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Development of Scoring System for Seismic Vulnerability Assessment of Indian Model Building Types

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***Abstract:*— In order to reduce subjectivity in quick seismic vulnerability assessment a scoring system is used. The general procedure of seismic vulnerability assessment using scoring method requires the building to satisfy a Basic Structural Hazard (BSH) score, below which advanced analysis is required to be performed. A BSH score reflects the estimated likelihood of collapse of the building subjected to the maximum considered earthquake ground motions for the region. Development of scoring system is a complex procedure involving various parameters related to structural vulnerability and anticipated hazards. Different Model Building Types (MBT) possess different structural capabilities for resisting earthquake force, consequently, the BSH score differs for different MBT's. Therefore, it is essential to identify MBTs based on its seismic resistance and develop scoring system for the same. Well established scoring system for buildings of United States has been developed by FEMA-155 based on detailed structural evaluation. However, for Indian MBTs only a few scoring system have been proposed and are primarily based on expert opinion rather than strong mathematical procedure. In present paper it is endeavored to develop score for Indian model building types. The present paper provides methodology to develop the BSH score for Indian MBTs by considering one model building type i.e. Concrete Moment frame (CM1). Further, the proposed procedure can be used to develop BSH score for other Indian MBTs.**

Index Terms **:-- Basic structural hazard score, Model building type, Vulnerability assessment, Rapid visual screening.**

I. INTRODUCTION

Rapid seismic risk assessment of huge building stock requires a comprehensive and precise scoring system based on systematic mathematical procedure. Many seismic evaluation methods have been developed across the world. Rapid Visual Screening (RVS) is one of the methods that have been used at many places [1]. A comprehensive RVS was first proposed by FEMA-154, and then it has been used by other countries after suitable modifications [2]. RVS is immediate aid to determine risk for buildings by observation only. Mainly this procedure includes carrying out survey of buildings in a particular area and completing data collection forms from the surveyed observations concerning structural and non-structural characteristics of the construction and determining a final score using a scoring system. The general procedure of seismic vulnerability assessment using scoring method requires the building to satisfy a BSH score, below which advanced analysis is required to be performed. Well established scoring system for buildings of United States has been developed by FEMA based on detailed structural evaluation. However, for Indian MBT's only a few scoring systems have been proposed and are primarily based on expert opinion rather than strong mathematical procedure. In present paper, systematic methodology to develop the basic structural hazard score for Indian model building types with an example of reinforced concrete moment frame (CM1) is presented.

II. MODEL BUILDING TYPE

In India, various types of buildings are present. Based on various classifying criteria (viz. construction material, lateral load resisting system, roof types and number of storey), group of buildings with common features are expected to behave in a similar fashion for a given earthquake and are classified under specific Model Building Type (MBT) [3], [4], [5], [6], [7]. It has been observed that different MBTs have different seismic vulnerability. Various guidelines have given classification of MBT's. Based on study of different MBTs proposed in literature, a comprehensive list consisting of 28 MBTs have been prepared. The proposed MBTs shown in Table 1 covers most of the buildings constructed in India.

III. SCORING SYSTEM

As described in FEMA-155 "Basic Structural Hazard (BSH) score reflects the estimated likelihood of collapse of the building subjected to the maximum considered earthquake ground motions for the region" [8].

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Table 1 Classification of MBT.

Sr. No.		Label	Description	Height Range	
				Name	Stories
1	Steel	SM1	Steel Moment Frame	Low Rise	1-3
2		SM2		Mid Rise	4-7
3		SM3		High Rise	8+
4		SB1	Steel Braced Frame	Low Rise	1-3
5		SB2		Mid Rise	4-7
6		SB3		High Rise	8+
7		SS1	Steel frame with concrete shear walls	Low Rise	1-3
8		SS2		Mid Rise	4-7
9		SS3		High Rise	8+
10		SMI1	Steel frame with unreinforced masonry infill walls	Low Rise	1-3
11		SMI2		Mid Rise	4-7
12		SMI3		High Rise	8+
13	Concrete	CM1	Concrete Moment Frame	Low Rise	1-3
14		CM2		Mid Rise	4-7
15		CM3		High Rise	8+
16		CS1	Concrete Shear Walls	Low Rise	1-3
17		CS2		Mid Rise	4-7
18		CS3		High Rise	8+
19		CMI1	Concrete frame with unreinforced masonry infill walls	Low Rise	1-3
20		CMI2		Mid Rise	4-7
21		CMI3		High Rise	8+
22	Masonry	RMWM1	Reinforced Masonry bearing walls with wood or metal deck diaphragms	Low Rise	1-3
23		RMWM2		Mid Rise	4+
24		RMC1	Reinforced Masonry bearing wall with precast concrete diaphragms	Low Rise	1-3
25		RMC2		Mid Rise	4-7
26		RMC3		High Rise	8+
27		UM1	Unreinforced Masonry bearing walls	Low Rise	1-2
28		UM2		Mid Rise	3+

FEMA 154 Scoring system is part of RVS data collection forms used for decision making regarding further analysis. Scoring system includes BSH scores of different MBT's, score modifier, cut-off score and a final score of MBT. Development of scoring system is a complex procedure involving various parameters related to structural vulnerability and anticipated hazards. Different Model Building Types (MBT) possess different structural capabilities for resisting earthquake shaking; consequently, the BSH score differs for different MBT's. Therefore, it is essential to identify MBTs based on its seismic resistance and develop scoring system for the same.

IV. RELATIONSHIP OF SEISMIC ZONES, MODEL BUILDING TYPE AND BSH SCORE

Fragility curves of any considered MBT provides the collapse probability of that MBT. Equation (1) can be used to find any probability value.

$$P\left[\frac{ds}{sd}\right] = \varnothing\left[\frac{1}{\beta ds}\ln\left(\frac{sd}{sdds}\right)\right] \qquad (1)$$

The collapse probability it calculated for the desired spectral displacement value. The Spectral displacement value can be calculated from time period of building and corresponding Sa/g (for the considered seismic zone obtained from response spectra) as given in [9], refer (2).

$$sd = \frac{Ti^2}{4\pi^2} \times sa \times g \qquad (2)$$

For four seismic zones, four values of spectral displacement and of collapse probability are obtained. Collapse probability related to BSH score, refer (3).

$$S = -\log_{10}[probability \quad of \quad collapse] \qquad (3)$$

Therefore, by using collapse probability for four seismic zones, score can be obtained for four zones.

V. PROCEDURE ADOPTED FOR CALCULATING THE BSH SCORE OF CM1 (CONCRETE MOMENT FRAME) MBT

General Procedure for calculating BSH score is as follows-

1. Development of capacity curve
2. Development of fragility curve
3. Finding probability of complete damage
4. Calculating probability of collapse
5. Relate probability of collapse to an associated BSH score
6. Determine the BSH score

Flowchart given in Fig. 1, explains the detailed procedure for developing BSH score. First of all generic plan is selected. As the basic score signify the probability of collapse of a low rise building (i.e. one, two or three storey), therefore, calculations has been done for a one storey

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building, two storey building and a three storey building. One, two and three storey buildings are modelled and designed in SAP 2000, followed by pushover analysis. The fragility curves developed have been used to find the damage probability matrices, and collapse probability is determined. The basic score was then calculated taking the average of the probability of collapse of the three different buildings.

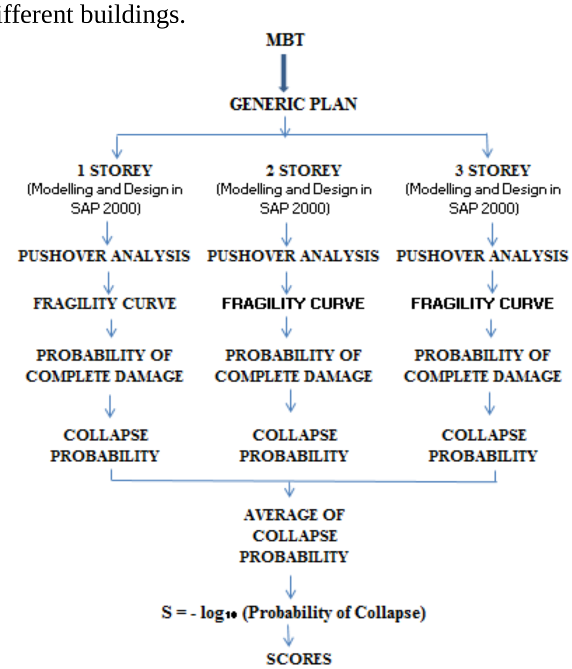

Fig. 1 Flowchart showing procedure for developing score

Equation (4) is used to calculate score by using probability of collapse.

$$S = -\log_{10}\left[probability \quad of \quad collapse\right] \qquad (4)$$

A. Generic Plan

Plan which represents all the building coming under same MBT is called generic plan. Fig. 2 shows generic plan of Concrete Moment Frame (CM1) MBT.

B. Building Parameters

The storey height is considered as 3m. The building is assumed to be situated on medium soil strata (Type II) and is located in the seismic zone V as per Indian standard code with peak ground acceleration (PGA) as 0.18g for design basis earthquake. The response reduction factor and importance factor considered as 5 and 1, respectively.

C. Fragility Curves and parameters

The building is modelled in SAP 2000 [10] as a 3D space frame structure and designed for prescribed base shear as per IS 1893-2002 [11] followed by non-linear static analysis.

Fragility curve is a plot between spectral displacement and the probability of damage state exceeding that spectral displacement. It describes the probability of reaching or exceeding structural damage states for the particular range of spectral displacements. This curve distributes damage in terms of slight, moderate, extensive and complete damage states [5].

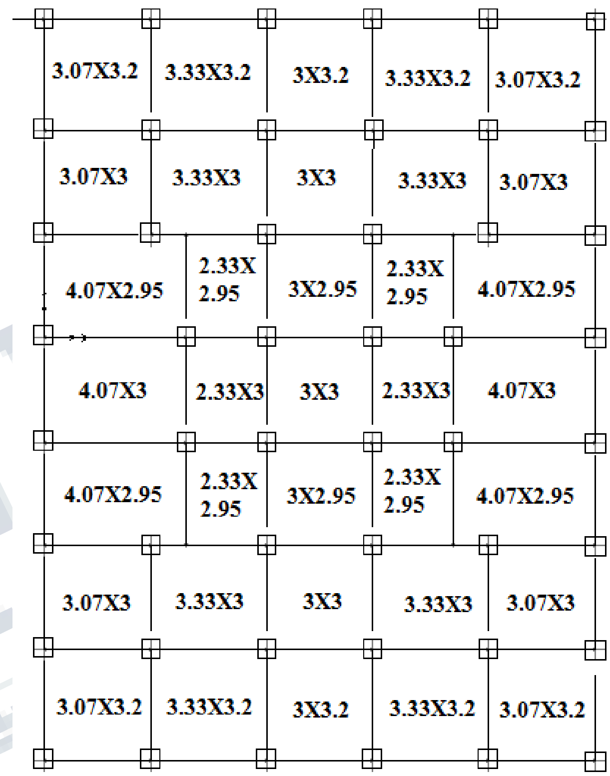

Fig. 2 Plan of MBT

Fragility curve parameters used in developing fragility curve are-

i) Damage-State Median spectral displacement, Sdds,

It represents Median spectral displacement value of damage state, *ds*. Different papers present different values of Sdds, in present study Sdds defined as per [12]. Table 1, Table 2 and Table 3 represents Sdds values used in developing fragility curves for one storey, two storey and three storey building respectively.

ii) Degradation Factor (Kappa factor)

Degradation factor (Kappa) is a function of the expected amplitude and duration of post-yield building response. These parameters depend on the level of ground shaking, which is different for each building site and scenario earthquake. Kappa factors should be selected considering the extent to which brittle failure of the elements and components

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reduces the strength of the structural system. Estimation of structural system degradation (minimum or maximum) is made on the basis of Kappa factors. Kappa factors decrease with increase in response level (and damage). [5]. In the present study, extreme degradation is considered. i.e. k<=0.1.

iii) Damage-State Variability

Lognormal Standard deviation (βds) values describe the total variability of fragility-curve damage states. Three primary sources contribute to the total variability of any given state, namely, the variability associated with the capacity curve, βC, the variability associated with the demand spectrum, βD, and the variability associated with the discrete threshold of each damage state, $\beta T,ds$, refer (5).

$$\beta ds = \sqrt{(CONV[\beta C, \beta D])^2 + \beta T, ds^2} \qquad (5)$$

Where: βds is the lognormal standard deviation parameter that describes the total variability of damage state, *ds*, βC is the lognormal standard deviation parameter that describes the variability of the capacity curve,

βD is the lognormal standard deviation parameter that describes the variability of the demand spectrum (values of βD = 0.45 at short periods and βD = 0.50 at long periods were used to develop Tables 6.5 – 6.7) of Hazus AEBM.

$\beta T,ds$ is the lognormal standard deviation parameter that describes the variability of the threshold of damage state, ds.

HAZUS(AEBM) [5] has given low-rise, mid-rise and high-rise building fragility beta's tables and for finding scores low rise buildings must be considered.

From HAZUS (AEBM) [5] βds values are need to be selected to develop fragility curves and for selecting βds values k, $\beta T,ds$ and βC, values need to be selected, as these values are needed for finding score of building therefore extreme degradation should be considered which shows k<=0.1. As plan is generic so to take large capacity curve variability is beneficial. So βC, considered is 0.4. Also damage variability $\beta T,ds$ considered should be large i.e. 0.6. Hence, value of βds is coming out to be 1.2.

D. Development of Fragility Curves

The conditional probability of being in, or exceeding, a particular damage state, ds, given the spectral displacement, Sd, (or other seismic demand parameter) is defined as shown, refer (6).

$$P\left[\frac{ds}{sd}\right] = \varnothing[\frac{1}{\beta ds}\ln\left(\frac{sd}{sdds}\right)] \qquad (6)$$

where:

Sd,ds is the median value of spectral displacement at which the building reaches the threshold of damage state, *ds*,

βds is the standard deviation of the natural logarithm of spectral displacement for damage state, *ds*, and is the standard normal cumulative distribution function

Fig.3, Fig.4 and Fig.5 shows fragility curves for one storey, two storey and three storey building respectively.

Table 1 Sdds values for one storey

Damage State	sdds	sdds
Slight	0.7 Sdy	0.0077
Moderate	1.5 Sdy	0.0165
Heavy	0.5 (Sdy+Sdu)	0.06
Complete	Sdu	0.109

Table 2 Sdds values for two storey

Damage State	sdds	sdds
Slight	0.7 Sdy	0.0133
Moderate	1.5 Sdy	0.0285
Heavy	0.5 (Sdy+Sdu)	0.06
Complete	Sdu	0.101

Table 3 Sdds values for three storey

Damage State	sdds	sdds
Slight	0.7 Sdy	0.0182
Moderate	1.5 Sdy	0.039
Heavy	0.5 (Sdy+Sdu)	0.105
Complete	Sdu	0.184

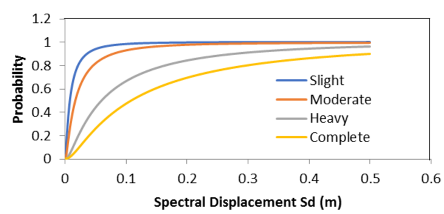

Fig. 3 Fragility curve for one storey

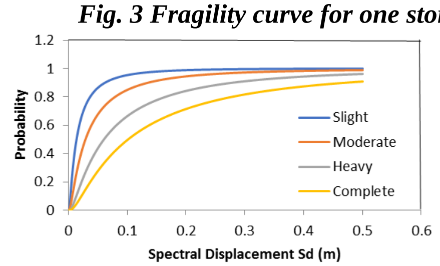

Fig. 4 Fragility curve for two storey

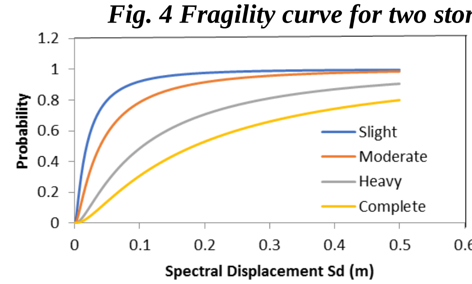

Fig. 5 Fragility curve for three storey

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Calculation of Basic Score

Formula for finding basic score is-

$$S = -\log_{10}\left[probability \quad of \quad collapse\right] \qquad (7)$$

Table 5 shows calculations for finding damage probabilities for one storey building. As per HAZUS TM [13] collapse probability of CM1 MBT is 13%. Therefore, as given in HAZUS TM [13], this 0.13 factor is multiplied with complete structural damage state to obtain collapse damage state as shown in Table 6. Similar calculations are done on two and three storey buildings from which Table 7 and Table 8 are obtained.

Table 5 Calculations for finding damage probabilities for one storey building

Seismic Zone	Z (DBE)	Sd (DBE)	P	Slight	P	Moderate	P	Heavy	P	Complete
II	0.05	0.004	-0.574	0.283	-1.209	0.113	-2.285	0.011	-2.783	0.003
III	0.08	0.006	-0.183	0.428	-0.818	0.207	-1.894	0.029	-2.391	0.008
IV	0.12	0.009	0.155	0.562	-0.480	0.316	-1.556	0.060	-2.053	0.020
V	0.18	0.014	0.493	0.689	-0.142	0.444	-1.218	0.112	-1.715	0.043

Table 6 Calculations for finding collapse probabilities for one storey building

Seismic Zone	None	Slight	Moderate	Heavy	Complete	Collapse	Sum
II	0.717	0.170	0.102	0.008	0.002	0.000	1
III	0.572	0.221	0.178	0.021	0.007	0.001	1
IV	0.438	0.246	0.256	0.040	0.017	0.003	1
V	0.311	0.245	0.332	0.069	0.038	0.006	1

Table 7 Calculations for finding collapse probabilities for two storey building

Seismic Zone	None	Slight	Moderate	Heavy	Complete	Collapse	Sum
II	0.655	0.194	0.101	0.031	0.016	0.002	1
III	0.503	0.237	0.157	0.058	0.039	0.006	1
IV	0.371	0.249	0.203	0.090	0.076	0.011	1
V	0.252	0.235	0.235	0.125	0.133	0.020	1

Table 8 Calculations for finding collapse probabilities for three storey building

Seismic Zone	None	Slight	Moderate	Heavy	Complete	Collapse	Sum
II	0.627	0.204	0.132	0.025	0.011	0.002	1
III	0.473	0.242	0.203	0.050	0.027	0.004	1
IV	0.343	0.248	0.263	0.082	0.056	0.008	1
V	0.229	0.228	0.306	0.119	0.103	0.015	1

Taking average of collapse probabilities of all the three stories refer Table 9.

Table 9 Average of collapse probabilities

Seismic Zone	Collapse Probabilities Average
II	0.001
III	0.004
IV	0.007
V	0.014

Therefore, the Basic Scores for CM MBT for four zones are as shown in Table 10.

Table 10 Basic Scores for CM1 MBT.

Seismic Zone	Basic Score
II	2.9
III	2.4
IV	2.1
V	1.9

VI. CONCLUSION

The present study shows the procedure for finding BSH score for CM1 MBT, the same procedure can be used to find BSH scores for different MBT's available.

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