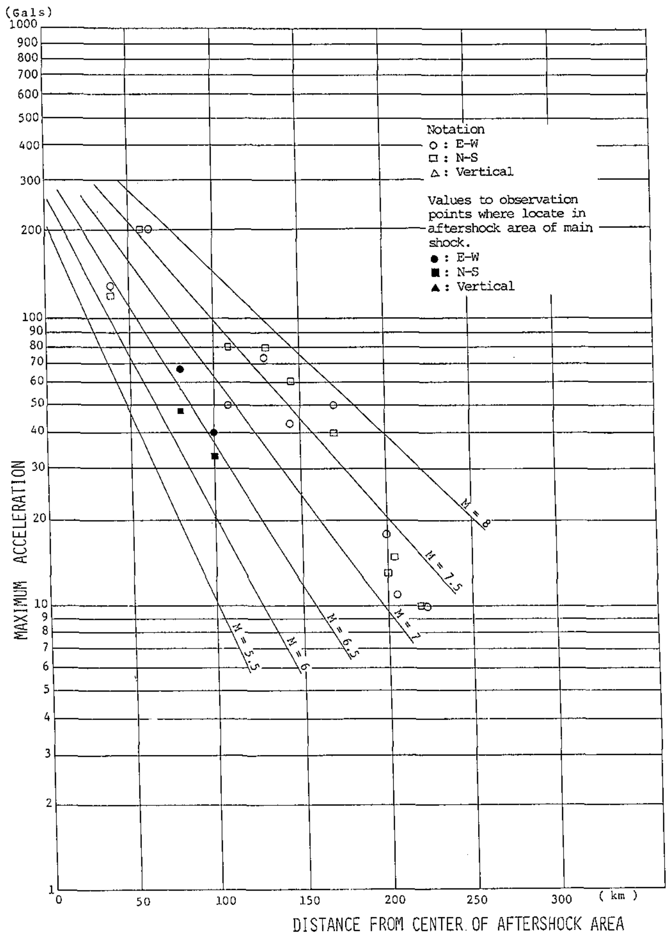


Fig. 3 Maximum acceleration in largest aftershock and distance from aftershock area.

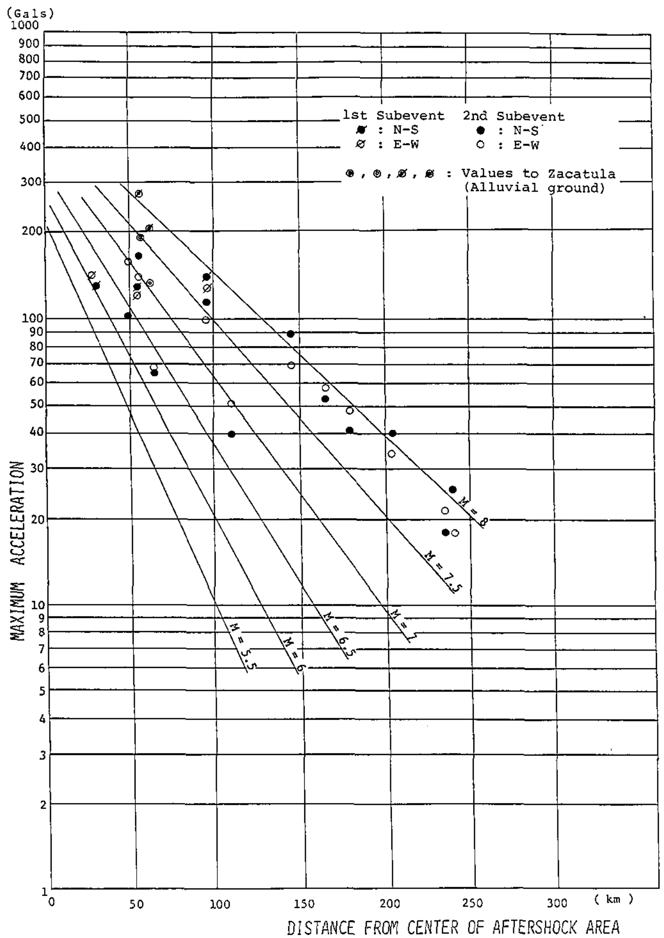


Fig. 2 Relationships between hypocentral distances and maximum accelerations (main shock).

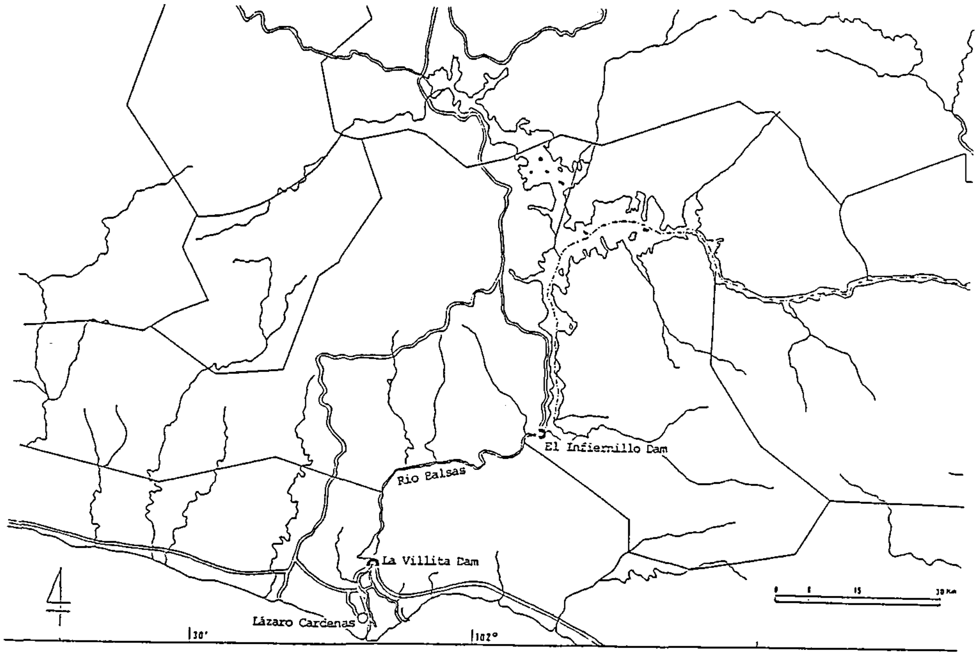


Fig. 4 Locations of dams.

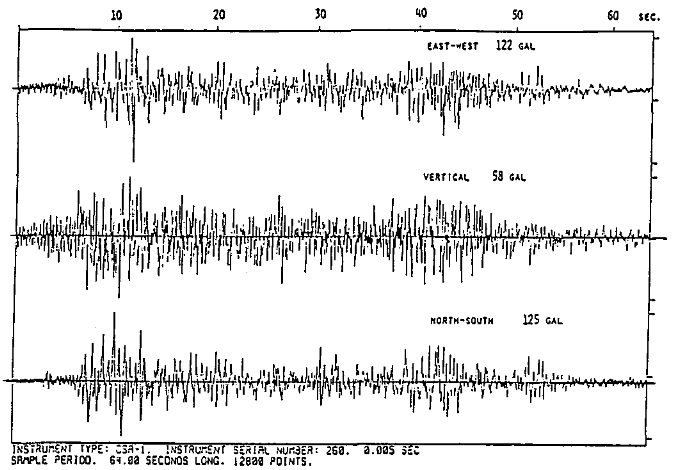
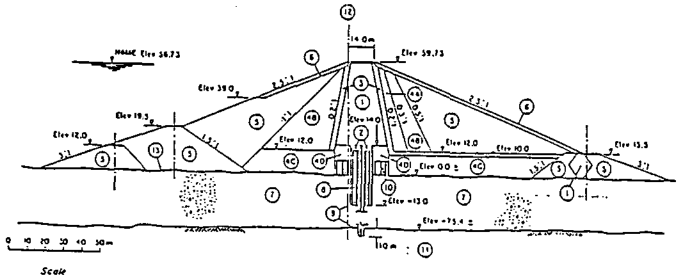
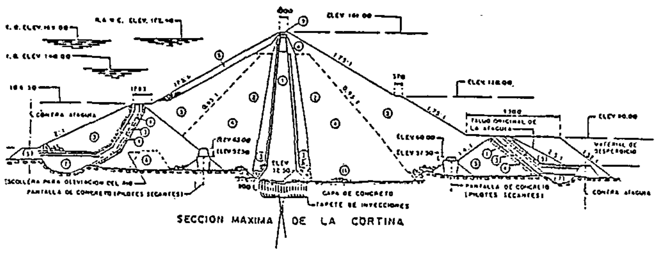


Fig. 5 Accelerograms on bedrock at La Villita Dam site.



1 Compacted impervious material
2 *Highly plastic clay*
3 Sand filters
4A Well graded gravel and sand
4B Gravel and sand
4C Compacted gravel, sand and muck
5 Rockfill
6 Selected rockfill
7 Alluvium(gravel and sand)
8 Grout curtain
9 ICOS- type concrete cut-off wall
10 Consolidation grouting
11 Andesitic breccia
12 Dam axis
13 Original ground surface
Elevation, in m
NAME Maximum water level

Fig. 6 Standard cross section of La Villita Dam.



1 Impervious material
2 Filter
3 Transition Zone
4 Compacted rockfill
5 Dumped rockfill
6 Large size rockfill
7 Impermiable apron
9 Base for coating
11 Hard rock

Fig. 7 Standard cross section of El Infiernillo Dam.

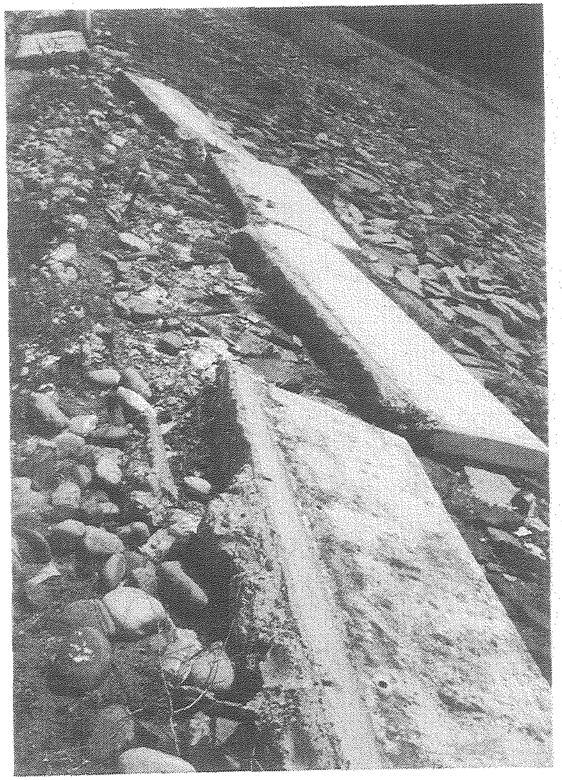


Photo 2; Overturning of concrete panels at the top of the down-stream slope, La Villita Dam.

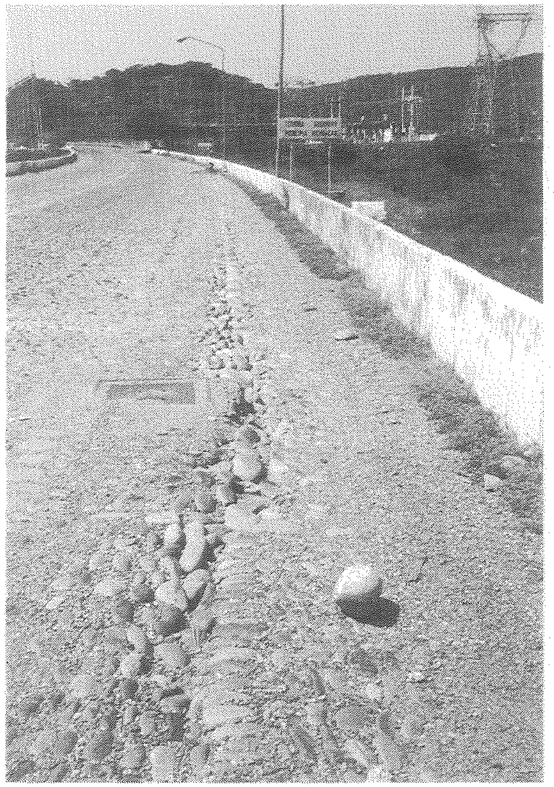


Photo 1; Longitudinal crack along the shoulder of upstream slope, La Villita Dam.

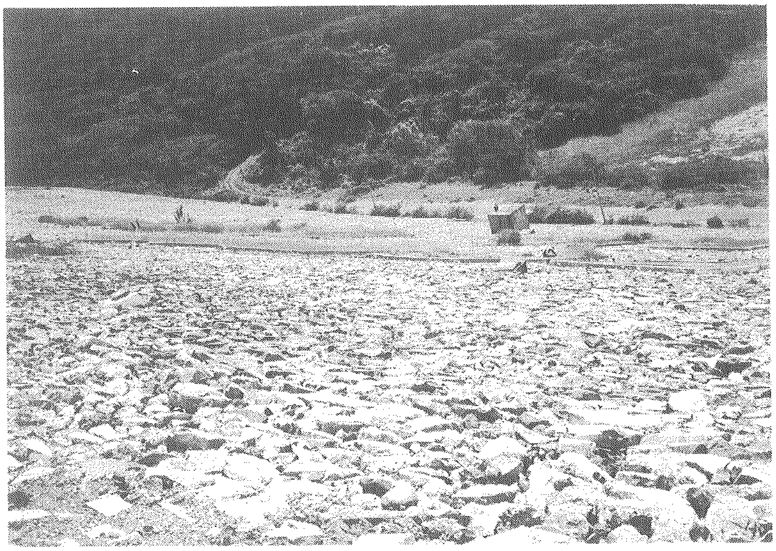


Photo 3; A cover lifted up by the tube of Piezometer owing to settlement of the down stream slope, La Villita Dam.

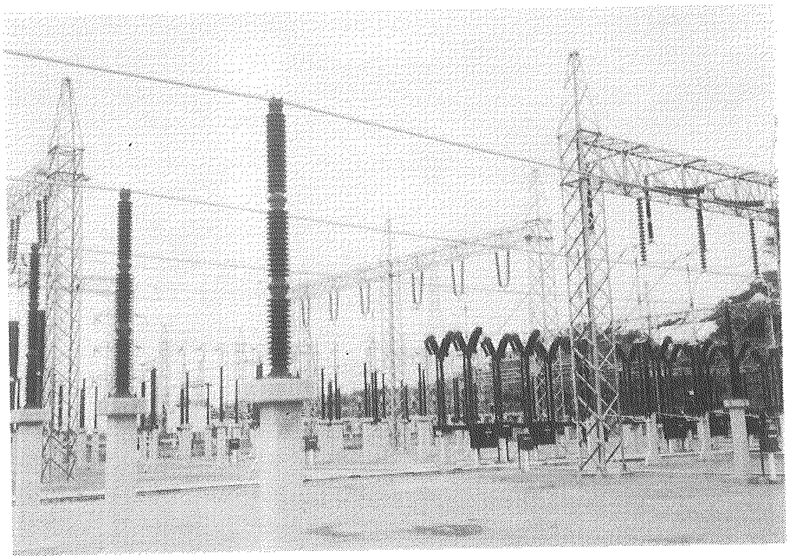


Photo 4; Substation of La Villita Dam. (No Damage)

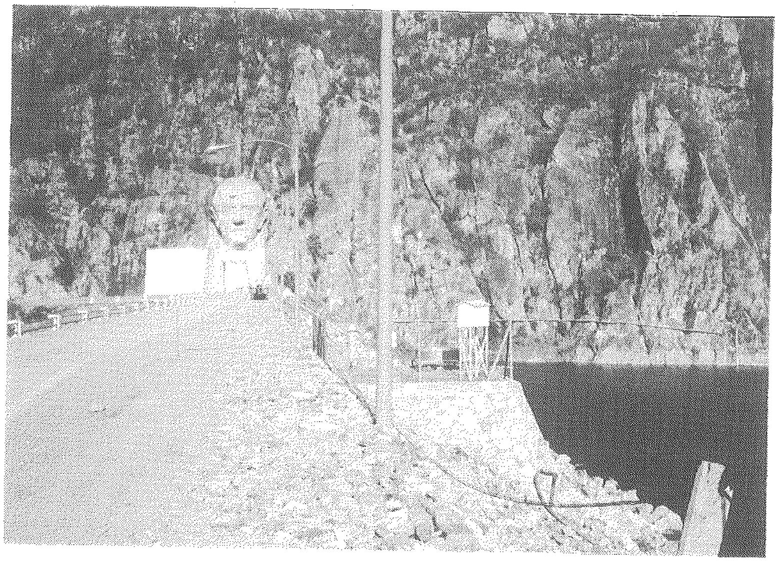


Photo 5; Top of the El Infiernillo Dam.

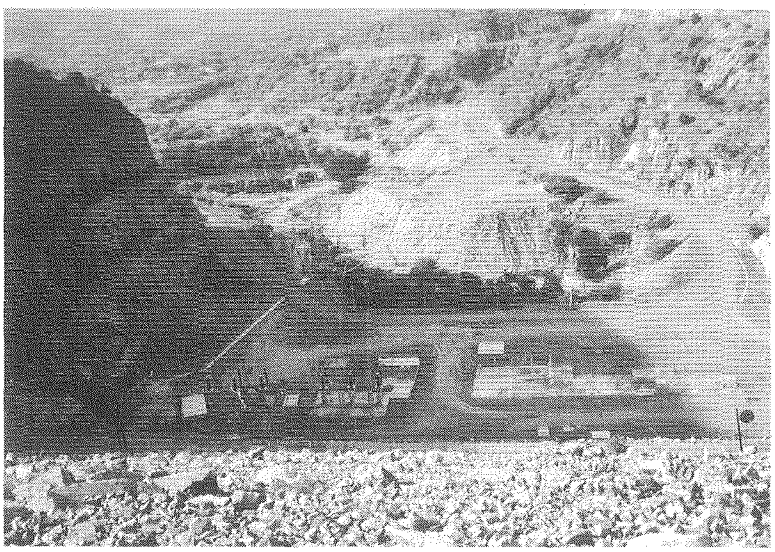


Photo 6; Downstream side, El Infiernillo Dam.