Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 02, February-2016

Vibration Control of Structures using Base-Isolation System under Dynamic Load

Supradip Saha
M. Tech Scholar
National Institute of Technology Agartala
Agartala, India

Dr. Rama Debbarma
Associate Professor
National Institute of Technology Agartala
Agartala, India

Abstract- **The performance of base isolated system attached with Single Degree of Freedom (SDOF) structures under dynamic load has been investigated in this paper. The parametric study is carried out to evaluate the influence of several parameters (mass ratio, damping of structure, damping of base isolator, time period of structure, time of loading etc.) on the effectiveness and robustness of the Base-Isolation system under harmonic excitation in time-domain approach. For numerical simulation, the algorithm used in this study is based on Newmark-Beta method. The effectiveness of the Base-isolation system is evaluated based on the response reduction of the structure. Numerical study is taken to obtain the effectiveness of the base isolation system and overall performance of structure. For comparative study, the responses are also obtained for a structure without base isolation system. It has been found that the structural responses are reduced to 44.925% and 41.70% for displacement and acceleration respectively. Therefore, it can be easily demonstrated from this study that the structural responses are reduced significantly due to the implementation of Base Isolation System.**

Key words- Base Isolation System, parametric study, response control, time-domain approach.

I. INTRODUCTION

Because of the deficiency of the land space availability precisely within the urban territories as well as due to the implementation of the modern construction techniques have caused an increased presence of skyscraper structures. These structures are flexible, gently damped, light in weight resulting in very little structural damping and low natural frequencies. To prevent the structural and non-structural failures of these structures during earthquake, along with the other passive vibration control devices, the concept of introducing some types of support that isolates it from the shaking ground is an alternative one. As a result, in recent years the Base-Isolation system has become a practical strategy for earthquake-resistant design. At the time of earthquake, the flexible base filters out high frequencies from the ground motion and prevents the structures form being collapsed. Since, Base-isolation is currently an active and expanding subject; several studies have been performed in the past few years regarding the application and effectiveness of base isolator devices in mitigating the seismic responses of structures. Fan et al. (1991) carried out a comparative study of several base isolation devices for a multi-storey building under seismic ground accelerations. Jangid and Datta (1995) studied the stochastic response of a one-storey torsionally coupled building model isolated by various base isolation systems subjected to random ground motion. Palazzo and Petti (1999) proposed a new methodology to control seismic vibrations by combining the base isolation with tuned mass damper. Mazza and Vulcano (2004) compared different base-isolation techniques, in order to evaluate their effects on the structural response and applicability limits under near- fault earthquakes. Roy and Chakraborty (2015) studied the robust design optimization (RDO) of base isolation system considering random system parameters characterizing the structure, isolator and ground motion model. The main objective of this present study is to perform a parametric study in order to evaluate the effect of the base isolation techniques on the structural responses. The effects of the variation of different parameters such as mass ratio, damping of base isolator, damping of structure, time period of structure and time of loading are considered here. The structural responses are obtained in time-domain using Newmark-Beta method. Numerical example is also taken to calculate the effectiveness and robustness of the base isolator and overall performance of the structure. For comparative study, the responses are obtained for a structure with and without base isolation system.

II. DETAILS OF THEORETICAL FORMULATION

The equation of motion of a Single Degree of Freedom (SDOF) system attached with Base Isolator Device can be expressed by the following equation

$$M\ddot{x} + C\dot{x} + Kx = P(t) \qquad (1)$$

M, C and K represents the mass, damping and stiffness matrix of the base isolated structure and are given by

$$M = \begin{bmatrix} Mb & 0 \\ 0 & Ms \end{bmatrix},\ C = \begin{bmatrix} Cs + Cb & -Cs \\ -Cs & Cs \end{bmatrix} \text{ and } K = \begin{bmatrix} Ks + Kb & -Ks \\ -Ks & Ks \end{bmatrix}$$

where, $M_b = K_b\omega_b^2$, $M_s = K_s\omega_s^2$, $C_b = 2(M_s + M_b)\omega_b\xi_b$ and $C_s = 2M_s\omega_s\xi_s$; ξ_b and ξ_s represents the damping coefficient of the base isolator and structure respectively and ω_b and ω_s are the frequency of base isolator and structure. P(t) is the harmonic excitation which is a time-dependent function. The mass ratio (μ) is the ratio of the mass of the base isolator (M_b) to the mass of the structure (M_s).

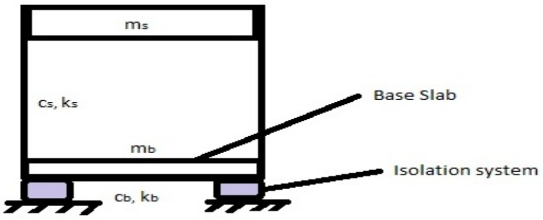

Fig.1. SDOF structure attached with Base Isolator

The algorithm used in this paper is Newmark-Beta method, which is based on the assumption that the acceleration varies linearly between two instants of time. Two parameters α and β are used in this method, which can be changed to suit the requirements of a particular problem. The parameters α and β indicates how much the acceleration enters into the velocity and displacement equations at the end of the intervalΔt. The value of these parameters takes as $\beta \geq 0.5$ and $\alpha \geq 0.25\,(0.5+\beta)^2$. The integration constants can be calculated by

$$a_0 = \frac{1}{\beta(\Delta t)^2}\ ;\ a_1 = \frac{\alpha}{\beta(\Delta t)}\ ;\ a_2 = \frac{1}{\beta(\Delta t)}\ ;$$

$$a_3 = \frac{1}{2\beta} - 1\ ;\ a_4 = \frac{\alpha}{\beta} - 1\ ;\ a_5 = \frac{\Delta t}{2}\left(\frac{\alpha}{\beta} - 2\right)\ ;$$

$$a_6 = \Delta t\,(1-\beta)\ ;\ a_7 = \beta\Delta t.$$

Equations used in this method are as follows:

K_b=K+a0*M+a1*C

F_b = F+M*[a0*{Xt} +a2*{$\dot{X}$t} +a3*{$\ddot{X}$t}]+
C*[a1*{Xt} +a4*{$\dot{X}$t} +a5* {$\ddot{X}$t}]

X(t+Δt)= F_b/K_b

$\ddot{X}$(t+Δt)= a0*[{X(t+Δt)}-{X(t)}]-a2*{$\dot{X}$t}-a3*{ $\ddot{X}$t}

$\dot{X}$(t+Δt)= a1*[{X(t+Δt)-X(t)}]-a4*{$\dot{X}$t} -a5*{$\ddot{X}$t}

A SDOF structure with Base-Isolation (BI) system subjected to harmonic excitation is undertaken here to study the effectiveness of the isolator. The time period of the SDOF structure considered in this investigation is 0.808 second. Unless mentioned otherwise, the following nominal values are assumed for various parameters:
mass ratio μ = 10%, damping of base isolator ξ_b = 10% and damping of structure ξ_s = 1%.

III. RESULTS AND DISCUSSION

After performing a number of surveys of numerical simulation of the base isolated system for the vibration control of the buildings, the obtained results are plotted in the graphical form which is listed below. The load considered in this study, which is imposed on the structure is harmonic in nature.

A. Variation of structural responses with time of loading

The variations of the displacement and acceleration time histories of the structure for mass ratio μ = 10%, damping of base isolator ξ_b = 10% and damping of structure ξ_s = 1% has been shown in Figs. 2 and 3. The responses are obtained for a structure with and without base isolation system, to conduct comparative study. It can be easily observed that due to the implementation isolator devices the responses of the structure reduces in a quite significant manner when compared to the responses without isolating system.

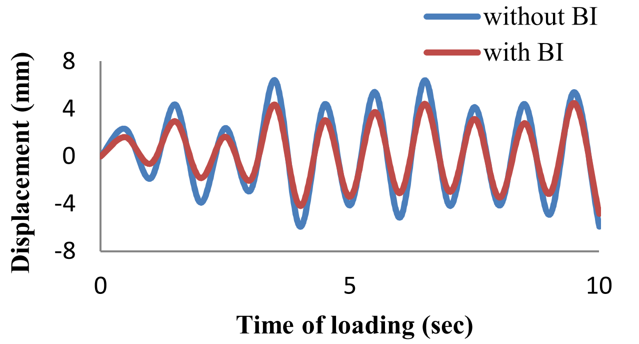

Fig.2. Variation of Displacement of structure with time (with and without BI) for mass ratio μ = 10%, damping of base isolator ξ_b = 10%, and damping of structure ξ_s = 1%.

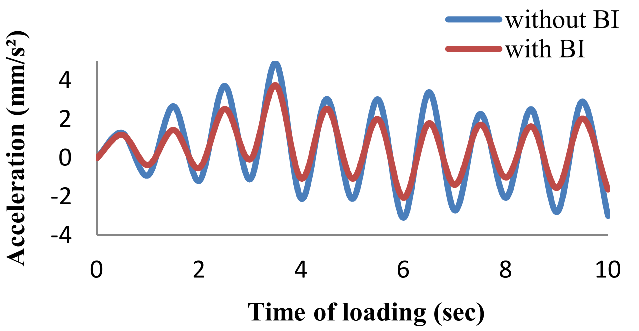

Fig.3. Variation of Acceleration of structure with time (with and without BI) for mass ratio μ = 10%, damping of base isolator ξ_b = 10%, and damping of structure ξ_s = 1%.

B. Variation of structural responses with time period of structure

The variation of displacement and acceleration with time period of the structure for various mass ratios μ = 5% to 10%, damping of base isolator ξ_b = 10% and damping of structure ξ_s = 1% has been shown in Figs. 4 and 5. The displacement of the structure goes on increasing with the increase of the Time period of the structure whereas the acceleration after achieving its peak value at the initial stage goes on decreasing. From these plots it can be easily demonstrated that with the increase in the mass of base isolator (i.e. increase in the mass ratio) responses reduces drastically.

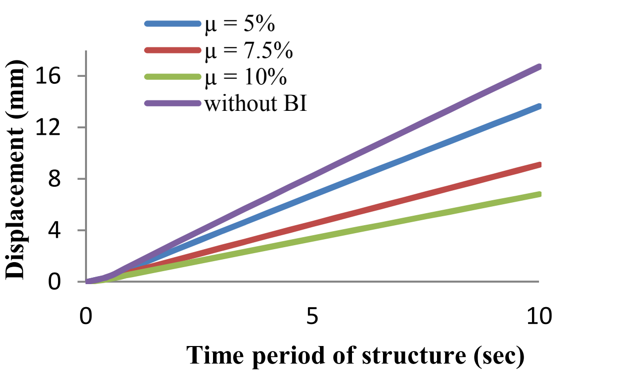

Fig.4. Variation of Displacement with Time period of structure for various mass ratios considering damping of base isolator ξ_b = 10% and damping of structure ξ_s = 1%

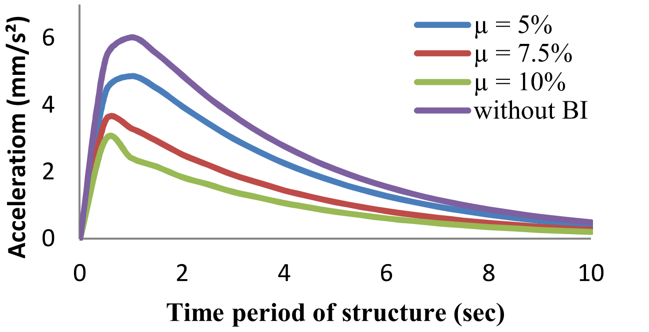

Fig.5. Variation of Acceleration with Time period of structure for various mass ratios considering damping of base isolator ξ_b = 10% and damping of structure ξ_s = 1%

C. Variation of structural responses with damping ratio of base isolator ξ_b

The effect of the damping of base isolator ξ_b on reducing the displacement and acceleration of the structure has been observed by implementing different damping ratio of base isolator ξ_b = 10% to 50% for different mass ratio μ = 5% to 10% with a constant damping ratio of structure ξ_s = 1%. These variations have been shown in Figs. 6 and 7. It can be easily demonstrated from these plots with the increase in damping of base isolator responses reduces linearly.

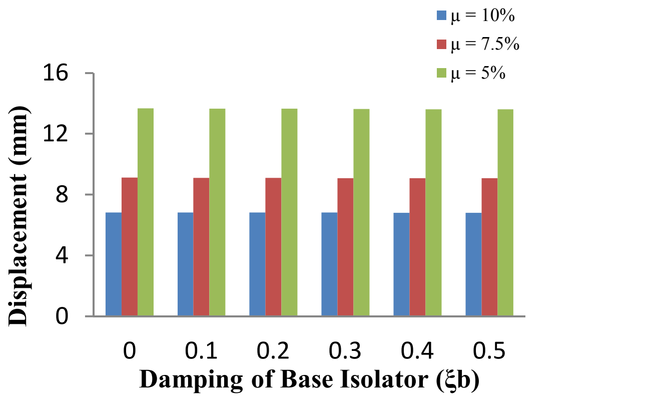

Fig.6. Variation of Displacement with damping ratio of base isolator ξ_b for mass ratio μ = 5% to 10%, damping of base isolator ξ_b = 10% to 50%, and damping of structure ξ_s = 1%.

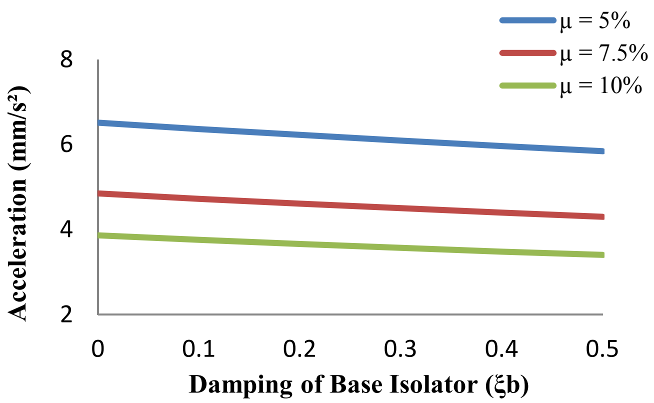

Fig.7. Variation of Acceleration with damping ratio of base isolator ξ_b for mass ratio μ = 5% to 10%, damping of base isolator ξ_b = 10% to 50%, and damping of structure ξ_s = 1%.

D. Effect on maximum displacement for different damping of structure ξ_s

The effect of the damping of the structure ξ_s on reducing the maximum displacement of the structure for mass ratio μ = 10%, different damping ratio of base isolator ξ_b = 10% to 50% and different damping ratio of structure ξ_s = 1% to 5% has been shown in Fig. 8. The results show that for a particular value of damping of base isolator, the response reduction for different damping ratios of structure is more or less same. But with the increase in damping of base isolator responses get reduced which implies that the effect of damping of structure is quite insignificant when compared with the damping of the Isolation system.

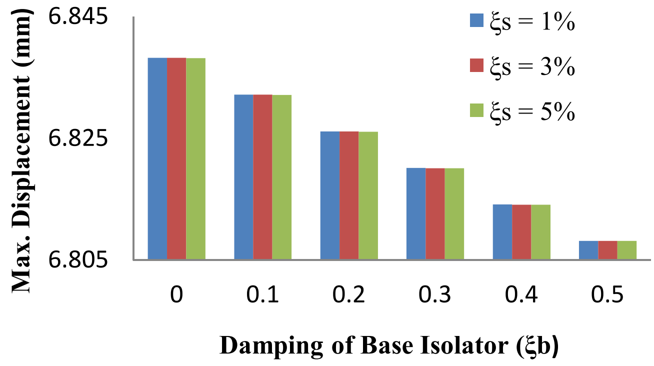

Fig.8. Variation of Maximum Displacement with damping ratio of base isolator ξ_b for mass ratio μ =10%, damping of base isolator ξ_b = 10% to 50%, and damping of structure ξ_s = 1% to 5%.

The effectiveness of the Base Isolator (BI) can be calculated in terms of the reduction of structural displacement or acceleration with BI compared to the corresponding value without BI.

$$\text{Effectiveness of the BI} = \frac{Xs - Xb}{Xb} \times 100\%$$

where, x_s and x_b are the peak displacement or acceleration values of without and with BI respectively. The effectiveness of the BI found here is 44.925% & 41.70% with respect to displacement and acceleration of the structure system.

IV. CONCLUSION

In this paper, a parametric study was performed to evaluate the performance of a base isolated device in reducing the responses of structure during earthquake (i.e. under dynamic load). Newmak-Beta algorithm was followed to obtain the responses. The various effects of the mass ratio, damping of the base isolator as well as the structure itself have been studied in this paper. It can be easily demonstrated from the results that with the increase of the mass ratio, the responses reduce significantly. The displacement of the structure increases with the Time period of structure whereas the acceleration reduces after achieving its peak value. It can be also seen that with the increase of damping ratio of the base isolator, the response reduces linearly. But the effect of the damping of the structure is not significant in reducing the responses. Therefore, it can be demonstrated from this study that lower damping values should be preferable. The effectiveness of the base isolator device is evaluated on the basis of the response reduction of the structure. It is found that the displacement and acceleration are reduced to about 44.925% and 41.70% respectively. The primary cause of the effectiveness of the base isolation system in reducing the earthquake-induced forces is as it increases the fundamental

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 5 Issue 02, February-2016

vibration period of the structure and, hence reduces the acceleration. Therefore, it can be easily demonstrated that Base Isolated Device effectively mitigated the responses of the structure.

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