THE ADANA-CEYHAN EARTHQUAKE OF 27 JUNE 1998: SEISMIC RETROFIT OF 120 R/C BUILDINGS

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SUMMARY

A severe earthquake measuring M_s 6.2 occurred near the city of Ceyhan (population 100 000) in Southern Turkey on 27 June 1998. Although the focal distance to Ceyhan was 32 km, fault rupture was directed towards Ceyhan, causing heavy damage in the city as a result of a strong motion with a PGA of 0.28 g. Out of a total number of 146 casualties, 86 were in Ceyhan. Twelve R/C buildings collapsed and 120 were classified as moderately damaged in Ceyhan. These 120 multistory buildings have been inspected and their seismic retrofit projects have been prepared by the Earthquake Engineering Research Center of the Middle East Technical University (METU/EERC). The retrofit works include detailed damage assessment and structural evaluation of the existing buildings, selection of the retrofit scheme, and final performance verification by the capacity spectrum method. Cast in place concrete infill walls are employed as the primary elements of seismic retrofit. The selected retrofit scheme has provided the required seismic safety and economy.

INTRODUCTION

Three severe urban earthquakes occurred in Turkey recently, in 1992, 1995 and 1998, in three different seismo-tectonic environments indicated in Figure 1. These earthquakes caused substantial damage to buildings in the cities of Erzincan, Dinar and Ceyhan. According to the Disaster Law in Turkey, each residential or commercial building affected by a natural disaster in a disaster area is quickly assessed by an official damage assessment team, and awarded a damage grade, light, moderate or severe. These inspection teams rate damage by applying uniform, simple procedures developed seperately for reinforced concrete and masonry buildings [Gülkan et al. 1994]. The severely damaged buildings are demolished and the moderately damaged buildings are entitled for seismic retrofit with financial loans provided by the government. In the aftermath of these three earthquakes, requests have been made by the Ministry of Public Works and Settlement on the expertise available at the METU/EERC for involvement in the rehabilitation works. The scope of this involvement prior to Ceyhan was developing seismic retrofit strategies for 29 three to four story R/C school buildings in Erzincan, and 34 three to six story R/C residential apartment buildings in Dinar [Wasti and Sucuoğlu, 1999].

After the 1998 Adana-Ceyhan earthquake [Gülkan, 1998], seismit retrofit works of all 120 moderately damaged R/C residential apartment buildings in Ceyhan have been assigned to METU/EERC. This building stock is composed of 3-9 story buildings, with a total floor area of 220 000 sq m. METU/EERC has coordinated geotechnical and structural engineering consultants in undertaking this task. The retrofit design of all buildings has been completed in June 1999. Technical supervision of construction will also be done by the same organization. This paper reviews seismic and engineering aspects of the Adana-Ceyhan earthquake and summarizes the seismic retrofit works carried out by METU/EERC.

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SEISMOLOGY AND STRONG MOTION

Adana-Ceyhan earthquake occurred at 4:56 PM local time on 27 June 1998. The epicentral coordinates of the main shock (M_s=6.2) were reported as 36.95 N and 35.31 E, and the focal depth as 23 km which is followed by numerous aftershocks that are shown in Figure 2. The strike direction of the causative Misis fault is in the left lateral sense, with a rupture directivity from Southwest to Northeast toward Ceyhan. Accordingly, earthquake shaking was felt most strongly in Ceyhan (population 100 000) with the evidence of heavy damage in the city (MM intensity VIII). It was also strongly felt and caused damage in the nearest provincial capital Adana (population 1.2 million) and its suburb Yüreğir.

The area shown in Figure 2 has been the scene for many earthquakes in the past. Eight earthquakes with magnitudes between 5.5 and 6.2 occurred during 1907 to 1952, where the last one in 1952 with M=5.6 was very similar to the 1998 event in epicenter and the intensity in the felt area [Gencoğlu et al. 1990].

The Adana-Ceyhan earthquake along the Misis fault triggered several SMA instruments deployed in the area. A summary of the instrumental recordings are given in Table 1. It is noteworthy that Ceyhan and Karataş Stations recorded very different ground acceleration peaks despite their similarity in epicentral distance. This difference may be attributed to two factors. First is the rupture directivity where Ceyhan is in the forward and Karataş is in the backward of the rupture direction, and the second is the difference in local soil conditions as indicated in Table 1. The notable amplification of horizontal acceleration at Mersin compared to the other stations with similar distances is also related to the difference in local soil conditions.

Table 1. Strong Motion Stations and Peak Ground Accelerations

Station	Epicentral distance (km)	Soil Conditions	PGA EW mg	PGA NS mg	PGA V mg
Ceyhan	32	Deep alluvium	273	223	86
Karataş	36	Sandstone	33	29	20
Mersin	80	Slope deposits	132	119	22
Hatay	90	Limestone	26	27	12
İskenderun	60	Limestone	15	14	12
İslahiye	85	Limestone	18	21	14

The corrected ground acceleration components recorded by the Ceyhan station are given in Figure 3. When these accelerations are integrated and resolved, peak ground velocities of 30 cm/s and 25 cm/s and peak ground displacements of 8 cm and 12 cm are obtained in the longitudinal and transverse directions to the fault respectively. The acceleration response spectra of the Ceyhan ground motion components are shown in Figure 4. This figure indicates similarity of the intensity and frequency content of ground motions in two horizontal directions. Ceyhan is located in the second most severe seismic zone in Turkey where the probability of exceeding an effective peak ground acceleration of 0.3 g is 10 percent in 50 years, or the return period is 475 years. Hence Ceyhan ground motion does not exceed the seismic hazard defined for Ceyhan in the seismic zones map of Turkey.

SOIL CONDITIONS AND DAMAGE DISTRIBUTION IN CEYHAN

Ceyhan is situated on the east bank of the Ceyhan river which approximately follows the Misis fault in Figure 2 in the Misis valley and flows in the southwest direction. The city is located on a large alluvial plane formed by the Ceyhan river. Various resistivity and borehole surveys have been conducted by METU/EERC in the vicinity of Ceyhan after the earthquake. Electrical resistivity studies within a depth of 250 m indicated that there is no distinct bedrock layer up to this depth. Eight boreholes with depths between 50-150 m were drilled in different locations and the laboratory experiments on the borehole logs revealed that the variation of soil conditions within the city is negligible. The soil formation consists of a thin vegetable soil on top (< 1 m), a sand and stiff clay layer of thickness 1-3 m below, and a deep silty clay layer at the bottom. Water table depth varies between 1.5-3.5 m.

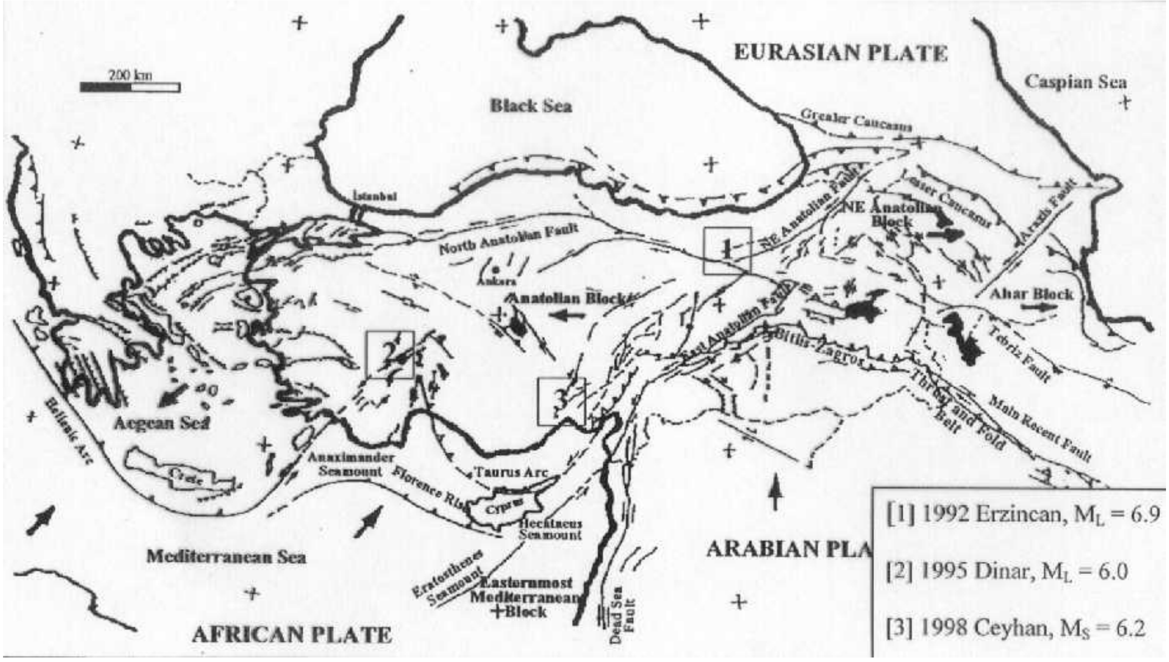


Figure 1. Seismic fault map of Turkey and epicenters of three recent earthquakes

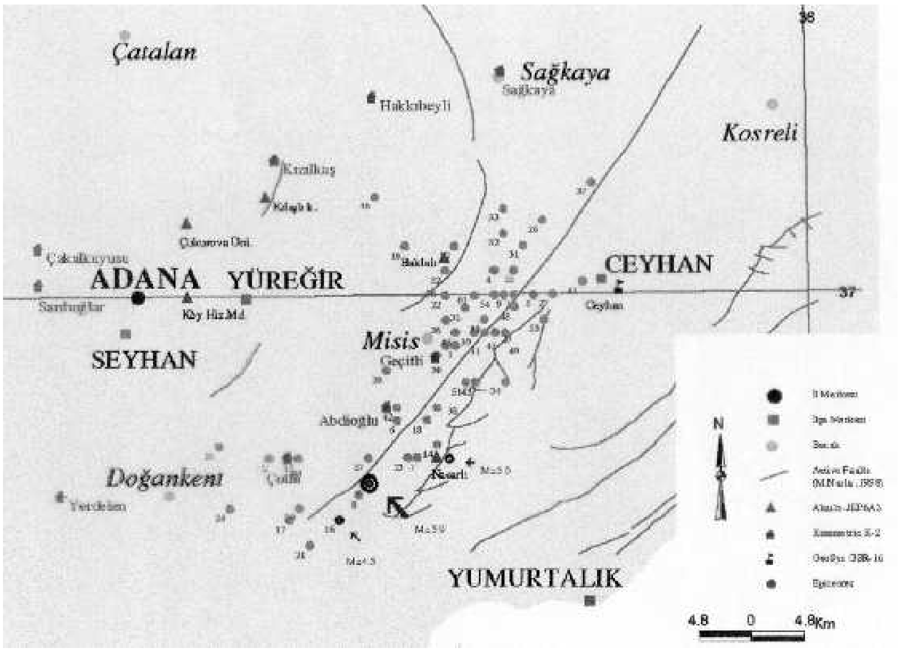
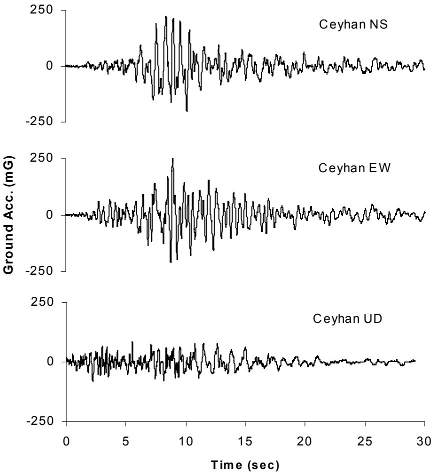


Figure 2. Misis fault and the epicenters of 27.6.1998 Adana-Ceyhan earthquake mainshock and aftershocks

Shear wave velocity profiles were obtained along three boreholes by exploiting the SPT values obtained at the laboratory. The profiles are shown in Figure 5, where SK-1 is the site of the Ceyhan strong motion station. These profiles confirm that mechanical characteristics of the deep alluvial deposit underneath Ceyhan do not exhibit appreciable spatial variation. This conclusion is important in assessing the distribution of structural damage in Ceyhan during the 1998 earthquake.



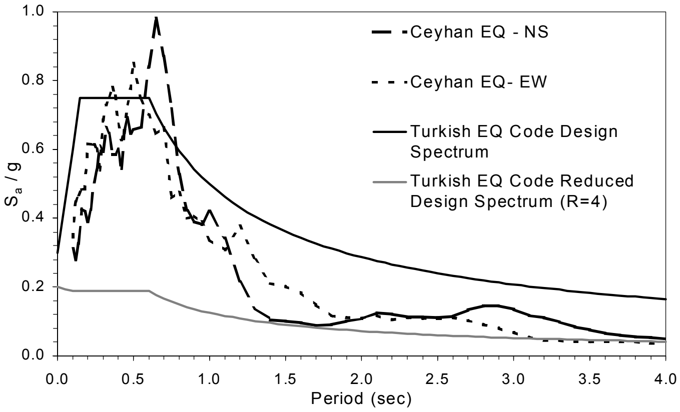


Figure 3. Accelerograms recorded at Ceyhan station

Figure 4. Acceleration response spectra of Ceyhan ground motions

If the extremely poor masonry houses are excluded in Ceyhan, structural damage is entirely confined to multistory reinforced concrete buildings which do not satisfy earthquake resistant design regulations in Turkey. The twelve collapsed, 30 heavily damaged and 120 moderately damaged apartment blocks were distributed randomly throughout the city. Figure 6 shows a collapsed and a heavily damaged block in the foreground and moderately damaged blocks in the background in Ceyhan after the earthquake. Since the difference in soil conditions are eliminated as a factor, the distribution in damage is expected to be in accord with the available seismic resistance of damaged buildings.

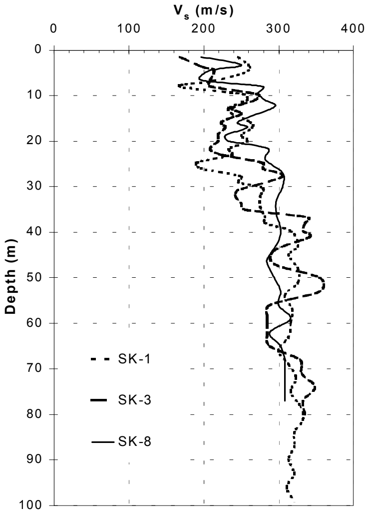


Figure 5. Shear wave velocity profile in Ceyhan

Figure 6. Collapsed and damaged buildings in Ceyhan after 1998 earthquake

SEISMIC RETROFIT OF MODERATELY DAMAGED R/C BUILDINGS

The distribution of the 120 moderately damaged buildings with respect to the number of stories are given in Figure 7. The procedure followed in seismic assessment and retrofit works is outlined below.

1. Field teams enter a building with the available architectural/structural drawings and control all structural dimensions. Reinforcement is controlled on selected elements by metal detectors and by stripping concrete shell where necessary. Foundations are inspected by excavating trenches at one or two exterior footings.

2. Existing concrete quality is investigated by taking 1-3 core specimens from each building and making hammer rebound readings on a large number of structural elements calibrated with the core test results.

3. Field teams inspect each structural and architectural element for damage and mark the observed damage grade (none, light, moderate or heavy) on the structural and architectural plans accordingly.

4. Damage score of the building is calculated based on a scale of 100 [Wasti and Sucuoğlu, 1999]. If it is found severely damaged, the building is demolished. Fourteen such buildings were demolished, otherwise analytical assessment is indicated.

5. Three dimensional linear elastic analytical model of the existing building is prepared and subjected to code specified [Ministry of Public Works and Settlement, 1997] vertical and lateral loads. The modulus of elasticity of concrete is reduced in accordance with the material test results.

6. If the building complies with code requirements and its damage score indicates light damage, it is excluded from seismic retrofit. There was only one such building among 120. All remaining buildings were considered for seismic retrofit.

7. Seismic retrofit strategy for the building is selected. This mainly consists of infilling appropriate frame bays by in-situ reinforced concrete shear walls with proper anchorage to the existing frame. New foundations are designed for these shear walls. Damaged columns or columns lacking required vertical load carrying capacity are jacketed. Where feasible, use of composite reinforced polymer fabric is recommended.

8. The upgraded building is analyzed under code specified loading and its compliance with the code is verified.

9. For selected buildings, capacity spectrum method is employed to assess the seismic performance level of the retrofitted building.

Naturally, the stiffnesses of buildings increase after seismic retrofit which leads to reduction in vibration periods. The overall shift in the fundamental periods of existing and strengthened buildings is shown in the form of a frequency distribution in Figure 8. This figure indicates that the mean increase in lateral stiffness for retrofitted buildings is roughly $\frac{k_r}{k_e} = \left(\frac{T_e}{T_r}\right)^2_{mean}$ x1.1

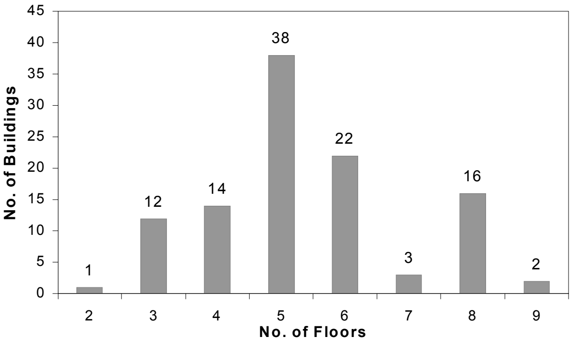


Figure 7. Story distribution of moderately damaged buildings in Ceyhan

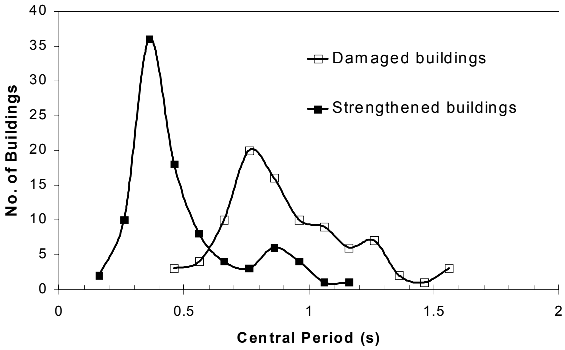


Figure 8. Vibration periods damaged and strengthened buildings

CASE STUDY : EIGHT STORY APARTMENT BUILDING

The building shown in Figure 9 is selected as a case study. It was constructed in 1984, its floor area is 245 m^2 and story height is 3 m. The structural system consists of reinforced concrete framing with columns and beams, strip foundation in both orthogonal directions, concrete slabs in the first six stories and joist slabs in the top two stories. There are structural walls around the elevator. Partition walls made of hollow factory bricks also contribute to the stiffness and strength of the building. The damage score for the building is calculated as 27 which places it into moderate damage category. In the structure, an extensive beam damage, especially between the first and the fifth floors, was observed.

First, three dimensional models of the structure in three stages, as-built, damaged and repaired, are prepared for elastic analysis to estimate the vibration modes [Computer and Structures Inc., 1998]. The typical story structural plan of the model, simplified from the real structure, is given in Figure 10. The adopted retrofit scheme of the building is shown in Figure 11. In the selection of the seismic retrofit scheme, closing exterior window openings, intervention with the existing piping system and limiting architectural functions are avoided as much as possible.

The lowest mode vibration periods of the original (as-built) building are calculated as 0.85 s (torsion), 0.68 s (translation in the short direction) and 0.65 s (translation in the long direction). In the damaged state, these periods become 1.09, 0.87 and 0.84 s respectively. After adding the shear walls shown in Figure 11 with ratios of 2.4 % and 1.6 percent in short and long directions, respectively, with respect to the floor area, periods of the first three modes are reduced to 0.65 s (torsion), 0.50 s (translation in the long direction) and 0.43 s (translation in the short direction). The building satisfies code requirements with the adopted retrofit scheme.

Figure 9. The photo of the 8-story apartment building

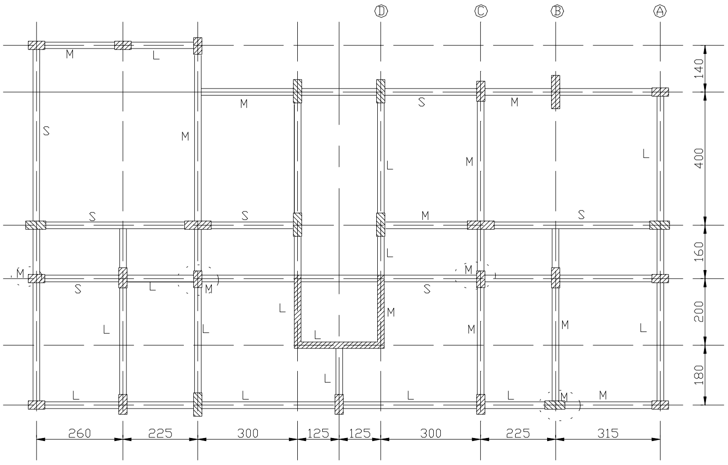


Figure 10. Simplified plan of a typical story of the building showing the damage observed on the structural elements (L: Light damage, M: Medium damage, S: Severe damage)

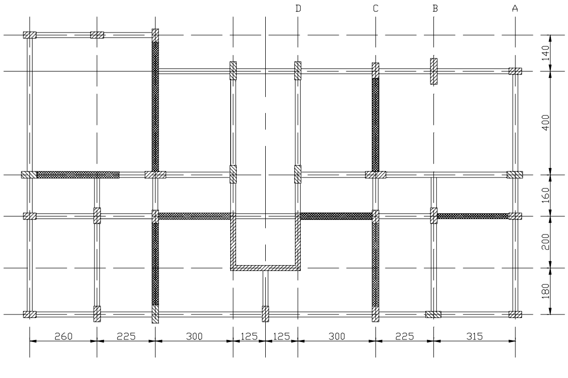


Figure 11. Strengthening scheme applied to the building (Darker shadings show newly added R/C walls)

In the second part of the study, two dimensional nonlinear models corresponding to the stages mentioned above were constructed for the short direction of the structure. Since the framing system of the building is almost symmetrical in the short direction, only the frames A, B, C and D shown in Figures 10 and 11 are used in modelling. The first mode periods of these models are calculated as 0.67 s (as-built state), 0.86 s (damaged state) and 0.40 s (repaired state). Pushover analysis procedure is carried out with these models using Drain-2Dx [Prakash et.al. 1993; Powell 1993]. In the ultimate response level of the models corresponding to all three stages, a hinging pattern which is a combination of beam mechanism and column mechanism is observed in between the ground floor and the fifth floor, similar to the observed damage in the building. The lateral load carrying capacities are given in Figure 12. The implemented seismic retrofitting results in an increase of 47 percent in ultimate strength and 22 percent in deformation capacity which satisfy seismic code requirements specified for an ordinary frame-wall system with limited ductility.

Further, Capacity Spectrum Method (CSM) is employed to estimate the performance level of the repaired frame under design spectrum [ATC, 1996; Freeman, 1998]. The acceleration-displacement response spectra (ADRS) format representation of the capacity of the structure and the earthquake demand are shown in Figure 13. The performance point cannot be obtained for the damaged state even for the maximum allowable damping value of 18.83 percent whereas for the repaired state, the capacity and demand curves coincide at 29.85 percent damping giving a performance of 0.176 g base shear coefficient and 0.127 m top displacement.

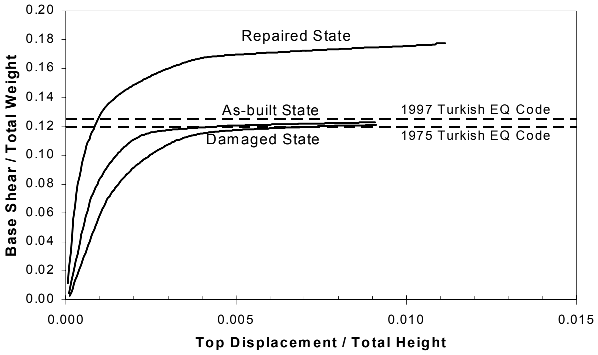


Figure 12. Capacity curves of three states of the structure in the short direction

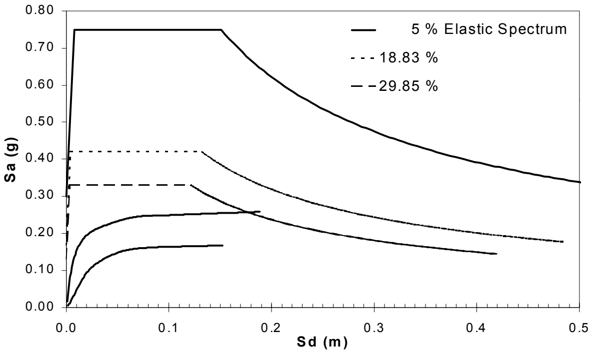


Figure 13. Application of Capacity Spectrum Method

Finally, time history analysis procedure was employed for the nonlinear models using the NS component of Ceyhan ground motion record. The normalised top displacement time histories are given in Figure 14 from which the effectiveness of the retrofitting applied to the structure is evident. The original and the damaged frames exceed global yield level in several cycles. The shear walls added to the system, however, limit the deformations which is important not only for structural safety but also for the protection of the non-structural elements.

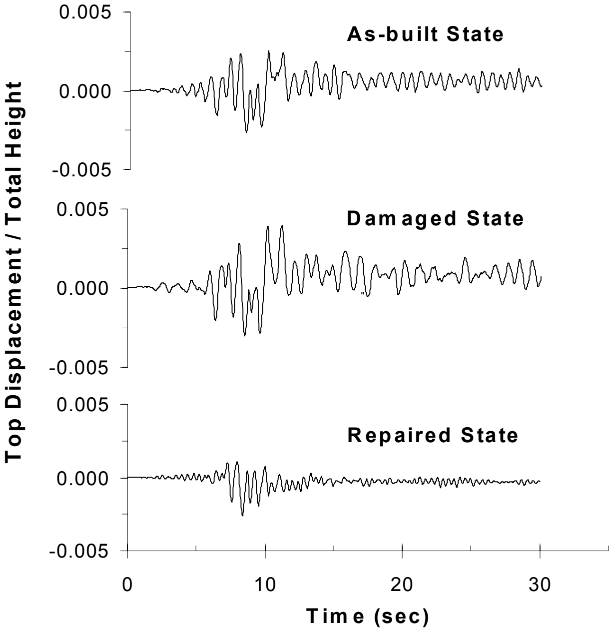


Figure 14. Top displacement time history of three states of the structure under the NS Component of Ceyhan ground motion record

CONCLUSIONS

The basic criteria in selecting the seismic retrofit scheme adopted in Ceyhan that is explained in this paper were simplicity in application and economy in construction. Although time is not considered as a major factor, it is expected that a well organized contractor can complete the rehabilitation within two months. Special equipment and advanced technology are not required at the site. Lastly, the cost of retrofit for the building presented as a case study is estimated at 50 USD/m2, totalling to 150 000 USD for the entire building by using the prices effective in the Turkish construction practice.

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