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Technical Note

2011 Sikkim Earthquake at Eastern Himalayas: Lessons learnt from performance of structures

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ABSTRACT

On 18 September 2011, all the Indian states and countries surrounding Sikkim witnessed a devastating moderate earthquake of magnitude 6.9 (*Mw*). Originating in Sikkim–Nepal border with an intensity of VI+ in MSK scale, this earthquake caused collapse of both unreinforced masonry buildings, heritage structures and framed structures followed by landslides and mud slides at various places of Sikkim. Significant damages have been observed in relatively new framed structures mainly in Government buildings, thick masonry structures, while, the older wooden frame (*ekra*) non-engineered structures performed well during the earthquake. Further, it is noteworthy that government buildings suffered more than private ones and damages were observed more in newer framed structures than older ones. Analysis of the damages identify lateral spreading of slope, pounding of buildings, out-of-plane rotation, generation of structural cracks, plastic hinge formation at column capitals and damage of infill wall material as predominant damage features. A few remedial measures are also attempted to be mentioned with future need of research and application. It has been felt to create awareness regarding these issues and is the need of the hour.

1. Introduction

1.1. Regional setting and seismological features

Sikkim is a small state in northeast India at the foothills of the Eastern Himalayas with the main thrust faults (main boundary thrust [MBT] and main central thrust [MCT]) crossing the state (Fig. 1). In the evening of 18 September 2011, it witnessed a moderate earthquake of magnitude 6.9 (*Mw*), which is referred hereafter as the '2011 Sikkim Earthquake'. This particular event, considered as the largest mid-to-deep crustal earthquake of the region recorded by the *Himalayan Nepal Tibet Seismic experiment*, was followed by a number of aftershocks, three of whose magnitudes were more than 4.2 (*Mw*) [2]. The earthquake had its origin near the Sikkim–Nepal border. The Gangtok and Teesta lineaments, transverse to the Himalaya's are responsible for many earthquakes in the region. A strong earthquake of *Mw* 8.1 struck in January of 1934 along the Bihar–Nepal border along the interplate boundary. Other major earthquakes in this area in the last 50 years include the September 2009 Bhutan earthquake of *Mw* 6.1, the February 2006 Sikkim Earthquake of *Mw* 5.3, the August 1988 Bihar–Nepal earthquake of *Mw* 6.5 and the November 1980 Sikkim Earthquake of *Mw* 6.0.The hilly terrain of Sikkim, ranging from 27°N to 20°N and 87°59′E to 88°56′E, is wedged between Nepal at its west and Bhutan at its East, flanked by the Indian states of Bihar at its South-West and West Bengal at its south, and surrounded by Tibetan China along its north to north-east boundary. Encircled by the three international boundaries with Bhutan, China and Nepal, this strategically located state is divided into four districts, namely, East Sikkim, North Sikkim, West Sikkim and South Sikkim. Impact of the quake was actively felt by all the Indian states and countries surrounding Sikkim, each of which was witness to human death and building collapse.The acceleration time history of the main shock was recorded at Gangtok and the PGA was 0.15 g. The death toll was beyond 100, the number being highest in Sikkim. It is worthy to mention here that the region falls in Zone IV of the Indian seismic zoning map [3] where a maximum intensity of VIII is expected.

1.2. Account of the disaster

The authors had a technical visit to the areas affected by 2011 Sikkim Earthquake in December 2011. Accordingly, a reconnaissance based damage survey was conducted in December 2011 in

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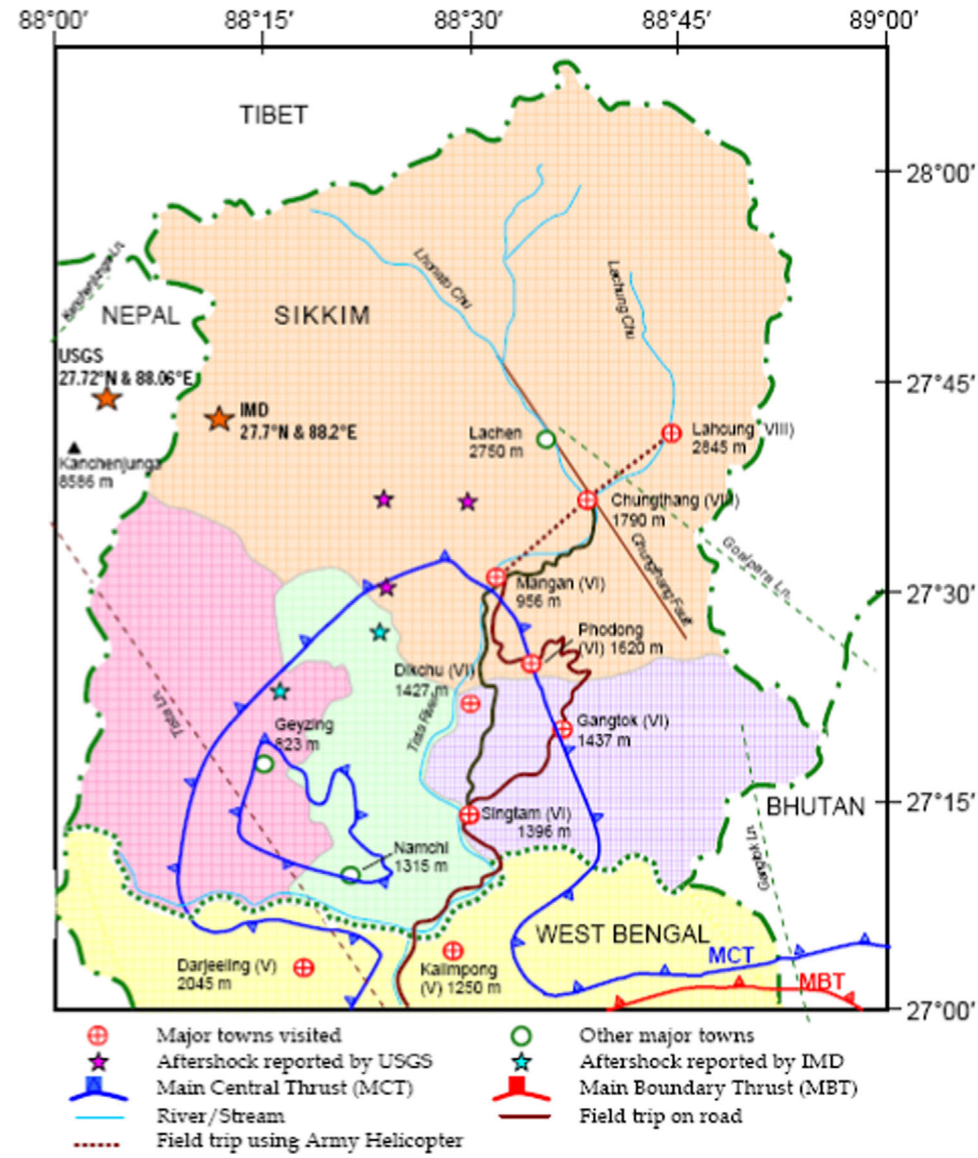

Fig. 1. Location of epicentres of the past earthquakes and thrust faults in Sikkim [1].

the four districts of Sikkim along with Kalimpong and Siliguri divisions of the Darjeeling district of West Bengal, as these areas were reported to have suffered significantly. Propagation of a large number of aftershocks is a typical feature of the seismic history of this region. However, each of the three aftershocks of the 2011 Sikkim Earthquake is individually capable of causing significant damage to the load-bearing unreinforced masonry structures (URM) of the region which are weak in tensile strength and shear strength. The catastrophic effect of the earthquake is mostly felt in North Sikkim, which is evident from Fig. 2 where one finds only the ruinous remaining of the entirely devastated Mangan Church situated in Mangan town, the district headquarter of North Sikkim.

The impact of the 2011 Sikkim Earthquake seems to be responsible for severe damage of a number of framed structures in addition to the usual damage of URM buildings and infill walls caused by the earlier 2006 Sikkim Earthquake, a moderate quake of magnitude 5.7 (*Mw*) [4,5]. A number of monasteries, living testimonies of the religio-cultural heritage of the Vajrayana sect of Indian Buddhism, suffered considerable damage.

Among the damaged framed structures, two general trends were noted. Firstly, the government buildings suffered more than their private counterpart. Secondly, damage was observed more in the newer structures than the older ones. These two primary observations point towards any one or combination of three reasons: (a) low-grade quality of material, (b) mediocre workmanship and (c) second-rate technical supervision. It is also to be noted that the magnitude of 2011 quake is relatively higher within last 50 years in comparison to the earthquakes struck in this area. In addition to areas with previous history, landslides further occurred at different places resulting damage of buildings, many portions of the national and state highway sand abutments of bridges as reported elsewhere [6]. However, there was no reported damage of any bridge. Amidst these havoc, it was notable that majority of the non-engineered buildings made with combination of wood and bamboo survived.

2. Damage profile

The buildings of the surveyed area can be broadly divided into three types, namely framed reinforced concrete (RC) structures with brick infill, unreinforced load bearing masonry buildings (URM), and timber-framed buildings with timber board or bamboo-matting (*ekra*) in between. The URM units are stone ashlars, kiln-burnt clay bricks or