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A REVIEW ON PERFORMANCE OF EARTHFILL DAMS DURING PAST EARTHQUAKES

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Abstract—**Dams which are constructed of earth and rock-fill materials they are generally referred as embankment dams or fill-type dams. Athani et al. (2015) examined that the Earth-fill dams are simple structures which are able to prevent the sliding and overturning because of their self-weight. Gahlot & Gajbhiye (2013) examine recently there has been remarkable development in the fields of design, research and construction of dam in India and India is now very much capable of designing and constructing a dam which resist the seismic vibrations and withstand without much failure. Developing countries need water for irrigation purpose to increase the production of food for good living. So dams are the best solution for storing water. Dam like structures are very risky for seismic vibrations so for that reason they are designed to resist the seismic vibrations. The vibrations from earthquake are dynamic in nature so static analysis is not sufficient for designing hydraulic structures like Dam. A failure of earth dam is: hydraulic failure, seepage failure, piping through dam body and structural failure due to earthquake. The design and construction of an earth-fill dam is one of the great challenge for the engineers in the field of geotechnical engineering, because of the unavoidable in variation foundation condition and also the properties of the material which are available for the construction. So the survival of dam is very crucial against seismic vibrations. This is a need to analyze and check the behavior of earthfill dam during and after the application of the seismic loading.**

Keywords—**Earthfill dam, Dam failures, Stability failure, Liquefaction failure, Earthquake failure**

I. INTRODUCTION

Earthquakes have always been a significant aspect of the design and safety of dams. About 2% of dam failures are said to be due to seismic activity (Foster et al. 2000). The vast majority of these are small, homogeneous earth dams many of which have been in China, India and Japan. In the case of dams, the main load is the water load, which in the case of concrete dams with a vertical upstream face acts in the horizontal direction. In the case of embankment dams the water load acts normal to the impervious core or the upstream facing. Hundreds of dam failures have occurred throughout history. The damage and loss of life caused by earthquakes are great. This is magnified when there is a collapse of an essential infrastructure, such as a dam or a power plant. These have the potential of destroying entire cities. Dams are essential for the survival of a community providing the needed water and power to supply a community. Not to mention the other benefits that it brings such as tourism and flood control. However, when it fails, the destruction is often deadly causing irreparable damage to the land, the people and the economy. In general, earth dams are the most common type of dam found because of its cost effectiveness. A number of earth dams exist throughout all over the world for serving multi purposes. In developing countries or even some developed countries such as those in Southeast Asia are not well prepared for the possibility of an earthquake. Perhaps this is due to the fact that only recently was it discovered that earthquakes are probable in these areas. Because of their lack of preparedness, most of the operating dams in these countries were designed and constructed based on static loading. Many earth dams have been built for irrigation water supply, flood mitigation, and hydropower. Therefore, to ensure dam safety, appropriate safety evaluation of such dams is crucial. This study aimed to understand and explain the dynamic behaviour of dams during earthquakes. ; there are many existing fill dams whose seismic safety needs to be evaluated to ensure the safety of people and their properties. Therefore, seismic safety evaluation of existing dams is crucial and indeed urgent. Otherwise, a future quake might prove to be disastrous for those living downstream of a dam.

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II. THE CAUSES OF DAM FAILURES

Dam failures are most likely to happen for one of five reasons:

1. Overtopping caused by water spilling over the top of a dam. Overtopping of a dam is often a precursor of dam failure. National statistics show that overtopping due to inadequate spillway design, debris blockage of spillways, or settlement of the dam crest account for approximately 34% of all U.S. dam failures.

2. Foundation Defects, including settlement and slope instability, cause about 30% of all dam failures.

3. Cracking caused by movements like the natural settling of a dam.

4. Inadequate maintenance and upkeep.

5. Piping is when seepage through a dam is not properly filtered and soil particles continue to progress and form sink holes in the dam. Seepage often occurs around hydraulic structures, such as pipes and spillways; through animal burrows; around roots of woody vegetation; and through cracks in dams, dam appurtenances, and dam foundations.

6. Disasters like natural hazards such as earthquake, landslides, faults etc.

7. **Liquifaction**

III. PAST EARTHQUAKE DAMAGES TO EARTH DAM STRUCTURES-

1) 1983 Nihon-Kai-Chubu Earthquake

Nihonkai-Chubu earthquake (also known as 1983 Sea of Japan earthquake**)** occurred on May 26, 1983 at 11:59:57 local time (02:59:57 UTC). It had a magnitude of 7.8 on the moment magnitude scale. It occurred in the Sea of Japan, about 100 km west of the coast of Noshiro in Akita Prefecture, Japan. The earthquake lasted approximately for about 60 seconds. Most of the damage was due to soil liquefaction which causing the collapse of houses and a number of road and dams. The degree of liquefaction was the worst seen in Japan since the Niigata earthquake. The greatest effects were observed in areas underlain by loose Holocene Aeolian and fluvial sands due to this earthquake about 145 dams failed and damaged in Japan.Hinks(2015) observed the failure was:

- Sliding of slope
- Longitudinal crack more than 50 mm wide
- Transverse crack
- Crest settlement more than 300 mm
- Leakage of water

Some of these failures may not have involved a catastrophic release of water although they would probably have required reconstruction of the dam.

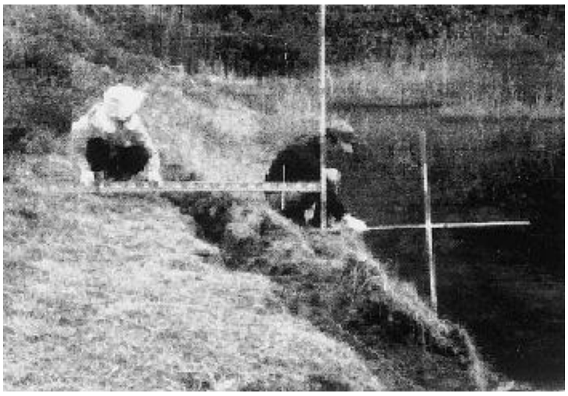

Fig.1 The damage to the Yamanaka dam caused by the 1983 Nihon-kai
Chubu earthquake

2) Tohoku earthquake in Japan in 2011-

The **2011 earthquake off the Pacific coast of Tōhoku** was a magnitude 9.0–9.1 (M_w) undersea mega thrust earthquake off the coast of Japan that occurred at 14:46 JST (05:46 UTC) on Friday 11 March 2011,with the epicentre approximately 70 kilometres (43 mi) east of the Oshika Peninsula of Tōhoku and the hypocenter at an underwater depth of approximately 29 km (18 mi).The earthquake is often referred in Japan as the **Great East Japan Earthquake** and is also known as the **2011 Tōhoku earthquake**, and the **3.11 earthquake.** It was the most powerful earthquake ever recorded in Japan, and the fourth most powerful earthquake in the world since modern record-keeping began in 1900.Ono et al.(2011) examines that the earthquake triggered powerful tsunami waves that may have reached heights of up to 40.5 metres (133 ft) in Miyako in Tōhoku's Iwate Prefecture,resulted 86 reservoir and agriculture dams were damage in 7 Prefectures of Aomori, Iwate, Miyagi, Fukushima, Ibaragi, Tochigi and Gunma during the earthquake of 3.11 East Japan. Fujinuma dam in Sukagawa city causing 8 person casualties. This dam is constructed 62 years ago. The dam is located in the south of damaged Fukushima Nuclear Plant with distance of 240 km and the nearest fault exists in 80 km from the dam. The dam had 18.5 meters height and 1.5 million cubic meters

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water reservoir that in used for irrigation purpose [JCOLD, 2011]. The embankment dam started to fail after the earthquake occurred and completely destroyed during 20 minutes. Before the earthquake occurrence, the dam reservoir was full. The bank of 18 m height and 133m length failed just after earthquake occurrence. The dam was not designed under consideration of seismic forces.

Fig.2 Dam failure at Fujinuma

3) Bhuj earthquake 2001-

A Magnitude 7.6 earthquake occurred in Gujarat state, India on 26 January 2001. The epicentre of the main shock of the event was near Bachau at 23.36° N and 70.34° E with a focal depth of about 23.6 km and lasted for over 2 minutes. The event, commonly referred to as the Bhuj Earthquake, was among the most destructive earthquakes that affected India. Paul (2004) examines that large number of small-to moderate-size earthen dams and reservoirs, constructed to fulfill the water demand of the area, were affected by Bhuj Earthquake. Most of these dams are embankment dams constructed across discontinuous ephemeral streams. Although many of these dams were within 150 km of the epicentre, the consequences of the damage caused by the earthquake to these facilities were relatively light primarily because the reservoirs were nearly empty during the earthquake.

Singh et al. (2005) Chang Reservoir of the Chang dam was nearly empty at the time of Bhuj Earthquake. However, the alluvium soils underneath the dam were possibly in a saturated state at that time. Bhuj Earthquake caused an almost complete collapse of the dam including damages to the impervious core and the masonry wall. Sand boils were observed near the upstream toe of Chang Dam following the earthquake. The deformation pattern is in fact indicative of a widespread liquefaction within the foundation soils.

Another dam Fatehgadh Dam, constructed in 1979, is an earth dam with a maximum height of 11.6 m and crest length of 4050 m and the Fatehgadh Reservoir was nearly empty during Bhuj Earthquake. However, the alluvium soils underneath the upstream portion of the dam was saturated at that time. Bhuj Earthquake triggered failure near the bottom portion of upstream slope (EERI 2001) possibly because of localized liquefaction near the upstream toe of the dam. The EERI (2001) also found cracks as deep as 1.5 to 1.7 m within the upstream portion of the dam and instability near the top portion of the downstream slope following the earthquake. The problem of appearance of longitudinal cracks may indirectly relate to liquefaction of foundation soils.

Fig.3 Dam failure at Bhuj 2001

Table -1 Yield Acceleration and Displacements

Dam	Yield acceleration	Estimated displacement	Observed displacement horizontal	Observed displacement vertical
Chang	**Marginal undrained stability**	**>8**	**7.1**	**4.3**
Shivlakha	**Marginal undrained stability**	**1.2**	**1.2**	**2.0**
Tapar	**.15g**	**0.4**	**0.6**	**0.5**
Fatehgadh	**0.07g**	**0.7**	**0.6**	**0.6**
Kaswati	**0.15g**	**0.3**	**0.6**	**0.5**
Suvi	**Marginal undrained stability**	**2.0**	**1.2**	**2.0**

Table 1 shows the yield accelerations and estimated displacements and observed horizontal displacements and vertical displacements of Bhuj Earthquake. Singh et al (2005)

4) San Francisco earthquake 1906-

San Francisco earthquake which is occurred in 1906 had a magnitude of 8.25, due to this earthquake there were 33 earth dams within 56 km of the fault and 15 dams within 8 km damaged and some failed. It seems likely

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that all these dams were subjected to ground motions having peak ground accelerations greater than 0.25 g and that those within 8 km probably experienced accelerations greater than about 0.6 g. Yet none of these old dams suffered any significant damage. The slopes were fairly steep (typically 1:2 to 1:3) and that the dams had generally been compacted by moving livestock or by teams and wagons and they were all constructed of clayey soils on rock or clayey soil foundations. Two dams were built largely of sand but this was apparently not saturated.

5) San Fernando earthquake 1971-

The 1971 San Fernando earthquake (also known as the Sylmar earthquake) occurred in the early morning of February 9 in the foothills of the San Gabriel Mountains in southern California. Due the earthquake the Liquefaction is a serious potential problem for dams built on or with low density, saturated sands. The crest of the 40 m high Lower San Fernando Dam settled 8.5 metres in the earthquake The dam was built of hydraulic fill, which is particularly vulnerable to liquefaction, because of the low density of the fill. Fortunately, the water level was about 10 m below the crest before the earthquake but only 1.5 m of badly cracked material remained after the event. 80,000 people living downstream of the dam had to be evacuated.

IV.CONCLUSION

Storage dams that have been designed properly to resist static loads prove to also have significant inherent resistance to earthquake action. Many small storage dams have suffered damage during strong earthquakes. However, no large dams have failed due to earthquake shaking. Earthquakes create multiple hazards at a dam that all need to be accounted for. There are still uncertainties about the behaviour of dams under very strong ground shaking, and every effort should be made to collect, analyse and interpret the observations of dam performance during earthquakes. In order to prevent the uncontrolled rapid release of water from the reservoir of a storage dam during a strong earthquake, the dam must be able to withstand the strong ground shaking from even an extreme earthquake. The dams to have failed in the largest numbers in earthquakes are probably small dams built of homogeneous materials. Many such dams have failed in China and India. The worst damage to embankment dams has often been associated with liquefaction of embankment materials or of the foundations. Loose sandy materials with particle size lying between 0.07mm and 0.6mm are particularly susceptible to liquefaction.

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