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Base Isolated connected buildings subjected to seismic and blast induced vibrations

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Abstract

In the present study, the passive control of closely spaced base isolated and fixed base buildings are investigated under the effects of earthquakes and blast induced vibrations. The study advocates the installation of viscous dampers (FVDs) to protect the closely spaced base isolated buildings adjacent to fixed base buildings against seismic and blast excitations. The performance of a five storied base isolated building is reviewed such that time period of isolated building (T_b) is 2.5 sec with isolation damping is assumed as 5% and connected to an adjacent fixed base building such that it has three storey and structural time period 0.5 sec. The effectiveness of damper connected base isolated and fixed buildings is also analyzed for isolation period 2 sec and 3 sec respectively. Nonlinear direct integration method has been adopted to evaluate the performance of fixed base and base isolated structures for connected and unconnected state. The equations of motions are formulated and solved using MATLAB code by Newmark's average acceleration method. The lead rubber isolators are designed and idealized as Bouc Wen model. A parametric study is also conducted to determine the optimum damper properties for the fixed base buildings and base isolated connected buildings with viscous dampers. Results exhibit the efficiency of viscous dampers in reducing the structural responses of the base isolated buildings. It has been observed that in case of fixed base buildings, the peak responses show an effective reduction in responses. The effectiveness of the passive control technique using viscous dampers in mitigating the bearing displacements of base isolated structures subjected to seismic and blast induced vibrations is also reported.

Keywords: Adjacent buildings, Blast induced vibration, viscous dampers, nonlinear analysis, seismic responses.

1. Introduction

Research and advancement in the field of earthquake engineering has minimized the computational efforts of complex problems with the use of software packages and coding. From the previous records of catastrophic earthquakes such as the 1985 Mexico City earthquake and 1989 Loma Prieta earthquake, which resulted in heavy toll to life and property, it has been clear that inherent damping of the material alone cannot dissipate the unwanted energy due to earthquakes and heavy wind actions. Hence there was an emerging need of structural vibration control devices which can reduce the severe responses of structure without altering the dynamic characteristics of structures, known as supplemental damping devices. Structural passive control systems have been developed with the design philosophy different than the conventional seismic design method, which have immediate effect of increasing the critical damping ratio right up to 25-30% (against 5% value usually used for structures) and at the same time reducing the response of the structure during seismic event. The passive energy dissipating system equipped within the main structure does not behave as an independent dynamic system but rather interact with main structure. The reduction in the structural responses shows the formidable potential of dampers in controlling the responses of the structure. In a passive control strategy, an external passive energy dissipation device is attached to the civil engineering structures. Soong and Dargush [1] have classified passive energy dissipation devices into metallic, friction, viscoelastic, viscous fluid, tuned mass and tuned liquid dampers.

Base isolation has an important role in decreasing the responses of structural systems and has been used with the development of science and technology. Many types of structures have been built using this approach. Most of the completed buildings and those under construction use rubber isolation bearings to isolate structures from the moving ground. The passive control systems do not require external power or energy to actuate during seismic event. Depending upon the intensity of lateral forces acting on a structure it dissipates seismic energy thus reducing inter-storey drift and bending moment induced in the structure.

The performance of optimal passive control is sometimes limited and is typically designed to protect the structure from one particular dynamic loading. The use of such dampers may also be extended to control the seismic and blast response of two closely spaced buildings. The free space between two adjacent buildings may be utilized in order to dissipate the unwanted energy due to earthquakes or blast induced ground vibrations. Such type of arrangement also prevents pounding (collision between two adjacent buildings due to heavy impact) of two structures, which occurred in past catastrophic

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earthquakes. The detailed investigation of the pounding phenomenon has been carried out by Anagnostopoulos [2], Westermo [3], Jeng et al. [4] and Maison and Kasai [5] between structures constructed in vicinities with limited availability of land resources. Xu et al. [6], Bhaskararao and Jangid [7], Kandemir and Mazanoglu [8] Patel and Jangid [9] and Bhaskararao and Jangid [10] employed the passive control dampers such as fluid viscous dampers, friction dampers and visco elastic dampers to mitigate the phenomenon of pounding between closely spaced buildings. The implementation of active and semi active control devices was studied by Seto and Matsumoto [11], Bharti et al. [12], Fisco and Adeli [13], Sandoval et al. [14] and a combination of both was studied by Palacios-Quinonero [15] and Pérez [16] to closely constructed buildings in mitigating the structural responses under seismic excitations. The performance of base isolated structures connected with visco elastic dampers and semi active dampers in improving the performance of adjacent buildings was adopted by Matsagar and Jangid [17] and Shrimali et al. [18] respectively. Based on these studies, the following buildings namely the Kajima Building complex (Akasaka, Tokyo, Japan), the Triton Square office in Tokyo, Japan and the Konoike Headquarter Buildings in Osaka, Japan have been equipped with dynamic tuned connector, active control actuators and visco elastic dampers to improve the structural performance respectively.

The present study aims to compare the potential of viscous dampers in controlling the structural responses of closely spaced base isolated and fixed base buildings when subjected to earthquakes and blast induced vibrations. The selected buildings are mounted on lead rubber bearings and the performance of the base isolated building connected with fixed base building using viscous dampers is evaluated. Newmark's step by step integration method is adopted to analyze the connected base isolated buildings using MATLAB code. Bouc-Wen model (BWM) is selected to model the non linear behaviour of the base isolation system such as lead rubber bearings (LRB) popularly known as N-Z bearing system. The work also aimed to study the effect of damping coefficient of viscous dampers on the performance of base isolated connected buildings.

2. Numerical Study

The base isolation system is modelled using the Bouc Wen model and isolation properties are calculated from the assumptions proposed by Jangid [19]. The other assumed isolation parameters include 5% isolation damping (η), post Yield Stiffness Ratio, α=0.1, yield strength ratio F_0= 0.1. The yield strength of the isolated bearings is calculated from the expression, F_Y=F_0 x W such that W is the total weight of the isolated building. The mass of the isolated system is assumed to be equal to the mass of the superstructure storey ($m_b/m=1$). The study also evaluates the variation of damping coefficient of viscous dampers on the performance of the base isolated building. The buildings are modelled with an assumption that the MDOF system represents a linear shear type structure with lateral degrees of freedom at each floor level and both the connected structures are subjected to same ground excitations. The two connected structures are symmetric buildings with their symmetric planes in alignment with equal number of floors of each structure are at same level whereas the base isolated buildings connected to adjacent fixed base buildings are selected such that floors of each structure are at same level and shown in Figures 1 (a) and 1(b). The study also incorporates the effect of isolation period (T_b=2, 2.5 and 3 sec) on the performance of base isolated buildings connected with fixed base buildings. The total external damping added when connecting the adjacent buildings with dampers is calculated from the Eq. 1 as proposed by Matsagar and Jangid [20] such that ξ_e is the equivalent viscous damping of the isolation system taken as 10% for the selected isolation systems and ω_e is the equivalent isolation frequency of the selected isolation system.

$$\eta_d = \frac{c_{db} + \sum c_{dj}}{2\xi_e \omega_e \sum M_i} \qquad (1)$$

In Eq. 1, the damper damping coefficients at isolation level is expressed by c_{db} whereas the damper coefficients at the j^{th} floor levels are given by c_{dj}. The expression ΣM_i represents the total mass of the base isolated buildings. The equation of motion adopted to solve the unconnected state of two selected buildings is given by Eq. 2. The mass, damping and stiffness matrices of the combined system is represented by M, C and K and given by Eqs.3, 4 and 5 respectively. The null matrices 0_1 and 0_2 are of order (m x n) and (n x m) respectively such that order m and n are the degree of freedom for adjacent base isolated and fixed base building respectively. In case of connected state, the viscous damper coefficient c_d is substituted in Eq. 6 to formulate additional damping matrix C_D and added to Eq. 4 to formulate the damping matrix of the connected state. The null matrices 03 and 04 are of order (m x n-m). The null matrices 05 and 06 are of the order (n-m x m). And the null matrix 07 is of the order (n-m x n-m). The bearing force vector of the connected system is given by Eq. 9. For fixed base system the bearing force, F_2 is taken as zero. In Eq. 8, F_1, is the bearing force in the isolation system and Z_t is a dimensionless hysteretic component of the isolation system satisfying the nonlinear first order differential equation given by Eq. 9, where q is the yield displacement given by F_y/k_b and F_y is the yield force, x_b and $\dot{x}_b$ are the displacement and velocity of the isolating device respectively. β, γ and A are the dimensionless shape parameters. Parameter η is an integer which controls the smoothness of the transition from elastic to plastic response and α is the post to pre yielding stiffness ratio. In the present study the values of the above-mentioned dimensionless parameters are A=1, β=0.5, γ=0.5 and η=1.

$$M\ddot{x} + C\dot{x} + Kx + F = -MI\ddot{x}_g \qquad (2)$$

$$M = \begin{bmatrix} M_1 & 0_1 \\ 0_2 & M_2 \end{bmatrix} \qquad (3)$$

$$C = \begin{bmatrix} C_1 & 0_1 \\ 0_2 & C_2 \end{bmatrix} \qquad (4)$$

$$K = \begin{bmatrix} K_1 & 0_1 \\ 0_2 & K_2 \end{bmatrix} \qquad (5)$$

$$C_D = \begin{bmatrix} c_d & -c_d & 0_3 \\ -c_d & c_d & 0_4 \\ 0_5 & 0_6 & 0_7 \end{bmatrix} \qquad (6)$$

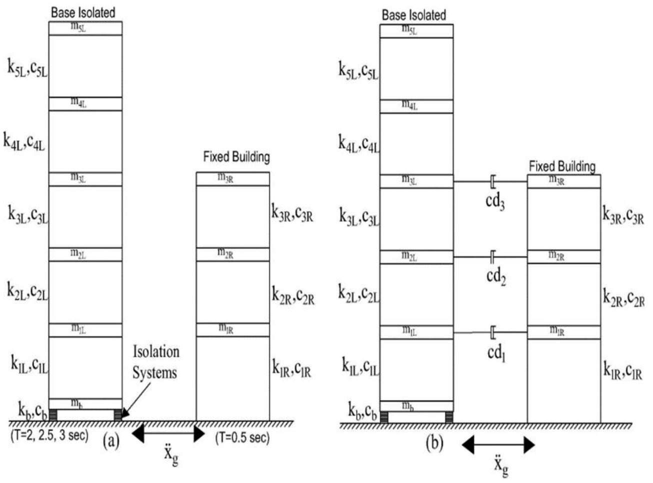

Fig.1- Schematic representation of the selected building models (a) Unconnected base isolate and fixed base buildings (b) Connected base isolated and fixed base building.

$$F = \begin{bmatrix} F_1 \\ F_2 \end{bmatrix} \qquad (7)$$

$$F_1 = \alpha \frac{F_y}{q} x_b + (1-\alpha) F_y Z_t \qquad (8)$$

$$q\, \dot{Z}_t = -\gamma |\dot{x}_b|\, Z_t |Z_t|^{\eta-1} - \beta\, \dot{x}_b\, |Z_t|^{\eta} + A\dot{x}_b \qquad (9)$$

3. Results

All the floors of the adjacent buildings are connected with dampers and the comprehensive assessment of two selected adjacent structures with and without dampers is done by applying earthquakes and blast loadings in the form of time histories using Newmark's step by step time integration method. The earthquakes include some of the most commonly cited seismic records i.e. Imperial Valley earthquake (Magnitude 6.6, 1979), Northridge Earthquake (Magnitude 6.7, 1994) and San Fernando Earthquake (Magnitude 6.6, 1971) for non linear dynamic analysis of the selected buildings. The responses of the buildings are also evaluated for the recently occurred New Zealand Earthquake (Magnitude 6.2, 2011) as shown in Fig.2. The adjacent buildings are further subjected to four blast induced ground acceleration time histories based on the previous studies by Kangda and Bakre [21] as shown in Fig.3. The blast induced ground vibration in terms of ground acceleration; $\ddot{x}_g$ (t) is modelled as an exponential decaying function given by Eq. 10:

$$\ddot{x}(t) = -\frac{1}{t_d} v\, e^{\frac{-t}{t_d}} \qquad (10)$$

In the above equation, v (m/s) is the peak particle velocity (PPV) obtained from the empirical equation proposed by Kumar et al. [22] using digitization software for various rock characteristics. The arrival time, t_d is evaluated using the expression t_d= R/c where R is the distance from charge point and c is wave propagation velocity (m/s) in soil obtained as the square root ratio of Young's modulus, E=73.9GPa and average mass density, ρ= 2650 kg/m^3.The present study investigates the performance of a five storied base isolated building such that time period of isolated building (T_b) is 2 sec, 2.5 sec and 3 sec.

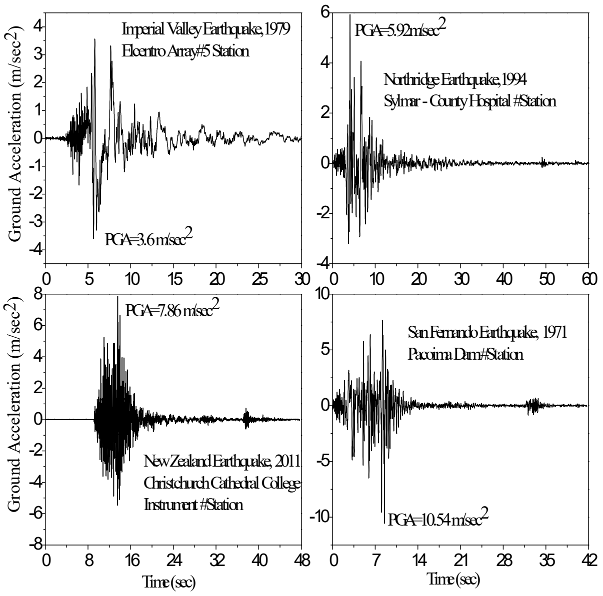

Fig.2- Selected earthquake records.

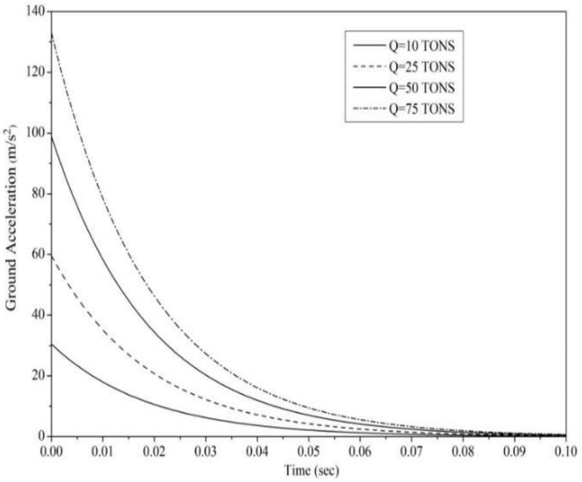

Fig. 3- Blast induced ground acceleration time histories.

The adjacent fixed base building is selected such that it has three storeys and structural time period 0.5 sec. It is observed from Fig. 4 that connecting the base isolated building with viscous dampers is an effective technique in mitigating the bearing displacement responses of a base isolated building having isolation period equal to 2.5 sec under selected ground motions at higher damping constant value (η_d) equal to 4. The bearing displacement responses are further plotted against the external damper damping property (η_d) of the viscous damper as shown in Fig.5 for the different isolation period and it is observed that the peak bearing displacement responses are reduced by 25-50% when evaluated under seismic excitations with the maximum reduction in responses obtained for Northridge Earthquake and the least responses obtained for New Zealand Earthquake. . It can be observed from Tables 1 and 2 that the structural responses in form of top storey absolute acceleration and normalized base shear responses are reduced by 10-20 % and 5-12% for blast induced vibrations. The performance of the fixed base building under earthquake histories harvest better structural

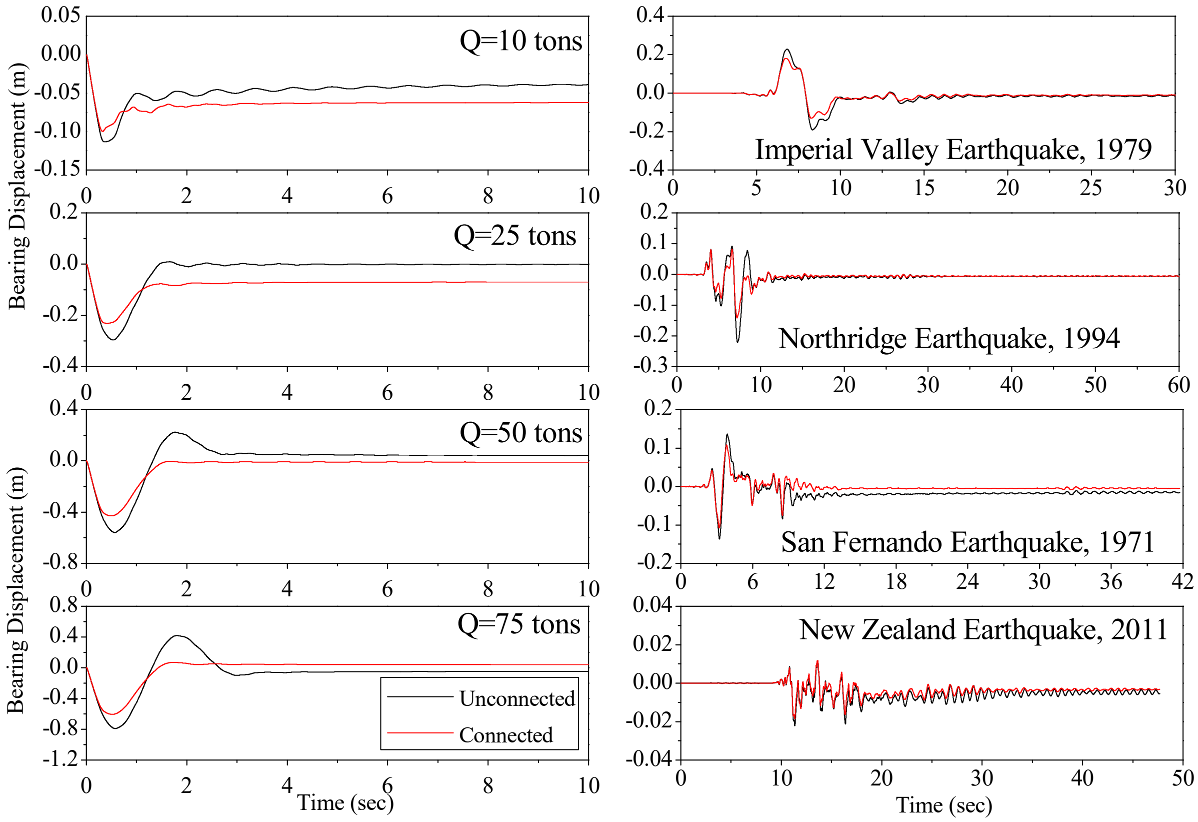

Fig.4-Bearing displacement responses of N-Z equipped buildings connected to fixed base buildings (η_d=4).

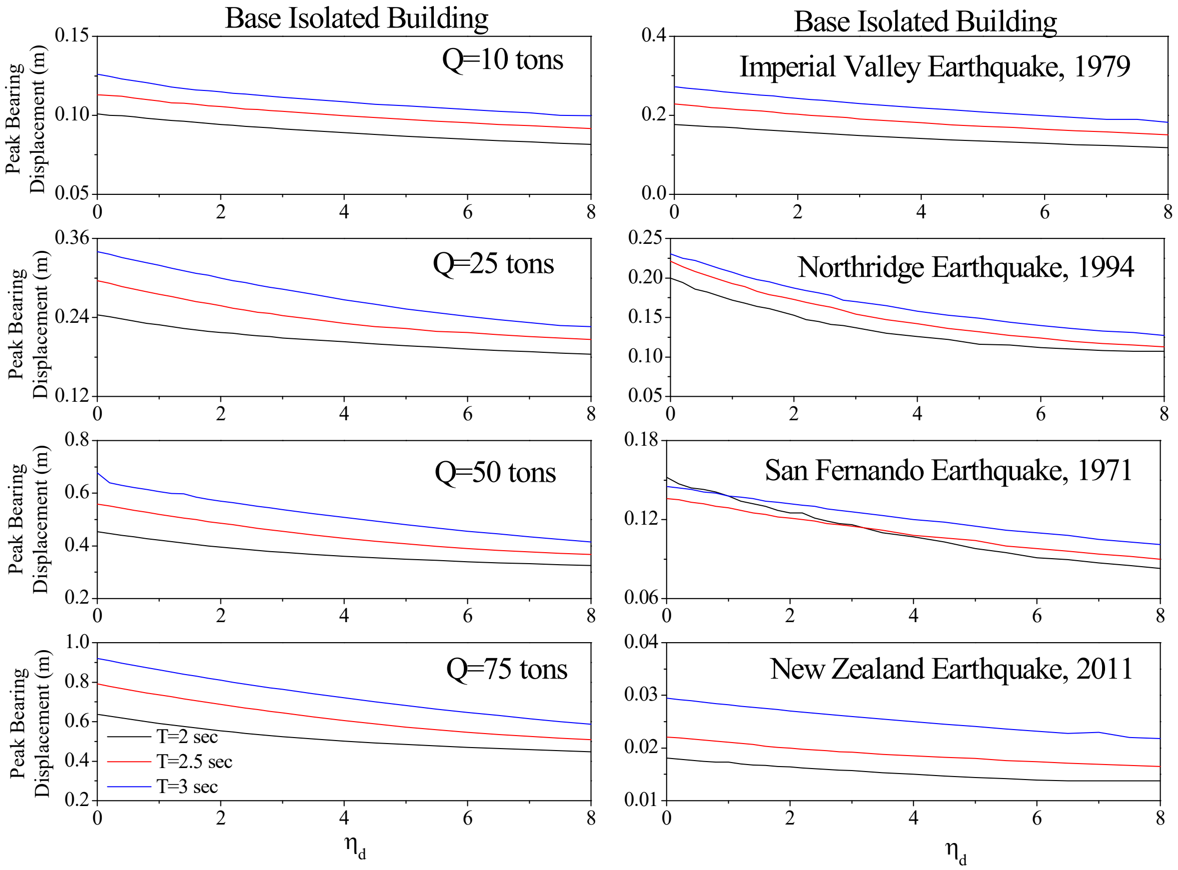

Fig. 5- Variation of peak bearing displacement responses of N-Z connected buildings against damping parameter (η_d)

Table 1 Performance of fixed building connected to adjacent base isolated building under blast excitations

Excitation	(η_d)	T_b=2 sec		T_b=3sec	
		Top storey accel. (% Reduc.)	Base Shear (% Reduc.)	Top storey Accel. (% Reduc.)	Base Shear (% Reduc.)
Blast=10 tons	1	3.02	11.08	2.19	9.36
	2	5.81	10.3	4.23	10.61
	4	10.72	8.27	7.92	9.52
	6	14.87	5	11.32	7.33
	8	18.49	2.18	14.34	4.84
Blast=25 tons	1	3.4	10.4	2.39	10.4
	2	6.53	9.92	4.63	10.4
	4	12.05	6.4	8.76	8.8
	6	16.77	3.2	12.43	6.08
	8	20.77	0	15.75	3.36
Blast=50 tons	1	3.54	10.91	2.49	11.06
	2	6.8	10.04	4.84	10.53
	4	12.56	6.25	9.16	8.65
	6	17.44	2.4	13.02	5.72
	8	21.6	0	16.49	2.89
Blast=75 tons	1	3.6	10.96	2.54	11.07
	2	6.91	10	4.93	10.57
	4	12.74	6.43	9.32	8.57
	6	17.7	2.14	13.26	5.71
	8	22	-1.43	16.78	2.5

Table 2 Performance of fixed building connected to adjacent base isolated building under seismic excitations

Excitation	(η_d)	T_b=2 sec		T_b=3sec	
		Top storey accel. (% Reduc.)	Base Shear (% Reduc.)	Top storey Accel. (% Reduc.)	Base Shear (% Reduc.)
Imperial Valley (1979)	1	11.80	10.17	8.49	7.63
	2	20.64	16.95	15.63	13.56
	4	33.60	26.44	27.0	22.0
	6	42.5	31.78	35.76	27.71
	8	48.91	34.58	42.64	31.61
Northridge (1994)	1	52.38	32.70	29.92	25.59
	2	57.94	36.50	37.64	34.60
	4	61.51	41.23	44.61	38.86
	6	64.08	43.60	47.63	42.18
	8	66.10	45.02	49.89	44.08
San Fernando (1971)	1	23.87	23.12	17.46	17.92
	2	36.17	36.13	29.13	28.61
	4	49.83	49.71	42.65	42.20
	6	57.15	56.36	50.74	50.58
	8	61.74	60.40	56.0	55.49
New Zealand (2011)	1	23.54	19.27	17.57	18.14
	2	38.13	25.40	30.22	23.58
	4	53.44	35.15	46.25	33.56
	6	60.12	41.72	55.19	41.72
	8	58.79	45.35	60.74	48.30

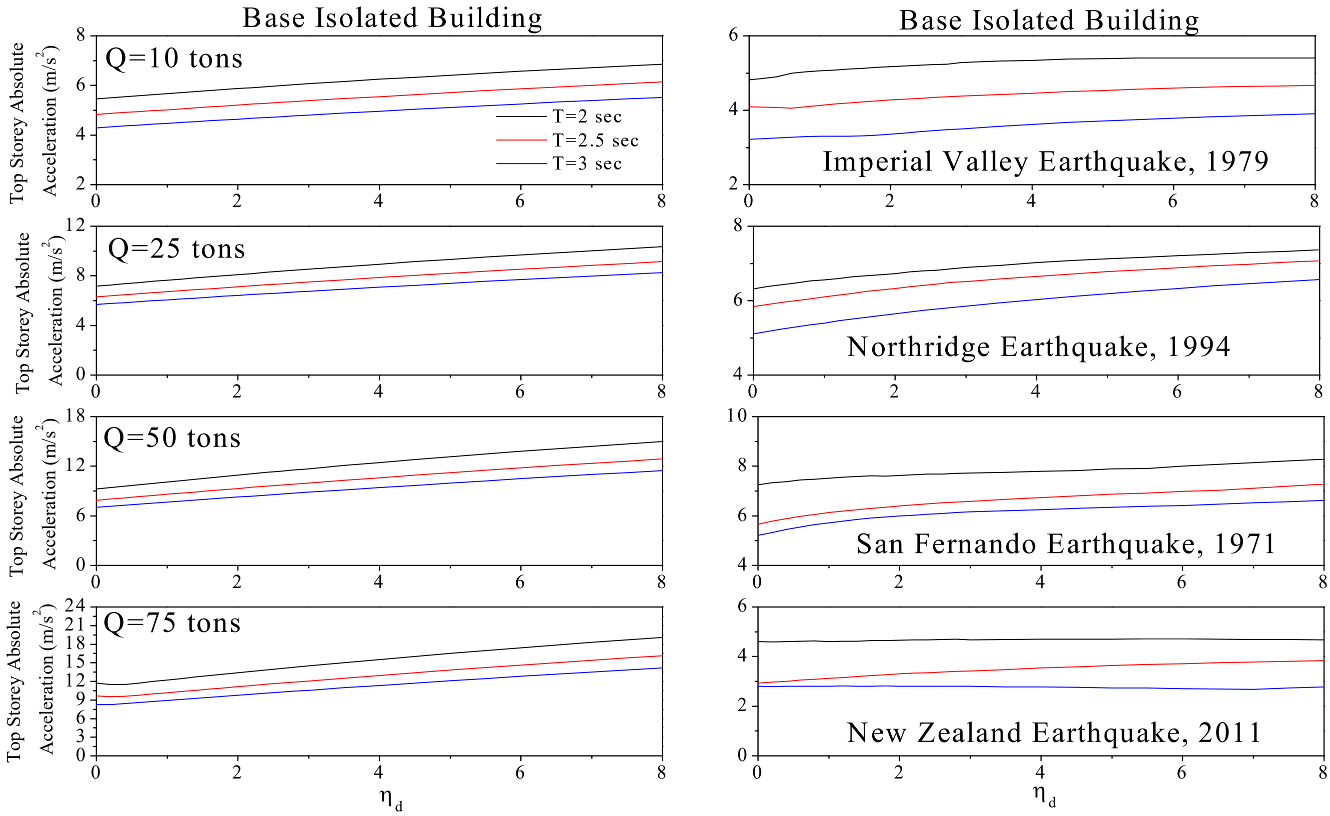

Fig.6- Variation of peak top storey acceleration responses of N-Z connected buildings against damping parameter (η_d).

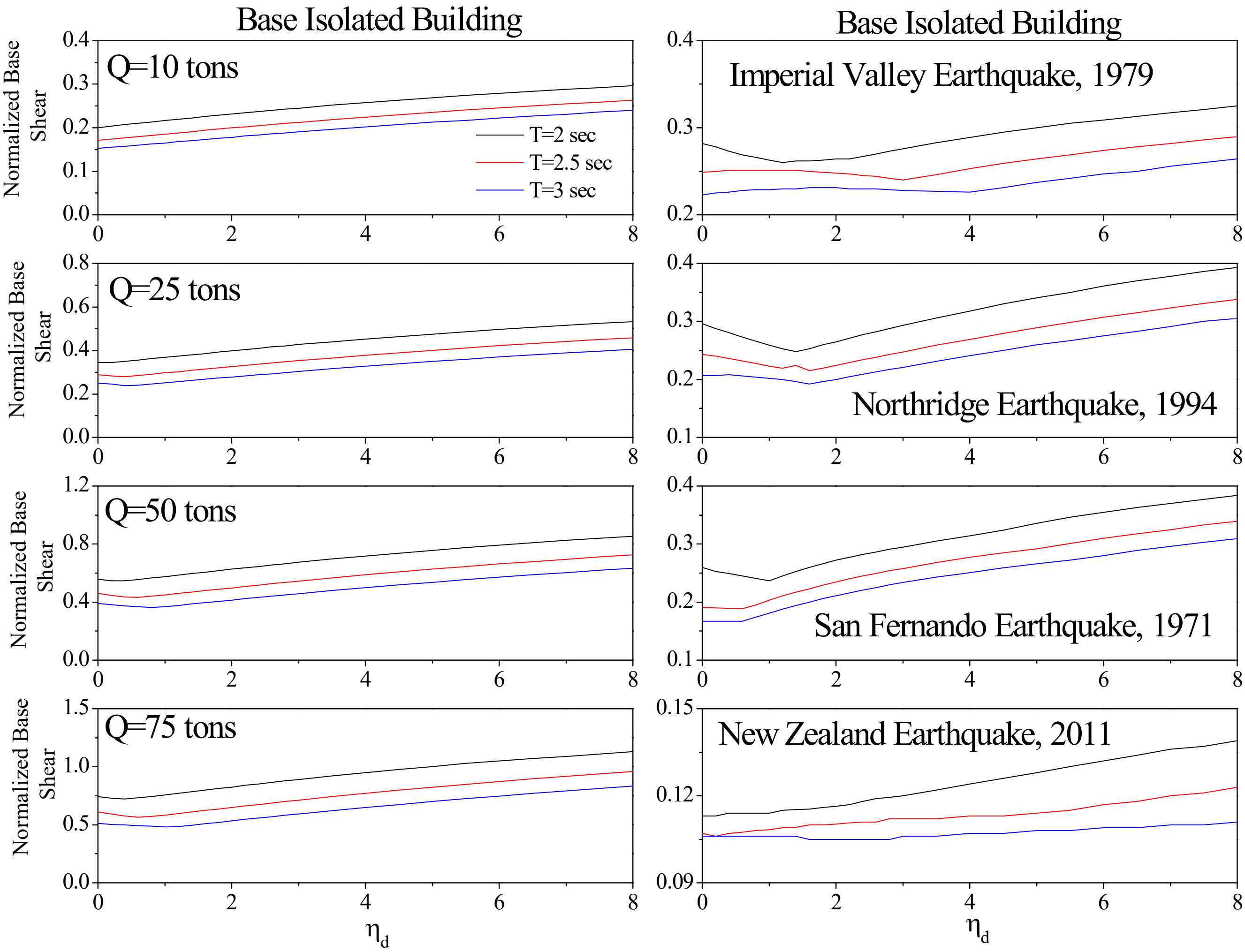

Fig. 7- Variation of normalized base shear responses of N-Z connected buildings against damping parameter (η_d)

response reduction efficiency of viscous damper in comparison to the responses obtained under blast induced vibrations. The fixed base building show reduction in the top storey displacement responses along with peak absolute acceleration and normalized base shear responses. The top storey displacement responses are reduced by 10-50 % for the selected ground motions at damper damping value varying from 1 to 8.

The absolute acceleration and normalized base shear values are reduced by 20-66% and 11-60% respectively under selected earthquake motions. The effect of isolation period of the adjacent isolation building on the performance of the connected fixed base building is also tabulated.

It is observed that an increase in the flexibility of the isolated building reduces the efficiency of the viscous damper in reducing the structural responses of the fixed base building. It is also observed that a higher value of η_d (η_d>2) resulted in the maximum reduction in the responses of the fixed base building in comparison to the lower value of η_d (η_d<2). Thus, it is concluded from the study, that connecting the closely spaced base isolated and fixed base buildings with viscous dampers susceptible to blast and earthquake induced vibrations is an effective technique in improving the structural performances of both the buildings.

4. Conclusions

Blast and seismic analysis of two adjacent fixed base and base isolated buildings is carried out using viscous dampers. The left building is base isolated (T_b=2 sec, 2.5 sec and 3 sec) and right building is fixed base (T=0.5 s), intrusion of dampers between the space available within two buildings is found to be a suitable means of mitigating the structural responses of structures subjected to transient loading. The study is extended further to protect the base isolated bearings installed to mitigate the structural responses by connecting the base isolated structures to adjacent fixed base buildings. Some of the interesting observations from the study are listed below.

i The installation of viscous damper is found to be very effective in controlling the seismic and blast responses of the connected buildings. There is a significant reduction in the peak bearing displacement responses of the base isolated building under all the selected ground motions and with an increase in the structural responses of the isolated building when connected using viscous dampers.

ii The comparison of structural responses in the form of base shear responses show that an optimum damper damping value of 1.5 yields maximum reduction in the responses under earthquake excitations by nearly 20%. It is important to note that in case of blast induced vibration no reduction in the normalized base shear responses is observed.

iii The peak absolute acceleration responses of the base isolated building when subjected to blast and seismic excitations exhibit an increase in the responses when connected to an adjacent fixed base building.

iv The performance of the fixed base building is predominantly improved in comparison to the adjacent fixed base building under both the selected ground motions. The results exhibit that the structural responses in the form of absolute acceleration and normalized base shear responses are reduced by nearly 10-20% under blast induced vibrations.

v The performance of the fixed base building in form of top storey displacement, absolute acceleration and normalized base shear responses when subjected to different earthquake excitations show reduction of more than 50% at a higher value of damper damping.

Disclosures

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References

1. Soong TT, Dargush GF. Passive energy dissipation systems in structural engineering. John Wiley & Sons Ltd., 1997.
2. Anagnostopoulos SA. Pounding of buildings in series during earthquakes. Earthquake Engineering & Structural Dynamics, 1998; 16 (3): 443-456.
3. Westermo BD. The dynamics of interstructural connection to prevent pounding. Earthquake Engineering & Structural Dynamics, 1989; 18 (5): 687-699.
4. Jeng V, Kasai K, Jagiasi A. The separation to avoid seismic pounding. Proceedings, 10th World Conference on Earthquake Engineering, 1992; Madrid, Spain.
5. Maison BF, Kasai K. Dynamics of pounding when two buildings collide. Earthquake Engineering & Structural Dynamics, 1992; 21(9): 771-786.
6. Xu YL, He Q, Ko JM. Dynamic response of damper-connected adjacent buildings under earthquake excitation. Engineering Structures, 1999; 21(2): 135-148.
7. Bhaskararao AV, Jangid RS. Seismic analysis of structures connected with friction dampers. Engineering Structures, 2006; 28 (5): 690-703.
8. Kandemir-Mazanoglu EC, Mazanoglu K. An optimization study for viscous dampers between adjacent buildings. Mechanical Systems and Signal Processing, 2017; 89: 88-96.
9. Patel CC, Jangid RS. Seismic response of dynamically similar adjacent structures connected with viscous dampers. The IES Journal Part A: Civil & Structural Engineering, 2010; 3 (1): 1-13.
10. Bhaskararao AV, Jangid RS. Seismic response of adjacent buildings connected with dampers. In 13th World Conference on Earthquake Engineering, 2004.
11. Seto K, Matsumoto Y Active vibration control of multiple buildings connected with active control bridges in response to large earthquakes. In American Control Conference, 1999.
12. Bharti SD, Dumne SM, Shrimali MK. Seismic response analysis of adjacent buildings connected with MR dampers. Engineering Structures, 2010; 32 (8):2122-2133.
13. Fisco NR, Adeli H. Smart structures: part I—active and semi-active control. Scientia Iranica, 2011; 18 (3): 275-284.
14. Sandoval MR, Ugarte LB, Spencer BF. Study of structural control in coupled buildings. In Proc., 15th World Conf. on Earthquake Engineering, 2012.
15. Pérez LA, Avila S, Doz G. Seismic response control of adjacent buildings connected by viscous and hybrid dampers. In Dynamics of Civil Structures, 2014; 4: 433-440.
16. Palacios-Quinonero F, Rubió-Massegú J, Rossell JM, Karimi HR. Semiactive–passive structural vibration control strategy for adjacent structures under seismic excitation. Journal of the Franklin Institute, 2012; 349(10): 3003-3026.
17. Matsagar VA, Jangid RS. Base-isolated building connected to adjacent building using viscous dampers. Bulletin of the New Zealand Society for Earthquake Engineering, 2006; 39 (1): 59-80.
18. Shrimali MK, Bharti SD, Dumne SM. Seismic response analysis of coupled building involving MR damper and elastomeric base isolation. Ain Shams Engineering Journal, 2015; 6 (2): 457-470.
19. Jangid RS. Optimum lead–rubber isolation bearings for near-fault motions. Engineering structures, 2007; 29(10): 2503-2513.
20. Matsagar VA, Jangid RS. Viscoelatic damper connected to adjacent structures involving seismic isolation. Journal of civil engineering and management, 2005; 11 (4): 309-322.
21. Kangda MZ, Bakre S. The Effect of LRB Parameters on Structural Responses for Blast and Seismic Loads. Arabian Journal for Science and Engineering, 2018; 43(4): 1761-1776.
22. Kumar R, Choudhury D, Bhargava K. Determination of blast-induced ground vibration equations for rocks using mechanical and geological properties. Journal of Rock Mechanics and Geotechnical Engineering, 2016; 8(3): 341-349.