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REVIEW OF SIMPLIFIED TECHNIQUES FOR SEISMIC EVALUATION OF EXISTING BUILDINGS

[1]Syed Farrukh Anwar,[2]Dr.A. K. Asthana
[1]Department of Civil Engineering, JNTUH, Kukatpally, Hyderabad
[2]Department of Civil Engineering, NSAKCET, Malakpet, Hyderabad

***Abstract* -** Most of the existing RC structures particularly the older ones are lacking adequate earthquake resistance. If such weak buildings can be identified they can be retrofitted so as to withstand the future earthquakes. Seismic vulnerability assessment of existing buildings is a costly, time consuming difficult process. Use of simplified techniques can be justified for most of the structures. The purpose of this Paper is to review such simplified methods for the seismic safety evaluation of existing buildings. Use of simplified techniques is justified for most of the structures. The available methods are either qualitative or analytical or a combination of both. These methods rely on conditional assessment, visual inspection and non-destructive testing. The analytical methods include Capacity/Demand method, Push over analysis, Inelastic time-history analysis etc. Another way of classification divides the methods into 3 categories – Level-1 procedure consisting of Rapid visual screening. Level 2 procedures involving simplified vulnerability assessment based on the information obtained from level-1 and structural drawings or site measurements. Level-3 procedure involves detailed vulnerability assessments, making use of computer. Lot of work in this area has been done in U.S, Japan, Europe and India.

***Keywords*:** RCBuildings, Seismic Safety, Evaluation, Vulnerability, Assessment.

I.Introduction

A large number of great earthquake magnitude of magnitude greater than 8, have occurred in several parts of the world, including the 4 in India. During the past 50 years about a dozen major and moderate earthquakes which occurred in India caused loss of life and severe damage to structures. Some of the early studies [1to 4] were carried by Okada and Bresler[1], who in 1976 came out with the "screening method'' for the strength and ductility evaluation of existing low-rise RC buildings. In 1977, Bresler et al. [2] developed methodologies for the evaluation of earth quake safety of existing buildings. Japanese standard [3] for seismic capacity of existing RC building also came out in 1977. In 1978, two steps stipulated for evaluation for "seismic hazards" by ATC[4]- Qualitative evaluation & Analytical Evaluation, Depending on values of capacity ratios, decision is taken whether the building is to be demolished or strengthened or is safe.

In 1987, ATC-14 covered the evaluation of seismic resistance of existing buildings [5]. In 1988, the 1st edition of the Hand book, FEMA-154 was published (ATC-21) on rapid visual screening (RVS) of building [6] for potential seismic hazards, along with the supporting documentation (FEMA-155), to aid the field surveyor. Original FEMA-178 report [7] included the NEHRP handbook for Seismic Evaluation of ExistingBuildings, prepared by the Building Safety Council in 1992. It was updated to FEMA-310, a Handbook for seismic evaluation of buildings [8] in 1998. ASCE turned it into a consensus based standard, known as ASCE:31-02, which super ceded FEMA-310. The data & of information gathered and experience in applying were used to update and improve the RVS procedure in the 2nd editionof FEMA-154report [9] brought out in March 2002. It is based more on experimental data and less on expert judgment than was the case with 1st edition.

One of the several initiatives that advanced the state-of-the art for seismic risk was the development of FEMA-P-154 ROVER software [10] in 2014 CD version 2 prepared by ATC for FEMA-2014. It can be used on smart phone to document and transmit data gathered in the field. The 3rd edition [11] of FEMA-154 was brought out in Jan'2015 along with the supporting documentation FEMA-155 prepared by ATC in 2015. ATC-55 brought out FEMA-440 in June 2015, which deals with the improvement of Non-linear Static Analysis Procedures [12]. It summarizes the studies to asses the ability of Displacement Coefficient method to estimate the max displacement of inelastic structural models.

In India, after Bhuj Earthquake of 2000 in Gujarat (M=7.9). DurgeshC.Rai [13] of IIT Kanpur presented GSDMA document on seismic evaluation and strengthening of existing buildings in Aug' 2005. This led to the development of IS Guidelines [14] on Seismic evaluation and strengtheningof existing RC buildings (IS: 15988-2013) in Feb 2013.

II. Methodology

The methods of analysis accept conditional assessment, visual examination and Non-destructive testing. The analytical strategies embody

[1]Corresponding Author

Capacity/Demand methodology, Push over analysis, spring less time-history analysis etc. another way of classification divides the methods into three classes – Level-1 procedure consisting of rapid visual screening. Level 2 procedures involving simplified vulnerability assessment depending on the data obtained from level-1 and structural drawings or site measurements. Level-3 procedure involves elaborated vulnerability assessments, making use of computer.

III. Rapid Visual Screening (RVS)

Rapid visual screening (RVS) of buildings for potential seismic hazards, originated in 1988 with the publication of the FEMA-154 Report[6], covered in Introduction.RVS provides a procedure to identify record and rank buildings that are potentially seismically hazardous. This screening methodology is encapsulated in a one-page form, which combines a description of a building, its layout and occupancy, and a rapid structural evaluation related to its seismic hazard. Although RVS is applicable to tall buildings, its principal purpose is to identify (a) older buildings designed and constructed before the adoption of adequate seismic design and detailing requirements (b) buildings on soft or poor soils, or (c) buildings having performance characteristics that negatively influence their seismic response. Once identified as potentially hazardous, such buildings should be further evaluated by a design professional experienced in seismic design to determine if, in fact, they are seismically hazardous.

The rapid visual screening method is designed to be implemented without performing any structural calculations. The procedure utilizes a scoring system that requires the evaluator to (i) identify the primary structural lateral load-resisting system, and (ii) identify building attributes that modify the seismic performance expected for this lateral load-resisting system.

The inspection, data collection and decision-making process typically occurs at the building site, and is expected to take around 30 minutes for each building. The screening is based on numerical seismic hazard and vulnerability score. Basic Structural hazard scores for various building types are provided on the RVS form. The screener modifies the basic structural hazard score by identifying and circling score modifiers which are then added (or subtracted) to the basic structural hazard score to arrive at a final structural score, S.

The basic structural hazard score, score modifiers, the final structural score S, all relate to the probability of building collapse. The result of the screening procedure is a final score that may range above 10 or below 0, with a high score indicating good expected seismic performance and a low score indicating a potentially hazardous structure. While the score is related to the estimated probability of major damage, it is not intended to be a final engineering judgment of the building, but merely to identify buildings that may be hazardous and require detailed seismic evaluation. If the score is 2 or less, a detailed evaluation is recommended. On the basis of detailed evaluation, engineering analysis and other detailed procedures, a final determination of seismic adequacy and need for rehabilitations can be made.

IV. Seismic Vulnerability

Seismic risk [15] can be defined as the possibility or probability of losses due to an earthquake, whether these losses are human, social or economic; seismic Risk(R) can be quantified through the convolution of 4 individual factors:

seismic Risk : R = H.V.E.C

where H = seismic Hazard;

V = Vulnerability;

E = Exposure;

C = specific Cost.

The seismic vulnerability of a structure can be described as its condition to wreck by ground shaking of a given intensity. The aim of a vulnerability assessment is to get the likelihood of a given level of damage to a given building type as a result of a severe earthquake. The different strategies for vulnerability assessment that are projected within the past to be used in loss estimation will be divided into two main categories: empirical or analytical, each of which might be utilized in hybrid strategies.

A vulnerability assessment has to be created for a selected characterization of the ground motion, which is able to represent the seismic demand of the earthquake on the building. The chosen parameter ought to be able to correlate the ground motion with the damage to the buildings. Historically, macro seismic intensity and peak ground acceleration (PGA) are used, while more modern proposals have connected the seismic vulnerability of the buildings to response spectra obtained from the ground motions. Every vulnerability assessment technique models the damage on a discrete damage scales like MSK,MMI AND EMS98.

In empirical vulnerability procedures, the damage scale is employed in reconnaissance efforts to provide post-earthquake damage statistics, whilst in analytical procedures this is often associated with limit-state mechanical properties of the buildings, like interstorey drift capacity.

Seismic vulnerability assessment of structures has been administrated by researchers in numerous parts of the globe; in 2007,Alam et al. [16] performed earthquake vulnerability analysis of buildings in sylhet (Bangladesh) using rapid Visual Screening methodology and a structural scoring system. Srikanth et al. [17] in 2010 performed earthquake vulnerability assessment of existing buildings in Gandidham and Adipur Cities in Kutch, Gujarat. Sadat et al. [18] in 2010, assessed the seismic vulnerability of reinforced cement concrete structures of selected area in Dhaka national capital city in Bangladesh using RVS and Turkish methodology.

Agrawal and Chourasia [19] in 2011 explained the method of seismic analysis on representative buildings in 134 zones /wards of Delhi using questionnaire framed based on Indian seismic codes. Both qualitative and quantitative ways were used. There exist no hard and fast rules concerning the magnitude of earthquake up to which a specific structure is safe. Kamatchi et al. [20] in 2011 reviewed the various methodologies accessible for seismic vulnerability assessment of buildings.

Earthquake vulnerability assessment may be carried out primarily in 2 steps: (i) a preliminary analysis using Rapid Visual Screening (RVS) and (ii) an in depth analysis.

V. Empirical Methods

The seismic vulnerability assessment of buildings at large geographical scales has been first carried out in the early 70s' through the empirical methods initially developed and calibrated as a function of macro seismic intensities. There are 3empirical vulnerability approach methods based on the damage determined after the earthquakes:

(i)Damage Probability Matrices: Whitman et al. [21] proposed the use of damage probability matrices (DPM) for the probabilistic prediction of damaged to buildings from earthquakes; the concept of DPM is that a given structural typology will have the same probability of being in a given damage state for a given earthquake intensity. Whitman compiled for various structural typologies according to the damaged sustained in over 1600 buildings after the 1971 San Fernando earthquake, whilst Barga et al. (1982) based his DPMs on the damage data of Italian buildings after the 1980 Irpinia earthquake. This method is termed "direct" because there is a direct relationship between the building typology and observed damage.

(ii)Vulnerability Index Method: This method has been extensively used in Italy in the past few decades, and is predicted on an over sized quantity of damage survey data; this technique is "indirect" as a result of a relationship between the seismic action and also the response is established through a "Vulnerability Index"(VI). The method uses a field survey form to collect information on the important parameters of the building which could influence its vulnerability: for example, plan and elevation configuration and type and quality of materials,

There are 11 parameters in total, which are each identified as having one of 4 qualification coefficients $K_{i,}$ in accordance with the quality conditions- from A (optimal) to D (unfavorable)- and are weighted to account for their relative importance. The VI ranges from 0 to 382.5, but is generally normalized from 0 to 100, where 0 represents the least vulnerable buildings and 100 the most vulnerable. The data from past earthquakes is used to calibrate vulnerability functions to relate the VI (I_v) to a global damage factor (d) of buildings with the same typology, for the same macroseismic intensity or peak ground acceleration (PGA).

(iii) Continuous Vulnerability Curves: Continuous vulnerability functions based directly of buildings from past earthquakes were introduced slightly later than DPMs. In 1998 Sabetta et al. [22] used data from post-earthquake damaged surveys of 50,000 buildings damaged by destructive Italian earthquakes in order to derive typological fragility curves for typical building classes.

VI.ISCode: 15988 – 2013 Method

The seismic evaluation by the IS code [23] consist of the following steps :

i)EVALUATION CRITERIA:

a) **General**: The seismic performance of existing buildings is evaluated in relation to the performance criteria in use for new buildings. A modification to seismic forces as given by IS: 1893 – 2002 (Part – 1) code [23].

b)Lateral Load Modification Factor(U):

The lateral force (base shear) for new buildings as specified in IS: 1893 [23] is multiplied by usable life factor U, for reduced usable life [14] given by

$$U = (T_{rem}/ T_{des})^{0.5} \qquad (1)$$

Where T_{rem}= remaining useful life of building ; T_{des} = design useful life of building ; U will not be taken less than 0.7 in any case.

c)Modified Material Factor (K): Strength capacities of existing building components will be based on the probable material strengths. For the uncertainty regarding the reliability of available material strength, the probable material strength are multiplied with a knowledge factor K, given in Table 1.

ii)PreliminaryEvaluation:is a quick procedure to establish lateral structural layout & assess its characteristics that may affect its seismic vulnerability. It is primarily based on observed damage characteristics in previous earthquakes along with simple calculations [14].

a) **Site Visit:** is conducted by the design performed to verify available existing building data or collect additional data & to determine the condition of the building & its components. 9 types of information needs to be confirmed or conformed during the visit.

b) Configuration- Related Check: are subdivided into 11 checks ; Load path, Redundancy, Geometry, Weak storey,Softstorey, Vertical discontinuities, Mass, Torsion, Adjacent Buildings, Short Columns, Mezzanines/ Loft/ Sub-floors.

c)Strength- Related Checks: Approximate of quick checks are used to compute the strength &stiffness of the building components. The seismic base shear (V_b) &storey shears computed from IS: 1893& the requirements of Sec. 5 of Code [14]:

1)Modified Demand Lateral Force: is obtained by considering the occupancy risk factor & factor for usable life (U). Hence, the modified seismic base shear $V_{bm}$is obtained by multiplying $V_b$by the factor U:

$V_{bm}= UV_b = U (A_h W) = (U A_h) W$ (2)

where W = seismic weight of the building

$$A_h = (Z I S_a) / (2 R g) \quad (3)$$

= design horizontal acceleration

Z = Seismic Zone factor (Table 2)

I = Importance Factor (Table 6)

R = Response reduction factor (Table 7) S_a/g = Spectral acceleration coefficient

(Obtained from Fig. 2 of code (24))

depending upon the Time period T

& Type of soil, Hard , Medium, Soft.

$$T = 0.075\ h^{0.75} \quad (4)$$

where, h = height of the building in meters

2)Shear Stress in RC Frame Columns: The average shear stress in columns (τ_{col})as per clause 6.51 of code [14] is given by

$$\tau_{col}= \{n_c/ (n_c- n_f)\}. \{V_j / A_c \} \quad (5)$$

where, n_c= total number of columns; n_f= total number of frames in the direction of loading ; V_j = storey shear at level j ; A_c = total area of columns in the storey under consideration.

$(\tau_{col})_{all}$ = lesser of 0.1 $\sqrt{f_{ck}}$& 0.4 MPa

wheref_{ck} = characteristic cube strength of concrete.

If $\tau_{col}>(\tau_{col})_{all}$ the check is not satisfied & hence a more detailed evaluation of the structure should be performed.

3)Shear Stress in Shear Walls: Average shear stress in concrete shear walls is calculated using Eq (6):

$$\tau_{wall}= (V_j / A_{wall}) \quad (6)$$

whereV_j = storey shear at level j &A_{wall} =

total area of shear walls in the direction of loading. Note : for concrete shear walls τ_{wall}should be less than 0.40 MPa.

4)Axial Stress In Moment Frames: The max. compressive axial stress (σ) in the columns of moment frames at base, due to overturning forces alone ((F_0) as calculated using Eq.7 shall be less than σ_{all}= 0.25 $f_{ck.}$

$$F_0 = 2/3 \{ V_B / n_f \} . \{H / L \} \quad (7)$$

where V_B = Base shear x Load Factor; n_f = no. of columns in the direction of loading;

H = total height & L = Length of building.

Axial stress in column, $\sigma= F_0 / a_c$ (8)

where a_c = cross sectional area of column.

If $\sigma<\sigma_{all}$ OK

Note : If the check is satisfied depending on DCR value it is OK; otherwise more detailed evaluation of the structure should be performed.

(iii)Detailed Evaluation:

a) General: The detailed evaluation procedure is based on determining the probable strength of lateral load resisting elements & comparing them with the expected seismic demands. The probable strength from conventional methods & applicable codes shall be modified with appropriate knowledge factor (K) given in Table 1 of code [14]. An assessment of its components & strength of materials is required.

Further, seismic demand on critical individual components shall be determined using seismic analysis methods described in IS: 1893: (Part – 1) [23] for lateral forces prescribed therein with modification for (reduced) useable life factor (U) described in Clause 5 of code [23].

b)Evaluation Procedure: (1) **Probable Flexure & Shear Demand & Capacity**: Estimate the probable flexural & Shear strength of the critical section of the members & joints of vertical lateral forces resisting elements. Perform calculations as per respective codes for various building types & modified with knowledge factor (K).

2)Design Base Shear: Calculate total lateral force (design base shear V_b) as per IS: 1893 (Part 1) & multiply with reduced useable life factor (U) (= 0.7 say) to get modified $V_{bm} = U. V_b$.

3)Analysis Procedure: Perform a linear equivalent state or dynamic analysis of the lateral load resisting system of the building in accordance with IS: 1893 (Part-1) for the modified base shear (V_{bm}) determined in the previous step & determine resulting member and action for critical components.

4)Demand Capacity Ratio: Evaluate the acceptability of each component by comparing its probable strength with the member actions. (Note: component stiffness must be determined based ion some rational procedure. Some standard values are given in Table 2 of Code [14].

5)Inter-StoreyDrift:Calculate the inter-storey drift & decide whether it is acceptable in terms of the requirement of IS: 1893. Drift must be < 0.004 h, h= storey height.

c)Ductility & Detailing Related Evaluation: For moment resisting RC frame buildings designed using response reduction factor R= 5, of [23] the supplemental criteria of Clause 7.4.1 of [14] need to be satisfied. Any deficiency should be considered by suitably reducing the value of R.

d)Acceptability Criteria: A building is acceptable if either of the following two conditions are satisfied (along with the supplemental criteria for a particular type of building described in Clause 7.4).

A) All critical elements of lateral force resisting elements have strengths greater than computed actions and drift checks are satisfied.

B) Except a few elements all critical elements of lateral force resisting elements have strengths greater than the computed actions & drift checks are satisfied.

VII. Conclusion

Of late the seismic activity in the world, including India has increased a lot. A number of catastrophic failures have occurred resulting in loss of life and property. In view of this many countries have upgraded their seismic codes. Hence, most of the existing buildings which were earlier safe, have now become unsafe. Further there are many old buildings which were not designed to resist earthquakes are more vulnerable. Lot of work has been done in the seismic evaluation of existing buildings. But the procedures are lengthy and time consuming. Hence in this paper a review of simplified techniques for seismic safety evaluation of existing RC buildings has been presented. These methods can be easily used by the structural engineers for seismic safety evaluation.

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