EARTHQUAKE RESISTANT TECHNIQUES AND ANALYSIS OF TALL BUILDINGS

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Abstract

The tall buildings are more flexible than the shorter buildings and they are sensitive to a different frequency range in the earthquake excitation. The earthquake success of tall buildings is reinforced by studies using average properties of earthquake and typical properties of tall buildings and there are no special earthquake hazards that arise simply as a consequence of height. The purpose of this paper is to discuss about different analysis methods, base isolation and soil structure interaction. Analysis method is used for a large variety of tall building configurations comprising slabs, beams, columns, foundations, walls, etc. Base isolation is a collection of structural elements which should substantially separate a superstructure from its substructure resting on a shaking ground which protects the integrity of building or non-building structures. It is one of the most powerful equipment's of earthquake engineering which uses the passive structural vibration control technologies. Soil Structure Interaction is the process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil. General goal of the Soil Structure Interaction analysis is to calculate seismic response of structure bases on seismic response of free field.

Keywords: *Tall buildings, Analysis methods, Base isolation, Soil structure interaction*

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1. INTRODUCTION

An Earthquake is Earth's Shaking or in other words release of energy due to the movement of tectonic plates. This can be destructive enough to kill thousands of people and bring huge economic loss. This natural disaster has many adverse effects on earth like ground shaking, landslides, rock falls from cliffs, liquefaction, fire, tsunami etc. Buildings are highly affected by an earthquake, and in some cases they are shattered down to the ground level. When the ground shaking occurs beneath the building's foundations they vibrate in an analogous manner with that of the surrounding ground. The inertia force of a structure can develop shearing effect on it which in turn causes stress concentration on the connections in structure and on the fragile walls. This results in partial or full failure of structure. The excitement and prevalence of shaking depends on the orientation of the building. High rise structures have the tendency to magnify the magnitude of long time periodic motions when comparing to the smaller one. Every construction has a resonant prevalence which are the characteristics of structure. Taller buildings have a tendency for long time periods than shorter one which make them relatively more susceptible to damage. Hence, one has to be careful while performing the analysis of a tall structure. In order to analyse a tall structure many analysis procedures are valid like a) Equivalent static analysis, b) Response spectrum analysis, c) Linear dynamic analysis, d) Nonlinear static analysis or nonlinear pushover analysis and e) Nonlinear dynamic analysis. Soil structure interaction analysis is also essential to be considered. After identifying the soil type, analysing procedure is selected to do the detailed analysis of the interaction between soil and structure. To reduce the seismic effects on tall buildings several equipment is used like dampers or base isolation process. In dampers viscous damper, friction damper, yielding damper, magneto rheological fluid dampers tuned mass damper or harmonic absorber can be used. In base isolator magneto rheological elastomer, elastomeric bearing system, sliding system can be used.

2. ANALYSIS METHODS

2.1. Different Analysis Methods

2.1.1. Equivalent Static Analysis

Equivalent static analysis is a kind of response spectrum of seismic design. It can also be defined as the forces which act on building and it represents the ground motion effect due to earthquake. In this procedure it is considered that the building responds with fundamental mode. For happening this, the building should be shorter and it should not twist significantly when movement of ground occurs. This type of analysis is used for estimating displacements of structures. For structures and individual frames this analysis is best suited. The earthquake load will be assumed as an equivalent force which is static and horizontal and applied to the individual frames. The given force will be same as the multiplication of acceleration response spectrum and its weight. In this analysis the response is studied from a response spectrum where the building's natural frequency is given either by calculating the building design criteria. It also defined by the building code. Application of the analysis procedure is highly used for many building codes. For taller buildings the factors are used with some higher modes which is also used in case of low levels of twisting. Yielding effects of structure are analysed by applying force reduction modification factors that reduce the design forces also.

2.1.2. Response Spectrum Analysis:

Response spectrum analysis is a kind of statistical analysis which is linear-dynamic. It measures the mode of vibration and indicates the maximum seismic response of elastic structure. It depends on the theory of structural dynamics and derived from basic principles. This analysis gives acuteness into dynamic behaviour with the help of velocity, acceleration, displacement, measurement as a structural period function for a given damping level and time history. As Response spectrum analysis relates type selection of structure to dynamic performance, this is very useful for decision-making in design. To pick out the response of linear system resulting plot can be used. This analysis includes the multiple modes of response of a building except very simple and very complex structures. This analysis is required in many buildings codes. The response of a structure is also prescribed as a summation of many special modes that in a vibrating string correlate with the "harmonics". To determine these modes for a structure computer analysis can be used. A response is studied from the spectrum design from each mode, depends on the modal mass, frequency. Then these are combined for providing the estimation of the all response of structure. Then we should do the calculation of magnitude forces in all directions and observe the building's effect. Combination methods include the addition of absolute peak values, square root of amount of squares, combination of complete quadratic.[1]

The result of this analysis is highly different by using the spectrum from ground's motion from that which is calculated from an analysis using the ground motion. Hence information of phase is spoiled in the response spectrum generating process.

The response spectrum analysis is not appropriate for the structures which are more irregular, taller. In this condition the non-linear static analysis or non-linear dynamic analysis is needed.

There are some limitations of response spectra. These are widely applicable for linear systems only. Response spectra can be originated for the non-linear systems, but these are only relevant to systems which have same non-linearity, though endeavours have been made for developing non-linear seismic spectra in design with broad structural application. But the outcome cannot be linked right away for multi-mode response.

2.1.3. Linear Dynamic Analysis:

For lower seismic effects, static analysis procedure is appropriate but for higher seismic effects, higher buildings, buildings with irregularities or non-orthogonal systems, dynamic analysis procedure is used. In this process of linear dynamic analysis, the structure is analysed as a multiple degree of freedom system with viscous damping matrix and elastic stiffness matrix. Time history analysis and modal special analysis are used when analysing the seismic effects. But in these cases, the displacements and internal forces are calculated with the help of linear elastic analysis. Higher modes are considered in the linear dynamic analysis and this gives an advantage over the linear static analysis. Even so these are depends on linear elastic response and thus the application of it reduces with increment in non-linear behaviour. Hence, it is imprecise by reduction factors of global force. In this analysis the reaction of the structure's ground motion is deliberated in the domain time and all the phase information is sustained. Only linear properties are taken up. In the analysis the modal decomposition can be used for decreasing the degrees of freedom.

2.1.4. Nonlinear Static Analysis:

Nonlinear static analysis, known as pushover analysis is an analysis which is under everlasting vertical loads and thinly rising lateral loads. The forces induced by earthquake are described by static lateral loads. A sketch of displacement versus total base shear in a structure is acquired by this analysis. It would specify any weakness and failure. This analysis is performed up to failure, thus it allows determining the ductility capacity and collapse load. Nonlinear static analysis is controlled by force and displacement. The combination of full load is attached in the pushover procedure which is controlled by force. This procedure is applied for the known loads.

As pushover analysis is very simple, the guidelines and codes propose this analysis as the tool for seismic performance evolution. For evaluation of seismic performance, pushover analysis is a suitable tool of old and new structures. It is more suitable in the analysis of seismic vulnerability. This analysis gives enough information on seismic demands decided by ground's motion on the system. The pushover analysis cannot describe the phenomena property and it depends on the loading which is static. This may not track out important notes of deformation that may fall out in a earthquake related structure, and this may enhance others.

To assess the structural system performance by estimating the strength, deformation of the structure is the motive of this analysis. The assessment depends on some important parameters like inter storey drift, global drift, inelastic element deformation, element connection forces and deformations between elements. This analysis can be prospected as a method to credit force and deformation, which calculates in an estimated manner for the new distribution of internal forces that cannot be resisted within the elastic range.[2]

Three primary elements (capacity, demand and performance) are required to determine the nonlinear static analysis procedure. Capacity spectrum can be acquired through the nonlinear static analysis. It is assumed that the initial mode of vibration is the principal response of the structure and the capacity spectrum is usually originated from the first response mode. The spectral reduction method reduces five percent damped design spectrum of standard elastic, thus the demand spectrum curve is normally estimated. The performance point is defined by the point where the pushover capacity and demand spectrum curves meet together. At this point, the response of building should be analysed by the help of accepting criteria. The responses can be examined against accepting limits on global system levels and local element levels.[3]

2.1.5 Nonlinear Dynamic Analysis:

Nonlinear dynamic analysis gives the results with low unpredictability. It is because this analysis exploits the summation of ground motion records with the details of structural model. In this analysis the structural model estimates the deformation for all the degrees of freedom.

It is considered that the properties of this analysis are portion of domain of time analysis. According to building codes this analysis is meticulous and necessary for important configuration. The response calculation can be sensorial to the ground's motion and it is used as a input of earthquake. Various analyses are necessary to calculate the records of ground's motion and for estimating the structural response distribution. As the characteristics of seismic response based on intensity and earth shaking, an extensive measurement is required to describe different earthquake.

2.2. Early Studies On Analysis Method:

Chambers et.al discussed in this paper about some of the obstructions preventing the extensive acceptance of NDP, and presents a number of examples where its uncompromised delegation is conclusive for satisfactorily predicting the structural seismic reactions. Specific case studies contain rocking systems, structures with important toughness irregularities and existing structures with insufficient earthquake resistance.[4]

The paper of Dorheim is divided into three sections, numerical methods, elastic analysis and inelastic analysis. Elastic and Inelastic analysis are divided into sections on symmetric and asymmetric plan. This paper inquired various methods for analysis of seismic loading on structure with their advantages and disadvantages.[5]

3. BASE ISOLATION:

Base isolation is a very effective procedure which keeps a structure safe from earthquake. In this process structural elements are collected which should significantly isolate a superstructure from the substructure. It protects the integrity of different structures.

Base isolation is potential equipment against earthquake. Technologies to control the vibration of structures are used in this process. Seismic sustainability and seismic execution of a structure can be raised significantly with the application of base isolation. But it is true that a building cannot be made fully earthquake proof by the base isolation process.[6]

3.1. Types of Base Isolation:

All the conceptions of this process are very easy. Base isolation process is basically divided into two types. Elastomer bearings are most widely being used as the base isolation system which has been adopted in recent years. Neoprene or natural rubber is used to make elastomer. Horizontal stiffness layer is used in this process between foundation and structure. By using this process the structure is separated from the elements of seismic motion. Base frequency is higher than the elemental frequency of the structure given by this layer. The primary frequencies are also higher than this frequency. In this process dynamic mode entangles deformation. The structural deformation is produced by higher modes which are perpendicular to the first mode. As these modes do not take part in the motion, the higher energy of ground motion cannot be emitted into structure. Isolation process does not take up the energy of earthquake, but it deviated the energy through the dynamic system. The process acts in undamped and linear system, though some damping is helpful to put down any vibration at isolation frequency.[7]

The second system of base isolation is the sliding system which acts to transfer the shear through the interface of isolation. Different sliding systems have been determined and some of these are useful. In China some chosen sand is used by sliding systems.[6]

3.2. Workability of Base Isolation:

Base isolation is not beneficial in all cases. The elementary periods of superstructure and the shape, vibration content of seismic design spectrum describes the effectiveness. Base isolation increase the fundamental vibration period of the structure and it decrease the strength earthquake. If natural period of the superstructure is relatively long, base isolation is only slightly beneficial and much less when the superstructure period is comparatively short. These systems are applied in low-rise buildings since the frequency period of structure can be less, so that it can perform more rigidly to maximize the benefit from the isolation system. Different isolation systems are set in mid-rise and high-rise structural systems. In such systems, the benefit of isolation has been demonstrated in past earthquakes. Moderate and taller base isolated buildings are expected to have different and variable response characteristics in comparison to shorter base-isolated buildings. Many studies suggest that the seismic response characteristics of base isolated buildings will be significantly different under different base-isolation systems. Only a limited number of studies have shown the response characteristics of taller or more flexible isolated buildings, and no study has specifically examined the influence of height by comparing comparably designed shorter and moderate to taller isolated buildings. Moderate and taller or relatively flexible buildings which are base isolated may not perform as well as shorter or relatively stiffer base-isolated buildings. Base-isolated buildings with larger height to width ratios were shown to be especially sensitive to soft soil. Shorter buildings have more toughness than base isolated taller buildings. To improve the performance of isolated buildings by reducing the building drifts, a number of passive or semi-active control systems have been developed.[8]

3.3. Base Isolation in High Rise Building:

Taller isolated buildings are more likely to generate overturning forces on the isolators that may be unacceptable. The simple elastomeric base isolation system and unrestrained friction system work best in low-rise structures. If the building is tall enough, floor accelerations will produce an overturning moment that might induce tension in corner bearings of an elastomeric isolation system or cause uplift off the bearings in a friction isolation system. The inverting moment of seismic isolation layer could overturn the resistance which is delivered by gravity for isolated taller buildings. As a result, the bearings could disconnect from superstructure. Overturning in friction pendulum isolation systems raise the forces of different isolators and reduces in others. Due to this a difference is seen in frictional and pendular components of force leading to a stiffness that causes accidental torsion. When a large earthquake occurs, the base isolation devices are used to take up main elements of input energy for base isolated buildings. For strong earthquake this process is not so useful. A special consideration for mid to high rise isolated buildings in extreme earthquakes is pounding with adjacent structure. Therefore, a systematic study of the response characteristics buildings which are base isolated is very fascinating when the buildings are under excessive earthquakes.[9]

3.4. Early Studies on Base Isolation:

Vladimir Calugaru concentrated on three principal objectives which are- (1) inquiring the earthquake loads on tall reinforced concrete buildings; (2) determining the properties of a base isolation system which results in nominally elastic response; and (3) demonstrating that the seismic performance, cost, and constructability of a base-isolated tall building can be appreciably enhanced by incorporating a rocking core-wall in the design.[6]

Ribakov investigated a hybrid seismic isolation system with inactive changeable friction dampers for maintenance of structures against earthquakes.[10]

4. SOIL-STRUCTURE INTERACTION:

An important area of seismic engineering is soil structure interaction in which the reaction of the soil impacts the structure's motion and the structure's motion impacts the reaction of the soil. This process has an adjuvant effect on reaction of earthquake of structures. Design codes suggest that soil structure interaction effects can be ignored for earthquake analysis. This process increases effective damping ratio of a system and the flexibility of a structure. It also increases the naturalistic period of structure as likened to the similar stiffly supposed structure. This method can have a harmful outcome on structural reactions and ignoring soil structure interaction may cause unsecured design for foundation.[11]

The goal of the soil structure interaction is to determine the earthquake's reaction of structure based on earthquakes reaction of free field. The format of soil structure interaction analysis is basements' motion acquired using the fact about structure, soil foundation, earthquake excitation given without structures. The other format is soil structure interaction forces which is essential to calculate the ability of soil foundation to resist earthquake. The effects of soil structure interaction figure on frequency and most effects act in a particular frequency limit. When the frequency is out of this limit it may cause inverse changes. For seismic excitation structure, interaction occurs between the soil and the foundation.[13]

4.1. Modelling Of Soil-Structure Interaction:

Soil-structure interaction is modelled from many points of view by using advanced numerical techniques such as FEM, BEM, and hybrid methods. All of the methods involve approximate simulations of the real soil-structure interaction with some simplifications. Each method has its own merit in modelling soil and soil-structure interface. These methods can be divided into the following groups as follows.[12]

4.1.1. Direct Method:

The direct method is used for modelling the soil and a tall building together. The substructure method is adopted to treat the unbounded soil and the tall building separately. The substructure method can decrease the degrees of freedom. Modelling of an important portion of soil is necessary for estimating for the divergence condition in direct method. The simulated soil boundary is situated at a distance of different times the width of the structure from the building. Direct method id generally used to estimate two dimensional models only. But three dimensional models substructure method is more effective than direct method.[14]

4.1.2. Substructure Method:

In this method, the soil domain is a layer around the foundation of the building. A relationship between force and displacement is made by creating a matrix of unit impulse of the unbounded soil. This soil is modelled with the help of this result which is analytical. In order to model the structure, instead of the soil, maximum count of degrees of freedom is developed. With this easy and practical method, it is not required to analyse the superstructure and the foundation together.[16]

4.1.3. System Identification Method:

Statistical methods are used in the system identification method in building dynamical systematic models which are mathematical with the help of measured data. The optimal design of experiments is also included by system identification for generating informative data for fitting such models as well as model reduction.[15]

4.1.4. Nonlinear Soil Structure Interaction Method:

Material nonlinearities of the soil and the structure, and geometrical nonlinearity from motions such as separation, sliding, and rocking contribute the nonlinearities of the interaction between the soil and structure. These nonlinear phenomena usually occur concurrently. It is difficult to simulate the coupling from the separation, sliding, and rocking. In analysing a nonlinear dynamic response of SSI, the nonlinear impedance method is modified from linear impedance method. The contact area depending on time is determined from the base-slab of the structure and soil under the structure. The initial nonlinear effect is normally isolation of the soil and the foundation.[17]

4.1.5. Boundary Element Method In SSI:

By applying boundary element method to the unbounded media, the time is avoided by implementing relevant border elements and searching the required mass finiteness. This method can be used in determining the impedance of hard strata or fixed circular type of foundation. The reflection and transmission coefficients help to satisfy the displacement and stress vector with continuity.[14]

4.1.6. Kinematics and Inertial Soil-Structure Interaction:

As the pile foundation is very much used in structures like wind turbines, bridges and offshore platforms, the area of research in seismic feedback due to short-term earthquake action on system of column-pile is increasing. The shear waves of earthquake inseminate through soil. So the foundation tends to increase the modified action due to the stiffness contrast between soil and the foundation. It also happens when the superstructure is not available and that condition is termed as kinematic interaction. On the other hand, the dynamic effect of superstructure also creates some deformations to the foundation and the soil near that. This process is named by inertial interaction. In soil structure interaction (SSI) the complicated and exclusive phenomena is inertial and kinematic interaction.[16]

4.1.7. Torsional Coupling Method:

The reaction of torsion coupled by SSI for asymmetrical building is obtained by an efficient modal analysis. This method allows a more realistic modelling of the building. However, this torsional coupling makes it much more complex in modelling the SSI effects.[11]

4.2. Soil Structure Interaction Equations:

Luco and Wong derived that the bottom displacement of foundation $\{\tilde{U}_0\} = (u_0, L\theta_0)^T$ characterised by foundation's half-width [L] is given as follows,

$$\{\tilde{U}_0\} = ([I] + [C(\omega)] \cdot \left([\tilde{K}_{B0}(\omega)] - \left(a_0^2/\rho_s L^3\right)[\tilde{M}_0]\right)\right)^{-1} \{\tilde{U}_0^*\}$$

Where [I] is the 2x2 identity matrix, $[\tilde{M}_0]$ is the normalized mass matrix for the digit foundation, $[C(\omega)]$ is the 2x2 normalized foundation compliance matrix, $a_0 = \omega L/\beta_s$. It does not have dimension and it is characterised by [L] and by shear wave velocity of soil β_s, ρ_s is the density of the soil and $\{U_0^*\} = (u_0^*, L\theta_0^*)^T$ is the foundation's input motion.[18]

4.3. Early Studies on Soil Structure Interaction:

In the paper of Han Yingcai a 20-storey building is tested as a representative structure which is supported on a foundation for various states like- (1) rigid base, (2) linear soil-pile system and (3) nonlinear soil-pile system. The displacements of pile foundation mode of tall buildings are observed and compared with the nature of buildings which are supported on shallow foundation.[15]

Zaicenco highlighted that the use of FEM and bi-directional lumped-mass-storey stiffness numerical models in studying of the soil–structure interaction (SSI) effects on a structure. Data on the structural reaction has been acquired through the project for earthquake instrumentation of a 16-storey r/c cast-in-place inhabited building during an earthquake. The reactions which are recorded on foundation and field are clearly seen by the effect of soil–structure interaction.[16]

5. CONCLUSION:

Earthquake is of serious concern in the construction field. There are some very complex design procedures which are very important. These are used not only in the foundation as a base isolation but also in the whole structure with protective elements of earthquake. Using different analysis methods very large and complex buildings can be modelled. The vibration of tall buildings with symmetrical or asymmetrical configuration is simulated for both harmonic loadings and real earthquake loadings. The mass asymmetrical tall building suffers more damages than the corresponding symmetrical buildings. It shows that the asymmetrical building is less seismic resistant than a symmetrical building during an earthquake. If the damping is underestimated and the stiffness is overestimated then the assumption about higher buildings on an undone soil structure interaction rigid base does not represent the earthquake response.

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7. FIGURES:

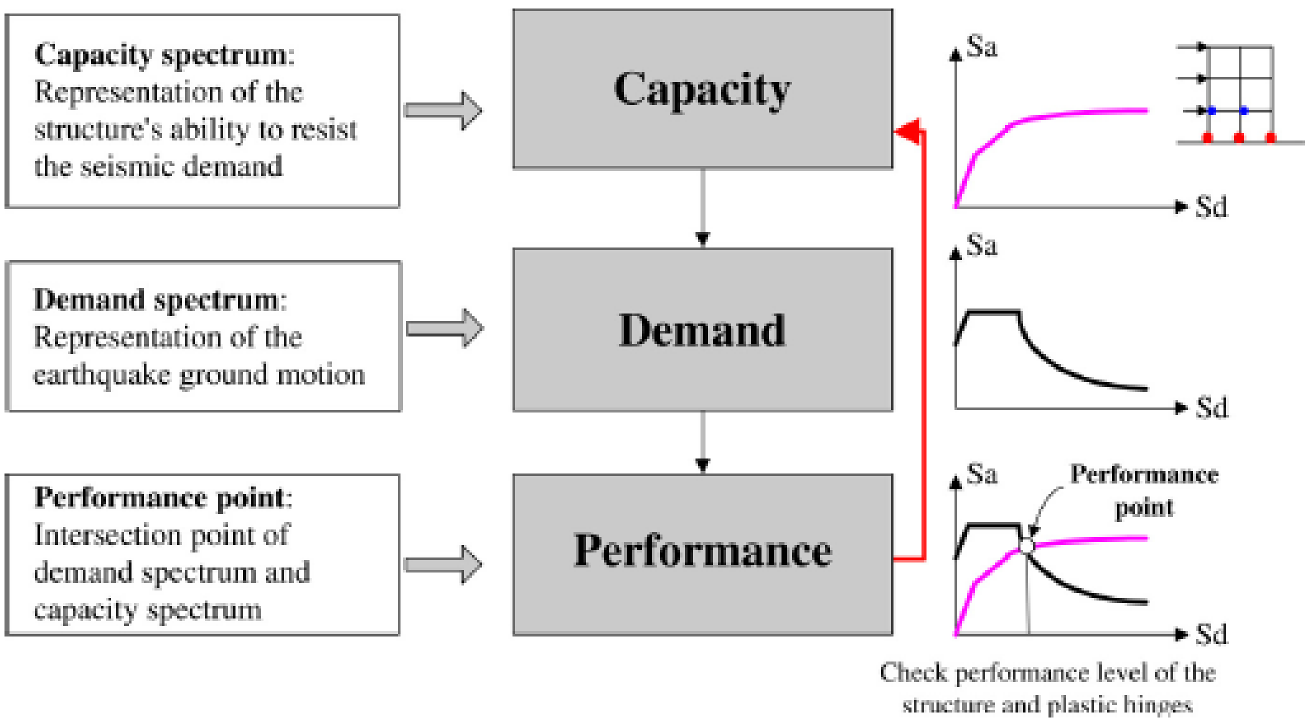

Fig. 1. Nonlinear analysis procedure.