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Review Article

Rapid visual screening vulnerability assessment method of buildings: a review

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Abstract
Seismic vulnerability assessment of any building is done to evaluate the expected damage from future earthquakes. The vulnerability assessment is a time-consuming procedure and difficult as well. Rapid visual screening (RVS) method is a quick and efficient process to identify and rank the buildings. This study describes and compares the outcome of previous researches on conventional RVS methods. This paper summarizes the comparative study among various RVS methods used around the world. Methods have been evolved on the basis of prevalent geographical conditions The various methods for RVS have different scoring patterns. The method differs with different parameters such as load path, no. of stories, weak stories, torsion, pounding effects etc. The comparison chart is drawn for the damageability scales of different countries. The limitations and advantages of various RVS methods have also been discussed. The review of the traditional method can help in the derivation of new techniques in the field of vulnerability study using fuzzy logic and artificial intelligence.

Keywords
Vulnerability, Rapid visual screening methods, Damageability, PERA.

1.Introduction
Earthquake disasters have caused a drastic rise in the loss of human life and properties in the past few decades [1]. Developing countries lack good urban planning and construction technology due to improper legislation and inadequate funding [2]. Such developments have resulted in the poor and unexpected behaviour of buildings during the earthquake, resulting in extensive damage and, in some cases building collapse. The seismic vulnerability is the number of buildings that are susceptible to being damaged by seismic ground motion [3−5]. The main goal of the assessment of seismic vulnerability is to determine the probable damage to be incurred on the structure due to earthquake. Evaluation of the risk of the damage and potential of loss of future earthquakes is equally vital in reducing earthquakes [6]. In the Tohoku earthquake of the year 2011 more than 15,000 people were injured, and 120,000 buildings were demolished [7, 8]. The Haiti earthquake of the year 2010 resulted in the death of more than 60,000 people, and at least 280,000 buildings collapsed [9].

Earthquake damage to buildings in developing countries around the world has prompted researchers to assess the seismic vulnerability of existing large stocks [10].

The Kashmir earthquake of the year 2005 led to the casualty of about 1,500 people and the collapse of more than 400,000 buildings [10, 11]. The Bhuj earthquake that occurred in the year 2001 resulted in more than 13,000 fatalities and the destruction of more than 200,000 buildings [6, 10]. The financial losses of the Van earthquake of the year 2011 in Turkey and the Sikkim earthquake in India were $2.2 billion and $ 1.7 billion, respectively [10]. As observed in the past, earthquake creates severe damage to older buildings even if the intensity of an earthquake is moderate.

In the last 120 years, the Himalayas has been seismically active and have been experienced significant earthquakes of Magnitude (Mw>=8.0) in Western Assam (1897), Kangara (1905), Bihar-Nepal (1934) and Eastern Assam (Arunachal) 1950 [12]. Seismic gaps created in the regions between rupture zones of these earthquakes have accumulated

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potential slip to generate significant earthquakes in future [13].
Extensive reviews have been conducted by researchers [14] on a variety of methods for assessing the effect of an earthquake in these regions.

Seismic vulnerability assessment has a three-tier procedure which involves (1) Rapid visual screening (RVS) of buildings (2) Preliminary Assessment and (3) Detailed Evaluation.

Experts have suggested different seismic vulnerability assessment methodologies [15−19]. Due to the increase in the number of vulnerable buildings, especially in urban areas, a quick and reliable procedure is needed to find unsafe buildings.

RVS is a simple walk-through process that does not require any structural calculations. RVS are used to recognize structures suitable for preliminary and detailed assessment of many existing buildings. The performance assessment of seismic behaviour is costly and time-consuming process. So, RVS is used quickly and efficiently.

RVS focus on on-site inspection of every house. In recent times, geographic information system strategies have proven to be helpful in this perspective. RVS survey format proposes a scoring system based on configuration elements of earthquake vulnerability, which is utilized for risk categorization [20].

The main objective of RVS is to reduce the application of resources to accommodate assessment of a large number of structures [21, 22].

RVS method is utilized for vulnerability study before the occurrence of earthquake and also after it. The pre-study recognizes the seismic performance of the structures, whereas the post study determines the suitability of occupancy of distressed buildings [23, 24]. RVS final scores can quickly categorize buildings which need more preliminary and detailed evaluation. A quick assessment method like this is vital for policymakers and decision-makers to use while allocating money and mitigating earthquakes [3, 25].

In the last few decades, several RVS methods for building safety assessment have been developed. Hassan and sozen [26] developed a method of RVS of low-rise buildings. In this method, a priority index was determined by using column index and wall index. Another method was developed by [27] in which area of a cross section of columns and walls along with drift was considered for assessment. Both the methods ignored the materials used in construction and the irregularities of the buildings. The study by researcher [28] gave a new RVS methodology. From their study it was concluded that site specific data of seismic hazard would be useful for accurately assessing vulnerability of the region.

Sucuoglu et al. [29] developed a procedure for assessment of high-risk buildings. The method developed is useful for medium-rise buildings. This method is similar to FEMA-154.The damage of buildings is quantified using statistical analysis. A study by researcher [30] developed a new scoring system which is linear and non-logarithmic. This method does not clearly define the cutoff score for ranking buildings. Other methods developed are Karabassi and Nollet [31]; Middle East Technical University (METU) [32]; Yakut [33]; Demartinos and Dritsos [34]. Also, methods were developed by Jain et al. [20, 35]; Tezcan et.al. [36]; Performance based rapid seismic assessment method (PERA) [37, 38]; Achs and Adam [39, 40].

Figure 1 is a picture taken during RVS by us at Shastri Nagar, Patna. Reinforcement bars have started corroding and concrete has spalled in several places. This is causing loss of structural integrity and capacity of the slabs. These are the common problems in most buildings which were built in the 1960s. So, the current issue is to identify vulnerable building and this can be done with the help of RVS. After the initial screening by RVS, further detailed study will be done, which can be useful in ranking of vulnerable buildings.

Figure 1 Spalled ceiling at QTR No. –19-24, Shastri Nagar, Patna

In this paper attempt has been made to compare different RVS methods being used in various countries worldwide. Seismic assessments are discussed in terms of their relevance to different countries.

2.Review of RVS documents

USA procedure

The procedure was developed by the federal emergency management agency (FEMA) for seismic vulnerability assessment of building and for providing support for rehabilitation. FEMA-178 [41] was developed in the year 1989 which was revised in the year 1992.FEMA-310[42] was developed after the revision of FEMA-178 and also FEMA-154[25] was developed in the year 1988 which got further revised in the year 2002.FEMA-154 provides guidelines for RVS of buildings. FEMA-154 utilizes survey forms for quick assessment of buildings. The Final score is the sum of the Basic score and Modifiers. The basic score depends upon the types of structural system. The modifiers depend upon the various parameters such as the storey height, type of soil, irregularity of the building (plan as well as elevation) and pre-code or post code benchmark. These parameters are included in FEMA-155[43], which was published in the year 1988 and revision of the code was done in the year 2002[25]. The year of construction is also an important parameter for the assessment of buildings. Many buildings in the US which were constructed in pre-codal era are vulnerable. FEMA-310 provides criteria for evaluation of different types of buildings and to classify their performance levels. The basic score and modifiers are as per FEMA-154 shown in *Table 1*. As seen in the *Table 1*, there is a provision of penalty for those buildings which were built in pre-code era.

Also, after the implementation and enforcement of significant improvements in the code, a post-benchmark characteristic is assigned as a modifier to the buildings. Because of the strict regulations in the United States, there is a lot of emphasis on the year of construction in relation to building codes. Thus, making it mandatory that a building must meet the code specifications in effect at the time of construction.

FEMA-154 gives separate consideration to buildings with four to seven stories, compared to buildings having more than seven stories. A higher score is assigned to more than seven-story buildings. As per FEMA-154, modifier value of -2.0 is assigned to vertical irregularities and -0.5 for plan irregularities. Variation in modifier value demonstrates that vertical irregularities are far more responsible for building vulnerability than plan regularity. During sidewalk surveys, it is easier to locate vertical irregularity than the plan irregularity. According to FEMA, soft storey buildings have got detrimental effects. FEMA considers the only type of soil with a modifier for dense, stiff and soft soil. It does not explicitly consider the impact of closely placed buildings, large overhangs, apparent building quality, and topography. A survey using the RVS form as specified in FEMA was done for 250 buildings in Malaysia and vulnerable buildings were identified for which detailed analysis needs to be done [44].

Table 1 Basic scores and modifiers for moment resisting frame buildings (as per FEMA-154[25])

Seismicity	Basic score	Mid-rise 4-7 storey	High-rise 7storeys	Irregularities		Pre-code	Post-Benchmark	Soil		
				Vertical	Plan			Dense	Stiff	Soft
Low	4.4	+0.4	+1.0	-1.5	-0.8	-	+0.6	-0.6	-1.4	-2.0
Moderate	3.0	+0.2	+0.5	-2.0	-0.5	-1.0	+1.2	-0.6	-1.0	-1.6
High	2.5	+0.4	+0.6	-1.5	-0.5	-1.2	+1.4	-0.4	-0.6	-1.2

Canadian procedure

This manual [45] adopts quick screening methods to rank different buildings and also detailed seismic assessment in future. This procedure is compliant with the national building code of Canada. It identifies the main characteristics affecting the risk of earthquakes. The method consists of inspection of the building from inside and outside. The review of architectural and structural drawing helps in assessment of seismic performance quickly and accurately. The data obtained through this procedure pave way for a decision as to whether a more detailed assessment is required to evaluate seismic adequacy. Essential factors considered for obtaining the score are as below:

1- Seismicity: This is the maximum expected earthquake motion for the building location.
2- Soil conditions: Due to the amplification of earthquake motion, a soil failure like liquefaction

may occur in deep soft soil condition. This may cause damage to the building.

3- Type of structure: Primary load bearing structures like foundation, columns, beams, joists etc. need attention during the investigation.
4- Building irregularities: Soft storey is more vulnerable in case of occurrence of earthquakes. Vertical and horizontal irregularities are checked.
5- Non-load bearing structures like partition are also hazardous in case of occurrence of earthquakes. Such structures are assessed with its effect on useful critical services of the building.
6- Design of building done as per latest building codes makes the structure less vulnerable.
7- Building importance: Some parts of the buildings are more important in case of post-earthquake consideration.

After the collection of data, the screening form is filled and appropriate numerical values are assigned. Total value is compiled to get the score, which is further utilized for the determination of characteristic value for overall seismic risk assessment. This score is used to decide the priority of next level seismic assessment. The screening of 102 numbers of buildings in Quebec was done and finding showed the difficulty of this method due to expert opinion in comparison to FEMA-154[46].

3.Sinha and Goyal method

In 2004, Sinha and Goyal adopted the criteria of FEMA-154 (2002 edition) with certain modification suitable for Indian conditions. In the method main aim is to recognize a building which needs assessment of its earthquake aspects in future [47]. This method has two important aspects, namely (1) basic score and (2) score modifier. A building typology with no seismic vulnerability is assigned a generic score, which is called a basic score, whereas the score given to vulnerability factors affecting the buildings in case of occurrence of earthquakes is score modifier. This method [48] distinctly gives a qualitative description of the anticipated qualitative damage condition of building like- moderate damage, slight damage etc. But the method does not clearly explain the basic score for each building typology. It also does not explain the score modifier values of each vulnerable parameter. The same is the case for cutoff values of each damage state. RVS was conducted for 623 numbers of buildings in Mussoorie. The critical zone having most vulnerable structures were identified in this study [49].

Arya method

According to the Arya's method, it is checked whether further assessment of the building is required or not [50]. According to this method, different categories of buildings experience a different type of damage levels. The damage levels in each building depend upon the inherent characteristics of buildings [50]. The main focus of this method is on seismic vulnerability of buildings which depends on the type of materials used, seismic zone of buildings and lateral load resisting system. The vulnerable parameters considered in this method are torsional irregularity, diaphragm discontinuity and re-entrant corners. Other vulnerable parameters considered in this method are plan irregularly, stiffness irregularity, mass irregularity and vertical geometric irregularity. In this RVS method, damageability is decided according to the grade and no score is given. It approves a detailed evaluation in case of the presence of any one of these parameters. The damage levels of buildings are dependents upon the building type, load resisting systems and quality of construction materials utilized. The Arya method is not standardized according to the earthquake occurred in India and this method is defective in various ways. The damageability in this method is defined according to the material and no strength parameter is considered. RVS of 5 numbers of single storey houses of Kharagpur were done by [51] use of this method. The result of the study showed the lack of consideration of irregularities (both plans as well as vertical) of this method which can have an impact on vulnerability of different building types.

Building material & technology promotion council (BMTPC) method

This method is developed by BMTPC [23] in 2012 to assess the seismic vulnerability for typical Indian housing typologies. The method was evolved after intensive survey with the historical document's investigation. In this method, an ideal building is compared with buildings of similar typology for safety index and performance ratio. It categorizes all vulnerability parameters into two parts. One is a life-threatening parameter, and the other is an economic loss-inducing parameter. Each of the two parameters is assigned score value based upon the earlier study and experience. This method basically categorizes each factor into two sets. Hence it is each to determine factors for life safety. There are some shortcomings to its usage. Firstly, this method takes time and detailed information is required. Sometimes it is not possible to collect another essential drawback is its non-verification with other RVS methods. RVS was done for 100 RC buildings of Pithoragarh Gangtok and Agartala [22]. The results obtained using BMTPC method was compared with different RVS methods such FEMA-154, Arya method, Sinha and Goyal method. From the study it was found to be the most appropriate method.

Japan procedure:

Japan Building Disaster Prevention Association (JBDPA) developed a three-tier assessment process, namely (1) First level inspection (2) Second level inspection (3) Detailed Inspection. This procedure was developed in the year 1977 which was further revised in the year 1990 and 2001[52]. In this method, seismic index of structures is calculated using Equation (1). The value of seismic index IS is calculated as shown in Equation (1):

$$I_S = E_0 \times S_D \times T \qquad (1)$$

Where E_0 = Basic seismic index, S_D = Irregularity index and T = Time index

Time index takes into account the effects of deflection, age of the buildings and cracking. Irregularity index takes into account effects of plan and section. In this method, no clear-cut ranking and scoring pattern defined in this method. Vulnerability assessment of 60 buildings was done using this method [53]. The result obtained were compared empirically with design of experiment (DOE) and found to be correct.

New Zealand procedure

New Zealand society for earthquake engineering (NZSEE) [54] proposed a two-tier procedure, namely (1) initial evaluation process (IEP) (2) detailed Evaluation of seismic vulnerability assessment. The initial evaluation process consists of performance assessment of existing building with respect to the percentage of new building standard (% NBS) [51].

The buildings have %NBS value less than 33% may be affected by earthquakes and hence they require detailed assessment. If the building is having value of %NBS is greater than 67%, there is no risk to these buildings due to earthquakes. If the building has a value of %NBS is between 33% and 67%, the building can have slight damages, and hence detailed assessment is required. The assessment is conducted by expert and trained surveyor. A total of 80 buildings was assessed using this method [55]. The result obtained can be useful for decision makers to assess vulnerability.

UNDP procedure

This is a part of the project of United nations development program (UNDP) in association with the governments of Greece, Romania, Yugoslavia, Bulgaria, Hungary & Turkey [56]. One volume out of 7 volumes of the project is related to this procedure which was carried out to study seismic conditions in the Balkan region. The manual technically describes mitigation methods of earthquakes for this region. Assessment programmes before and after the earthquake were discussed. The document by UNIDO studies the present structure in the light of structural principles. Strength, deformability and ductility were checked. Classification was made as good, acceptable and unclear. The value of strength index(R) is calculated. Classification of buildings into 5 categories is done on the basis of structural layout quality and Strength index(R)-values. Then, considering the deformability and ductility needed, the strengthening type is decided. The axial load-moment interaction diagram simplifies the calculation of R. With the help of stress under gravity and required base shear coefficient, the R-Value for a column is calculated. There is a realization of evaluation of existing structure for its remaining life. Seismic demand is modified with help of correction factor as shown in Equation (2) below: -

$$C_{Corrected} = \left(\frac{T_{Service}}{T_{Code}}\right)^{\frac{1}{2},\dots,\frac{1}{1.5}} \times C_{Code} \qquad (2)$$

Where T_{code} = Reference lifetime of structures, C_{code} = Design factor for structures of a given class, $T_{service}$ = The subsequent lifetime for existing structure, $C_{corrected}$ = Design factor for the existing structure should be checked or designed.

Italian procedure

This vulnerability index method depends upon the scoring system [57−60]. The building is categorized on the basis of 11 factors. The survey work of the post-earthquake situation is done with the help of a first level assessment form, and the factors with scores are decided. With the use of a first level assessment form, a vulnerable index is assigned to the building, a damage index is determined. The value of the vulnerability function shows the relation between observed damage of a certain type of building due to a particular earthquake and the vulnerability index. This depends mainly on the construction material, construction process, compliance of code and so many other factors. It was concluded that further detailed study is required [61].

Euro code procedure

This method was approved by the Committee of European Standardisation (comité européen de normalisation [CEN]) in the year 1995[62]. This method consists of guidelines for seismic evaluation of the buildings and to provide corrective measures. In this method, seismic resistance of existing buildings is checked for seismic as well as non-seismic actions. In This method uncertainty factors are considered; higher value of the uncertainty factor denotes more damage to the structure. The analysis to calculate seismic damage under actual load is carried out. The computed values are verified at component level for all cross sections. Vulnerability assessment of 2933 buildings in Sarajevo and Banja Luka was done [63]. The vulnerability index was calculated and the result obtained can be helpful in earthquake disaster mitigation.

3.1Comparison of different methods

The *Table 2* below shows the comparison of different RVS procedures based upon 10 parameters, namely load path, soft storey, weak storey, effective mass, torsion, pounding effect, prior damage, guidelines for the design professional, seismicity and soil type. The graphical representation of various characteristics in RVS has been done and is represented in *Figure 2*. The graph of characteristics vs. guidelines of the country has been plotted using origin software in *Figure 2*.

Table 2 Various parameters considered in RVS methods for different countries

Parameters	USA	Canada	New Zealand	Italian	EURO-CODE	UNDP	BMTPC	Arya Method	Sinha and Goyal	Japan
Load path	1	1	1	1	1	0	1	1	1	1
Soft storey	1	1	1	0	1	0	1	0	1	1
Weak storey	1	0	0	0	1	0	1	0	0	0
Effective Mass	1	0	0	0	1	0	1	1	1	0
Torsion	1	1	1	0	1	0	1	1	1	0
Pounding effect	1	1	1	0	0	0	0	0	0	1
Prior Damage	0	0	1	1	1	0	0	0	0	1
Guidelines for design professional	1	1	1	1	0	0	1	1	1	1
Seismicity	1	1	1	1	1	1	1	1	1	1
Soil Type	1	1	1	1	1	1	1	1	1	1

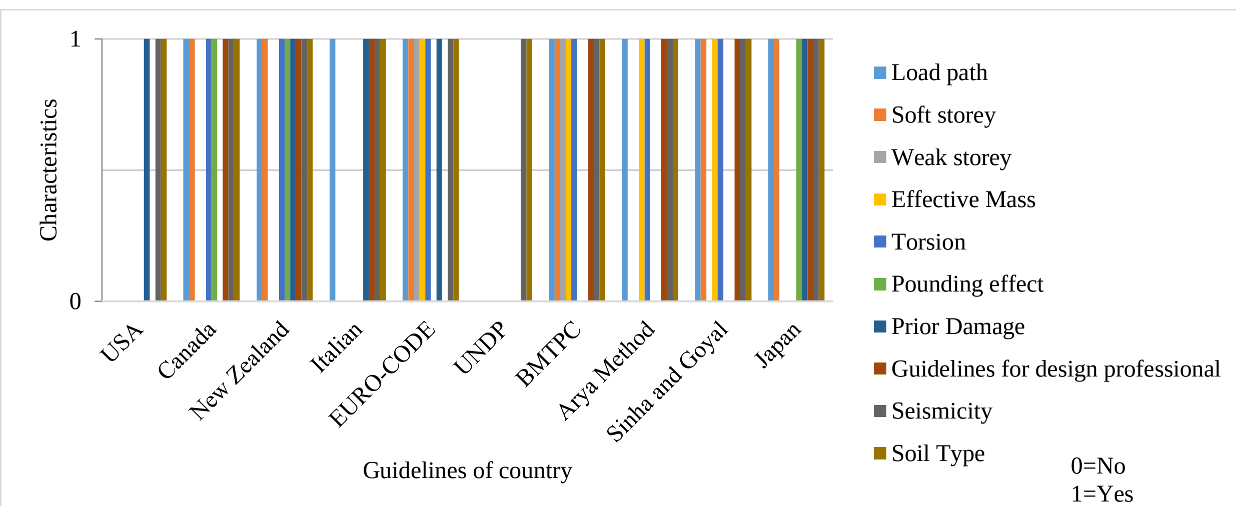

Figure 2 Characteristics Vs. guidelines of the country

The comparison of different RVS Procedure according to their damageability scale has been done in *Table 3*. The various RVS procedures classifies buildings, according to damageability scale have been given in *Table 3.*

The comparison of advantages of the various RVS method is done in *Table 4*. The shortcomings of different RVS methods have also been compared in *Table 4.*

Table 3 Comparison of damageability scales for different RVS procedures of different countries

S. No.	RVS procedure	Damageability scale				
1.	USA Procedure	Low	Moderate	High /Very High Collapse	Very High/Severe	Destruction
2.	Canada Procedure	Low	Medium	High	-	-
3.	Italian Procedure	Damage Limitation (Low)	Significant Damage (Medium)	Near-Collapse (High)	-	-
4.	New Zealand Procedure	Low	Medium	High	-	-
5.	BMTPC Procedure	Economic Loss Induced in Structural Elements Factors	-	Economic loss induced in structural element factors	-	-
6.	Sinha And Goyal Method	No Damage	Slight Damage	Moderate	Severe Damage	-
7.	Arya Method	No Damage	Slight Damage	Moderate	Severe Damage	-
8.	UNDP	No Damage	Slight Damage	Moderate	Severe Damage	-
9	Japan Procedure	No Damage	Slight Damage	Not Repaired Damage	-	-
10	Euro code	Slight Damage	Moderate	Heavy	Very Heavy	Destruction

Table 4 Comparison of advantages and limitations of RVS procedures of different countries

S. No.	RVS procedure	Advantage	Limitation
1.	USA Procedure	Generalized Method	No Clarity on Liquefaction
2.	Canada Procedure	Generalized Method	No Criteria for Weak Storey
3.	Italian Procedure	Considers Less Parameters for Screening	No Clarity on Ranking of Buildings and Weak Storey.
4.	New Zealand Procedure	Generalized Method	It is Difficult Method to Understand as it Requires Experts.
5.	BMTPC Procedure	Scoring is Defined Based Upon Delphi Method.	Time Consuming Method
6.	Sinha And Goyal Method	More Clarity on Damage State of Buildings	No Clarity of Score Modifiers
7.	Arya Method	More Clarity on Damage State of Buildings	No Scoring Pattern
8.	UNDP	More Clarity on Damage State of Buildings	No Provision of Pounding Effects
9.	Japan Procedure	Considers Less Parameters for Screening	No clarity of Scoring Pattern and Ranking of Building.
10.	Euro Code	Generalized Method	No Provision of Pounding Effects

Vulnerability assessment

The impact of damage to the buildings due to earthquake needs to be known. Large scale damage can be avoided by accurate knowledge of level of deterioration. This may include a pre or post-earthquake assessment. Several methods for assessing vulnerability have been developed. The majority of vulnerability assessment methods used around the world follow a three-step screening process, which is outlined below:

Tier 1: Screening phase

Professionals involved in the design field get acquainted with the building, its probable behaviour and possible deficiencies to readily confirm whether the building comply with RVS method provisions. Assessment statements obtained from tier-1 screening for structural and non-structural features are provided as checklists for the chosen level of performance and the particular seismicity regions. In the beginning, on the basis of the collected data it is to be determined whether the building meets the code provisions and benchmark criteria of buildings. For the non-benchmark buildings, the professionals stick to all check lists. However, for benchmark buildings the assessment steps regarding structural requirements are ignored. After completing checklists, non-compliant deficiencies lists are compiled and requirement for further evaluation is determined.

Tier 2: Evaluation phase

Experts in the design field have got two choices-a) detailed study of the building which includes all the deficiencies that were found in Tier-1 b) only the study of deficiencies. In the stage of Tier-2, study and assessment is done for the adequacy of the resisting system of lateral force. This study is restricted to a simplified linear analysis process. A common linear static or dynamic analysis process could be used for it.

Tier 3: Detailed evaluation phase

The Tier-3 study is carried out if there is a deficiency in Tier-2. In case the assessment of Tier-1 and Tier-2 are found too conservative and importance of financial or other benefits are visible, the Tier-3 study is done with a more detailed assessment. This includes non-linear and linear process for dynamic and static analysis of buildings. To evaluate expected performance of components in existence, it is necessary to compare it with a calculated demand for the components with its capacity. A multiplication factor of 0.75 is used for design of existing buildings for reducing the force levels used in Tier-2 and Tier-3 analysis. This reduction in force level is reasonable in the light of two considerations – 1) Elements will have greater strength than as utilized in evaluation 2) Remaining useful life of the building in existence is not same as a new building which necessitate a different level of factor of safety.

Various researches are being done to assess vulnerability. In Koyna, Maharashtra, a researcher [64] conducted a vulnerability assessment study. In this study, 120 reinforced concrete buildings were surveyed using the earthquake disaster risk index method, and it was determined that the risk index of buildings in the Koyna region was severe, necessitating retrofit measures. Also, a study was done by [65] for seismic vulnerability assessment of a 6- storey building built in the year 2010, located in Columbia. The study concluded that the use of steel jacketing can improve the compressive strength and flexural study of the columns. RVS was done by [66] to assess vulnerability in the city of Coimbatore and concluded that building present were vulnerable and hence required retrofitting.

4.Discussion

The various RVS methods have been developed in the aftermath of the disastrous earthquakes. The methods are the outcome of the lesson learnt. Data of previous earthquake were utilized for the formation of Italian method and FEMA-154 of 1988.

RVS method also differs in terms of pre-earthquake and post-earthquake surveys. USA method, Canada method and New-Zealand method is used for pre-earthquake surveys. The euro-code method is used for the post-earthquake survey. Japan method takes more time in comparison with other methods. Methods such as Sinha and Goyal, Arya Method, FEMA-154 and BMTPC do not consider irregularities which may result in the same score for different configuration of buildings. Many researches have been done [67− 69] in specific areas and they have specified the need of further research for implementation. RVS was done by [70] to assess vulnerable buildings. It was concluded that the old built masonry structures were more vulnerable than the newly constructed load bearing buildings. In this study some features such as fire exits, gas pipelines etc. are not taken care of, which might also affect the vulnerability of buildings. A complete list of abbreviations is shown in *Appendix I*.

5.Conclusion

To mitigate the damage before any anticipated earthquake in the future, the deficient buildings amongst the stock of large buildings of a town or city are required to be identified. For this, RVS method is adopted and after detailed assessment the benchmarking of the score is done. The various guidelines have been compared according to the different parameters such as load path, soft storey, weak storey, effective mass, torsion and pounding effect etc. Also, the different methods of various countries are compared to the damageability scales. After comparing different RVS methods, it has been seen that most methods follow a three-tier assessment approach. FEMA-154 and New Zealand guideline can be used for development of a generalized process. The data collected through RVS can be utilized by using fuzzy logic and artificial intelligence for the development of new methods.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Author's contribution statement

Siddharth: Conceptualization, investigation, writing – review and editing. **Ajay Kumar Sinha:** Investigation, writing – original draft and supervision.

References

[1] Glaister S, Pinho R. Development of a simplified deformation-based method for seismic vulnerability assessment. Journal of Earthquake Engineering. 2003; 7(spec01):107-40.
[2] Coskun O, Aldemir A, Sahmaran M. Rapid screening method for the determination of seismic vulnerability assessment of RC building stocks. Bulletin of Earthquake Engineering. 2020; 18(4):1401-16.
[3] Cockburn G, Tesfamariam S. Earthquake disaster risk index for Canadian cities using bayesian belief networks. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards. 2012; 6(2):128-40.
[4] Hill M, Rossetto T. Comparison of building damage scales and damage descriptions for use in earthquake loss modelling in Europe. Bulletin of Earthquake Engineering. 2008; 6(2):335-65.
[5] Alam N, Alam MS, Tesfamariam S. Buildings' seismic vulnerability assessment methods: a comparative study. Natural Hazards. 2012; 62(2):405-24.
[6] Jain SK, Lettis WR, Arlekar JN, Ballantyne D, Chaubey SK, Dayal U, et al. Preliminary observations on the origin and effects of the January 26, 2001 Bhuj (Gujarat, India) earthquake. EERI Spec Earthq Report, EERI Newsletter 2001.
[7] Kazama M, Noda T. Damage statistics (summary of the 2011 off the Pacific Coast of Tohoku earthquake damage). Soils and Foundations. 2012; 52(5):780-92.
[8] Miyamoto HK, Gilani AS, Wada A. The 2011 eastern Japan earthquake: facts and reconstruction recommendations. Proc. 15 WCEE. 2012.
[9] Daniell JE, Khazai B, Wenzel F. Uncovering the 2010 Haiti earthquake death toll. Natural Hazards and Earth System Sciences Discussions. 2013; 1(3):1913-42.
[10] Rai DC, Murty CV. Effects of the 2005 Muzaffarabad (Kashmir) earthquake on built environment. Current Science. 2006; 90(8):1066-70.
[11] Kumar RP, Murty CV. Earthquake safety of houses in India: understanding the bottlenecks in implementation. Indian Concrete Journal. 2014.
[12] Thakur VC. Reassessment of earthquake hazard in the Himalaya and implications from the 2004 Sumatra–Andaman earthquake. Current Science. 2006; 90(8):1070-2.
[13] Bilham R, Gaur VK, Molnar P. Himalayan seismic hazard. Science. 2001; 293(5534):1442-4.
[14] Rai DC. Review of documents on seismic evaluation of existing buildings. Department of Civil Engineering, Indian Institute of Technology, Kanpur, India. 2005.
[15] Calvi GM, Pinho R, Magenes G, Bommer JJ, Restrepo-vélez LF, Crowley H. Development of seismic vulnerability assessment methodologies over the past 30 years. ISET Journal of Earthquake Technology. 2006; 43(3):75-104.
[16] Guéguen P, Michel C, Lecorre L. A simplified approach for vulnerability assessment in moderate-to-low seismic hazard regions: application to Grenoble (France). Bulletin of Earthquake Engineering. 2007; 5(3):467-90.
[17] Spence R, So E, Jenny S, Castella H, Ewald M, Booth E. The global earthquake vulnerability estimation system (GEVES): an approach for earthquake risk assessment for insurance applications. Bulletin of Earthquake Engineering. 2008; 6(3):463-83.
[18] Tesfamariam S, Saatcioglu M. Seismic vulnerability assessment of reinforced concrete buildings using hierarchical fuzzy rule base modeling. Earthquake Spectra. 2010; 26(1):235-56.
[19] Ningthoujam MC, Nanda RP. Rapid visual screening procedure of existing building based on statistical analysis. International Journal of Disaster Risk Reduction. 2018; 28:720-30.
[20] Jain SK, Mitra K, Kumar M, Shah M. A proposed rapid visual screening procedure for seismic evaluation of RC-frame buildings in India. Earthquake Spectra. 2010; 26(3):709-29.
[21] Erberik MA. Seismic risk assessment of masonry buildings in Istanbul for effective risk mitigation. Earthquake Spectra. 2010; 26(4):967-82.
[22] Bhalkikar A, Kumar RP. A comparative study of different rapid visual survey methods used for seismic assessment of existing buildings. Structures 2021; 29: 1847-60. Elsevier.
[23] https://bmtpc.org/topics.aspx?mid=549&Mid1=552. Accessed 14 January 2022.
[24] Murty CV, Rai D, Kumar H, Mitra K, Bose AK, Koushik HB, et al. A methodology for documenting housing typologies in the moderate-severe seismic zones. Lisbon, SN. 2012.
[25] Federal emergency management agency (US), editor. Rapid visual screening of buildings for potential seismic hazards: a handbook. Government Printing Office; 2017.
[26] Hassan AF, Sozen MA. Seismic vulnerability assessment of low-rise buildings in regions with infrequent earthquakes. ACI Structural Journal. 1997; 94(1):31-9.
[27] Gulkan P, Sozen MA. Procedure for determining seismic vulnerability of building structures. Structural Journal. 1999; 96(3):336-42.
[28] Yang Y, Goettel KA. Enhanced rapid visual screening (E-RVS) method for prioritization of seismic retrofits in Oregon. Portland, OR, USA: Oregon Department of Geology and Mineral Industries; 2007.
[29] Sucuoğlu H, Yazgan U, Yakut A. A screening procedure for seismic risk assessment in urban building stocks. Earthquake Spectra. 2007; 23(2):441-58.

[30] Yadollahi M, Adnan A, Zin RM. Seismic vulnerability functional method for rapid visual screening of existing buildings. Archives of Civil Engineering. 2012:363-77.

[31] Karbassi A, Nollet MJ. Development of an index assignment procedure compatible with the regional seismicity in the province of Quebec for the rapid visual screening of existing buildings. Canadian Journal of Civil Engineering. 2008; 35(9):925-37.

[32] Municipality IM. Earthquake master plan for Istanbul. Istanbul Metropolitan Municipality, Istanbul. 2003.

[33] Yakut A. Preliminary seismic performance assessment procedure for existing RC buildings. Engineering Structures. 2004; 26(10):1447-61.

[34] Demartinos K, Dritsos S. First-level pre-earthquake assessment of buildings using fuzzy logic. Earthquake Spectra. 2006; 22(4):865-85.

[35] Jain S, Mitra K, Kumar M, Shah M. A rapid visual seismic assessment procedure for RC frame buildings in India. In proceedings of the 9th US national and 10th Canadian conference on earthquake engineering, Toronto, ON, Canada 2010.

[36] Tezcan SS, Bal IE, Gulay FG. P25 scoring method for the collapse vulnerability assessment of R/C buildings. Journal of the Chinese Institute of Engineers. 2011; 34(6):769-81.

[37] Ilki A, Comert M, Demir C, Orakcal K, Ulugtekin D, Tapan M, et al. Performance based rapid seismic assessment method (PERA) for reinforced concrete frame buildings. Advances in Structural Engineering. 2014; 17(3):439-59.

[38] Joshi GC, Ghildiyal S, Rautela P. Seismic vulnerability of lifeline buildings in Himalayan province of Uttarakhand in India. International Journal of Disaster Risk Reduction. 2019.

[39] Adam C, Furtmüller T, Achs G. Seismic assessment of historical brick-masonry buildings in Vienna. In Proc. of the 15th world conference on earthquake engineering 2012 (pp. 24-8).

[40] Achs G, Adam C. Risk assessment of historic residential brick-masonry buildings in vienna by rapid-visual-screening. In III ECCOMAS thematic conference on computational methods in structural dynamics and earthquake engineering 2011.

[41] https://www.preventionweb.net/files/7543_SHARPISDRFLOOR120081209171548.pdf. Accessed 14 January 2022.

[42] https://www.wbdg.org/FFC/DHS/ARCHIVES/fema310.pdf. Accessed 14 January 2022.

[43] https://nehrpsearch.nist.gov/static/files/FEMA/PB2007111312.pdf. Accessed 14 January 2022.

[44] Harith NS, Jainih V, Ladin MA, Adiyanto MI. Assessing the vulnerability of Kota Kinabalu buildings. Civil Engineering and Architecture. 2021; 9(5A):68-77.

[45] National Research Council of Canada. Institute for Research in Construction. Manual for screening of buildings for seismic investigation. 1993.

[46] Tischer H, Mitchell D, Mcclure G. Comparison of north american seismic screening methods applied to school buildings. Journal of Civil Engineering and Architecture. 2012; 6(7):799-811.

[47] Sinha R, Goyal A. A national policy for seismic vulnerability assessment of buildings and procedure for rapid visual screening of buildings for potential seismic vulnerability. Report to Disaster Management Division, Ministry of Home Affairs, Government of India, Hindistan. 2004:1-9.

[48] BIA. The assessment and improvement of the structural performance of earthquake risk buildings-draft for general release.

[49] Joshi GC, Kumar R. Preliminary seismic vulnerability assessment of Mussoorie town, Uttarakhand (India). Journal of Building Appraisal. 2010; 5(4):357-68.

[50] Arya A. Rapid visual screening of RCC buildings. New York: UNDP. 2003.

[51] Ishack S, Bhattacharya SP, Maity D. Rapid visual screening method for vertically irregular buildings based on seismic vulnerability indicator. International Journal of Disaster Risk Reduction. 2021.

[52] Takahashi A, Tago S, Ilki A, Okada T. Seismic capacity evaluation of existing reinforced concrete buildings in turkey (effect of retrofit). In proceedings of world conference on earthquake engineering, Canada: Vancouver 2004 (pp. 1-6).

[53] Islam N, Roy KS, Islam K, Imran M, Hoosain A. Seismic vulnerability assessment of existing reinforced concrete residential buildings by Japanese method. In first international conference in advances in civil infrastructure and construction materials 2015.

[54] https://www.nzsee.org.nz/db/PUBS/2006AISBEGUIDELINESCorr3_(incl_2014_updates).pdf. Accessed 14 January 2022.

[55] Marotta A, Sorrentino L, Liberatore D, Ingham JM. Vulnerability assessment of unreinforced masonry churches following the 2010–2011 Canterbury earthquake sequence. Journal of Earthquake Engineering. 2017; 21(6):912-34.

[56] UNDP/UNIDO, Post-earthquake damage evaluation and strength assessment of buildings under seismic conditions. 1985.

[57] Benedetti D, Petrini V. On the seismic vulnerability of masonry buildings: an evaluation method. a method for evaluating the seismic vulnerability of masonry buildings. The Construction Industry. 1984 (149): 66-74.

[58] Angeletti P, Bellina A, Guagenti E, Moretti A, Petrini V. Comparison between vulnerability assessment and damage index, some results. In proceedings of the world conference on earthquake engineering 1988 (pp. 181-6).

[59] Barbat AH, Moya FY, Canas J. Damage scenarios simulation for seismic risk assessment in urban zones. Earthquake Spectra. 1996; 12(3):371-94.

[60] https://emidius.mi.ingv.it/GNDT2/Pubblicazioni/Lsu_96/vol_1/schede.pdf. Accessed 14 January 2022.

[61] Fortunato G, Funari MF, Lonetti P. Survey and seismic vulnerability assessment of the baptistery of san giovanni in Tumba (Italy). Journal of Cultural Heritage. 2017; 26:64-78.

[62] En BS. 1-1. Eurocode 2: design of concrete structures–part 1-1: general rules and rules for buildings. European Committee for Standardization. 2004.
[63] Ademovic N, Hadzima-nyarko M, Zagora N. Influence of site effects on the seismic vulnerability of masonry and reinforced concrete buildings in Tuzla (Bosnia and Herzegovina). Bulletin of Earthquake Engineering. 2022; 20(5):2643-81.
[64] Shendkar MR, Pradeep KR, Mandal S, Maiti PR, Kontoni DP. Seismic risk assessment of reinforced concrete buildings in Koyna-Warna region through EDRI method. Innovative Infrastructure Solutions. 2021; 6(3):1-25.
[65] Villar-salinas S, Guzmán A, Carrillo J. Performance evaluation of structures with reinforced concrete columns retrofitted with steel jacketing. Journal of Building Engineering. 2021.
[66] Satish D, Lalith PE, Anand KB. Seismic vulnerability assessment of city regions based on building typology. In national conference on structural engineering and construction management 2020 (pp. 443-52). Springer, Cham.
[67] Bektaş N, Kegyes-brassai O. Conventional RVS methods for seismic risk assessment for estimating the current situation of existing buildings: a state-of-the-art review. Sustainability. 2022; 14(5):1-40.
[68] Aldemir A, Guvenir E, Sahmaran M. Rapid screening method for the determination of regional risk distribution of masonry structures. Structural Safety. 2020.
[69] Aung MM, Aye MN. Seismic safety assessment of existing low-rise rc buildings with rapid visual screenings and preliminary evaluation methods. ASEAN Journal on Science and Technology for Development. 2021; 38(1):29-36.
[70] Jha S, Pal S. Prioritizing buildings for seismic retrofit on the basis of RVS score. In advances in construction materials and sustainable environment 2022 (pp. 779-91). Springer, Singapore.

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Appendix I

S. No.	Abbreviation	Description
1	BMTPC	Building Material & Technology Promotion Council
2	DOE	Design of Experiment
3	FEMA	Federal Emergency Management Agency
4	IEP	Initial Evaluation Process
5	JBDPA	Japan Building Disaster Prevention Association
6	NBS	New Building Standard
7	NZSEE	New Zealand Society of Earthquake Engineering
8	METU	Middle East Technical University, Istanbul
9	PERA	Performance Based Rapid Seismic Assessment Method
10	RVS	Rapid Visual Screening
11	UNDP	United Nation Development Program