REHABILITATION OF DAMAGE REINFORCED CONCRETE COLUMNS

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Abstract

In order to restore the strength of failed reinforced concrete columns, the cracked shell was replaced by new materials of repair: plain concrete, fiber-reinforcement concrete and cement- mortar alternatively. Three groups of reinforced concrete squared tied columns were tested concentrically. The columns were short-columns reinforced with 2% longitudinal steel reinforcement ratio. Behavior of repaired columns have been presented by measuring concrete surface strain with axial load up to cracking load.
Effects of both concrete compressive strength of materials of repair and preloading on the restoring column strength have been established. Test results have ,also, shown that the strength of failed column can be restored by replacing the cracked shell with new shell having high compressive strength. the strength of columns repaired by these materials can reach up to 136% of their original strength depending on both the compressive strength and the condition of preloading.
Furthermore ,axial strength of repaired columns was derived by modifying the equation given by ACI-Code for calculating design axial load strength of reinforced concrete column.
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Keywords: columns, fiber, failure load, reinforced concrete, repair

أعادة تأهيل الأعمدة الخرسانية المسلحة الفاشلة

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الخلاصة

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يهدف هذا البحث إلى دراسة إمكانية استعادة مقاومة الأعمدة الخرسانية المسلحة الفاشلة وذالك باستبدال القشرة الخارجية المتشققة لهذه الأعمدة و إعادة صبها باستخدام ثلاثة أنواع من مواد التصليح إلا وهي : مادة الخرسانة , الخرسانة الليفية ، مونة السمنت على التوالي. اجري الفحص على ثلاثة مجاميع من الأعمدة المسلحة ذات المقطع المربع وذلك بتحميلها محوريا. لقد كانت الأعمدة من النوع القصير والمسلح بالقضبان الحديدية طوليا بنسبة تسليح 2%. درس سلوك هذه الأعمدة من خلال قياس الانفعال السطحي إثناء التحميل ولغاية مرحلة الفشل.
تم في هذه الدراسة بيان تأثير مقاومة مادة التصليح وكذلك تأثير نسبة التحميل قبل التصليح على مقاومة الأعمدة الخرسانية المؤهلة.
لقد بينت نتائج الفحص إن من الممكن استعادة مقاومة الأعمدة الخرسانية الفاشلة بتشقق قشرتها الخارجية وذالك بواسطة استبدال القشرة الخارجية بمواد خرسانية عالية المقاومة حيث أظهرت النتائج إن بالأمكان تحقيق زيادة بالمقاومة تصل إلى 135% من المقاومة الأصلية قبل الفشل ويعتمد ذالك على مقاومة مادة الإصلاح وعلى حالة التحميل التي أدت إلى الفشل.
إضافة إلى ما جاء أعلاه فان هذه الدراسة تقدم معادلة نظرية لاحتساب مقاومة الأعمدة الخرسانية المسلحة الفاشلة بعد إصلاحها اعتمادا على معادلة الكود الأمريكي.

Nomenclature

A_c = cross sectional area of concrete.
A_s = cross sectional area of steel.
A_{cr} = cross sectional area of original concrete core.
A_{sh} = cross sectional area of outer shell.
f_c' = concrete compressive strength.
f_y = yield stress of steel reinforcement.
f_{csh} = compressive strength of the new shell.
K = factor related to creep and rate of loading.
P = load exerted on reinforced column before repair.
P_u = axial ultimate load of reinforced concrete column before repair.
P_{ur} = axial ultimate load of reinforced concrete column after repair.

Introduction

In reinforced concrete column, the outer concrete shell has a significant contribution in carrying the design loads. Such contribution may reach up to 40% of the ultimate loads, especially, in column having small cross sectional area (less than 900cm^2).This can be simply determined using equation derived by (Richart and Brown,1934). On the other hand, the outer shell acts to protect the steel reinforcement against corrosion and fire attack. Therefore any damage or cracks in the outer shell will affect seriously both the strength and performance of the column.
In practice, the column is considered to be reached its own maximum carrying capacity when the outer shell starts to spall off (at spalling load). The ultimate load in tied column is nearly equal to the spalling load, whereas, it may be more than that in spiral column. Generally a complete failure in reinforced concrete column takes place when the concrete fails by crushing or shearing outward along inclined planes and the longitudinal steel fails by buckling outward between (Richart and Staehle,1931).

Partial cracking of outer shell may also occur due to different causes, such as earthquake, fire attack, end of design age of column…etc.
In any case, the presence of partial spalling in concrete column does not mean that the column has a complete failure, but is ultimate capacity is reduced and it may no longer be considered serviceable. However, proper repairing of spalled shell can restore or even increase its original ultimate capacity.

Repair of cracked shell of column can be commonly made by jacketing technique. This includes casting new reinforced concrete shell around the damage column. The new concrete can be preplaced aggregate concrete or normally placed concrete. These techniques are often used for both retrofitting and strengthening of reinforced concrete column (Suleiman,1991&Ersoy et al,1993).

There are many factors affecting the strength of the repaired column such as the strength, shrinkage and creep of both old and new concrete. However, the problem of repairing involves many uncertain factors which have not yet been fully investigated.

The primary objective of this research is to restore the ultimate carrying capacity of spalled column without increasing its original size by using three types of material of repair (plain concrete with 12mm maximum size of aggregate , fiber reinforced concrete and cement mortar). Effect of both instaneous preloading and the compressive strength on the strength of repaired column were also investigated.

Theoretical consideration

Numerous careful test (Richart,1934 and ACI 318-02) have shown the ultimate load of a concentrically loaded reinforced concrete column is reached when the concrete crushes while the steel yields satisfying the following equation:

$$P_u = 0.85\, f_c'\, A_c + f_y\, A_s \qquad (1)$$

Where:

P_u = ultimate load.

f_c' = concrete compressive strength.

A_c = cross sectional area of concrete.

f_y = yield stress of steel reinforcement.

A_s = cross sectional area of steel reinforcement.

Equation (1) was modified here to take into account the contribution of replaced outer shell. This can be done by partitioning the first term of the right-hand side of Equation(1) , (**$0.85\, f_c'$**) into two parts as:

$K\, A_{sh}\, f'_{csh}$ = compressive strength of the outer shell

$K\, A_{cr}\, f'_c$ = compressive strength of inner core

When the outer shell of column is replaced by new concrete shell after repairing. The total ultimate load of repaired column (**Pur**) can be expressed here as:

$$P_{ur} = K\, [A_{sh}\, f'_{csh} + A_{cr}\, f'_c] + A_s\, f_y \qquad (2)$$

Where:

K = factor related to creep and rate of loading.

A_{sh} = cross sectional area of outer shell.

$f_{c\,sh}$ = compressive strength of the new shell.

A_{cr} = cross sectional area of original concrete core.

The bond between old concrete and new concrete shell was secured by roughing the old concrete face to have a full amplitude of approximately 5mm (as recommended in Article 11.7.9, ACI-318 02 Code). This type of bond is interlock type of bond between old and new surfaces of concrete.

When the concrete core and outer shell cast monolithically, (as the usual case in practice), K is equal to 0.85 as given by (ACI-318 02 Code). In case of column with repaired shell, (K) may be evaluated from test results taking in consideration the effect of creep and shrinkage in both the old concrete core and new outer shell as carried out later in this investigation.

Experimental Investigation

To study the possibility of restoring the ultimate capacity of spalled shell column, three groups (A,B,C) of reinforced concrete squared tied columns were considered. The cross sectional dimensions of each column was 150mm x 150mm with 900mm length. Each column is reinforced with 4-12mm diameter longitudinal bars and 6mm diameter at 200mm transverse ties [**Figure:(1)**]. The yield stress of steel reinforcement used for both longitudinal and transverse reinforcement was obtained from test to be 270 N/mm^2. The compressive strength (f_c') of all columns were about 12N/mm^2.

Such low yield stress of steel reinforcement and low concrete compressive strength used in specimens to stimulate those columns which have been widely constructed in most building during sixties and seventies of the past century and their compressive strength may be deteriorated due to carbonation and other climate conditions. Furthermore ,most of the old reinforced concrete buildings in the developed countries have been built with low material strength.

However, group (A) consist of six identical basic columns which belongs into three couples. The first couple were loaded concentrically to the spalling load and it is stopped when the outer shell started to spall off. This load is considered to represent about 100% of the ultimate load. The second couple were loaded in similar way to about 75% of the ultimate load. These types of loading are called preloading in this investigation. The third couple have been left without loading (0%). Then the outer shell of all columns were removed [**Figure:(9)**] by chisel making the concrete surface rough with a full amplitude of approximately 5mm.

In order to insure good repairing and to restore the original strength capacity of damage column, plain concrete with high compressive strength was used to replace cracked shell. The average thickness of new shell in the specimen tested here is about 25mm as shown in Figure**L**1). The average compressive strength of about 45.8N/mm^2 was used in this group. The proportion of concrete mix used for repair was 1 cement : 1sand : 1.5 gravel (by weight) with maximum size 6mm. Water-cement ratio in this mix was 0.37 .To increase workability ,water reducing agent (Feb-flow) was added to the mix by amount of 2.5 kg/m3. Details of test specimen are shown in **Figures: (5),(6),(7).**

Group B and C are similar to group A except, the materials of repair used for the outer shell were reinforced fiber concrete and cement mortar respectively. The average compressive strength of shell materials of group B and group C were 51.2N/mm^2 .The reinforced fiber concrete was made of similar concrete mix as in group A.

The fibers were high yield strength, deformed and brass coated. They were 45mm long and o.5mm diameter with aspect ratio of 90 .

1- Behavior of Test Columns

All columns were tested concentrically after repair Figures:(6),(7),(8),(9),(10). The test results are given in **Table(1).** During tests, the compressive strain was measured at each load increment until the concrete shell started to crack. The average value of test results of each couple of columns were recorded. The load concrete strain curves for repaired columns, (loaded to cracking load before repair), are shown in **Figure: (2).**

The behavior of repaired column under load can be summarized:

1-The columns after repair show similar behavior compared to the original columns before repair.

2-Slight increase in the stiffness of repaired columns were observed relative to the original column. This may be attributed to the high compressive strength of the outer shell which increase the modulus of elasticity.

3-Repaired columns show higher spalling load (with sudden and brittle cracking of the outer shell) than those of original column. Gradual cracking was observed for columns repaired by fiber reinforced concrete.

4-The cracking load of repaired columns is higher than that of original column with range of about 5% to 27% depending mainly on the compressive strength of the outer shell.

2 Effect of Preloading

Figure:(3) shows that there is a slight consistent decrease in the relative spalling load (Pur/Pu ×100) due to increase in the relative preloading percentage (P/Pu). Such behavior is similar for the three types of repairs(plain concrete, fiber reinforced concrete and cement mortar). The decrease in the relative spalling load is ranging between about 5% in columns repaired by cement mortar to about 10% in columns repaired by plain concrete. This decrease may be attributed to the effect of restrained shrinkage in the new shell besides the effect of preloading on the original core.

Tests by Rusch and others have shown that for concentrically loaded, un reinforced concrete prisms or cylinders, the strength under sustained load is significantly smaller than f̒ç of the order of 75percent of fc’ for loads maintained for a year or more (Winter&Nilson,1972). However, instantaneous preloading, in this investigation, has clearly reduced the spalling load of columns repaired by plain concrete, fiber-reinforced concrete and cement mortar.

3- Effect of Compressive Strength

Figure (4) indicates that the increase in the compressive strength of the outer shell resulted in considerable increase in the relative spalling load. This relationship is similar in pattern for the three types of repair. The relative spalling load increased to about 25% when the compressive strength increased to about 38%. The compressive strength of outer shell was observed to be the major factor affecting the strength of repaired column.

4- Evaluation Factor K

Based on **Figure (4)** the spalling, load seems to be not directly proportional with the compressive strength of the outer shell as given by Equation (2). This is mainly because of the effects of preloading and restrained shrinkage of the new shell (Suleiman,1991). These effects can be taken in consideration through evaluating the factor K from test results of this investigation as:

$K = 0.39 – 0.0005\ P/P_u$ for plain concrete shell and fiber reinforced concrete
$K = 0.33 – 0.0006\ P/P_u$ for cement mortar shell

Effect of creep can also be included when test results are available.
Using Equation 2 with the above imperical values of K, the spalling load can be predicted for repaired reinforced concrete column.

Conclusions

1. It is possible to restore the ultimate capacity of concentrically loaded column by replacing the outer spalled shell with new one having high compressive strength. Plain concrete, fiber reinforced concrete and cement mortar can effectively be used for this purpose but the fiber reinforced concrete may have the best results.

2. The spalling load of repaired columns is adversely affected by the instantaneous preloading.

3. The compressive strength of the material of repair was observed to be the major factor affecting the spalling load of the repaired column.

4. The proposed Equation (1) can be modified to include the effect of creep to be used for predicting the ultimate capacity of column after repair.

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Table (1) Test Results

Group	Material of repair	Column	Load before repair (P/Pu×100)*	Spalling Load after Pur (KN)
A	Plain concrete	A1	0	380
		A2	75	355.4
		A3	100	347.6
B	Fiber reinforced concrete	B1	0	391.4
		B2	75	376.7
		B3	100	366.4
C	Cement mortar	C1	0	307.5
		C2	75	301
		C3	100	292.3

*P = applied load before repair.
Pu= average spalling load obtain from specimens A3, B3, C3 before repair.

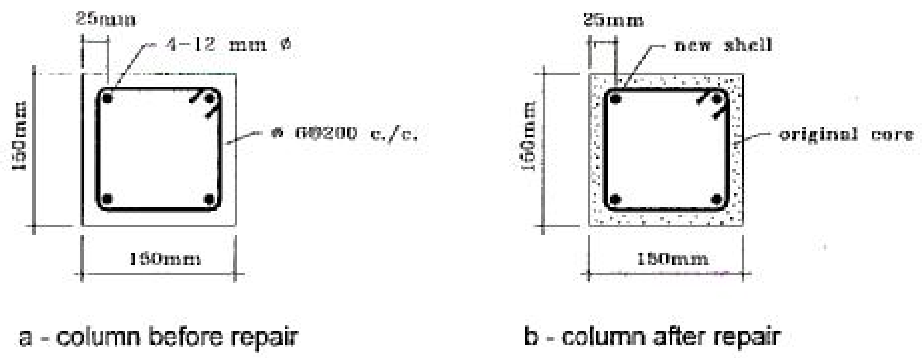
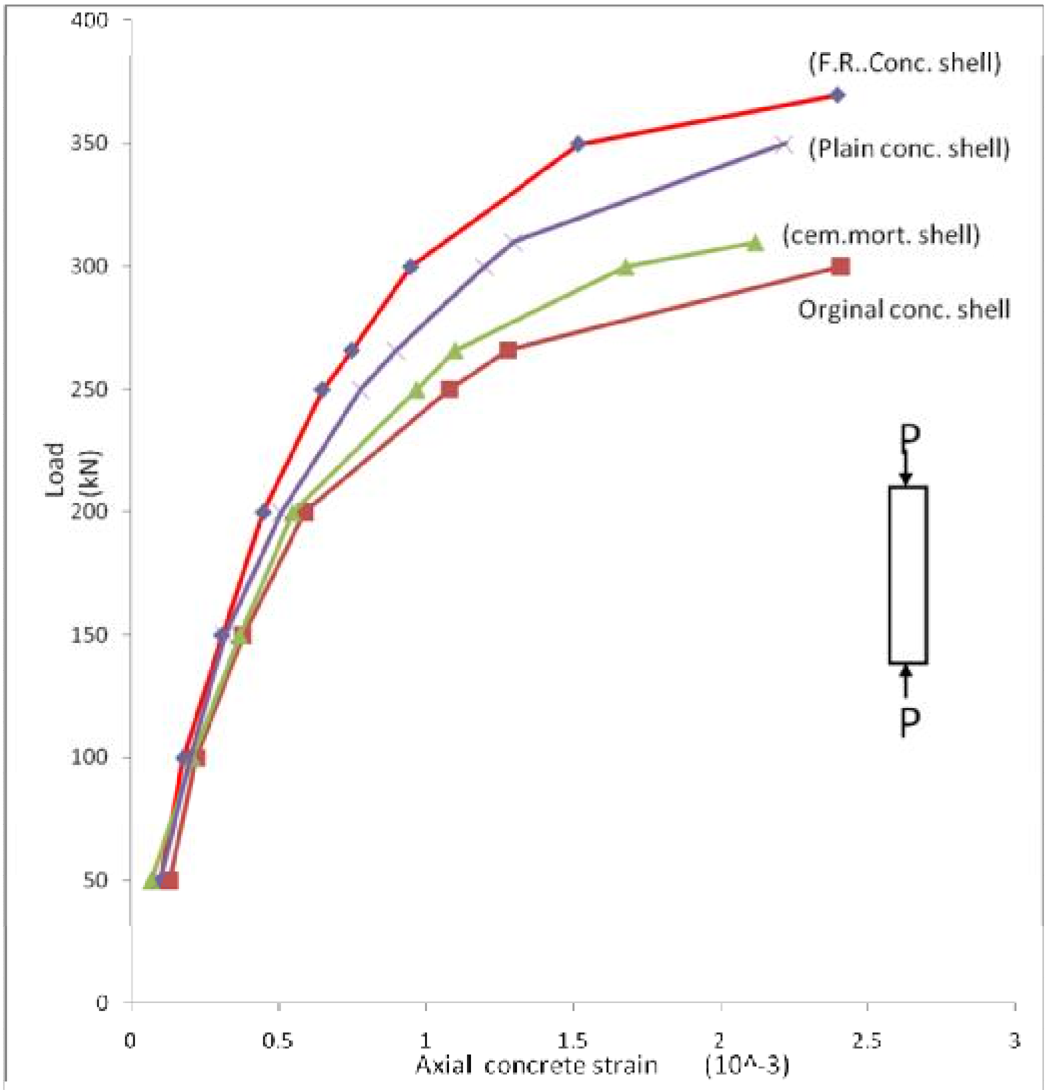
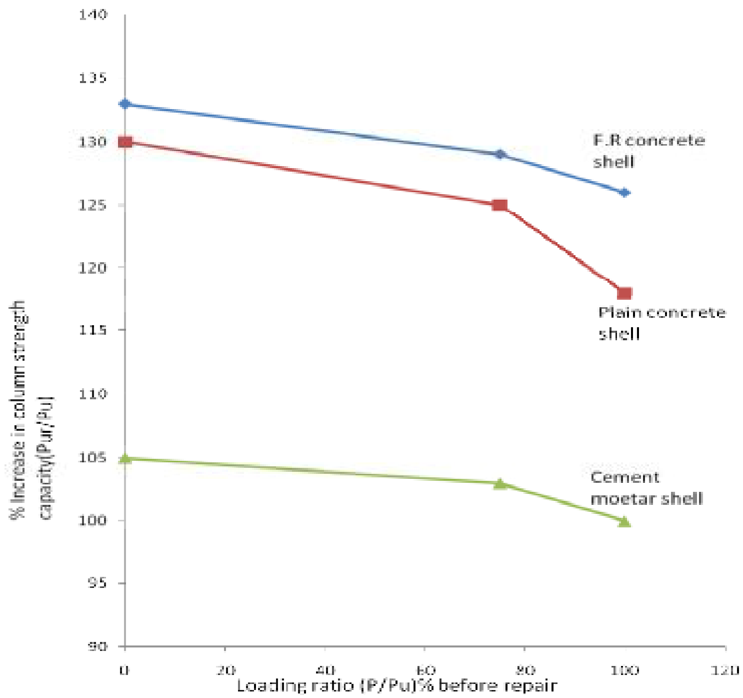


Fig. 1 Typical details of test columns .



Figure(2): Load-axial strain curve of concrete column under axial load with three types of repair



Figure(3) :Relationship between % Increase in column strength capacity due to repair with preloading ratio

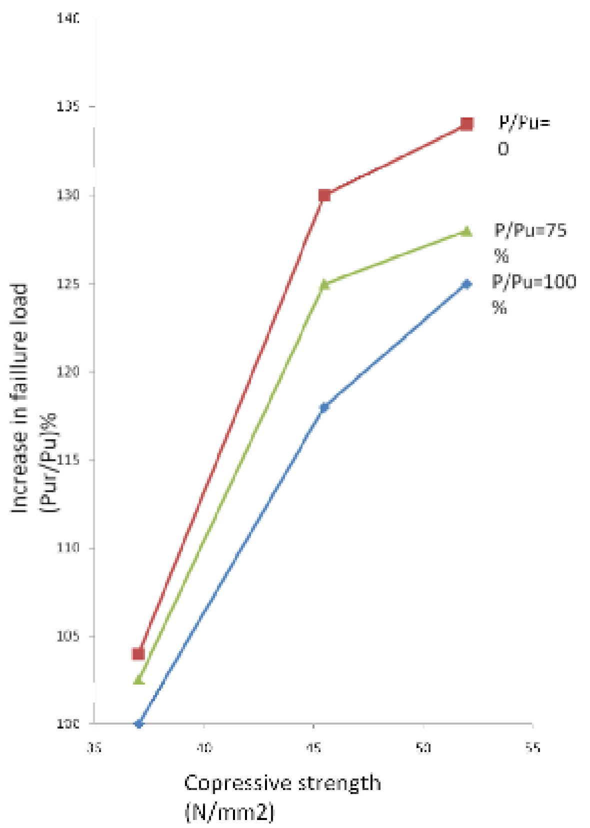


Figure (4) Relationship between compressive strength and percent increase in ultimate strength of column

percent of increase in failure load (Pur/Pu)%

Figure (5) : Forms and steel reinforcement of test specimens

Figure (6) : Experimental setup of test specimen

Figure (7) : Typical specimen (A2) under loading

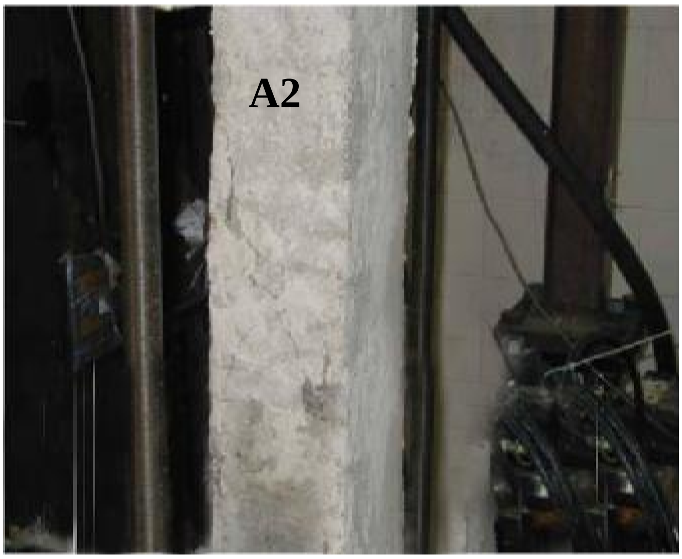


Figure (8) : initiation of 1^{st} crack in specimen at 70% of ultimate load

Figure (9) : Removing of cracked shell of specimen A2

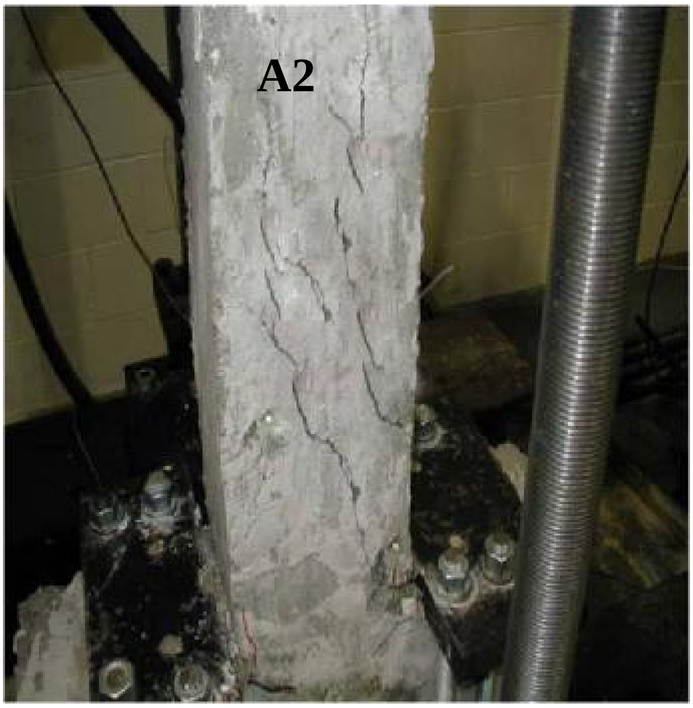


Figure (10) : Testing of A2 after repair up failure