CHAPTER 2

METHODS OF ANALYSIS FOR EARTHQUAKE FORCES

2.1 GENERAL

Seismic analysis is related to calculation of the response of a building or other structures under earthquakes. It is a part of the process of structural design which includes earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent.

During earthquake many of the buildings collapse due to lack of understanding of the inelastic behavior of structure. Elastic analysis gives only elastic capacity of the structure and indicates where the first yielding occurs. It cannot give any information about redistribution of forces and moments and failure mechanism.

For study of inelastic behavior of structure nonlinear analysis is necessary. The development of rational methodology that is applicable to the seismic design of new structures using available ground motion information and engineering knowledge, and yet is flexible enough to permit the incorporation of new technology as it becomes available has been supported for sometimes now. This is the focus of several major research and development efforts throughout the world. In majority of cases nonlinear analysis is used.

2.2 METHOD FOR LINEAR STATIC ANALYSIS

This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves.

The response is read from a design response spectrum, given the natural frequency of the building. The applicability of this method is extended in many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces.

2.3 METHODS FOR LINEAR DYNAMIC ANALYSIS

2.3.1 Linear Dynamic Analysis

Static procedures are appropriate when higher mode effects are not significant. This is generally true for short, regular buildings. Therefore, for tall buildings, buildings with torsional irregularities, or non-orthogonal systems, a dynamic procedure is required.

In the linear dynamic procedure, the building is modeled as a multi-degree-of-freedom (MDOF) system with a linear elastic stiffness matrix and an equivalent viscous damping matrix. The seismic input is modeled using either modal spectral analysis or time history analysis but in both cases, the corresponding internal forces and displacements are determined using linear elastic analysis. The advantage of these linear dynamic procedures with respect to linear static procedures is that higher modes can be considered. However, they are based on linear elastic response and hence the applicability decreases with increasing nonlinear behavior, which is approximated by global force reduction factors.

In linear dynamic analysis, the response of the structure to ground motion is calculated in the time domain, and all phase information is therefore maintained. Only linear properties are assumed. The analytical method can use modal decomposition as a means of reducing the degrees of freedom in the analysis.

2.3.2 Linear Time-History Analysis

Time-history analysis is a step-by-step analysis of the dynamical response of a structure to a specified loading that may vary with time. The analysis may be linear or non linear.

2.4 METHODS FOR NONLINEAR ANALYSIS

The nonlinear static procedures constitute an inelastic analysis that considers what happens to buildings after they begin to crack and yield in response to realistic earthquake motion. This approach differs from traditional static linear procedure that reduces seismic forces to levels that allow to design buildings under the assumption that they remain undamaged. Although unrealistic and potentially misleading, this simplistic approach works well for new buildings and for regular existing buildings.

2.4.1 Secant Method

When the analysis of building is done with the Secant method, a global elastic model of the structure is constructed. Special stiffness values are calculated for the modeled elements and components. The global elastic model is analyzed using elastic response spectrum analysis. The ground motion used in the analysis is either a code specified 5 % damped response spectrum or the 5 % site specified spectrum.

In general, the response spectrum analysis will predict a different displacement pattern than originally assumed. At this point, iteration begins. The pushover curves are used to select a new set of element secant stiffness based on the displacements predicted by the global analysis. The global elastic model is modified with the new secant stiffness, and the response spectrum analysis is repeated. This process continues until the displacements predicted by the computer model reasonably match the displacements used to calculate the secant stiffness, at which point the analysis has predicted the earthquake demand.

The principal advantages of the secant method are that it accounts for three dimensional effects including torsion and multi-direction loading and that it accounts for higher mode effects. The main disadvantage of the approach is that it can be somewhat more time consuming than other static nonlinear procedures.

2.4.2 Method of Pushover Analysis

Pushover analysis is a static, nonlinear procedure in which the magnitude of the structural loading is incrementally increased in accordance with a certain predefined pattern. With the increase in the magnitude of the loading, weak links and failure modes of the structure are found. The loading is monotonic with the effects of the cyclic behaviour and load reversals being estimated by using a modified monotonic force-deformation criteria and with damping approximations. Static pushover analysis is an attempt by the structural engineering profession to evaluate the real strength of the structure and it promises to be a useful and effective tool for detailed performance evaluation of building. The pushover analysis can be performed either under load control or displacement control as mentioned below.

1. **Load Control:** It is used when the load is known (such as gravity load) and the structure is expected to be able to support the full magnitude of the load which is applied in steps.
2. **Displacement Control:** In this method, the magnitude of the load combination is increased or decreased as necessary until the control displacement reaches a predefined value. It is used when specified drifts are sought, magnitude of the applied load is not known in advance,

structure can be expected to lose strength or become unstable or when displacement occurring in the design earthquake is known.

2.4.3 Nonlinear Time History Analysis Method

Some buildings may be too complex to rely on the nonlinear static procedure. Those cases may require time history analysis of the nonlinear behaviour of the structure during analysis for a particular example of earthquake. The kinds of the buildings that may require this specialized analysis are highly irregular or complicated.

This method is performed using time histories prepared according to the actual ground motions recorded. The requirements for the mathematical model for time history analysis are identical to those developed for response spectrum analysis. The damping matrix associated with the mathematical model shall reflect the damping inherent in the structure deformation levels less than the yield deformation.

Response parameters shall be calculated for each time-history analysis. If three time-history analysis are performed, the maximum response of the parameter of interest shall be used for design. If seven or more pairs of horizontal ground motion records are used for time-history analysis, the average response of the parameter of interest may be used for design.

2.4.4 Fast Non-linear Analysis Method

The response of real structures when subjected to a large dynamic input often involves significant nonlinear behavior which includes the effects of large displacements and/or nonlinear material properties. The use of geometric stiffness and P-Delta analyses includes the effects of first order large displacements. If the axial forces in the members remain relatively constant during the application of lateral dynamic displacements, many structures can be solved directly without iteration.

The more complicated problem associated with large displacements, which cause large strains in all members of the structure, requires a tremendous amount of computational effort and computer time to obtain a solution. Fortunately, large strains very seldom occur in typical civil engineering structures made from steel and concrete materials. However, certain types of large strains, such as those in rubber base isolators and gap elements, can be treated as a lumped nonlinear element using the Fast Nonlinear Analysis (FNA) method.

The more common type of nonlinear behavior is when the material stress-strain, or force-deformation, relationship is nonlinear. This is because of the modern design philosophy that "a well-designed structure should have a limited number of members which require ductility and that the failure mechanism be clearly defined." Such an approach minimizes the cost of repair after a major earthquake.

2.5 MODAL ANALYSIS

Modal analysis is used to determine the vibration modes of a structure. These modes are useful to understand the behavior of the structure. They can also be used as the basis for modal superposition in response-spectrum and modal time-history analysis cases.

2.6 RESPONSE SPECTRUM METHOD

This approach permits the multiple modes of response of a building to be taken into account. This is required in many building codes for all except for very simple structures. The response of a structure can be defined as a combination of many special shapes (i.e. modes) that in a vibrating string correspond to the "harmonics". Computer analysis can be used to determine these modes for a structure.

For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass, and they are then combined to provide an estimate of the total response of the structure. Modal combination methods are:

1. **Absolute Sum Method (ASM)** combines the modal results by taking the sum of their absolute values.
2. **Square Root of the Sum of the Squares (SRSS)** combines the modal results by taking the square root of the sum of their squares.
3. **Complete Quadratic Combination (CQC)** method takes into account the statistical coupling between closely spaced modes caused by modal damping and also it is a method that is an improvement on SRSS for closely spaced modes.

It should be noted that the result of a response spectrum analysis using the response spectrum from a ground motion is typically different from that which would be calculated directly from a linear dynamic analysis using that ground motion directly, since phase information is lost in the process of generating the response spectrum.

In cases where structures are either too irregular, too tall or of significance to a community in disaster response, the response spectrum approach is no longer appropriate, and more complex analysis is often required, such as non-linear static or dynamic analysis.