

# **SEISMIC PERFORMANCE EVALUATION OF EXISTING RC STRUCTURES ACCORDING TO THE JAPANESE STANDARD AND RETROFITTING WITH PRESTRESSED PRECAST CFT AND FRC BRACES**

**Ahmet Utku YAZGAN\***  
**MEE06003**

**Supervisor: Minehiro NISHIYAMA\*\***

## **ABSTRACT**

Turkey has frequently suffered major damaging earthquakes in this century. Still, there are thousands of apartment buildings in earthquake-prone regions in Turkey that need the evaluation and seismic rehabilitation. So that, the seismic capacity of an existing RC school building at Turkey have been evaluated according to the 1<sup>st</sup> and 2<sup>nd</sup> screening level as it is represented at Japanese guidelines for seismic retrofitting of existing RC buildings, 2001. Once the seismic capacity of the building is evaluated and it was found that the seismic indexes are within 0.19 – 0.77, a simple seismic strengthening method of a new brace system using concrete filled tube and fiber reinforced concrete is analysed as a retrofitting scheme. Either of these braces is a single line element and easily placed in a frame.

Keywords: Earthquake, Existing RC Buildings, Seismic Evaluation, Seismic Retrofitting, Concrete Braces

## **INTRODUCTION**

Turkey is the one of the countries with the most rapid process of urbanization in the world. This rapid urbanization created by the population coming from the rural areas increases the number of large cities on the one hand and causes serious problems from the viewpoint of sound urbanization in the large metropolises on the other hand. As a result of this, the recent earthquakes that hit the densely populated urban areas resulted in a large-scale destruction and loss of life (Gülkan et al., 2000).

The most effective way to reduce human casualties is through the retrofit of the existing building stock. Earthquake damaged structures may need strengthening along with the repair of damaged parts (post-earthquake rehabilitation) so that their seismic performance can be improved. Also, structures not conforming to the current code may also require rehabilitation (pre-earthquake rehabilitation) so that they can satisfy the provisions of the current code (Buyukozturk et al, 2000).

On the other hand it is of critical importance that the structures that need seismic retrofitting are identified correctly, and an optimal retrofitting is conducted in a cost effective fashion to reduce the vulnerability of the building stock. As a result, it is an urgent need to develop an easy and fast evaluation method and cost effective, applicable and efficient retrofitting techniques for the improvement of the large vulnerable building stock in Turkey.

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\* Civil Engineer, Ministry of Public Works and Settlement, General Directorate of Disaster Affairs, Earthquake Research Department, Turkey

\*\* Assoc. Prof. Minehiro Nishiyama , Dept. of Urban and Environmental Engineering, Kyoto University, Japan

## JAPANESE STANDARD FOR SEISMIC PERFORMANCE EVALUATION

Three screening levels have been introduced in the Japanese standard (2001) for seismic capacity evaluation. Each level consists of a set of procedures to evaluate the basic seismic index  $E_0$ , which is the basic seismic performance of the building. The basic seismic index  $E_0$  shall be calculated for each story based on the ultimate strength, failure mode and ductility of the building. In a  $n$ -story building,  $E_0$  shall be calculated based on approximate evaluation of strength index  $C$ , the ductility index  $F$ , the effective strength factor  $\alpha$  and the story shear modification factor which represent the lateral earthquake force distribution along the building height as it stated below the equation 1 and 2 for the first screening method, equation 3 and 4 for the second screening method.

$$E_0 = \frac{n+1}{n+i} (C_w + \alpha_1 C_c) \times F_w \quad (1)$$

$$E_0 = \frac{n+1}{n+i} \sqrt{E_1^2 + E_2^2 + E_3^2} \quad (3)$$

$$E_0 = \frac{n+1}{n+i} (C_{sc} + \alpha_2 C_w + \alpha_3 C_c) \times F_{sc} \quad (2)$$

$$E_0 = \frac{n+1}{n+i} \left( C + \sum_j \alpha_j C_j \right) \times F_1 \quad (4)$$

## SEISMIC PERFORMANCE EVALUATION OF TURKISH SCHOOL BUILDING

The structure is a reinforced concrete building with 3 stories. The total floor area is about 594m<sup>2</sup> and the floor weight is 7125 kN. The transverse direction has five spans while the longitudinal direction has eight spans. Only longitudinal direction will be studied since it is weaker than the transverse one. It has windows with 160 cm openings in height at outer axe, A1-A12 and F1-12, and to study the short column effect it is assumed that it has openings of 80 cm in height at axes C6-C12 and D6-D12. Figure 1 shows the plan view of this school. The seismic performance of the school building has been investigated according to both 1<sup>st</sup> and 2<sup>nd</sup> screening levels. Only the basic seismic index of the structure ( $E_0$ ) is calculated,

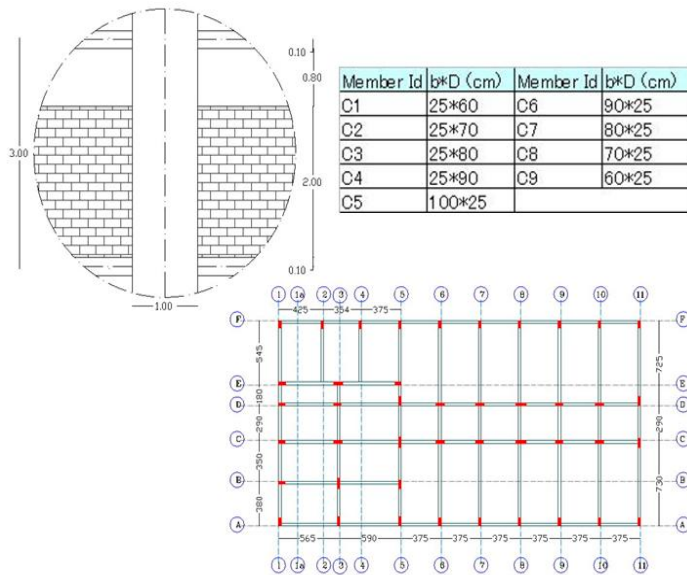


Figure 1 The plan view, column size and part of elevation of Turkish school building

therefore the procedure for the second-class prime elements is ignored, and the irregularity index ( $S_D$ ) and the time index (T) are assumed as 1.0. The unit weight area is assumed as 12 kN/m<sup>2</sup> for the building, the compressive strength of concrete is assumed as  $F_c=17.7$  N/mm<sup>2</sup>, while for steel  $\sigma_y=343$  N/mm<sup>2</sup>. Since the calculated basic seismic index  $E_0$  are less than the minimum required seismic index (0.80), the seismic performance have re-evaluated again with 1<sup>st</sup> screening method after eliminating short columns by making the seismic slits. Also by using STERA-3D (Structural Earthquake Response Analysis 3D) software the pushover analysis of the school building is done to confirm the results obtained from the screening methods.

## **SEISMIC RETROFIT OF RC STRUCTURES WITH PRESTRESSED PRECAST CFT AND FRC BRACES**

After the evaluation of the building, an optimal retrofitting must be conducted in a cost effective fashion to the building to meet the seismic performance demand by improving strength and/or ductility of it. Two types of Precast Prestressed Bracing have been developed at Kyoto University for the seismic strengthening of the buildings. One is concrete filled steel tube (CFT- M18), and the other is Fiber Reinforced Concrete (FRC-M42). In the case of FRC bracing, gaps between brace ends and frame corners are filled with high strength non-shrinkage mortar. After hardening of grout mortar, the pre-stressing force is released. Then the diagonal brace can be jointed to a boundary frame by passive interface compression due to elongation of the flat spring at the end of the brace. When a frame with bracing is subjected to lateral seismic load, only in one direction the diagonal members work efficiently in compression. However, in the opposite direction it becomes free because a concrete brace can only work in compression. This may result that the brace comes off the frame. To avoid this phenomenon, a special device with a flat spring and steel pipe (FSSP) is installed at the bottom end of diagonal member. This device makes possible to maintain a certain amount of compressive force in the diagonal member regardless of lateral response (Watanabe et al. 2004).

Two half-scale specimens (CFT1 and FRC01) were constructed with different brace materials. The surrounding reinforced concrete portal frames were identical as the sub-assembly of a four-story reinforced concrete building, which was designed following the pre-1980 Japanese Building Standard. The column section was 300 x 300 mm and had sixteen longitudinal D10 deformed bars at the top and bottom. Before applying the horizontal load, prestressing force of 450 kN ( $0.28f_{cb}D$ ) and 324 kN ( $0.20f_{cb}D$ ) was applied to the beam and each column, respectively, with internal unbonded prestressing steel bars. The column axial force corresponds to the axial force of the first story column due to the gravity loading. The beam was prestressed to avoid the tension failure. Drift angle controlled reversed cyclic loading tests were conducted. Lateral displacements were computed by averaging four measurements values (both side of the specimen) at two frame corners. The lateral loads with equal magnitude were applied at either end of the beam. In this research imposed positive displacements were five times as large as negative displacements so that the surrounding reinforced concrete portal frame does not suffer too much damage in the negative loading.

A commercial frame analysis program is used to find out the shear force at the columns, beams and column-beam joint by introducing the design compression stress of the brace to the frame.

## **DISCUSSION**

### **Evaluation results of the existing RC school building**

After the evaluation, it was found out that the seismic capacities of that building are less than what is proposed in that standard. The resulted basic seismic index  $E_0$  for each story is less than the judgment index (0.8) of the first screening level as it is shown in Table 1. The second screening level was carried out for the same building and the resulted basic seismic indices for the first two stories are still less than the judgment index (0.6) as it is shown in Table 2. In typical case, the first level method is better to screen safe buildings. Next a higher-level method can be applied to those buildings that do not pass the lower level procedure.

The response of the building is also obtained by STERA-3D after applying lateral load with a triangular distribution in the X-direction up to a target drift of 1/50 to compare with the results of the screenings. Drift-Shear relation and capacity curve can be seen below in Figure 2.

Table 1 The results of 1<sup>st</sup> screening level for Turkish school building before retrofitting and after

story	floor area	floor weight	total weight	member category	stregth index initial	stregth index after	$\phi = \frac{n+1}{n+I}$	F	$E_0$ (initial)	$E_0$ (after)	difference (%)
3	593.8	7125.5	2293.9	column	0.56	0.77	0.67	1	0.37	0.52	0.28
				short column	0.38	-		0.8			
2	593.8	7125.5208	4587.8	column	0.28	0.40	0.80	1	0.22	0.32	0.30
				short column	0.19	-		0.8			
1	593.8	7125.5208	6881.6	column	0.19	0.27	1.00	1	0.19	0.27	0.31
				short column	0.13	-		0.8			

Table 2 The results of 2<sup>nd</sup> screening level for Turkish school building

Story No.	F=0.8		F=1		F>1		$(C1+S_{a1} * C_2)F$	$\phi = \frac{n+1}{n+I}$	$E_0$
	F1	C1	a2	C2	a3	C3			
3	0.8	0.462	0.65	1.161	0.51	0.093	1.01146542	0.667	0.674
	1	1.161	0.72	-	-	-	1.161457687	0.667	<b>0.774</b>
	3.2	0.093	-	-	-	-	0.297180121	0.667	0.198
2	0.8	0.237	0.65	0.626	0.51	0.052	0.535825057	0.800	0.429
	1	0.626	0.72	-	-	-	0.62574562	0.800	<b>0.501</b>
	3.2	0.052	-	-	-	-	0.166031727	0.800	0.133
1	0.8	0.156	0.65	0.450	0.51	0.041	0.375629447	1.000	0.376
	1	0.450	0.72	-	-	-	0.449740685	1.000	<b>0.450</b>
	3.2	0.041	-	-	-	-	0.130135821	1.000	0.130

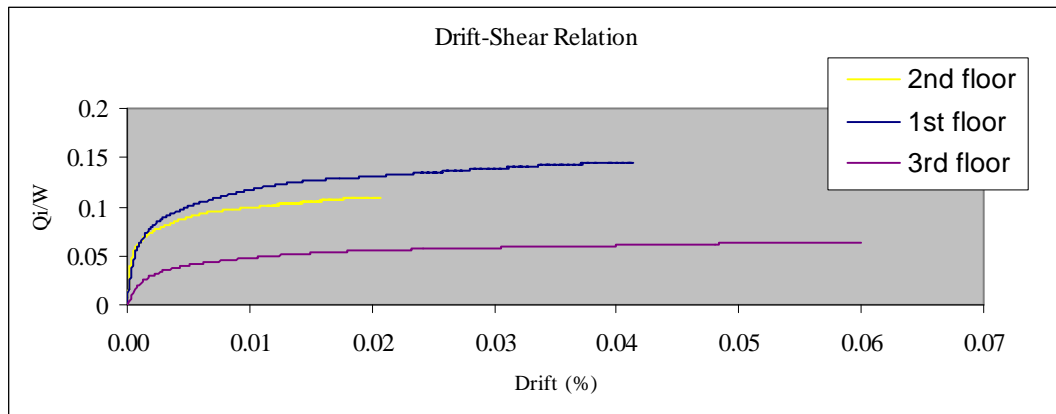


Figure 2 Drift Shear relation of the RC school building

### Precast CFT and FRC braces

The lateral load carrying capacity of the reinforced concrete portal frame without the brace was 190kN. By installing the brace, CFT01 and FRC01 were designed to have 320 kN for CFT and 547 kN for FRC in lateral load capacity at which the brace was to buckle.

The lateral load – total drift ratio relations for the CFT-M18 and FRC-M42 braces are shown in Figure 4 and Figure 6. Both curves show elastic response, where CFT-M18 shows more ductile behavior than FRC-M42. A solid line represents the total load and a slightly shaded line represents the sum of shear forces of two columns. The shear forces of the columns were obtained by subtracting lateral load contribution of the brace from the total lateral load. Lateral load contribution of the brace was the horizontal component of the axial force that is computed based on the measured concrete longitudinal strain.

In CFT-M18, the reinforced concrete portal frame had some shear cracks which were not severe and the specimen failed due to local buckling of the brace when the  $R=1.40\%$  and the lateral force reached 547 kN. FRC-M42 failed due to buckling of the brace at the mid span when  $R=0.40\%$  and the lateral force reached 320 kN and the brace had 5 mm in plane and 2 mm out of plane displacements, at  $R=0.58\%$  the out of plane and in plane displacements suddenly increased at the center of the bracing and buckling occurred. Damage to the other members was restricted to minor flexure cracks. Observed damage of CFT-M18 and FRC-M42 is shown in Figure 3 and Figure 5 respectively.



Figure 3 Observed damage of CFT-M18

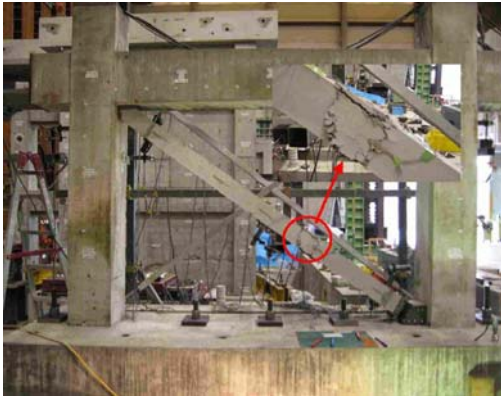


Figure 5 Observed damage of FRC-M42

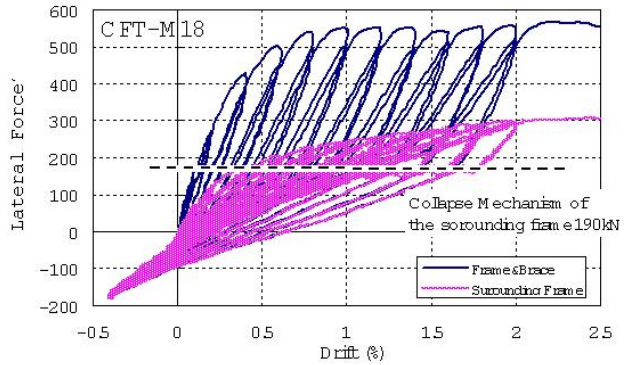


Figure 4 Lateral Force – Drift relation of CFT-M18

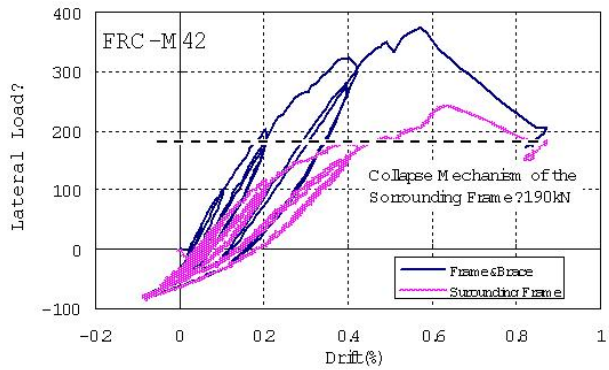


Figure 6 Lateral Force – Drift relation of FRC-M42

## CONCLUSIONS

There are so many vulnerable buildings and houses designed and constructed by old fashioned seismic engineering in Turkey. The seismic evaluation and retrofit of these buildings are one of the most important, effective and urgent measures for earthquake disaster mitigation.

By following the Japanese standard for the evaluation of existing structures, a RC school building in Turkey was analyzed and it was found that the seismic capacity was lower than the required. The columns were classified according to their strength index and ductility index to find out their contribution to the seismic capacity of the building by considering each floor. As a result the strength of the building needs to be improved by an appropriate retrofitting method. This result was also confirmed by a pushover analyze of the building with Stera-3D program.

Then a new brace system using concrete filled tube and fiber reinforced concrete was tested to find out its contribution to the strength and ductility of a concrete portal frame and following conclusions have been drawn. It was experimentally shown that the developed prestressed brace system could easily

retrofit existing reinforced concrete frames with no rebar and bolt anchorage. CFT failed by buckling of the brace but the lateral load-drift relation was relatively ductile until  $R=2\%$ , even after the buckling took place at  $R=1.40\%$ . CFT may also allow the ductile design procedure due to its enhanced ductility. FRC failed due to buckling occurring at  $R=0.58\%$  when the out of plane and in plane displacements suddenly increased at the center of the bracing. The lateral load capacity of the frame was improved. It is seen that the proposed system showed good seismic performance from the strength-resisting mode to the ductility enhancement mode. In any case, the braced system showed much larger lateral load carrying capacity than that of the original frame. The system can be used in Turkey for existing reinforced concrete buildings susceptible to the earthquake damage as in Japan. As a result houses fragile to earthquake motion caused most of the devastation having been seen in Japan and Turkey. Sudo et al (1999) mentioned that many similar problems must be solved and issues must be studied in both countries in order to reduce earthquake disasters.

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