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Seismic vulnerability assessment through RVS for critical infrastructure and commercial built-ups along the national highway 109 in Haldwani, Uttarakhand, India

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Abstract
Entire Himalayan terrain is recognized as being highly prone to intense seismic activity and in the past, the region has been jolted by four great Earthquakes (Magnitude >8 on Richter scale); Shillong (1897), Kangra (1905), Bihar-Nepal boarder (1934), and Assam (1950) apart from Kumaun earthquake (1720) and Garhwal earthquake (1830). The presence of major thrusts like Main Central Thrust (MCT), Main Boundary Thrust (MBT), Main Frontal Fault (MFF) and Himalayan Frontal Fault (HFF) along with innumerable structural discontinuities like faults, lineaments etc have made the region more vulnerable to seismic activity.
As a newly formed state, Uttarakhand has witnessed rapid growth in urban areas. The result of rapid growth of urban areas has led to unplanned growth of towns and cities. Negligence to the skilled construction practices due enormous concentration of population has led to a boom in unsafe infrastructure. With every city growth comes also the growth of critical infrastructure and commercial centers. CIs include a range of engineered systems, assets and facilities which are essential for day-to-day societal functions, as well as continued economic and societal functioning in the aftermath of a disaster event. Therefore, while assessing the vulnerability of housing in newly developing cities one should also need to assess the critical infrastructure like transport and communication, so that the worst-case scenario if a disaster struck could be mitigated. Also, the commercial centers along the national highway which are of economic importance can be assessed for seismic vulnerability.

Keywords: critical infrastructure, seismic, vulnerability

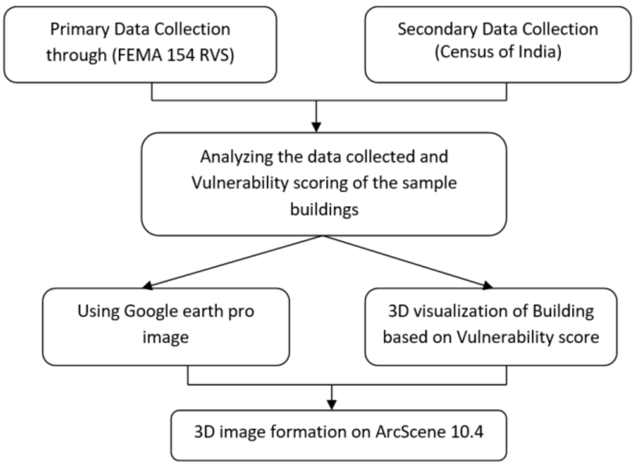
Introduction

The constant struggle between Indian and Eurasian plate has led to many major and minor earthquakes in the Himalayan region. But due to the altitude and mountainous terrain the events of earthquake are usually followed by landslides, rock falls, flooding, and liquefaction. This complex topography and lack of awareness of seismic threat has also led to haphazard construction of towns which has further added to the vulnerability of the hilly regions. This mountain region is followed by the great Indian plains which consist of huge density of population and therefore any such earthquake event has billion of population's life on stake. Hence the way out is to educate and make people aware of earthquake resistant construction which will further help in mitigation the risk.

In order to sharpen our understanding regarding critical infrastructure there are few important definitions given in the following:

- The U.S. Government states that the country's critical infrastructure is the "infrastructure and assets vital to national security, governance, public health and safety, economy and public confidence".
- Australian government defines critical infrastructure as physical facilities, supply chains, information technologies and communication networks are deemed critical for the functioning of a nation state, because, if destroyed or degraded, they would impact social and economic well-being or affect the ability to ensure national security
- EU has also defined critical infrastructure as: an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions.
- CIs include a range of engineered systems, assets and facilities which are essential for day-to-day societal functions, as well as continued economic and societal functioning in the aftermath of a disaster event.

Methodology



Objective

The purpose of this research is to provide a general insight of seismic vulnerability together with the critical infrastructure. This is in order to help the authorities in the planning phase to mobilize the outcome and implement the building codes necessarily and make the built-up environment seismic resistant. The work also aims to bring awareness among the community regarding the seismic vulnerability of the critical infrastructures around them.

Study area

The study area covers the municipal corporation city of Haldwani-Kathgodam that has been located in the vicinity of fragile and active seismic Shiwaliks and Himalayan Frontal Fault. The area comes under Zone 4 as per the seismic zonation of India and becomes a zone of High damage risk. This region is also called "Gateway of Kumaun".

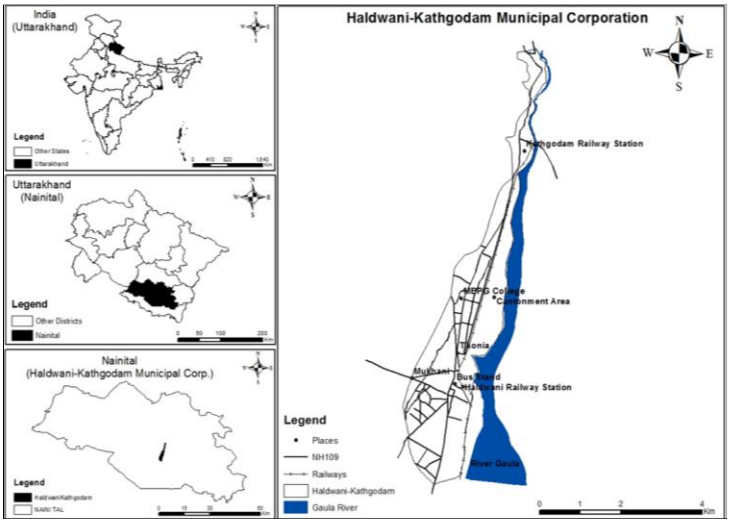


Fig 1: Location map of Study area

This is also the largest town of Kumaun with a good connectivity through Railways and Roadways. The region is 424 meters above mean sea level which makes it more suitable for the people to build their houses and hence this region has witnessed reckless construction of buildings with no proper plan and techniques in past few decades.

The area towards the east of the national highway lies in ward number 19 i.e., Haripur Colonal Awas Vikas and the area towards the west of national highway lies in ward number 9 i.e., Damuadhonga Malli Bamauri.

For this study a total of 29 buildings along the National Highway number 109 are taken with an area of a kilometer north to south. These are both the critical infrastructure and commercial towers and buildings along the highway.

Determining Vulnerability

Table 1: Classification of Buildings based on Age of the building, RVS Score and Usage of the building.

S. No.	Name of the Building	Age (in years)	Height (in feet)	RVS score	Usage	Damage Grade	Day population	Night Population
1	Building 1	6	33	0.7	Critical Infra.	3	10	5
2	Building 2	6	50	2.3	Commercial	2	50	2
3	Building 3	10	40	1.3	Commercial	3	30	3
4	Building 4	25	15	0.3	Critical Infra.	5	50	5
5	Building 5	40	36	0.4	Critical Infra.	4	2500	10
6	Building 6	7	33	1.9	Commercial	3	20	1
7	Building 7	35	44	0.5	Commercial	4	60	10
8	Building 8	08	30	0.7	Commercial	4	10	-
9	Building 9	17	40	0.9	Commercial	3	50	10
10	Building 10	65	22	0.2	Critical Infra.	5	300	7
11	Building 11	40	22	0.3	Critical Infra.	5	40	5
12	Building 12	6	40	0.9	Commercial	3	50	2
13	Building 13	25	34	0.9	Critical Infra.	3	60	15
14	Building 14	5	35	2.8	Commercial	2	10	1
15	Building 15	40	22	0.3	Critical Infra	5	2500	10
16	Building 16	25	15	0.5	Critical Infra.	4	50	1
17	Building 17	3	50	2.3	Commercial	2	100	2
18	Building 18	8	36	1.5	Critical Infra.	3	50	30
19	Building 19	8	50	2.3	Commercial	2	50	20
20	Building 20	16	60	0.9	Mixed	3	1000	30
21	Building 21	8	45	1.3	Mixed	3	100	20
22	Building 22	8	45	1.5	Commercial	3	50	20
23	Building 23	16	36	2.1	Commercial	2	60	2
24	Building 24	40	24	0.3	Critical Infra.	5	2000	20
25	Building 25	35	40	0.5	Critical Infra.	4	200	100
26	Building 26	35	40	0.5	Critical Infra.	4	100	80

27	Building 27	4	50	3	Commercial	1	100	2
28	Building 28	45	24	0.4	Critical Infra.	2	3000	10
29	Building 29	5	33	1.9	Critical Infra.	3	50	2

Table 2: Classification of damage to buildings and expected damage level based on RVS score (FEMA, 2015)

RVS score	No. of Buildings	Damage Intensity	Classification of Damage
Score < 0.3	5	High probability of Grade 5 damage	Very Heavy structural damage
0.3 < S < 0.7	6	High probability of Grade 4 damage	Heavy Structural damage, very heavy non-structural damage
0.7 < S < 2.0	11	High probability of Grade 3 damage	Moderate structural damage, heavy structural damage
2.0 < S < 3.0	6	High probability of Grade 2 damage	Slight structural damage, moderate non-structural damage
Score < 3.0	1	Negligible to slight damage	Negligible to slight damage

Fig 2: Clipped Google earth pro image of NH 109 in Haldwani-Kathgodam Municipal Corporation used for 3D Visualization

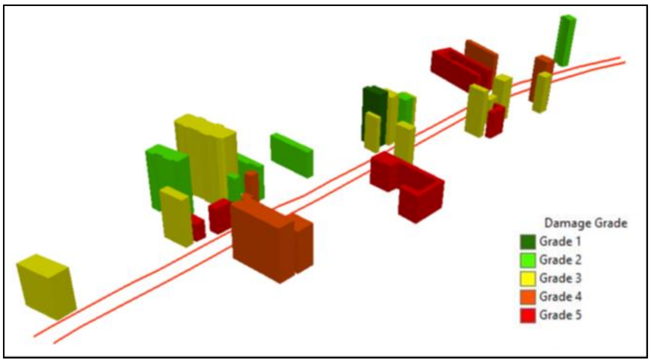


Fig 3: 3D building model based on Seismic Vulnerability score of RVS of Critical Infrastructure and commercial built-ups along NH109

Table 1.2 and Figure 1.3 clearly bring forward the status of vulnerability of 29 building along the national highway. 9 buildings out of 29 have high probability of grade 5 damage. These buildings mainly consist of schools with their average age above 45 years. The occupancy of these buildings is comparatively high during day time as per the school timings. According to the classification of damage, this damage grade brings very high structural damage from near to complete collapse.

Out of the total sample buildings, 6 buildings are in grade 4 category which possesses the threat of heavy structural damage, very heavy non-structural damage. Maximum number of sample buildings fall in the damage grade 3 category, here the number of buildings are 11. The type of damage here includes moderate structural damage to heavy structural damage.

The remaining two categories of grade 2 and grade 1 damageability includes 6 and 1 building respectively.

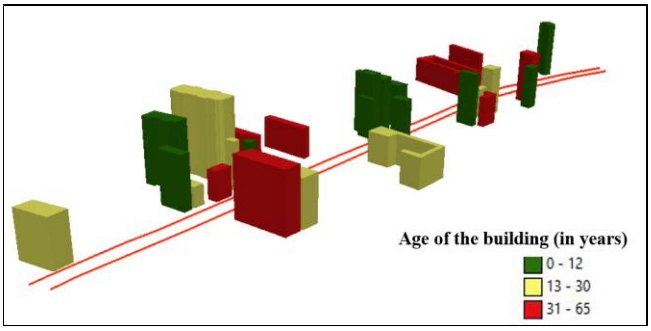


Fig 4: Classification of critical infrastructures based on age of the buildings (In years)

Age of the buildings remains a very important parameter for assessing vulnerability of any building. With the passage of time the strength of the building declines if not maintained and looked after. These kinds of buildings are not just threat to people living in it but also to the adjacent buildings. With the passage of time buildings lose its strength, especially in the way it behaved when it was new. Time to time maintenance and repair prevents the structure from ageing deterioration. As per Figure 1.3, 8 out of 29 building structure fall between the age of 31-65 years. 5 of these buildings also fall in the damage grade 5 which means the age of the building does contribute to the seismic vulnerability of any structure. With the passage of time old buildings are subject to more damage because of the loosening of material, cracks developed in the building because of absence of maintenance, and also the use of old technique and no up gradation of the building code as per the standards (Bora, 2019) [1].

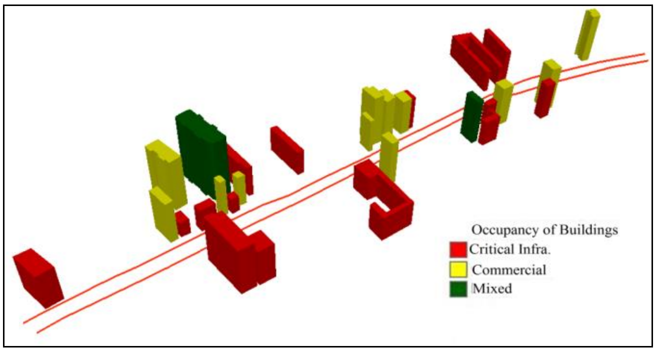


Fig 5: Classification of buildings based on Occupancy of the buildings

Occupancy of the building reflects usage of the building. Vulnerability of the building has very less to do with the occupancy of building but it simply allows you to understand the priorities for mitigation. Based on the functions of the buildings, the structures have been classified as critical infrastructure, commercial built-ups and mixed occupancy of buildings.

Here mixed occupancy details structures that are both commercial and critical in nature of usage. The functions could be miscellaneous.

This parameter of vulnerability could be simply explained by this small example. If an earthquake strikes at a day time the priority for mitigation would be a school with a total student, teacher and staff count close to 2500 rather than a building as a shopping store with less than 10 persons. This database of the usage and occupancy of the buildings helps in knowing the priority of mitigative actions during and post a seismic activity.

Results and Discussion

Seismic vulnerability assessment of these crucial buildings is important because the urban region is at the highest risk of damage during any seismic activity. The post-independence growth of Indian cities has led to vast expansion of poorly designed infrastructures which has also led to congestion.

The south Asian cities are typically marked with high population density, poorly designed buildings, traffic congestion, water supply, waste management, urban heat island, and mismanaged administration. The seismic vulnerability of high population region of Indian cities is now becoming a matter of great concern for disaster managers and administration. The loss of life and property in the cities of developing countries is always high in numbers with the kind of preparedness measures existing and the majorly because of poorly designed buildings.

It has been concluded with the above data and discussion that the commercial and critical infrastructures in Haldwani city captures major portion of the National Highway (109). Assuming a scenario of an earthquake for this region may lead to the following:

- Considering the buildings with grade 4 and 5 damage intensity, nearly 7000 persons are under the risk of getting injured during day time because the buildings may encounter from serious damage to complete collapse of the building. This estimate has been made based on the damage grade and probability of damage that could occur in area with High seismic risk (zone IV).
- The day time population of these cities is more because the buildings mostly consist of schools.
- The night population of the building is less as these have no residential buildings within them.
- Absence of disaster management policy and awareness in government and community
- Poor structural conditions of critical infrastructure.
- Lack of open space within the city.
- Building and population congestions.
- Municipal Corporation is deprived of response/evacuation plan.
- Non availability of building database
- Inappropriate organizational structure

The area is geologically fragile and settles on soft soil which is also prone to liquefaction which is a common phenomenon during any seismic activity. There is no pro active approach for any probable disaster that may occur. The administration has no preparedness, prevention and mitigation plan for the region. Eventually with no preparedness plan and lack of mitigation strategies, the local government and community is bound to respond at the eleventh hour of the situation.

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