Seismic Upgrading of the 111 Serie Residential 10 Story R.C.Frame Buildings in Armenia, using Additional Isolated Upper Floor

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Abstract

Widely distributed 111 serie, 10 story R.C. frame buildings are constructed during former soviet union in Armenia and Nagorno Karabakh province. Current research is completed to illustrate the concept of seismic upgrading of above mentioned buildings, using an Additional Isolated Upper Floor (AIUF). After constructing the finite element model, Time history analyses are applied on it, using six pair of accelerograms recorded on rock or very stiff soil ($750<V_s<1200$ m/s), and loose rock or stiff soil ($375<V_s<750$ m/s), scaled to S_a=0.4g. Later, the AIUF which behaves as a Tuned Mass Damper (TMD) is added to the model and after tuning for the frequency and damping ratios, the same time history analyses are applied on this new model too. The final analyses results show considerable reduction on lateral displacement and base shear force when using AIUF, satisfying the overall seismic behavior of the building.

Keywords: Seismic upgrading, accelerogram, lateral displacement, Time History analysis, Additional isolated upper floor

Introduction

Previous experience of earthquakes illustrates that many types of structures behave nonlinearly during a severe earthquake. So a huge amount of input energy is mainly dissipated through the form of damping and hysteresis. The aseismic behaviour analysis and accurate design of structures for severe earthquakes are mainly carried out using Nonlinear Time history Analysis method (NTHA). The Tuned Mass Damper Passive Aseismic Control system (TMD) reduces both the lateral displacement and base shear forces caused by the earthquakes. If truely tuned, structures equiped with TMD could behave linearly during a severe earthquake. The TMD control system could be used for to be constructed buildings and also for buildings which do not satisfy the seismic code requirements. In this research, by using the TMD concept, an Additional Isolated Upper Floor (AIUF) is added to the top of the 111 serie, 10 story R.C. frame building, and tuned for the frequency and damping ratios, so that could reduce the lateral displacements and base shear forces to a great extent, to ensure the overall linear behavior of the building during a severe earthquake.

Tuned Mass Damper's (TMD) Theoritical Bases

The two-DOF systems shown in Figure 1 is excited by a harmonic force $p_1(t) = po \sin\omega t$ applied to the mass m_1. For both systems the equations of motion are as equation (1):

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{Bmatrix} \ddot{u}_1 \\ \ddot{u}_2 \end{Bmatrix} + \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{Bmatrix} u_1 \\ u_2 \end{Bmatrix} = \begin{Bmatrix} p_o \\ 0 \end{Bmatrix} \sin\omega t \tag{1}$$

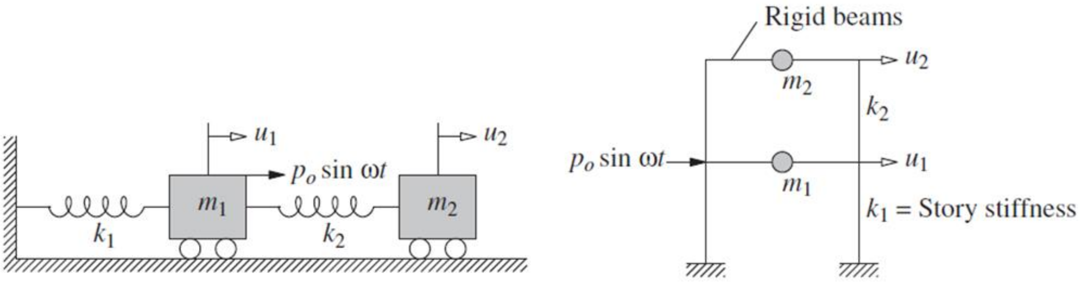


Figure 1- Two-Degree of freedom systems

For harmonic force applied to the main mass we already have the solution given by Eq.(2) &(3):

$$u_{1o} = \frac{p_o(k_2 - m_2\omega^2)}{m_1 m_2(\omega^2 - \omega_1^2)(\omega^2 - \omega_2^2)} \tag{2}$$

$$u_{2o} = \frac{p_o k_2}{m_1 m_2(\omega^2 - \omega_1^2)(\omega^2 - \omega_2^2)} \tag{3}$$

Introducing the notations below:

$$\omega_1^* = \sqrt{\frac{k_1}{m_1}} \qquad \omega_2^* = \sqrt{\frac{k_2}{m_2}} \qquad \mu = \frac{m_2}{m_1} \tag{4}$$

The vibration absorber is a mechanical device used to decrease or eliminate unwanted vibration. The description tuned mass damper is often used in modern installation; this modern name has the advantage of showing its relationship to other types of dampers. In the brief presentation that follows, we restrict ourselves to the basic principle of a vibration absorber without getting into the many important aspects of its practical design. In its simplest form, a vibration absorber consists of one spring and a mass. Such an absorber system is attached to a SDOF system, as shown in Figure 2. The usefulness of the vibration absorber becomes obvious if we compare the frequency-response function of Figure 2(b) with the response of the main mass alone,without the absorber mass. At $\omega = \omega_1^*$ the response amplitude of the main mass alone is unbounded but is zero with the presence of the absorber mass. Thus, if the exciting frequency ω is close to the natural frequency ω_1^* of the main system, and operating restrictions make it impossible to vary either one, the vibration absorber can be used to reduce the response amplitude of the main system to near zero. The preceding presentation indicates that a vibration absorber has its greatest application to synchronous machinery, operating at nearly constant frequency, for it is tuned to one particular frequency and is effective only over a narrow band of frequencies.

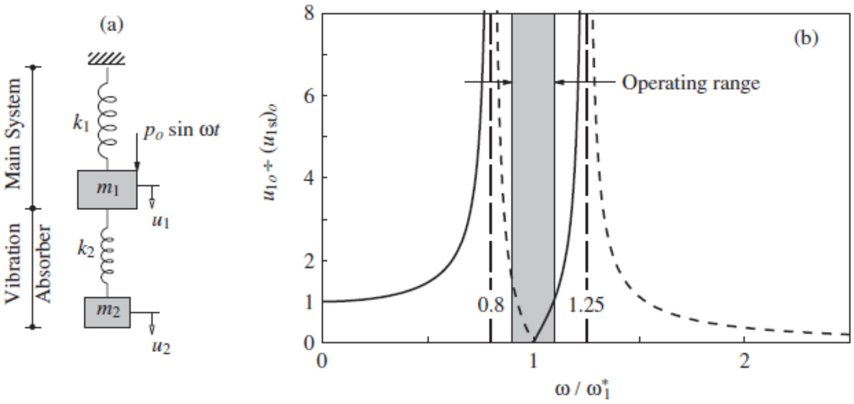


Figure 2- (a) Vibration absorber attached to an SDOF system; (b) response amplitude versus exciting frequency

The available solution can be rewritten as equations 5 & 6:

$$u_{1o} = \frac{p_o}{k_1} \frac{1-\left(\omega/\omega_2^*\right)^2}{\left[1+\mu\left(\omega_2^*/\omega_1^*\right)^2-\left(\omega/\omega_1^*\right)^2\right]\left[1-\left(\omega/\omega_2^*\right)^2\right]-\mu\left(\omega_2^*/\omega_1^*\right)^2} \tag{5}$$

$$u_{2o} = \frac{p_o}{k_1} \frac{1}{\left[1+\mu\left(\omega_2^*/\omega_1^*\right)^2-\left(\omega/\omega_1^*\right)^2\right]\left[1-\left(\omega/\omega_2^*\right)^2\right]-\mu\left(\omega_2^*/\omega_1^*\right)^2} \tag{6}$$

The usefulness of the vibration absorber becomes obvious if we compare the frequency-response function of Fig. 2b with the response of the main mass alone, without the absorber mass. At $\omega = \omega^*_1$ the response amplitude of the main mass alone is unbounded but is zero with the presence of the absorber mass. Thus, if the exciting frequency ω is close to the natural frequency ω^*_1 of the main system, and operating restrictions make it impossible to vary either one, the vibration absorber can be used to reduce the response amplitude of the main system to near zero. This implies that the absorber system exerts a force equal and opposite to the exciting force. Thus, the size of the absorber stiffness and mass, k_2 and m_2, depends on the allowable value of displacement. There are other factors that affect the choice of the absorber mass. Obviously, a large absorber mass presents a practical problem. At the same time the smaller the mass ratio μ, the narrower will be the operating frequency range of the absorber. According to uncertainities in earthquake prediction and dynamic characteristics of the MDOF systems, for instance natural frequencies and modal damping ratios, it would be more accurate to use several dampers in this kind of structures. It is suggested that these damper's vibration frequencies differ from each other to a little extent. By this, a wider band of frequencies could be included.

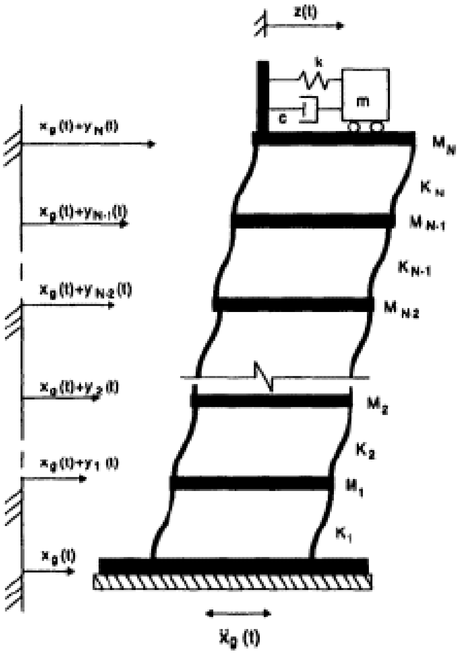
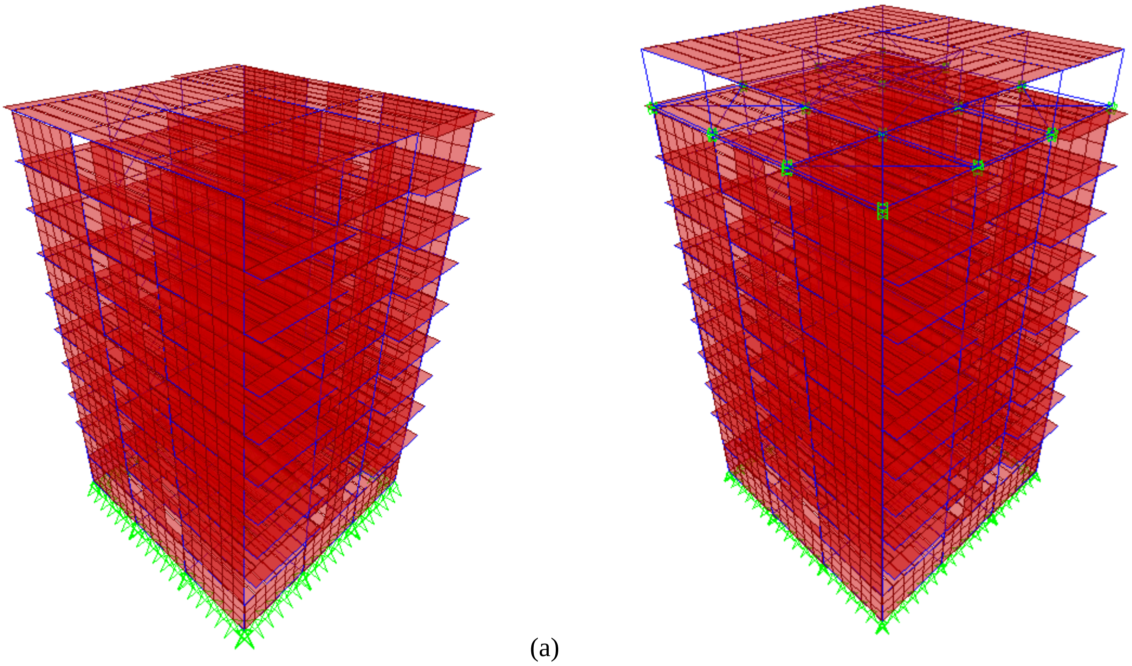


Figure 3- Multi Degree of Freedom Model of Structure + TMD

Finite Element Computational Models

Type 111-c serie residential building is chosen, which is composed of 3 bays of 6m on each direction, containing a basement on -3.0m level. Gravity load bearing system is of precast concrete beams and columns. The slabs are hollow core precast reinforced concrete slabs with a thickness of 22cm. Lateral load bearing system is of precast concrete shear walls, located on inner and outer frame lines on the y-direction. All beam and column connections and also shear wall connections to beams and columns are supposed to be simple.

On the x-direction, the building is partially braced, demonstrating a very weak stiffness. Steel Chevron (Λ) bracing is add to the x-direction for additional stiffness and preventing the torsional displacement of the building at the meantime as figure 4(a). Therefore the AIUF is added to the preliminary model weighting about 3~5% of the weight of the whole structure resulting secondary model as figure 4(b). The AIUF behaves like a Tuned Mass Damper (TMD) and is mainly tuned to act on the x-direction of the building. SAP2000 software is used for structural modeling and analysis. All above mentioned assumptions are included in the 3D structural modeling as shown in Figure 4.



(a) (b)

Figure 4- Computational Models a) Without AIUF, b) With AIUF

Figure 5- Seismic Upgraded Buildings using AIUF

Figure 6- AIUF Implimentation Technique on Roof Floor of 111 Serie building

All seismic isolation devices used for AIUF are of HDRB (High Damping Rubber Bearing) type. After completing the modeling process, frequencies of vibration and damping ratios of the secondary model is tuned to minimize the lateral displacement of the roof story. The results are summerized in Table (1):

Table 1- Stiffness and Damping Ratio results of AIUF after Tuning

	Stiffness (kN/mm)	Damping (kN-sec/mm)
AIUF (with 16 Columns)	2.24	0.56

Time History Analyses

In order to perform the time history analyses, 6 accelerograms of earthquakes recorded on soil type were selected. Then each record was scaled to spectral accelerations of S_a=0.40g, due to the related response spectrum in Armenian seismic code. Selected records are of the earthquakes listed in Table 2.

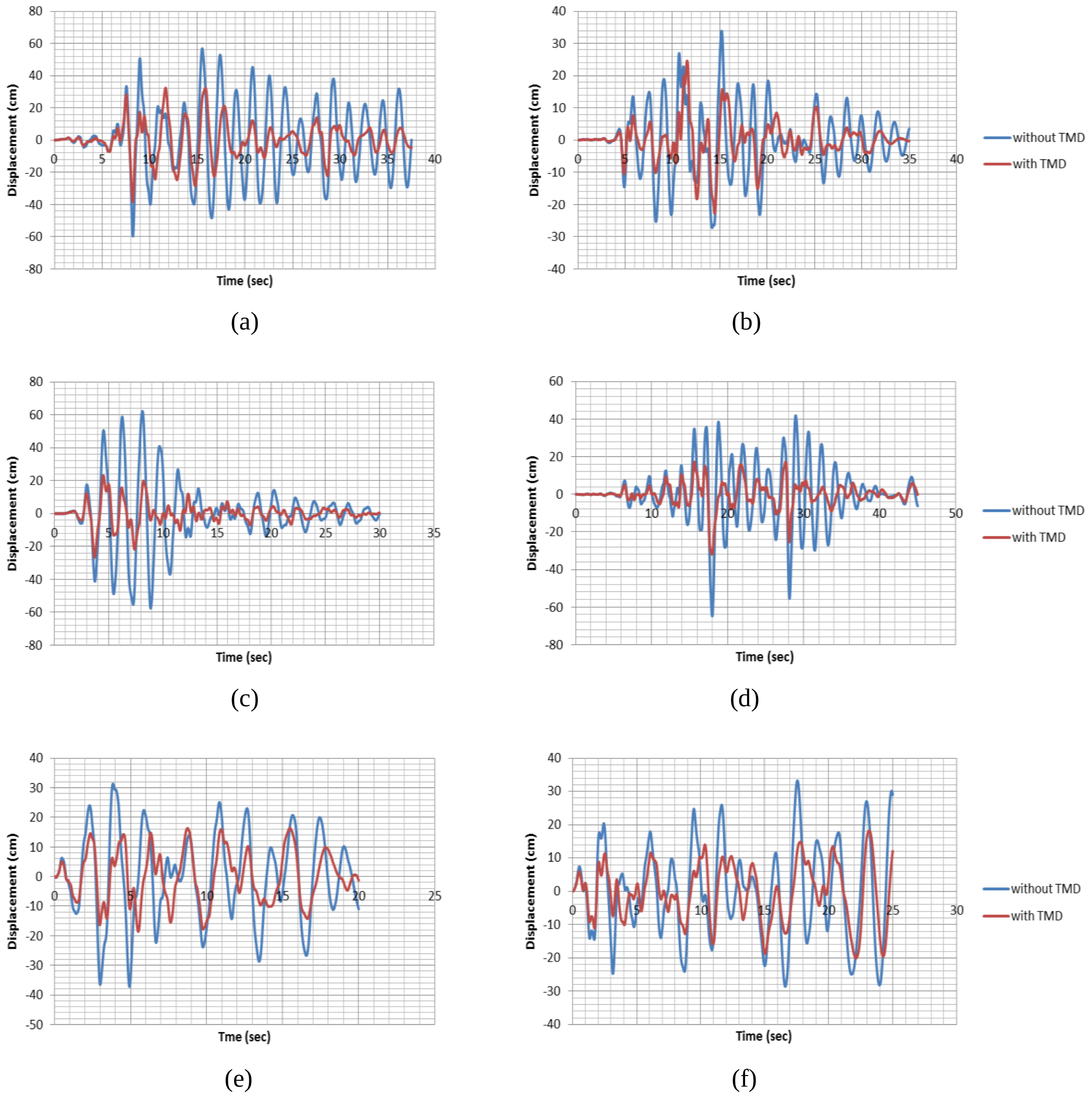
Table 2-Charachteristics of used Eartquakes

Event	Year	Mag.	Mechanism
Chi-Chi-Taiwan	1999	7.62	Reverse - Oblique
Irpinia-Italy	1980	6.9	Normal
Tabas-Iran	1978	7.35	Reverse
Kocaeli-Turkey	1999	7.51	Strike-Slip
San Fernando	1971	6.61	Reverse
Hector Mine	1999	7.13	Strike-Slip

Then the scaled records were applied to the computational models separately due to the soil type and spectral acceleration for which the selected model was analyzed. For linear Timehistory analyses, the “Modal Extension Method of Earthquake forces” technique was used. Nonlinear Timehistory analyses for preliminary model (without AIUF) and secondary models (with AIUF) were completed using Newmark–β method. Due to structural characterestics, the damping ratio for linear analyses was determined equal to 0.05 for all mode shapes. For nonlinear analyses the Rayleigh damping was used, determining damping ratio equal to 0.10 for the first two modes of vibration on x-direction. For performing the Time History Analyses (both Linear and Nonlinear), SAP2000 analysis software is used.

Analysis Results

According to TimeHistory analysis results, maximum lateral displacement timehistory for all records used in Table 2, are summerized in Figure 7.



(a) (b)

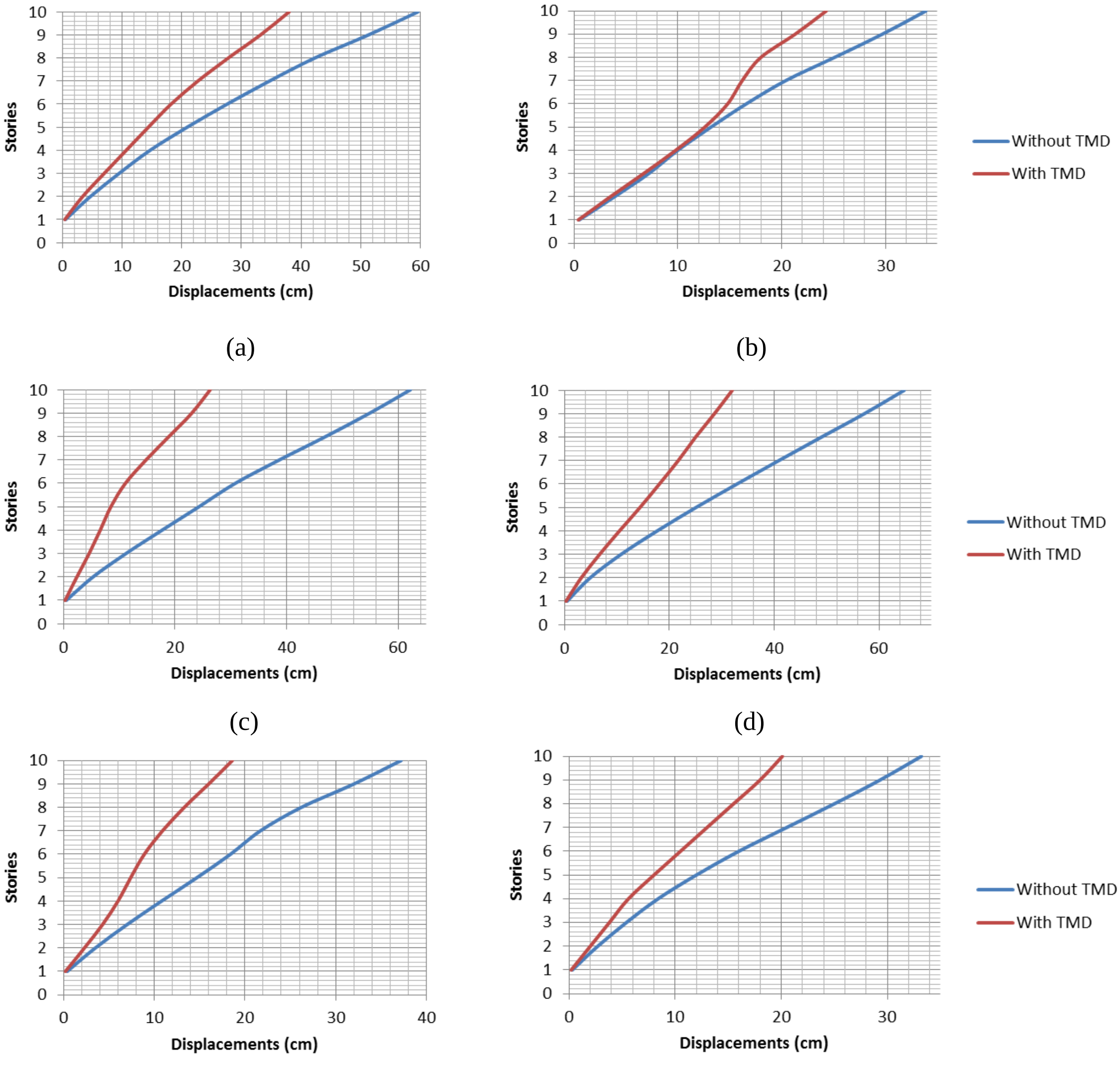
(c) (d)

(e) (f)

Figure 7- Lateral Displacement TimeHistory of Earthquake Records:

(a) Irpinia-Italy, (b) Tabas-Iran, (c) Izmit, (d) Chi-Chi -Taiwan, (e) Hector Mine, (f) San Fernando

As could be observed, well tuned Additional Isolated Upper Floor (AIUF), is able to reduce a great amount of the lateral displacement of the structure during a severe earthquake. Maximum lateral displacement extension for 10 stories for both with and without AIUF cases, are displayed in firgure 8.



(a) (b)

(c) (d)

(e) (f)

Figure 8- Maximum Lateral Displacement Extension of Earthquake Records:

(a) Irpinia-Italy, (b) Tabas-Iran, (c) Izmit, (d) Chi-Chi -Taiwan, (e) Hector Mine, (f) San Fernando

According to Time History analyses for mentioned records, results for Displacement Reduction due to AIUF are summarized in Table 3:

Table 3- Displacement Reduction due to AIUF

Soil Category	Records	Displacement w/o AIUF (cm)	Displacement with AIUF (cm)	Ratio %	Reduction %
Rock or very stiff soil 750<Vs<1200 m/s	Irpinia-Italy	59.6	38.0	63.8	36.2
	Izmit	62.2	26.3	42.3	57.7
	Tabas	33.9	24.3	71.7	28.3
Loose rock or stiff soil 375<Vs<750 m/s	ChiChi	64.8	32.0	49.4	50.6
	Hector Mine	37.2	18.6	50.0	50.0
	San Fernando	33.2	20.1	60.5	39.5

Results for Lateral Base Shear Force Reduction due to AIUF are summarized in Table 4:

Table 4- Lateral Base Shear Force Reduction due to AIUF

Soil Category	Records	Base Shear Force w/o AIUF (Ton)	Base Shear Force with AIUF (Ton)	Ratio %	Reduction %
Rock or very stiff soil 750<Vs<1200 m/s	Irpinia-Italy	2220.0	1658.0	74.7	25.3
	Izmit	2462.0	1251.0	50.8	49.2
	Tabas	2231.0	1821.0	81.6	18.4
Loose rock or stiff soil 375<Vs<750 m/s	ChiChi	2131.0	1374.0	64.5	35.5
	Hector Mine	1684.0	1127.0	66.9	33.1
	San Fernando	1369.0	885.1	64.7	35.3

Conclusion

The project on upgrading seismic resistance of nine-storey R.C. frame buildings by means of additional isolated upper floor (AIUF) pioneered the applications of seismic isolation structures to the top part of the buildings and was implemented in 1995-1997 in Armneia. It is worth noting that the isolated upper floor allows not only upgrading the earthquake resistance of a building, but enlarging its useful space as well. The most distinctive feature of the new earthquake resistance upgrading method, however, is that there is no need to re-settle the occupants of the building during construction. Under the earthquake impact AIUF, acting as vibration damper, reduces the deformed state of the building up to 58% and increases earthquake resistance by reducing the lateral base shear fore up to 49%. It could be observed from the obtained results that using AIUF for seismic upgrading of existing R.C. structures is an effective one, using the minimum energy and cost, without any need for re-settling the occupants, demonstrating effective results.

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