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The Effect of using Additional Isolated Upper Floor on the Performance Point of R.C. Frame Structures in Armenia

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ABSTRACT

Widely distributed 111 series, 10 story R.C. frame buildings are constructed during former soviet union in Armenia and Nagorno-Karabakh province. In current research we illustrate the concept of seismic upgrading of above mentioned buildings, using an Additional Isolated Upper Floor (AIUF). For this purpose, a three dimensional of 111-c R.C. frame building is modeled and analyzed according to Armenian SNIP II-6.02 code, based on 3 soil categories of Rock (Vs>800m/s), Dense Soil (500<Vs<800m/s) and Loose Soil (150<Vs<500m/s) respectively and spectral acceleration level of Sa=0.40g. Later, the AIUF which behaves as a Tuned Mass Damper is added to the model and after tuning for the frequency and damping ratios, Modal Pushover Analysis is carried out on both preliminary and secondary structural models. Finally by the means of FEMA356 guideline, Capacity Spectrum and Performance Point characteristics due to related soil categories are computed for each model, using Armenian SNIP II-6.02 pseudo-acceleration spectrums. The final analysis results show a constant base shear forces with variable displacements during soil degradation, when using Additional Isolated Upper Floor.

Keywords:

Seismic Upgrading, Additional Isolated Upper Floor, Performance Point, Modal Pushover Analysis, Capacity Spectrum.

1. 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 behavior 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 truly tuned, structures equipped with TMD could behave linearly during a severe earthquake. The TMD control system could be used to construct 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 series, 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. It should be noted that the 111 series buildings are well distributed all around in Armenia's provinces and Nagorno-Karabakh province as well, and were damaged during the 1988 Spitak earthquake to a great extent.

2. Tuned Mass Damper's (TMD) Theoretical Bases

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

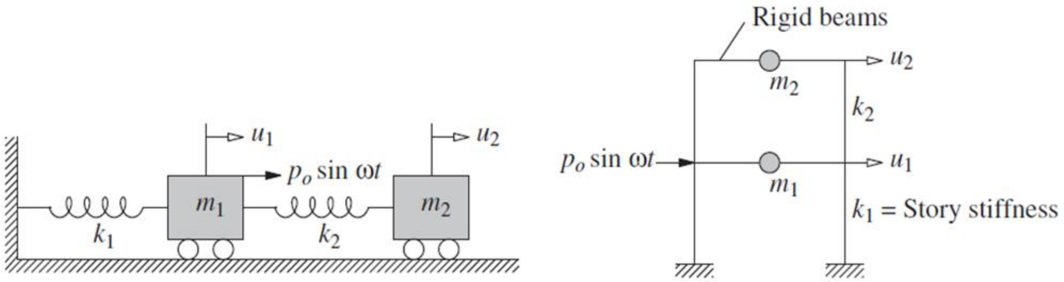


Figure 1. Two-Degree of freedom systems.

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

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.

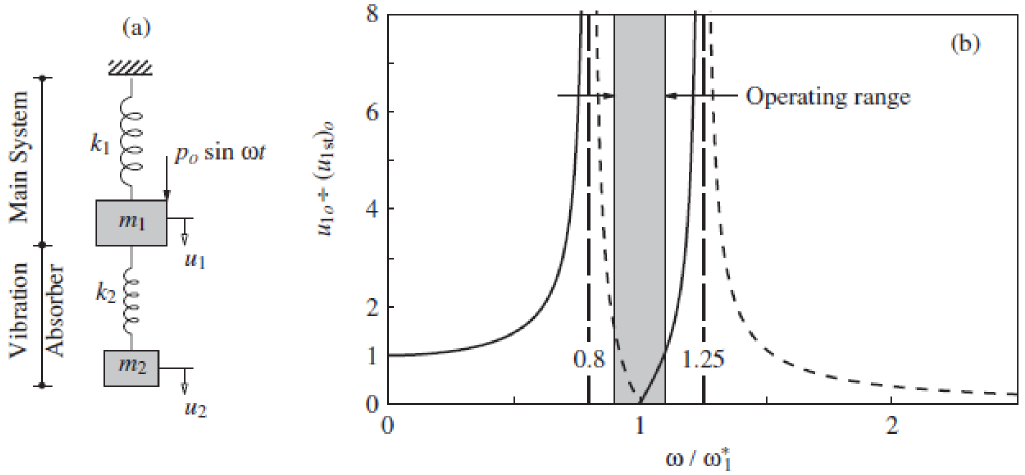


Figure 2. (a) Vibration absorber attached to an SDOF system; (b) response amplitude versus exciting frequency

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

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

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

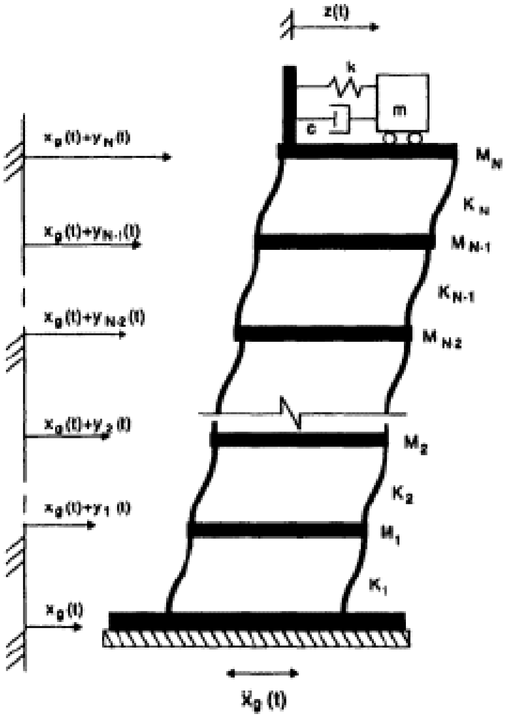


Figure 3. Multi Degree of Freedom Model of Structure + TMD.

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 uncertainties 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.

3. Target Displacement Determination Basis (Due to FEMA 356)

Using the Displacement Coefficient Method, the target displacement can be computed due to equation (7):

$$\delta_t=C_0\,C_1\,C_2\,C_3\,S_a.\ g.\ T_e/4\pi^2 \qquad (7)$$

C_0 is a modification factor to relate the spectral displacement and likely building roof displacement.The value of C_0 ranges 1.0~1.5 according to number of stories.

C_1 is a modification factor to relate maximum inelastic displacements to displacements calculated for linear elastic response. The values of C_1 would never be taken less than 1.0.

C_2 is a modification factor to represent the effect of hysteresis shape on the maximum displacement response. The values of C_2 depends on the framing type and performance level of the structure and can be taken 1.0~1.5.

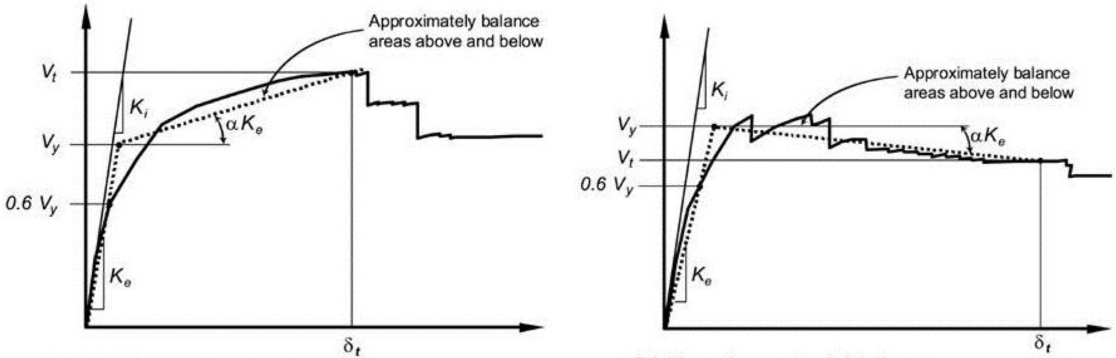
C_3 is a modification factor to represent increased displacements due to dynamic P-Delta effects. For buildings with positive post-yield stiffness, C_3 can be set equal to 1.0.

S_a is response spectrum acceleration at the effective fundamental period, T_e and damping ratio for the building in the direction under consideration.

T_e is the fundamental period and is computed according to equation (8):

$$T_e=T_i\sqrt{K_i}\,/\,K_e \qquad (8)$$

Where T_i and K_i are the initial elastic fundamental period in seconds and initial stiffness of the building in the direction under considered.



(a) Positive post-yield slope

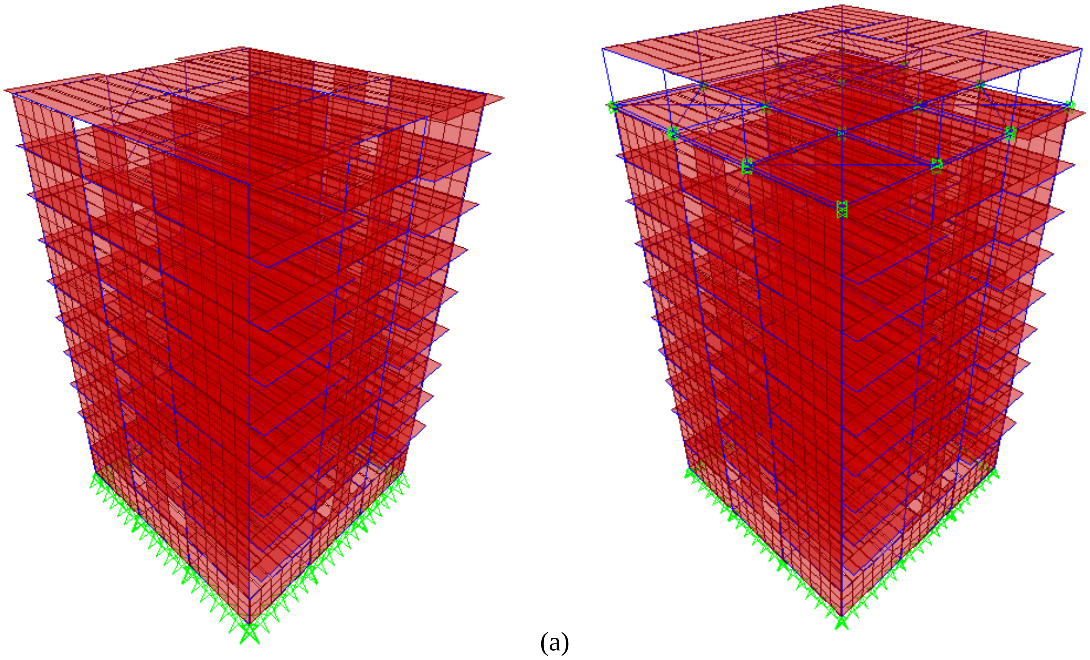
(b) Negative post-yield slope

Figure 4. Calculation of target displacement δt.

It is obvious that in order to determine the effective fundamental period, T_e, and the target displacement, δ_t, the pushover curve for the building is needed.

3. Finite Element Computational Models

Type 111-c series 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 5(a).



(a) (b)

Figure 5. Computational Models: a) Without AIUF, b) With AIUF.

Figure 6. Seismic Upgraded Buildings using AIUF.

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 5(b). The AIUF behaves like a Tuned Mass Damper (TMD) and is mainly tuned to act on the x-direction of the building. All mentioned assumptions are included in the 3D structural model as shown in Figure 5. Figures 6 demonstrates the applied Additional Isolated Upper Floor for a residential 111-c series R.C. building. In Figure 6 the implementation of additional floor is demonstrated in details. The connection details of the AIUF to the existing structure is shown in Figure 7. As could be observed, the steel trusses are used to provide the needed horizontal stiffness of both existing and AIUF floors.

Figure 7. AIUF Implementation Technique on Roof Floor of 111 Series building.

Both computational models are analysed and designed for Sa=0.40g spectral acceleration level, considering 3 soil types of Rock, Dense Soil and Loose Soil, including P-Δ effects. Seismic isolation devices used for AIUF are of HDRB (High Damping Rubber Bearing) type. After completing the modelling 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 summarized 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

Finally Modal Push-over analysis is performed to determine the Performance Points, according to FEMA guidelines, using Armenian SNIP II-6.02 pseudo-acceleration spectrums. Perform-3D analysis software is used to complete the nonlinear analysis.

4. Numerical Results

All performance point displacements and base shear forces according to soil categories are computed separately. The capacity curves are indicated in Figures 8 & 9:

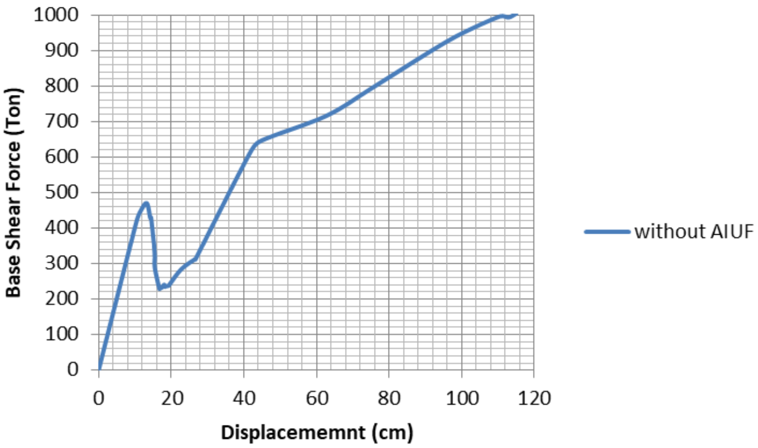


Figure 8. Capacity Spectrum of numerical model without AIUF.

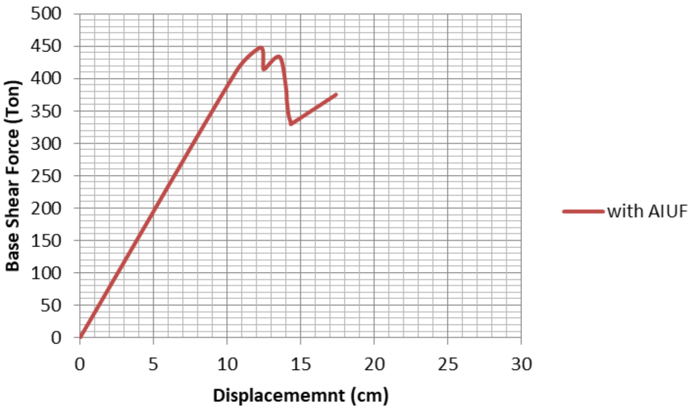


Figure 9. Capacity Spectrum of numerical model with AIUF.

The Performance Point Base Shear Force & Displacement values are computed according to FEMA 356 guideline requirements and summarized in Table 2, taking into account the Soil-Structure Interaction effects and without it respectively.

Table 2. Performance Point character results according to FEMA356 guideline (* V= base shear force (Ton) and D= displacement (cm))

Soil Type	P.P.	With SSI	Without SSI
Rock	V	305.0	375.5
	D	25.5	23.9
Dense Soil	V	494.5	375.5
	D	35.8	41.2
	V	660.8	375.5

5. Conclusions

The project on the upgrading seismic resistance of 111 series 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 Armenia. 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. The current analytical results demonstrate that using a soft story on the top of the structures, imposes an artificial ductility and causes the target displacement to get increased up to 72.4% for Dense Soil and 236.0% for Loose Soil, in comparison with Rock, while the base shear force remains the same. By payaing attention to the capacity curves, one can observe that when the structure is equipped with AIUF, the behaviour is mainly remaining linear, rather than the system without AIUF which demonstrates almost elasto-plastic behaviour. This fact proves that by using the AIUF, we can ensure the linear behaviour of the structure and preventing it to enter the nonlinear region, which could ensure the minimum structural and specially nonstructural damages during a severe earthquake. This fact leads us to use the new concept of AIUF to seismically upgrade the existing R.C. frame prefabricated structures easily, without resettling the occupants of the building and to ensure the linear behaviour of the structurre meanwhile.

6. References

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