RETROFITTING OF PRECAST REINFORCED CONCRETE STRUCTURES WITH ROTATION FRICTION DAMPERS

I. Mualla[(1)], S. Yildirm[(2)]

[(1)] Chief Technical Officer of DAMPTECH, ihm@damptech.com
[(2)] Manager of retrofitting department of Promer, syildirim@promerengineering.com.tr

Abstract

This paper presents seismic retrofit of a typical single-story industrial-type precast reinforced concrete building structure using rotational friction dampers. This project consists of retrofitting twelve precast reinforced concrete buildings.

Precast concrete is one of the most preferred type of construction for all type of industrial structures due to their low cost, fast construction and availability in rural areas. Unfortunately, most of these structures constructed before "Specification for Buildings to be Built in Seismic Zones are not well-engineered and are expected to have very poor performance when exposed to a major seismic event.

Rotational friction dampers are selected as the supplemental energy dissipation device. ASCE 41-06 is employed for the damper design and performance evaluation. Before damper study, some instability and weak connection problems are solved by some measures taken. The most effective damper configuration and capacities are selected after an intensive iterative trial-and-error linear study. Finally, nonlinear time-history analyses are performed for seven pairs of historical ground motion acceleration data and it is shown that proposed retrofit scheme satisfies the desired performance goals for both DBE and MCE events. In overall, it is considered that proposed retrofit scheme with dampers provides a viable solution to the stakeholders of the project from performance, design, constructability and economical points of view. Some application photos will be presented and methods are explained in detail in the paper.

The damper behavior is based on the rotational friction hinge concept. The dampers are designed to provide passive energy dissipation and protect buildings, from structural and nonstructural damage during moderate and severe earthquakes.

Intensive Testing of dampers of this type with different slip capacity has been carried out at the technical Univ. of Denmark and in Japan over the last decade.

Keywords: retrofitting; friction dampers; precast structures; earthquake protection; passive control

Introduction

Precast structural forms have been developed for economic and time dependent reasons with evolving technology. Especially in industrial buildings, precast concrete structures are widely used due to their advantages such as low cost, short construction period and availability in rural areas. Unfortunately, most of the precast concrete buildings built before Turkish Code 2007 [9] is not well engineered or not well contracted in Turkey. It is expected that these buildings have very poor structural performance in an expected major seismic event in Turkey. In 1999 Kocaeli and 1999 Duzce earthquakes, many precast concrete structures were either fully collapsed or had significant damage causing economical and life lost Figure 1. Also suspension of production due to the earthquake damages in industrial buildings, have led to catastrophic economic losses.

Figure 1: Damaged precast RC frames

Precast reinforced concrete buildings have some design disadvantages such as non-satisfactory weak connections, bad load transfer mechanism, overturning problems of the main beams in an earthquake and no diaphragm behavior at the roof level of the building. Beam column connections are simple connections using pin or welding. It is observed in previous earthquakes that these types of connections were not successful to keep the beam in place. Beams were dropping down or having overturning problem breaking the pin or welding. Horizontal load transfer between columns generally provided by gutter beams in these building. Mostly gutter beams are structurally weak members and have heavy corrosion damage as a reason of water drainage system in the roof. Moreover they are connected to columns via simple pins. Thus, load carrying and transfer capacity of these beams are not strong enough. Also, the structures have a roof frequently that is either not designed to act as a diaphragm or low diaphragm capacity. This can be resulted as failure of secondary beams at the roof due to seismic loads.

Existing precast concrete building stock possesses a major risk and needs to be mitigated. Due to the low quality of engineering or construction explained above, most of the industrial buildings do not fulfill requirements of existing Turkish Seismic Code (2007). Generally, retrofit of these buildings is not considered because the cost of retrofit may exceed to the original cost of the structure. Also, building owner is not willing to proceed a retrofit due to high cost of evacuating the building or stop working. In addition, classical retrofitting methods like as jacketing and adding structural elements require a major disturbance to the operations of buildings including relocation expenses. Further, it is hard to retrofit weak connections of the building. Therefore, retrofitting of precast reinforced concrete buildings are not feasible mostly and has not been applied much in Turkey. Having understood this risk, Ministry of The Official Institution [6] decided to undertake a major project to retrofit their single story precast concrete buildings, where twelve buildings are planned to be retrofitted as the first phase of the project. It is required that buildings will not be vacated during retrofit and disturbance to the building operation will be the lowest level. Existing building structures are examined and reviewed in detail, and based on the comparison of several retrofitting schemes, it was concluded that seismic retrofit with energy dissipation devices is a feasible option for the subject buildings.

The structure is exposed to high seismic energy during a major earthquake. Structural elements absorb this energy by having damage. Friction dampers are designed to transform this earthquake energy to heat by means of friction to reduce the load on structural elements. In this project rotational Rotation Friction Dampers, RFDs are selected as the supplemental energy dissipation. This paper presents seismic retrofit of a typical one of twelve single-story industrial-type precast reinforced concrete building structures located in Turkey. This project is considered to be the first fully-engineered and completed application of supplemental energy dissipation devices for retrofitting purpose in Turkey.

Rotation Friction Dampers (RFDs)

Rotation Friction Dampers RFD, developed by the 1st author more than 20 years ago [1], [2]. It consist of several steel plates rotating in opposite direction in between high tech friction material in order to provide very stable performance over many cycles. Different models were developed as shown in Figure 2 down below. These dampers are installed in more than 52 projects in 12 countries around the world.

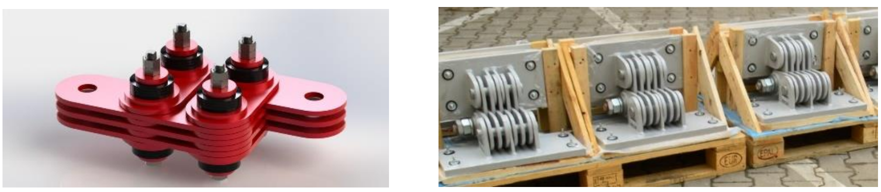
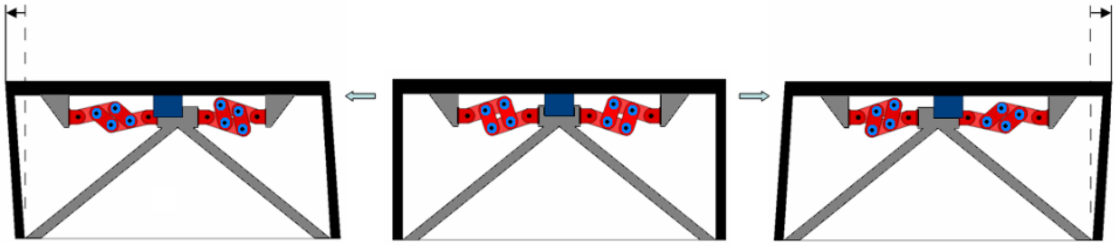


Figure 2. Two different types of Rotation FrictionDampers

The mechanism of these Rotation Friction Dampers, RFD are shown in Figure 3. down below.



Ftigure 3. Mechanism of Rotation Friction Dampers (RFD)

Applications of Rotation Friction Dampers (RFDs)

RFDs were used in many projects around the world . In japan they were used in 12 buildings among them Japan tallest building HARUKAS 300 in Osaka , Figure 4.

Ftigure 4. Japan tallest building Harukas 300, with Rotation Friction Dampers

Existing Structure Information

The typical structure which is subject to this paper, was one story building and have 9 nine bays in long direction. Outside and inside photos of the structure are given in Figure 5a, Figure 5b. Geometrical properties of the building are given in Figure 6. There are 18 columns which have dimension of 40cmx40cm.

(1a) **(1b)**

Ftigure 5. Ouside and inside photos of the structure(4a. Left Side, 4b. Inside)

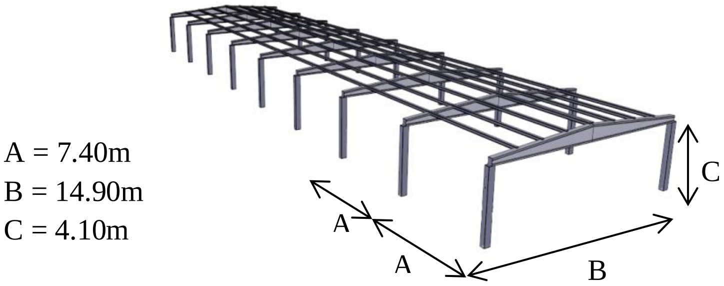


Figure 6. Geometrical properties of the building

Site investigation was performed in the structure to determine condition and geometry of the building. All investigation of the structural elements was made according to TEC (2007). Reinforcements were determined by using both ferroscan equipment and visual inspection after removing clear cover of concrete of columns Figure 7.

Figure 7. Identification of column reinforcement with clearing the cover and ferro-scan.

Compressive concrete strength of the columns was determined by taking core samples. Compressive strength core sample results of concrete were corrected and calculated according to methods suggested by ACI 318 [3]. According to results of the experiments of 9 core samples, concrete compressive strength was found as 35 MPa which was suitable and proper to use damper application. Interactive diagram of 40x40 column type was calculated by using Xtract Section Analysis software [10]. Soil type of the land was determined as Z2 according to TEC. Also, snow load was considered as 75 kg/m2 according to TS498.

Analysis of the Structure

Mathematical model of the building was created by using SAP2000 analysis software [7]. Both linear analysis and nonlinear part of analysis were conducted with Sap 2000. Structural model of bare frame was given in Figure 8.

Figure 8: SAP2000 Structural Model

Design objectives are set Immediate Occupancy for the Design Basis Earth (DBE) and Collapse Prevention for the Maximum Considered Earthquake (MCE) for the structure according to ASCE41-06 [4]. Assessment analysis results and number of elements which was is not satisfy the regulations properly was given in Table 1.

Table 1: Analysis results of existing buildings for DBE and MCE earthquakes

	EXISTING BUILDING			
	X DIRECTION		Y DIRECTION	
	DBE	MCE	DBE	MCE
STORY DRIFT	2.04%	3.06%	2.04%	3.06%
BASE SHEAR FORCE (KN)	1537.98	2307.78	1537.98	2307.78
IMMEDIATE OCCUPANCY	4	0	0	0
COLLAPSE PREVENTION	14	4	0	18
COLLAPSE	0	14	0	0

Infill walls, which contribute to the stiffness of the structure, are investigated by using strut models. Strut model dimensions were calculated by using model which proposed by Mainstone (1979). Four strut models were defined to model as equivalent of infill wall with different openings. Infill walls were considered in linear analysis but disregarded in nonlinear analysis of retrofitting since the load on the walls was much higher than infill walls capacity, leading cracking all of the walls.

There is a steel plate in the roof with a 0.5mm thickness, it was proved that this plate effects modal behavior of the structure to a limited extend. Thus, a representative sheet cover was defined to top of the building in the analysis. Comparison of modal information between bare frame and frame with dampers were given in Table 2.

Table 2: Modal information of the buildings

	WITHOUT INFILL WALL		WITH INFILL WALL	
	Tx (sec)	Ty (sec)	Tx (sec)	Ty (sec)
BARE FRAME	0.613	0.613	0.598	0.267
FRAME WITH DAMPERS	0.431	0.361	0.428	0.263

RETROFITTING OF THE STRUCTURE

Retrofitting structure with conventional methods are very difficult and costly because of the hinged design of structure and it was required that building will not be vacated during retrofit. Therefore, RFD dampers were used to retrofit the building.

Moreover some more precautions were taken to assure load transfer mechanism of the structure such as designing compression bars between columns and some steel members to keep the beam in its place. Equivalent static procedure was used for preliminary analyses, where design base shear was reduced based on the added equivalent damping. Effective damping ratios of the dampers were calculated by using Equations 1 which was suggested by ASCE7-10 [5].

$$\beta_H = q_H \times (0.64 - \beta_1) \times \left(1 - \frac{1}{\mu}\right) \qquad \text{(Eq. 1)}$$

In Equation 1, q_H is hysteresis loop adjustment factor which is taken as 0,5. β_1 is the component of effective damping of the structure due to the inherent dissipation of energy by elements of the structure. μ is effective ductility demand on the seismic force-resisting system. Equation 2 which was suggested by ASCE41-13 [11] was used to calculate reduced base shear force due to the equivalent damping energy of the system. In Equation 2, B_1 is the reducing coefficient and β is equivalent damping.

$$B_1 = 4/[5.6 - \ln(100 \times \beta) \qquad \text{(Eq. 2)}$$

The most promising damper configuration and capacities are selected after an intensive iterative trial-and-error study. According to this configuration, dampers are placed at the beam-column connections, which are pin-connected, in the short direction. In the long direction, steel compression members are designed in order to provide load transfer between frames. Then, steel braces with dampers are placed in one or several bays. Locations were given in Figure 9, Figure 10, Figure 11, respectively. SAP2000 structural models of retrofitted frame were given in Figure 12. Performance of the columns was shown to satisfy the desired goals for both DBE and MCE events.

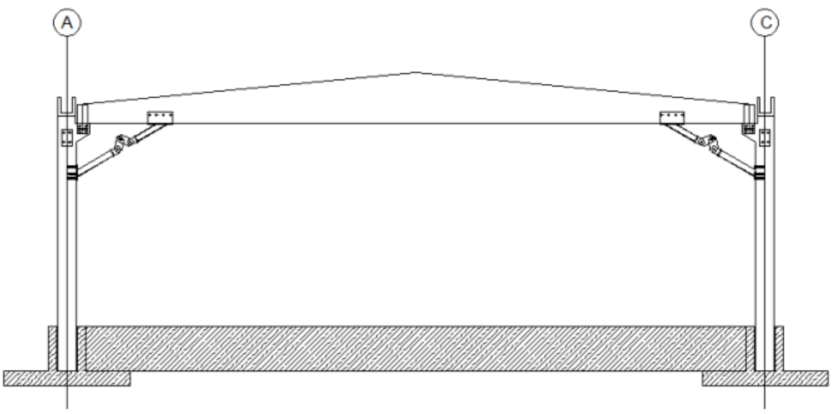


Figure 9. Dampers locations in X Direction

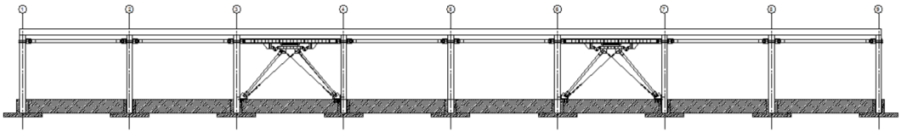


Figure 10. Dampers locations in Y Direction

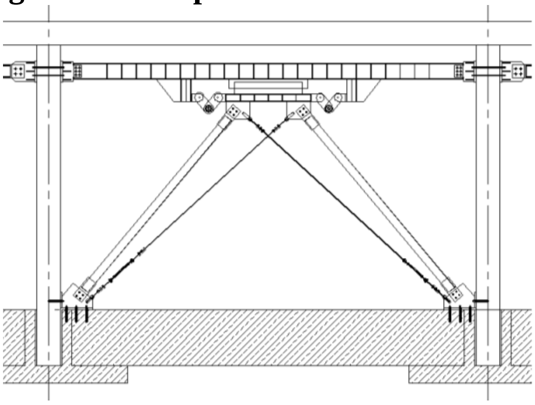


Figure 11. Dampers locations in Y Direction

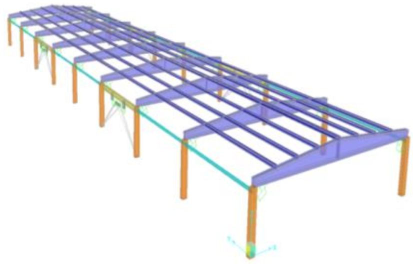


Figure 12: SAP2000 Structural Model

Finally, nonlinear time-history analyses are performed for seven pairs of historical ground motion acceleration data. Historical ground motion acceleration data were scaled to the MCE response spectra by using SeismoMatch software [8]. Information of earthquakes that used in nonlinear time-history analysis was given in Table 3.

Table 3: Earthquake information

	Station	Magnitude (Mw)
Düzce (1999)	Bolu	7.2
Düzce (1999)	Düzce	7.2
Erzincan (1992)	Erzincan	7.8
Hector (1999)	Hector Mine	7.1
Kobe (1995)	Shinosaka	6.9
Kocaeli (1999)	İzmit	7.6
Landers (1992)	Joshuatree	7.3

The comparison of damping ratios for both linear and nonlinear methods was given in Table 4. Nonlinear damping ratios for different seven pairs of historical ground motion acceleration data were given in Figure 13. Also base shear force – time and displacement – time diagrams were given between Figure 13 and Figure 15 for Kocaeli (1999) – İzmit and Düzce (1999) – Düzce earthquakes. The earthquake name numbered as (1) like (Kocaeli(1)) represents that the earthquake FN data(Fault normal) was loaded in X direction while FP data(Fault parallel) was loaded in Y direction and vice versa for the earthquake name numbered as (2).

Table 4: The comparison of damping ratios for analysis type

MCE Earthquake	X Direction	Y Direction
LINEAR DAMPING	11%	16%
NONLINEAR DAMPING (AVERAGE)	17%	34%

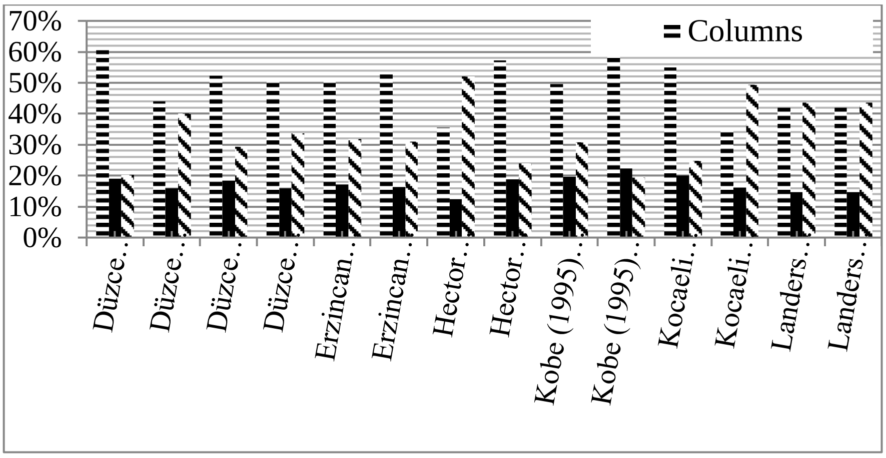


Figure 13. Nonlinear energy consumption ratios of columns and dampers for different seven pairs of historical ground motion acceleration data

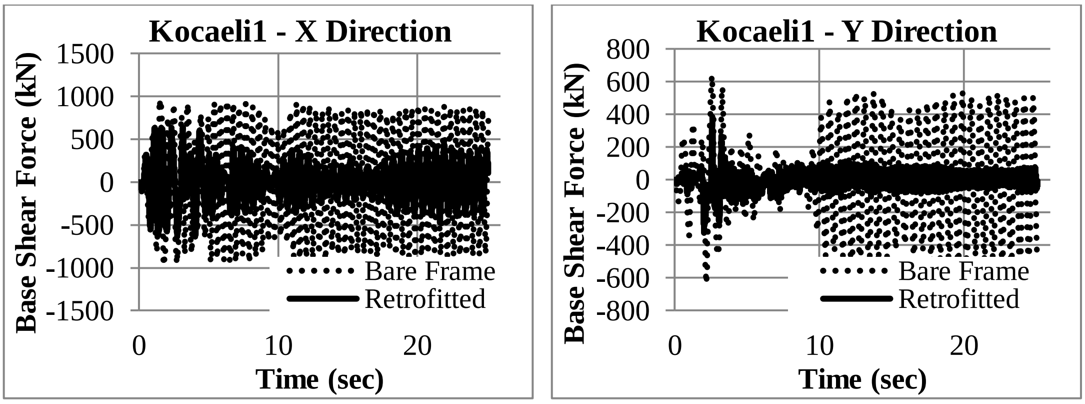


Figure 14. Base Shear Force – Time diagram of Kocaeli (1999) - İzmit – 1 earthquake

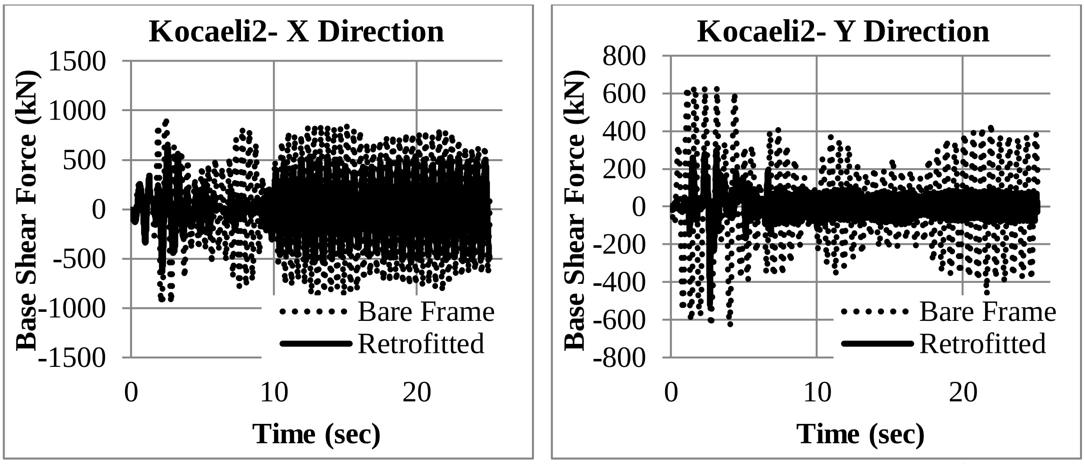


Figure 15. Base Shear Force – Time diagram of Kocaeli (1999) - İzmit – 2 earthquake

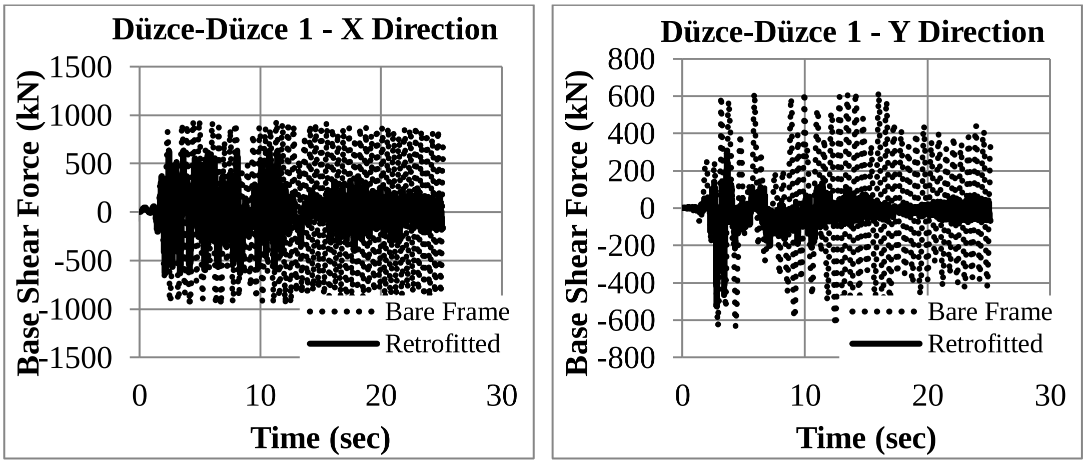


Figure 16. Base Shear Force – Time diagram of Kocaeli (1999) - İzmit – 1 earthquake

Linear assessment analysis of the retrofitted structure for DBE and MCE events were given in Table 5. Results show that proposed retrofit scheme satisfies the desired performance goals for MCE events.

Table 5: Linear assessment analysis results

	RETROFITTED BUILDING			
	X DIRECTION		Y DIRECTION	
	DBE	MCE	DBE	MCE
STORY DRIFT	1.14%	1.02%	1.18%	1.20%
BASE SHEAR FORCE (KN)	1010.82	1368.41	903.627	1247
IMMEDIATE OCCUPANCY	18	18	18	18
COLLAPSE PREVENTION	0	0	0	0
COLLAPSE	0	0	0	0

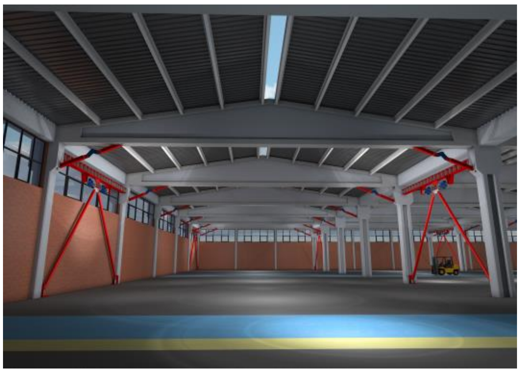
Retrofitting Process

After design analysis was done, detailed technical drawings were prepared and application of retrofitting was started. Retrofitting installation processes were accomplished in 1 month with minimum disturbance in the building. There were no need to vacate the building during the retrofitting process. Photos of the retrofitting application were given in Figure 16.

Figure 16. Photos of retrofitted structure

New Projects

After the success of installing this damping solution in 12 buildins new projects are going on the way now in 2 different industrial projects as shown in Figure 17



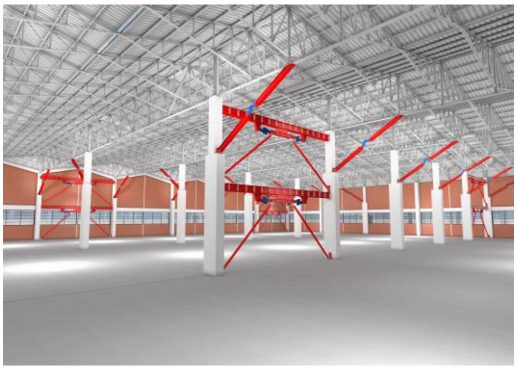


Figure 17. Images of 2 new retrofitting industrial projects

Conclusions

Performance goals of ASCE 41-06 and Turkish Earthquake Code 2007 were satisfied retrofitting using Rotational Frictional Dampers and some additional steel members. Installations of steel members and dampers at site were completed more or less within 1 month without any need to evacuate the building meeting requirements of client as well.

Total damping ratios calculated were 11% and 16 % for linear calculations for X and Y directions respectively whereas the damping ratios were calculated as 17% and 34% for nonlinear calculations for X and Y directions respectively. Calculated ratios showed that linear analysis is 45%-50% conservative for this project.

Acknowledgements

The authors thank Official Institution, Istanbul Technical University Civil Engineering Department, DAMPTECH and Promer Company for all contributions to this paper. This paper covers some of the studies in Retrofitting project of an important Official Institution .

References

[1] Mualla, I.H., Belev, B. [2001], Performance of steel frames with a new friction damper device under earthquake excitation. Journal of Engineering Structures, Elsevier.

[2] Liao, W.I., Mualla, I.H., Loh, C.H. [2004,1], Shaking-table test of a friction-damped frame structure., Struct. Design Tall Spec. Build. 13, 45–54, Published online 9 June 2004 in Wiley Interscience (www.interscience.wiley.com). DOI:10.1002/tal.232

[3] American Concrete Institute(ACI), (2014). *Building Code Requirements for Structural Concrete,* Farmington Hills, Michigan, USA.

[4] American Society of Civil Engineers (ASCE), (2006). *Seismic Rehabilitation of Existing Buildings,* USA.

[5] American Society of Civil Engineers (ASCE), (2010). *Minimum Design Loads for Buildings and Other Structures,* USA.

[6] Ministry of Public Works and Settlement, (2007). *Specification for Buildings to be Built in Seismic Zones,* Government of Republic of Turkey, Turkey.

[7] SAP2000, Integrated Structural Analysis and Design Software, Computers and Structures, Inc.

[8] SeismoMatch, Seismosoft Earthquake Engineering Software Solutions, Italy

[9] Turkish Standard Institue(TS), (1997), Calculation values of load on structural design(TS498), Ankara.

[10] Xtract Cross Section Analysis Program for Structural Engineers, 3.0.8, 2007.

[11] American Society of Civil Engineers (ASCE 41-13), (2013). *Seismic Evaluation & Retrofitting of Existing Buildings,* USA.