A Critical Review of Road Failures due to Major Earthquakes in Asian Continent

Arijit Kumar Banerji*, Pijush Topdar** and Aloke K Datta***
*National Institute of Technology Durgapur, Department of Civil Engineering, W.B, India
arijit.banerji@bcrec.ac.in
**National Institute of Technology Durgapur, Department of Civil Engineering, W.B, India
topdar72@yahoo.co.uk
***National Institute of Technology Durgapur, Department of Civil Engineering, W.B, India
dattarec@yahoo.com

Abstract: Asian continent has witnessed a number of devastating earthquakes in the past decades. While in Indian scenario, the Himalayan belt comes out to be the most tectonically active belt. Such tectonic movement not only cause huge damage to vertically standing structures like buildings and bridges; but also damage roads and subsequently disrupts traffic flow. Even though earthquakes cannot be prevented from occurring, yet understanding the appropriate mechanism of road failures due to earthquake is the need of the hour. In view of the above, this paper aims to assess and analyze some of the major past earthquake induced damages of roads in the Asian continent, and, it was observed that the failure pattern consists of both structural and functional failure. Hence, further study is required to enhance the design methodology for constructing roads, such that damages can be minimized to an extent.

Keywords: Asian continent, Earthquakes, Road failure, Failure pattern, Design methodology.

Introduction

In the history of civilization, natural calamities like earthquake, flood, tsunami, landslide etc. have created huge loss of property and lives. Researchers have put their best effort in recent past to mitigate these unacceptable phenomenon to the civilized society. Road being the most important infrastructural component in any civilized society, the researchers have paid special attention on understanding the failure and preventive measures of this component. Yet Asian continent has witnessed a number of devastating earthquakes in the past decades. Whereas in Indian scenario, the Himalayan belt comes out to be the most tectonically active belt. Such tectonic movement not only cause huge damage to vertically standing structures like buildings and bridges; but also damage roads and subsequently disrupts traffic flow. Even though earthquakes cannot be prevented from occurring, yet understanding the appropriate mechanism of road failures due to earthquake is the need of the hour.

This paper presents a critical review of some of the major past earthquake induced damages of roads in the Asian continent and attempts to address the studies that have been conducted regarding the damage assessment of roads.

Earthquake Damage Measures

The most popular method/scale to assess damage of structures and to quantify seismic intensity is Modified Mercalli Intensity (MMI) scale. Intensity scale of VIII and above includes different ground damages due to earthquakes such as cracks, liquefaction, landslides and slope failures but none of the MMI scale values focus on the cracks or damages of roads [1]. Consequently, in 2012, Anbazhagan et al. proposed a new damage scale to categorize the road damages due to earthquakes. The proposed damage measure is termed as “Road Damage Scale (RDS)’’. Table 1 shows the proposed RDS with road damage description considering the MMI scale [2].

Road Damage due to Major Earthquakes

The shaking of the earth surface due to earthquake causes the movement of base material of roads in the form of cracking, lurching, differential settlement, liquefaction, lateral Completespreading, landslides etc. [1]. Normally, the road materials are very brittle in nature, hence, roads are susceptible to failure during earthquake. In view of the road damage scenerio limited literatures were available, therefore, this section summarizes major road damages due to past earthquakes in the Asian continent from past few decades. Summary of such road damages with earthquake details are mentioned below:

Complete collapse of road structure due to the Kobe earthquake that occurred on January 17, 1995, is shown in Fig. 1. The reported moment magnitude is 6.9, MMI scale value is X and RDS is 5. This figure shows the complete collapse of road

Table 1: Proposed Road Damage Scale (RDS) with Description [2]

RDS	Damage Description	MMI Scale
1	Damage is in the form of many minute cracks, one or two moderate cracks not exceeding 20 mm width, slight damage of shoulders and footpath. Very little repair work is usually necessary to restore road for full traffic.	VIII
2	Damage is in the form of settlement or moderate cracks, cracks or separation of pavement layers for width of less than 100 mm. Failure of sides and shoulder/footpath of the roads which reduces the road utility.	IX
3	Formation of big cracks and settlement of road is seen. Crack width may exceed more than 100 mm. Many bigger cracks in either one side or both sides of the road. Failure or crack can be attributed by liquefaction, landslide, fault rupture, and failure of subgrade and sub-base.	V, VI, VII, VII, IX, XI and XII
4	A portion of the road is rendered completely useless. Loose soil and debris are found all around. Road layers are washed away or slides.	VIII, IX, X and XI
5	Maximum damage occurs to a road during an earthquake. Damage of total width of road, road may not be useful for smooth walking and cycling. Complete relaying and rebuilding is needed.	VIII, X, XI and XII

structure, where the road segment is completely malfunctioned requiring to repair thoroughly or re-construct. Possibly, due to formation of large tensile stresses in the surface layer because of strong ground motion, the surface course of flexible pavement is severely divided into big plates, where some plates settled down of few feet because of the brittle behavior of the underlying layers. It has been reported that various areas has suffered subsidence due to strong ground motions and severe liquefaction of the soil [3]. Ground surface rupture due to Bhuj (Gujrat) earthquake January 26, 2001, is shown in Fig.2. The reported moment magnitude is 7.7, MMI scale value is X and RDS is 5 [4]. Longitudinal cracks in the crest of the embankment were observed in some locations of the affected area due to inelastic deformation and these ground splitting at several places were developed as a part of slope failure. Cracks were also seen in some asphalt roads at few locations, indicating the possibility of failure due to ground slippage and landslides [5,6]. The damage of road due to October 8, 2005 Muzaffarabad earthquake is shown in Fig. 3. The reported moment magnitude is 7.6, MMI scale value is X and RDS is 4. The flexible pavement surface was cracked transversely in that particular location and ripped a fault line in the surface layer possibly due to the presence of soft soil or weaker underlying layers. However, it can be assessed that due to ground shaking large amount of tensile stress was developed which tends to create a fault line in this road section. [7]. The damaged and blocked road due to Wenchuan, China earthquake on May 12, 2008, is given in Fig. 4. The reported moment magnitude is 7.9, MMI scale value is IX and RDS is 4 [9]. This figure shows that trucks were smashed and trapped by rolling boulders due to the effect of landslides affecting traffic movement. In this image, the road structure is not severely affected, but resulted in partial or complete blockage to short sections of road. Such landslides mostly occurs as shallow and localized slope failures in roadside cuttings, though below-road slope failures are also common. Even some damage of roads were also observed in the city, where the road was un-passable for vehicles [10]. Damaged road in Tarlay, Shan due to Myanmar earthquake on March 24, 2011 is shown in Fig. 5. The reported moment magnitude is 6.8, MMI scale value is X and RDS is 5 [11]. This figure shows damaged road having deep longitudinal crack pattern with vertical displacement in the affected area. Vertical displacement of 1.5 metres in subsidence was observed in the area [12]. Perhaps, such failure were observed due to fatigue failure or shrinkage and as well as due to hardening of flexible pavement layers. Damages were also reported in Tachileik, Naryaung, and Monglin, but limited details about the road damages are available.

A section of road splitted due to Sikkim earthquake September 18, 2011, is shown in Fig. 6. The reported moment magnitude is 6.9, MMI scale value is VII and RDS is 3. This figure shows that the wearing course of flexible pavement surface was ruptured longitudinally in that particular location probably due lack of mix stiffness and ductile behavior, which were unable to sustain the tensile stress generated during earthquakes. However, in some sections transverse cracks also occurred on the pavement surface and extended the entire width of the pavement [14]. Fig. 7 shows the tear down of road due to Nepal earthquake on April 25, 2015 . The reported moment magnitude is 7.8, MMI scale value is IX and RDS is 5. This figure shows the settlement of the pavement after transversely cracked. Perhaps such type of failure happens due to weaker subgrade; as due to ground vibration the shear strength of the subgrade soil mass and stiffness of the base layers gets

Figure 1. Road damage due to Great Hanshin/Kobe earthquake [3]

Figure 2. Ground cracks due to Bhuj earthquake [5]

Figure 3. Road damage due to Balakot, Pakisthan earthquake [8]

Figure 4. Road collapse due to Wenchuan earthquake (China) [10]

destabilized, which creates large amount of underlying layers to shift position. Primarily the earthquake triggered an avalanche on Mount Everest, and hence landslides occurred in the Trishuli River Valley also [16]. Such roads require complete reconstruction for effective traffic movement.

Figure 5. Road collapse due to Myanmar earthquake [13]

Figure 6. Road damage due to Sikkim earthquake [15]

Figure 7. Road damage due to Nepal earthquake [17]

Overall it was observed that the failure patterns are more or less similar and the mechanism of road failures does not follow any similar trend with respect to the moment magnitudes and MMI scale, but, RDS follows some similar trend to failure pattern. However, from the critical review of the road damage scenario, it was observed that the failure pattern consists of both structural and functional failure; nevertheless, the impact of destruction is relatively same i.e liquefaction of subgrade soil, inadequate stiffness in soil-foundation system and failure of base and subbase materials which triggered slope failures, ground cracks, vertical displacement of roads etc.

Conclusion

Researchers are mainly focussing on pavement design based on the axle load and climatic conditions; because pavement as a layered media is designed for providing adequate structural support and durability. But still, due to such improvements pavement gets deteriorated due to huge dynamic forces like earthquake. Basically, pavement failure consists of the failure of pavement layers, which may precede either from the subgrade upwards or from the surface course to the subgrade; and in case of earthquake water migrates into the pavement structure through surface infiltration, inadequate shoulders, edge cracks, and via rise of capillary pore water pressure in the subgrade soil. Available damaged roads with image and earthquake parameters have been collected. Study clearly shows that, these phenomenons's also deteriorates the sub-base and base layer, where the pavements is completely collapsed and are totally inaccessible. Complete failure of pavement surface and sublayers occurs mainly due to landslide and liquefaction and these roads require complete reconstruction for effective traffic movement. Ultimately in this respect, there is a burning need for proper understanding of the mechanism of failure of roads due to earthquake. To enhance the proper modelling based design methodology; amplitudes of ground motion in terms of acceleration, velocity and displacement of previous major earthquakes needs to be utilized for constructing roads, such that seismic damages can be minimized. In fact, the road infrastructure design code must be enhanced according to the earthquake resistant design code of practice.

References

[1] S. Elnashai, and L. Di Sarno, Fundamentals of earthquake engineering. Chichester, UK: Wiley, 2008.

[2] P. Anbazhagan, S. Srinivas, and D. Chandran, "Classification of road damage due to earthquakes". Natural hazards, 60, vol. 2, pp. 425-460, 2012.

[3] P. T. Tung, Road vulnerability assessment of earthquakes. Master of Science Dissertation, International Institute for Geo-information Science and Earth Observation, Enschede, 2004.

[4] Wikipedia 2001 Gujarat earthquake, [cited 2016 May 10]. Available from: http://en.wikipedia.org/wiki/2001_Gujarat_ earthquake.

[5] Gordan, and A. B. Adnan, "Effect of material property in foundation during earthquake on the embankment". ISRN Civil Engineering, pp. 1-6, 2012, doi:10.5402/2012/629369.

[6] SAARC SDMC (2001), Case Study: Gujarat Earthquake, [cited 2016 May 12]. Available from: http://saarc-sdmc.nic.in/pdf/Earthquake3.pdf.

[7] M. Zare, and S. Karimi-Paridari, "An investigation on Balakot, Muzaffarabad (Pakistan) earthquake, Mw 7.6; geological aspects and intensity distribution". Journal of seismology, 13, vol. 3, pp. 327-337, 2005.

[8] Earthquake Devastation in Kashmir (2005), [cited 2016 May 15]. Available from: http://news.nationalgeographic.com/news/2005/10/photogalleries/earthquake/photo2.html.

[9] W. Zifa, "Strong motion, damage, and loss of Wenchuan earthquake". Institute of Engineering Mechanics, China Earthquake Administration, NCREE Newsletter, vol. 3, pp.97, 2008.

[10] W. D. Mooney, Earthquake Science Center Seminars, [cited 2016 May 19]. Available from: http://earthquake.usgs.gov/regional/nca/seminars/data/slides/543/web/slide063.jpg.

[11] USGC (2011) Magnitude 6.8—MYANMAR, [cited 2016 May 11]. Available from: http://earthquake.usgs.gov/earthquakes/ recenteqsww/Quakes/usc0002aes.php#details.

[12] Documenting Reality (2011), Burma's Trio of Earthquakes, [cited 2016 May 21]. Available from: http://www.documenting reality.com/forum/f241/burmas-trio-earthquakes-24-march-2011-a-74273/.

[13] International Business Times (2011), Powerful earthquake hits Myanmar, [cited 2016 May 21]. Available from: http://www.ibtimes.com/powerful-earthquake-hits-myanmar-photos-706301.

[14] Wikipedia 2011 Sikkim earthquake, [cited 2016 May 13]. Available from: http:// http://en.wikipedia.org/wiki/2011_Sikkim_ earthquake.

[15] A. Nath, The struggle to recover begins for victims of Himalayan earthquake, [cited 2016 May 21]. Available from: http://www.naplesnews.com/news/images-photo-victims-himalayan-earthquake.

[16] Wikipedia 2015 Nepal earthquake, [cited 2016 May 21]. Available from: http://en.wikipedia.org/wiki/2015_Nepal_earthquake.

[17] Financial Express (2015) Nepal earthquake leaves over 3,200 dead, India toll at 66, [cited 2016 May 4]. Available from: http://www.financialexpress.com/photos/business-gallery/66828/earthquake-magnitude-7-9-quake-hits-nepal-causing-big-damage-india-witnesses/15/.