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DETAILED VULNERABILITY ASSESSMENT OF MASONRY BUILDINGS – CASE STUDY, INDIA

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Abstract

State of Uttarakhand, India is located in high to very high seismic zone along the Himalayan Belt. In past, the region has experienced huge loss of lives and assets due to frequent seismic events. To address this issue, the State Government with support of an external funding agency, launched a series of projects for creating safer and resilient infrastructure. The state authority developed systematic approach for structural vulnerability assessment in close consultation with leading technical institution. To prioritize the facilities for vulnerability assessment and retrofitting design, Rapid Visual Screening process was developed and conducted for 18,835 buildings located in 11,239 sites for various government infrastructure. Based on the RVS outcome, 150 critical health buildings (134 masonry and 16 RCC) in 90 sites spread across all 13 districts were proposed for Simplified Vulnerability Assessment followed by Detailed Vulnerability Assessment. The current paper explains the methodology used for assessment and design of retrofitting schemes for masonry structures. In view of the old building stock, assessment was agreed to meet Life Safety performance level.

Retrofitting scheme was designed to make the structure act monolithically using Hard Drawn and stainless steel wire mesh in form of bands and complete wall jacketing, where required. The trusses were tied through steel sections in horizontal and inclined planes. Strip footing was checked for safe bearing capacity for vertical and earthquake load combinations following Indian codes. The paper discusses the approach with facts and figures followed by challenges faced during the implementation and opportunities with way forward plan.

Keywords: Uttarakhand State; Seismic Retrofitting; Detailed Vulnerability Assessment; Life Safety

1. Introduction

India has experienced several catastrophic earthquakes, which caused immense loss of life and destruction of property in very large geographical areas. List of earthquakes of magnitude greater than or equal to 8.0 are Kutch in the year 1819 (M8.0), Shillong (Meghalaya) in 1897 (M8.7), Kangra (Himachal Pradesh) in 1905 (M8.0), Bihar - Nepal Border in 1934 (M8.6), Andaman Islands in 1941 (M8.1), Arunachal Pradesh – China Border in 1950 (M8.5).

Bureau of Indian Standards, India has divided the Indian Territory into four seismic zones ranging from II to V defining hazard severity. The dstribuion of these seismic zones are shown in IS 1893(Part 1):2016. The seismic zone factors assigned in order from low to high are 0.10g, 0.16g, 0.24g and 0.36g, respectively. It is pertinent to note that about 58.6% of India's landmass is prone to moderate to very high intensity earthquakes. Of the total 58.6%, 10.9% area lies in Zone V, 17.3% area in Zone IV and 30.4% area in Zone III. The remaining area corresponding to 41.4% lies in Zone II [1] .

The State of Uttarakhand which lies in high to very high seismic zone corresponding to Zone IV and V, comprises of thirteen districts. Districts Pithoragarh, Bageshwar, Chamoli and Rudraprayag and some parts of the districts of Almora, Champawat, Tehri, Uttarkashi and Pauri lie in seismic Zone V and the rest of the region falls in seismic Zone IV, as seen in the seismic map of the State of Uttarakhand under Figure 1.

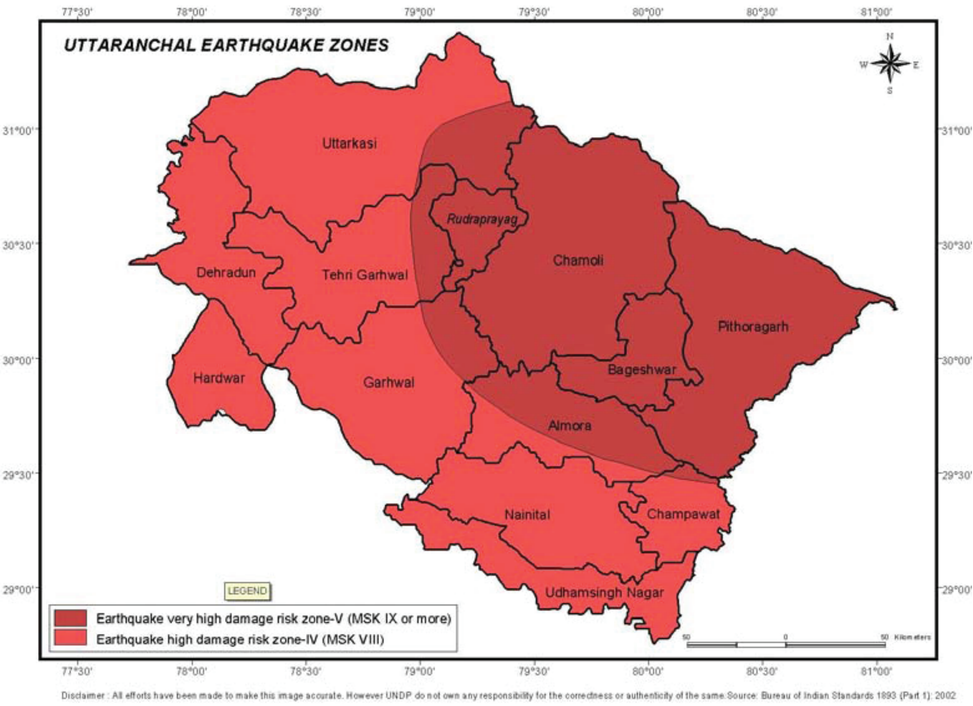

Fig. 1 - Uttarakhand Earthquake Hazard Map [2]

Aware of the above fact and after experiencing huge losses both in terms of lives and assets in previous two earthquakes, namely Uttarkashi (1991) and Chamoli (1999), the State Government showed increased alertness and thereafter carried out multiple studies to access the seismic vulnerability of the building stock in the state. Seismic vulnerability assessment of the built stock in the township of Mussoorie, Uttarakhand, India using the FEMA technique for Rapid Visual Screening (RVS) and the European Macro-seismic Scale (EMS-98) to assess the damage was carried out. Of the total 3,344 buildings that were surveyed, around 18% buildings were likely to face high probability of Grade 5 damage and very high probability of Grade 4 damage. The surveyed buildings included 14 hospitals. The study revealed that around 12 of the 14 hospitals were likely to be non-functional in post-earthquake scenario due to varying structural and non-structural damage. A total expected direct economic loss of approximately US$52.47 million would be due to damages of these vulnerable buildings (Disaster Mitigation & Management Centre, Uttarakhand 2010) [3].

Disaster Mitigation & Management Center, Government of Uttarakhand conducted study to assess the seismic performance of existing building stock to get an idea about its vulnerability and an estimate of the probable economic losses. Accordingly, seismic vulnerability studies for two townships namely, Bageshwar and Nainital were carried out. 1,165 buildings in Bageshwar and 2,865 buildings in Nainital were surveyed. It was found that most construction in both townships were non-engineered with RCC slab being preferred for roofing in Bageshwar whereas sloping roofs dominated the buildings in Nainital. Overall study revealed that in event of an earthquake of intensity VIII on MSK scale, 8% of the surveyed buildings in Bageshwar with most of these buildings (pre-2002 period) and 14% of buildings in Nainital (pre-1951) showed high probability of Grade 5 damage and very high probability of Grade 4 damage. Buildings under high probability of Grade 5 damage corresponded to 48,116m^2 in Bageshwar and 3,85,870m^2 in Nainital with total direct economic losses estimated to be Rs. 128.2 Million in Bageshwar and Rs. 962.8 Million in Nainital. Apart from the economic losses, study suggested that almost 1200 people would undergo life threatening injuries in both townships [4] .

Seismic Vulnerability assessment of 18,835 buildings of different lifeline departments of the State of Uttarakhand was conducted. 14,748 buildings were load bearing structures whereas 4,087 buildings were RCC frame structures. Out of the 14,748 masonry buildings, 72.14% of the buildings were found to be in Grade 5 and Grade 4 damage category. Similarly, out of the 4,087 RCC frame buildings surveyed, 36.14% of the buildings were found in Grade 5 and Grade 4 damage category. This is due to 92.0% masonry and 48.9% RCC buildings were found to be non-engineered in construction. Moreover, the study also revealed that all the Government buildings were self-constructed i.e. by self or some other State engineering department. Most of these above buildings would be damaged to such an extent that they would be rendered non-functional immediately after an earthquake leading to heavy exposure of remaining buildings to immense pressure. This could create a panicky situation for the State Government [5].

2. Rapid Visual Screening (RVS) Study, Uttarakhand

A RVS [5] form comprising of parameters such as year of construction, number of stories, building typology, construction material, foundation material, etc. required to assess the seismic vulnerability of the buildings was compiled. 28 engineers hired in March'2016, were trained to understand and populate the RVS form. Training was imparted for a period of a month. Thereafter additonal 26 engineers were hired in August'2016 to assist assistant engineer to prepare the architectural drawings and structural configuration.

To evaluate the RVS, each component of the building was assigned a basic score which is a function of the performance history of that type of structural / non-structural component, and the seismicity of the site. These scores were derived from fragility data of component performance under past earthquakes. This was developed for broad categories of major structural / non-structural components. These basic scores are modified by Performance Modification Factor (PMF) that indicate the decrease in reliability due to specific configuration or details that may be present. Each detail that may affect the seismic vulnerability is assigned a PMF consistent with its relative effect on functionality. The evaluation and checklist are completed such that the basic score and all applicable PMF are identified. Finally, a Structural Score "S" equal to its basic score minus the largest worst case applicable PMF is computed. If further evaluations or system modifications lead to the determination that a particular PMF is no longer relevant, the second most critical PMF is then used [6]. The RVS outcome revealed the following:

- Out of the surveyed buildings, 80% are masonry whereas only 20% are RCC Frame structures.
- Almost 85% of the surveyed building stock used non-engineered construction practices.
- Around 86% of the buildings surveyed are single storey but many of them are non-engineered, 13% buildings are double storey and 0.5% of buildings have 3 or more stories.
- Maximum percentage of buildings i.e. almost 57% has been constructed in the period 2002-2016.
- 36% of the buildings are asymmetric in plan, 5% of the buildings are irregular in elevation and 11% buildings have Re-entrant corners was observed during the survey.
- 21% masonry buildings and 4-5% RCC buildings will suffer losses due to pounding.
- 76% of the buildings surveyed have overhang length > 1.5m making them more vulnerable.
- 38-40% of buildings surveyed are located in hilly slope, 60% buildings are located in mild slope and 1.5% buildings are located in River bed area.
- 60% buildings have medium, 37% buildings have low and only 2% buildings have high construction quality. More than 50% of the buildings are distressed and damaged.
- Based on the RVS score, 49%-58% of buildings lie in very bad category, 13%-14% lie in bad category and 7%-9% lie in worse condition.

90 Hospitals comprising of 150 buildings spread across all thirteen districts of Uttarakhand in both seismic zones IV and V were selected for preparation of Detailed Project Report (DPR) for seismic retrofitting. The process involved carrying out Simplified Vulnerability Assessment (SVA) of all 150 buildings. Thereafter, for buildings failing in SVA, Detailed Vulnerability Assessment (DVA) was carried

out to assess the seismic vulnerability followed by design of an apt retrofitting scheme to retrofit the building to meet the desired performance level.

The 150 buildings comprised of 134 masonry structures and 16 RCC Frame structures. Table 1 below shares the breakup of all masonry buildings in respective districts of Uttarakhand. This paper concentrates on the 134 masonry buildings in specific. The 134 masonry buildings varied in size from very small size measuring up to 16.5 square meters to large size buildings measuring up to 2219.0 square meters. The age of buildings varied from as old as 121 years to as recent as 5 years. The selected buildings were single storey to two storeys with both rigid diaphragm and flexible diaphragm, respectively.

Table 1- District wise break up of Numbers of Buildings (Masonry & RCC)

S. No.	Name of District	No of Health Centres	No. of Blocks/ Units		
			Total	Masonry	RC
1	Almora	7	12	12	-
2	Bageshwar	4	6	4	2
3	Chamoli	9	16	14	2
4	Champawat	4	7	3	4
5	Dehradun	8	18	17	1
6	Haridwar	7	8	8	-
7	Nainital	4	5	5	-
8	PauriGarhwal	9	10	10	-
9	Pithoragarh	7	18	15	3
10	Rudraprayag	6	6	6	-
11	TehriGarhwal	9	17	15	2
12	Udham Singh Nagar	6	10	9	1
13	Uttarkashi	10	17	16	1
	Total	90	150	134	16

The overall methodology adopted for the preparing the detailed Project Reports for the all the buildings in sequential form was: (i) Preliminary site survey and data collection; (ii) Conduct Simplified Vulnerability Assessment i.e. Configuration checks, geometric checks and strength checks as per relevant IS codes; (iii) Proceed for DVA only if SVA results show building to be unsafe: (iv) Obtain material properties by conducting NDT and Geotechnical Investigation followed by sample testing in laboratory; (v) Incorporate material properties in the simulated numerical model and conduct vulnerability assessment; (vi) If DVA outcome reveals checking parameter values to be greater than the permissible values as per relevant codes; (vii) Select and design retrofitting scheme for building; (viii) Prepare DPR.

3. Simplified Vulnerability Assessment (SVA)

SVA involved visit to the site, collect basic visual data about the structure. Material properties were assumed to be on the conservative end and most stringent values as mentioned in the IS codes. The material properties were modified with Knowledge Factor that was taken as minimum i.e. 0.5 due to lack of accurate data initially. The idea was that if the building was found to be safe when considering the most conservative values of permissible stresses and material properties, then it could be said to be within safe limits and would not require Detailed Vulnerability Assessment. Figure 2 shows the brief proposed SVA methodology. The detailed SVA methodology is explained thereafter.

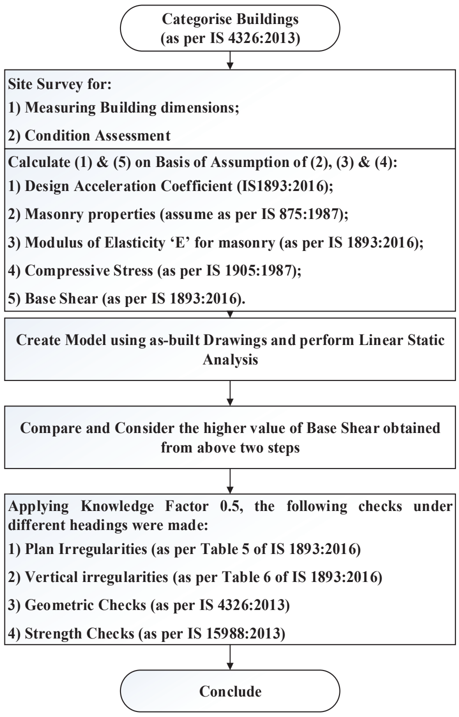

Figure 2 - SVA Methodology Flowchart

3.1 Detailed SVA Methodology

Categorisation of buildings depends upon the Importance Factor and the Seismic Zone as per IS4326-2013. Since entire state of Uttarakhand lies in earthquake zone IV and zone V and all buildings were hospital buildings i.e. critical buildings having Importance Factor 1.5, hence all buildings considered under Category "E" i.e. the most critical category. As no architectural or structural drawings were available for any building in the above list, teams comprising of four trained architects surveyed the buildings. During the survey, the teams measured the as-built dimensions of the buildings and collected pictures of distress such as dampness, cracks, etc. that was observed. Thereafter, as-built and condition assessment drawings were developed for each building. The design acceleration coefficient was calculated as per equivalent static method mentioned in IS 1893-2016 to obtain the base shear. Masonry properties, Modulus of Elasticity (E) and Compressive Stress were assumed as per IS 15988-2013 and IS 1905:1987. Model using as-built drawings of building was created on ETABs platform and analysis carried out as per Equivalent Static Method mentioned in IS 1893:2016 to obtain the time period and base shear. Using higher value of Base Shear from the manually calculated and that obtained from ETABs, average shear stress check as per clause 6.5.2 of IS 15988:2013 (note no. 2) using knowledge factor of 0.5 was considered. Thereafter Configuration Checks, Geometric Checks, Strength Checks as per IS 1893(Part 1):2016, IS 4326:2013, IS 15988:2013 and IS 13935:2009 were made to identify the deficiencies. Based on the deficiencies observed, conclusion was drawn whether the masonry building was found to be safe in SVA or whether detailed vulnerability Analysis (DVA) was required to be carried out for respective structures.

3.2 SVA Outcome

From site survey data, it was deduced that 72 buildings corresponding to 53.73% of the buildings lie in seismic zone IV whereas 62 buildings corresponding to 46.27% lie in seismic zone V. Further analysis of the site data revealed that single storied buildings in seismic zones IV and V corresponded to 61 and 50 numbers, respectively. Similarly, 11 and 12 number buildings lying in seismic zones IV and V were double storied. The SVA outcome for all three acceptance criteria i.e. configuration checks, geometric checks and strength checks is summarised below.

3.2.1 Configuration Checks

Torsional irregularity was found in 18.05% masonry buildings in seismic Zone IV and in 24.20% masonry buildings in seismic zone V. Existence of re-entrant corners was checked and found to exist in most of the buildings. It was noticed that around 52.78% of the masonry buildings in seismic Zone IV were having re-entrant corners and hence were irregular structures whereas 56.45% of the masonry buildings in seismic zone V were found with re-entrant corner irregularity. With regards to irregular modes of oscillation in two principal plan directions, it was found that around 59.72% of the masonry buildings in seismic Zone IV were having irregular modes of oscillation in the two principal plan directions and hence were irregular structures whereas 75.80% of the masonry buildings in seismic zone V were found with this irregularity.

3.2.2 Strength Checks

Under strength related checks, for masonry buildings, the shear stress check was the most important requirement for obtaining the strength of the walls directly. Accordingly, the permissible average shear stress for unreinforced masonry shear walls as per IS 15988:2013 i.e. 0.1 MPa was multiplied with the modified material factor i.e. knowledge factor of 0.5 to get the permissible average shear stress in masonry walls as 0.05MPa. It was found that around 93.05% of the masonry buildings in seismic Zone IV were found with average shear stress more than allowable value as per code, whereas 82.25% of the masonry buildings in seismic zone V were found with this deficiency. With regards to the presence of earthquake strengthening measures mentioned in Table 5 “Strengthening Arrangements Recommended for Masonry Buildings” as per Clause 8.4.1 of IS 4326:2013, it was observed that none of the masonry buildings had all the earthquake strengthening measures in them. Few buildings had bands running in few walls only, while vertical steel at corners was found partially within few structures. Moreover, it was not practical to uncover all walls and corners to check for the covered earthquake resistant measures and hence it was ignored when conducting the DVA.

Another very strange but important fact that came to notice during the SVA study was that almost all buildings had fundamental time period below 0.4 seconds, suggesting that the soil typology factor which comes into play after 0.4 seconds was not becoming a criteria for analysing such structures. This was probably due to the fact that all buildings were either single or double storied and hence of very short time period.

3.2.3 Geometric Checks

Geometric checks for ‘Openings in Bearing Walls’ as the bearing walls were the primary elements in resisting the lateral forces and IS4326:2013 mentions in details five limiting parameters for this condition to be within limits. It was identified that around 93.05% of the masonry buildings in seismic Zone IV were found failing this criteria whereas 93.54% of the masonry buildings in seismic zone V were found with this deficiency.

3.2.4 Non-Structural Appendages Checks

Clause 7.4.3 (c) of IS15988:2013 specifies the maximum allowable h/t ratio. Accordingly, the h/t ratio was calculated for parapets of all buildings where the unreinforced masonry parapet walls was found on site and this check was applied. It was found that around 19.45% of the masonry buildings in seismic Zone IV were having this deficiency, whereas 6.45% of the masonry buildings in seismic zone V were found with this deficiency. Some buildings did not have parapet walls. With regards to the Non-Structural elements, most small buildings that were remotely situated – Primary Health Centers and Community Health Centers and hence had very few medical equipment. Generally, only storage almirah, storage racks and overhead water tanks were noted in these buildings, whereas in larger sized buildings located in proper towns - few Community Health Centers and District Hospitals had Operation Theatre lights, sterilizing equipment, refrigerators, water coolers, invertors, X-Ray machine, anaesthesia machine, ultrasound machine, medical gas cylinders, split and window ACs, incubators, geysers, computers, printers and projector etc.

None of the buildings had any non-structural component fastened properly with a structural member. The unreinforced parapet walls were simply resting over the slabs and water tanks placed without stoppers/anchorage over the terrace tops. In event of earthquake, such loose non-structural items cause more damage due to their collapse / partial collapse. No medicine or equipment rack was found in a secured condition with any structural system.

4. Detailed Vulnerability Assessment (DVA)

Since all buildings were found to be failing in few of the checks made during SVA, it was decided to conduct the DVA of all the 134 masonry buildings. Hence, the methodology for conducting the DVA was devised as is shown in the flowchart under figure 3 below. Non-Destructive Testing and collection of masonry unit and mortar samples were collected. Limited pit excavation to get the details and depth of footing was carried out. Based on the depth of footing, geotechnical investigation was conducted to get soil properties at base of footing. During the testing, samples were collected which were later tested in laboratories to get the material properties. Thereafter, 3D models were created with as-built drawings generated during SVA and existing material properties were incorporated to get actual stress values.

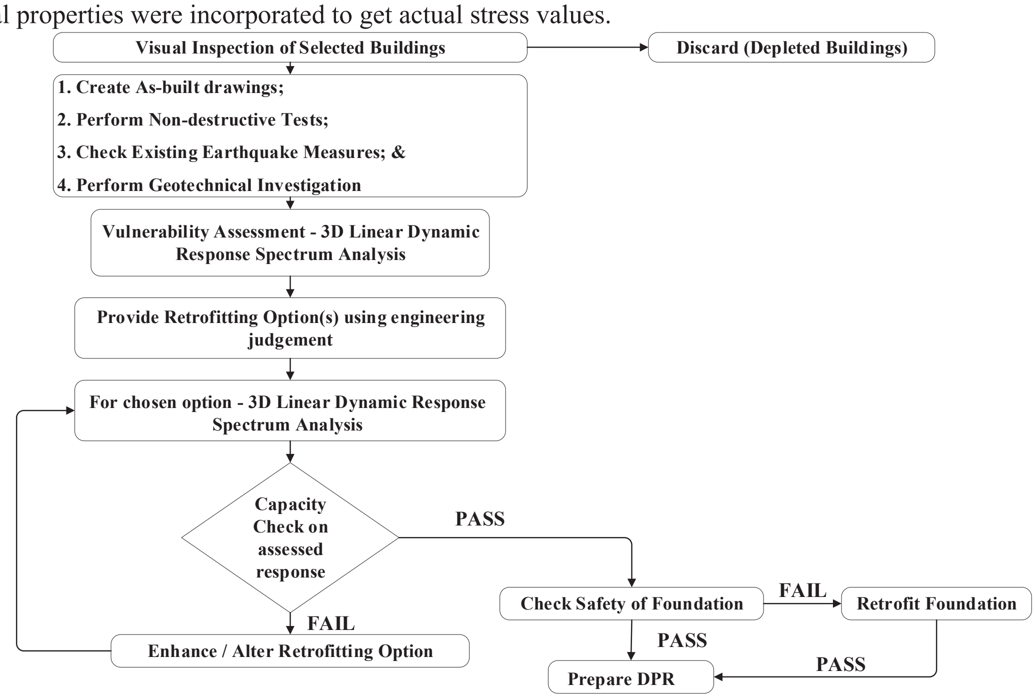

Figure 31: DVA Methodology Flowchart

4.1 Detailed DVA Methodology

To get existing material properties for accurate modelling, in-situ tests under two categories i.e. semi-destructive tests and non-destructive tests were performed. In semi-destructive tests, samples of masonry units and mortar were collected for each building. Minimum three to four samples were collected for each storey spanning across the entire floor in a random manner to get average material properties for every storey. Earthquake strengthening measures were identified as per IS 4326:2013. Under non-destructive tests, Rebound Hammer test as per IS 13311(Part 2):1992 and Ultra-sonic Pulse Velocity tests as per IS 13311(Part 1):1992 was carried out on concrete beams, slabs and lintel beams to get the grade and quality of concrete. Similarly, to check the safety of footing, trial pit was excavated at base of an external wall on outside of the building to get details such as type of footing, material of construction of footing and most importantly, the dimensions of the footing. Soil properties were obtained from Standard Penetration (IS 2131:1981) and Dynamic Cone Penetration test (IS 4968(Part 1):1976). The samples of the materials collected during the testing were then tested in laboratory to get existing material properties. Masonry Unit Samples were tested to obtain dimensions (as per IS 1077:1992), water absorption (as per IS 3495 (Part 2):1992) and compressive strength (as per IS 3495 (Part 1):1992). Mortar Samples were subjected to chemical analysis (as per ASTM C-1084-97) to get the mix ratio. Soil Samples were subjected to multiple tests to obtain various properties such as shear strength parameters of soil i.e. 'c' and 'Ø', liquid and plastic limit, density and specific gravity, etc. at the base of the footing.

Material Properties & Permissible Stress Parameters were calculated using the test results & relevant codes. Table 1 of IS 1905:1987 was used to get grade and compressive strength of mortar from mix ratio obtained from laboratory test results. Knowing the grade of mortar and compressive strength of masonry unit from laboratory test results, Table 8 of IS 1905:1987 was used to calculate the basic compressive stress of masonry. The permissible compressive stress of masonry was obtained by multiplying the basic Compressive Stress with three parameters, i.e. Stress Reduction Factor (Ks) obtained from Table 9 of IS 1905:1987 which further depends upon two parameters i.e. eccentricity of loading calculated as per Table A (Appendix A) and slenderness ratio that calculated as per clause 4.7 in IS 1905:1987, Area Reduction Factor (Ka) determined by Clause 5.4.1.2 of IS 1905:1987, and Shape Modification Factor (Kp) as per Clause 5.4.1.3 and Table 10 of IS 1905:1987 whereas, permissible flexural / tensile stress based on the grade of mortar is obtained from Clause 5.4.2 of IS 1905:1987. Permissible shear stress is calculated as per Clause 5.4.3 of IS 1905:1987 whereas Clause 7.9.2.1 in IS 1893 (Part 1):2016 is used to calculate the modulus of Elasticity 'E'.

Performance Level for masonry buildings was kept equivalent to Life Safety (LS). The parameters considered to achieve the Life Safety performance level were: Earthquake Force (as per IS 1893(Part 1):2016); Permissible Compressive, tensile and Shear Stresses (as calculated above); Limiting Drift (as per IS 1893(Part 1):2016). Commercial software ETABs was used to model and analyse all 134 masonry buildings. The material properties and footing details obtained from the trial pit during limited geotechnical investigation was incorporated in the model generated during SVA. Linear Response Spectrum Method i.e. Linear Dynamic Procedure as per IS 1893(Part 1):2016 was used to analyse the masonry buildings. Vulnerability assessment to identify failing / deficient members and their locations was done. Retrofitting options i.e. Splint-Bandage Technique and Jacketing with Stainless Steel / Galvanised wire mesh with minimum specifications as specified in IS 13935:2013 were considered for design of the retrofitting scheme. The retrofitting scheme was incorporated in the existing model and re-analysis done. The Analysis outcome was checked to be within permissible limits. If any parameter was found to be exceeding the corresponding permissible value obtained from the code, the retrofitting scheme was enhanced and incorporated in the model. This process was followed until all checking parameters were found to be within limits.

Once, the superstructure was found to be upgraded up to LS performance level, the strip footing was checked. If found deficient, the retrofitting in form of increasing the width of the strip footing was designed. For those buildings where the existing footing could not be retrofitted due to technical and cost limitations, buildings were declared as unfit for retrofitting. Finally, the detailed bill of quantities was generated as per Standard Schedule of Rates of Center and State. For items not mentioned in the respective schedules, rate analysis in prescribed format acceptable by the State of Uttarakhand was prepared and incorporated in the Bill of Quantities. However, for buildings found unfit for retrofitting, it was decided to prepare BOQ using the plinth area rate of new construction. All the above activities and findings of all tasks carried out under DVA including the preparation of detailed bill of quantities was compiled and Detailed Project Report (DPR) prepared for each masonry building for further tendering by the State.

4.2 DVA Outcome

The multiple tasks such as NDT and Geotechnical Investigation, Vulnerability Assessment of existing buildings and vulnerability assessment of retrofitted buildings under DVA revealed many findings.

4.2.1 NDT & Geotechnical Investigation Findings

Table 2 shows 7 different parameters which categories the masonry buildings. They were: (i) Masonry Wall construction material i.e. Brick / Stone / CC Blocks; (ii) Average compressive strength of masonry unit i.e. 7.5N/mm^2<Fm<10N/mm^2, 10N/mm^2<Fm<20N/mm^2 and Fm>40N/mm^2; (iii) Mortar Grade categorised as M1, M2 or H2; (iv) Construction material for strip footing was Brick / Stone / CC Blocks; (v) Range for width of footing i.e w<500mm, 500mm<w< 750mm and w>750mm; (vi) Rnage for depth of footing i.e. d<500mm, 500mm<d<750mm and d>750mm; and (vii) Safe Soil Bearing Capacity at base of strip footing i.e. SBC<50KN/m^2, 50KN/m^2<SBC<80KN/m^2 and SBC>80KN/m^2.

Table 2 - NDT & Geotechnical Investigation Findings

Criteria	**Seismic Zone IV**						**Seismic Zone V**					
	Single Storey			**Double Storey**			**Single Storey**			**Double Storey**		
Masonry Wall Material	57	8	6	7	3	2	19	19	1	7	5	-
Avg. Comp. Strength of Masonry Unit	8	55	8	3	7	3	1	19	19	0	5	6
Grade of Mortar	26	33	12	5	7	0	26	10	3	6	6	0
Strip Footing Construction Material	36	35	0	1	11	0	10	29	0	1	11	0
Width of Footing	7	28	36	1	3	8	4	22	13	3	3	6
Depth of Footing	4	29	40	1	5	6	22	9	7	7	2	2
Safe Bearing Capacity	23	38	10	1	8	3	14	14	11	2	4	6

4.2.2 Vulnerability Assessment of Existing Building Findings

Storey displacement check revealed that all single and double storey masonry buildings were well within the permissible limit of 0.4% as specified in IS 1893(part 1):2016. However, when check for the various stress criteria was applied, the results showed many buildings to be failing. Table 3 shows the number of buildings failing for different stress checks.

Table 3 - Findings of Vulnerability Assessment of Existing Building

Criteria	**Seismic Zone IV**				**Seismic Zone V**			
	Single Storey		**Double Storey**		**Single Storey**		**Double Storey**	
	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail
Compressive Stress Check (N/mm^2)	32	39	3	9	31	8	3	9
Out-of-Plane Flexural Stress Check (N/mm^2) (walls deform along Height)	31	40	2	10	13	26	2	10
Out-of-Plane Flexural Stress Check (N/mm^2) (walls deform along Length)	34	37	3	9	20	19	1	11
In-Plane Shear Stress Check (N/mm^2)	11	60	0	12	11	28	0	12
In-Plane Tensile / Compressive Stress Check (N/mm^2) (Overturning)	1	70	0	12	0	39	0	12

From Table 3 the compressive stress check revealed that 45.07% single storey buildings and 25% double storey buildings in seismic Zone IV passed whereas 79.49% single storey and 25% double storey buildings in seismic zone V passed. Tensile stress check, when the walls deformed along height revealed that 43.66% single storey buildings and 16.67% double storied buildings in seismic Zone IV passed and similar exercise in zone V revealed that for 33.33% single storey buildings and 16.67% double storied buildings the tensile stress was within allowable limits. Tensile Stress check, when walls deform along the length revealed that for 47.89% single storey buildings and 25% double storied buildings in seismic Zone IV, the tensile stress was within allowable limits whereas similarly study in zone V revealed that for 51.28% single storey buildings and 8.33% double storied buildings, the tensile stress was within allowable limits. In-plane shear stress check showed that 15.49% single storey buildings and no double storied buildings in seismic Zone IV were within allowable limits. The same exercise for zone V revealed that 28.21% single storey buildings and no double storied building passed. Stress check due to in-plane overturning action showed that 1.41% of single storey buildings and no double storied buildings in seismic Zone IV passed whereas, similar exercise for buildings in zone V showed that in both single storey and double storey buildings, the in-plane tensile / compressive stress was exceeding the allowable limit for all 100% buildings.

4.2.3 Vulnerability Assessment of Retrofitted Building outcomes

Mostly the superstructure of all masonry buildings were found fit after retrofitting. However, when the existing footing was checked for its capacity to safely transfer the all load combinations i.e. vertical loads and earthquake load combinations to the founding soil, it was found that since the depth of strip footing was not possible to be increased, hence, increase in load carrying capacity of the footing was attempted through retrofitting by increasing the width of the footing till maximum width allowable as per the relevant codal provision. Three criteria were obtained for footing checking: (i) Footing where no retrofitting was required i.e. they were passing in existing state; (ii) Footing that was failing but could be retrofitted to enhance their load carrying capacity and bring them in safe zone; and (iii) Footing which cannot be retrofitted i.e. even upon increasing the width of the footing to maximum width permissible, still it is incapable of transferring the loads safely to the founding soil.

Based on the above criteria, it was found that in single storey buildings in zone IV, 32.39% (23 out of 71) building footings were passing in existing state, 39.44% (28 out of 71) building footings were passing after retrofitting and 28.17% (20 out of 71) building footings were not fit even after retrofitting. In case of double storey buildings in zone IV, it was observed that 8.33% (1 out of 12) building footing passed after retrofitting whereas 91.67% (11 out of 12) building footing were not fit even after retrofitting and no building footing passed in existing state. Similarly, in Zone V in single storey buildings, 23.08% (9 out of 39) building footings were passing in existing state, 15.38% (6 out of 39) building footings passed after retrofitting and 61.54% (24 out of 39) building footings were not fit even after retrofitting whereas in case of double storey structures, 8.33% (1 out of 12) building footings passed in existing state, 8.33% (1 out of 12) building footings passed after retrofitting and 83.33% (10 out of 12) building footing pass even after retrofitting. Table 4 shows the above outcome.

Table 4 - Findings of Vulnerability Assessment of Retrofitted Buildings

Criteria	**Seismic Zone IV**						**Seismic Zone V**					
	Single Storey			**Double Storey**			**Single Storey**			**Double Storey**		
Footing specification *	23	20	28	0	11	1	9	24	6	1	10	1

* Note- Safe Footings / Footings found unsafe and cannot be retrofitted / Footings found unsafe but can be retrofitted (Pass / Fail / Pass with Retrofitting)

Further, the vulnerability assessment of retrofitted buildings revealed that the 134 masonry buildings could be grouped into three categories: (i) Buildings that only required retrofitting of the superstructure; (ii) Buildings that required retrofitting of superstructure and strip footing; and (iii) Buildings Unfit for Retrofitting. 33 masonry buildings fell under (i) categorywhereas 35 masonry buildings came under category (ii) and 66 out of the 134 masonry buildings were found unfit for retrofitting. Few common reasons observed

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for buildings found unfit for retrofitting were: (i) Low SBC at base of existing footing ([SBC<50KN/m^2] / [50KN/m^2<SBC<75KN/m^2] / [SBC>75KN/m^2]); (ii) Insufficient depth of footing ([Depth<500mm)] / [500mm<Depth<750mm] / [Depth>750mm]), sometimes as low as 300mm only; (iii) Insufficient width of footing ([Width<500mm] / [500mm<Width<750mm] / [Width>750mm]). Table 5 below depicts the percentage of buildings found unfit under various criteria.

Table 5: Percentage Buildings found unfit for retrofitting for various reasons

Criteria	% of Buildings	% of Buildings	% of Buildings
Low SBC	47%	33%	20%
Depth of Footing	18%	49%	33%
Width of Footing	48%	23%	29%

5. Implementation Approach

The State Government is engaged in various projects and schemes that are proposed for implementation of retrofitting of government buildings. The State has submitted a comprehensive Project of building retrofitting for multilateral funding to Government of India and Department of Economic Affairs is reviewing the Project. The State Government has approved funding from next financial year, the DPRs prepared in above project and will start execution soon as per their priority list.

The execution of the retrofitting works is planned in a phase wise manner and all districts will be taken up in parallel as per the damageability clasification of the buildings. Most of the buildings classified under G-5 category where the retrofitting cost is exceded as per retrofitting criteria will undergo demolition.

Simultaneously, the State Government is working to draft a retrofitting policy to promote this technology to common masses where subsidy provision is suggested. It is also working on risk transfer through insurance scheme designo n the basis of catastrophic risk modelling.

6. Challenges Faced and Opportunities

Many of the buildings were located in very difficult terrain which were only accessible on foot. Moreover, the local site conditions, extreme and harsh weather conditions, etc. delayed the normal course of the work and it took longer than usual for completion.

BOQ for masonry buildings saw the cost of retrofitting varying anywhere between 0.31 - 1.64 times the cost of new construction per unit area. Moreover the entire building would be rendered non-functional during the execution of the retrofitting. This would attract additional costs in terms of rental, shifting of activities in another building for interim functioning, re-shifting when building has been retrofitted, etc. Hence, maybe another option such as incremental seismic retrofitting where the retrofitting works are done in stages and where only portion of building is affected during the execution of the retrofitting works can be looked into.

7. Conclusion

68 out of the 134 buildings i.e. around 50.74% of the masonry buildings were found to be fit for retrofitting. The probable reason for this can be attributed to the fact that many buildings that were constructed in the last decade were not constructed as per codal provisions and the older buildings were non-engineered. However, this study was carried out on a small sample size of 134 buildings. A larger sample size of masonry buildings of multiple departments needs to be considered along with Cost Benefit Analysis of the retrfoitting schemes. This willl support in taking policy decision in carrying forward the safe and resilient infrastrutcure and operation mandate in earthquake región. Along with mitigation planning, there is dire need for creating supporting policy environment and adequate skills and knowledge in development departments.

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