International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395 -0056
Volume: 04 Issue: 02 | Feb -2017 www.irjet.net p-ISSN: 2395-0072

SEISMIC ANALYSIS OF REINFORCED CONCRETE BUILDINGS -A REVIEW

Krishna G Nair[1], Akshara S P[2]

[1]*PG Student, Department of Civil Engineering, FISAT, Angamaly, India*
[2]*Assistant Professor, Department of Civil Engineering, FISAT, Angamaly, India*

Abstract - *The response of building when subjected to seismic excitation can be evaluated in a number of ways. Structural analysis methods can be mainly divided into four categories Equivalent Static Analysis, Linear dynamic analysis, Nonlinear Static Analysis, Nonlinear dynamic analysis. Equivalent Static Analysis method or linear static analysis, defines a series of forces acting on a building to represent the effect of earthquake ground motion. In this method, the design base shear is computed for the whole building, and it is then distributed along the height of the building. The response spectrum analysis determines the natural frequencies and mode shapes via eigen value analysis. It is used to estimate the peak response whereas the time history analysis provides a method for obtaining the exact response of a structure as a function of time. The response-history is normally determined using step by step numerical integration of the equation of motion. Nonlinear Static Analysis is also known as pushover analysis. A pattern of forces is applied to a structural model that includes non-linear properties (such as steel yield), and the total force is plotted against a reference displacement to obtain a capacity curve. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model.*

Key Words: Dynamic Analysis, Base shear, Seismic forces, Pushover analysis, Time history

1. INTRODUCTION

All over the world, there is a high demand for construction of tall buildings due to increasing urbanization and spiraling population, and earthquakes have the potential for causing the greatest damages to tall structures. Reinforced concrete multi-storied buildings are very complex to model as structural systems for analysis. Usually, they are modeled as two-dimensional or three-dimensional frame systems using finite beam elements. Since earthquake forces are random in nature and unpredictable, the engineering tools need to be sharpened for analysing structures under the action of these forces. Earthquake loads are required to be carefully modeled so as to assess the real behaviour of structure with a clear understanding that damage is expected but it should be regulated. Analysing the structure for previous earthquakes of different intensities and checking for multiple criteria at each level has become essential and pivotal these days. The main parameters to be checked in the seismic analysis of structures are load carrying capacity, ductility, stiffness, damping and mass. The design can be divided into two main steps. First, a linear analysis is conducted with dimensioning of all structural elements, ensuring the functionality of the structure after minor earthquakes, and then the behaviour of structures during strong earthquakes has to be conducted using nonlinear methods. Dynamic analysis should be performed for symmetrical as well as unsymmetrical buildings. In unsymmetrical building structures the major parameter to be considered is Torque.

2. SEISMIC ANALYSIS OF STRUCTURE

For the determination of seismic responses it is necessary to carry out seismic analysis of the structure. The analysis can be performed on the basis of external action, the behaviour of structural materials, structure and the type of structural model selected. Based on the type of external action and behaviour of structure, the analysis can be further classified as:

(1) Linear Static Analysis
(2) Nonlinear Static Analysis
(3) Linear Dynamic Analysis
(4) Nonlinear Dynamic Analysis

2.1 Linear Static Analysis

This method is also known as Equivalent Static Analysis method. This procedure does not require dynamic analysis, however, it account for the dynamics of building in an approximate manner. The static method is the simplest one among all the other analysis procedures. It requires less computational efforts and is based on formulas given in the code of practice. First, the design base shear is computed for the entire building and it is then distributed along the height of the building. The lateral forces at each floor levels thus obtained are distributed to individual lateral load resisting elements. The equivalent static analysis procedure involves the following steps:

- Calculation of the Design Seismic Base Shear, V_B
- Vertical distribution of base shear along the height of the structure
- Horizontal distribution of the forces across the width and breadth of the structure
- Determination of the drift and overturning moment

Calculation of the Design Seismic Base Shear, V_B

The total design lateral force or design seismic base shear, V_B as per Clause 7.5.3, IS 1893(Part 1)-2002, along any principal direction shall be determined by:

$$V_B = A_h W$$

where,

W is the seismic weight of the building
A_h is the horizontal seismic coefficient

Horizontal Seismic Coefficient, A_h

The horizontal seismic coefficient, A_h depends on several factors and can be written in different manner according to the seismic codes. In all cases the controlling parameters are the same. As per Clause 6.4.2, IS 1893(Part 1)-2002,

$$A_h = \frac{Z\, I\, S_a}{2\, R\, g}$$

Provided that for any structure with T < 0.1 s, the value of A_h will not be taken less than Z/2 whatever be the value of I/R where,

Z - Zone factor
I - Importance factor
Sa/g - Average response acceleration coefficient
T - Undamped Natural period of the structure
R- Response Reduction factor

Zone Factor (Z)

It is a factor to obtain the design spectrum depending upon the maximum seismic risk characterized by Maximum Considered Earthquake (MCE) in the zone in which the structure is located. The basic zone factors included in Table 2, IS 1893(Part 1)-2002 are reasonable estimate of effective peak ground acceleration.

Average response acceleration coefficient (Sa/g)

The design ground motion is one of the important factors used to determine the required seismic resistance (strength) of structures and supported non-structural components. Average response acceleration coefficient depends on the type of rock or soil sites and also the natural period and damping of the structure. It is a factor denoting the acceleration response spectrum of the structure subjected to earthquake ground vibrations. Average response acceleration coefficient for rock and soil sites can be determined from Figure 2 of IS 1893(Part 1)-2002.

Importance Factor (I)

The importance class or factor of a building depends on the occupancy category of the building. Hence, essential facilities such as hospitals, police stations, schools are designed for seismic forces greater than normal. The minimum value of importance factor are given in Table 6 of IS 1893(Part 1)-2002.

Site Class (Ground Conditions)

To consider the site effect on the estimation of the equivalent lateral static force, the concept of Site Class is used to categorize common soil conditions into broad classes to which typical ground motion effects are assigned. Site Class is determined based on the average properties of the soil within a certain depth (30 m) from the ground surface.

Response Reduction factor (R)

The behavior factor or the reduction factor R, which is determined by the type of lateral load resisting system used, is a measure of the system's ability to accommodate earthquake loads and absorb energy without collapse. The values of R, are prescribed in Table 7 of IS 1893(Part 1)-2002 for different types of building systems.

Fundamental Period (T)

The fundamental period, T of the structure is used to determine the design ground acceleration and in some codes to establish the distribution of the shear along the height of the structure. The fundamental time period for buildings are given in Clause 7.6 of IS 1893(Part 1)-2002.

Vertical Distribution of Base Shear to Different Floors

After the total base shear is known, it is used to determine the forces on the various building elements. The sum of the loads at each level equals the total base shear. Since the greatest force is at the top, the shear increases from zero at the top to its maximum at the base of the building. Each floor shear is successively added to the sum from above. As per IS 1893(Part 1)-2002, Clause 7.7.1, the lateral force induced at any level h_i can be determined from the following equation:

$$Q_i = V_B \frac{W_i h_i^2}{\sum_{j=1}^{n} W_j\ h_j^2}$$

where,

Q_i - Design lateral force at floor i
W_i - Seismic weight of floor i
n - Number of storey's in the building is the number of levels at which the masses are located
h_i - Height of floor i measured from base

Horizontal Distribution of Base Shear

For buildings whose floors are capable of providing rigid horizontal diaphragm action, the total shear in any horizontal plane shall be distributed to the various vertical elements of lateral force resisting system, assuming the floors to be rigid infinitely in the horizontal plane. The distribution expression by FEMA P749 is as follows:

$$F_{ij} = \frac{K_{ij}}{\sum_{k=1}^{nk} K_{ik}} F_i$$

where,

F_{ij} - force acting on the lateral force-resisting line j at a floor level i
K_{ij} ,K_{ik} - story stiffness of the lateral force-resisting element (line) k and j at level i
F_i - seismic force at floor (level) i
nk - number of lateral force-resisting elements

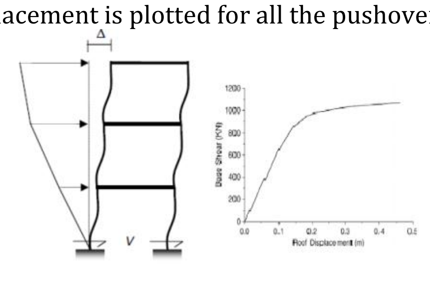
Drift Storey
Design of structures against seismic loading must ensure that the anticipated lateral deflection in response to earthquake shaking does not exceed acceptable levels. The lateral deflection is expressed as the inter-storey drift which is a measure of how much one floor or roof level displaces under the lateral force relative to the floor level immediately below.

Overturning Moment
There is a tendency for the moment created by the equivalent lateral force acting above the base to overturn the structure. This overturning force must be counteracted by stabilizing load. Usually, the dead weight of the building also acting through the center of mass of the structure is sufficient to resist the overturning force, but it must always be checked.

2.2 Nonlinear Static Analysis

Nonlinear static analysis also known as Pushover Analysis procedure is mainly used to estimate the strength and drift capacity of existing structure and the seismic demand for this structure subjected to selected earthquake. This analysis procedure can be used for checking the adequacy of new structural design as well. The effectiveness of pushover analysis and its computational simplicity brought this analysis procedure in to several seismic guidelines (ATC 40 and FEMA 356) and design codes (Eurocode 8 and PCM 3274).

Pushover Analysis Procedure
The magnitude of the lateral load to be applied is increased monotonically maintaining a predefined distribution pattern along the height of the building (Fig. 1.a) for the pushover analysis procedure. Building is displaced till the "control node" reaches the "target displacement" or building collapses. The sequence of cracking, plastic hinging and failure of the structural components is observed throughout the procedure. The relation between base shear and control node displacement is plotted for all the pushover analysis.



a) Building model b) Pushover curve

Fig-1: Schematic representation of pushover analysis procedure

For the generation of base shear, control node displacement curve is single most important part of pushover analysis. This curve is called as pushover curve or capacity curve. The capacity curve is the basis of "target displacement" estimation.

Lateral Load Patterns
A specific load distribution pattern is applied along the height of the building in pushover analysis procedure. The magnitude of the total force is increased but the pattern of the loading remains same till the end of the process. Pushover analysis results are very sensitive to the load pattern.

Target Displacement
Target displacement can be defined as the displacement demand for the building at the control node subjected to the ground motion which is considered for the analysis. It is an important parameter in pushover analysis procedure because the global and component responses (forces and displacement) of the building at the target displacement are compared with the desired performance limit state to know the building performance. Therefore, the success of a pushover analysis largely depends on the accuracy of target displacement obtained.

2.3 Linear Dynamic Analysis

Response spectrum method is a linear dynamic analysis method. In this method the peak response of structure during an earthquake is obtained directly from the earthquake response, but this is quite accurate for structural design applications. In this approach multiple mode shapes of the building are taken into account. Computer analysis can be used to determine the different modes for a structure. Based on the modal frequency and the modal mass, for each mode a response is read from the design spectrum, and they are then combined to provide an estimate of the total response of the structure using modal combination methods. In this we have to calculate the magnitude of forces in all directions i.e. X, Y & Z and then see the effects on the building. Combination methods include the following:

- Square Root Sum of Squares (SRSS)
- Complete Quadratic Combination (CQC)
- Absolute Sum method

Modal analysis is an alternative procedure to the equivalent lateral force method performed to obtain the design lateral forces at each floor level along the height of the building and its distribution to individual lateral load resisting elements.

Modal Analysis
The buildings with regular or irregular, plan configurations may be modeled as a system of masses lumped at the floor levels with each mass having one degree of freedom. In the modal analysis the variability in masses and stiffness is accounted for in the computation of lateral force coefficient. The following expressions given in IS 1893(Part 1)-2002, are used for computations of various quantities.
a) Modal Mass (clause 7.8.4.5(a))
The modal mass M_k of mode k is given by

$$M_k = \frac{\left[\sum_{i=1}^{n} W_i \emptyset_{ik}\right]^2}{g \sum_{i=1}^{n} W_i (\emptyset_{ik})^2}$$

where, g is the acceleration due to gravity, $\emptyset_{ik}$ is the mode shape coefficient at the floor i in the mode k, and W_i is the seismic weight of floor i.

b) Modal Participation Factor (clause 7.8.4.5 (b))

The modal participation factor P_k for mode k is given by

$$P_k = \frac{\sum_{i=1}^{n} W_i \emptyset_{ik}}{\sum_{i=1}^{n} W_i (\emptyset_{ik})^2}$$

c) Design lateral force at each floor level in each mode(clause7.8.4.5(c))

The peak lateral force Q_{ik} at each floor i in k^{th} the mode is given by

$$Q_{ik} = A_K \emptyset_{ik} P_k W_i$$

where, A_K is the design horizontal acceleration spectrum value(clause 6.4.2) using the natural period of vibration T_K of k^{th} mode.

d) Storey shear forces in each mode (clause 7.8.4.5(d))

The peak shear force V_{ik} acting in storey i in mode k is given by

$$V_{ik} = \sum_{j=i+1}^{n} \emptyset_{ik}$$

e) Storey shear forces due to all modes considered(clause 7.8.4.5(e))

The peak storey shear force V_i in storey i is due to all modes considered is obtained by combining those due to each mode as explained in modal combination.

1) Since the modal maximum values generally do not occur simultaneously, approximate methods such as square root of sum of squares (SRSS) or maximum absolute response (ABS) methods are used.

2) The ABS method gives upper limit for maximum response and is therefore conservative. The SRSS method provides reasonable estimate of total maximum response.

f) Lateral forces at each storey due to all modes considered(clause 7.8.4.5(f))

The design lateral forces, F_{roof} and F_i, at roof and at floor i are given by

$$F_{roof} = V_{roof}$$

$$F_i = V_i - V_{i+1}$$

2.4 Nonlinear Dynamic Analysis

Nonlinear dynamic analysis is also referred as Time history analysis. It is an important method for structural seismic analysis especially when the evaluated structural response is nonlinear. To perform this analysis, a representative earthquake time history data is required for a structure being evaluated. Time history analysis is a step-by step analysis procedure of the dynamic response of a structure for a specified loading that may vary with time. Time history analysis is used to determine the seismic response of a structure under dynamic loading for a representative earthquake.

Although the spectrum method, outlined in the previous section, is useful technique for the elastic analysis of structures, it is not directly transferable to inelastic analysis because the principle of superposition is no longer applicable. Also, the analysis is subject to uncertainties inherent in the modal superimposition method. The actual process of combining the different modal contributions is a probabilistic technique and, in certain cases, it may lead to results not entirely representative of the actual behaviour of the structure. The THA technique represents the most accurate method for the dynamic analysis for buildings. In this method, the mathematical model of the building is subjected to accelerations from earthquake records that represent the expected earthquake that may occur at the base of the structure. The method consists of a step- by- step direct integration over a time interval; the equations of motion are solved with the accelerations, velocities and displacements of the previous step serving as initial functions.

The equation of motion can be represented as

$$kx(t) + c\dot{x}(t) + m\ddot{x}(t) = p(t)$$

where,

k is the stiffness matrix, c is the damping matrix, and m is the diagonal mass matrix.

In case of an earthquake, p(t) includes ground acceleration and the displacements, velocities and accelerations are determined relative to ground motion.

The time-history method can be applied to both elastic and inelastic analysis. In elastic analysis the stiffness characteristics of the structure are assumed to be constant for the whole duration of the earthquake. In the inelastic analysis, the stiffness is assumed to be constant through the incremental time only. Modifications to structural stiffness caused by cracking, forming of plastic hinges, etc are incorporated between the incremental solutions. Even with the availability of sophisticated computers, the use of this method is restricted to the design of special structures such as nuclear facilities, military installations, and base-isolated structures.

3. CONCLUSIONS

Based upon the accuracy of results needed and the importance of the building that needs be analysed various seismic analysis procedures can be adopted like Linear Static Analysis, Nonlinear Static Analysis, Linear Dynamic Analysis and Nonlinear Dynamic Analysis. Study of all these analysis procedures were carried out in this work.
Wrong model, simplified in the wrong places, can cause very different results compared to the real building. This is especially important in seismic loading, because when a section is designed to yield, and it turns out to be stronger than designed, it may cause the wrong part to yield, putting the whole structure into failure.

In smaller structures it may not be worth the effort needed to construct a proper detailed model to investigate the effects of seismic loading. Therefore, response spectrum analysis or equivalent static analysis can be used with little effort.
If very accurate and precise result is required from the analysis, non-linear dynamic analysis should be carried out. But this method is more complicated and it requires more computations. Finding relevant time histories for the location chosen can also be a challenge. Therefore alternative methods are needed.

REFERENCES

[1] Chopra AK (1995). “Dynamics of Structures Theory and Application to Earthquake Engineering”, University of California at Berkeley, USA.
[2] Duggal S K (2010). “Earthquake Resistance Design of Structure”, Fourth Edition, Oxford University Press, New Delhi.
[3] FEMA 356 (2000). “Pre-standard and commentary for the seismic rehabilitation of buildings”, American Society of Civil Engineers, USA.
[4] IS 1893 Part 1 (2002). “Indian Standard Criteria for Earthquake Resistant Design of Structures”, Bureau of Indian Standards, New Delhi.
[5] Jan. T.S, Liu. M.W. and Kao. Y.C. (2004). “An upper-bond pushover analysis procedure for estimating the seismic demands of high-rise buildings”, Engineering structures. 117-128.
[6] Nouredine Bourahla (2013)."Equivalent static analysis of structures subjected to seismic actions", Encyclopedia of Earthquake Engineering, Springer-Verlag Berlin Heidelberg.
[7] Pankaj Agarwal and Manish Shrikhande (2014), "Earthquake Resistant Design of Structures", PHI Learning Private Limited, Delhi.
[8] Prof. Sakshi Manchalwar, Akshay Mathane, Saurabh Hete and Tushar Kharabe (2016) "Comparative study of seismic analysis of 3-storey RC frame", International Journal of Science, Engineering and Technology Research (IJSETR), ISSN: 2278- 7798
[9] Saurabh G Lonkar and Riyaz Sameer Shah, ''Comparative study of static and dynamic analysis of multi-storey Regular & irregular building-A Review", International Journal of Research in Engineering, Science and Technologies, ISSN 2395-6453.