International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 11
November 2017

Developments in Simple Seismic Safety Evaluation Methods for Existing RC Buildings in Some Countries

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ABSTRACT

A large number of existing RC buildings in India and other countries do not have sufficient seismic safety which is required as per the latest earthquake resistant design codes. However, since the number of existing buildings which must be evaluated in terms of safety is too high, it is not possible to carry out detailed structural analysis for all existing buildings practically and economically. Consequently utilization of quick evaluation methods for determining the priorities is inevitable [1]. By the help of these quick evaluation methods, valuable information can be attained for deciding which buildings need further detailed analysis and which can be used with their existing safety levels. Hence in this paper the developments in such methods for seismic safety evaluation of existing RC buildings in critically reviewed in some countries like Japan, Turkey, Algeria, US and India.

KEYWORDS

RC buildings, Seismic, Safety, Evaluation, Vulnerability, Assessment

INTRODUCTION

The 1968 Tokachi-Oki earthquake caused significant damage for the first time in Japan to RC buildings; RC columns failed in shear in school buildings. So, concern was expressed about the earthquake safety of existing RC buildings. Various methods were developed for the seismic vulnerability assessment of existing buildings against future earthquakes. An integrated method to evaluate the seismic vulnerability of existing low to mid-rise RC buildings was published [2] in 1977 by JABDP. After the 1995 Hyogo-Ken Nanbu earthquake, a seismic vulnerability assessment procedure was outlined in the Ministry of Construction Notification No. 2089, which examines if a structure possesses the seismic resistance of a level specified in the buildings standard law [3].

Following the strong 1999 Kocaeli earthquake (M=7.4) in Western Turkey a seismic evaluation of retrofits of existing buildings were promoted in Turkey. The Turkish Code [4] is similar to the Japanese seismic design code in seismic capacity level. Bourmerdes earthquake [5] in Algeria caused more than 2,200 deaths and 19,000 buildings collapsed leading to seismic evaluation by Japanese standard.

In India, the buildings constructed before the publication of IS: 1893-2002 (Part-1) Code [6], both the level of lateral earthquake loads are too small and the reinforcing details for providing adequate ductility, were not considered as desired in ductile detailing Code [7] IS: 13920-1993. Consequently, the existing buildings must be repaired and strengthened or demolished and built again in order to reduce the risks and prevent the loss of life and property [1].

A number of procedures have been proposed to assess the seismic performance of existing buildings. The procedures have varying degree of accuracy and complexity; thus their selection depends on the need and the objective. Rapid screening procedures are generally employed to determine the vulnerability ranking of a group of buildings based on rapid assessments carried out from the strut survey. Preliminary procedures are proposed to assess the buildings using more data and some simple calculations for prioritization ranking of a group of buildings [8]. Detailed assessment procedures aim to determine weakness and rehabilitation/

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strengthening needs of existing buildings. The developments in some countries are briefly reviewed as follows.

JAPANESE SEISMIC INDEX METHOD

This method is used for rapid seismic evaluation of building type structures with frame, frame-shear wall and shear wall systems [1]. The standard consists of 3 different levels of procedures. 1st level procedure: is the simplest and most conservative. Only the strength of concrete and the sectional areas of columns and walls are considered to estimate the seismic capacity, and the ductility is neglected. In the 2nd and 3rd level procedures, ultimate lateral load carrying capacity of vertical members of vertical or frames are evaluated using material and sectional properties together with reinforcing details based on the field inspections and structural drawings. The 2nd level procedure: evaluates the building seismic capacity based upon the strength and ductility of columns and walls assuming a strong beam concept. The 3rd level procedure: considers the strength of beams in addition to the strength of columns and walls to evaluate the seismic capacities of buildings, which are expected to beam failure types [10].

Out of the 3 levels of seismic procedures, the 1st level screening is simple and the result is on safe side. The 2nd level screening is performed based on the column collapse mode. The 3rd level screening is performed including beam collapse mode, but calculation volume increases. Column collapse mode is dominant for buildings in Algiers [5].

First step: of investigation involves the examination of the structural system, age and physical conditions of the building. After this examination, the performance index I_s can be determined. Comparing I_s with the adequate reference index I_{so}, the seismic safety of the building can be estimated [1].

This comparison should be repeated for all critical stories and for 2 principal directions. If for all comparisons $I_{so} < I_s$, then the building may be assumed to be safe against earthquake. If for any of the comparison case, $I_{so} > I_s$, then it is concluded that the behavior of structure is indeterminate against earthquake. Note that $I_{so} < I_s$ does not mean that the structure will not be damaged; however, it indicates that very probably the total collapse will be prevented.

The criterion of the seismic performance of a building is expressed by the reference index I_{so} or seismic demand index of the structure [5] given by Eq. (1):

$$I_{so} = E_s \,.\, Z.\, G.\, U \qquad (1)$$

Where, E_s is a basic structural judgment or reference index or basic seismic demand index of structure, can be considered = 0.8 for 1st stage analysis. E_s is modified by reduction factors due to seismic zonings (Z), ground conditions (G) and building uses (U).

The zone factor Z = 1.0 for areas that are identified as 1st or 2nd degree of earthquake zone by Turkish earthquake resistant design code- 1998 [4] and other areas of high risk. In other areas Z can be reduced according to the seismicity of the region. In any case Z should be > 0.7.

G is the ground index or coefficient having values between 1.0 and 1.1, with lower values for better ground conditions [1].

U is the usage index or coefficient related with the importance and usage of the building. It should be decided considering the importance of the structure and the extent of possible effects of damage after earthquakes. Since the buildings, which need to be in service after earthquakes like hospitals, schools, fire stations etc, it is convenient to use U = 1.0; however if necessary U can be increased [1] up to 1.50.

The seismic performance Index I_s of the structure is given by Eq. (2);

$$I_s = E_o \,.\, S_D \,.\, T \qquad (2)$$

Where E_o is the basic structural index calculated from the product of strength index (C), ductility index (F) and the storey index (Ø); thus

$$E_o = Ø \,.\, C \,.\, F \qquad (3)$$

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As seen from Eq. (3), the load carrying capacity is a function of both strength and ductility; the storey index Ø accounts for the storey level being considered. $Ø = (n + 1)/(n + i)$ (4)

Where n = no. of storeys and i = no. of storey level.

In each of the 3 screenings a separate procedure is used to compute the strength index (C), which is defined as

$$C = \frac{\text{la} \quad \text{l} \quad \text{c} \quad \text{c} \quad \text{o fl} \quad \text{b} \quad \text{c}}{\text{t} \quad \text{m} \quad \text{a} \quad \text{t} \quad \text{fl} \quad \text{l}}$$

The value of ductility index (F) in the first screening are; F =1.0 for wall & column h/d > 1.0 and for short column h/d ≤ 2, F = 0.8. For 2nd & 3rd screenings F values are higher than of 1st.

S_D is the irregularity Index, to evaluate the physical properties and geometry of the structure like irregularity in plan, length/ width ratio of plan, eccentricity in plan; for symmetric plan S_D =1.0; for asymmetric plan L, T or U, S_D =0.9 for others see Ref. [9].

T is the time index; it is determined according to the existing damage of the building done to environment effects, aging etc. for deformations, cracks and other damage see [9]. Time index T can be taken between 0.8 & 1.0.

Note: Seismic evaluation and retrofit plan by the Japanese standards for 3 existing RC buildings (an apartment house, a school and a hospital) of Algiers capital of Algeria can be introduced [5]. Seismic judgment is done by the comparison of seismic Index of structure I_s, and the seismic demand I_{so}, which is adjusted based on expected seismic intensity of Algiers.

US BASED RAPID VISUAL SCREENING (RVS) METHOD

Rapid visual screening (RVS) of buildings for potential seismic hazards, originated in 1988 with the publication of the FEMA-154 Report [11], 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.

IS CODE: 15988 – 2013 METHOD

The seismic evaluation by the IS code [12] consisting of the following steps:

A. Evaluation Criteria:

1. 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 [6].

2. Lateral Load Modification Factor (U):

The lateral force (base shear) for new buildings as specified in IS: 1893 [6] is multiplied by usable life factor U, for reduced usable life [12] given by

$$U = (T_{rem} / T_{des})^{0.5} \quad (5)$$

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.

3. 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 of code [12].

B. PRELIMINARY EVALUATION:

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 [12].

1. 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 need to be confirmed or conformed during the visit.

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

3. 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 [12].

Remaining calculations can be performed using formulae given in code [12].

CONCLUSIONS

The developments in preliminary seismic safety evaluation methods for existing RC buildings in some countries (like Japan, Turkey, Algeria, US & India) have been briefly reviewed in this paper. These methods are 1st level screening procedures. In general there are 3 levels of seismic screening procedures. These procedures have varying degree of accuracy and complexity thus their selection depends on the need and the objective. Rapid screening procedures are generally employed to determine vulnerability ranking of a group of buildings based on rapid assessments carried out from the street survey. Preliminary procedures are proposed to assess the buildings using more data and some simple calculations for prioritization ranking of a group of buildings. Detailed assessment procedures aim to determine weakness and retrofit needs for existing buildings.

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