IDENTIFICATION OF SOIL LIQUEFACTION POTENTIAL BY USING MULTIPLE GEOTECHNICAL CRITERION: A CASE FOR MUZAFFARABAD CITY AZAD JAMMU AND KASHMIR

BY

ATTIQUE UR REHMAN[1], MUHAMMAD SANAULLAH[1]*, SAJID RASHID AHMED[2], AND MUHAMMAD IMRAN[1]

[1]Institute of Geology, University of the Punjab Lahore, Quaid-e-Azam Campus 54590, Lahore

[2] College of Earth & Environmental Sciences, University of the Punjab Lahore

*E-mail: sana.ullah.geo@pu.edu.pk

Received: 29-09-2021 Accepted: 18-03-2022 Published: 10-10-2022

Abstract: *Current work is an application of several geotechnical criterion to investigate the geological hazard associated with soil liquefaction potential of Muzaffarabad City AJ&K. Seismic history of the study area demonstrate ground failure, sourced by soil liquefaction that caused vast destruction of infrastructure and lifeline damages in the urbanized areas. Muzaffarabad (MZD) city is an urban area residing dominantly on the alluvium and colluvium deposits and is characterized at the brisk regime of zone "4" on the seismic hazard zonation map of Pakistan. Study area is underlined by three major faults, having high stresses and is seismically active. To assess the vulnerability of soil to liquefaction, geotechnical laboratory testing was performed and the results are analyzed for different risk assessment criterion (Geological Based Criteria, Modified Chinese Criteria, Chinese Criteria and Bray & Sancio Criteria) in accordance to the suggested relationship. Geotechnical parameters; Natural water content (Wn), Plasticity Index (PI), Soil Density, Coefficient of uniformity (Cu) and Fine particle content were determined for collected soil samples. The produced micro-zonation soil liquefaction susceptibility maps demonstrate a "Not Susceptible" status for major parts of MZD city, while the areas of lower Chatta. Chilla Bandi and lower Plate are identified as "Moderately Susceptible" to soil liquefaction potential.*

INTRODUCTION

Soil liquefaction plays major role in the instability of the ground and appeared in response to the sudden rise of pore-water pressure due to the cyclic-stresses by subjgating the effective-stresses which results in abteing of the bearing capacity in the soil and act as liquefied material instead of solid (Kuribyashi et al., 1952 ; Kochar et al., 2015). This most hazardous ground failure type constraint the areas which have low-density, water-logged, granular-sediments near the surface, are amenable for liquefaction, confessing the facts by disastrous events Alaska and Nigatta earthquakes (1964), China (2008), Pakistan (2005), Izmit (1999) and India (2001). Japan, U.S, Canada and other countries, provides the good assistance for advancing the liqeufaction studies by granting it a beneficial engineering tool. The estimation of destruction due to the liquefaction in the world till 1995 is approximately 100 billion dollars (Dobry, 1995; Seed et al., 2001).

The occurrence of this hazarduos event depends upon the ground water table depth and other site conditions.When holocene depostis are there, then a chance of clear liquefaction is present. Not only the sandy deposits, the silty-sandy deposits are also amenable for this engineering property (Wang and chen, 2017) Kuribayashi et al., 1952). The alluvium deposits (Late Holocene), calyey-sand and silt that are water logged by the flood plains are prone for liquefaction (Kelson et al., 1999; Marto and Soon, 2012). Geology of the area plays an efficacious role to study the susceptibility of liquefaction for the sediments that are formed 500 years to 10 Ka (Holocene age). The region, that consists of deposits which possessed the age greater than Holocene have very low chance to supervened this engineering property (Youd and Perkins, 1978).

Major Structural Features of the study area are: a) Jhelum Fault, The youngest fault passes alongside the western margin of the axial zone of Hazara Kashmir Syntax (HKS) marked as Jhelum Fault (Kazmi, 1977b; Baig and Lawrence, 1987), b) Main Boundary Thrust (MBT) that shows the southward movement and contortion of the Himalayas. MBT extends towards the north-west, bends towards the west direction almost from the crest of HKS and then take a turn in the south direction towards Balakot (Calkins et al., 1975; Basharat et al., 2014). This geological feature is between the Abbottabad and Muree Formation, that devides the rocks of Lesser-Himalayas i.e. is the hanging wall and the Sub-Himalayas i.e. is the foot wall. c) Muzaffarabad Fault, also known as Himalayan Frontal Thrust (HFT), a major tectonic characteristic of the area and it extends towards the Jhelum Valley, Bagh, Poonch City, and in the Disputed Kashmir in the south-east direction (Baig and Lawrence, 1987; Baig et al., 2006; Kazmi and Jan, 1977b). This fault is much disrupted approximately 120km amid the north direction (Balakot) and in the south direction (Bagh) by the catastrophic event that is the MZD earthquake 2005 (Avouac et al., 2006; Baig et al., 2006).

METHODS AND MATERIALS

A frame work to assess the liquefaction-potential of an area consist of different parameters: Geology, Ground water, Soil Type and Density. The most important and effectual way to describe the unsafe region due to its seismicity is the geological settings of the area, and the components that act as considerable elements to restraint the vulnerability of an area before liquefaction is its surficial-geology (Youd and Perkins, 1978; Green et al., 2015). . Study area has been investigated to estimate its vulnerability for a hazardous engineering property (liquefaction) includes: preparation of base maps, analysis of existing seismological data, plotting of seismo-geological events and detailed laboratory testing for geotechnical characterization of the area. The topographic maps (43F-7, 43F-11, and 43F-12) from Geological survey of Pakistan were used for preparation zonation maps of the study area. The represented depth of the ground water, the geology of the area, and the type of soil has been investigated for liquefaction-potential assessment. Ground water table an important parameter, experience a simple criteria, the sites comprised of feasible soils are prone for liquefaction if the subsurface water depth within the confines of less than 50 ft. The soils that are executed as a liquefiable soils are the silts (P1<7), gravels with some exceptions and the sand with the SPT blow-count (N1) 60<30, or CPT resistance (qc1N) <60, and the factors that subjugate the potential for liquefaction is the increment in the fine-content. Most of the materials that not fulfill the criteria of (N1) 60 are some of the clayey-soils and rocks (Seed and Idris, 1971; Tineley et al., 1985).

Modified Chinese Criteria (2001)

After the modification in the Limits of Chinese-Criteria (Andrew & Martin, 2000), Chinese building code version (2001) stated that the soils are contemplated as non-liquefiable (with no-mentions made to LL. or wn), if clay fraction is higher than 10%, 13% and 16% (CNS 2001).

Chinese Criteria (1979)

Wang the first researcher set a standard for the soils which are vulnerable for liquefaction if they match the criteria, which based on the surveillance of a seismic activity (earthquake) of different areas. This is the first Criteria used in USA to assess the liquefaction potential of the area (Wang, 1979). The soils that are unsafe due to this precarious property, appeared with the characteristics: Percent finer than 0.005mm <15%, Liquid Limit <35 % and water content (wn %) > 0.9 x LL. Chinese Criteria is represented graphically by Marcuson et al. (1990).

Seed and Idriss Criteria (1982)

Seed and Idriss in 1982 developed the Chinese criteria and established a relationship between percent fines and liquid limit of the soil. They identified the liquefaction from the sensitivity of the soils where they loss its strength and proposed a, which associate with the inconstant degrees of susceptibility. According to the given criteria soils are susceptible to liquefaction only if: percent of particles less than 5μm < 15%, LL < 35 and wc > 0.9LL. If the soil does not full fill the criteria than assessed as non-liquefiable soil (Green et al., 2015).

Bray & Sancio Criteria (2006)

Susceptible, Moderately Susceptible and Not Susceptible are the three zones that are identified in this criteria. “Susceptible” zone are deemed as highly susceptible for this vigorous property, the soils lies in the “Moderately” susceptible zone are less susceptible, but the soils lies in these two zone are sampled and tested for the evaluation of liquefaction potential. The soils that are present in the “Not-Susceptible” zone are considered as sensitive for liquefaction due to the reduction of strength upon remolding (Green et al., 2015).

RESULTS AND DISCUSSION

Origin of the soil and geological-age of the deposits are distinguished as a considerable element to cause the liquefaction in the area.The Cohesion less deposits present in the saturated condition will be susceptible for liquefaction. The Holocene deposits are contemplated as very High to low susceptible to liquefaction while the deposits possessing the age greater than Pre-Pleistocene (>16 Mya) are considered as very low susceptible (Youd & Perkins 1978). Chehla Bandi, Lower plate, Centre Plate, Upper Plate (some area), Bala Pir, Gojra, Old Secretariat (some area), Upper Chatter, Chatter and Lower Chatter can be included to the areas having high susceptibility for liquefaction according to the geological composition. While Sethi Bagh, Tariqabad Jalabad, Ambore and some areas of Upper Plate are very low susceptible as the geological age of the formations: Muree of Miocene and Muzaffarabad of Cambrian according to the proposed criteria of (Youd and Perkins, 1978) (Fig. 1). Andrew & Martin 2000, modified the old Chinese criteria and transform it with new characteristics. In this criterion, establish a relationship of clay-content percentage instead of water content with liquid limit to assess the vulnerability of soil to liquefaction. Modified Chinese criteria is not considered as a reliable Criteria because only clay-fraction can’t be used as an indicator for liquefaction. Observations of different earth-quake (North ridge earthquake 1994, Chichi earthquake 1999) shows that the silty and clayey-sands also exhibit potential for liquefaction (Marto & Soon, 2012).

By using this criterion, it has been found that most of study area: Chehla Bandi, Upper Plate, Lower Plate, Centre Plate, Bala Pir, Gojra, Lower Chatter, Chatter are susceptible to liquefaction due to their clay-content percentage (<10%) but the other areas, Sethi Bagh, Tariqabad, Jalabad, Old Secretariat, and Upper Chatter, have high clay-content percentage and assessed as Not Susceptible to liquefaction (Fig. 5 a)

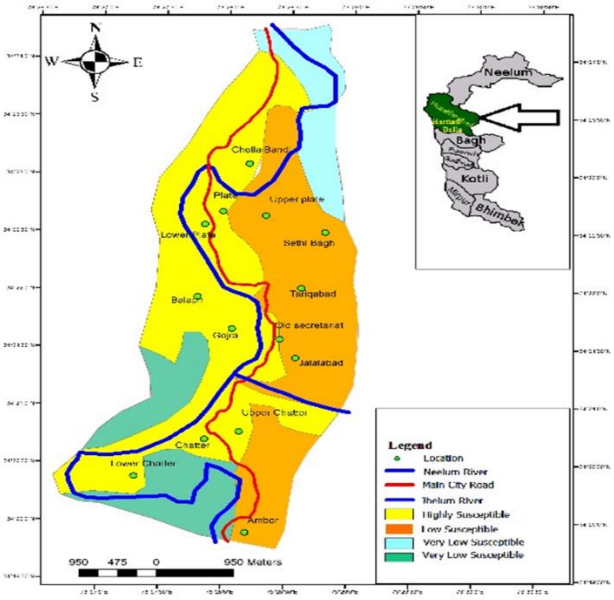


Fig.1. Micro zonation map based on Geological Criteria

The first researcher "Wang" set a standard for different soils to assess the liquefaction-potential. The soil that are endowed with following characteristics are considered as unsafe for this hazardous property. The areas: Chehla Bandi, Lower Plate and Lower Chatter have percent finer (0.005) percentage less than 15%, LL. less than 35% and the water content greater than 0.9xLL, so we can say that these areas are "Moderately Susceptible" to liquefaction. The remaining areas Upper Plate, Centre Plate, Bala Pir, Gojra, Sethi Bagh, Tariqabad, Old Secretariat, Jalabad, Upper Chatter, and Chatter does not fulfill the given criteria and considered as "Not Susceptible" to liquefaction (Fig. 2 & 5b).

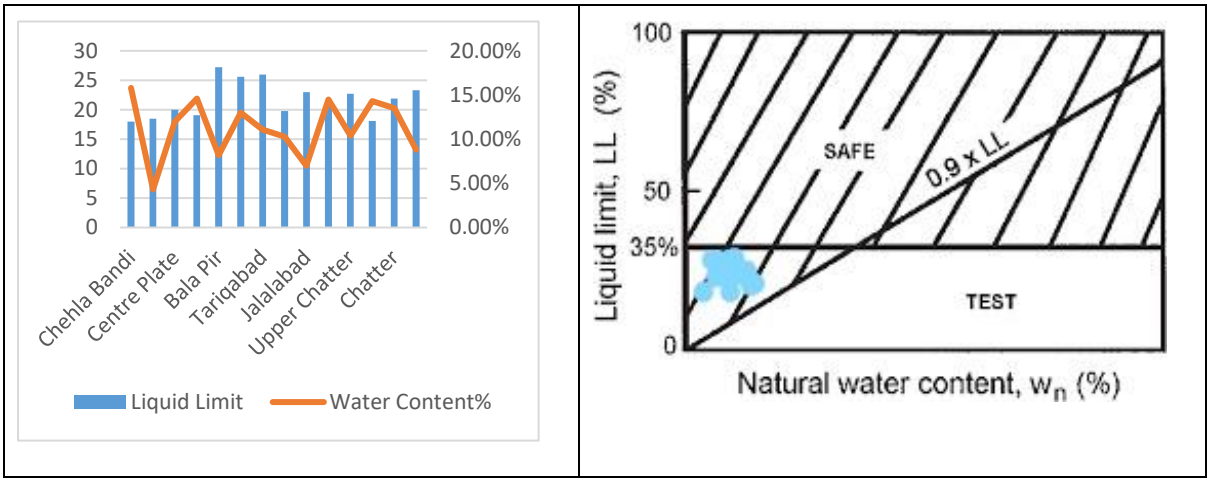


Fig. 2 Liquefaction Susceptibility Criteria proposed By Wang (1979)

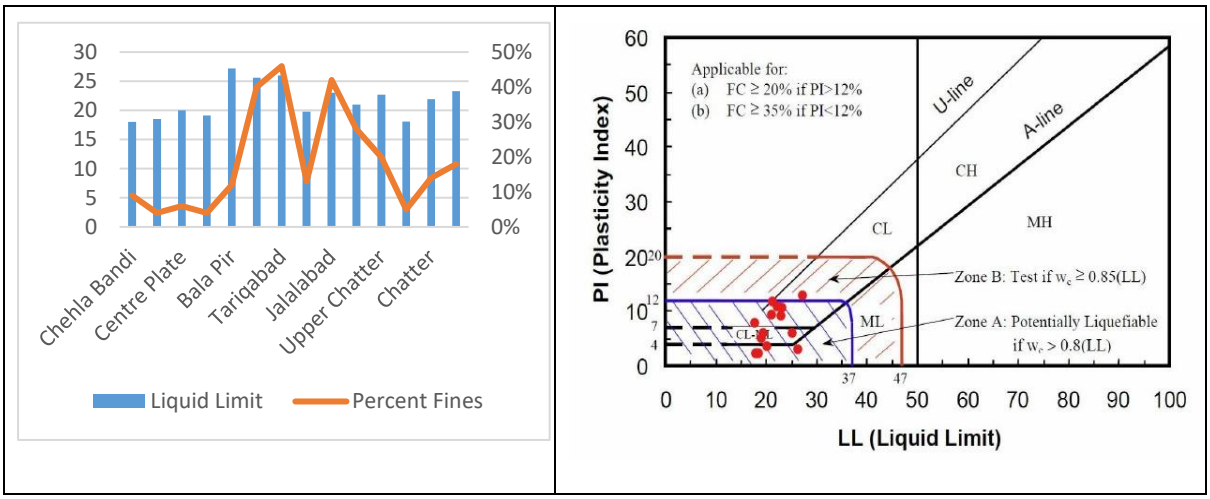


Fig. 3 Liquefaction Susceptibility Criteria Proposed by Seed & Idriss (1982)

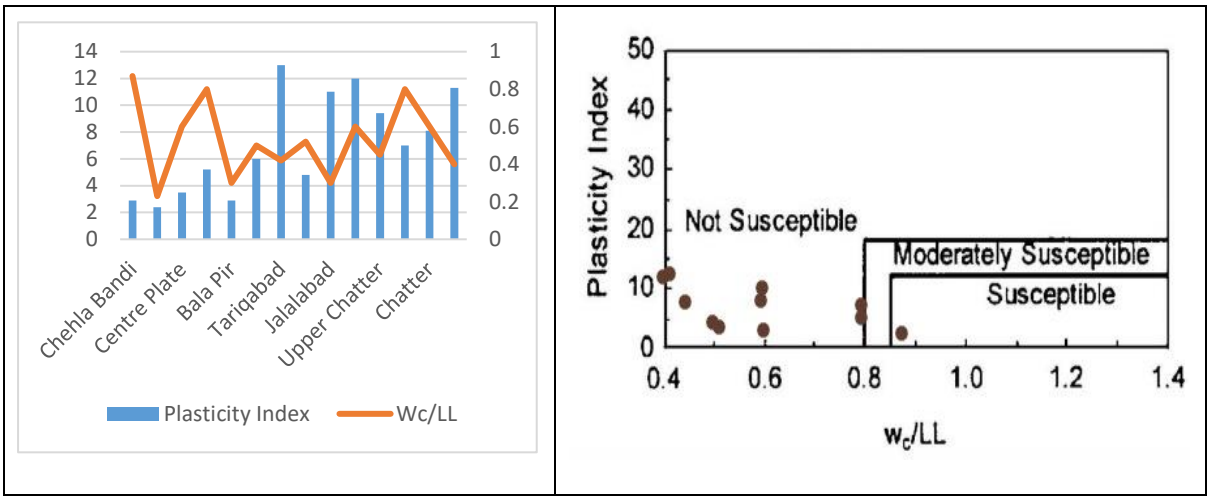
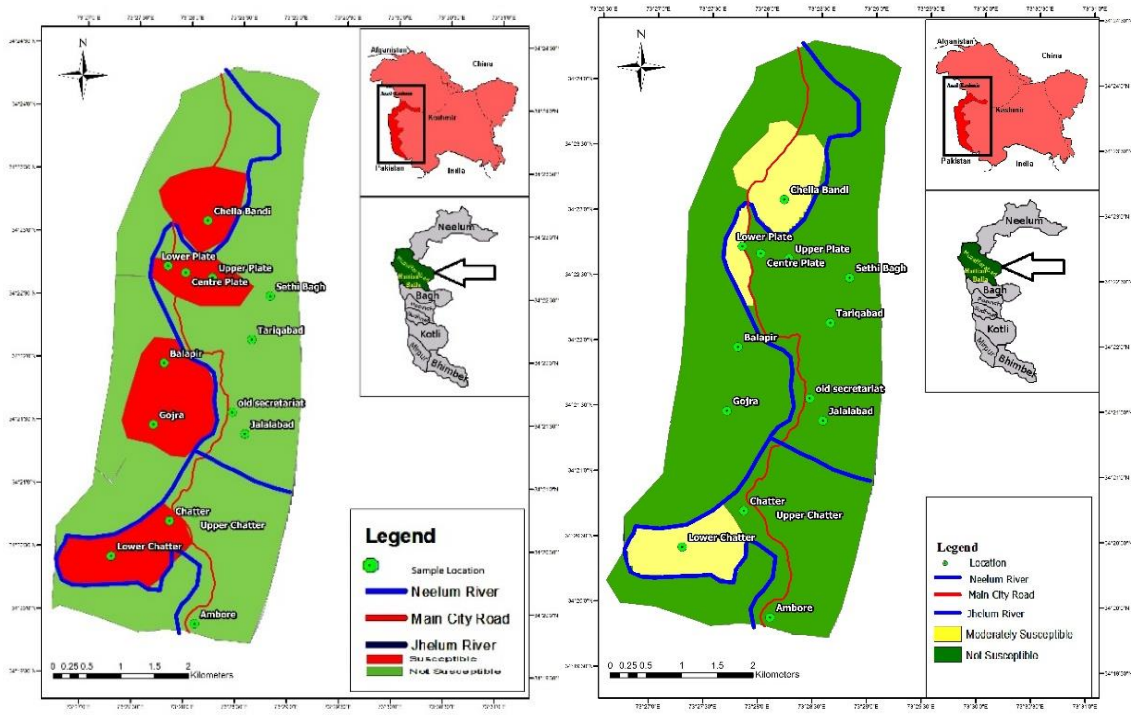


Fig. 4 Liquefaction susceptibility Criteria proposed by Bray & Sancio (2006)



A) B)

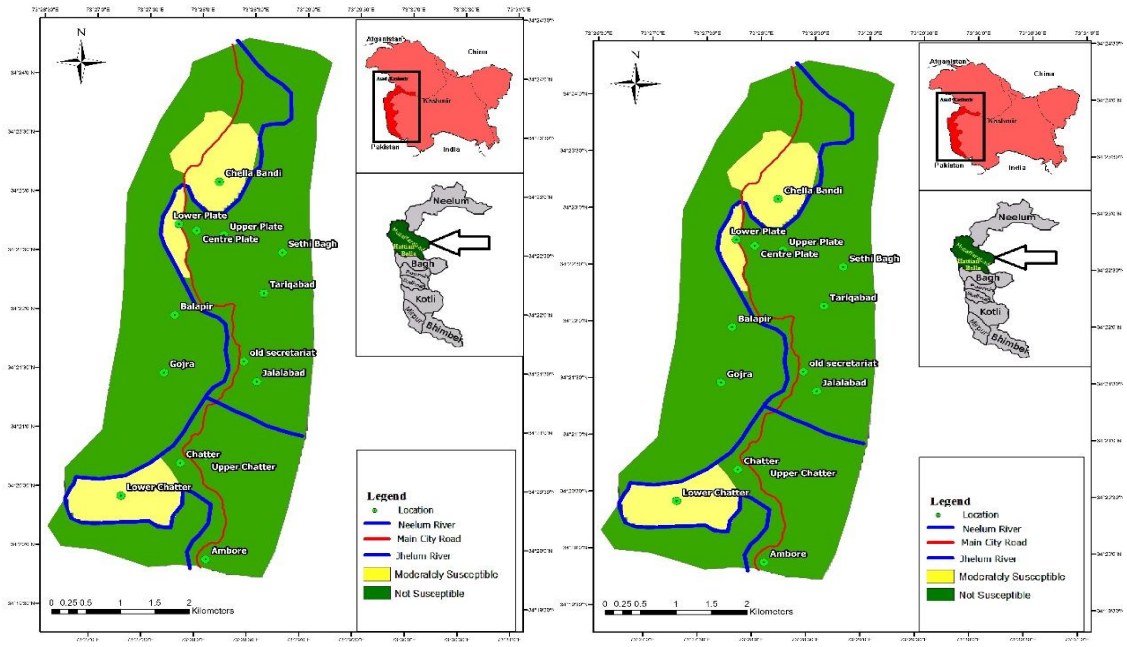


Fig. 5 A) Micro zonation map based on Modified Chinese Criteria B) Micro zonation map of study area based on Chinese Criteria C) Micro zonation map of study area based on Seed & Idriss Criteria. D) Micro zonation map of study area based on Bray & Sancio Criteria

This criteria is based on the relationship between the percent fines and the liquid limit. According to these criteria the areas: Chehla Bandi, Lower Plate and Lower Chatter are assessed as "Moderately Susceptible" for liquefaction and the areas Upper Plate, Centre Plate, Bala Pir, Gojra, Sethi Bagh, Tariqabad, Old Secretariat, Jalabad, Upper Chatter, and Chatter does not fulfill the given criteria and consider as "Not Susceptible" to liquefaction (Fig. 3 & 5c).

Susceptible, Moderately Susceptible and Not Susceptible are the three zones that are designed by Bray and Sancio, based on the Plasticity index and wc/LL. Maximum wc/LL is found in the Chehla Bandi, Lower Plate and Lower Chatter, and identified as "Moderately Susceptible", while the areas that are "Not Susceptible" to liquefaction are Upper Plate, Centre Plate, Bala Pir, Gojra, Sethi Bagh, Tariqabad, Old Secretariat, Jalabad, Upper Chatter, and Chatter evaluated on the basis of Bray and Sancio Criteria (Fig.4 & 5 d).

CONCLUSIONS

MZD city the majorly effected area in Oct. 8, 2005 earthquake, is explored for soil liquefaction risk during earthquake. Results of the 14 sampling locations in the study area were applied used for four liquefaction criteria to identify the susceptible zones of the study area. Chinese Criteria, Seed & Idriss Criteria, Bray and Sancio Criteria, shows that Chehla Bandi, Lower Plate and Lower Chatter area are moderately susceptible, while Modified Chinese Criteria differs a bit. On the basis of these criteria liquefaction susceptibility maps are produced which are very efficacious and very useful for development plans for engineers, planners and risk management practices in the different areas of Muzaffarabad city.

REFERENCES

Avouac, J.-P., Ayoub, F., Leprince, S., Konca, O., & Helmberger, D. V. (2006). The 2005, Mw 7.6 Kashmir Earthquake: Sub-Pixel Correlation of ASTER Images and Seismic Waveforms Analysis. Earth and Planetary Science Letters, 249(3), 514–528. https://doi.org/https://doi.org/10.1016/j.epsl.2006.06.025

Baig, M. S., & Lawrence, R. D. (1987). Precambrian to Early Paleozoic Orogenesis in the Himalaya. Kashmir Journal of Geology, 5, 1–22.

Basharat, M., Rohn, J., Baig, M. S., Khan, M. R., & Schleier, M. (2014). Large Scale Mass Movements Triggered by the Kashmir arthquake 2005, Pakistan. Journal of Mountain Science, 11(1), 19–30. https://doi.org/10.1007/s11629-012-2629-6

Bolton, S. H., & M., I. I. (1971). Simplified Procedure for Evaluating Soil Liquefaction Potential. Journal of the Soil Mechanics and Foundations Division, 97(9), 1249–1273. https://doi.org/10.1061/JSFEAQ.0001662

Calkins, J. A., Offield, T. W., Abdullah, S. K. M., & Ali, S. T. (1975). Geology of the Southern Himalaya In Hazara, Pakistan, and Adjacent Areas. United States Geological Survey Professional Paper.

Dobry, R. (1995). Liquefaction and Deformation of Soils and Foundations Under Seismic Conditions. International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics., 1465–1490.

Green, R., & Ziotopoulou, K. (2015). Overview of Screening Criteria for Liquefaction Triggering Susceptibility.

Iwasaki, T. (1986). Soil Liquefaction Studies in Japan: State-Of-The-Art. Soil Dynamics and Earthquake Engineering, 5(1), 2–68. https://doi.org/https://doi.org/10.1016/0267-7261(86)90024-2

Kazmi, A. H., & Jan, M. (1997). Geology and Tectonics of Pakistan. Graphic Publishers, Karachi,Pakistan.

Kelson, K. I., Hitchcock, C. S., Randolph, C. E., & Lettis, W. (1999). Structural Geology and Liquefaction Susceptibility in the Inner Rio Grande Valley Near Albuquerque, New Mexico. In U.S Geological Survey National Earthquake Hazards Reduction.

Kochar, A., Agrawal, A. and Sachan, R. A. (2015). Analysis of Liquefaction Prone Area In India And It's Remediation's. International Journal for Research in Applied Science and Engineering Technology, 3, 247–254.

Leslie, Y. T., & M., P. D. (1978). Mapping Liquefaction-Induced Ground Failure Potential. Journal of the Geotechnical Engineering Division, 104(4), 433–446. https://doi.org/10.1061/AJGEB6.0000612

Marcuson, W. F., Hynes, M. E., & Franklin, A. G. (1990). Evaluation and Use of Residual Strength in Seismic Safety Analysis of Embankments. Earthquake Spectra, 6(3), 529–572. https://doi.org/10.1193/1.1585586

Marto, A., & Soon, T. (2011). Short Review on Liquefaction Susceptibility. International Journal of Engineering Research and Applications (IJERA), 2(3), 2115–2119.

Seed, H. B., & Idriss, I. M. (1971). Simplified Procedure for Evaluating Soil Liqufaction Potential. Journal of the Soil Mechanics and Foundations Division, 97(9), 1249–1273.

Seed, H.B. and Idriss, L. M. (1982). Ground Motions & Soil Liquefaction during Earthquakes. Earthquake Engineering Research Institute, University of California, Berkeley., 134.

Seed, R., Cetin, K., Moss, R., Kammerer, A., Wu, J., Pestana, J., & Riemer, M. (2001, March). C.9 Recent Advances in Soil Liquefaction Engineering and Seismic Site Response Evaluation. International Conference on Recent Advances in Geotechnical Earthquake Engineering and Soil Dynamics and Symposium.

Tinsley, J. C., Youd, T., Perkins, D. M., & Chen, A. T. F. (1985). Evaluating Liquefaction Potential. U.S Geological Survey Professional Paper, 1360, 263–316.

Wang, C., & Chen, Q. (2018). A Hybrid Geotechnical and Geological data-based Framework for Multiscale Regional Liquefaction Hazard Mapping. Géotechnique, 68(7), 614–625. https://doi.org/10.1680/jgeot.17.P.074

Wang, W. S. (1979). Some Findings in Soil Liquefaction. Water Conservancy and Hydroelectric Power Scientific Research Institute, Beijing, China