Project 3 - Evaluation of seismic performance of a template design RC school building before and after strengthening

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Abstract

The aim of the project was to introduce the participants into advanced requests in the field of earthquake engineering. The studies were concentrated on a template design RC school building (Figure 1), which revealed low seismic resistant in the past earthquakes in Turkey. Therefore the Turkish Government started after the damaging events in 1999 a campaign to investigate and strengthen these buildings all over Turkey.

In the frame of these campaign one typical school building, with quite similar ground plans to the school building which failed during the Bingöl Earthquake in 2003 could be instrumentally investigated before and after strengthening.

The participants of the project assessed the performance of the structure before and after the applied strengthening measures on the basis of measured building response data and evaluate the earthquake resistant design. They carried out damage prognosis for the given seismic action and compared it with the real occurred damage after the Bingöl EQ by using modern software tools.

Introduction

School buildings belong to the building class of higher priority according to the common code requirements, because of their use as meeting point and shelter in the immediate aftermath of a disaster as well as their high occupancy rate.

The major part of the school buildings (80%) were constructed before 1997, which means according to the requirements of the 1972 earthquake code and under the consideration of obsolete seismic demands. In many cases rules of earthquake resistant design were not applied.

The devastating Marmara Earthquake (17th August 1999) and Bingöl Earthquake (1st May, 2003) caused heavily damages and collapses on a serious number of school buildings. Therefore the Turkish Government initiated a programme for the systematic inspection of school and hospital buildings in Turkey together with the application of strengthening measures for governmental buildings with poor performance.

In the frame of a project the project partner of the summer course Mustafa Kemal University could accompany a strengthen measure of a school building by dynamic investigation.

Study Object

General Information

The considered school building is one of three school buildings in Hatay (Turkey), which could be dynamically investigated before and after strengthening. It is a 3-story RC frame structure building and was constructed in 1997 according to the 1972 earthquake design code (see Fig. 1).

Figure 2 show the modification of the ground plan by the replacement of non-structural masonry infill walls with reinforced concrete structural walls (red walls), which is a common strengthening technique in Turkey to increase the building capacity and to decrease the maximum displacements. The chosen school building is thus representative for a large number of school buildings in whole Turkey before and after strengthening.

Evaluation of the structural system

A first evaluation of the study object before and after strengthening was carried out on the basis of regularity and construction details check. The general layout obeys with the regularity criteria of an earthquake resistant designed structure which will be confirmed by the check of the location of the centre of mass (red point) and rigidity (blue point) in Figure 2.

The location of the centre of mass and rigidity a translational behaviour of the building in both directions can be expected under seismic action due to the quite small distances between as well as the location

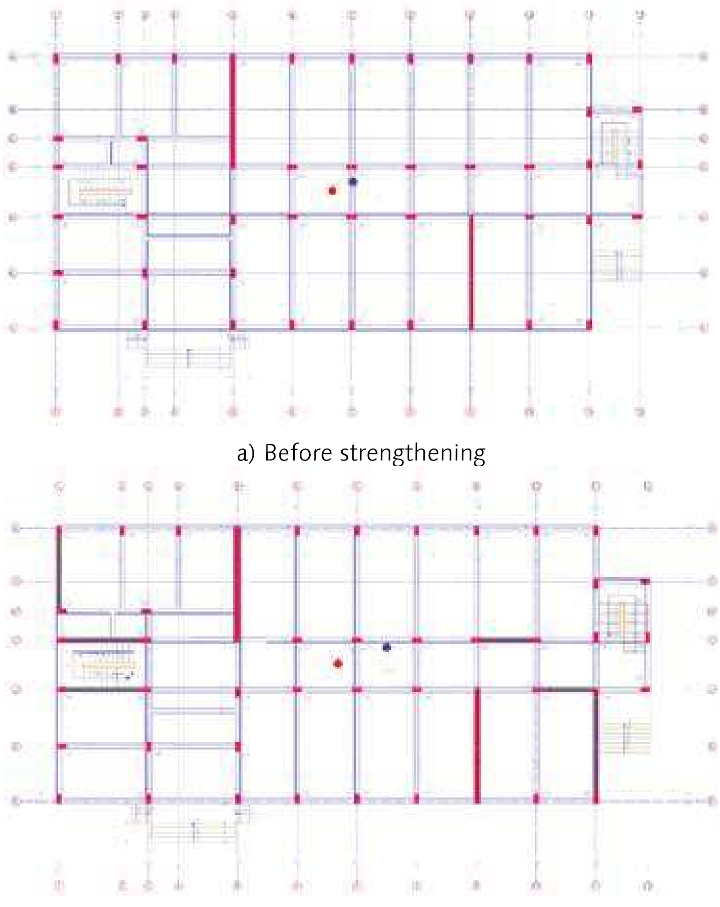
Figure 1 — Front view of the study object [1]

of both points. That means in case of the unstrengthen structure only less additional forces can be expected due to torsional behaviour. Due to the retrofitting of the structure the centre of rigidity was shifted, thus a larger distance occurred and the influence of torsional motion will become higher.

The reinforcement details are in general of poor quality, which was also the highest motivation for the retrofitting.

Observed building performance after the Bingöl EQ

The magnitude 6.6 Bingöl (Türkiye) earthquake on May 1, 2003 caused severe damages and collapse to school buildings (see Figure 3). The comparison of the general layouts from the damage structures and the study object indicates the representativeness of the studied object and provides the opportunity to adopt the experiences from the Bingöl earthquake to the study area Antakya. Thus, the results of the damage prognosis can be compared with the observed damages on school building with a nearly identical (template) design for a known seismic action.



a) Before strengthening

b) After strengthening

Figure 2 — Ground plan of the study object

Figure 3 — Damage of a school building caused by the 1st May Bingöl earthquake [2]

Experimental tests

Building response measurements
Mustafa Kemal University carried out building response measurements before and after strengthening of the school building in 2011. The building was equipped with five triaxial velocity sensors Type MS2004+ and the corresponding recorder Type MR2002 (SYSCOM Inc.). The sensors are oriented at the main axis of the building. In general, two sensors were installed in two opposite corners on the roof and two sensors in the same corners on a mid-floor story. The fifth sensor was installed in the middle of the ground floor. Sensor number six was installed outside of the building (see scheme in Figure 4).

A "lightweight" exciter (transportable by two men; covering a frequency range between 1 and 15 Hz) was successfully applied [3].

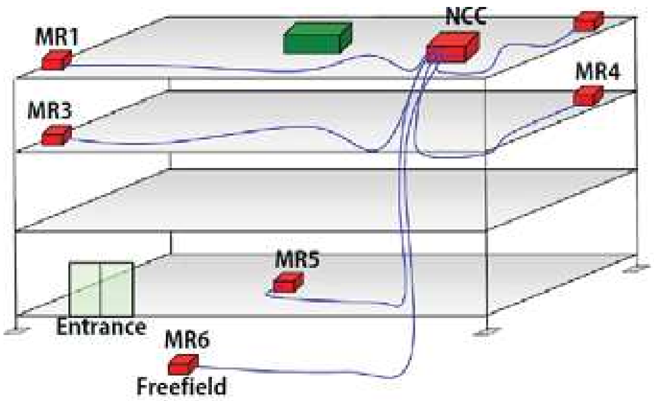


Figure 4 — Applied instrumentation scheme [1]

Elaboration and interpretation of the measured data

Different programmes were applied to determine the eigenfrequencies and corresponding mode shapes. The ambient and forced vibration data were conditioned with the programme MATLAB for the use in the programme ARTeMIS, the MATLAB toolbox MACEC as well as MATLAB routines.

The signals were than analysed by the application of FFT techniques [3] and use of the Stochastic Subspace Identification Method [1]. Thus only the programme ARTeMIS and the toolbox MACEC provide directly a sketch of the mode shape.

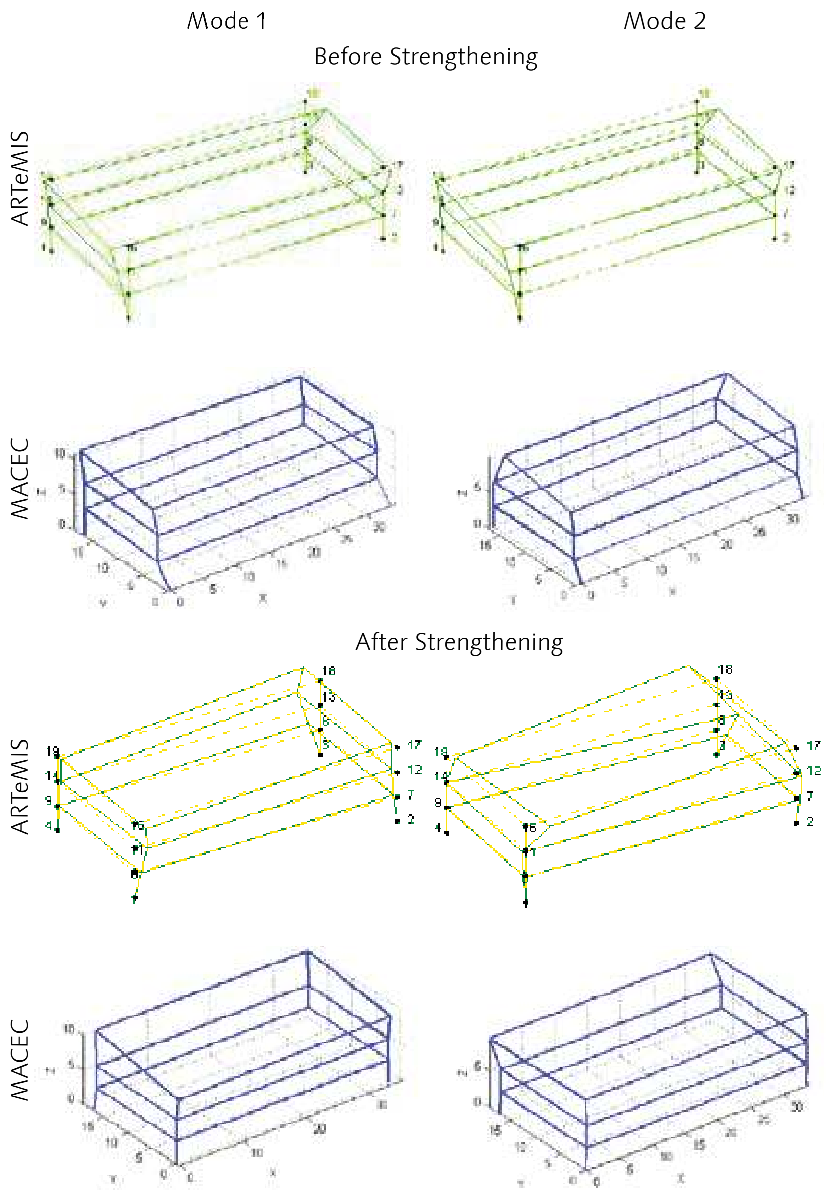


Figure 5 — Determined characteristic modes before and after strengthening by the use of instrumental data

The pure analysis of the data by the application of FFT techniques only identifies the natural frequencies of the building at each measurement point.

Figure 5 show the first two mode shapes analysed with the programme ARTeMIS and MACEC, which could be determined for the building before and after strengthening with. It can be clearly seen,

Figure 6 show the normalized FFT response values from the sensor MR1 and MR3 in x- and y-direction before and after strengthening; the normalization accounts for different amounts of weights which were used during the measurements to cover the whole frequency band [3]. Especially in the case without strengthening clear peaks can be determined, which indicate the highest amplification of the introduce signal due to the resonance to the natural frequencies of the building in each direction.

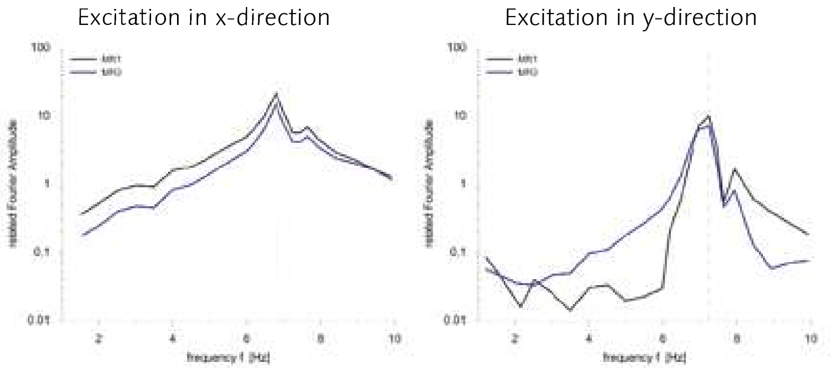
Table 1 provide the summary of the determined first structural frequencies. The comparisons show quite identical results for the first two modes (f_1, f_2) before and after strengthening. But it has to be noted, that the identification of the natural frequencies by the FFT approach only might be lead to other results, because at some sensors no clear peak can be identified and a comparison to other sensors or approaches is recommended.

Table 1 — Determined fundamental frequencies from the experimental testing

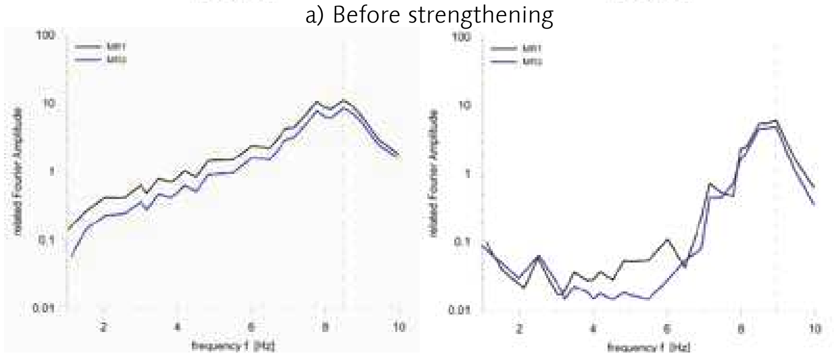
Frequency [Hz]				
Software	before strengthening		after strengthening	
	f_1	f_2	f_1	f_2
MACEC	6.90	7.50	8.30	9.12
ARTeMIS	7.08	7.52	8.25	9.03
FFT	6.79	7.25	8.25	8.97

Analytical Studies

For the building investigated, a 3-dimensional model was created using the software tools ETABS and Sap2000. Provided construction plans of the building supplied the required geometrical data. Material properties for the given quality were assumed according to the Turkish standards.



a) Before strengthening



b) After strengthening

Figure 6 — Recorded building response (normalized FFT Amplitude) at Sensor MR1 and MR3 for excitation in x- and y- direction

Columns were generally assumed as rigidly connected to the underground. Floors were modeled as rigid diaphragms; roof constructions were taken into account by planar loads. Masonry infill walls were neglected to reduce the modeling and analysis effort, because of the limited time window.

The material parameters for concrete were assumed to have characteristic cube strength of 16 MPa (as denoted in construction plans). Reinforcement was assumed to be of Turkish steel grade S220a (220 MPa yield strength and 10% strain at ultimate strength; generally smooth, not profiled), also corresponding with specifications in plans.

Figure 7 show the 3D model before and after strengthening modeled with beam and shell elements. The adaption of beam elements for the added shear walls was necessary to apply nonlinear hinges for the push over analysis.

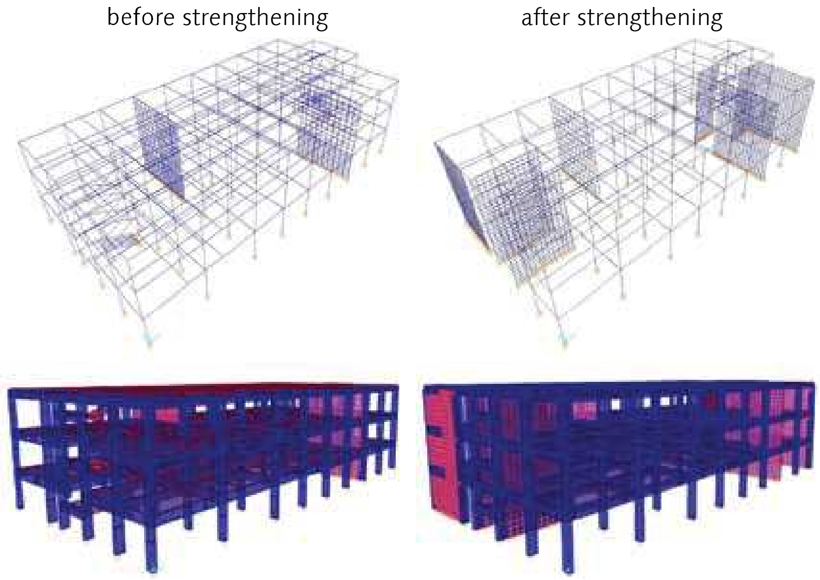


Figure 7 — 3D model before and after strengthening (Using shell elements for the modeling of the structural walls)

The fundamental periods of the buildings, which were known due to the dynamic recordings, were used as a measure for the calibration of the stiffness parameters. Young's Moduli were reduced (in comparison to recommended values given in code specifications) for all elements of identical material. In the frame of the project the goal was not to achieve a perfect match for the building. Congruency of the main mode shapes and frequencies/periods was nevertheless seen as important.

Table 2 shows the comparison of the experimental and first analytical (without calibration) determined fundamental periods of the school building before and after strengthening. The calibration of the model was foreseen by the link of SAP2000 with an optimization MATLAB program prepared by the participants of Project 5. Due to technical problems and limited time only the communication could be realized and the routine be rune. A final calibration could not be achieved.

Therefore the natural frequencies of the analytical model are so far not comparable with the results from the measurement, which indicates the need of model calibration. The results show, that modeling of complex 3D structures bases on the construction plan can lead to much different dynamic behavior and thus to un-conservative seismic load assumption (see Figure 8).

Table 2 — Comparison of the fundamental periods before and after strengthening

Period [sec]				
Software	before strengthening		after strengthening	
	T_1	T_2	T_1	T_2
MACEC	0,145	0,133	0,120	0,110
ARTeMIS	0,141	0,133	0,121	0,111
FFT	0,147	0,138	0,129	0,118
SAP2000	0,310	0,180	0,135	0,132

Damage Prognosis

Nonlinear static pushover analysis was applied to determine the building capacity in form of the capacity spectrum in x- and y-direction and to carry out a damage prognosis. The N2-method proposed by Fajfar [4] was applied to investigate the response of the school building to a design spectrum excitation. A design spectrum according to the Turkish seismic code and assuming different PGA level, factor of building importance class I = 1.0, and subsoil conditions Z2 was used. For a PGA of 0.4 g corresponding to the highest seismic zone no intersection between the capacity spectrum and the design spectrum resulted; thus, according to the calculations performed here, the building would not be able to withstand an earthquake corresponding to the required specifications. Further calculations were carried out in order to determine the level of peak ground acceleration the building could resist. The value of PGA = 0.33 g was found to be the threshold for total collapse (see Figure 9).

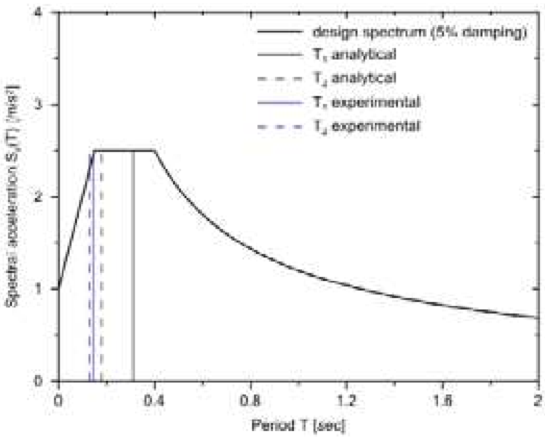
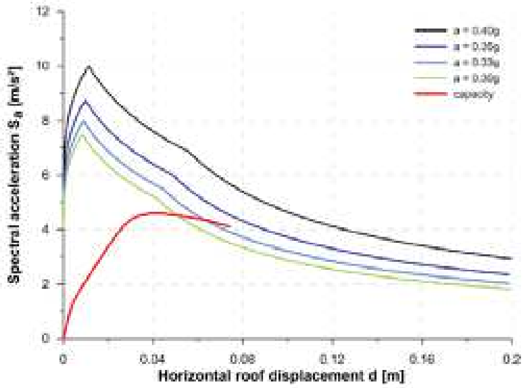
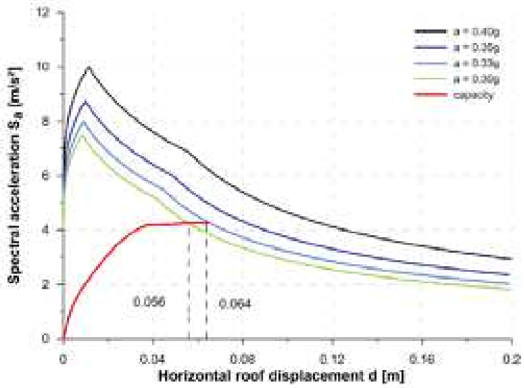


Figure 8 — Indication of the influence of the considered characteristic periods on the example of the Turkish Code Spectrum



a) x-direction



b) y-direction

Figure 9 — Demand spectrum in x- and y- direction by the application of N2-method

Conclusions

In the frame of the project a damage prognosis was carried out for a 3-story RC frame school building under the use of building response measurement data and modern software tools. Experimental testing at the building could be done before and after strengthening of the structure by the project partner MKU, who provided the data for the project. For the strengthening of the structure shear walls were added to increase the building capacity and to decrease the maximum displacements.

The provided building response data were analyzed to determine the principle fundamental periods and corresponding mode shapes, which were used for the calibration of the structural models. The comparisons of the experimental and first analytical periods indicate the necessity of model calibration. First analytical results indicate a much weaker behavior of the structure, which can lead to un-conservative seismic load assumptions.

Estimations of structural performance were conducted using site-specific response spectra reflecting subsoil conditions of class Z2 according to Turkish code and the application of the N2-Method. The results for the origin structure indicate that the vulnerability of the 3-story school building does not fulfill the requirements by the design code. For the site considered ground acceleration of 0.4 g will cause heavy damages or collapse of the building. The structure is only capable to withstand ground motion smaller than 0.33 g. There was a need to strengthen the structure. The check of the sufficiency of the carried out strengthening measures could not be realized in the frame of the project.

References

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