lian Geotechnical Conference IGC 2022
15th – 17th December, 2022, Kochi

Kochi Chapter

Impact of Seismic Environment on Tunnel Design in the Indo-Gangetic Plains of Jammu, Jammu and Kashmir

Abdullah Ansari [1][0000-0003-1515-7628], K. Seshagiri Rao [1][0000-0003-1412-9545] and Arvind K. Jain [1]

[1] Department of Civil Engineering, Indian Institute of Technology Delhi, New Delhi – 110016

aamomin183@gmail.com

Abstract. In the last few decades, the Jammu and Kashmir has faced many moderate to large earthquake events that caused catastrophic damage to the physical infrastructure and significant socioeconomic loss. The ex- panding infrastructural projects together with the prior historical records of the significant earthquakes including the world's deadliest 2005 Kash- mir earthquake in the Himalayan region, urge to analyse the probabilistic seismic damage of tunnels in Jammu and Kashmir. During the field sur- vey, it has been found that Simbal and Jatah towns were triggered during the far-field 2019 Mirpur earthquake in Pakistan. In this paper, an attempt has been made to develop the seismic fragility curves for circular tunnels located in the Indo-Gangetic Plains of the Jammu Region in the north- western part of the Himalayas. To achieve this, the seismic performance of the circular tunnels at different depths is quantified by using closed- form analytical methods based on longitudinal and transverse seismic waves. For a given earthquake intensity, the fragility curves presented in this work show the conditional probability of a circular tunnel reaching or surpassing a specified damage state. This study will aid the tunnel de- signers in understanding the expected damage of circular tunnels for a specific seismic intensity measure in the Jammu and Kashmir.

Keywords: Seismic fragility, Tunnelling, Jammu and Kashmir, Closed form solution, Indo-Gangetic, Underground Structures

1 Introduction

Jammu and Kashmir is situated in the northwestern Himalayas, one of the world's most seismically active areas, with major earthquakes occurred in 1555, 1828, 1885, 1905, and 2005. In Jammu and Kashmir, earthquakes of moderate to large magnitude have been common because to the continuous collision between the Indian and

Eurasian plates [1-3]. Recent moderate earthquakes in this region include the 2013 Kishtwar earthquake (Mw = 5.7) and the 2019 Mirpur earthquake (Mw = 5.6). Only one highway tunnel was destroyed during the 2005 Kashmir earthquake along the route between Murree and Muzaffarabad [4, 5]. Northbound traffic was directed to a bypass road that went down the slope of the hill, while southbound traffic was routed to the tunnel.

Jammu and Kashmir has seen massive infrastructure projects in the previous two decades, including bridge abutment, tunnelling, and the construction of railway tracks and national roads, all of which would aid the region's overall economic development. The Udhampur Srinagar Baramulla Rail Link (USBRL) is a 345 km mega rail project of national importance in the Himalayan terrain that is flanked by active seismic sources including the Main Boundary Thrust (MBT) and Main Central Thrust (MCT). The ac- tive seismicity of the region, as well as the growth of existing infrastructure projects, have prompted to the investigation of the seismic vulnerability of tunnels in Jammu and Kashmir.

In the present study, attention has been given to check to the seismic behaviour and vulnerability of circular tunnels at a shallow depth of 10 m for minor (DS_1); moderate (DS_2); and extensive (DS_3), damage states in the Indo-Gangetic Plains of Jammu. The western and southeastern parts of Jammu, samba, Kathua, and a few villages in the southern section of Udhampur are part of this area. This location features soft alluvial soil deposits, a low SPT (N) value, liquefaction-prone spots, and the maximum structural and free-field deformation, demonstrating the effect of the surrounding medium, which is induced based on local geology and site characterisation. If the geological context and seismic microzonation are identical, the proposed fragility function might be utilised to analyse the seismic risk of circular tunnels anywhere over the world. This study can help tunnel engineers better understand the seismic behaviour of circular shaped tunnels with similar geological settings and structural typologies at shallow overburden depths, while also accounting for additional damage models and other fac- tors that impact seismic performance.

2. Geomorphology, Geology, and Tectonics of Jammu Region (JR)

The Jammu and Kashmir is located in the northern part of India covered with the natural landscape and has two major divisions: the Jammu Region (JR) and Kashmir Valley (KV). The JR in the northwestern Himalayas is limited on the north by KV and on the east by Ladakh, where the southwestern part has flat terrain, and the rest is made up of Jammu hills. The Chenab, Tawi, and Ravi are the main rivers flowing in the JR, which further enters the territory of Pakistan. After passing through the Kashmir Himalayas, the Chenab River emerges into the plains near Akhnoor in Jammu. The southern por- tions of Samba and Kathua, near Pathankot in Punjab fall under the basin of the Ravi River [6]. The Tawi River passes through the Doda, Udhampur, and Jammu and then merges with the Chenab River near Sialkot in Pakistan.

The Jammu, Samba, Kathua, and southwestern part of Udhampur districts lie at the foothills of Siwalik, built over deep sedimentary basins made up of unconsolidated qua- ternary sediments of the Jammu formation, older and younger alluvium. Subsurface strata from Jammu to Reasi show Dolomite formation, Murre formation, Precambrian group consisting of phyllites and volcanic rocks, post-Siwalik

conglomerate, upper; middle; and lower Siwalik consisting of loose boulder conglomerate; grey to red shales; and sandstones, Dogra slates consisting of quartzite; slates; phyllites; and limestones [7].

The Nagrota formation is found in the northern portion of Jammu, whereas younger alluvium along the Tawi River is found in the southern section. Clast-supported deposits may be found near the top of the fan on the northern side of Samba and Kathua, sandy deposits in the center area, and clay deposits inside gravel bands towards the bottom of the fan [8].

The JR has impacted due to near-field as well as far-field earthquakes in the Himalayan region extending up to Hindukush in Afghanistan (Lister et al., 2008; Asim et al., 2017). The Jhelum Fault (JF), Attock Fault (AF), Reasi Fault (RF), Balakot-Bagh Fault (BBF), Deosai Fault (DF), Jwalamukhi Thrust (JT), Hanna Fault (HF), Batal Fault (BF), and Mawer Fault (MF) are few of the active faults that surround this area [9]. The Main Central Thrust (MCT) distinguishes the crystalline rocks of the higher Himalayas from the formations of the lower Himalayas [10]. Along the JR's northern boundary, the Main Boundary Thrust (MBT) and Panjal Thrust (PT) run parallel. The BBF, which is NE dipping in Pakistan, is the primary cause of the 2005 Muzaffarabad earthquake. Active Reasi Fault (RF) and Udhampur Fault (UF) pass through the core center section of the JR in addition to the MBT. In 2013, an earthquake of a magnitude of Mw 5.7 struck Kishtwar, with the epicentre 258 km from Jammu [11]. In Fig. 1, all active seis- mic sources in a 350 km radius around Jammu along with epicentres of past earthquake events having magnitude Mw > 5.0 are illustrated.

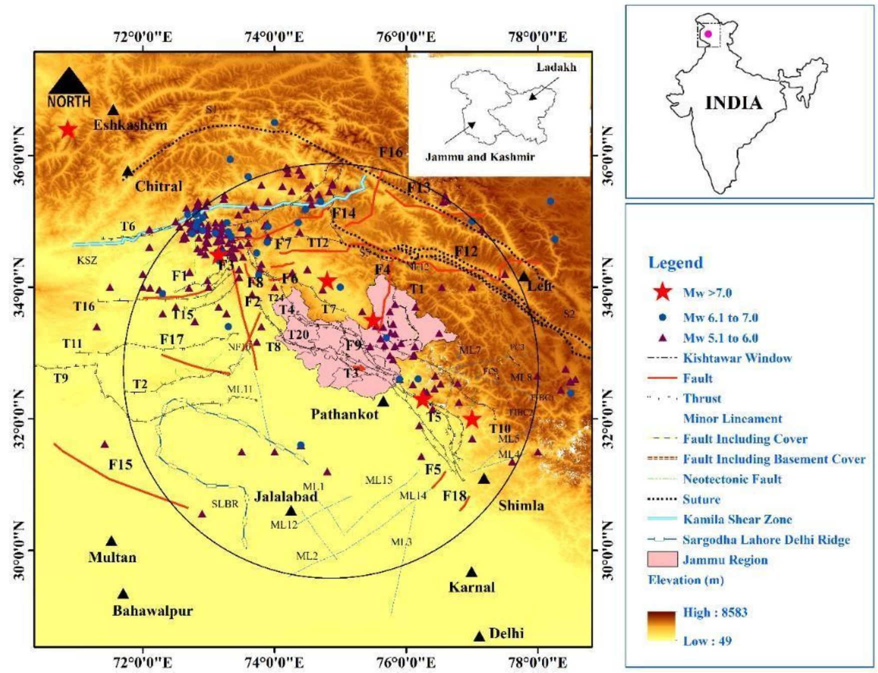

Fig. 1. Seismotectonic map of the Jammu Region (JR), Jammu and Kashmir, and encircling areas depicting the active seismic sources and epicenter of past seismic activities with magnitude, $M_w \geq 5.0$.

3. Field shreds of evidence of 2019 Mirpur Earthquake and Assessment of Liquefaction Hazard

The epicentres of the 2005 Muzaffarabad earthquake and the 2019 Mirpur earthquake are around 232 and 122 km from Jammu, respectively. The well-developed liquefaction characteristics in the Simbal area near Jammu airport were described by [12]. Liquefaction evidence includes open fractures and sand blowing on the ground due to strong seismic activity in that region [13-15]. A field survey is undertaken in the Jatah town, which is located near Degh Nala in the JR's Samba district, in June 2021. A few people in Jatah on the Indo-Gangetic Plains of JR felt intense shocks and witnessed the swaying of power lines during the 2019 earth- quake near Mirpur. This event produced a change in the water table due to the far- field earthquake's shaking influence. Sand blows were seen at three spots as signs of liquefaction induced by the far-field earthquake, which had an epicentre 137 km distant near Mirpur. A 20 m long ground rupture has been discovered in Simbal, which was caused by violent vibrations during the 2019 Mirpur earthquake (Fig. 2a). The largest sand blows developed on the eastern side of Degh Nala, as indi- cated in Fig. 2b. The reported liquefaction features for these two locations, which are far from the epicentres of both the 2005 Muzaffarabad earthquake and the 2019 Mirpur earthquake, are owing to dynamic stress transmission within subsurface strata.

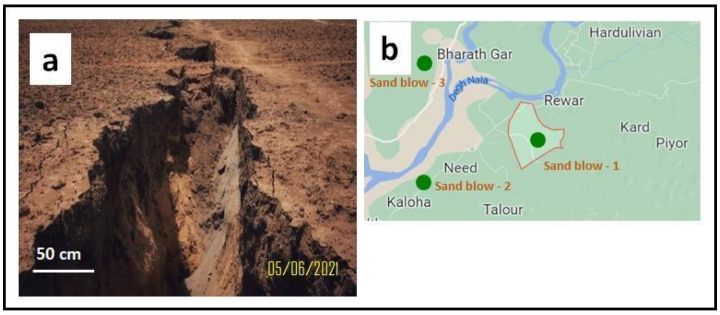

Fig. 2. (a) Ground rupture observed at Simbal town and, **(b)** Sand blows identified near Degh Nala in Jatah during the field survey in Jammu Region (JR), Jammu and Kashmir.

The geotechnical consultants in Jammu and Kashmir have provided extensive borehole data for the selected study area falling in the Indo-Gangetic Plains of Jammu. The stand- ard penetration test (SPT) estimates the N value, density, and plasticity index for a borehole at a specific location of interest at various depths to indicate penetration re- sistance. [16] suggested the SPT (N) value-based updated method to estimate the factor of safety against liquefaction. The liquefaction hazard assessment of the study area is done, and a vulnerability map is prepared, as shown in the following Fig. 3. The lique- faction threat is severe in Gandhi Nagar, Talab Tillo, and Hakal in Jammu, as well as other locations near the Tawi River's bank, such as Simbal, Ram Bagh, and Jammu University, and eastern areas of Rajouri, such as Laal Haveli and Jamia Masjid. Samba and Kathua contain a thick covering of young sedimentary formations with uniformly graded soils that are particularly liquefiable.

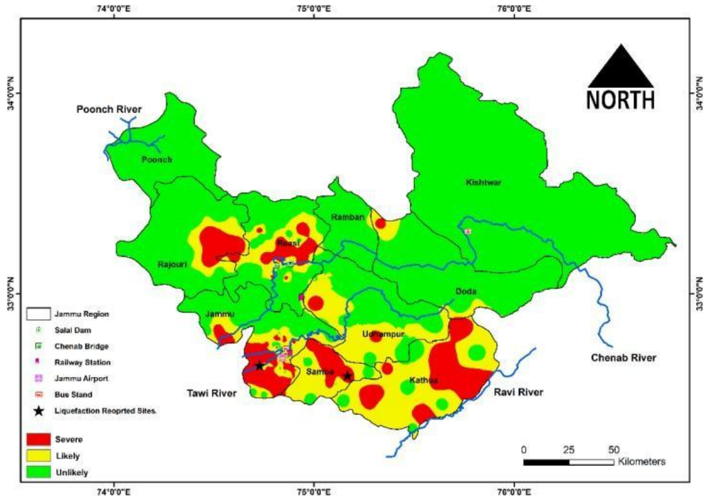

Fig. 3. Liquefaction hazard map of Jammu Region (JR), Jammu and Kashmir.

4. Seismic Behaviour of Circular Tunnels at Shallow Depth

This study looked at the tunnel behaviour at a 10 m overburden depth, considering lining specifications (L1 for 300 mm and L2 for 600 mm) and site characterisation. The combination of a large magnitude earthquake event, a short epicentral distance, and shallow overburden depth invite catastrophic tunnel damages. It should be highlighted that the maximum tangential thrust represents the dynamic response of tunnel lining under earthquake loading. The parametric analysis of tunnel models under seismic con- ditions is done using both P-wave and S-wave-based methods proposed by [17] and [18-21], respectively. The change in tangential thrust for Peak Ground Acceleration (PGA) ranging from 0.1 to 1.0 g under both full and no slippage situations is shown in Fig. 4 below. [18] calculated the maximum tangential thrust of tunnel lining for no- slip circumstances, which is significantly higher than [21] calculated for complete slip conditions for the same tunnel model. The disparities between [21] and [18] are due to different assumptions concerning contact slippage. [17] used the longitudinal wave mechanism of the P-wave as the basic wave to affect the total damage and overesti- mated the maximum tangential thrust for the selected range of PGA.

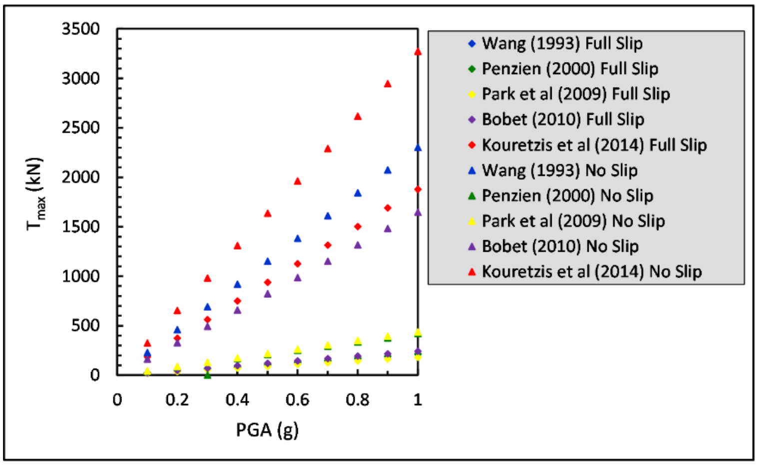

Fig. 4. Variation of maximum tangential thrust in tunnel lining under different seismic scenarios.

5. Seismic Vulnerability of Circular Tunnels

The seismic vulnerability is presented using the fragility functions, which are important tools in this context since they allow for seismic risk assessment of tunnels in both pre and post-earthquake stages, establishing the conditional probability of a structure reach- ing or exceeding a specified damage state (DS_i) for the intensity measure (IM) of earth- quake motion [22, 23]. Using regression analysis, the damage indices proposed by [22] were utilised to construct an empirical relationship between tunnel damage condition and intensity measure in terms of PGA (Fig. 5). For minor (DS_1); moderate (DS_2), and extensive (DS_3) damages, fragility functions are developed, as presented in Fig. 6.

Minor tunnel cracking and spalling, as well as small rockfalls at tunnel portals, are fairly typical kinds of damage in shallow tunnels subjected to minor damage [24]. A practical consequence of these observations is that the probability of extensive damage is very high in the case of soft soil, even for low seismic intensity. The tunnels exhibit consid- erable shear deformation values, which indicate the variety of the underlying strata and significant variances in site-specific geotechnical and geophysical characterization [25]. It's also been shown that thickening the tunnel lining reduces the chance of tunnel damage. For minor, moderate, and extensive damage, the probability of damage in- creases to 12.11%, 29.32%, and 9.14%, respectively, indicating that the analysed tun- nels maintain their fundamental performance but may suffer small damages at this level of earthquake intensity. There is a considerable decline in the damage probability from $[DS \geq DS_1|\ \mathrm{PGA} = 0.5\ \mathrm{g}\ ] = 0.92$ to $P[DS \geq DS_2|\ \mathrm{PGA} = 0.5\ \mathrm{g}\ ] = 0.64$, as damage state tends from minor to extensive, respectively.

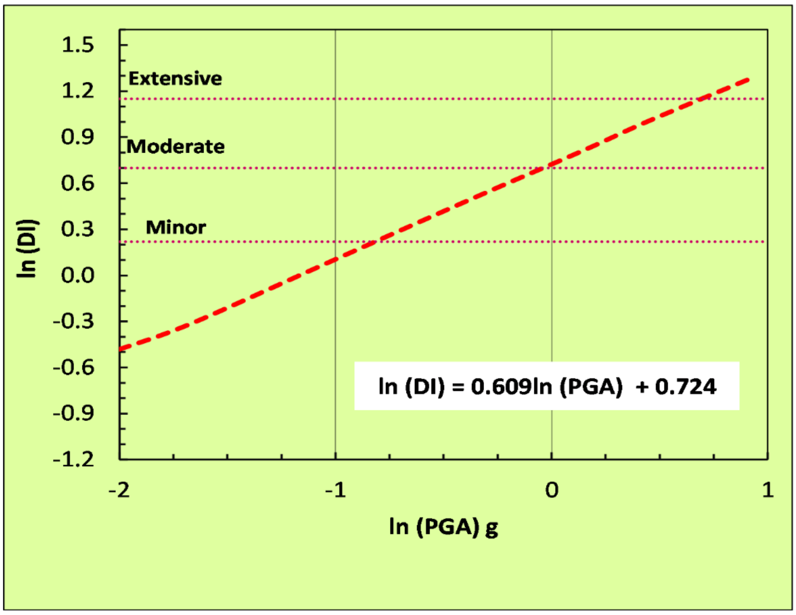

Fig. 5. Empirical relationships between damage index and peak ground acceleration (PGA) suggesting the boundary between minor, moderate and extensive damage states.

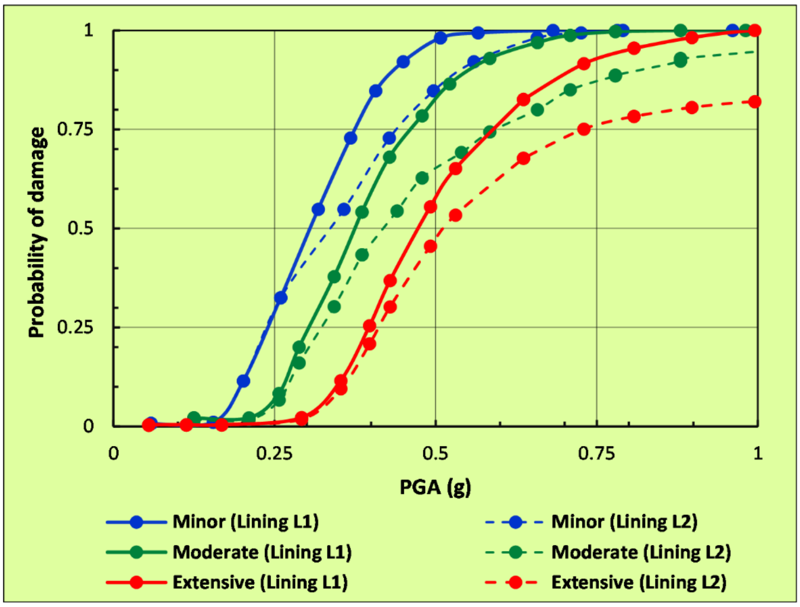

Fig. 6. Seismic fragility curves for circular shaped tunnels in Indo-Gangetic Plains of Jammu (Jammu and Kashmir), at shallow overburden depth of 10 m for different damage states.

6. Conclusions

The Indo-Gangetic Plains of the Jammu region located in the northwestern part of the Himalayas frequently triggered by moderate to large magnitude earthquakes. During the 2005 Kashmir earthquake, this region also showed considerable property damage. In this study, the seismic vulnerability of shallow circular tunnels at 10 m overburden depth passing through various geological conditions is assessed using fragility functions defined for minor (DS_1); moderate (DS_2); and extensive damage (DS_3) states. The geology, geotechnical characteristics, and geophysical parameters of this area in the northern Himalayas are quite diverse. Deep tunnels appear to be more resistant to seis- mic shaking than shallow tunnels [26]. According to previous research, an earthquake with a magnitude of Mw ≥ 6.0 and an epicentral distance of ≤ 70 km is the optimum combination for causing extensive to severe damage to underground infrastructure [27, 28]. A field survey carried out in the study area revealed the liquefaction-induced ground rupture and damage scenarios in Simbal and Jatah, located in Jammu Region (JR). The fragility functions developed for different damage states can be employed to check the vulnerability of tunnels for pre as well as post-seismic conditions. The over- burden depth of the tunnel plays a significant role in allocating the expected damage during ground motion. This study is going to help the tunnel engineers to modify the design parameters according to the subjected earthquake loading conditions and ex- pected damages in tunnel lining and at portal sections.

References

1. Ansari, A., Rao, K.S., Jain, A.K.: Seismic Hazard and Risk Assessment in Maharashtra: A Critical Review. In: Sitharam, T.G., Kolathayar, S., Sharma M.L. (eds.) Seismic Hazards and Risk, Lecture Notes in Civil Engineering, vol 116, pp. 33-45. Springer, Singapore (2021). https://doi.org/10.1007/978-981-15-9976-7_4
2. Ansari, A., Rao, K. S., Jain, A. K. & Ansari, A. (2022). Deep Learning Model for Predicting Tunnel Damages and Track Serviceability under Seismic Environment. Modeling Earth Systems and Environment, 8(4), 1-20. https://doi.org/10.1007/s40808- 022-01556-7
3. Ansari, A., Zahoor, F., Rao, K.S., Jain, A.K.: Seismic hazard assessment studies based on deterministic and probabilistic approaches for the Jammu region, NW Himalayas. Arabian Journal of Geosciences 15(11), 1-26 (2022c) https://doi.org/10.1007/s12517- 022-10330-z
4. Durrani, A.J., Elnashai, A.S., Hashash, Y., Kim, S.J., Masud, A.: The Kashmir earthquake of October 8, 2005: A quick look report. MAE Center CD Release 05-04 (2005).
5. Ansari, A., Zahoor, F., Rao, K.S., Jain, A.K.: Deterministic Approach for Seismic Haz- ard Assessment of Jammu Region, Jammu and Kashmir. In Geo-Congress 2022: Geo- physical and Earthquake Engineering and Soil Dynamics. GSP 334, pp. 590-598 (2022d) https://ascelibrary.org/doi/abs/10.1061/9780784484043.057
6. Ansari, A., Rao, K. S., & Jain, A. K. (2022). Seismic vulnerability of tunnels in Jammu and Kashmir during post-seismic functionality. Geotechnical and Geological Engineer- ing
7. Tiwari, G., Latha, G.M.: Stability analysis and design of stabilization measures for Chenab railway bridge rock slopes. Bulletin of Engineering Geology and the Environ- ment, 79 (2), 603-627 (2020). https://doi.org/10.1007/s10064-019-01602-2

8. Mahajan AK, Mundepi AK, Chauhan N, Jasrotia AS, Rai N, Gachhayat TK.: Active seismic and passive microtremor HVSR for assessing site effects in Jammu city, NW Himalaya, India—A case study. Journal of Applied Geophysics. 1(77), 51-62 (2012).
9. Rao, K. S., Ansari, A., & Zaray, A. H. (2022). Deadliest Earthquake in 2022: The Afghanistan Earthquake on June 22nd, 2022. IGS NEWS April-June 2022 ; A Bulletin of the Indian Geotechnical Society, 54(2), 10-11.Gupta H, Gahalaut VK.: Seismotecton- ics and large earthquake generation in the Himalayan region. Gondwana research. 25(1), 204-13 (2014).
10. Ansari, A., Rao, K.S., Jain, A.K.: Damage Analysis of Seismic Response of Shallow Tunnels in Jammu. In: Das, B.B., Hettiarachchi, H., Sahu, P.K., Nanda, S. (Eds.) Recent Developments in Sustainable Infrastructure (ICRDSI-2020)—GEO-TRA-ENV-WRM. Lecture Notes in Civil Engineering, vol 207. Springer, Singapore. pp. 611-619 (2022a) https://doi.org/10.1007/978-981-16-7509-6_47
11. Jayangondaperumal R, Thakur VC, Suresh N.: Liquefaction features of the 2005 Muzaffarabad–Kashmir earthquake and evidence of palaeoearthquakes near Jammu, Kashmir Himalaya. Current Science. 25, 1071-7 (2008).
12. Rai DC, Murty CVR.Effects of the 2005 Muzaffarabad (Kashmir) earthquake on built environment. Current Science 90(8), 1066-1070 (2006).
13. Malik JN, Sahoo AK, Shah AA, Rawat A, Chaturvedi A.: Farthest recorded liquefaction around Jammu caused by 8 October 2005 Muzaffarabad earthquake of Mw= 7.6. Jr. Geolg. Soc. India 69(1), 39 (2007).
14. Ansari, A., Zahoor, F., & Rao, K. S. (2022). Assessing Liquefaction Hazard - A case study of Jammu. CURRENT SCIENCE, 123(7), 837.Boulanger RW, Idriss IM.: CPT and SPT based liquefaction triggering procedures. Report No. UCD/CGM.-14, 1 (2014).
15. Kouretzis, G.P., Andrianopoulos, K.I., Sloan, S.W., Carter, J.P.: Analysis of circular tunnels due to seismic P-wave propagation, with emphasis on unreinforced concrete liners. Computers and Geotechnics, 55, 187-194 (2014). https://doi.org/10.1016/j.compgeo.2013.08.012
16. Wang, J.N.: Seismic Design of Tunnels: A State-of-the-Art Approach. Monograph 7. New York: Parsons Brinckerhoff Quade and Douglas. Inc. Wu, C (1993).
17. Penzien, J.: Seismically induced racking of tunnel linings. Earthquake Engineering & Structural Dynamics, 29 (5), 683-691 (2000).
18. Park, K.H., Tantayopin, K., Tontavanich, B., Owatsiriwong, A.: Analytical solution for seismic-induced ovaling of circular tunnel lining under no-slip interface conditions: A revisit. Tunnelling and Underground Space Technology, 24 (2), 231-235 (2009). https://doi.org/10.1016/j.tust.2008.07.001
19. Bobet, A.: Drained and undrained response of deep tunnels subjected to far-field shear loading. Tunnelling and Underground Space Technology, 25 (1) 21-31 (2010). https://doi.org/10.1016/j.tust.2009.08.001
20. Argyroudis, S.A., Pitilakis, K.D.: Seismic fragility curves of shallow tunnels in alluvial deposits. Soil Dynamics and Earthquake Engineering, 35, 1-12 (2012). https://doi.org/10.1016/j.soildyn.2011.11.004
21. Andreotti, G., Lai, C.G.: Use of fragility curves to assess the seismic vulnerability in the risk analysis of mountain tunnels. Tunnelling and Underground Space Technology, 91, 103008 (2019). https://doi.org/10.1016/j.tust.2019.103008
22. Ansari, A., Rao, K. S., Jain, A. K.: Damage Assessment of Tunnels in Seismic Prone Zone during Earthquakes: A Part of Hazard Evaluation. In: Sitharam T.G., Kolathayar S., Jakka R. (eds.) Earthquakes and Structures, Lecture Notes in Civil Engineering, vol 188, pp. 161-169. Springer, Singapore (2022). https://doi.org/10.1007/978-981-16- 5673-6_13

23. Ansari, A., Rao, KS., Jain, AK.: Seismic Analysis of Shallow Tunnels in Soil Medium. In: Satyanarayana Reddy C.N.V., Muthukkumaran K., Vaidya R. (eds.) Stability of Slopes and Underground Excavations, Lecture Notes in Civil Engineering, vol 185, pp. 343-352. Springer, Singapore (2022). https://doi.org/10.1007/978-981-16-5601- 9_29
24. Hashash, Y.M., Hook, J.J., Schmidt, B., John, I., Yao, C.: Seismic design and analysis of underground structures. Tunnelling and underground space technology, 16 (4), 247- 293 (2001). https://doi.org/10.1016/S0886-7798(01)00051-7
25. Ansari, A., Zahoor, F., Rao, K.S.: Liquefaction hazard assessment in a seismically active region of Himalayas using geotechnical and geophysical investigations: a case study of the Jammu Region. Bull Eng Geol Environ 81, 349 (2022). https://doi.org/10.1007/s10064-022-02852-3
26. Patil, M., Choudhury, D., Ranjith, P.G., Zhao, J.: Behavior of shallow tunnel in soft soil under seismic conditions. Tunnelling and Underground Space Technology, 82, 30- 38 (2018). https://doi.org/10.1016/j.tust.2018.04.040