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RETROFIT OF A REINFORCED CONCRETE BUILDING WITH FRICTION DAMPERS

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This paper presents retrofit project of a reinforced concrete building using friction dampers. The building is an 8-story government office building, where disturbance of the operations cannot be allowed. Preliminary studies shows that this building, which was designed and built using earlier Turkish seismic codes, do not satisfy the current Turkish seismic and structural code requirements. The lateral system of the building is interacting shear walls and moment frames. However, shear walls are not significant, and the structure is quite flexible. A study based on conventional retrofit approaches is conducted, where some of the moment frames are converted to shear walls and jacketing or CFRP wrapping of columns are used. Conventional retrofit method requires vacating the building for the construction, which is estimated to be costly, considered to be problematic and which will disturb the operations of the office significantly. In overall, the owner decided that conventional method is not feasible and requested an alternate approach for retrofit. Preliminary studies showed that use of energy dissipation devices can be a feasible solution for this specific building. It is required by the owner that retrofitted building has immediate occupancy performance under design basis earthquake level hazard and collapse prevention under maximum considered earthquake hazard. Upon receiving approval for proceeding with the detailed retrofit project, response spectrum analyses are conducted to estimate the number of dampers, damper capacities and locations. In this study, the building is modeled as linear and dampers are modeled as equivalent linear springs, where spring stiffness is estimated after an iterative study. Supplemental damping is reflected to the design response spectrum curve. Performance evaluation based on internationally accepted standards are used. Also, damper to structure connections are checked for feasibility and possible details are developed. In this part, both of the clients requested performance criteria are satisfied. In the next part of study, time-history analysis are conducted, where the structure is modelled linearly and dampers are modeled nonlinearly and performance of the building is evaluated for seven set of earthquakes and the second performance criteria is evaluated and is shown to be satisfied. After these studies, which confirms that proposed retrofit method satisfies the required performance objectives, details of the connections, foundations and detailed calculations are prepared. Proposed retrofit scheme and conventional retrofit scheme are compared. It is shown that there are numerous advantages of retrofitting with dampers compared to conventional approaches.

1. INTRODUCTION

Retrofitting of existing buildings in Turkey has recently become an important engineering field, especially after 1999 Kocaeli and Bolu earthquakes. Common retrofitting techniques used in Turkey are conventional methods such as addition of R/C shear walls, R/C jacketing columns, addition of new steel or R/C members or CFRP applications. Conventional techniques are preferred by designers and contractors due to several reasons:

- Engineers are more familiar with conventional methods,
- Conventional methods do not require highly skilled workers in the field,
- Construction materials are readily available in Turkey with reasonably low costs.

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Use of supplemental energy dissipation devices (dampers) for seismic design of new structures or for retrofit of existing structures is another method that has been implemented in the past several decades (Mualla et al., 2002, Mualla et al. 2010). Compared to other types, rotational friction dampers (Figure 1) provide simple, robust, low-cost and low-maintenance option for seismic applications. A sample force-deformation relation is shown in Figure 1, which almost has a rectangular shape and is a good indication of superior energy dissipation capability.



Figure 1. Rotational friction dampers, application and behavior

Seismic retrofit with dampers may be a sound alternative to conventional retrofit techniques for certain structures including the following:

- If wet construction is avoided, it will lead to short construction times,
- In many cases, evacuation of the building during installation is not necessary as opposed to conventional methods such as column and wall jacketing.
- Dampers provide solutions suitable for overall structure and cause less architectural and services disturbance compared to conventional methods.
- Although material cost of conventional retrofitting methods may be lower than the material cost of retrofitting with dampers, damper solution may be more economical if the total cost is considered particularly for structures that are heavily occupied and it is costly to temporarily relocate.

There are several reasons for minor to none application of dampers for seismic design and retrofit in Turkey including,

- Engineers are not familiar with analysis techniques of dampers which requires advanced engineering knowledge.
- Stakeholders, including owners and consultants, are not aware of the advantages of dampers
- There are no production of any kind of dampers in Turkey.
- In general, damper application require more skilled workers compared to conventional method.

In the current study, retrofit of a building with friction dampers is considered, which will be the first application of friction dampers in Turkey when completed. To demonstrate advantages of the solution with dampers, proposed method is compared with a conventional retrofit scheme. There are several characteristics of the building that makes the use of dampers very attractive. First of all, the building is heavily occupied, equipped and used. The evacuation of the building for retrofitting purposes is found to be expensive, time consuming and problematic. As such, the tenants is not willing to disturb the operation of the building. Also, fundamental periods of the structure is higher than its counterparts in Turkey due to the low shear wall ratio. In addition, the structure does not possess infill walls between its frame elements, which is very typical to reinforced concrete (RC) buildings in Turkey and increases initial stiffness of the structure significantly. Firstly, preliminary studies are conducted to compare conventional methods and retrofitting with damper. It is seen that dampers can achieve the required performance without disturbing the operation of the building and with lower cost. Afterwards, detailed analysis are conducted, and all other necessary design calculations, including foundation check and retrofitting, are performed.

2. EXISTING BUILDING INFORMATION

Subject building has 2 basement floors and 8 normal stories including the roof. The structural system is mixed RC frame and shear walls. It is found that shear wall stiffness is not significant and the building is considered to be “flexible” and suitable for damper applications. The concrete properties is determined as $f_{cm}=16.5$ MPa (including ACI reduction factors), $f_{tm}=1.42$ MPa, $E_{cm}=27202$ MP after testing of in-situ samples. Reinforcement determined is listed in Table 2. 3-D model of the building is seen in Figure 2. Periods are determined as 1.712 s for X-dir and 1.496 sec for Y-dir. Performance criteria was Immediate Occupancy for Design Basis Earthquake (DBE) and Collapse Prevention for Maximum Considered Earthquake (MCE).

Table 1: Storey Information

Storey	#	Height	Area
Basement	2	3.50 m	677 m ²
Ground	1	3.50 m	441 m ²
Normal Stories	6	3.15 m	538 m ²
Roof	1	3.15 m	350 m ²

Table 2: Reinforcement Information

Columns (cm x cm)	Long. Reinf.		Confinement Reinf.	
	Type	No	Type	Rebar/Spacing
50 x 50	STI	12 - Φ 16	STI	Φ 10/25
20 x 120	STI	14 - Φ 12	STI	Φ 10/25
40 x 60	STI	2 - Φ 16	STI	Φ 8/25
20 x 60	STI	2 - Φ 16	STI	Φ 8/25

3. CONVENTIONAL RETROFITTING

The following is considered to be part of conventional retrofit:

- RC shear walls are added to increase lateral flexural and torsional rigidity.
- RC jacketing of columns that do not have adequate moment and axial load capacity is considered.
- CFRP application for members that do not have adequate shear capacity.
- Mat foundations are added for added shear walls.

Typical retrofitted floor plan can be seen at Figure 2. Additional shear walls and column jacketing are shown in red color. It is found that addition of shear walls increases the rigidity of the structure, which increases the seismic loads on the structure. This requires addition of more shear walls. It is also found that this option results changes in the interior architecture that are costly. In addition, the owner could not find a suitable building for temporary relocation during the construction period.

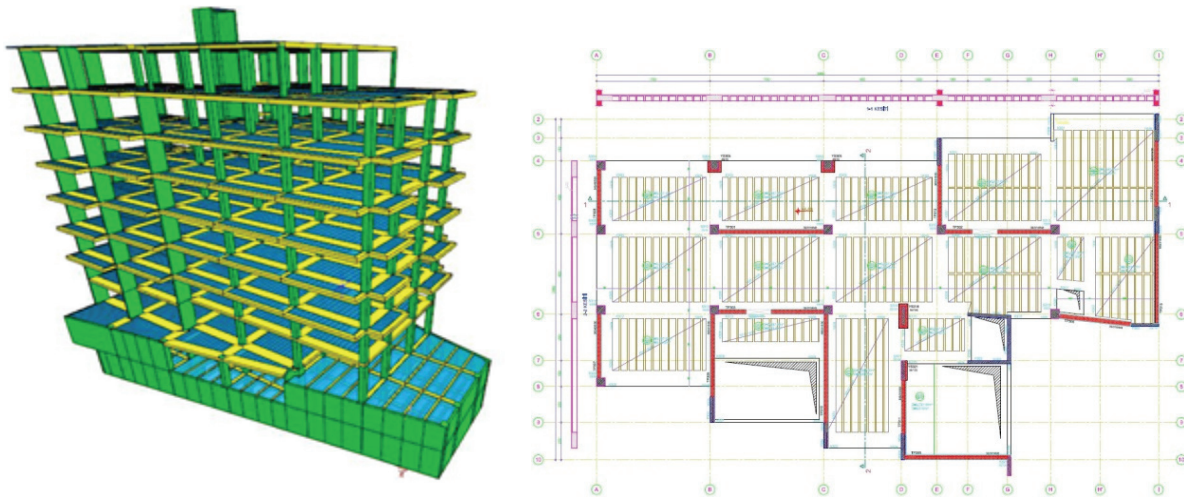


Figure 2: 3-D view of existing building and typical retrofitted floor plan

4. RETROFITTING USING SEISMIC DAMPERS

Retrofitting using frictional dampers are studied in order to overcome the problems mentioned above. ASCE 41 is used as the main design code for retrofitting with dampers since current Turkish Seismic Code (TEC 2007) does not have a chapter on damper design. Firstly, additional energy dissipation capabilities are estimated for several damper locations using modal strain energy theory and assuming the first mode is the governing mode. Plan and

elevation configurations shown in Figure 3 are found to be the most effective configuration and are used in the design. Two dampers are placed in each bay. It was found that damper installation at five stores is adequate.

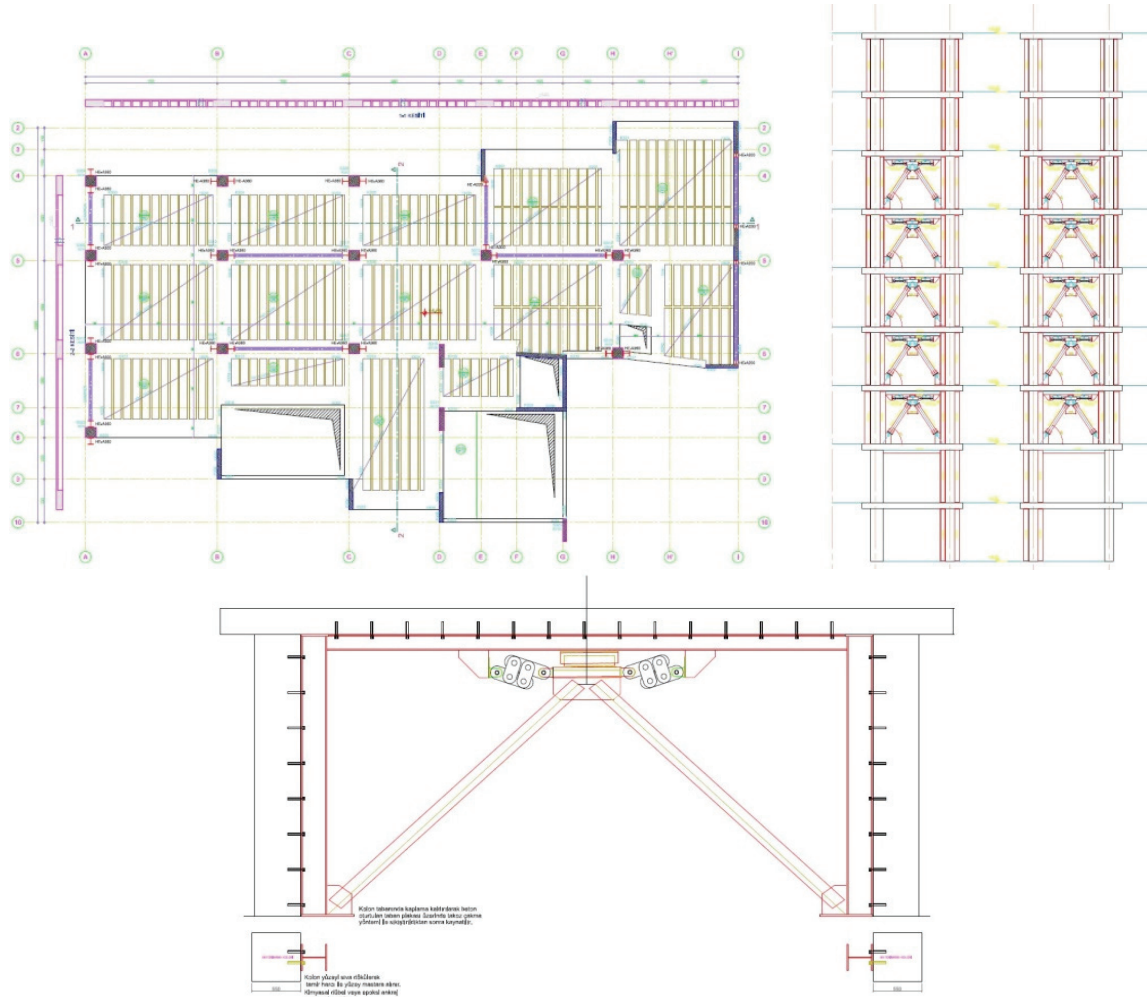


Figure 3: Configuration of dampers and typical damper bay

Steel frames are built in existing reinforced concrete frames where the dampers will be installed (Figure 3). Steel frame also increases moment and axial load carrying capacities of the RC columns. Critical steel frame components such as connections and anchorages are designed such that they stay linear under MCE level earthquake for continuous operation of dampers.

Iterative modal analysis was performed to determine effective stiffness and effective modal damping of the structure with dampers for the configuration shown above (Table 3 is shown for MCE). Design response spectrum is reduced per ASCE 41 considering the added damping (Table 3). The structure is designed using the reduced design spectrum to achieve the required performance levels.

Table 3: Properties of the structure with dampers for MCE

Effective Period, X-Dir:	1.616 sec
Effective Period, Y-Dir:	1.386 sec
Added Modal Damping X-Dir:	13.64%
Added Modal Damping X-Dir:	12.70%
Spectrum Reduction Factor X :	1.495
Spectrum Reduction Factor Y :	1.467

Next, time history analyses are conducted for performance evaluation where set pairs of scaled historical ground motion acceleration data is used, two of which are given in Figure 4 as example. In the scaling process, error based on a weighted average is used. The weights are considered to be modal mass participation ratios of significant modes (shown in light green colored line). Average of the results of the seven time history analyses is used to evaluate the structure performance

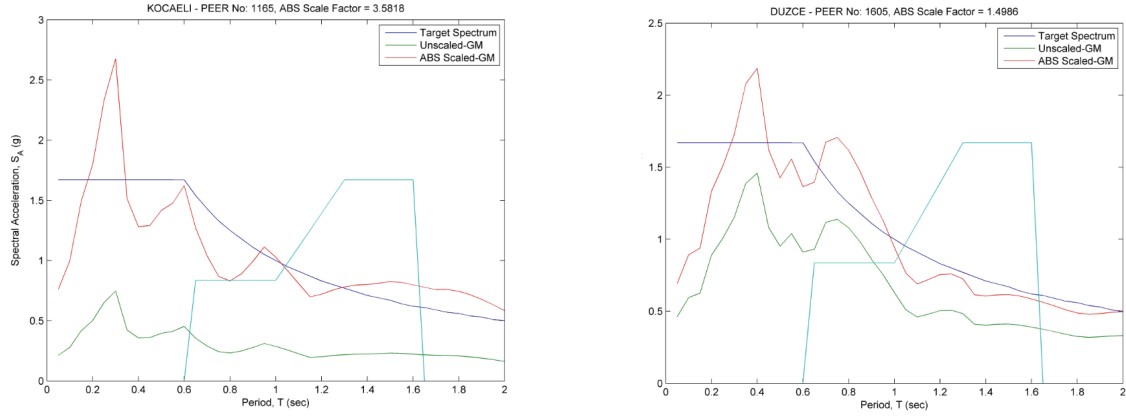


Figure 4. Kocaeli and Duzce ground motion acceleration data scaling

In the time-history analysis, the structure is modeled linearly and the dampers modelled nonlinearly. To verify that dampers are effective in dissipating energy, force-deformation plots of all dampers are checked. Sample plots are shown in Figure 5. Performance assessment based on m -factors as explained in ASCE 41 is conducted and necessary changes are implemented. It is found that base shear, displacements and storey drifts of a structure without dampers, but with the steel framing, are reduced significantly with the addition of dampers (Figures 6 and 7). Also shown in Figure 8 are the story drift for MCE, which meets Life Safety performance. While not shown here, the retrofitted structure shows Immediate Occupancy performance level for DBE. An interesting comparison of base shears for classical retrofitting and retrofitting with dampers is given in Figure 9. Base shear is almost doubled with classical retrofitting technique, which requires addition of many shear walls to the structure.

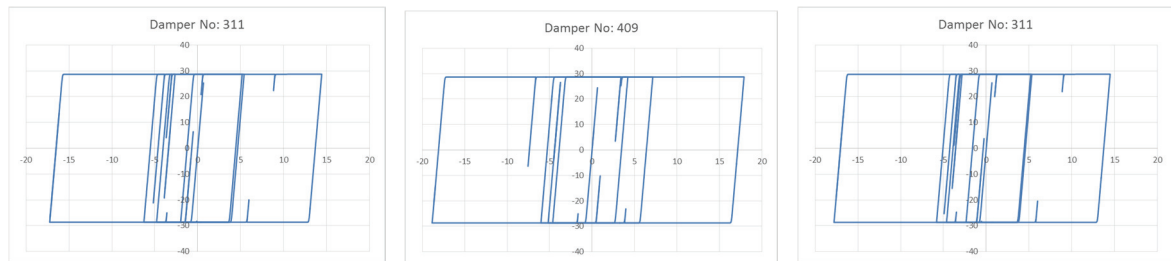


Figure 5. Sample hysteresis plots of dampers (displacements in mm, forces in tons) .

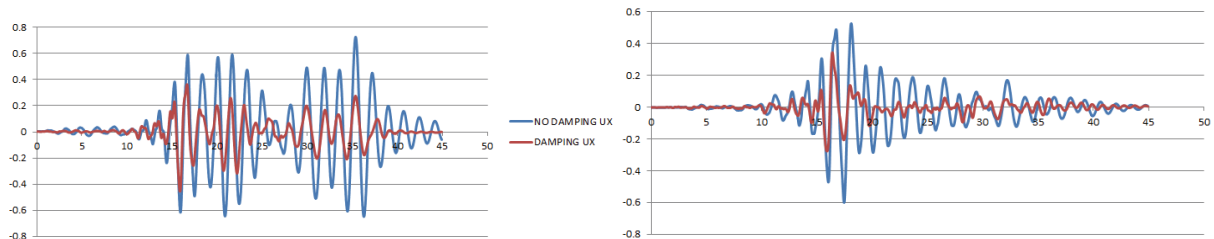


Figure 6. Roof displacement comparison for X and Y-directions

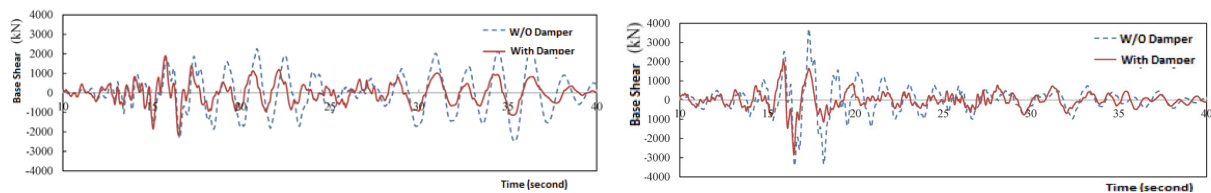


Figure 7. Base shear comparison X and Y-directions.

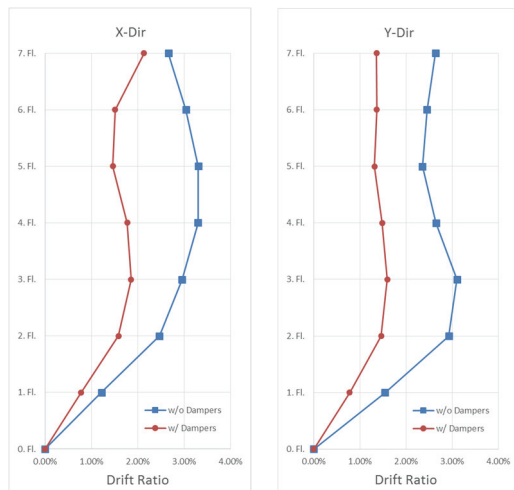


Figure 8: Storey Drift Comparison

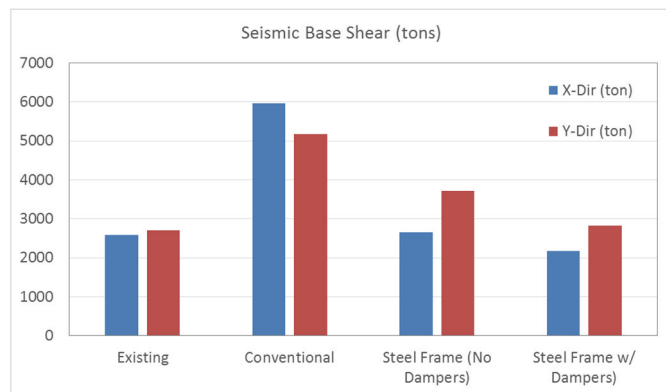


Figure 9: Base Shear Comparison of Retrofitting Techniques

5. CONCLUSIONS

Retrofitting of RC building structure with rotational friction dampers is studied and the following are concluded:

- 1- Damper application achieved additional 13.64% and 12.70% modal damping for X- and Y-directions, respectively. This allowed reduction of design spectra with factors of 1.495 and 1.467 for X- and Y-directions.
- 2- Conventional retrofitting almost doubled the seismic design base shear of the existing building.
- 3- Retrofitted structure shows Immediate Occupancy performance for DBE and Life Safety for MCE.
- 4- It is possible to implement the retrofit with damper without disturbing the operation of the building since concreting and wet applications are not used at superstructure.

6. REFERENCES

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