Damage assessment of recent Indian earthquakes: review of existing rapid visual screening schemes

Pranab Kumar Das, Sekhar Chandra Dutta* and Piyali Sengupta

Department of Civil Engineering, Indian Institute of Technology, Dhanbad 826 004, India

To comprehend the seismic vulnerability of a particular region, seismic damage assessment of a large number of buildings needs to be conducted. However, a realistic representation of structural damage can only be obtained through post-earthquake field observations and reconnaissance survey reports. Post-earthquake damage survey reports for Nepal (Gorkha) earthquake (2015) and Imphal (India) earthquake (2016) presented in this study are utilized to give an overall idea about the nature of seismic damage prevalent for the widespread civil engineering infrastructural developments in the particular geographical regions. Further, the study applies the existing rapid visual screening (RVS) schemes for predicting seismic vulnerability of the structures to judge the sanctity of the schemes. An extensive state-of-the-art review of the existing RVS schemes reported in the literature is presented. A comparative study exhibiting the efficacy of the existing RVS schemes is conducted on the basis of damage survey reports obtained from the Nepal and Imphal earthquakes. Finally, a modified RVS scheme is proposed here for seismic damage assessment of masonry and low-rise reinforced concrete buildings located in hilly regions of the Indian subcontinent and other developing countries. Excerpts from the study can be useful for researchers and practising engineers to perform seismic damage assessment of buildings using the proposed RVS scheme.

Keywords: Buildings, damage assessment, rapid visual screening, reconnaissance, seismic vulnerability.

RAPID visual screening (RVS) provides pre-awareness about the possibility of damage from earthquakes. This process can be performed by a non-technical person after short-term training in relatively less time. The Nepal (Gorkha) earthquake (2015) resulted in devastating consequences in the country, with complete or partial destruction of a large number of buildings. The Imphal earthquake (2016) in Manipur, India, had caused enormous economical as well as structural damage. Both places are located at the foothills of the Himalaya within the high seismicity zones (Figure 1). Further, the socio-economic conditions and nature of habitats are similar in both locations, with the two places being populated primarily by people from low to medium income background. During the earthquakes, a large number of reinforced concrete (RC), unreinforced brick masonry and non-engineered structures were damaged. Several recently constructed buildings were also heavily damaged, even though they were located far away from the epicentre. The newly constructed buildings should have suffered minor damage if adequate earthquake-resistant design and construction procedures were followed for them. However, the level of damage observed was not minor.

A few enlightening studies in Tripura, North East India highlight all geological features of the earthquakes along with providing useful information about structural damage[1–4]. Such observations underline the requirement of a quick vulnerability assessment methodology in tune with geological features and nature of the structures. Unreinforced masonry buildings were severely damaged in this region, in addition to severe damage in some mud houses. A previous study attempted to arrive at some RVS schemes applicable for mud houses[5].

The present study examines the efficacy of the existing RVS methodologies for structures of the Indian subcontinent and other developing countries. A thorough study has been carried out to verify the applicability of the existing RVS schemes proposed by different codal standards[6–8] and researchers[9–15] for structures located in the Indian subcontinent or other developing countries. Also, an effort is made to validate the existing RVS strategies compatible with the Indian subcontinent[5,6,16–24]. Few studies performed are based on reconnaissance survey of damaged structures at various places due to natural hazards[15,25–30]. Two reconnaissance-based surveys of damaged buildings during the Nepal earthquake 2015 and Imphal earthquake 2016 were jointly considered to compare the performance of different existing RVS methodologies, as both places have similar socio-economic conditions and other similarities. Further, we propose a modified RVS scheme for certain categories of buildings, for which existing schemes do not perform satisfactorily. Figure 2 shows several damaged RC frame buildings and unreinforced brick masonry buildings. The vulnerability assessment covers basically RC and unreinforced brick masonry structures.

*For correspondence. (e-mail: sekhar@iitism.ac.in)

Figure 1. Geographical location of Nepal and Imphal (source: ref. 65).

A modified RVS scheme for the Indian subcontinent and other developing countries is also proposed here for implementation. Before discussing the RVS scheme application, its validation and fine-tuning with a brief reconnaissance-based damage surveys for Nepal and Imphal earthquakes are presented for better understanding. Later, such damage features are related to prediction through the scheme for region- and habitat-specific tuning of RVS.

The Nepal (Gorkha) earthquake occurred at 11:56 am Nepal Standard Time (NST) on 25 April 2015, with a magnitude of 7.8 on the Richter scale (Figure 1). The epicentre of the earthquake was in Lamjung district and its hypocentre was at a shallow depth of approximately 15 km. Imphal (Manipur, India) earthquake occurred on 4 January 2016 at 4:35 am local time with magnitude 6.7 on the Richter scale (Figure 1). The epicentre of the earthquake was located at Tamenglong district, Manipur, with shallow focal depth of 17 km.

Existing rapid visual screening methodologies

Several RVS methodologies have been proposed by various codes, handbooks and the literature till date. The procedures for conducting reconnaissance survey of damaged buildings have been illustrated so as to determine the scoring of damaged structures based on empirical quantification of predicted vulnerabilities. RVS procedures can be applied to structures made of RC, brick masonry or other non-engineered materials. However, while determining the scores of the damaged buildings, there methodologies could not adequately represent the damage scenario of all building types. In this study, a modified RVS scheme is implemented, which may predict the damage of RC and brick masonry structures more reasonably. Before describing such an approach, a brief discussion on the literature in this field is made here for the convenience of understanding.

Rainer *et al.*[16] proposed data collection and score calculation as a form of seismic screening procedure following the National Building Code (NBC) of Canada[31], which incorporates several categories of structures according to the materials used and structural configurations. The scoring system referred as seismic priority index (SPI), is a combination of structural index (SI) and non-structural index (NSI). SI and NSI can be expressed as follows

$$\mathrm{SI} = \mathrm{A.\ B.\ C.\ D.\ E}, \tag{1}$$

$$\mathrm{NSI} = \mathrm{B.\ E.\ F}, \tag{2}$$

where A is the seismicity, B the soil conditions, C the type of structure, D the type of irregularity, E the importance level of buildings and F the maximum falling hazards to life or vital operation. SPI value less than 10 is considered as low priority, where values between 10 and 20 indicate medium priority and those more than 20 as highly vulnerable. If SPI increases to more than 30, then it is categorized as potentially hazardous.

The evaluation process of Japan Building Disaster Prevention Association (JBDPA)[17] consists of calculation of seismic index of structure I_S and index of non-structural element I_N. Equations (3) and (4) are used for calculating I_S and I_N respectively.

$$I_S = E_O.\ S_D.\ T, \tag{3}$$

$$I_N = 1 - B.\ H, \tag{4}$$

where E_O is the basic seismic index of the structure, S_D the irregularity index, T the time index and B and H are indices of construction and human risk respectively, according to their consideration.

In FEMA 154, RVS procedure and data collection sheets are separately available for high, moderate and low seismicity regions[6]. Structural scores (or final scores) are classified into three categories: low (L), medium (M) and high (H). Final score ranges from 0 to 7. Higher score corresponds to better seismic performance.

Arya and Agarwal[18] proposed a RVS procedure for buildings located in the Indian seismic zones II–V. It followed the European Micro Seismic (EMS-98) standard[32] and divided structures into six different categories, namely types A–F. Type A structures are maximum vulnerable, whereas type F structures are minimum vulnerable. In fact, some other intermediate types of structures are also mentioned as A, B, B$^+$, etc. RC buildings were classified into six groups, viz. C, C$^+$, D, E, E$^+$ and F. Grade of damage of buildings was classified into five categories, viz. grades 1–5. Earthquake master plan for Istanbul guidelines[19] was prepared by two groups, namely Istanbul Technical University-Middle East Technical University (ITU-METU) and Bogaziçi University-Yildiz Technical University (BU-YTU). The number of storeys, configured as soft storey, existence of heavy overhangs, apparent quality of structure and materials, topographical nature, properties of soil, presence of short columns and pounding effect were the parameters considered in this process. Using these vulnerability parameters, performance score (PS) was calculated using eq. (5).

$$\text{PS} = (\text{Initial score}) - \sum (\text{Vulnerability parameter}) \times (\text{Vulnerability score}). \tag{5}$$

According to Sinha and Goyel[20], buildings are divided into four major categories according to the materials used, namely RC, masonry, steel and timber-made structures. Vulnerability is further divided into six different parameters according to EMS-98 (ref. 32). Damage classification for RC and masonry buildings are divided into five grades according to the RVS score. The guidelines of New Zealand Society for Earthquake Engineering (NZSEE)[21] had followed the New Building Standard of New Zealand to evaluate the seismic performance of structures. It included factors like fault, scaling, hazard, return period, ductility, structural performance, site characteristics, earthquake risk and type of irregularity to calculate performance achievement ratio (PAR). Sucuoglu *et al.*[22] performed multiple linear regression analysis for 3–6 storied ordinary RC buildings based on 1999 Duzce earthquake data. It proposed expected performance score (EPS), which depends on the presence of soft story, apparent building quality and heavy overhang. *Handbook of the Central Public Works Department and Indian Building Congress*[23] had followed the study of Arya and Agarwal[18]. It classified masonry buildings into seven categories, viz. A, A$^+$, B, B$^+$, C, C$^+$ and D. The state of damage of masonry buildings was classified into five grades as mentioned in table 9 of IS 13935 (ref. 30). Jain *et al.*[24] focused on RC structures and performed regression analysis based on Bhuj earthquake damage data. They proposed a numerical equation for predicting expected performance score (EPS) of a structure as follows

$$\text{EPS} = 85 + 10x_0 + 10x_1 - 20x_2 - 10x_4 - 10x_5 - 10x_7, \tag{6}$$

where x_0 to x_7 are various vulnerability parameters, viz. basement, number of storeys, level of maintenance, staircase asymmetry with respect to plan, re-entrant corners, open storey, and stub columns and short columns respectively.

Mukhopadhyay *et al.*[5] studied semi- and non-engineered structures. As the study was based in the Indian subcontinent, other developing countries with similar seismic regions may adopt the methodology with suitable modifications. FEMA 154-P additionally differentiated the regions as very high, high, moderately high, moderate and low seismicity[7]. The screening procedure was divided into level 1 and level 2 (optional) parts. Some studies have also reported RVS methodologies according to different locations[33–46]. Few studies also included brick masonry structures[47–49] and wooden structures[50,51].

We present various existing propositions for RVS schemes as prescribed in several documents and guidelines. Since these schemes are from different countries having different structural constructions, the present study explores the extent of applicability of such schemes to predict the damage scenario as observed in the recent Nepal and Imphal earthquakes. Modifications are suggested to such RVS methodologies to refine the procedure for predicting seismic damage with reasonable accuracy in hilly regions of the Indian subcontinent and countries with similar socio-economic and geological conditions.

Reconnaissance survey after the Nepal earthquake 2015 and Imphal earthquake 2016

We made two reconnaissance-based surveys after the Nepal earthquake (2015) and Imphal earthquake (2016).

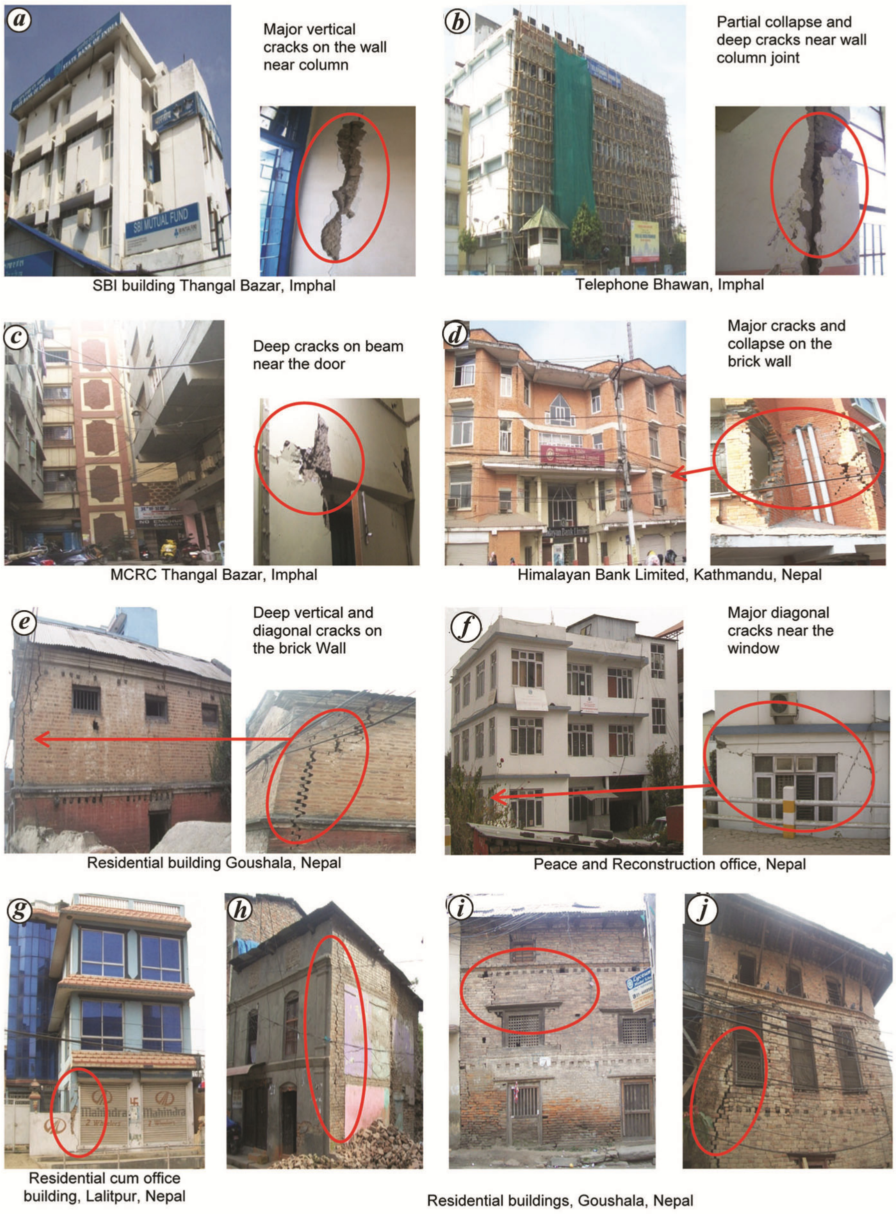

Figure 2 *a–j*. Damaged buildings during the Nepal earthquake 2015 and Imphal earthquake 2016.

During the surveys, many damaged structures having different damage patterns were observed closely. Examples are presented in Figure 2 for visualizing the actual vulnerabilities of some chosen damaged buildings during the earthquake. This also helps in the validation of the proposed methodology. These observed damages are correlated to the level of damage predicted by various schemes to evaluate the efficacy of the schemes.

Damage observed on various types of buildings in Nepal and Imphal

Some important buildings like the State Bank of India (SBI) office building (Figure 2 *a*), Telephone Bhawan (Figure 2 *b*) and Medical Care and Research Center (MCRC) (Figure 2 *c*) in Imphal and Peace and Reconstruction office of Kathmandu in Nepal (Figure 2 *f*) are multi-storied RC buildings with brick masonry infill walls and staircase not placed at the middle with respect to the building plan, except MCRC. Some portion of the ground floor of Telephone Bhawan was used for parking purpose. Damage occurred at every storey level. Moderate to major vertical, horizontal and inclined cracks were found throughout the buildings. Other multi-storey RC buildings work for residential, official and temple religious purposes in Nepal and Imphal were observed to have moderate to major cracks. A large number of brick masonry buildings were found in Nepal and Imphal. Masonry structures like the Himalayan Bank Limited of

Kathmandu (Figure 2 *d*) and several residential buildings in Goushala, Nepal (Figure 2 *e*, *h*, *i*, *j*), were heavily damaged. During the survey in Imphal, we found that some non-engineered buildings were also damaged.

Nature and analysis of damage

In cases of damaged buildings during the recent earthquakes in the Indian subcontinent are due to inadequate design, lack of adequate construction and maintenance. On the other hand, plan asymmetry due to functional reasons or sometimes due to eccentric placement of staircase or elevated water tank results in early failure due to stress concentration. Similarly, irregular geometry is found to be a primary cause of failure in some cases for both places.

The major reason for failure of brick masonry buildings during the Nepal earthquake appears to be failure of joint between two perpendicular walls followed by out of plane collapse of one wall. Low-cost remedial measures for such failure have been documented in the recent literature[49]. The literature and a few case studies may be referred for remedial measures[48,52–63].

Comparison of different rapid visual screening schemes based on the Nepal and Imphal earthquakes reconnaissance surveys

After completion of reconnaissance surveys of damaged structures during the Nepal and Imphal earthquakes, RVS scores were estimated using the existing methodologies[5,6,16–24]. Table 1 shows basic scores and score modifier by various methodologies, while Table 2 shows scores calculated for damaged buildings. Predicted damages are presented for each type of structure with various existing methodologies and the proposed modified methodology and compared with observed actual damage during field visit. In case of comparison of RC buildings (Table 2), the methods proposed by Rainer *et al.*[16] and Sucuoglu *et al.*[22] provided about 59% accurate results. On the other hand, some other methods have given 47% good results[18,20,23]. Jain *et al.*[24] reported 35% accuracy with actual observed assessment during field visit, whereas others reported 12% accuracy[6,21]. Further, for unreinforced brick masonry buildings (Table 2), some studies provided 18% proficiency[5,16,21]. While others provided 29% accuracy[6,23], Sinha and Goyel[20] reported 42% accuracy in the assessments compared to actual damage observed. The scheme proposed by Mukhopadhyay and Dutta[5] for non-engineered structures is acceptable for observed damaged buildings during reconnaissance surveys. In fact, this is presented on the basis of observations and application of these methodologies on about 40 buildings, including all categories.

Proposed modified rapid visual screening methodology and implementation for the Indian subcontinent

After thorough comparison of the scores obtained by various methods and their implications, it was observed that the existing RVS methodologies do not predict seismic vulnerability of existing buildings located in the Indian subcontinent in a realistic manner. The damage indicated by existing procedures and actual observed damage do not match in most of the cases. Previous methods did not provide correct prediction for RC structures as well as for unreinforced brick masonry structures. The RVS methodology for non-engineered structures proposed by Mukhopadhyay *et al.*[5] provided reasonably good prediction for the particular case.

In the present study, a modified RVS data collection sheet has been proposed (Table 3), following the RVS methodology proposed in FEMA 154 (ref. 6). In the proposed format, buildings are classified in two columns – one is RC framed structure with masonry infill wall and RC roof slab (RCFM), and the other is unreinforced brick masonry structure with RC roof for ground storey and asbestos, tiles, galvanized iron sheet or RC slab for upper storey (UBMS). These parameters and sub-parameters are selected from the literature[5,6,16,22]. The grades considered correspond to final score and have been developed using the existing methodologies[5,6,16,18,20–22,24]. The modifications considered are briefly discussed below.

Basic scores for each type of building

The BS values had increased for both types of structures, namely RC framed structure with masonry infill (RCFM) and unreinforced brick masonry structure (UBMS) compared to FEMA-154 (ref. 6). In fact, the basic qualities of structures in the affected regions were inferior as implicated by FEMA-154 and thus most of the structures had negative scores, finally if BS of FEMA-154 was considered. FEMA-154 is based on the consideration of very high seismicity as located in the United States. On the other hand, the India subcontinent experiences minor to moderate earthquakes, where common mistakes are the reason of failure of structures in most cases. Therefore, BS is considered 3.5 for RCFM and 3.2 for UBMS, compared to 1.6 and 1.8 respectively, in FEMA-154 (ref. 6).

BS modifying score for storey height

Scores are also included for storey number (single, double and multi-storey), as indicated in a recent study[5]. Vulnerability increases with increase in storey height. So the scores are negatively reduced as storey height increases. For a single storey, the scores are taken as positive for UBMS and zero for RCFM, as the structure of a

Table 1. Comparison of rapid visual screening (RVS) schemes using various-existing methodologies

FEMA 154 (ref. 6)	Rainer *et al.*[16]	JBDPA[17]	Arya and Agarwal[18]; CPWD and IBC Handbook[23]	BU-ITU-METU-YTU[19]
Basic score/structure index/performance score				
Structural score the combination of basic score (BS) and several modifiers. BS = 1.6 for reinforced concrete (RC) structure and BS = 1.8 for unreinforced masonry structure.	Seismic priority index (SPI) = Structural index (SI) + Non-structural index (NSI) = (A. B. C. D. E) + (B. E. F)	Seismic index of structure $I_S = (E_O.S_D.T)$ + Index of non-structural element I_N $(1 - B.H)$	Buildings are divided into six categories (C, C^+, D, E, E^+ and F).	Performance score (PS) = (Initial score) – ∑(Vulnerability parameter) × (Vulnerability score)
Score modifier/influence factor				
Number of stories, vertical irregularity, plan irregularity, soil type.	A, Seismicity; B, Soil conditions; C, Type of structure; D, Type of irregularity; E, Importance level of buildings; F, Maximum falling hazards to life or vital operation.	E_O, Basic seismic index of the structure; S_D, Irregularity index; T, Time index; B and H are indices of construction and human risk respectively, according to their consideration.	Damageability grades of buildings are divided into grades 1–5 depending upon the nature and location of cracks, buckling of reinforced rods and quantity of collapse.	Soft storey, heavy overhangs, apparent quality of structure, short columns, pounding effect and topography effect.
Sinha and Goyel[20]	NZSEE[21]	Sucuoglu *et al.*[22]	Jain *et al.*[24]	Mukhopadhyay and Dutta[5]
Basic score/structure index/performance score				
According to the materials used, buildings are classified into four categories, viz. RC, masonry, steel and timber structures.	Performance achievement ratio (PAR) is estimated considering several factors.	Expected performance score (EPS) is based on various factors.	$EPS = 85 + 10x_0 + 10x_1 - 20x_2 - 10x_4 - 10x_5 - 10x_7$	Structural score is a combination of BS and several modifiers. BS = 1.6 for unreinforced masonry structure.
Score modifier/influence factor				
Vulnerability class is divided as: most likely vulnerability class, most likely lower range and most likely upper range. Nature of damage to RC and masonry buildings is classified into five steps (grades 1–5)	Scaling factor of near fault, seismic hazard, return period, ductility, structural performance, earthquake risk, plan irregularity, vertical irregularity, short columns, pounding potential, site characteristics and other factors.	Presence of soft storey, heavy overhangs and apparent building quality of the structures.	Vulnerability parameters considered: x_0 = basement; x_1 = number of storeys; x_2 = level of maintenance; x_3 = staircase asymmetry with respect to plan; x_4 = re-entrant corners; x_5 = open storey; x_6 = stub columns; x_7 = short columns.	Number of storeys, vertical irregularity, plan irregularity, wall length between two cross-walls, ratio of wall opening length to wall length, ratio of wall height to wall width and soil type.

Table 2. Comparison of RVS score and damage grade using various existing methodologies, proposed modified RVS scheme and actual visual assessment of damaged structures

Reference	Figure	2 *a*	2 *b*	2 *c*	2 *d*	2 *e*	2 *f*	2 *g*	2 *h*	2 *i*	2 *j*
FEMA 154 (ref. 6)	RVS score (*S*)	0.7	1.4	1.2	0.9	1.4	0.7	1.1	1.4	0.9	0.9
	Grade of damage	High	High	High	High	High	High	High	High	High	High
Rainer *et al.*[16]	RVS score (*S*)	15	14	14	25.6	6.55	4.5	4.5	6.55	17.7	17.7
	Grade of damage	Moderate	Moderate	Moderate	Heavy	Slight	Slight	Slight	Slight	Moderate	Moderate
JBDPA[17]	RVS score (*S*)	1.51	2.18	1.51	–	–	0.84	0.84	–	–	–
Arya and Agarwal[18], CPWD and IBC Handbook[23]	Grade of damage	Heavy	Heavy	Very heavy	Very heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy
BU-ITU-METU-YTU[19]	RVS score (*S*)	125	90	125	85	135	160	160	135	92	92
Sinha and Goyel[20]	RVS score (*S*)	0.7–2	0.7–2	0.3–0.7	0.3–0.7	0.7–2	0.7–2	0.7–2	0.7–2	0.7–2	0.7–2
	Grade of damage	Heavy	Heavy	Very heavy	Very heavy	Heavy	Heavy	Heavy	Heavy	Heavy	Heavy
NZSEE[21]	RVS score (*S*)	23	21	23	40	26	24	22	26	33	33
	Grade of damage	High	High	High	Very high	Very high	High	High	Very high	Very high	Very high
Sucuoglu *et al.*[22]	RVS score (*S*)	88.4	86.8	88.4	–	–	88.7	88.7	–	–	–
	Grade of damage	Light	Light	Light	–	–	Light	Light	–	–	–
Jain *et al.*[24]	RVS score (*S*)	65	65	55	–	–	75	75	–	–	–
	Grade of damage	Moderate	Moderate	Moderate	–	–	Moderate	Moderate	–	–	–
Mukhopadhyay and Dutta[5]	RVS score (*S*)	–	–	–	–0.3	0.9	–	–	0.9	0.2	0.2
	Grade of damage	–	–	–	Destruction	Very heavy	–	–	Very heavy	Very heavy	Very heavy
Proposed modified RVS scheme	RVS score (*S*)	2.4	1.3	2.8	1.0	2.	2.4	2.6	2.8	2.4	1.9
	Grade of damage	Moderate	Heavy	Moderate	Very heavy	Moderate	Moderate	Moderate	Moderate	Moderate	Heavy
Actual assessment of damage during reconnaissance survey by authors	Moderate	Heavy	Moderate	Very heavy	Moderate	Moderate	Moderate	Moderate	Moderate	Heavy	

Table 3. RVS data collection sheet for structure in the Indian subcontinent

		Year built:		
		Building owner's name:		
		Address:		
		Pincode:		
		Other identifiers:		
		Overall dimensions:		
		Total floor area:		
		Geological hazard: Land slide/liquefaction		
		Screener:		
		Date of screening:		
Plan/elevation/photograph		Soil type: Stiff	Medium	Soft
Occupancy				
Residential/educational/government/		Falling hazard		
assembly/commercial/historical		Chimney	Parapet	
industrial/storage/hazardous		Cladding	Others	
Building type		RCFM	UBMS	
Basic score		3.5	3.2	
Parameter	Sub-parameters	BS modifying score		
Storey	Single	+0.0	+0.1	
	Double	–0.2	–0.1	
	3–5	–0.3	–0.5	
	> 5	–0.5	n/a	
Vertical irregularity	No/negligible	+0.2	+0.2	
	Moderate	–0.2	–0.5	
	Severe	–1.0	–1.0	
Plan irregularity	No/negligible	+0.2	+0.2	
	Moderate	–0.3	–0.5	
	Severe	–0.5	–0.8	
Open storey	Yes	–1.0	n/a	
	No	+0.2	n/a	
Basement	Absent	+0.0	+0.0	
	Present	+0.5	+0.5	
Staircase	Symmetry	+0.0	+0.0	
	Asymmetry	–0.3	–0.3	
Soil type	Hard/stiff	–0.4	–0.4	
	Medium	–0.6	–0.6	
	Soft	–1.0	–1.0	
Final score (S)				
Grading of damaged structures according to final score		Any other information		
$S > 3$	Slight damage	Grade I		
$2 < S \leq 3$	Moderate damage	Grade II		
$1 < S \leq 2$	Heavy damage	Grade III		
$0 < S \leq 1$	Very heavy damage	Grade IV		
$S \leq 0$	Destruction	Grade V		

*RCFM, Reinforced concrete framed structure with masonry infill. **UBMS, Unreinforced brick masonry structure.

single storey is less vulnerable compared to a multistoried building.

BS modifying score according to irregularity

Introducing irregularities in scoring is one of the major features for assessing vulnerability of a structure located in any region. Additionally, the domestic structures are often constructed without following a proper planning and design. Therefore, negative scores increase with increase in plan irregularity and vertical irregularity. In case of regular buildings (in plan or vertical height), the scores are considered as positive. In fact, such a proposition is supported by a recent study on irregular structures[64].

BS modifying score having open storey, basement and staircase

For open storey, the score is taken as negative as it increases the limit or risk of damage in structures during seismic excitation (specially for RCFM); such cases are frequent and dangerously introduced for utilization of ground space in urban areas of the Indian subcontinents. On the other hand, presence of basement makes the structures more stable; therefore positive values are considered. If the staircase is not located symmetrically in the plan of the structure, it will also make the structure vulnerable. So negative values are attributed for this type of situation.

Table 4. Detailed calculation of final scores of observed buildings using the proposed modified RVS scheme

Proposed modified RVS scheme		Figure 2 *a*	Figure 2 *b*	Figure 2 *c*	Figure 2 *d*	Figure 2 *e*	Figure 2 *f*	Figure 2 *g*	Figure 2 *h*	Figure 2 *i*	Figure 2 *j*
Building type		RCFM	RCFM	RCFM	UBMS	UBMS	RCFM	RCFM	UBMS	UBMS	UBMS
Basic score		3.5	3.5	3.5	3.2	3.2	3.5	3.5	3.2	3.2	3.2
Storey	Single										
	Double					–0.1			–0.1		
	3–5	–0.3	–0.3		–0.5		–0.3	–0.3		–0.5	–0.5
	> 5			–0.5							
Vertical irregularity	No/negligible	+0.2				+0.2	+0.2	+0.2	+0.2	+0.2	+0.2
	Moderate		–0.2		–0.5						
	Severe										
Plan irregularity	No/negligible		+0.2	+0.2		+0.2			+0.2	+0.2	
	Moderate	–0.3						–0.3			–0.3
	Severe				–0.8		–0.5				
Open storey	Yes		–1.0								
	No	+0.2		+0.2	n/a	n/a	+0.2	+0.2	n/a	n/a	n/a
Basement	Absent	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0	+0.0
	Present										
Staircase	Symmetry			+0.0	+0.0						
	Asymmetry	–0.3	–0.3			–0.3	–0.3	–0.3	–0.3	–0.3	–0.3
Soil type	Hard/stiff				–0.4	–0.4	–0.4	–0.4	–0.4	–0.4	–0.4
	Medium	–0.6	–0.6	–0.6							
	Soft										
Final score (S)		2.4	1.3	2.8	1.0	2.8	2.4	2.6	2.8	2.4	1.9
Grading of damage		II Moderate	III Heavy	II Moderate	IV Very heavy	II Moderate	II Moderate	II Moderate	II Moderate	II Moderate	III Heavy

BS modifying score for soil parameter

Soil parameters are considered into three categories, viz. hard or stiff, medium and soft in nature. These types of soil are available in the Indian subcontinent. The values are considered from the existing RVS methodologies[5,6].

Damage grade according to final score

Grades of damage is provided in relation to calculated final score (S) of the structure. In the present study, these grades of damage assessment are divided into following five categories. Grade I ($S > 3$, slight damage): It refers to a structure with few hairline cracks and slight loosening of building materials. Grade II ($2 < S \leq 3$, moderate damage): It refers to moderate cracks on load-bearing wall and minor cracks on structural elements. Grade III ($1 < S \leq 2$, heavy damage): It refers to major cracks on load-bearing wall and moderate to major cracks on structural elements. Grade IV ($0 < S \leq 1$, very heavy damage): It refers to major or deep cracks on load-bearing wall and structural elements, and partial damage in the structure. Grade V ($S \leq 0$, destruction): It refers to a portion or complete collapse of the structure, which cannot be retrofitted.

Rapid visual screening is an empirical method developed by co-relating the nature of damage observed during various earthquakes with physically understood positive or negative features of structures. For instance, the nature of basic framing action offers primary resistance to seismic force. On the other hand, asymmetry and irregularity result in local stress concentration causing damage propagation leading to early failure. Similarly, other effects are considered. Nature of joints between two walls for unreinforced brick masonry building regulates the nature of vulnerability, as junction failure followed by out-of-plane collapse of one wall is frequently observed. Such physical effects about which the idea of seismic engineers is qualitative measures are co-related to the feature of damage.

The basic score or structure index or performance score reflects basic seismic resistance depending on the structural framing system adopted. On the other hand, score modifiers attribute the influence of various other characteristics. Obviously, as discussed earlier, these modifiers vary for different methodologies. Table 1 gives a schematic idea about consideration of such parameters in various methods.

The process of grading in this study is broadly based on the existing literature[5,6,16,18,20,21,23,24]. The proposed values of BS and BS modifying scores as suggested in the literature are compared in Table 1 to understand their range and nature in different locations within different socio-technical conditions.

The final score is an algebraic summation of BS and modifiers. To explain the methodology more clearly, the score calculation and damage prediction of ten buildings by various methods are presented in Table 2, while Table 4 detailed scores presents calculations using the proposed method. This includes the numerical calculation of scores for five reinforced concrete and five unreinforced brick masonry buildings. On the other hand, Table 2 presents comparison of performance of the present method with those of ten buildings in the limited scope of the study. Table 4 exhibits consistently reasonable performance by the proposed method. The results for a number of buildings though worked out are not presented here.

Concluding remarks

Post-earthquake reconnaissance-based damage assessment is one of the most effective ways of learning for researchers and practising engineers about seismic behaviour of buildings. RVS is a simple and economical method for seismic damage prediction, which requires neither much of technical expertise nor time. In this study, post-earthquake reconnaissance surveys are presented following the Nepal earthquake (2015) and Imphal earthquake (2016). Damage identification and corresponding analysis of buildings may prove useful for earthquake engineers.

The documentation of a brief reconnaissance survey highlighting the features of damage has been one of the primary objectives of the present study. Thereafter, a comprehensive synopsis of the existing RVS schemes is presented so as to provide a better understanding among the readers about the existing methodologies. A comparative study of the RVS scores deduced from different methodologies reported in the literature is conducted on the basis of actual damages observed during the Nepal earthquake (2015) and Imphal earthquake (2016). Considering the discrepancies observed between predicted and observed damages, a modified RVS methodology is proposed for the Indian subcontinent and other developing countries.

The performance of existing schemes is adjusted from examples of damages, and few modifications over the existing schemes are proposed which may be more suitable for locations with similar socio-economic conditions, nature of geology and local technology used for habitats as in the affected regions.

The proposed modifications are found to be suitable with respect to the observed seismic damage patterns for various types of masonry and RC buildings. Therefore, this methodology is effective in predicting the nature of seismic vulnerabilities of various types of buildings, if required along with the other methodologies as well. Additionally, this study may enable pre-earthquake vulnerability assessment of structures. The methodology may help arrive at adequate retrofitting and strengthening strategies for such localities as suggested in the literature.

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