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A Case Study on Vulnerability Risk Assessment of Buildings in Chennai Using Rapid Visual Screening

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ABSTRACT

India is witnessing drastic urbanization and economic growth which in turn helps in building its infrastructure rapidly. A large amount of construction of multistorey buildings has been done in many metropolitan cities, where one such city is Chennai, Tamil Nadu. In the recent scenario, being an unplanned and most densely populated city, there is a chance of an increase in threats to several natural hazards viz, earthquake, fire etc.This shifts our focus in understanding the risk associated with these hazards to ensure the safety of the structures. Many studies have been carried out to estimate the risk of the structure but are proven to be quite cumbersome. To counterpart, such complex methods, a simple approach namely Rapid Visual Screening (RVS) Method is used which is proven to be simple and reliable. Rapid visual screening has been widely used but the application of this method in India is limited. The present study helps in identifying the seismic risk associated with an area of interest in Chennai (Mylapore, Santhome, Triplicane) and elaborates its usability for other metropolitan cities. A total of 100 buildings of different housing typologies have been studied and its RVS score is calculated based on various building parameters. The pushover analysis is done for selected 5 buildings based on obtained RVS score and the results are used for further investigation. The RVS scores were correlated with the damage state curves and it is observed that buildings with RVS score greater than 120 are known to have no damage for a design earthquake with peak ground acceleration of 0.16g.Finally, the risk assessment in terms of building damages during an earthquake is correlated based on its RVS score and push over curve.

KEYWORDS

Rapid Visual Screening, Vulnerability, Push Over Analysis.

Introduction

Vulnerability assessment of the existing buildings is very much essential in the recent past. This is because of the risk associated with an unexpected earthquake. Earthquakes lead to structural failure or collapse which in turn leads to loss of lives, property loss and disruption in the economy. Due to rapid urbanization, the construction practices were poorly designed in urban areas. Based on the past earthquake data it is inferred that around 23 earthquakes with intensity ranging from M6.8 to M7.7 were experienced in India. During these earthquakes, a lot of structural damages happened due to inefficient construction practices. Especially during the Bhuj earthquake, the large number of reinforced concrete structures located at Bhuj, Kutch, and Gandhidham was completely collapsed. Many of the Reinforced Concrete multi-storey buildings were non-engineered and experienced damage in Bhuj and Sikkim earthquakes. So, based on these considerations there is a requirement for evaluating the seismic performance of existing buildings with different typologies. But the detailed assessment of every building is impossible because the procedure is time-consuming and also expensive. Many seismic evaluation methods were adopted by many countries i.e. USA, New Zealand, Japan, and Canada, etc. to assess the seismic vulnerability of buildings. Most of these methods follow the 3 level assessment procedure – RVS (Rapid Visual Screening), Simplified vulnerability assessment (SVA) and detailed evaluation. In this study, the RVS procedure which is developed by FEMA (Federal Emergency Management Agency) is used for seismic assessment of buildings located in Chennai.

Research Background

Rajaram et al. [2010] has worked on Preliminary Seismic Hazard Map of Peninsular India and have observed that 30% of peak acceleration is overestimated and 12% is underestimated by comparing the Peak Ground Acceleration values of different regions given in Indian seismic code IS:1893-2002. The author suggested that there is a great requirement for detailed micro zonation of an area within peninsular India. Sudhir et al. [2010] proposed a Rapid Visual Screening procedure for seismic evaluation of a large number of buildings and also stated that the poor performance of RC buildings in India during recent past earthquakes is a matter of serious concern. Also, this study gives a review of some of the available methods for RVS of RC buildings. A new RVS method has been proposed based on the systematic studies on the damage data of the Bhuj earthquake. Many studies on vulnerability risk assessment of buildings have been done on various cities based on RVS approach as follows:

- Srikanth et al (2010) have investigated risk assessment of 20000 buildings and the observed RVS scores were ranging from 60-120 which reflects the quality of building in the selected area.
- Achs G et al (2012) has studied 375 historic buildings and showed the results for identifying the critical objects vulnerable to seismic loading.
- TanayaSarmah and Sutape das (2018) have investigated 100 Reinforced Concrete buildings in Guwahati city and the results helped in formulating the local level policy to prioritize the building stock for necessary remedial measures.

The present study focuses on vulnerability risk assessment of buildings located in Chennai using the RVS method and the detailed seismic assessment of buildings is also studied for selected buildings using pushover analysis. Pushover analysis is performed using ETABS and the possibility of damage to the building is also identified.

Research Significance

Study on Vulnerability assessment of buildings located in Chennai is essential because of the following reasons:

- Chennai city experienced moderate tremors during the Bhuj earthquake 2001, Pondicherry earthquake 2004 and Sumatra earthquake 2004.
- Chennai city has upgraded to zone III from zone II as per IS: 1893-2002 when comparing with IS: 1893-1984 with Peak Ground Acceleration of 0.16g. This indicates that Chennai city has moderate risk during earthquakes. The maximum magnitude of earthquake observed in Chennai based on the past earthquake data is M5.2.

The locations specifically selected in Chennai are Mylapore, Triplicane and Santhome. The specified locations were selected based on sidewalk survey. Buildings observed were with different typologies and the ages of some buildings are more than 30 years. Risk in these buildings due to an earthquake can be high and hence the vulnerability assessment of buildings situated in the selected location is essential. In this study, vulnerability risk assessment along with detailed seismic assessment is carried out to evaluate the performance of the building during earthquakes.

Rapid Visual Screening Method

Rapid Visual Screening (RVS) procedure was first proposed in the USA in 1988 and was later developed by the Applied Technology Council (ATC). The detailed procedure was published by FEMA: 154 in 1988 and later on guidelines were revised. For the present study, RVS procedure is followed based on recommendations from FEMA 154- 2015 (Third edition). This method relies on data collection and the visual examination will be done for various building features like the type of building, seismic zone, horizontal irregularities, vertical irregularities, apparent quality, etc. Finally, the performance score will be calculated and this score will determine the vulnerability of building for seismic effects. Parameters considered for the present study based on FEMA 154-2015 recommendations are as follows:

1. **Soft storey:** Buildings with parking garages, wide doors commercial establishments with large floors act as the soft storey and these buildings are substantially more flexible or weak in lateral resistance under the action of seismic load.
2. **Vertical irregularities:**Buildings with setbacks and buildings resting on the sloped ground will have vertical irregularities.
3. **Plan irregularities:** Buildings with irregular plan configuration and reentrant corners will have plan irregularities. Buildings with vertical and plan irregularities are subjected to additional moments during earthquakes.

4. **Heavy Overhangs:** Heavy overhangs in the form of large size balconies and overhanging floors induce overturning moments during earthquakes.
5. **Apparent quality:** Apparent quality of the building depends upon the quality of material used during construction. The skill of workmanship based on the finished surfaces and maintenance of the building indicates the apparent quality of the structure. Apparent quality of the building is classified as poor, moderate and good based on visual examination. It will be correlated with the age of buildings.
6. **Effect of Short columns:** Short columns are stiffer than the normal column and the probability of failure of short columns during earthquakes is high. RC frames with ribbon windows, stair landings infill walls, the formation of mid-storey beams generally have short column effect.
7. **Pounding:** Pounding may result in building collisions during earthquakes.
8. **Soil Condition:** The failure of the structure during earthquakes also depends on the local soil conditions.
9. **Frame action:** Frame action depends upon the beam-column connections provided in buildings
10. **Falling hazards:** Non-structural elements such as elaborate parapets, AC unit grills, Hoardings, etc. cause more damage to the structure during earthquakes.

All these parameters are found to be vulnerable features during the action of earthquakes on various scales ranging from low to high. Based on the above parameters, the seismic performance score of the buildings can be calculated and the Performance score (PS) is calculated using, [Sudhir K. Jain et al (2010)].

$$PS=BS+\sum [VSM\times VS] \qquad (1)$$

Where

BS represent the Base Score

VSM represent the Vulnerability Score Modifier

VS represent the Vulnerability Score

A Case Study of Chennai City

Chennai is located on the southeastern coast of the Indian subcontinent in the Northeastern part of the Tamilnadu off to the Bay of Bengal. It is the 6th most populous city and 4th most populous urban agglomeration in India. Types of the soil generally observed in Chennai are clay, sandstone, and shale. Chennai is classified under seismic Zone-III as per IS: 1893-2002. Buildings located in the selected locations were built before 2001 and were not designed for Zone-III requirements to resist earthquake forces. Hence moderate earthquakes can even lead to greater damage to buildings due to the increased density of unsafe buildings.

Data Collection

Mylapore, Triplicane, and Santhome were the locations specifically selected for this study. These locations are near to the coastal area of Chennai and the type of soil is sandy soil. Data was collected through site visit as a primary source and secondary sources of the data were collected from Chennai Municipal Corporation, Geological data of Chennai and published reports. These reports were used for understanding the seismic vulnerability profile of Chennai city. The data were collected using Customized RVS forms [Sudhir K. Jain et al 2010] and the photographs of buildings were taken as reference. Required RVS parameters were filled in the RVS form and the parameters considered were soft storey, vertical irregularities, plan irregularities, heavy overhangs, apparent quality, the effect of short column, pounding, soil condition, frame action, and falling hazards. Data collection was quite difficult specifically to identify the age of the building and horizontal bands for well-plastered masonry buildings. 100 buildings were surveyed and the buildings were observed for the selected parameters.

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Table 1. Building details with structural deficiencies

Name of the Street[S]	Buildings count	Soft Story	Pounding effect	Heavy Overhangs
Mundakannai Amman [S1]	6	2	3	2
NattuVeeerachi Street [S2]	12	3	8	3
VSV KovilStreet [S3]	8	2	4	3
NattuSubbarayanStreet [S4]	4	0	2	0
KaraneeswarKovilStreet [S5]	3	0	2	1
MuttuPandyanStreet [S6]	6	2	0	1
PapanasasivanStreet [S7]	7	2	3	2
Bazar Road [S8]	6	1	4	4
KutcheryStreet [S9]	4	1	2	1
Ram nagarStreet [S10]	5	3	2	1
Natesan Road [S11]	13	2	7	4
KandappanStreetv[S12]	2	2	1	2
Mutthaiah 2nd Street [S13]	7	2	5	5
MallanponnappanStreet [S14]	9	2	4	3
Triplicane Highroad Street [S15]	8	2	8	4
Total	**100**	**26**	**55**	**35**

Table 1 gives details about the number of buildings located in each street and observed seismic vulnerable parameter for those buildings. 26 buildings are observed to have soft stories, 55 buildings are observed to have a pounding effect and 35 buildings with heavy overhangs.

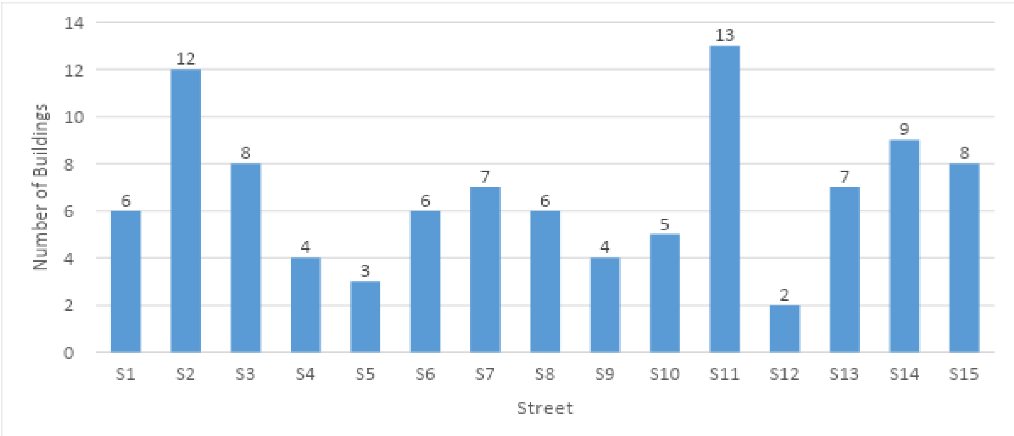

Fig. 1. Graphical visualization of buildings located in each street

Figure 1 shows the number of buildings that were screened in various streets in the areas of Mylapore, Santhome and Triplicane in Chennai.

RVS Score Calculation

RVS scores have been calculated for 100 buildings as per Equation 1. Base Score (BS), Vulnerability Score Modifier (VSM) and Vulnerability Score (VS) are calculated from collected building parameters for 100 buildings. Figure 2 shows the calculation sheet used for obtaining Performance Score (PS). Performance Score (PS) for screened buildings was calculated and the score ranges from 60 to 145 and around 61% of buildings were in the range of 101-130. There will be moderate damage to the buildings during earthquakes for the buildings with PS score of 101-130.

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CALCULATION SHEET FOR PERFORMANCE SCORE / RVS SCORE

NO. OF STORIES	SEISMIC ZONE V	SEISMIC ZONE IV	SEISMIC ZONE III-II	Base Score(BS)
1 (or) 2 ✓	100	130	150	150
3	90	120	140	
4	75	100	120	
5	65	85	100	
>5	60	80	90	

Number of stories	1 (or) 2 ✓	3	4	5	>5	Vulnerability Score Modifiers	
Vulnerability scores (VS)						VSM	(VSxVSM)
Soft storey	0	-15	-20	-25	-30	Doesn't exist=0 ✓	0
						Exists=1	
Vertical Irregularities, Set backs, Buildings on slopes	-10	-10	-10	-10	-10	Doesn't exist=0	
						Exists=1 ✓	−10
Plan Irregularities	-5	-5	-5	-5	-5	None=0	
						Moderate=1 ✓	−5
						Extreme=2	
Heavy Overhangs	-5	-10	-10	-15	-15	Doesn't exist=0	
						Exists=1 ✓	−5
Apparent quality	-5	-10	-10	-15	-15	Good=0	
						Moderate=1	
						Poor=2 ✓	−10
Short Columns	-5	-5	-5	-5	-5	Doesn't exist=0 ✓	0
						Exists=1	
Pounding	0	-2	-3	-3	-3	Doesn't exist=0	
						Unaligned floors=2	
						Poor apparent quality of adjacent building=2 ✓	0
Soil Condition	10	10	10	10	10	Medium=0 ✓	0
						Hard=1	
						Soft=-1	
Frame Action	10	10	10	10	10	Doesn't exist=-1 ✓	−10
						Exists=-1	
						Not sure=0	
						Σ[(VSM)*(VS)]	−40
Performance Score= (BS)+Σ[(VSM)*(VS)] where VSM represents the vulnerability score modifiers and VS represents the Vulnerability Score that is multiplied with VSM to obtain the actual modifier to be applied to the Basic Score(BS)						Performance Score	110

Field Survey by: DINESH	Reviewed by:	Approved by:
Date: 25/01/2020	Date:	Date:

Fig. 2. Calculation sheet used for RVS score

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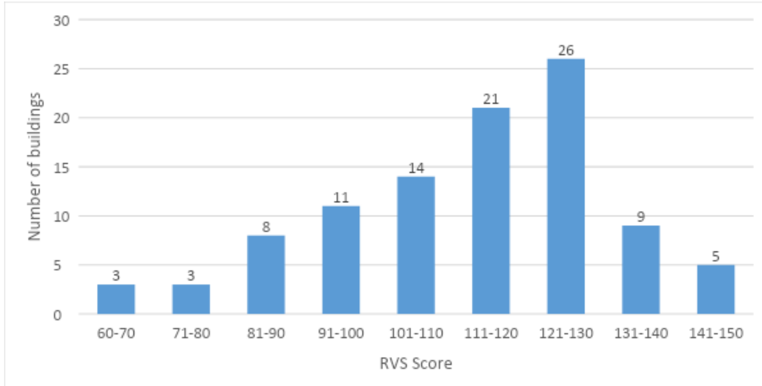

Fig. 3. RVS score for selected buildings

Figure 3 shows the RVS score calculated for selected buildings and from the figure it is observed that 14% of buildings are having less RVS score ranging from 60 to 90. Buildings with less RVS will have more damage during earthquakes compared to buildings with more RVS score. Around 47% of building has performance score ranging from 111 to 130. Figure 4 shows RVS score for brick masonry buildings and RC buildings separately. Number of RC buildings and brick masonry buildings surveyed was 57 and 43 respectively. Brick masonry buildings are found to have less RVS score compared with RC buildings.

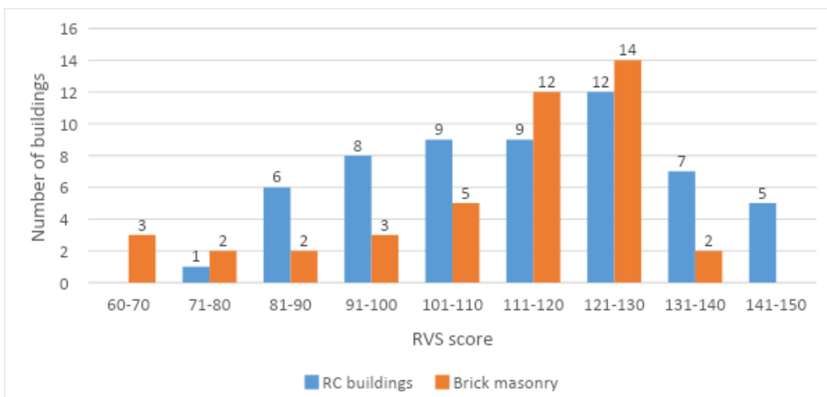

Fig. 4. Range of buildings with different RVS scores for RC and masonry buildings

From Figure 2 it is observed that building parameters such as soft storey, heavy overhangs, apparent quality and pounding effect has different scale ranging from low to high and this scale value varies with storey height. Other parameters have same scale and it is independent of storey height. Hence the buildings with soft storey, heavy overhangs and pounding effect are identified and their streetwise distribution is represented as shown below.

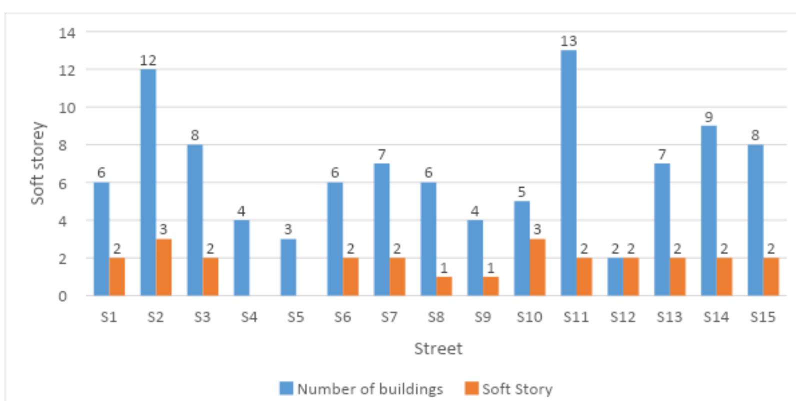

Fig.5. Presence of soft story in buildings

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Figure 5 shows the streetwise distribution of buildings and the number of buildings with soft storey in various streets. Soft storey is an important parameter in finding the vulnerability risk assessment of buildings. Around 26% of buildings are constructed with soft storey. Buildings located in S4 and S5 streets do not have soft storey and hence damage during earthquake will be comparatively less compared to other buildings.

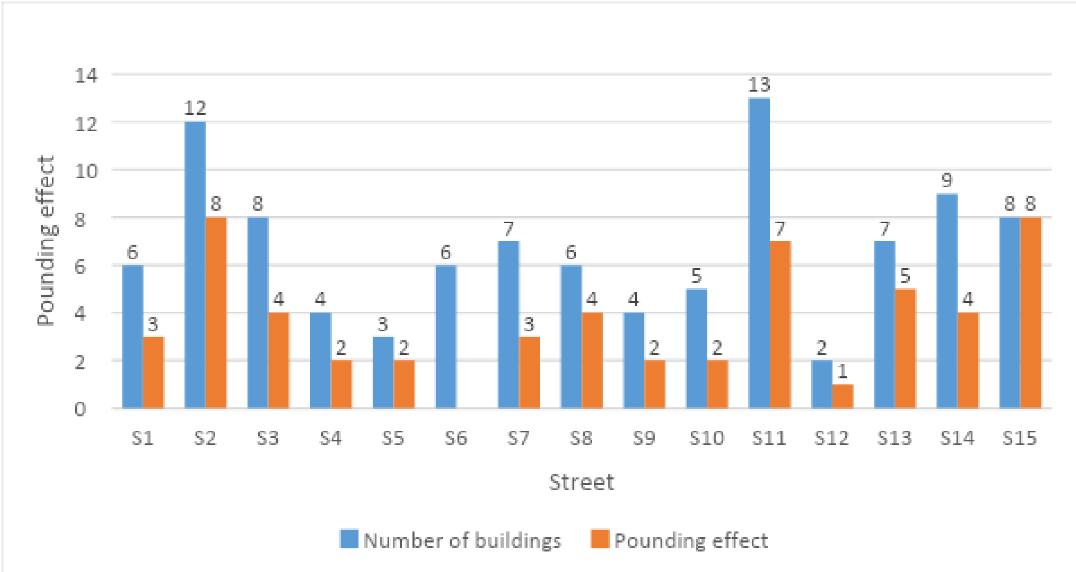

Fig.6. Presence of pounding effect in buildings

Figure 6 shows the distribution of buildings and the number of buildings with pounding effect in various streets. Pounding effect for adjacent buildings during seismic loading makes the building as vulnerable.Buildings located in streets S1,S11 and S15 are found to be more vulnerable during earthquake due to pounding effect.

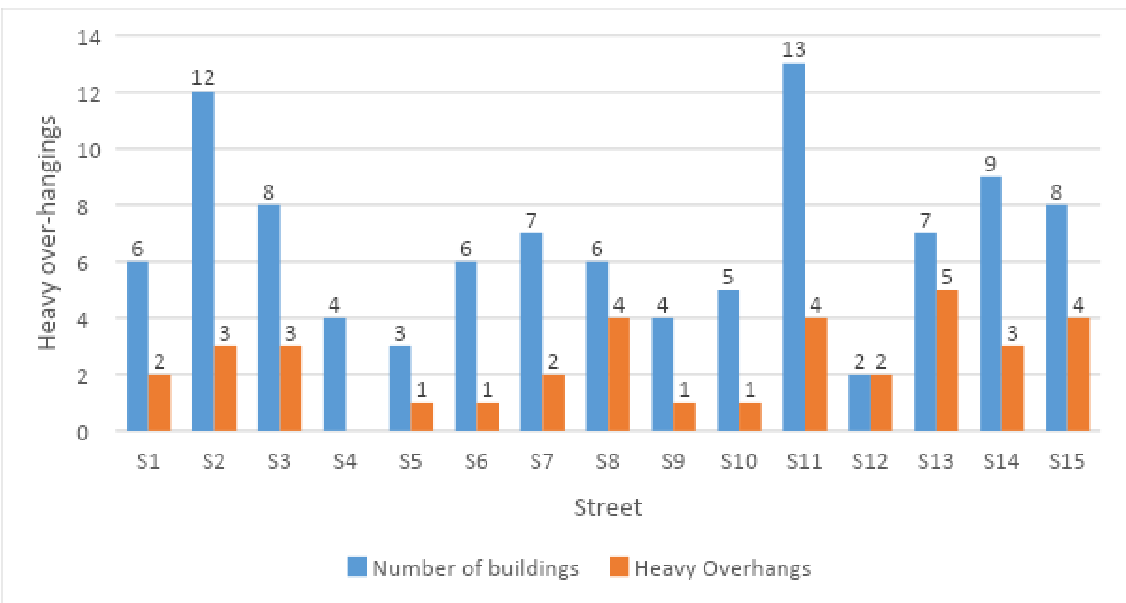

Fig.7. Presence of heavy overhanging in buildings

Figure7 shows the details about distribution of building with heavy overhanging present in buildings. Presence of overhangs in the buildings leads to more damage during earthquake and non-structural elements such as canopies, large balconies, hoardings, and AC's get damaged first during earthquakes. Figure 8 shows the methodology adopted for the present study.

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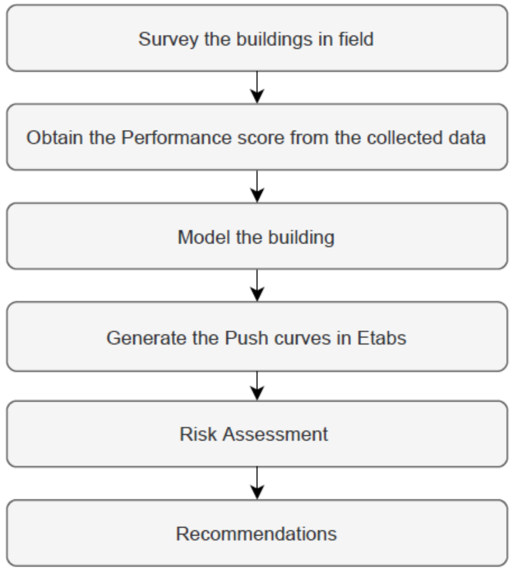

Fig. 8. Methodology for seismic assessment of a building

Nonlinear Static Pushover Analysis

Pushover analysis is a non-linear static procedure to estimate the seismic structure deformation by using simplified non-linear technique. The structure is subjected to gravity loads and the horizontal loads in a prescribed manner, incrementally to determine the force-displacement relationship. The capacity curve for the structure is obtained by plotting the total applied lateral force and associated lateral displacement at each increment, until the structure achieves collapsedstate. The results generate the static-push curve which plots the total base shear versus roof displacement of a structure that would indicate any premature failure or weakness.

In this study the pushover analysis was done for the selected 5 buildings from 100 buildings based on the obtained RVS score. The buildings can be generally analyzed by either displacement control or load control for obtaining push over curve. In this study displacement control method is used and the analysis is carried out until the structure is collapsed. Table 2 shows the specifications for the selected buildings.

Table 2. General specifications for the selected buildings

Specifications	**Building-1**	**Building-2**	**Building-3**	**Building-4**	**Building-5**
Location	Mallanponnappan street, Triplicane	Mallanponnappan street, Triplicane	R.K.Mutt Road, Mylapore	ShaikDawood Street, Triplicane	East Abhiramapuram 1st Street, Mylapore
Storey	G+4	G+2	G+2	G+2	G+1
Seismic zone	III	III	III	III	III
RVS Score	69	89	135	110	125
Utility	Residential	School	Residential	Mixed	Residential
Length(m)	8.4	12	12	9	15.24
Width(m)	4.3	7	9.14	16.5	10.5
Storey Height	3	3	3	3	3
ColumnDim.(m)	0.3×0.3	0.3×0.3	0.3×0.3	0.3×0.3	0.3×0.3
Beam Dim.(m)	0.3×0.3	0.3×0.3	0.3×0.3	0.3×0.3	0.3×0.3
Slab thickness(mm)	150	150	150	150	150
External wall thickness(m)	0.23	0.23	0.23	0.23	0.23
Internal wall thickness(m)	0.1	0.1	0.1	0.1	0.1
Live Load(kN/m^2)	2.5	2.5	2.5	2.5	2.5
Lintel Height(m)	2.85	2.85	2.85	2.85	2.85

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Results and Discussion

From the result of pushover analysis, it is observed the initial stiffness remains same for all the buildings. Figure 9 shows the pushover curve for selected 5 buildings. Out of 5 buildings, building-3 has more strength compared to all the buildings because it has less vulnerable parameters like no heavy overhanging, no irregularities in plan and with the presence of good soil condition and frame action the performance score is obtained as 135 and the building-3 is less vulnerable compared to other buildings that are analyzed. Similarly, the capacity of building is observed to be lower for buildings with low RVS scores. Also, from Figure 9 it is observed that performance of building is low for buildings with low RVS score.

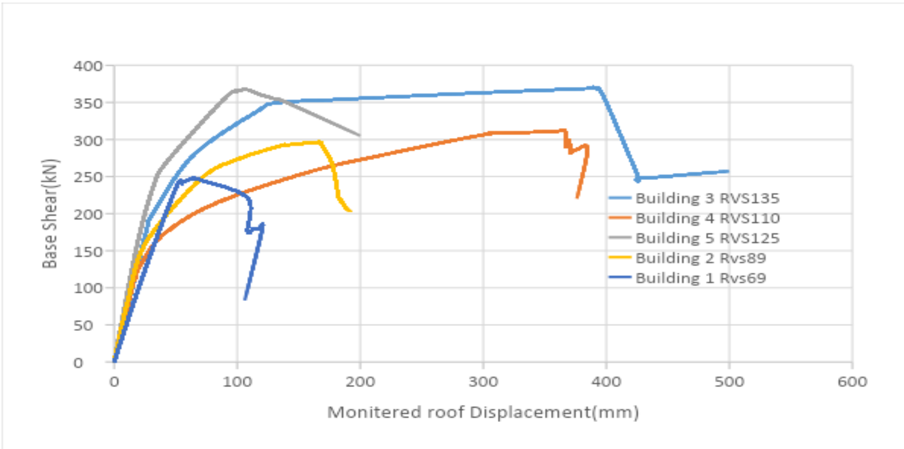

Fig. 9. Pushover curve for different RC buildings

To simplify the findings an attempt is made to correlate the RVS scores from the present study to the damage state curves from previous study of Ajay et.al. In their study damage state is identified based on RVS scores. When the obtained RVS scores from the present study is compared with the curves as given in Figure 10, it is seen that buildings with less RVS scores (69) are subjected to slight damage. As Chennai falls under seismic zone III with a maximum PGA of 0.16g [IS 1893(Part-1):2002], building with RVS score 69 will undergo moderate damage whereas buildings with RVS scores 89 and 110 will undergo slight damage. Also, buildings with RVS 125 can withstand seismic load without any damage till a PGA of 0.27g and buildings with RVS 135 can withstand seismic load without any damage till a PGA of 0.3g. So, it can be concluded that buildings with higher RVS scores perform better during an earthquake event.

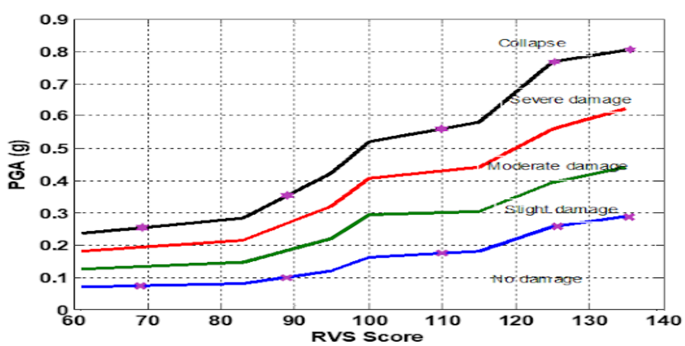

Fig. 10. RVS score and PGA for RC Buildings for Damage state of building from Ajay et.al

In the present study, 60% of buildings that were screened have RVS score ranging from60-120.It is suggested that buildings with RVS score less than the 100 has to be studied further by detailed seismic assessment procedure. The buildings with RVS score greater than 100 will experience moderate damage from the earthquake effects. So, from this study it can be inferred that the selected locationsare potentially vulnerable for the future earthquakes. It is also suggested that buildings with RVS score less than 100 should be provided with the preliminary precautions like retrofitting and renovation. Disaster management organizations can predict the damage that can occur from natural disasters in these areas based on the present study.

Conclusion

The study primarily identified the need of vulnerability study for a metropolitan city like Chennai. It focuses on adaptability of asimple RVS toolfor vulnerability risk assessment in a selected area of interest. A total of 100 buildings were studied for preliminary assessment and 5 buildings were studied with detailed assessment procedure by push over analysis. It is observed that buildings with RVS score greater than 120 are known to have no damage for a design earthquake with 0.16g acceleration. Also,the buildings with less RVS scores will be subjected to slight and moderate damage. It is also observed that use of damage curves from Ajay et.al.,Studies have a potential to adapt for Indian housing typologies. The buildings with lower RVS scores are typically seen with structural deficiencies like soft story, pounding effect, poor quality of construction materials etc. A further detailed study is required to develop damage curves for Chennai city, for which a huge number of buildings have to be considered for the study.

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