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Earthquake Vulnerability Assessment of Buildings in Uttarkashi Township of Uttarakhand using RADIUS

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Abstract
Uttarkashi Township is the district headquarters of Uttarkashi district, and is one of the most vulnerable towns in Uttarakhand when it comes to various natural disasters. The natural calamity in the form of floods and landslides were the most recent events that struck the town. Also, the town is seismically vulnerable too with the calamity of 1991 earthquake in the region. The present study tries to put things on perspective about the seismic vulnerability of buildings in the region, estimating the damage if an earthquake of seismic intensity and magnitude of as in 1991 struck the town again.

Keywords: Earthquake Vulnerability, Buildings, Uttarkashi Township

1. Introduction

The study area is the municipality town administratively divided into nine wards. The Ward No. 3 of Gyansu and Ward No. 5 of Gangori making the western and eastern boundary respectively. There is also a good settlement on the southern bank of the river, but the municipality only covers the northern bank of the river with the area of 2.51 sq. kms. The town has crescent shape with a considerable amount of longitudinal variation. Thus the average length of town is manifold of the average breadth. The perimeter of the town is 15.86 km, mostly covering the lengths along the River Bhagirathi in the south and southeastern extremities, while the Varunavat Parvat marks its northern boundary. The town is located in the longitudinal valley of river Bhagirathi, the south and southeastern boundaries are marked by the *Bhagirathi*, while a small area in the north-eastern flank of town is drained by *Asi Ganga*, a tributary of Bhagirathi.

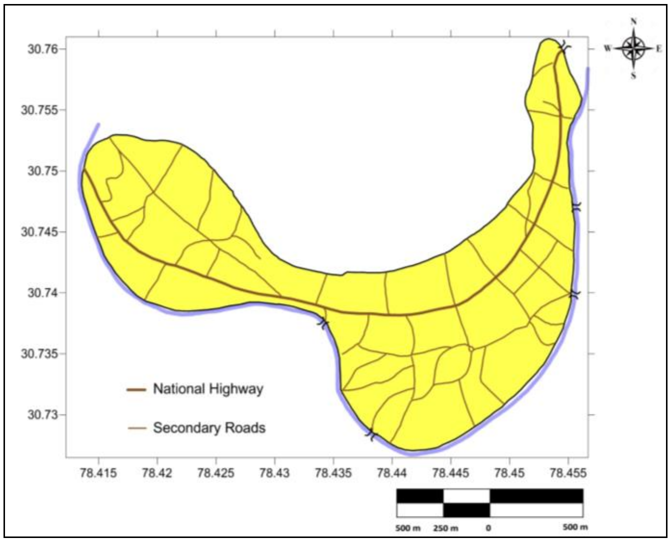

Fig 1: Uttarkashi Township and Types of Roads

2. Methodology Adopted

1. The collection of ground data with the help of the door-to-door sampling survey of each ward in which mainly the information regarding the occupancy and condition of the different building is collected in the Uttarkashi municipality.
2. Data on past seismicity is collected to understand the magnitude, seismic intensities and recurrence of earthquakes. Based on these data the scenario of a hypothetical future earthquake is created. To choose the scenario earthquake, the local seismic potential, past events, recent seismic events, geology and other factors are taken into perspective, depending on the future urban planning and management.
3. The satellite data in the form of Google satellite imagery is taken to visually interpret the land use, drainage, lithology and other characteristics of the landform. The ward map obtained from the municipality is georeferenced, rectified from the boundary and scale errors and then digitised with the help of the satellite image.
4. Ground classification is the next step in earthquake hazard analysis. In-depth study of geological structures is conducted around the town, including the soil types in various wards. The contour map of the town is put into perspective while doing a ground survey in which vulnerability of different building is analysed keeping in mind the slope factor and soil types, along with the information data obtained during the primary survey.
5. An inventory of the buildings, lifelines and infrastructures is prepared, and vulnerability classes for them are decided, from the past earthquake event as well as the hypothetical earthquake in both towns. Damages to the lifelines are calculated based on these vulnerability curves.

The data obtained now is incorporated in the RADIUS program with the help of GIS tools where the digital elevation model of the towns is created. The data is inserted in the programs and processed thoroughly. Then the processed data is analysed, rectified and represented through maps and tables for a better presentation. The damage estimation is discussed and compared using different input data.

2.1 Data Analysis

The study calculate and analyse the damage by the prospective earthquakes in the area. The estimates are discussed as following:

2.2 Estimated Building Damage

The study area of Uttarkashi Township is firstly put into the scenario earthquakes irrespective of the historical events in the town. Then the town is put into a worst-case scenario by producing the event of Nepal Earthquake of April 2015 to the respective study area (however, there is the possibility of even worse, seismically speaking). When considering the building damage, the severe damage and building collapse are only taken into account. The partial damage being ambiguous to interpret is excluded from the analysis.

2.3 Estimated Building Damage in Uttarkashi (1991) Scenario

According to 2012-13 survey of Municipal Corporation, Uttarkashi, the town has 3184 buildings in total. There was significant damage to many buildings in the past earthquake of 1991 here in the township that is discussed in preceding section. The number of buildings has grown since then, but so is the craft in the building. Now, most of the buildings are reinforced concrete frame building with brick infill construction and are taking over the stone masonry construction that is more prevalent at the time. The scenario taken has the same occurrence time as the original earthquake on 2:53 AM in the morning.

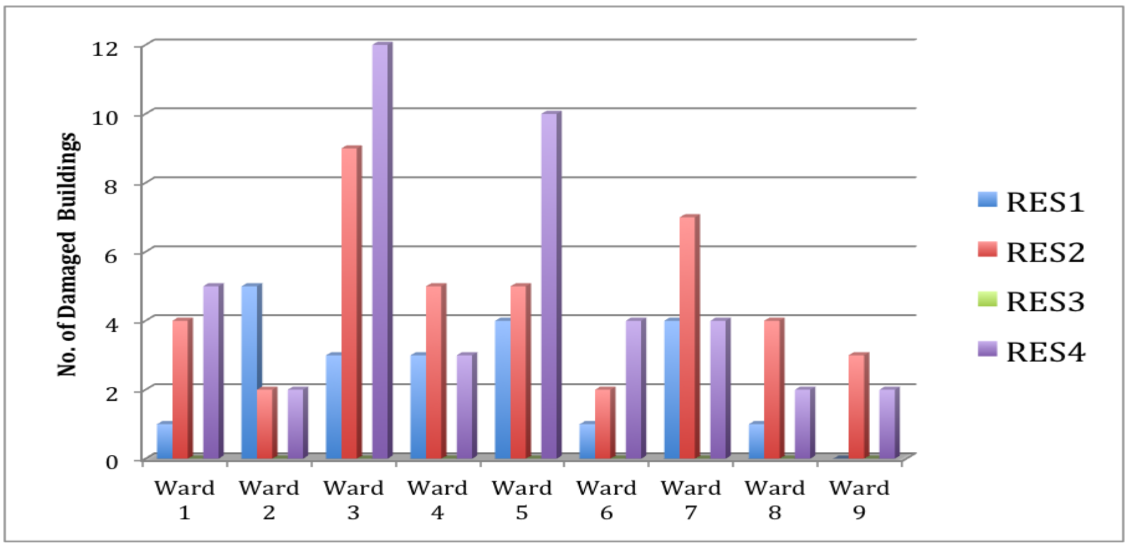

Fig 1: No. of Damaged buildings of various classes

The Peak Ground Acceleration (PGA) experienced by the town is expected to be 0.1 g, and the resultant Modified Mercalli Intensity (MMI) as an average on the town is 6.7. However MMI levels vary in different wards being a scale that is not based on any scientific basis, rather it has evolved based on experiences from observed damages in the aftermath of earthquakes. The most MMI experienced is in Ward one, three, six and seven. The MMI depends upon the mesh weight given as well as the soil profile of particular ward.

As expected, the RES1 construction type have the maximum MDR with lowest being 10.4 and highest being 14.5 in different wards. The average MDR for RES1 is 12.2 for the whole township. So in total 22 buildings of RES1 stock is estimated to be damaged. (Table 1)

For RES2, the highest MDR is 4.9, and the lowest is 3.8, the average being 4.3. It is the second most vulnerable stock of buildings in view of proportional damage and also total damage. If we look at the number of buildings damaged, in total 41 buildings are estimated to get damaged.

Table 1: No. of Damaged Buildings in Uttarkashi 1991, Scenario

Name of Ward	RES1	RES2	RES3	RES4	Avg. MDR	Total Building	Damaged Building
Ward 1	1	4	0	5	3.4	298	10
Ward 2	5	2	0	2	4.1	222	9
Ward 3	3	9	0	12	3.4	720	25
Ward 4	3	5	0	3	3.4	283	10
Ward 5	4	5	0	10	2.7	728	19
Ward 6	1	2	0	4	3.5	202	7
Ward 7	4	7	0	4	4.5	324	14
Ward 8	1	4	0	2	3.0	222	7
Ward 9	0	3	0	2	2.9	185	5

The RES4 category of buildings can be considered as relatively safe. However, all the RES4 construction do not comply the FEMA guidelines and not all the constructions are engineered constructions. So these structures are also bound to succumb to the seismic forces and get partial to complete damages. The MDR of the construction in this category ranges from 1.9 to 2.4, the average being 2.1. However, even the MDR as low as that do not prevent the RES4 from being the building types as most damaged at 44 buildings, clearly, the reason being the share of about 64 % of total buildings in the town.

2.4 Estimated Casualties in Uttarkashi (1991) Scenario

There are three types of casualties that can affect an individual during any disaster. The individual can either be moderately or severely injured or can succumb to death. The casualty is directly proportional to the buildings damaged, and it is important to determine building damage before the casualty estimation. In Uttarkashi town, the average injury ratio is 0.4, so out of the total population, only 0.4 percent of population i.e. in total 77 persons are estimated to be injured. The injury ratio ranges from 0.3 to 0.6, and maximum injuries can be seen in Ward Number Seven.

In total 73 persons are expected to be moderately injured, maximum of them are in Ward Number Three and minimum injured in Ward Number Nine, while only four persons are estimated to be severely injured. The casualty in terms of death is expected to be zero to only one person.

If the similar earthquake with same parameters occurs in daytime the results would be quite different. It is because the occupancy is more in commercial buildings then, like schools, offices, hospitals, colleges etc. The population inside the buildings drastically decreases in the daytime, most of the people are working outside or are in relatively safer buildings than their nonengineered houses, since most of the government or big private enterprises have engineered structures. Also in daytime, the population also has more time to respond to an earthquake then in night time when most population is asleep. So in daytime, the casualties are relatively less than in the night time.

The average injury ratio ranges from 0.3 to 0.5 in daytime, with the average being 0.3 only. The total injuries are expected to be 31 persons, with 29 being moderately and two of them being severely injured. The total possibility of death is nil to one person.

2.5 Expected line line damages in Uttarkashi

Uttarkashi town has an area of 2.51 square kilometres. The National Highway 34 (NH 108 [old system]) passes through the township of Uttarkashi. Besides, there are other roads and pavements joining various sections of the town. The town has a tunnel, *Tamaba Khani* tunnel that is about 200 m in length.

In an event as strong as previous 1991 earthquake of Uttarkashi, there is the possibility of 1.7 % of local road damage that counts to about 200 m in the town. Then the National Highway has got a 1.1 % of damage ratio that counts roughly to about 100 m of damage. A couple of bridges in Uttarkashi have a possibility of 3.7 % of damage. There is also the possibility of damage to *Tamaba Khani* tunnel. However the possibility as calculated due to a seismic event as that of Uttarkashi (1991) is very less, but the secondary disaster of *Varunavat* landslide after the earthquake poses a higher threat, hence increasing the potentiality of damage to the tunnel.

The telecommunication and electricity are basic and immediate requirements after the disaster. It is necessary for them to keep working, so let's see how they fare. There is a possibility of 9.3 % for the damage of electrical and telecommunication substations, and the mere possibility of 1.2 % for the damage of the electrical and telecommunication towers. So basically there is not much danger of non-working damage to these infrastructures. However, being more in frequency and present in various locations, the poles and electricity wires do have a larger possibility of damage.

There is also a reservoir in Bhagirathi River, which is flowing through the town. There is a possibility of 3.6 % damage in the reservoir. Also, a possibility of gasoline station damage is recorded to be 6.8 %.

3. Conclusion

The present study analyses and calculate the damages to a prospective earthquake of same magnitude and intensity as that of Uttarkashi strikes it again. The damages well exceed from the previous damages that the town experienced in 1991 due to the unplanned extension of town now and a significant increase in population.

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