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VIBRATIONAL BUFFETING OUTCOMES IN STRUCTURES

Gajendra Singh Bhadoriya[*1] **& Prof. Satish Parihar**[2]
[*1&2]Rama University, Kanpur, Uttar Pradesh

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ABSTRACT

Major vibrational events during the past decade such as those that have occurred in Northridge, Imperial Valley (May 18, 1940), California (1994), Kobe, Japan (1995), Turkey (1999), Taiwan (1999) and Bhuj, Central Western India (2001) have continued to demonstrate the destructive power of earthquakes, with destruction of engineered structures, bridges, industrial and port facilities as well as giving rise to great economic losses. Among the possible structural damages, vibrational induced buffeting has been commonly observed in several earthquakes. As a result, a parametric study on structures buffeting response as well as proper vibrational hazard mitigation practice for adjacent structures is carried out. Therefore, the needs to
improve vibrational performance of the built environment through the development of performance-oriented procedures have been developed. To estimate the vibrational demands, nonlinearities in the structure are to be considered when the structure enters into inelastic range during devastating earthquakes. Despite the increase in the accuracy and efficiency of the computational tools related to dynamic inelastic analysis, engineers tend to adopt simplified non-linear static procedures instead of rigorous non-linear dynamic analysis when evaluating vibrational demands. This is due to the problems related to its complexities and suitability for practical design applications. The push over analysis is a static, nonlinear procedure that can be used to estimate the
dynamic needs imposed on a structure by earthquake ground motions. This project entitled

"**Vibrational Buffeting Effects in Structures**." aims at studying vibrational gap between adjacent structures by dynamic and pushover analysis in SAP2000. A parametric study is conducted to investigate the minimum vibrational buffeting gap between two adjacent structures by response Spectrum analysis for medium soil and Elcentro Earthquake recorded excitation are used for input in the dynamic analysis on different models.. The effect of impact is studied using linear and nonlinear contact force on models for different separation distances and compared with nominal model without buffeting consideration. Buffeting produces acceleration and shear at various story levels that are greater than those obtained from the no buffeting case, while the peak drift depends on the input excitation characteristics. Also, increasing gap width is likely to be effective when the separation is sufficiently wide practically to eliminate contact. The results of pushover analysis viz. pushover curves and capacity spectrum for three different lateral load patterns are observed to study the effect of different lateral load pattern on the structural displacement to find out minimum vibrational gap between structures.

I. INTRODUCTION

1.1 General

Investigations of past and recent earthquake damage have illustrated that the building structures are vulnerable to severe damage and/or collapse during moderate to strong ground motion. An earthquake with a magnitude of six is capable of causing severe damages of engineered structures, bridges, industrial and port facilities as well as giving rise to great economic losses. Several destructive earthquakes have hit Egypt in both historical and recent times from distant and near earthquakes. The annual energy release in Egypt and its vicinity is equivalent to an earthquake with magnitude varying from 5.5 to 7.3. Buffeting between closely spaced building structures can be a serious hazard in vibrationalally active areas. Investigations of past and recent earthquakes damage have illustrated several instances of buffeting damage (Astaneh-Asl et al.1994, Northridge Reconnaissance Team 1996, Kasai& Maison 1991) in both building and bridge structures. Buffeting damage was observed during the 1985 Mexico earthquake, the 1988 Sequenay earthquake in Canada, the 1992 Cairo earthquake, the 1994 Northridge earthquake, the 1995 Kobe earthquake and 1999 Kocaeli earthquake. Significant buffeting was observed at sites over 90 km from the epicenter thus indicating the possible catastrophic damage that may occur during future earthquakes having closer epicenters. Buffeting of adjacent structures could have worse damage as adjacent structures with different dynamic characteristics which vibrate out of phase and there is insufficient separation distance or energy dissipation system to accommodate the relative motions of adjacent structures. Past vibrational codes did not give definite guidelines to preclude buffeting, because of this and due to economic considerations including maximum land usage requirements, especially in the high density populated areas of cities, there are many structures worldwide which are already built in contact or extremely close to another that could suffer buffeting damage in future earthquakes. A large separation is controversial from both technical (difficulty in using expansion joint) and economical loss of land usage) views. The highly congested building system in many metropolitan cities constitutes a major concern for vibrational buffeting damage. For these reasons, it has been widely accepted that buffeting is an undesirable phenomenon that should be prevented or mitigated zones in connection with the corresponding design ground acceleration values will lead in many cases to earthquake actions which are remarkably higher than defined by the design codes used up to now. The most simplest and effective way for buffeting mitigation and reducing damage due to buffeting is to provide enough separation but it is sometimes difficult to be implemented due to detailing problem and high cost of land. An alternative to the vibrational separation gap provision in the structure design is to minimize the effect of buffeting through decreasing lateral motion (Kasaiet al. 1996, Abdullah et al. 2001, Jankowski et al 2000, Ruangrassamee & Kawashima 2003,Kawashima & Shoji 2000), which can be achieved by joining adjacent structures at critical locations so that their motion could be in-phase with one another or by increasing the buffeting structures damping capacity by means of passive structural control of energy dissipation system or by vibrational retrofitting. The focus of this study is the development of an analytical model and methodology for the formulation of the adjacent building-buffeting problem based on the classical impact theory, an investigation through parametric study to identify the most important parameters is carried out. The main objective and scope are to evaluate the effects of structural buffeting on the global response of building structures; to determine the minimum vibrational gap between structures and provide engineers with practical analytical tools for predicting buffeting response and damage. A realistic buffeting model is used for studying the response of structural system under the condition of structural buffeting during elcentro earthquakes for medium soil condition at vibrational zone V. Two adjacent multi-story structures are considered as a representative structure for potential buffeting problem. Dynamic and pushover analysis is carried out on the structures to observe displacement of the structures due to earthquake excitation. The behavior of the structures under static loads is linear and can be predicted. When we come to the dynamic behaviors, we are mainly concerned with the displacements, velocity and accelerations of the structure under the action of dynamic loads or earthquake loads. Unpredictability in structural behaviors is encountered when the structure goes into the post-elastic or non-linear stage. The concept of push over analysis can be utilized for estimating the dynamic needs imposed on a structure by earthquake ground motions and the probable locations of the failure zones in a building can be ascertained by observing the type of hinge formations. The strength capacity of the weak zones in the post-elastic range can then be increased by retrofitting.

For the purpose of this study, SAP2000 has been chosen, a linear and non-linear static and dynamic analysis and design program for three dimensional structures. The application has many features for solving a wide range of problems from simple 2-D trusses to complex 3-D structures. Creation and modification of the model, execution of the analysis, and checking and optimization of the design are all done through this single interface. Graphical displays of the results, including real-time animations of time-history displacements, are easily produced.

1.2 Vibrational Buffeting Effect between Structures

Buffeting is one of the main causes of severe building damages in earthquake. The non-structural damage involves buffeting or movement across separation joints between adjacent structures. Vibrational buffeting between two adjacent structures occur

- during an earthquake
- different dynamic characteristics
- adjacent structures vibrate out of phase
- at-rest separation is insufficient

1.3 Methods of Vibrational Analysis of a Structure

Various methods of differing complexity have been developed for the vibrational analysis of structures. The three main techniques currently used for this analysis are:

1. Dynamic analysis.

- Linear Dynamic Analysis.

- Non-Linear Dynamic Analysis.

2. Push over analysis.

1.3.1 Dynamic Analysis

All real physical structures, when subjected to loads or displacements, behave dynamically. The additional inertia force from, Newton's second law, are equal to the mass times the acceleration. If the loads or displacements are applied very slowly then the inertia forces can be neglected and a static load analysis can be justified. Hence, dynamic analysis is a simple extension of static analysis.

II. REVIEW OF LITERATURE

2.1 General

A series of integrated analytical and experimental studies has been conducted to investigate the vibrational gap between adjacent structures located in regions of high vibrational risk. When a building experiences earthquake vibrations its foundation will move back and forth with the ground. These vibrations can be quite intense, creating stresses and deformation throughout the structure making the upper edges of the building swing from a few mm to many inches dependent on their height size and mass. This is uniformly applicable for structures of all heights, whether single storeyed or multi-storeyed in highrisk earthquake zones. In Mexico earthquake it was observed that structures of different sizes and heights vibrated with different frequencies. Where these were made next to each other they created stresses in both the structures and thus weakened each other and in many cases caused the failure of both the structures. Buffeting produces acceleration and shear at various story levels that are greater than those obtained from the no buffeting case. Buffeting between closely spaced building structures can be a serious hazard in vibrationalally active areas. Also, increasing gap width is likely to be effective when the separation is sufficiently wide practically to eliminate contact. After a brief evaluation of methods currently standard in engineering practice to estimate vibrational gap between structures, nonlinearities in the structure are to be considered when the structure enters into inelastic range during devastating earthquakes. To consider this nonlinearity effects inelastic time history analysis is a powerful tool for the study of structural vibrational performance. A set of carefully selected ground motion records can give an accurate evaluation of the anticipated vibrational performance of structures. Despite the fact that the accuracy and efficiency of the computational tools have increased substantially, there are still some reservations about the dynamic inelastic analysis, which are mainly related to its complexity and suitability for practical design applications. Moreover, the calculated inelastic dynamic response is quite sensitive to the characteristics of the input motions, thus the selection of a suite of representative acceleration time-histories is mandatory. This increases the computational effort significantly. Nonlinear static procedures are enlightened due to their simplicity and, its accuracy is towards time history analysis.

Viviane Warnotte summarized basic concepts on which the vibrational buffeting effect occurs between adjacent structures. He identified the conditions under which the vibrational buffeting will occur between structures and adequate information and, perhaps more importantly, buffeting situation analyzed. From his research it was found that an elastic model cannot predict correctly the behaviors of the structure due to vibrational buffeting. Therefore non-elastic analysis is to be done to predict the required vibrational gap between structures.

Robert Jankowski addressed the fundamental questions concerning the application of the nonlinear analysis and its feasibility and limitations in predicting vibrational buffeting gap between structures. In his analysis, elastoplastic multi-degree-offreedom lumped mass models are used to simulate the structural behavior and non-linear viscoelastic impact elements are applied to model collisions. The results of the study prove that buffeting may have considerable influence on behavior of the structures.

Shehata E. Abdel Raheem developed and implemented a tool for the inelastic analysis of vibrational buffeting effect between structures. They carried out a parametric study on structures buffeting response as well as proper vibrational hazard mitigation practice for adjacent structures. Three categories of recorded earthquake excitation were used for input. He studied the effect of impact using linear and nonlinear contact force model for different separation distances and compared with nominal model without buffeting consideration.

ANAGNOSTOPOULOS SA, SPILIOPOULOS KV studied the earthquake induced buffeting between adjacent structures. They idealized the building as lumped-mass, shear beam type, multi-degree-of-freedom (MDOF) systems with bilinear forcedeformation characteristics and with bases supported on translational and rocking springdashpots. Collisions between adjacent masses can occur at any level and are simulated by means of viscoelastic impact elements. They used five real earthquake motions to study

the effects of the following factors: building configuration and relative size, vibrational separation distance and impact element properties. It was found that buffeting can cause high overstresses, mainly when the colliding structures have significantly different heights, periods or masses. They suggests a possibility for introducing a set of conditions into the codes, combined with some special measures, as an alternative to the vibrational separation requirement. Hasan et al. [17] presented a simple computer based pushover analysis technique for performance based design of building frameworks subject to earthquake loading. The concept is based on conventional displacement method of elastic analysis. To measure the degree of plastification the term plasticity factor was used.

2.2 Outcomes of Literature Review

From the available literature it was observed that most of the studies are confined on study of 2D frames and simple 3D structures with one story and one bay. The relative areas in which the dynamic and pushover analysis can be applied were discussed. Only a limited number of published works on comparison of use of dynamic and pushover analysis to find out the vibrational gap between structures.

III. STRUCTURAL MODELING AND ANALYSIS

3.1 General

In order to evaluate the Vibrational gap between structures with rigid floor diaphragms using dynamic and pushover procedures two sample building was adopted The details of the building are reproduced in section 3.2. The finite element analysis software SAP2000 Nonlinear [31] is utilized to create 3D model and run all analyses. The software is able to predict the geometric nonlinear behavior of space frames under static or dynamic loadings, taking into account both geometric nonlinearity and material inelasticity. The software accepts static loads (either forces or displacements) as well as dynamic (accelerations) actions and has the ability to perform eigenvalues, nonlinear static pushover and nonlinear dynamic analyses.

3.2 Details of the Models

The models which have been adopted for study are asymmetric four storey(G+4) and eight storey (G+8) structures. The structures are consist of square columns with dimension 500mm x 500mm, all beams with dimension 350mm x 250mm. The floor slabs are taken as 125mm thick. The foundation height is 1.5m and the height of the all four stories is 3m. The modulus of elasticity and shear modulus of concrete have been taken as E = 2.55 ×107 kN/m2 and G = 1.06 ×107 kN/m2.

Three models have been considered for the purpose of the study.

- ***1. Four storey(G+4) adjacent building with equal floor levels.***
- ***2 Eight storey(G+8) adjacent structures with Unequal floor levels.***

The plan and sectional elevation of the two structures are as shown below.

3.2.1 Defining the material properties, structural components and modeling the structure:
Beam, column and slab specifications are as follows:
Column 500mm x 500mm
Beam 350mm x 250mm
Slab thickness 125mm
Reinforcement
Columns 8-25 mm bars
Beams 4-20 mm bars at both top and bottom

The required material properties like mass, weight density, modulus of elasticity, shear modulus and design values of the material used can be modified as per requirements or default values can be accepted. Beams and column members have been defined as 'frame elements' with the appropriate dimensions and reinforcement. Soil structure interaction has not been considered and the columns have been restrained in all six degrees of freedom at the base.

3.2.2 Assigning loads.

After having modeled the structural components, all possible load cases are assigned. These are as follows:

3.2.2.1 Gravity loads

Gravity loads on the structure include the self weight of beams, columns, slabs, walls and other permanent members. The self weight of beams and columns (frame members) and slabs (area sections) is automatically considered by the program itself. The wall loads have been calculated and assigned as uniformly distributed loads on the beams.

3.2.2.2 Earthquake lateral loads

The design lateral loads at different floor levels have been calculated corresponding to fundamental time period and are applied to the model. The method of application of this lateral load varies for rigid floor and flexible floor diaphragms. In rigid floor idealization the lateral load at different floor levels are applied at centre of rigidity of that corresponding floor in the direction of push in order to neglect the effect of torsion. While idealizing the floor diaphragms as flexible, the design lateral load at all floors is applied such that the lateral load at each floor is distributed along the length of the floor in proportion to the mass distribution. In our case, the slabs have been modeled as rigid diaphragms and in this connection, the centre of rigidity at each floor level has been determined and the earthquake lateral loads
have been applied there.

3.2.3 Analysis of the structure

Namely three types of analysis procedures have been carried out for determining the various structural parameters of the model. Here we are mainly concerned with the behavior of the structure under the effect of ground motion and dynamic excitations such as earthquakes and the displacement of the structure in the inelastic range.

The analyses carried out are as follows:

- Response Spectrum Analysis
- Time History Analysis.
- Pushover analysis.

3.2.3.1 Response Spectrum Analysis

Here we are primarily concerned with observing the deformations, forces and moments induced in the structure due to dead, live loads and earthquake loads. The load case ‘Dead’ takes care of the self weight of the frame members and the area sections. The wall loads have been defined under a separate load case ‘Wall’ and the live loads under the case ‘Live’. Analysis is carried out for all three cases for obtaining the above mentioned parameters.

3.2.3.1.1 Response spectrum analysis in SAP 2000

The step by step procedure is as follows

- Defining quake loads under the load type ‘quake’ and naming it appropriately.
- Defining response spectrum function as per IS 1893 (Part 1) 2002. The values of Sa/g Vs. T shown in Table 3.1 can be linked in the program in the form of a data file.
- Modifying the quake analysis case with the appropriate analysis case type, applied loads and scale factors.
- Running the analysis**.**

IV. CONCLUSION

The purpose of this study has been to analyze vibrational buffeting effects between structures and to observe the structural behaviour in the post elastic range. For this, SAP3000, a linear and non-linear static and dynamic analysis and design program for three dimensional structures has been used. Dynamic analysis has been carried out to know about the deformations, natural frequencies, and time periods, floor responses displacements. The non-linear static procedure or simply push over analysis is carried out to estimate the displacement at the performance point of the structure in the post-elastic range. The models that have been studied are

1. Four storey (G+5) building
2. Eightstorey (G+7) structures of which have been created in SAP3000. The first phase of the study involves the creation and analysis of the model and Linear dynamic analysis(Response Spectrum Analysis) for medium soil condition has been carried out on those models to observe displacement at the joint of the structure. Depending upon the analysis results, modification of the same for the purpose of no buffeting is carried out on those models. Based on the observations from the analysis results, the following conclusions can be drawn. Response Spectrum analysis gives result that the two models have displacement within the permissible limit for vibrational buffeting between adjacent structures with the vibrational gap provided as per IS 4326-2005. It was found that minimum vibrational gap can be provide 0.014m per storey between two four storey building and two eight storey building for no vibrational buffeting between structures. In the second phase of the project Nonlinear dynamic analysis with Elcentro earthquake excitation data as input is carried out on those models to observe the behaviour of the structure under earthquake excitation. The floor responses due to earthquake excitation in the Eight storey building is higher than the Four Storey building. In pushover analysis three different lateral load patterns are used; parabolic, triangular and uniform. Based on the results obtained from these analyses, the following conclusions are drawn for the structures under study. From the pushover curves obtained for three lateral load pattern shows displacement of the both structures is maximum for parabolic lateral load pattern among all three lateral load pattern. Similarly, the displacements at performance point obtained from capacity spectrum for three lateral load patterns on the two structures with rigid floor diaphragm follow the same trend. The maximum displacements of the structures obtained from pushover analysis are higher than the results obtained from response spectrum analysis. Therefore, more research work needed in the pushover analysis to obtain minimum vibrational gap between adjacent structures.

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