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Different Methods of Seismic Drift Evaluation in Multi-storied RCC Buildings

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ABSTRACT
The seismic analysis and design of buildings has traditionally focused in reducing the risk of loss of life in the largest expected earthquake. Building codes have based their provisions on the historic performance of buildings and their deficiencies and have developed provisions around life safety concerns. Hence successful performance of buildings in the area of high seismicity depends on a combination of strength, ductility and completely on lateral force resisting system. Deflection is the most important parameter to be considered in design and analysis of multi-storied buildings because excessive inter-storey seismic drift can cause severe damages in building during earthquake. It is found that medium to high rise structures, the intensity of axial forces and deformation in columns and accumulation of their effects over a height can cause the flexural component of displacement to become dominant. So relative horizontal deflection within the building must be limited nearly 1.0% to 1.5% of storey height. This paper deals with the existing calculation methods with there merits/demerits to know the suitability in evaluating drift.

Keywords – Earthquake, Seismic forces, Inter-storey drift, Deformations, Ductility, flexural members.

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I. INTRODUCTION

Most of seismic codes specify criteria for the design and construction of the new structures subjected to earthquake ground motions with three goals.

- To minimize the hazard to life for all structures.
- Increase the expected performance of structures having a substantial public hazard due to occupancy or use.
- Improve the capability of essential facilitate to function after an earthquake.

It is also assumed that most of structures that are subjected to moderate to strong earthquake, economical earthquake resistant can be achieved by allowing yielding in some structural members. So, in seismic design yielding is permitted in predetermined structural members or location with the provisions that the vertical load carrying capacity of the structure is maintained even after strong earthquake. It is also important to distinguish between forces due to wind and those induced by earthquake. Earthquake forces results directly from the distortions induced by the motion of the ground on which the structure rest. The magnitude and the distribution of the forces and displacement resulting from ground motion is influenced by the properties of the structure and its foundation (soil strata) including the character of ground motion. The magnitude of the earthquake forces is a function of the mass of the structure rather than its exposed surface in wind induced forces.

A. BEHAVIOR OF BUILDING DURING EARTHQUAKE

It is seen during past earthquakes that building suffers a vibration problem due to internally generated inertial forces caused by vibration of the building mass. An increase in mass has two undesirable effects as on the earthquake design. First, it results in an increase in the force and secondly it can cause buckling or crushing of columns, walls. It causes mass pushes down on a member bent or moved out of plumb by the lateral forces. This effect is known as P-delta effect and greater the vertical forces, the greater the moment due to P-delta. It is almost always the vertical load that causes building to collapse. The distribution of the dynamic deformation caused by the ground motions and duration of motion are of concern in seismic design. Lateral deflection that occur during earthquake should be limited to prevent distress in structural members and in architectural components. Non-load bearing infills, external wall panels and window glazing should be designed with sufficient clearance or with flexible supports to accommodate the anticipated moments. Total building drift is the absolute displacement of any points relative to the base. Adjoining building or adjoining section of the same building may not have identical mode of response and therefore and may have a tendency to pound against one another. So, building separation and joint must be provided to permit adjoining building to respond independently to earthquake ground motions.

B. STRUCTURAL RESPONSE

During earthquake, the base of the structure suddenly moved where as the upper part of the structure will not respond instantaneously and it will lag because of the inertial resistant and flexibility of the structure. The resulting stress and distortion in the building are the same as the base of the structure were to remain stationary, while time varying horizontal forces are applied to the upper part of the building. These forces called inertia forces which is equal to the product of the mass of the structure times the acceleration. We know that the earthquake ground motion is the three dimensional (one vertical and two horizontal) so the structure in general deforms in a three-dimensional manner. Generally, inertia forces generated by the horizontal component of the ground motion required greater consideration for seismic design because adequate resistant to vertical seismic load is provided by the member capacities required for gravity load design. One of the basic goals in design is to distribute yielding through out structure. Distributed yielding dissipates more energy and helps prevents the premature failure of any one element or group of elements. For moment frames it is desirable to have strong columns related to the beams so to help and distribute the formation and plastic hinges throughout the building and prevent storey collapse mechanism.

C. IRREGULAR BUILDING

The impact of irregular parameters in estimating seismic force levels, first introduced in Uniform Building Codes (UBC) in 1973 and further in 1988. Some configuration parameters have been quantified to established the condition of irregularity and specific analytical treatments have been mandated to address these flaws. Typical building configuration deficiencies include an irregular geometry, a weakness in storey, a concentration of mass or a discontinuity in the lateral force resisting system. Vertical irregularities are designed in terms of strength, stiffness, geometry and mass. Although these are evaluated separately and may occur simultaneously. A building that has a tall first storey can be irregular because of soft-storey or a weak-storey or both depending on the stiffness and strength of this storey relative to those above. It is found that the safe and proportion of the building have a major effect on the distribution of the earthquake forces as they work their way through the building. When a building has irregular feature such as asymmetry in plan and vertical discontinuity, the assumption used for regular features may not apply. But when regular features are unavoidable, special design considerations are required to account for the unusual dynamic characteristics and the load transfer and stress concentration that occur at abrupt changes in structural resistance. Thus, a good designer must visualize the response of the complete structure and to keep in mind that the real forces involved are not static but dynamic and these forces are erratic and repetitive and can cause deformations well behind those determined from the elastic design.

D. DAMAGE CONTROL FEATURES

It is found during earthquake that the design of a structure in accordance with seismic provisions will not fully ensure against earthquake damages because the horizontal deformations that can be expected during a major earthquake are several times larger than those calculated under design load. Thus, following list of features that can minimize the earthquake damages.

- Provide detail that allow structural moment without damage to non-structural elements. The damages to such items as piping, glass, plaster, veneer, and partition may constitute a major financial loss. We must try to isolate these elements or to accommodate the moment where needed.
- Damages to non-structural partitions can be largely eliminated by providing a detail at the top and sides which will permit relative moment between partitions and at the adjacent structural elements.
- For piping installation, the expansions roofs and flexible joints used to accommodate temperature moment.
- Concrete stairways often seismic damages due to their inhibition of drift between connected floors. This can be provided a slip joint at the lower end of each stairway to eliminate the bracing effects of the stairways or by tying stairway to stairway shear wall.

II. DYNAMIC ANALYSIS

Symmetrical buildings with uniform mass and stiffness distribution behave in a fairly predictable manners, Where as buildings that are asymmetrical or with areas of discontinuities do not. For such buildings dynamic analysis is used to determine significant response characteristics.

Mostly two method of dynamic analysis is permitted, first one elastic response analysis and second is elastic or inelastic time history analysis. The response spectrum method is preferred in one because it is easier to use. The second one is used if it is important to represent inelastic response characteristics or to incorporate time dependent effects when computing the structures dynamic response. The word spectrum in seismic engineering conveys the idea that the response of the building having a broad range of period is summarized in a single graph. This graph is useful and evaluating different seismic lateral forces. The more superposition or spectral method is useful only for elastic analysis of structure but when the analysis is subjected to uncertainties in the model superposition not applicable. Thus, the actual process of combining the different model contribution is after all a probabilistic technique and in certain cases may not be entirely representative of the actual behavior of the structure. For the time history analysis overcomes these two uncertainties but it also requires a large computational effort. It is not normally employed as an analysis to in practical design of buildings.

A. DEFORMATION COMPATIBILITY

In the year 1994 north ridge earthquake taught a number of lessons that even in a building with properly designed and detailed lateral system collapse can occur if all structural elements are not capable of deforming with the building during an event. Like wise if certain non-structural elements in the building are not capable of deforming with the building, the resulting following hazard mat threaten life safety or impede egress from the building thus, designing for deformation, compatibility consist of establishing deformation demands and assessing the individual elements and their connections for the capacity to reform. Deformation in building include mostly inter-storey drift but other type of deformation should also be considered as vertical racking of structural framing in eccentrically braced frames, shear distortion of concrete coupling beam including vertical racking of structural bays in dual system.

III. CALCULATION METHODS OF INTER-STOREY DRIFTS

Inter-storey drift of building structure is relative translational displacement between two consecutive floors. The Inter-storey drift is also divided into two parts which include harmful and harmless drift. The harmful Inter-storey drift refers to the drift that can directly make damages to the calculated storey and is induced by deformation of the vertical member of the calculated storey. The harmless Inter-storey drift is caused by the flexural deformation of the vertical members in inferior member of the storey or the rotation of the inferior flow. It is considered to be harmless to the calculated storey as no internal drift but rigid body deformation occurs. For shear type buildings such a frame structure, the displacement induced by floor rotation is much smaller than the translational displacement so the harmful Inter-storey drift is usually ignored in engineering analysis. However. with the increment of height this rotation effect may be rise up and cannot be ignored. In addition, the inferior floor rotation will be induced large rigid body displacement for shear wall and framed shear wall structures.

The following method describes to evaluate drift.

A. Secant Method:

One of the first formal provisions for calculation harmful Inter-storey drift of building is giving by Guangdong provincial regulation (JGJ3, 2005) by this code harmful Inter-storey drift can be calculated by

$$\Delta\tilde{u}_i = u_i - u_{i-1} - \theta_{i-1}h_i = \Delta u_i - \theta_{i-1}h_i \qquad (3.1)$$

Where $\Delta\tilde{u}_i$ denotes harmful inter-storey drift of the i-th storey, u_i and u_{i-1} refer to the i-th and i-1-th storey horizontal displacement, θ_{i-1} is the horizontal displacement angle of the i-1-th store, h_i is the i-th storey height. This method essentially shows the idea that the harmless inter-storey drift induced by the inferior floor rotation (rigid body rotation) should be subtracted from the total deformation. But in actual practice it is not happen so as a result it may bring some errors and obtain relatively larger harmful inter-storey drift theoretically.

B. Improved Secant Method:

It is also based on the same principle of secant method, Deng (2008) derived a simple expression of the harmful inter-storey drift based on recursion method denotes as

$$\Delta\tilde{u}_i = \Delta u_i - \Delta u_{i-1} \qquad (3.2)$$

This equation can also be obtained directly assuming $h_{i-1} = h_i$. By this assumption harmful inter-storey drift us defined as

$$\tilde{\theta}_i = \theta_i - \theta_{i-1} = \frac{u_i + u_{i-1}}{h_i} - \frac{u_{i-1} - u_{i-2}}{h_{i-1}} = \frac{\Delta u_i}{h_i} - \frac{\Delta u_{i-1}}{h_{i-1}} \qquad (3.3)$$

This approach provides an easy and convenient way to calculate harmful displacement but it is also producing same error as the first method described above.

C. Tangent method:

This method replaced θ_{i-1} as θ_i, the average value of the tangent angle at the bottom end of all vertical members in the whole storey. This tangent angle is much approach to the practical floor rotation than secant angle method. However, the tangent angle is a mean value, which is averaged by deformation of the vertical structural members. It is also proved in practical engineering that the inter-storey drift are some time predominated by the deformation of the critical members so it is still need to be further studied for the relationship between the global inter-storey drift and local member deformation.

D. Fixing Floor Method:

In this method when we calculate $\Delta\tilde{u}$, fix the i-1th floor by limiting all the rotation and translational rotation and degree at the bottom ends of all vertical members. And then we can apply the same statically loads at floors behind the i-1th floor as the case without fixing floor. On this principle there is no harmful drift induced by the rotation of inferior floor and the total calculated deformation is considered to be harmful to structures hence we can easily obtain.

$$\Delta\tilde{u}_i = \Delta u_i \qquad (3.4)$$

This method provides a direct way to calculate harmful inter-storey drift but this also has certain shortcomings. Firstly, this method consumes too much time to get the harmful drift at each storey and needs to build *n* structural model and fix an identical floor at each case. So, it also seems to be complicated in practical analysis, secondly the boundary conditions which are changed when fixing a floor are different from origin model and it can make certain errors. Finally, this method is just suitable for the static analysis cases because in dynamic analysis case it becomes impossible to predict the dynamic load carried by each floor due to the randomness of earthquake.

IV. CONCLUSION

From the above discussion it is very clear that deflection must be limited during earthquake for a number of reasons so, provision of adequate stiffness is important. The low stiffness of moment resisting frames tends to cause high storey drifts (inter-storey deflection) which may lead to unacceptable damages to structural and non-structural elements. Thus, all the tall structures should consider the effect of drift to avoid the loss of life and property. In this paper we have discussed four methods to know the type of deformations in structure and its evaluation. The secant method shows that the idea of harmless inter-storey drift should be subtracted from total inter-storey drift, which may lead to some errors. But when we move to improve secant method it provides a relatively simple expressions to avoid the errors introduced by secant angle, the tangent method seems to be much reasonable but the relationship between global inter-storey drift and local vertical members deformations needs to be studied. The fourth approach refers to fixing floor method which can directly calculate the harmful inter-storey drift but it is difficult for engineering application and for dynamic analysis of typical structures.

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