Determination of immediate and long term effects of Earthquake-2005 on Tarbela Dam, Pakistan

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Abstract: The catastrophic earthquake of 7.6 magnitude on Richter scale hit Northern Pakistan on October 8th 2005 at 084955 PST. The yellow earthquake drill was performed immediately after the earthquake to investigate the effects of this earthquake on the different structures of the Tarbela dam .The earthquake drill comprising of hydrographic survey, monitoring of all the instruments, physical inspection of the major structures, movement survey, and comparisons of seepage. The data indicates changes in the seepage pattern and pore pressures before and after earthquake. The pore pressures rise upstream as well as downstream of grout curtain was observed. The maximum seepage increase up to 1.11 cfs in RDA-22 and drainage adit discharge from l827 to 1913.64 gallons per minute were recorded. No significant change, movement or settlement of expansion joints were observed, however displacement of a retaining wall 13 to 14 mm at the top of" a retaining wall at construction joint was recorded. Minor movement of top set slope and deposition of sediments in front of tunnels have also been found. Long term monitoring to study the effects in depth such as micro fracturing of the structures, seepage at right abutment and allied problems is suggested to ensure the safety of the dam.

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Introduction

The earthquake of October 8, 2005 has caused a catastrophic damage to life and property in Northern areas of Pakistan. The earthquake has occurred due to motion in MBT (main boundary thrust) and Kashmir fault. This earthquake has greatly changed and affected the geomorphology of the area by development of large number of landslides which caused catastrophe. Mushtaq and Haq (2006) reported more than 2500 aftershocks recorded by seismic station at Tarbela. Many researchers have studied the earthquake of 2005 to assess the damages and future protection (Mahdi, & Siddique, 2006; Sharif et al 2006; Dunning et al 2007).

Quittmeyer, et al 1979 and NESPAK, 1995 studied the seismicity of Pakistan with reference to Tarbela Dam. According to Mahdi et al (2005),"The earth response to a particular reservoir depends upon regional tectonics stresses, on the porosities and permeabilities of the geological formations under laying the reservoirs, on the presence of the faults in the vicinity and on the depth/volume of water in the reservoir". Mushtaq & Haq (2006) carried out a study on dam performance and seismicity after 2005 earthquake with their focus on the two large dams, Tarbela and Mangla and concluded," that all the structures have contributed to perform satisfactorily and that there was no abnormality of any cause for concern". Ghumman and Masood (2006) studied the slope stability analysis of earth dam against earthquake loading and highlighted the role of soil properties," a soil having good shear strength will contribute better safety against slope failure than a soil having low cohesion and angle of internal friction of soil". Keeping in view of importance of the large dams, it is a standard practice that after every earthquake of 5 and above magnitude special dam safety monitoring exercise is performed to find out any effects on large dams. Hence a special monitoring yellow drill was performed after the earthquake at Tarbela Dam.

Tarbela Dam is one of the greatest water resources development projects of the world built on Indus River. The project consists of the 9000 feet long and 479 feet high earth and rock filled embankment across the entire width of the river with two spillways and two auxiliary embankment dams, located on the left bank valley. Four tunnels through right abutment have been constructed for irrigation releases and power generation. The dam has developed a lake of 97 km long, spread over an area of 260 square km with a gross storage of 11.62 MAF.

This study is performed to evaluate the effects of the catastrophic earthquake on the Tarbela Dam of Pakistan. Data of seepage for various structures at similar levels have been included for seven consecutive years after earthquake i.e., 2005- 2011 to access long term affects of the earthquake on seepage behavior.

Materials and methods

Data have been collected for seepage, delta movement and, settlement and pore pressures changes through extensive measurements carried out immediately after the earthquake by the project authority. To investigate the effects of earthquake, following methodology has been adopted.

1 Physical inspection of all major structures
2 Hydrographic survey
3 Monitoring/comparison of instrumental seepages.
4 Movement survey
5 Comparison of seepage data at similar reservoir level from 2005-2011.

Results and Discussions

The physical inspection indicated that no significant effects were observed immediately after the earthquake except reported by Qureshi (2005),"a retaining wall around the top of gate shaft structure near the rock slope has been displaced in order of 13-14 mm at the top of wall at construction joint. Two expansion joints on the upstream wall have opened up to 1 mm due to earthquake. The radial expansion joint of penstock unit 4 has further expanded after earthquake".

Hydrographic survey of the reservoir from, range line No 1-18 was carried out on October 8, 2005 by the project authority of Tarbela Dam. The results are given in Table 1. The comparison with hydrographic survey performed during September 2005, indicates that shifting of sediments up to two feet from Range No 12.75 to 13.33 and 13.75 to 15 on top set slope and deposition of 2.2 feet from Main Embankment Dam to Range line No 12 took place due to earthquake. The hydro-graphic survey of intake area for tunnels T-1 to T – 4 was carried out on October 9, 2005. The field record shows that I feet sediments.

The pore pressure rise in a number of piezometer took place as a result of shaking of earthquake. Monitoring data of these instruments (Table-2) shows that the effects are more prominent at right abutment near KGA-4 and especially upstream as well as downstream of FGA-3. Although pressure rise was nominal and recorded upstream as well as downstream of RGA-5 grout curtain and RDA-2 this was retained for sometime.

Table 1 Results of hydrographic survey conducted on Oct. 8, 2005 showing the movement of delta due to earthquake

Range Line No	Elevation on Sept., 2005	After Earthquake on Oct 8, 2005	Move-ment
1.	1202.5	1203.6	+1.1
2.	1203.0	1203.6	+0.6
3	1205.0	1204.6	–0.4
4	1208.7	1208.6	–0.1
5	1210.0	1209.6	–0.4
6	1216.0	1215.6	–0.4
7	1222.3	1221.6	–0.7
8	1229.4	1228.6	–0.8
9	1239.4	1238.6	0.8
10	1248.0	1247.6	–0.4
11	1258.4	1260.6	–0.2
12	1275.4	1277.6	+2.2
13	1356.4	1357.6	+1.2
14	1373.6	1371.6	–2.0
15	1377.5	1377.6	+0.1
16	1380.0.	1379.6	–0.4
17	1377.0	1375.6	–1.4
18	1379.5	1377.6	–1.9

deposition in front of Tunnel No T-1 and T-4.(Qureshi,2005)

Comparison of seepage from different important structures has been made which indicates that a change in the seepage pattern has been induced by the earthquake. Measurements made at different weirs before and after earthquake are given in Table-3. It has been observed that in a number of drain holes turbid flow has started just after earthquake which is attributed due to movement in the sediments deposits of the lake. The hydrographic survey confirmed that there is erosion of the upper two feet layer of the sediment deposit in the lake. Measurements of suspended fines from various outlets of the dam are given in Table-4. The survey conducted immediately after the earthquake show that maximum settlement of 0.055 feet has occurred at station 71+00 at crest of main embankment dam.

Long term monitoring data given in Table-5 shows that seepage at critical locations returned to original values during the subsequent years after earthquake.

Table 2: Comparison of Pore Pressure Changes before and after Earthquake at Right Abutment

Piezo No	Location	Before E/quake	After Earthquake						
Date→		03.10.2005	08.10.2005	09.10.2005	10.10.2005	11.10.2005	13.10.2005	15.10.2005	17.10.2005
B-273(1)	RDA-2	1316.06	1327.76	1344.49	1344.49	1344.49	1342.81	1342.81	1342.81
B-275	-do-	1350.31	1360.34	1362.01	1302.01	1362.01	1360.34	1360.34	1360.34
B-277(1)	-do-	1286.69	1300.07	1300.07	1300.07	1300.07	1300.07	1300.07	1300.07
B-277(2)	-do-	1286.89	1300.07	1300.07	1300.07	1300.07	1300.07	1300.07	1300.07
B-287(1)	-do-	1352.47	1370.5	1361.17	1301.17	1361.17	1360.5	1359.83	1359.83
B-288(1)	RGA-3	1354.49	1362.52	1363.19	1360.51	1363.91	1362.52	1361.85	1361.85
B-579	RGA-5	1360.7	1365.71	1365.71	1365.71	1365.71	1365.71	1365.71	1365.71
B-665	RGA-4	1445.44	1450.45	1452.13	-	1452.13	1452.13	1456.13	1452.13
B-609	-do-	1349.69	1354.71	1356.38	1356.36	1358.38	1358.38	1356.38	1356.38
B-560	RGA-8	1363.09	1366.43	1371.46	-	1369.7Sf	1369.78	1369.78	1369.78
B-562	-do-	1388.51	1413.6	1396.88	-	1403.56	1410.25	1410.25	1410.25
563	-do-	1416.17	1431.22	1432.9	-	1432.9	1431.22	1431.22	1431.22
612	-do-	1382.62	1387.64	1409.38	-	1407.71	1406.04	1406.04	1406.04
613	-do-	1388.42	1388.49	1394.85	-	1396.53	1396.53	1396.53	1396.53
652A	-do-	1391.96	1401.99	1432.1	-	1408.68	1408.68	1408.68	1408.68
654A	-do-	1387.2	1398.73	1407.09	-	1407.09	1405.42	1405.42	1405.42
655	-do-	1415.23	1430.28	1435.3	-	1436.97	1433.63	1433.63	1433.63
657	-do-	1416.36	1429.74	1433.09	-	1433.09	1431.41	1431.41	-
658	-do-	1417.06	1430.44	-1430.44	-	1430.44	1430.44	1430.44	-
P8-1	Debris Dam	1441.72	1445.55	--	-	-	-	-	1442.88
P8-2	-do-	1439.91	1445.41	--	-	-	-	-	1442.82
B-728	RGA-5 u/s	1471.07	1476.43	--	-	-	-	-	1472.75
B-729	RGA-5 d/s	1407,23	1409.24	--	-	-	-	-	1405.56
B-730	RGA-3 u/s	1416.4	1418.07	-	-	1418.07	1416.4	-	-
B-742	RGA-8	1311.24	1314.58	1314.58	-	1314.58	1314.58	1314.68	-
769(1)	Con tunnel	1428.33	1429.75	-	1430.83	-	-	-	1431.67
769(3)	-do-	1327.33	1428.42	-	1428.75	-	-	-	1429.25

Table 3: Comparison of the Adit Seepage (cfs) before and after Earthquake)

Adits	Before E/quake	After Earthquake 8.10.2005 to 22.10.2005															
	1.10.05 Morning	8 Morn	8 Even	9 Morn	9 Even	10 Morn	10 Even	11 Morn	12 Morn	12 Even	13 Morn	14 Morn	15 Morn	17 Morn	18 Morn	19 Morn	20 Morn
	RL→1525.7	1525.25		1525.38		1525.31		1525.25	1528.06		1624.76	1624.31	1524.55	1524.38	1524.88	1524.94	1525.26
	1.10.05	9.10.05	9.10.05	9.10.05	9.10.05	10.10.05	10.10.05	11.10.05	12.10.05	12.10.05	13.10.05	14.10.05	15.10.05	17.10.05	18.10.05	19.10.05	20.10.05
RAA15-1	0.32	0.23	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.27	0.24	0.23	0.23	0.23	0.23	0.23

RAA-2	2.25	2.25	2.31	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37	2.37
RDA-22	4.44	4.44	4.53	5.08	5.03	5.17	5.21	5.25	5.27	5.29	5.27	5.36	5.27	5.55	5.55	5.55	5.55
LLA-1	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
LLA-2	2.48	2.18	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.48	2.44	2.38	2.38	2.38	2.38
SSDA-1	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16
SSDA-2	0.22	0.22	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.26
ADA-2	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
ASDA-3	1.58	1.58	1.62	1.58	1.58	1.58	1.58	1.58	1.53	1.58	1.58	1.58	1.58	1.58	1.58	1.58	1.58
LDA-3	0.94	0.94	0.94	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92	0.92

Table 4 Results of suspended fines collected from various outlets of the dam.

Outlet		U-1		U-6		TR-1		U-10	
Date	RL	Time	Fine mg/l	Time	Fines mg/l	Time	Fines mg/l	Time	Fines mg/l
8-10-2005	1525.05	1245	554	1250	514	1705	199	1651	366
		1330	634	1335	626	2245	113	2240	71
		1645	248	1655	352	-	-	-	-
		2235	115	2238	74	-	-	-	-
10-10-2005	1525.35	1218	34	1216	41	1210	25	2218	43
		1600	27	-	-	2210	30	-	-
		2214	32	-	-	-	-	-	-
11-10-2005	1525.23	-	-	-	-	1105	154	1810	575
		-	-	-	-	1335	70	-	-

Table.5 Comparison of Adit seepage (wiers) in cfs at similar reservoir levels from 2005 to 2011 at rising leg.

Adit No	Year	2005	2006	2007	2008	2009	2010	2011
	Reservoir Level	1525.05		1525.10	1525.82	1526.40	1525.34	1525.31
RAA-2		2.115		1.6512	1.5944	1.4279	1.3738	1.3140
RDA-22		4.71		4.477	4.3345	4.3878	4.1235	4.019
LLA-2		1.58		1.179	1.219	1.439	1.280	1.266
ASDA-2		0.36		0.618	0.584	0.580	0.563	0.537
ASDA-3		0.81		1.335	1.285	1.335	1.285	1.219

Conclusions and recommendations

The investigations indicate that the performance of various structures of the dam remained satisfactory during the earthquake. The increase in seepage was temporary and returned to original level during the post earthquake period.

The existing seismic network is required to be further strengthened by providing additional seismic instruments in the northern parts of the country for the periodic monitoring and prediction of seismicity in Pakistan..

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