# ORTA HASARLI BETONARME BİNALARIN GEÇİCİ OLARAK TAKVİYESİ

## TEMPORARY SEISMIC REHABILITATION OF MODERATLY DAMAGED REINFORCED CONCRETE BUILDINGS

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ÖZET

*Türkiye'de her bir büyük depremden sonra, pek çok binada zayıf inşaat kalitesinden dolayı bazı hasarlar görülür. Büyük depremden bir kaç hafta hatta aylar sonra bile artçı şokların oluşabileceği bilinen bir gerçektir. Şayet hızlı ve uygun bir şekilde onarım yapılmazsa, hasar görmüş yapıdaki hasar miktarı binanın göçmesine bile yol açabilecek tehlikeli bir sınıra ulaşabilir, bu da can güvenliğini tehdit eder ve barınak ihtiyacını artırır. Bu makalede yapısal sistemin deplasman talebini azaltarak sismik performansını yükseltmeyi amaçlayan pratik, geçici bir onarım metodu önerilmektedir. Bu amaçla püskürtme hafif beton paneller kullanılmıştır. Kalıp kullanılmaması ve kalifiye elemana gerek duyulmamasından kaynaklanan düşük maliyetinin yanında hafiflikleri, taşıma kolaylığı, inşa hızı ve ısı izolasyonlarının iyi olması gibi nedenler bu panellerin kullanımını cazip kılmaktadır. Dahası hasar görmüş yapıya eklenen püskürtme beton paneller sayesinde yapının rijitlik ve dayanım eksikliklerinin de giderileceği tahmin edilmektedir.*

*Öncelikle ½ ölçekli 3 boyutlu tek katlı betonarme çerçeve modeli Boğaziçi Üniversitesi, Kandilli Deprem Mühendisliği laboratuarında kuruldu ve sarsma masasında El Centro 1940 depremi yer hareketi altında test edildi.Ortalama bir hasar seviyesine ulaşıncaya kadar amplitüdü yükseltilmiştir. Sonra 2 adet paralel betonarme çerçeveden oluşan orta hasarlı 3 boyutlu model püskürtme beton panelle onarıldı ve aynı skaladaki depremle test edildi. Onarımdan önce ve sonraki test sonuçları, rijitlik dayanım ve deforme olabilmesi bakımından değerlendirildi. Ümit verici sonuçlar elde edildi.*

Anahtar Kelimeler: panel, *püskürtme beton*, çerçeve

**ABSTRACT**

*After each major earthquake in Turkey several building suffers moderate damage due to poor construction. As it is known fact the aftershocks follow the major earthquake may late a couple of weeks or even months, and if a proper fast temporary retrofit is not applied, the level of damage of moderately damaged buildings may increase even up to a dangerous level leading to collapse, thus threaten life safety and increase the need for shelter .In This paper a practical temporary retrofit method is proposed to increase the seismic performance of the structural system by reducing the displacement demand on the system. Shotcreted lightweight panels are used for this purpose. Their light weight, easy handling, high construction speed, good heat insulation properties, in addition to their low cost by avoiding formwork and need for skilled workers attracted the idea for their selection. Moreover it was estimated that the panels fitted inside a moderately damaged reinforced concrete frame will compensate the lacking stiffness and strength.*

*First a half scale single story 3D reinforced concrete frame was constructed in the Bogazici University, Kandilli Earthquake Engineering Laboratory and was tested on the shaking table under El centro1940 earthquake ground motion. El Centro time history was scaled by a factor of 2 and the amplitude was increased until a moderate damage level was reached. Then the two parallel RC frames of the moderately damaged 3D model was retrofitted by means of shotcreted lightweight panels and tested under the same scaled earthquake .Test results before*

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*and after retrofitting were compared and evaluated in terms of stiffness, strength and deformability. Promising results were obtained.*
Keywords: Panel, shotcrete, Lightweight, frame

## INTRODUCTION

In high seismic regions in the world and especially in Turkey there are too many residential low rise buildings up to seven stories made of RC frames and brittle brick masonry partition walls. Most of these buildings were designed to carry gravity loads only; because the local design codes requirements at the date ( i.e design codes before 1970 ) in which these building built do not include seismic design procedure. It just include some simple formula that it roughly estimate the seismic demand .Moderate or heavy damage were observed on these structures after each major earthquake; due to its low concrete strength and poor reinforcement details .It can be said that the structural system of these buildings consists of non-ductile RC frames; which is not able to withstand the ductility seismic demand. Retrofitting these poor constructed structures using traditional methods such as adding new RC shear wall or jacketing some columns ; may cost a lot of money and time which may make the choice of reconstruction better than retrofitting .Decision of retrofit or reconstruction needs a detailed study which may consume a considerable time period .Hence during this time period a need for fast and low cost temporary retrofit method to avoid the sever damages or total collapse of these structures during earthquakes or after shocks; thus saving lives and decreasing the need for shelter. In this research prefabricated lightweight shotcreted panels called in the United States 3D Panels is proposed for temporary retrofitting these non-ductile RC frame structures. Their light weight( i.e only weights a quarter of the masonry wall), easy handling, high construction speed, good heat insulation properties, in addition to their low cost by avoiding formwork and need for skilled workers attracted the idea for their selection. In practice these panels are used to construct low rise residential building as an alternative to wood-frame construction .It is known in the US as formless building system. This system consists of a three-dimensional welded wire frame utilizing a truss concept for stress transfer and stiffness. Each surface of the wire frame has a 10 cm square welded mesh pattern of longitudinal and transverse wires of 3mm diameter, and are made of galvanized steel with yield strength of 500 MPa.. The expanded lightweight polystyrene core is placed between the two layers of welded wire fabric. The skin is welded and finished with shotcrete, which is a concrete material that is sprayed into the wall at the job site. Cross section details of the panel are shown in Figure 1.

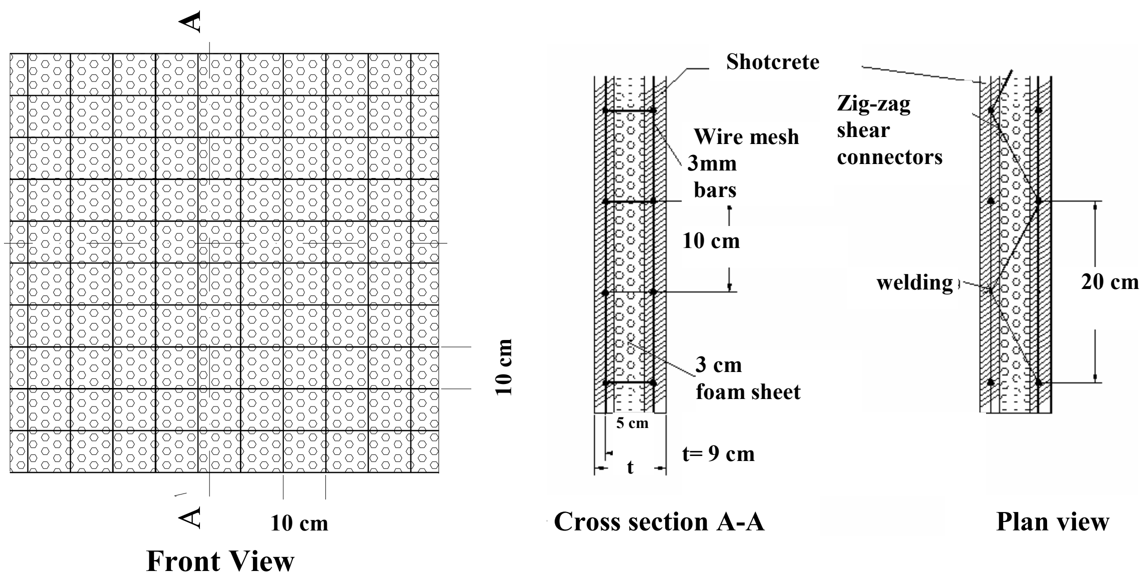
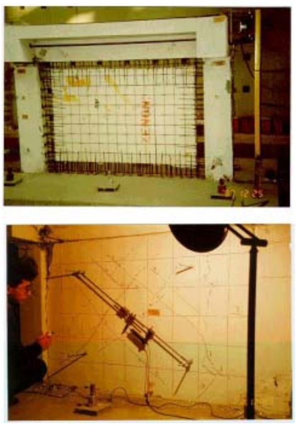
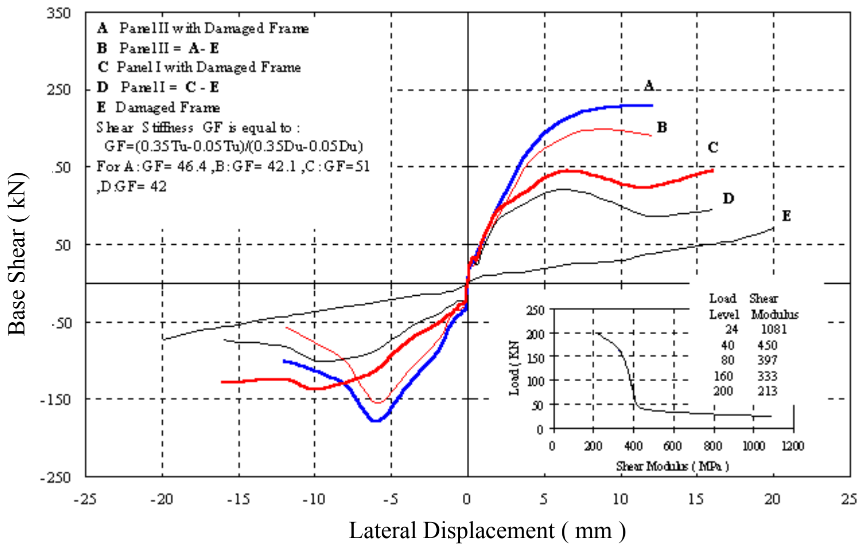



Figure 1. Cross section details of the lightweight shotcreted Panel

Some preliminary tests using these panels have been carried out in the laboratory, such as uniaxial-loading tests of the panels, and out-of-plane loading of panels ( Karadogan et al, 1998). Depending on these early findings, these panels are expected to have more ductile behavior, higher energy absorption capacity, higher safety margins and reparable local failures rather than overall brittle failures. Karadogan and Mowrtage(1998) use these special lightweight panels as infill walls to strengthen ½ scale 2D damaged RC frames as shown in Figure 2a. Several techniques, to connect the damaged frames to the Panels have been employed and tested. The envelopes of the hysteresis curves achieved at the end of these static cyclic loading are presented all together in Figure.2b The details of this investigation can be found elsewhere (Mourtage et al ,1998 and Mourtage,2001). Curve E in Figure.2b belongs to the reinforced concrete frame subjected to the same displacement pattern prior to the installation of infill lightweight panel. Curve B which has been obtained analytically subtracting the curve E from curve A**.** The efficiency of added diaphragms on the lateral stiffness and strength of the damaged frame can easily be observed by the comparison of the slopes at the beginning and the ultimate points they reached. In Figure.2a one can hardly see the fine cracks at ultimate load level on the surface and the limited amount of damage at the daphragm corners.






(a) Fabrication of Specimen and Tested Panel (b) Load Displacement Envelope Curves

Fig.2. Test results of 2D RC frames strengthened with Shotcreted Lightweight Panels

In this Paper a shaking table tests on a ½ scale 3D RC frame model specimen, aimed to investigate the seismic behavior of the frames before and after retrofitting them by the lightweight shotcreted panels. The paper documents the details of the test program, including specimen properties, test setup, instrumentation and test procedure. Test results and major observations are also presented and discussed.

## SHAKING TABLE TESTS

### Test Specimen and Test Setup

Two identical one story ½ scale reinforced concrete bare frame specimens were constructed in the laboratory and cast at the same time using same concrete mix ,to ensure identical concrete properties. Average compressive strength of concrete obtained from standard cylinder tests after 28days was 20 Mpa .Each RC frame specimen had an identical reinforcement layout . No 8 bars with 50 mm2 cross-sectional area and 8 mm nominal diameter ,were used as longitudinal reinforcement. The stirrups was 8 mm in diameter and it was 100 mm spaced . After concrete harden the frames were connected by I-shape steel beams to form 3D model specimen shown in Figure.3.

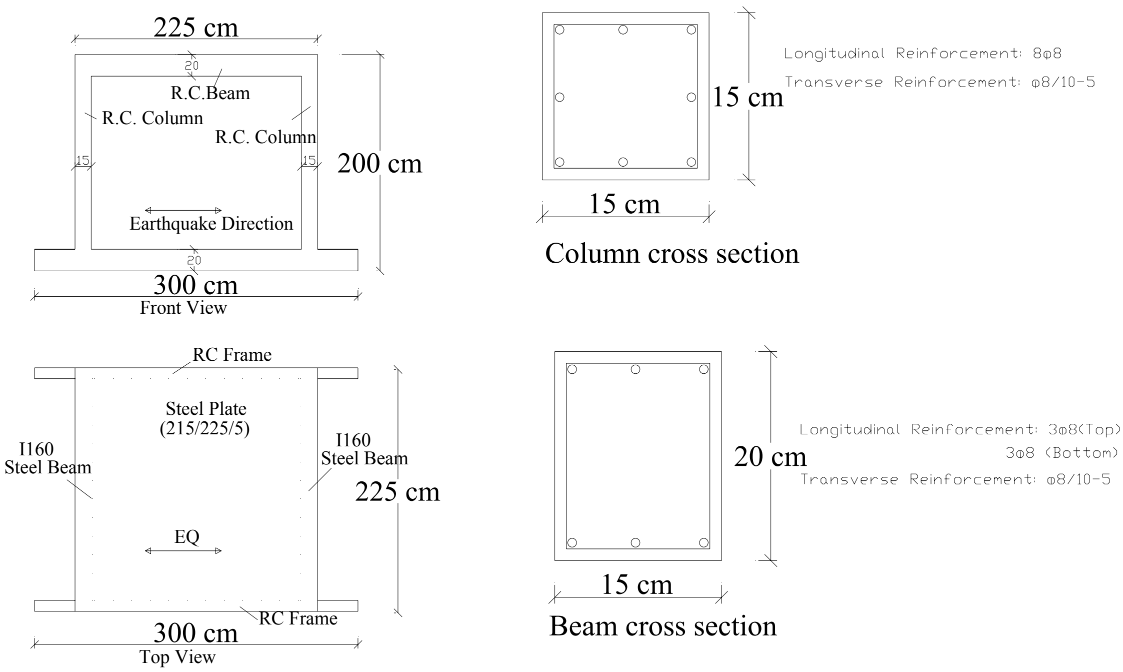



Figure 3. Test Specimen and cross section details

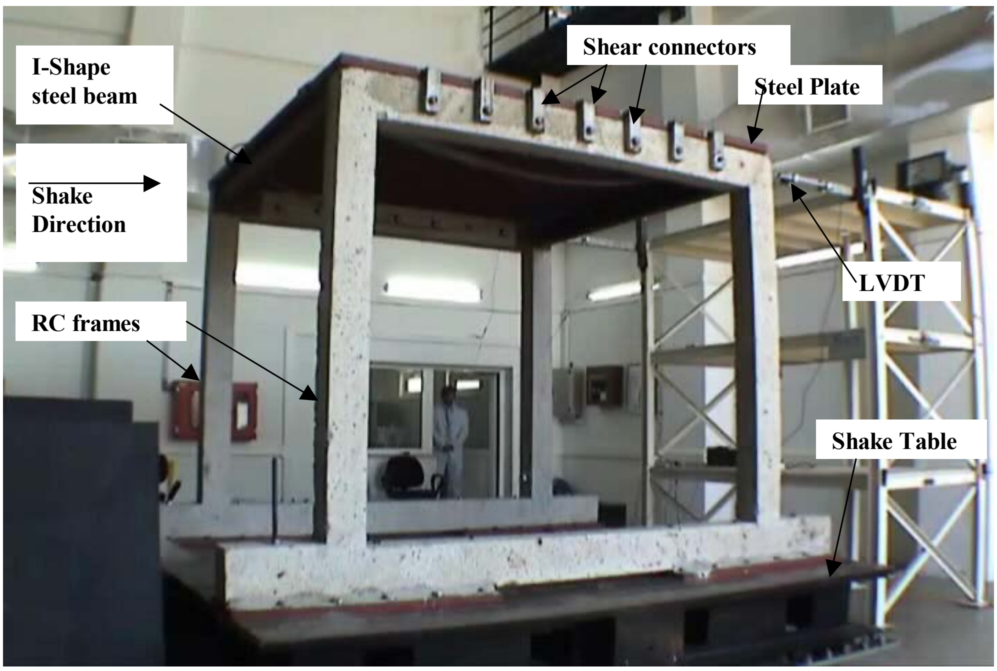



Figure 4. Testing Setup

Taking into account the similitude requirements, the artificial mass simulation (Harry , 1999) has been applied as a method for model design of the specimen. Accordingly to simulate the mass of the model the beams of the RC frames were connected to 50mm thick steel plate by means of shear connectors ,and a mass of concrete blocks were added on the top of the steel plate making the total weight of the specimen equal to 34 KN. Bogazici University shaking table on which the 3D model specimen were installed is used to impose uni-axial earthquake motion to the specimen .This shaking table is a uni-axial horizontal vibration shake table driven by a servo-hydraulic actuator. It is 3 m x 3 m in plan and it is capable of shaking a 10 -ton payload with 2 g acceleration (i.e. two times the acceleration of gravity in the horizontal direction). The shake table is ideally suited to seismic applications, because the hydraulic actuator can produce a stroke of +/- 12 cm (24 cm total stroke). The actuator has a 3-stage servo-valve controlled by an analog inner-loop control system (displacement based), and a digital outer-loop control system (acceleration feedback based ). Table motion and data acquisition are carried out by a Data Physics 550 WIN digital data control and acquisition system. Three displacement transducers (LVDT ) were placed at the top of the model specimen to measure the top displacements ( i.e mid top displacements, right top displacement, and left top displacement ) and one displacement transducer were place at the shaking table level to measure the shake table displacement as shown in Figure.4. Seven capacitive accelerometers were placed at several points of the specimen to measure the dynamic response of the specimen ,specially the top acceleration and out of plane accelerations.

**Testing and Results**

The model specimen have been subjected to the El Centro earthquake 1940(E-W component) applied in the longitudinal direction of the specimen. Because of the similitude requirements the time scale and the intensity of earthquake records have been altered to ensure that the shaking table motion will produce the required inelastic behavior of the model.The original record consisting of 1562 points with time step of 0.02 sec has been changed to the time step increment of 0.0141 sec .So the total span of the earthquake applied on the shaking table was 21.6 sec. The acceleration values of the record were not scaled. See Figure.5**.** The amplitude of the scaled record was increased up to ( 0.42 g ) at which a moderate damage level was reached (i.e plastic hinges occurs in the cloumns ), and the base shear-top displacement hysteresis loops were recorded and presented in Figure.6 .

The moderately damaged specimen were retrofitted by adding the proposed light weight panels in the middel of the bare frames . The width of the added panels were 600 mm and shear connectors of 8mm renforcement steel bars were epoxy anchord to the upper and lower RC frame beams to connect the panels to the damaged frames as shown in Figure.7a. Then the panels were shotcreted from each side .The shotcrete is ready to use mortar with added synthetic fibres and its compressive strength after 4 days was 20 MPa. The retrofitted specimen were tested after 4 days of shotcreting under the same scaled earthquake used before retrofitting ,and the base shear - top displacement hysteresis loops were recoreded and presented in Figure.7c. In the end of test only very fine cracks were observed on the surface of the shotcreted panels and failure occurs at the shear connectors as shown in Figure.7b .

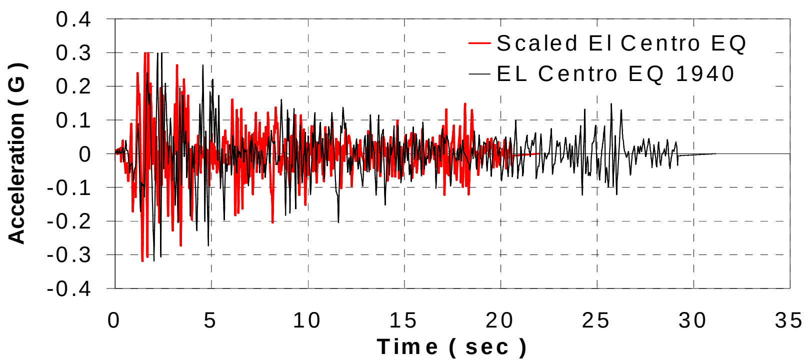


Figure 5. Shaking Table input motion ( Scaled El Centro earthquake )

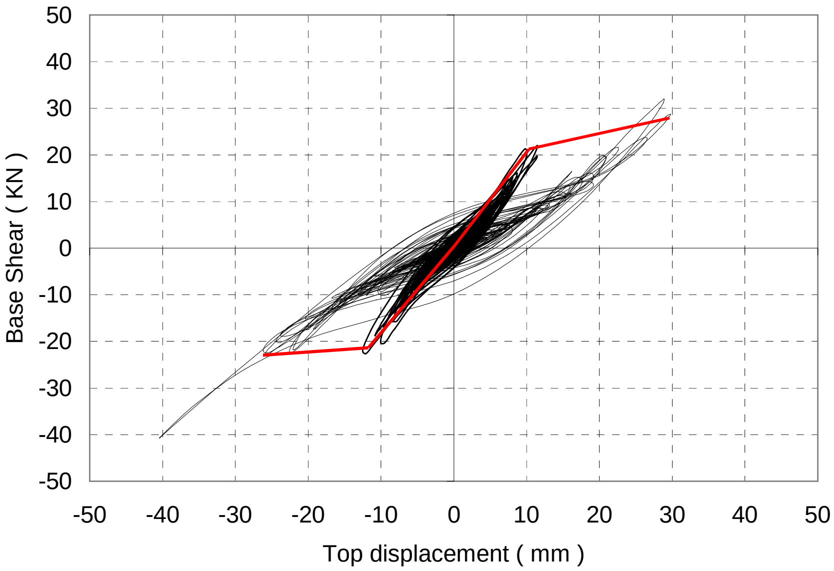
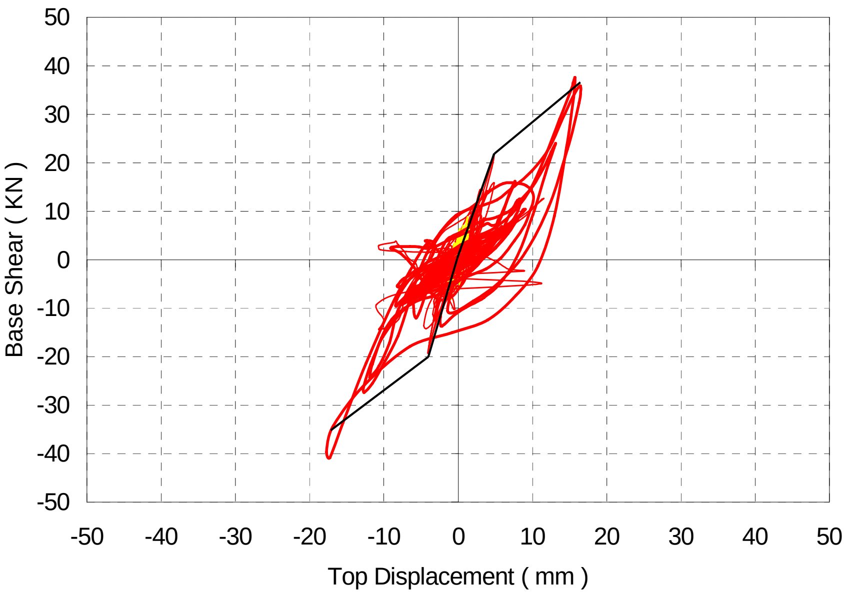



Figure.6. Base shear-top displacement hysteresis loops of 3D RC Frame

( a ) Shear Connectors ( b ) Retrofitted Specimen After Test




( c ) Base shear-top displacement hysteresis loops of 3D RC Frame with Panels
Fig.7. Test Results of the Retrofitted Specimen

Comparing the behavior of the specimen before and after retrofiting ( i.see Figure.6 and Figure.7c ) it is clear that adding the lightweight panels to the RC frame specimen results in reduction of story drift in half and increase the stiffness of the damaged frames. Some increase in the strength were observed as well. Free vibration tests were conducted before and after each test to measure the natural periods of the test specimen .Slight change of test specimen natural priod were observe due to adding the light weight panel as shown in Table.1.

Table 1. Natural Periods of Test Specimen

| | Period Before Retrofit (sec) | Period After Retrofit (sec) |
|---|---|---|
| Test Specimen before damage | 0.16 sec | 0.12 sec |
| Test Specimen After damage | 0.5 sec | 0.4 sec |

From Figure.6 and Figure.7c hysteresis damping of the test specimen before and after retrofit were calculated and it was 7% and 28 % respectively .

## CONCLUSIONS

Based on the results of this experimental work, the following conclusions are drawn:

1. Special light weight shotcreted Panels are able to reduce the story drift in half and increase the stiffness and strength of the damaged RC frames.
2. Adding light weight panels to the RC frames will increase the structural damping to more than three times.
3. The fine reinforcement mesh of the panels acts to prevent or limit the cracks

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