Soil Dynamics and Earthquake Engineering 97 (2017) 37–47

Contents lists available at ScienceDirect

Soil Dynamics and Earthquake Engineering

journal homepage: www.elsevier.com/locate/soildyn

Soil liquefaction in Kathmandu valley due to 25 April 2015 Gorkha, Nepal earthquake

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ARTICLE INFO

Keywords:
Gorkha earthquake
Soil liquefaction
Lateral spreading
Standard penetration test
Liquefaction potential index
Kathmandu valley

ABSTRACT

The April 25, 2015 Gorkha earthquake (M_W 7.8) affected central Nepal and neighboring areas. Kathmandu valley witnessed severe damage in terms of structural collapse and casualties. Apart from this, soil liquefaction in the form of sand blows and lateral spreading were observed in 12 locations. Soil liquefaction in Kathmandu valley during 1934 (M_W 8.1) earthquake was believed to be one of the major cause of damage in structures and lifelines but detail records are not available. To fulfill the gap of documentation in case of strong earthquake events like the Gorkha earthquake, field reconnaissance and collection of samples from each sand blow location have been carried out. In addition to this, numerical analyses based on geotechnical investigation records for seven locations that manifested sand blows have been performed. Common approach of liquefaction susceptibility analysis based on standard penetration resistance is found to be consistent with the surface manifestations. Our comparison between existing susceptibility maps and results of numerical analyses as well as field evidence concludes that the existing susceptibility maps are unrepresentative.

1. Introduction

Soil liquefaction is one of the major effect of earthquake that may cause severe damage in buildings and lifelines. Recent world earthquakes have depicted that the considerable damage is attributed to liquefaction [1–8]. Liquefaction case histories can be insightful for advancement of liquefaction phenomenon as well as to downscale the effects of soil liquefaction in buildings and lifelines.

Several historical earthquakes like Alaska (1964), Nihonkai-Chubu (1983), Loma-Prieta (1989), Kushori-Oki (1993), Northridge (1994), Kobe (1995), Koecali (1999), Chi-Chi (1999), Bhuj (2001), Kashmir (2010), Chile (2010) and Emilia-Romagna (2012) have depicted the detrimental effect of soil liquefaction on buildings and lifelines. In Nepal, historical earthquake of 1408, 1833 (M_L ~7.7), 1934 (M_W ~8.1) and 1988 (M_W ~6.8) have manifested liquefaction occurrence in various parts of country including the capital city districts in Kathmandu valley. During 1833 and 1934 earthquakes considerable damage attributed to liquefaction was reported by Rana [9]. Apart from this, Fujiwara et al. [10] reported occurrence of sand blows across the east-west highway section in the southern Indo-Gangetic plains of Nepal that affected hundreds of kilometers of highway in eastern and central regions. The Bihar-Nepal earthquake of 1934 depicted widespread surface manifestations in Kathmandu valley too. Due to lack of accelerometric recording stations the exact ground motion parameters are not known for this earthquake but Rana [9] estimated the approximate surface velocity to be ~245–300 cm/s. In case of 1988 eastern Nepal earthquake, Fujiwara et al. [10] estimated the ground acceleration in Kathmandu valley ~20–50 gals and surface manifestations were not reported during this event. The peak ground acceleration (PGA) during 1988 earthquake was below the threshold estimated by Santucci de Magistris et al. [11] hence surface manifestation may not have occurred within Kathmandu valley. After 1988, a strong earthquake struck Kathmandu valley in 2011 (M_W 6.9) but the epicenter was located some 650 km east of valley and no case of liquefaction was reported. Thereafter the 2015 Gorkha earthquake depicted several liquefaction surface manifestations across Kathmandu valley.

Liquefaction is an intriguing topic in earthquake engineering but it is relatively new for Nepal. Many historical earthquakes in the past have depicted occurrence of liquefaction in various parts of the country both in near field and far field thus liquefaction deserves remarkable attention. Despite such importance, no one to the best of our knowledge has studied liquefaction in Kathmandu valley or elsewhere in Nepal using geotechnical observations. Liquefaction is accepted as an important factor in major seismic codes worldwide, however Nepal Building Code (NBC) fails to incorporate any consideration against liquefaction. In addition to this, none of the guidelines used for road and bridge construction and other important lifelines in Nepal include

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http://dx.doi.org/10.1016/j.soildyn.2017.03.001
Received 10 October 2016; Received in revised form 24 February 2017; Accepted 2 March 2017
0267-7261/

provisions against soil liquefaction. NBC was developed in light of the damage occurred during 1988 earthquake but one of the major aspect that caused or aggravated the damage in southern plains remained excluded. Such exclusion leads potential damage due to liquefaction in case of strong to major earthquakes as buildings and lifelines. Apart from this, soil liquefaction may aggravate the damage even in well-designed structures due to lack of adequate provisions against liquefaction effect.

Existing liquefaction hazard maps prepared by JICA (for details see: http://un.org.np/node/10640) [12] and UNDP (for details see: http://www.un.org.np/node/9886) [13] did not represent the occurrence of soil liquefaction during 2015 Gorkha earthquake. Surface manifestations occurred during such earthquake happen in areas different than the zones that depicted surface manifestations during 1934 earthquake. Due to this fact, previous mapping based on historical evidence and extrapolation may have shown discrepancy in terms of liquefaction susceptibility. In particular, discrepancy occurred in liquefaction susceptibility maps and surface manifestations during earthquakes highlight the use of geotechnical observations for improved liquefaction susceptibility status of area. To fulfill the gap between existing maps and surface expressions occurred during Gorkha earthquake, the geotechnical database collected before the earthquake was used to perform numerical analyses based on Idriss and Boulanger method [14]. Numerical calculation, field investigation and laboratory analysis were used to depict the liquefaction susceptibility of affected areas during Gorkha earthquake and to check validity of widely used standard method.

2. Gorkha earthquake

On April 25, 2015, central Nepal and surrounding areas were struck by a strong earthquake of moment magnitude (M_w) 7.8 at Barpak village of the Gorkha district at 11:56 local time. The epicenter was located ~80 km NW of the capital city (Fig. 1) and the focal depth was estimated to be 8.2 ± 2.9 km [15]. Gorkha seismic sequence occurred along one of the most active Main Himalayan Thrust fault which is understood to be responsible for major devastating earthquakes in entire Hind-Kush-Himalayan region. Preliminary modeling of Gorkha earthquake depicted dimension of ~120×80 km (length×width) directed towards the east of hypocenter [15]. Due to lack of adequate accelerometric stations, exact ground motion parameters in the epicentral and other damage locations are not available. The devastating effects of Gorkha earthquake occurred in several sectors and damage in terms of loss of lives, properties and cultural heritages were devastating. Apart from this, soil liquefaction was observed in 12 locations of Kathmandu valley and some of the liquefied areas witnessed severe structural damage too. The Gorkha seismic sequence caused 8790 casualties, 22,300 injuries and affected 8 million people (1/3 of total population) and displaced at least one million people for some months due to continuous aftershocks following the main shock of 25 April 2015. National Planning Commission Nepal [16] reported that 498,852 buildings were completely collapsed and 256,697 buildings witnessed minor to severe damage due to Gorkha earthquake and its aftershocks. In addition to this, 446 public health facilities were completely collapsed and 765 were partially damaged. Similarly, at least 2900 cultural and historical constructions were affected by Gorkha seismic sequence.

2.1. Ground motion records in Kathmandu valley

The main shock of Gorkha earthquake was followed by 475 aftershocks of local magnitude greater than 4 ($M_L > 4$) until January 2016 [17]. Gorkha seismic sequence consists of four significant events that caused severe damage or aggravated the damage extent. The main shock of 25 April and the three major aftershocks occurred on 25 April (M_W 6.7), 26 April (M_W 6.9) and May 12 (M_W 7.3) were the dominant events that led to severe damage in 14 out of 75 districts in Nepal. PGA records and significant durations of the four significant events recorded at National Seismological Center's accelerometric station in Kathmandu valley are presented in Table 1. Nepal has limited accelerometric stations and most of such stations are located inside Kathmandu valley as a result of this, only six accelerometric stations within Kathmandu valley recorded the main shock of 25 April 2015. The recorded PGA, duration and epicentral distances for the main shock are presented in Table 2 and the locations of accelerometric stations and liquefaction sites are depicted in Fig. 2. Details in terms of geology, historical occurrence of liquefaction and ground motion occurrence during Gorkha earthquake are discussed in following

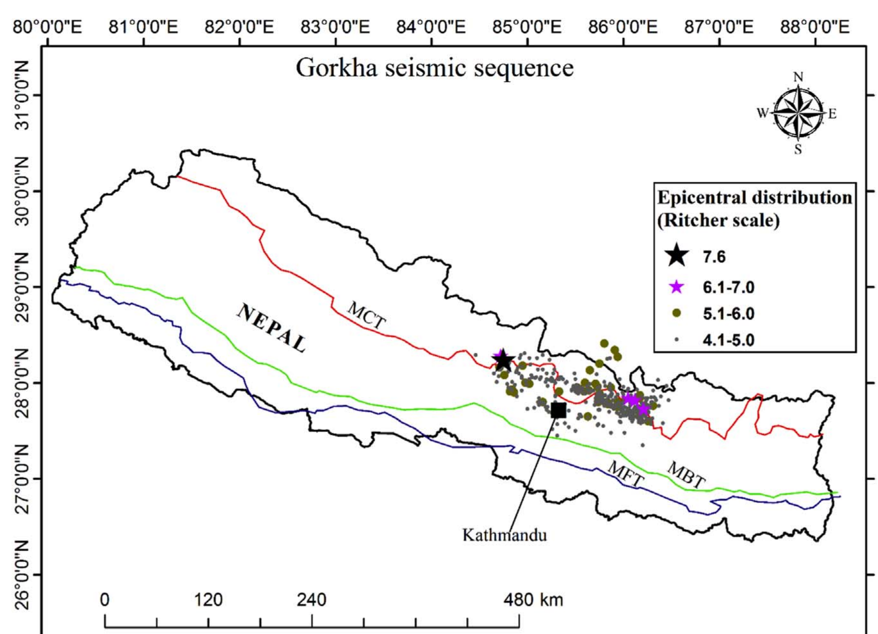

Fig. 1. Gorkha seismic sequence [Dark black star (M_L 7.6) corresponds to the M_W 7.8 main shock event of 25 April 2015]. East-west trending colored lines represent major faults in Nepal Himalaya wherein MCT: Main Central Thrust, MBT: Main Boundary Thrust and MFT: Main Frontal Thrust.