

Liquefaction of Soil During Earthquake- A Case Study

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Abstract

The 26th January 2001 earthquake in Bhuj, India, caused extensive damage and impacted areas, offering a rare chance to assess a variety of geotechnical problems. Massive liquefaction caused a sizable portion of the Rann of Kutch to liquefy, which caused lateral flow and ground subsidence. The Kutch district's several dams experienced moderate to serious damages. In the city of Ahmedabad, which is located on the bank of the Sabarmati River, several structures were destroyed or fell down. In this work, the ground reaction investigations at a location in Ahmedabad City are addressed along with observations of geotech background issues related to the Bhuj earthquake, such as ground cracking and volcanoes, and soil liquefaction.

According to ground response studies, the collapse and unwelcome settling of partially wet silty sand deposits were the main causes of the different degrees of damage to multistory structures in Ahmedabad along the Sabarmati river area. Large settlements are ascribed to ground amplification and the presence of resonance.

Key words: Earthquake frequency, liquefaction, seismic reaction, and soil amplitude.

1. Introduction

The seismic waves that an earthquake produces shock the earth and trigger major natural disasters. Vibration causes several sorts of ground deformations, and deformations that result in failure are known as ground failures. In seismic zones where such soil deposits are present, the abrupt response of saturated loose sand deposits due to earthquakes might pose a risk to build infrastructure. The Kutch region was most severely damaged by the strong Bhuj earthquake, which also brought about widespread liquefaction. Large soil masses have become unstable as a result of this liquefaction, creating flow slides. The Kutch region is known for its numerous multistory structures that have been damaged or failed, as well as its earth dams, masonry arch and reinforced concrete bridges, rail roads, and highway embankments. An estimated 19,000 people have died and around 166,000 people have been injured. 348,000 homes were destroyed, leaving almost 600,000 people homeless. Many buildings and multi-story complexes in Ahmedabad City, which is over 300 kilometres from the epicenter, have also been damaged by the Bhuj earthquake. (epicenter was in the Bhuj district). This terrible earthquake caused a lot of mid- to high-rise residential complexes in Ahmedabad to fall.

That settling of soil which is also called liquefaction is a system in which the soil behaves unstable and

the stiffness of soil is reduced via earthquake shaking. Liquefaction and associated phenomena were liable for exquisite quantities of harm in historic earthquakes worldwide. After analysis of the liquefaction of different regions with different specifications reported that the soil layers have a corrected SPT blow count where it defines that less than 14 blow count results of soil behave as liquefied soil and also defines soil layers having a corrected SPT blow count greater than 20 are resistant to liquefaction. Concerning liquefaction, LiqIT soil software is also used to analyze soil behavior based on Cyclic Stress Ratio (CSR), Cyclic Resistance Ratio (CRR) methods calculated by using Magnitude by Scaling Factor, and Factor of Safety (Ch. Hari Naga Prasad, M. Rathna Chary and K. Thangamani, 2019).

In addition to a discussion of important geotechnical concerns such ground cracking, sand volcanoes, and soil liquefaction, this study summarizes some of the damages found in the dams, embankments, and multistory structures in Ahmedabad City during the Bhuj earthquake. Additionally, an effort has been made to comprehend the causes of Ahmedabad's multistory structures built on soft alluvial deposits that failed. Using soil exploration data from a site in Ahmedabad that is quite near to the Sabarmati river region, SHAKE91 was used to study the seismic response of the chosen site while treating

the ground as a one-dimensional layered elastic system. (Schnabe et al., 1972). For evaluation of the liquefied problem, some records collected from the Semani site (Fieri prefecture in Albania) defined particular values of assessment of the liquefaction and liquefaction-prompted ground deformations including lateral spreading displacement and post-liquefaction reconsolidation settlement (Idriss and Boulanger, 2008). In general, hazard analysis can be divided into the following categories (Yu Huang and Miao Yu, 2017) first one is a liquefaction potential analysis and a liquefaction damage evaluation. This chapter introduced the assessment of the extensive behavior of soil liquefaction by mainly In-situ tests, dynamic laboratory tests, and model tests.

2. Case Study

Liquefaction has been detected in conjunction with earthquakes for last few years. In fact, accounts of earthquake impacts that are now recognized to be connected with liquefaction can be found in written records reaching back hundreds, if not thousands, of years. Liquefaction, on the other hand, has been so across-the-board in recent earthquakes that it is frequently associated with them. Some of those events are powerful.

1. Bhuj earthquake (mag
2. Chi-Chi, Taiwan earthquake (magnitude Mw =7.6) 1999
3. Sikkim earthquake (magnitude Mw =6.9) 2011
4. Kashmir earthquake (magnitude Mw =7.6) 2005

2.1 BHUJ EARTHQUAKE:-

Gujarat's Kutch region was hit by the Mw 7.7 Bhuj earthquake on January 26, 2001, at 8:46 AM. To the north of Bacchau town, at 23.4N and 70.28E, at a depth of 25 km, was where the earthquake's epicentre was found (Srivastava, 2001). In India, this earthquake caused the biggest destruction in the previous 50 years. Numerous tiny towns near to the epicentre have been completely destroyed by the earthquake, and numerous dams, embankments, ports, bridges, and buildings have sustained significant damage. Widespread liquefaction that resulted in sand volcanoes, ground cracking, sideways expansion of the ground and embankments, and water spouts were the hallmarks of this earthquake.

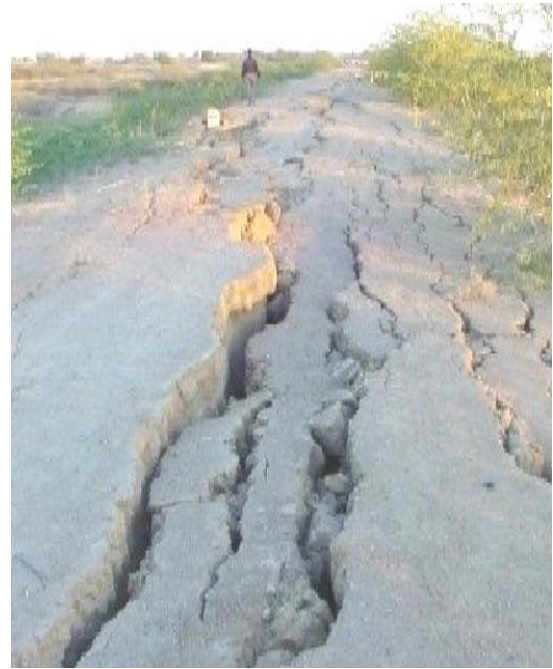


Figure-1: The Indian Bhuj earthquake of 2001 resulted in the crest embankment cracking and undergoing inelastic deformations. Nonlinear dynamic analysis and dam material models are required for the prediction of fractures and damage.



Figure-2: Extensive liquefaction near Lodai

Steven L. Kamal Mohamed Hafez Ismail Ibrahim (2014) proposed an approach using SPT, CPT, and VS methods for liquefaction analysis of the soil profile in Bedsa. Their study attributes liquefaction susceptibility to loose sandy silt layers juxtaposed with sandy areas within the soil profile. In their research, Kamal Mohamed Hafez Ismail Ibrahim referenced the CPT triggering method and the VS-based method (P.K. Robertson and C.E. Wride,

1998) for comparison. This comparison involved two VS coefficients and correlations to predict average VS values for both calcareous and siliceous soils. Their analysis highlights a consistent CPT–SPT relationship.

According to study of research papers this are the following points i want to conclude here:- Most of the researchers are firstly select a specific location and Identify problem generates related to soil of that location's surface.

- On the other side researcher analyzed hazards effects on Soil which is also called liquefaction after earthquake. Also analyze the form of liquefaction like Soil Boiling, Surface failure, Ground Surface Motion or Spread etc.
- Based on recent analyses, methods such as CPT, SPT, and Shear wave methods have been predominantly adopted to examine various factors of this issue, aiming to mitigate hazards and safeguard soil from liquefaction. These methods are favored by researchers for their accuracy and ability to yield practical outcomes based on real data and problems.
- This research utilized various methods previously employed in studies related to similar issues, including empirical methods, case studies, and specialized software for analyzing liquefaction in saturated soils known as LiqIT Software.
- Soil behavior analysis also reviewed by help of journal papers and books in different Ground Motion.

2.2 EFFECTS OF EARTHQUAKES AS A RESULT OF SUBSURFACE CONDITIONS

Studies on earthquakes have shown a clear connection between soil type, soil layering, and the intensity of seismic shocks. Structures founded on rock and stable ground generally perform better than those on softer ground. Factors such as surface topography, frequency of seismic waves, and soil composition affect the maximum acceleration the ground can withstand. Previous research indicates that soft soils experience higher peak accelerations compared to hard ground.

The natural frequency at which soil vibrates under dynamic forces, like those from earthquakes, depends on soil type, groundwater level, proximity to hard rock, and other geological factors. Furthermore, when a building is constructed on soil, the soil-structure system has its own natural

frequency, which may differ from that of the soil alone. Despite earthquakes being brief and unpredictable, resonance-like conditions can occur if an earthquake's main frequency aligns closely with the natural frequency of the soil-structure system. Seismic microzonation, a specialized assessment of local conditions, helps evaluate the actual soil conditions' impact. Microzonation integrates data from engineering geological surveys and instrumented observations to determine the quantitative aspects of ground shaking.

Various levels of saturation exposed to a scaled-down version of the El Centro earthquake of 1940.

- The seismic damage resulting from the series of earthquakes in Nepal in 2015, also referred to as the 2015 Gorkha earthquake
- Regarding liquefaction, it is well-established that saturated silty sands are highly susceptible to liquefaction (Seed and Idriss, 1971; Hardin and Drnevich, 1972; Iwasaki et al., 1978; Kokusho et al., 1982; Seed et al., 1986; Chung et al., 1984).

The piled foundations of the Kandla Port and Customs Tower in Kandla Port, India, during the 2001 Bhuj earthquake. The 22-meter tall tower with an eccentric mass on the roof was supported by a piled-raft foundation that significantly tilted afterward. The site's soil comprises 10 meters of clay overlaid by a 12-meter deep. Also take some data sans considered research papers on the 1964 Niigata earthquake, the 1995 Kobe earthquake, the 2001 Bhuj earthquake or the 2004 Sumatra earthquake.

2.3 SOIL CONDITIONS AROUND BHUJ AREA

The Rann of Kutch consists entirely of marshy areas with fully saturated soils. In the regions of Bhuj, Gandhidam, and Anjar, structures have either fully or partially subsided due to the liquefaction of loose sediments that extend to considerable depths. Table 1 presents the index characteristics of sand extracted from a location near the epicenter of the Bhuj earthquake. These characteristics indicate a significant proportion of medium and fine sand, along with substantial amounts of non-plastic fines, which are prone to liquefaction during ground shaking.

Understanding and predicting the phenomenon of liquefaction in sands and other granular materials under both static and cyclic loading hinges on grasping the initiation and development of excess

pore pressure. According to this theory, even a slight reduction in the degree of saturation can substantially diminish the liquefaction potential of sandy deposits.

During numerous devastating earthquakes, extensive areas have witnessed severe soil liquefaction, resulting in ground failures such as settlements, flow slides, reduced bearing capacity, horizontal displacements, lateral spreads, landslides, ground cracks, sand boils, dam instability, and highway embankment failures.

3. Methodology

In our search for specific elements, we began with a review paper encompassing extensive literature. We compiled the elements mentioned in that article into a list. As we examined each new publication, we identified elements that were not previously mentioned and added them to the list. We subsequently categorized these elements to identify closely related or overlapping meanings. This process resulted in a condensed list of distinct elements.

3.1 Semi-Empirical Procedures for Evaluating Liquefaction Potential

In general, semi-empirical field-based methods used to assess liquefaction potential during earthquakes typically involve two main steps: (1) establishing a framework to organize previous case histories, and (2) developing an appropriate in-situ index to represent soil liquefaction characteristics (Fatima Ezzahraa Latifi and Khadija Baba et al., 2012). Despite ongoing re-evaluations of individual components, the original simplified approach by H.B. Seed and I.M. Idriss (1971) for calculating earthquake-induced cyclic shear stresses remains a crucial part of this analytical process.

This update recommends using several key relationships: the stress reduction coefficient (r_d), the magnitude scaling factor (MSF), the overburden coefficient (K) for cyclic stress ratios, and the overburden correction factor (CN) for penetration resistances.

3.2 CPT, SPT and Wave Shear Test

In the 1964 Niigata earthquake in Japan (Kenji Ishihara and Yasuyuki Koga), semi-empirical methods were developed and applied using the SPT to distinguish between liquefiable and non-liquefiable conditions. This study explores a semi-

empirical approach to differentiate between liquefiable and non-liquefiable conditions using SPT data from significant seismic events discussed in review papers, such as the 1999 earthquakes: the Chi-Chi earthquake in Taiwan ($M_w=7.6$) and the Bhuj earthquake ($M_w=7.5$) (M. Manga and C.Y. Wang, 2015).

According to Raghukanth and Iyengar (2006), who analyzed liquefaction in Mumbai city, major fault lines are located beneath Thane creek, Panvel, and Dharamtar creeks. They recommended evaluating liquefaction potential using a simplified SPT procedure. The results and contour maps suggest a high likelihood of liquefaction-induced failures at multiple sites within the city during severe seismic events.

3.3 LiqIT Software

The software mentioned is utilized to analyze liquefaction in loosely saturated cohesionless soil subjected to seismic or strong motion. In the study cited, it is employed to assess liquefaction potential using advanced methods such as CPT, SPT, and Vs. It accurately predicts vertical settlements and lateral displacements caused by liquefaction.

3.4 Ground response analysis

The study utilized the widely used computer program SHAKE 91 to evaluate how local soil properties affect ground response during earthquakes (Schnable et al., 1972). Inputs such as shear wave velocity or other dynamic soil parameters like shear modulus were required for the program. To determine these dynamic soil characteristics from specific soil profile data, empirical equations recommended by the Japan Road Association (JRA) were applied (Shannon, 1992). The JRA method considers Standard Penetration Test results (N-value) and soil type to calculate shear wave velocity.

4. Expected Outcomes

According to the assessment of the SPT method, the maximum observed depth of soil liquefaction is up to 20 m and this test has proved that medium-density sand layers at a depth of more than 30 m could be liquefied. This method was also investigated by technical demand parameters and with help of the soil model and its parameters also used the CPT method for correlation between SPT & CPT (Kristin J. Ulmer, Russell A. Green, and

Adrian Rodriguez-Marek, 2020). In this study, the results of soil material damping on the seismic analysis of soil-MDOF structure systems are assessed.

From this, it can be shown that the natural frequency value corresponding to the highest amplification between the motion at the surface and 3.51 Hz is the basis. This proves unequivocally that the significant degree of damage is caused by the deep sandy soil deposit's large-scale amplification of shear waves. and the ensuing disparate settlements. Some buildings have seen significant accelerations as a result of the soil amplification, particularly those with four or more stories and up to 10 stories. One of the causes of the high-rise buildings collapsing was the close alignment of the generated wave frequencies with their resonance frequencies.

On the other hand, the Cone Penetration Test (CPT) is taken into consideration and reviewed in many papers, so it is one of the most common methods which are mostly used to identify the response of cohesive soils during liquefaction. It is not that suitable for any type of soil applications like discipline explorations, layout parameters, and first-rate control assessments (Sayed M. Ahmed and Sherif W. Agaiby et. al., 2013).

LiqiT Software is an application based on SPT & CPT parameters and it gives the same result. Advantages of this application reduce the time for assessment, the best result, applies to any type of soil and it provides various factors according to cohesive or non-cohesive soil (Ch. Hari Naga Prasad, M. Rathna Chary and K. Thangamani, 2019).

Therefore it's far essential to correlate those assessments to every different in order that both of the assessments may be used in the absence of the alternative, specifically for initial assessment and design purposes. The number one cause of this takes look at became to analyze the relationships among the SPT and CPT for a specific form of sandy soil. So in this process of review of papers I conclude that this all the methods are good to acknowledge the behavior of soil and ground surface response during earthquakes but they are not capable to protect soil from liquefaction, we should identify the precautions or provide

protection to the soil, especially in important sectors from before and after earthquake hazards.

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