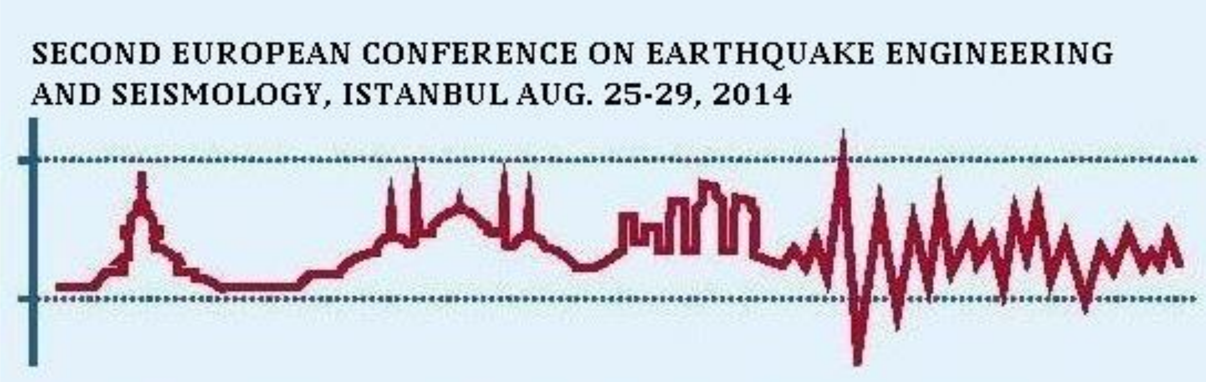

SEISMIC RETROFIT OF SINGLE STORY PRECAST REINFORCED CONCRETE STRUCTURES WITH INFILL WALLS USING FRICTION DAMPERS

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This paper presents seismic retrofit of single story precast reinforced concrete structures with infill walls using friction dampers. Single story precast structures are very common in Turkey due to their low costs and short construction durations. Unfortunately, these structures possess various major issues with their seismic behavior when not engineered properly. As such, most of the existing single story precast structures do not satisfy current Turkish seismic and building codes and retrofit is required. For structures that are heavily under operation, vacating the structure is not possible and conventional retrofitting techniques are not feasible. As an alternate method, retrofit with dampers is considered. In the current project, a stock of 96 single-story precast buildings are required to be retrofitted. As representative of this building stock, four types of structures with varying widths and heights are considered. For each structure a separate study is conducted, but the retrofit scheme is same. In the long direction of the structure, dampers are placed on one bay both sides and each bay are connected with steel compression members forming a full frame on both faces of the structure. In the short direction, dampers are placed at the column-beam joints, which can be considered as pinned connections. Friction dampers are suitable for both configurations. Design objectives are Immediate Occupancy for Design Basis Earthquake (DBE) and Collapse Prevention under Maximum Considered Earthquake (MCE). One challenge with this type of structure is the effect of infill walls on the structural properties. Infill walls are located on all faces of the building and have significant rigidity compared to the rigidity of the bare frames. For the sake of design purposes, two mathematical models are considered. In the first model, infill walls are assumed to reduce the period of the structure without infill walls to its half. To achieve this reduction, artificial braces are used in the model. This modification is done to all faces of the structure. In the second case, no infill walls are considered. These two cases care considered to be the limiting conditions that affect the performance of dampers. Equivalent static procedure is used instead of response spectrum procedure since there is only one structural mode in each direction, and no modal combination is required. Damper capacities verified after several iterative studies. Based on the final damper capacities, added steel members and connections are designed, and existing member performances are obtained using equivalent static load procedure, which are shown to satisfy required performance levels. Then, for the two cases, time-history analyses are conducted for seven pair of historical ground acceleration that are scaled to MCE response spectrum. In these analysis, the structural elements are considered to be linear and dampers are nonlinear. Overall retrofit is considered to be satisfying the design goals and to be feasible for building owner from both construction and economical points of view.

1. INTRODUCTION

Precast Reinforced Concrete have been widely used for industrial structures in Turkey. These structures have low construction costs and are fast to construct. There are currently, thousands of precast concrete structures in Turkey used of industrial or similar purposes (e.g. storage), and a significant portion of this building stock is single story with frames are only located on the faces of the building.

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There are several issues regarding the seismic design and behavior of common precast structures that are used of industrial purposes due to low quality of engineering for reduced cost. One important issue is the typical connection used between the column and roof beams. The beam simply sits on the top of the column, which are weakly connected with a rod. In most of the cases, no engineering is conducted for the rod or overturning of the beam. In some cases, detailing of columns and beams may not provide high ductility, which may result low performance. Also, almost all the structures does not have a roof that is either not designed to act as a diaphragm or low diaphragm capacity, which may result failure of secondary beams at the roof due to differential motion of the frames in the short direction of the building.

Due to the low quality of engineering explained above, most of the industrial buildings do not satisfy current Turkish Seismic Code (2007) and may receive considerable damage or may collapse if they experience a major seismic event. In most of the cases, retrofit is not considered since cost of retrofit may be comparable to the original cost of the structure. There are also cases where the building owner is willing to proceed with the retrofit due to high value of the contents of the building or the business conducted. In these cases, however, an important challenge with the retrofitting of the structure is regarding the disturbance of the business. In most cases, classical retrofitting methods, such as column jacketing and adding shear walls, require a major disturbance to the operations including temporary relocating. Relocation of an industrial facility is generally not feasible and economical due to heavy machinery and etc., which prevents retrofitting. Further, classical methods may result large member sizes and complicated connection details, which are difficult to construct. Therefore, retrofit of precast reinforced concrete structures using classical methods has not been applied much in Turkey.

On approach proposed to overcome the difficulties associated with the classical retrofit methods for precast reinforced concrete structures for industrial use is to implement supplemental energy dissipation devices (Moren and Kurama, 2008). Use of dampers may result simpler retrofitting schemes, which do not disturb the operation of the building significantly and do not require relocation. Among various types of dampers, rotational friction dampers are more feasible for this purpose since they can have a configurations suitable for precast structures, e.g. for the beam-column joints. Also, concrete quality of precast members are generally high compared to cast-in concrete of existing buildings. This property makes it easier to design the connections of the dampers and associated elements.

There are several points that need to be considered in the retrofitting of precast industrial structures with dampers that are typical to Turkish practice. The first point is regarding the beam column joints. For both overall structural behavior and performance of dampers, beam-column joints are required have a well-defined behavior and design. Second, actual rigidity of the structure is required to be correctly reflected into the analysis model since damper performance mainly depends on the displacements of the structure and there is no so-called conservative approach for the representation of the structural rigidity. This is an important point for single story precast structures: Normally the bare structure has highly flexible and is very suitable for damper application. On the other hand, precast structures in Turkey have infill walls that have significant initial stiffness and low capacity on the faces of the building. While infill walls are considered to be non-structural elements and are not included in the mathematical model in general, they have significant influence on the behavior of dampers and need to be considered in the analyses.

In this paper, retrofitting of a stock of single-story precast reinforced concrete structures with infill walls using rotational friction dampers is studied. There are 96 buildings in the stock, however, after evaluating these structures on site, 59 of them are considered to be suitable for damper applications. All these buildings are occupied and actively used and hence, classical retrofitting methods are not suitable and desired by the owner. The buildings are classified into for groups and four prototypes that represent each group are considered. For each of the prototype, damper design and performance evaluation are conducted. As for the analysis used for damper connection design, equivalent static procedure is used instead of response spectrum analysis since only one dominant mode exist for each direction. Then time-history analyses are conducted for performance evaluation based on ASCE 41-06, where the structure is modelled linearly and the dampers are modelled non-linearly. To consider the effects of the infill walls, two limiting cases are considered. In the first case, infill walls are assumed to reduce the structure period to half of the period of the structure without the infill walls. To simulate this scenario, braces are placed at the locations of the infill walls and the stiffness of the braces are adjusted so that the period reduces to the half of the structure's period that does not have infill walls. In this case, the dampers do not operate efficiently, however since the displacements are reduced, the members do not receive damage. In the second case, it is assumed that there are no infill walls, which allows dampers to operate efficiently and allows increased displacements and increased damage to the structural members. For the sake of design purposes, it is assumed that these two cases are assumed to be the two limiting cases that need to be considered. To effectively use the dampers for energy dissipation. Steel frames are formed in the long direction and dampers are placed as part of braced bay of the frame. In the short direction, dampers are placed at the beam-column joints to take advantage of the pinned-connection behavior of the joints. All the connections and anchorages are designed accordingly. Due to the low diaphragm effect of the roof, differential movement of the frames is considered in the design of primary and secondary roof beams. Also, to avoid the overturning of the primary beams, special details are developed at the column top. The resulting retrofit scheme resulted a well-behaved structure and is considered to be feasible and economical by the owner.

2. EXISTING BUILDING INFORMATION

In the original stock, there are 96 buildings. However, not all the buildings are convenient for retrofitting with dampers including buildings having corrosion, foundation settlement problems and etc. Moreover, two story structures are out of the scope of this study. After reviewing the stock, it is decided that 59 buildings is suitable for retrofitting with dampers. Selected buildings are categorized into four groups. Each group is represented by one type of generic structure, and the design of each of these generic types is considered to be valid for the overall group they are representative of. These generic types of structures are summarized in Table 1 and Figure 1.

Table 1. Geometrical properties of the types of the structures established

Type	**Frame Span, L (m)**	**Frame Spacing, A (m)**	**Height, H (m)**	**No of Buildings**
1	16.0	8.0	4.5	19
2	16.0	8.0	3.5	15
3	12.0	8.0	4.5	18
4	12.0	8.0	3.5	7

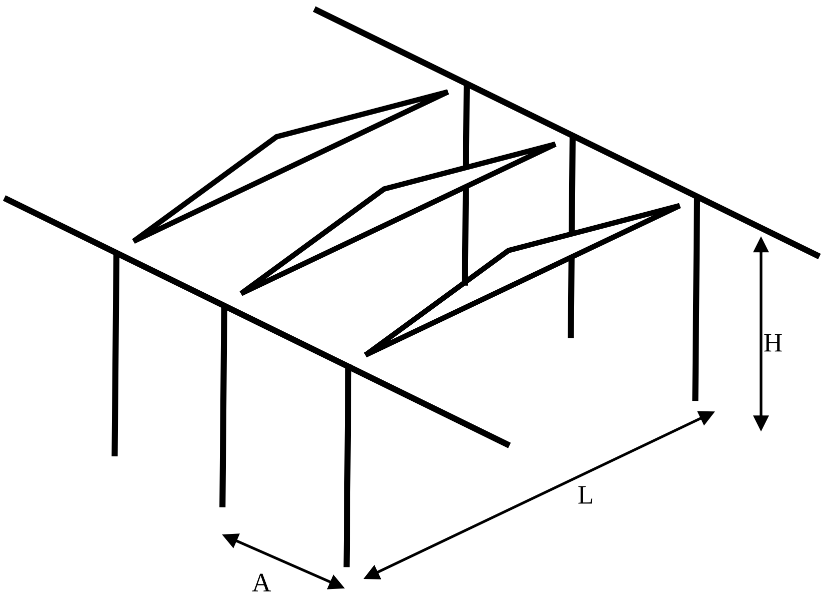


Figure 1. Notation used for the definition of the types of the structures

The buildings are visited on site for investigating the condition of the buildings (Figure 2). Three groups of columns are identified: 30cm x 30cm, 40cm x 40cm and 45cm x 45cm. Existing reinforcement of the columns is investigated using two procedures according to TEC (2007). These methods are visual inspection and measurement of the rebar after removing clear cover of concrete of columns and using ferro-scan equipment as a means of nondestructive evaluation. Number of columns that are to be investigated using these methods are stated in TEC (2007). Due to precast construction, the reinforcement measured are quite similar. The reinforcement are shown in Table 2.

A study on the concrete strength of samples taken form various structures suggested that characteristic strength of concrete for all generic types can be conservatively assumed to be 16.0 MPa. Furthermore, soil type is accepted to be Z4 according to Turkish code, which is considered to be conservative for most of the structures. While it is believed that above values would be mostly conservative for most of the structures, it is required by owner and the design team that separate studies for determination of concrete strength and local soil conditions for each of the building should be conducted for verification of the design. Also considered is the snow load as 135 kg/m^2 for all structures. All types are considered to have 5 bays in the long directions.

Figure 2. A typical building to be retrofitted

Figure 3. Identification of column reinforcement with clearing the cover and ferro-scan.

Table 2: Existing reinforcement and column dimensions

Column Dim.	Long. Reinf., Dia. – Spacing	Lat. Reinf., Dia. – Spacing
35cm x 35cm	STIII, Φ8 – 18cm	STIII, Φ8 – 25cm
40cm x 40cm	STIII, Φ8 – 18cm	STIII, Φ8 – 25cm
45cm x 45cm	STIII, Φ8 – 18cm	STIII, Φ8 – 25cm

3. ANALYSIS OF EXISTING STRUCTURES

Existing structures are investigated by establishing two models for four generic types discussed. First a model that represents that bare frame is established. Columns are modeled as fixed base due to the grade beams that are connected between the individual footings of the columns, which is typical to the precast structures investigated. Beam-column joints are modeled as pin connection that cannot transfer moment similar to purlin-beam connections. Earthquake reduction factor (R) is used as 1 as required in both TEC (2007) and ASCE 41-06. DBE and MCE level of earthquake design spectrums are obtained from TEC (2007). A 3-D view of the mathematical model is shown in Figure 4a. Equivalent linear static procedure is applied. Summary of the results are shown in Table 3. In this table X- and Y-directions represent the long and short directions, respectively.

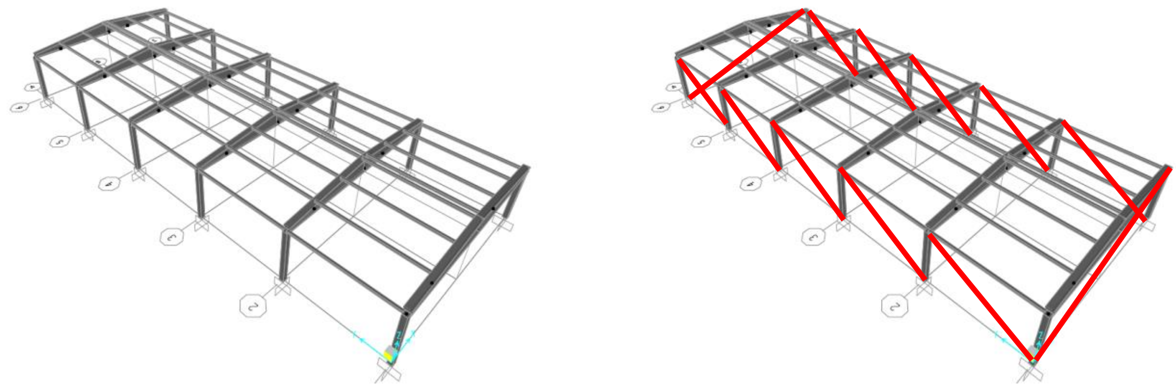


Figure 4 Mathematical model for one generic type. (a) bare frame (b) with braces

Table 3: Period and drift values for the bare frame model for DBE and MCE.

Type	Period X-Dir. (sec)	Period Y-Dir. (sec)	Drift X-Dir. DBE (%)	Drift X-Dir. MCE (%)	Drift Y-Dir. DBE (%)	Drift Y-Dir. MCE (%)
1	0.637	0.959 int. frame 0.822 ext. frame	5.85	8.76	2.91	4.38
2	0.441	0.868 int. frame 0.741 ext. frame	4.65	7.14	2.33	3.50
3	0.570	0.681 int. frame 0.580 ext. frame	3.77	5.65	3.81	5.72
4	0.394	0.565 int. frame 0.480 ext. frame	3.30	4.95	2.01	3.02

In the analysis, it is understood that since the frames in the short direction are not connected with a roof diaphragm, they are behaving independently from each other. Therefore, frames on both faces of the building have different periods that the frames inside the building. These are shown as "interior` and "exterior" frames in Table 3. In overall, the following issues are identified for the existing structures:

- Columns do not satisfy performance requirements as stated in ASCE 41-06.
- Beam column joints, which are connected only by a rod, do not have enough strength to resist seismic load (Figure 5).
- Secondary beams (purlins) have an potential issue of failure when the frames in the short direction have out-of-phase behavior due to lack of a roof diaphragm action.
- Primary roof beams have potential of overturning over the columns.

It is concluded that all four type of generic structures cannot achieve the required performance.

Figure 5. Existing beam-column connections

It should be noted that these issues are typical to precast reinforced concrete structures constructed for industrial use in Turkey. The approach of energy dissipation with dampers does not directly address these issues. However, when applying dampers, some of these issues are addresses indirectly or additional measures should be taken along with the damper application. For example, when dampers are placed into this structure, a steel frame is established which makes the frames in the long direction act as a frame, which would not otherwise due to the pin connection of the beam-column joint. For the overturning of the primary roof beams, steel plates are considered to be placed on both faces of the columns that the beams are sitting on.

To consider the effect of the infill walls, a second model is established (Figure 4b). In the second model, braces that represent the infill walls are placed within the frames (Figure 5.). Axial rigidity of these braces are adjusted such that the periods given in Table 3 are halved. In the analysis of the retrofitted structure, these braces are used to represent the infill walls except that the braces at the damper bay are removed.

4. ANALYSIS OF THE RETROFITTED STRUCTURE

In this study, rotational friction dampers are used (Mualla and Belev, 2002, Mualla et al., 2002). There are several advantages of these dampers that make them suitable for the retrofit of precast concrete structures. First of all, rotational friction dampers can have configurations suitable for the subject structure. Also, these dampers have well-defined behavior that translates into large energy dissipation capacities. In overall, frictional dampers have low cost of maintenance and easy to inspect. Some examples of these dampers and typical force-deformation hysteresis are shown in Figure 6.

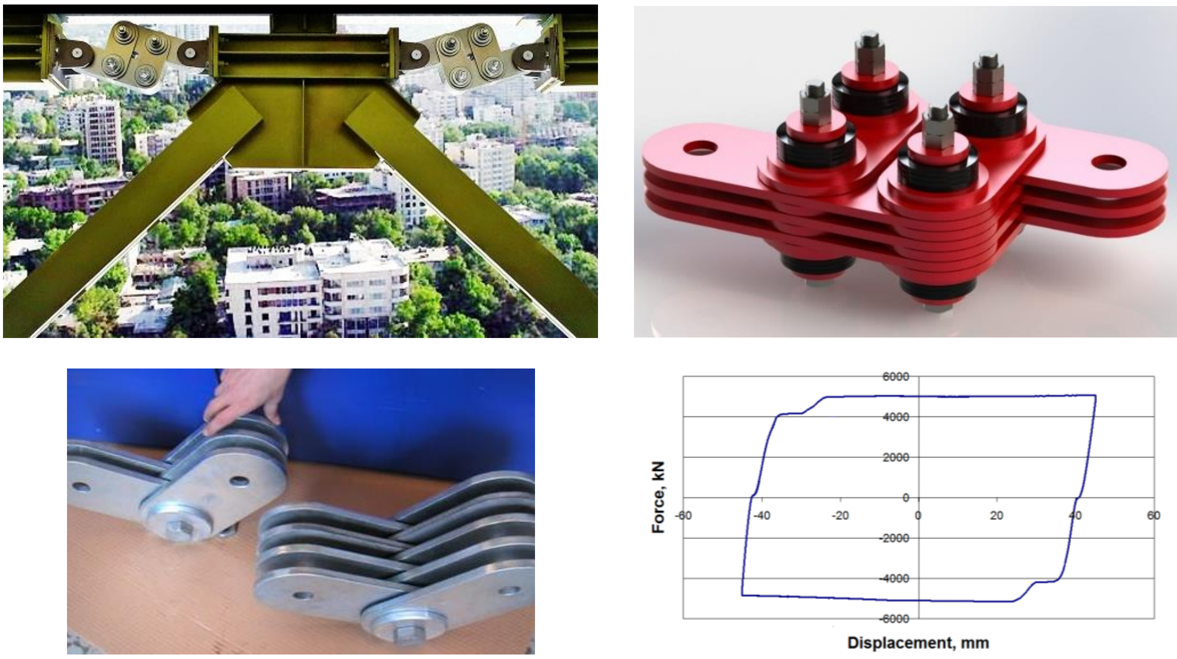


Figure 6: Several types of rotational friction dampers and typical hysteresis loops for force-displacement beahvior

For the precast structures, dampers are placed in both short and long directions. In the short direction dampers are located at the beam-column joint as shown in Figure 7. It is assumed that damper connections can easily be anchored to the reinforced concrete column and beam. Preliminary assessment of these connections show that resulting details are feasible.

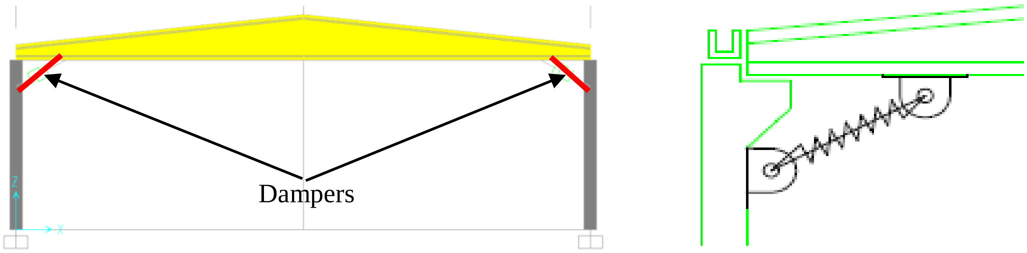


Figure 7: Damper location in the short direction beam-column connection.

In the long direction, dampers are placed to form a brace as shown in Figure 8. To establish full frame action in the long direction on the faces of the building, steel compression members, which are anchored to the concrete column, are used. As in the previous analysis, two models are considered. The first model is a bare frame model as shown in Figures 7 and 8, and it represents the case where large displacements of the structure are allowed, which in turn increases the energy dissipation by the dampers. Equivalent linear analyses are conducted for this model, and drifts of the structure under DBE and MCE hazards are shown in Table 4. It is shown that the structure satisfies the performance criteria for the first model.

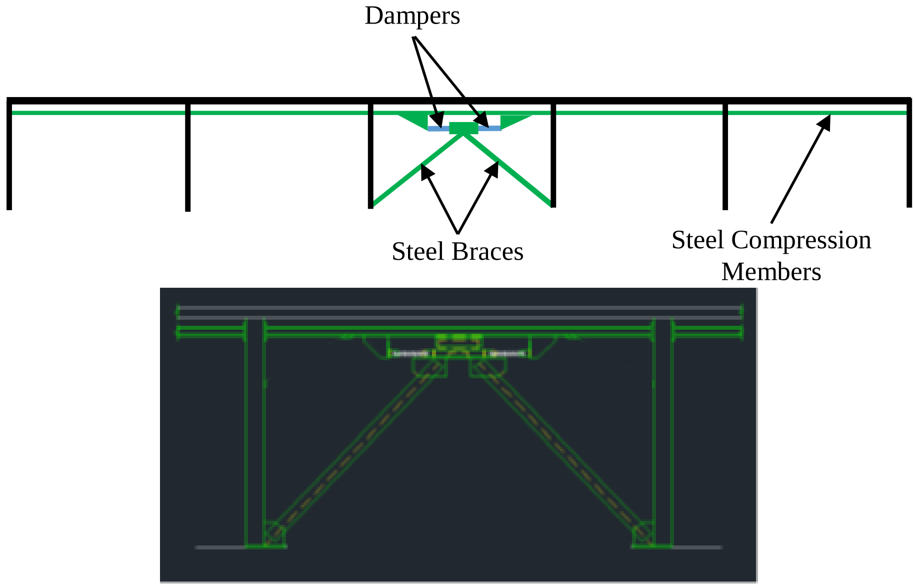


Figure 8. Damper configuration in the long direction.

Table 4. Drift values for the bare frame model for DBE and MCE when dampers are used.

Type	Drift X-Dir. DBE (%)	Drift X-Dir. MCE (%)	Drift Y-Dir. DBE (%)	Drift Y-Dir. MCE (%)
1	1.60	2.20	1.53	1.90
2	1.20	1.90	1.57	1.94
3	1.52	2.60	1.20	1.80
4	1.10	1.90	1.16	1.60

The second model represents the case where the infill walls are considered. In this model the fictious braces that are obtained in the previous section that represents the infill walls are placed at the frame bays except the bay where the dampers are placed. It is considered that the infill wall of this bay will be demolished, and architectural enclosure elements that have low rigidity or that have no connection to the reinforced concrete frames will be placed instead. Equivalent linear static procedure applied to the second model, and it is show that the drifts of the structure are considerably smaller in the second model, which does not results large member deformations (results now shown in this paper). On the other hand, dampers are not efficient due to low displacements. However, in overall, the structure also satisfies the performance objectives when the second model is used.

Table 5. Equivalent damping added by the dampers

Frame	First Model (Bare Frame)	Second Model (w/ Infill Walls)
X-Dir (internal)	13.1%	13.1%
X-Dir (external)	9.1%	0%
Y-Dir	5.1%	0.5%

The equivalent static analysis is conducted based on the equivalent damping estimation as defined by ASCE 7-10. Comparison of the equivalent modal damping ratios added by the dampers are given in Table 5. It can be seen from this table that infill walls simply stalls the damper. Seismic loads are updated based on the new damping ratios and design and verification of the retrofitted structure are performed. Damper capacities and performance evaluations are calculated after an iterative study.

As discussed before, only installation of dampers do not address issues that are associated with the deficiency of the structural system. Overturning of the primary roof beams is one of these issues. To address this issue, steel plates are considered to be placed on both faces of the columns as shown in Figure 9. As a conclusion, only installation of the dampers may not fully achieve a retrofitted structure and additional details should be considered for a complete retrofit.

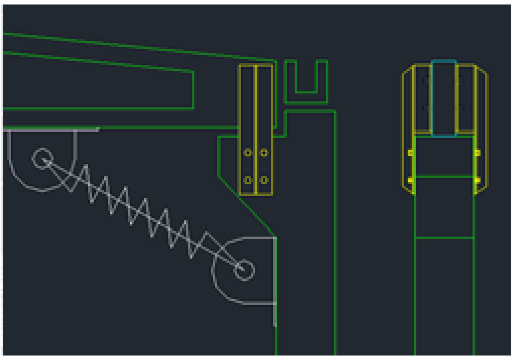


Figure 9: Steel support for beam

To verify the proposed retrofit scheme, time-history analyses are performed. In these analyses, the structure is modeled as linear and the damper is modelled by a bilinear elasto-plastic model. The properties of the damper are provided by the damper manufacturer. To satisfy the structural codes, three pairs of earthquake ground motion are considered. These are Duzce, Erzincan and Kocaeli earthquakes. As an example, Duzce earthquake data are shown in Figure 10. The aground acceleration data are scaled to MCE spectrum. In these analysis, structural damping is considered to be a value around zero percent.

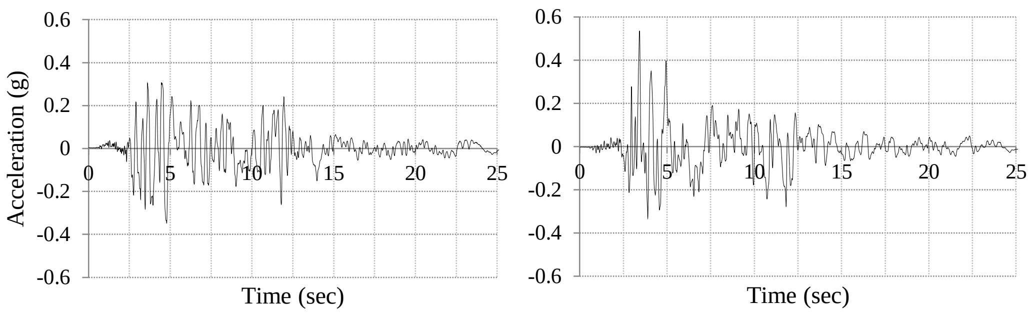
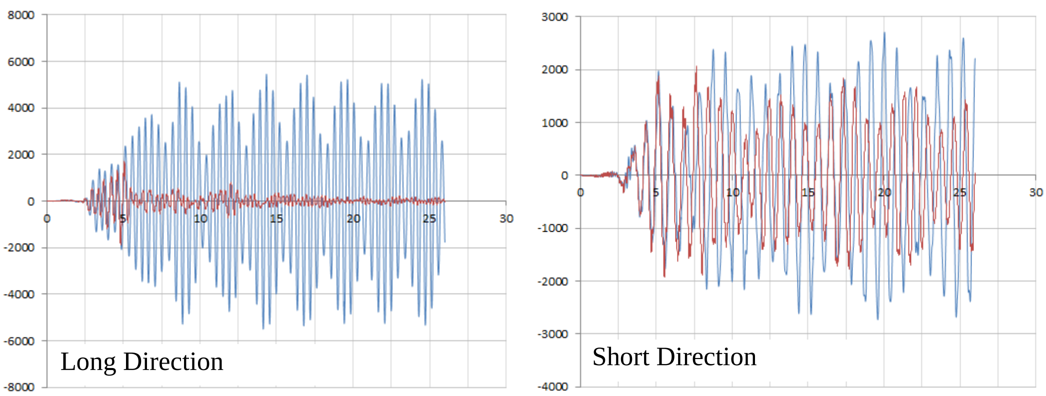


Figure 10: Duzce Earthquake ground acceleration data (X- and Y-directions).



Blue: Existing Structure, Red: Retrofitted Structure

Figure 11: Base shear comparison of retrofitted and non-retrofitted Type 2 bare-frame structures (kN)

To compare the basic results of the time-history analysis, base shears of the Type 2 bare-frame buildings are compared in Figure 11 for Duzce Earthquake. In these plots, an important observation can be made about the response of the original structure. It can be seen that the original structural has a major structural flaw. It shows a behavior of vibration rather than a structure excited by earthquake. There are two reasons for this behavior. The first reason, is the low damping used for the structure. The second reason is simply the pin-connected beams and columns of the structure does not respond as a frame. In the long direction, addition of steel members and forming a frame makes the structure behave in a more rational way. In the short direction, the behavior is improved but not as obvious as in the case of long direction. This is probably due to the low damping added to the structure. Nevertheless, performance checks on the columns reveal that the structure retrofitted with dampers satisfy the requirements. A summary of the performance of the members in the existing and retrofitted structure are given in Tables 6 and 7.

Table 6: Assesment results of existing building with MCE loading

TYPE	TOTAL NUMBER OF COLUMNS	NUMBER OF COLUMN BELOW IO	NUMBER OF COLUMN BELOW LS	NUMBER OF COLUMN BELOW CP	NUMBER OF COLUMN ABOVE CP
TYPE 1, X-Dir	12	0	0	0	12
TYPE 1, Y-Dir	12	0	0	0	12
TYPE 2, X-Dir	12	0	0	0	12
TYPE 2, Y-Dir	12	0	0	0	12
TYPE 3, X-Dir	12	0	0	0	12
TYPE 3, Y-Dir	12	0	0	0	12
TYPE 4, X-Dir	12	0	0	0	12
TYPE 4, Y-Dir	12	0	0	0	12

Table 6: Assesment results of retrofitted building with MCE loading

TYPE	TOTAL NUMBER OF COLUMNS	NUMBER OF COLUMN BELOW IO	NUMBER OF COLUMN BELOW LS	NUMBER OF COLUMN BELOW CP	NUMBER OF COLUMN ABOVE CP
TYPE 1, X-Dir	12	0	0	12	0
TYPE 1, Y-Dir	12	0	0	12	0
TYPE 2, X-Dir	12	3	9	0	0
TYPE 2, Y-Dir	12	0	1	11	0
TYPE 3, X-Dir	12	0	12	0	0
TYPE 3, Y-Dir	12	3	9	0	0
TYPE 4, X-Dir	12	4	8	0	0
TYPE 4, Y-Dir	12	12	0	0	0

5. OTHER CONSIDERATIONS

The retrofitting schemes developed are for four types of generic structures. Based on the retrofitting scheme developed, it is planned to have a bidding for construction. Before the construction, it is required that each building is evaluated on site and assumptions considered in this study should be verified. Based on the building specific conditions, this study will be revised and final construction details will be issued to the contractor.

Another study conducted is regarding the cost of the project, where details are not given here. This study reveals that the cost of the retrofit with the dampers is about 20% to 25% of a new building that satisfy the code requirements, which is considered to be economical.

Although details are not provided herein, other parts of the retrofitting schemes are verified abased on the analysis explained above. These are foundation checks, anchorage design, design of steel elements, verification of roof beams and etc. As noted above, the design check of these items are based on the current analysis and generic models. These design check will be finalized based on the data obtained from each building after the bidding.

6. CONCLUSSIONS

A stock of 59 single story precast concrete buildings with infill walls mostly used for industrial purposes are studied for retrofitting with friction dampers. As design basis, TEC (2007), ASCE 41-06, ASCE 7-10 are used. The design objective is selected to be Immediate Occupancy for DBE and Collapse Prevention for MCE. The building stock is divided into four groups, where each group is represented by a generic structure model. For each type of the stock, two models are considered: a model represent the effects of infill walls and a bare frame model. It is assumed that infill walls reduces the period of the bare-frame model to its half value. It is found that none of the existing structures can satisfy the performance levels. As the retrofitting scheme, dampers are placed at the beam column joins in the short direction and at one of the bays of the frames in the long directions. For the long direction, a steel frame is established using compression members. There are also several issues identified due to the poor design and construction practices of the existing structures, including the beam-column connections that consist of a rod connecting beam to columns. Equivalent linear static procedure is used to obtain equivalent damping ratios that are used to update seismic loads. Design and performance evaluations are conducted based on these loads, which are then verified by time-history analysis. In overall, retrofit of the precast concrete structures with friction dampers is shown to be feasible and economical.

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