STRENGTHENING OF CRACKED REINFORCED CONCRETE T-BEAM BY JACKETING

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ABSTRACT

This investigation presents an extensive experimental study on the behaviour and strength of reinforced concrete T-beams before and after strengthening by using reinforced concrete jacket. Four full scale beams were first loaded to certain levels of ultimate capacity (0, 60%, 77%, 100% of failure load). Then, after formation of cracks or failure, they were repaired by reinforced concrete jacketing method and tested again up to failure.

The main objective of this study is to restore the full ultimate capacity beams failed by flexure and to strengthen the cracked beam. Also, it is aimed to investigate the effect of loadig condition on beam before repair on the ultimate capacity after repair. Extensive measurements of deformations, cracking and strength were made before and after repair throughout all stages of loading.

Test results showed that the repairing by reinforced jacketing can effectively restore more than 150% of the full flexural capacity of the original beam. Also reinforced jacket can effectively increase the ultimate capacity of cracked T-beam after repair up to 250%. Furthermore, the use of reinforced jacket for the cracked or failed beams is greatly improved serviceability, deformation behaviour, cracking behaviour as well as ductility of T- beams compared to those of the original beams.The ultimate flexural strength of T-beams failed by flexure and repaired by reinforced concrete jacket can accurately be predicted using conventional ultimate strength method of reinforced concrete .

KEYWORD: **cracks,flexure, jacketing, reinforced concrete, repair, strengthening,T-beam**.

الخلاصة:

يقدم هذا البحث دراسة عملية شاملة لسلوك و مقاومة الروافد الخرسانية المسلحة بمقطع نوع T قبل وبعد تقويتها باستخدام الغلاف الخرساني المسلح .تم تحميل اربعة نماذج من الروافد الخرسانية الى مستويات متفاوتة من التحميل وهي:
0%،60%،77%،100% من التحمل الاقصى لهذه الروافد و بعد حدوث التشققات او حدوث الفشل في هذه الروافد تم إصلاحها بإحاطتها بالغلاف الخرساني المسلح ومن ثم أُعيد فحصها لغاية الفشل.
ان الغرض الاساسي من هذه الدراسة هي بحث امكانية استرجاع مقاومة الروافد الفاشلة او المتشققة. و تهدف هذه الدراسة كذلك الى بحث تاثير التحميل المسبق قبل الاصلاح على قابيلية تحملها بعد الاصلاح.
أجريت قياسات مكثفة للتشوهات و التشققات اثناء كافة مراحل التحميل قبل و بعد عملية الاصلاح.
اظهرت نتائج البحث ان الغلاف الخرساني المسلح كان فعالاً في استرجاع المقاومة القصوى بنسب تصل الى 150% من مقاومة الثني لهذه الروافد.
لقد اظهرت النتائج كذلك بان الغلاف الخرساني المسلح قد ادى الى زيادة المقاومة القصوى في الروافد المتشققة بنسب تصل الى اكثر من 250% من اقاومتها الاصلية.

اضافة الى ذلك فان استخدام الاغلفة الخرسانية المسلحة في تقوية الروافد المتشققة قد حسنت بصورة كبيرة قابلية الخدمة في هذه الروافد وادت الى زيادة في اللدونة مقارنة الى حالتها الاصلية.
من الممكن ايجاد قابلية تحمل هذه الروافد التي صلحت بالاغلفة الخرسانية المسلحة بالاعتماد على الطريقة المالوفة في الكود الامريكي الخاص بحساب المقاومة القصوى للروافد الاعتيادية.

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-INTRODUCTION

In recent years, the repair of existing structures is rapidly emerging as new sector in structural engineering. Sometimes, repair of deteriorated concrete structures (strengthening, rehabilitation and retrofitting) becomes more economical than building new one, if by repairing a safe and serviceable structure can be achieved. The success of a rpair or rehabilitaion projet will depend upon the degree to which the work is excuted in conformance with plans and specifications.

Due to the importance of the problem, many international conference are currently been held (7th International Conference,2001) to investigate the problems and to suggest the solutions involving the repair of damage structures or unserviceable structures.Guidance manuals are also presnted for evaluation and repair of concrete structures (U.S.Army Corps of Eng.,2002). In fact, the repair involves many uncertain factors, which has not yet been fully investigated.

One of the main problem related to repair is the bond between the surface of the damaged concrete and the material of repair. The short-term properties (shrinkage and creep) of both the damage concrete and the material of repair would significantly affect the performance of the structure after repair.It is important that the design engineer reponsible for the investigation of the distress and selection of repair materials and construction techniques.

In certain cases, reinforced concrete structures may require to increase its own ultimate capacity by strengthening some main structural members like beams and columns.Strengthening may also used to stop the deterioration of the structures by repairing the harmful cracks and preventing the excessive deflection.

The reduction in the strength of reinforced concrete members can be resulted from different reasons. These may be due to natural disasters (earthquake), wars, successive deflection, cracking due to misuse of the structures and corrosion of steel reinforcement, especially, at offshore structures.... etc.

Repair and strengthening of reinforced concrete beam is commonly carried out by “Jacketing” . Jacketing is casting new reinforced concrete shell around the damage member. There are several methods and materials for concrete repair [Emmons,1993].

The concrete used in the jacket may be pre-replaced aggregate concrete with compressive strength higher than that for the old concrete. The bond strength between the new concrete and the old concrete can be assessed by slant shear tests [Ersoy,1993].

In other cases of repairing of damaged beam, additional steel is required. Full anchorage of the additional steel is necessary and should be located at the region of minimum flexural stresses. Anchorage of the additional links at the top of the beam is also necessary. However,, jacketing may be one of[Johnson,1965] more reliable method of strengthening than externally bonded plate, but, it would increase the size of the original beam. On the other hand, externally bonded plate method, may be easier than jacketing method.

Very few research works have been done on experimental behaviour of jacketed reinforced concrete beams. Cheong and MacAlevey, [2000] carried static and dynamic load tests to failure on 61 slant shear prisms and 13 jacketed reinforced concrete T-beams. The concrete used in the jacket was replaced aggregate concrete. The strength of the bond between preplaced aggregate concrete and plain concrete was assessed by slant shear tests and a Mohr-coulomb type failure envelope was derived. Static failure of the beam specimens was related to this failure envelope. Test results showed the importance of adequate reinforcement detailing on the beam strength (i.e. that full anchorage of the additional steel at simple supports and points of counter flexure and anchorage of the additional links at the top of the beam was necessary).However, they concluded that good reinforcement detailing in beams was fully contributing to the strength of the jacketed beams. Furthermore, moderate dynamic loading of jacketed beam does not seem to result in significant reduction in the load capacity.

Cracks can form in reinforced concrete members due to several reasons .Errors in design and detailing that may result in unacceptable cracking include use of poorly detailed corners in walls, precast members and slabs. The use of an inadequate amount of reinforcing may result in excessive cracking.

Generally, deterioration of concrete structures is mainly due to formation of cracks as aresult of many reasons. Inadequate detailing of reinforcement, expansion, and construction joints, creep and shrinkage and unexpected loads may cause cracks in concrete.

Crack width increases with increasing steel stress, cover thickness, and area of concrete surrounding each reinforcing bar. The width of a bottom crack increases with an increasing strain gradient between the steel and the tension face of the beam.However, jacketing method of repair for T-beam is adopted in this study ,since, it can provide new reliable hollow sectins around the existing damage member. The research work is aimed to investigate the following objectives:

-To restore the capacity of partially and totally failed reinforced concrete T-beams by flexural.

-To increase the flexural capacity of existing reinforced concrete T-beam
-To investigate the behaviour of T-beam repaired by jacketing using ordinary reinforced concrete .
The main variables considered in this research are the effect of working loads before strengthening on the behaviour and strength of reinforced concrete beams after repair.

EXPERIMENTAL INVESTIGATION

The test program reported in this study is intended to investigate the possibility of restoring the capacity of reinforced concrete T-beam which was failed by flexure. Four reinforced concrete T-beams were subjected to two point load which was increased up to certain level of failure load. The behavior and strength of repaired T-beam under two point loads were observed at all stages of loading. The method of repair used here was the reinforced concrete jacketing. Jacketing is generally used where there is no limitation for the increase in the size of the member.
The main variables considered in the test beams are the effect of cracking condition caused by applied loads (preloading) on their strength after repairing or strengthening. The preloading is defined here to be the ratio of applied load on the member before repair to its own ultimate load. It is well known that the applied load is variable during the useful life of the member. It could be less or more than the maximum service load.
Therefore, it may causes instantaneous deformation or long term deformation in addition to invisible cracks. The intensity of the deformation and cracks depend mainly on the amount and the period of application of the applied load. Test programme involves four beams given in Table 1.

Table (1) Test Beams

Beam	Stage-One Loading condition		Stage-Two Test after jacketing	
	Applied load as % of ultimate load (λ)	Cracking condition	Repairing details	Applied load
B0	0	No cracks	Fig.1	up to failure
B60	60	Flexural cracks	Fig. 1	“
B77	77	Flexural cracks	Fig.1	“
B100	100	Flexural failure	Fig.1	“

Test beams

Series BO beams is designed to investigate the effect of preloading (λ=0 %, 60%, 77% and 100%) on the strength and behaviour of beams B0, B60, B77, B100) after repair .Beam B100 is loaded first to failure ,then repaired by jacketing method (see Figure (1)) and tested again up to failure. This beam was designed to study the possibility of restoring the flexural capacity by using jacketing method. Beam B0 was not loaded at first stage and therefore has no cracks whereas the other (B60,B77) were loaded at first stage up to 60% and 77% of failure load which produced flexural hair cracks at first stage.All beams have same flexural capacity. Then, all these beams were strengthening by jacketing as shown Figure(1) and Figure(2).
The main tensile reinforcement (bottom reinforcement) is kept constant (2¢12) .Minimum stirrups of ¢6@100mm cc was used in the original beams and same amount was used again at jacketing to prevent shear failure. The new stirrups added to the beams during repair are welded from the top by overlapping the bar's end at a distance 4 times diameter of bars [BS, 1990]. The original beams (B60,B77,B100) were loaded first up to the degree of loading λ mentioned above (60%,77%,100%), then, they were repaired as shown in Figure(1) and (2).Then, all beams retested again up to failure.

Strengthening of beams by jacketing

- Remove all the concrete which has been cracked or crushed at compression zone and else
- where due to failure of beams (B100)
- Remove the concrete covers of the sides and bottom reinforcement for beams (B0, B60,
- B77), which are prepared for strengthening.
- Clean concrete surface by washing with water for all beams.
- Fix the new main steel reinforcement for beam (B0, B60, B77, B100) as shwn in Figure (1)
- and (2).
- Prepare concrete mix in same quantities of materials used for the original beams.
- Before casting the new concrete, all concrete surface should be covered with 1:1 water :
- cement liquid.
- Concrete was compacted by using damping rod and vibrators.
- Beams were cured again for 28 day before testing.

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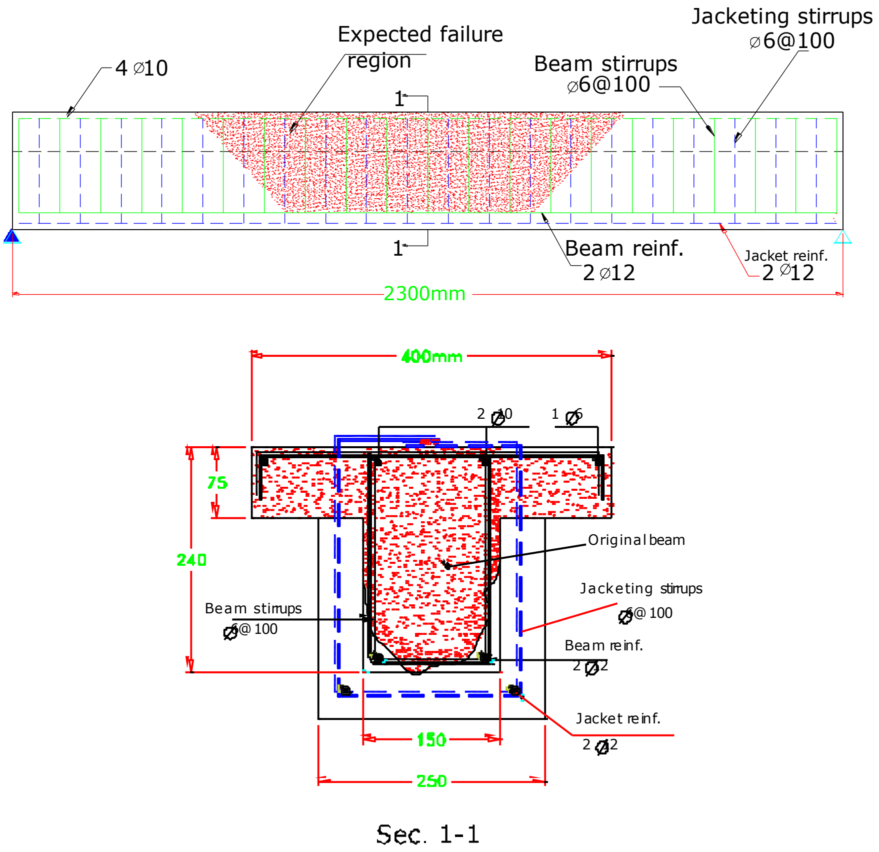

Figure (1) Typical jacketing of test beams

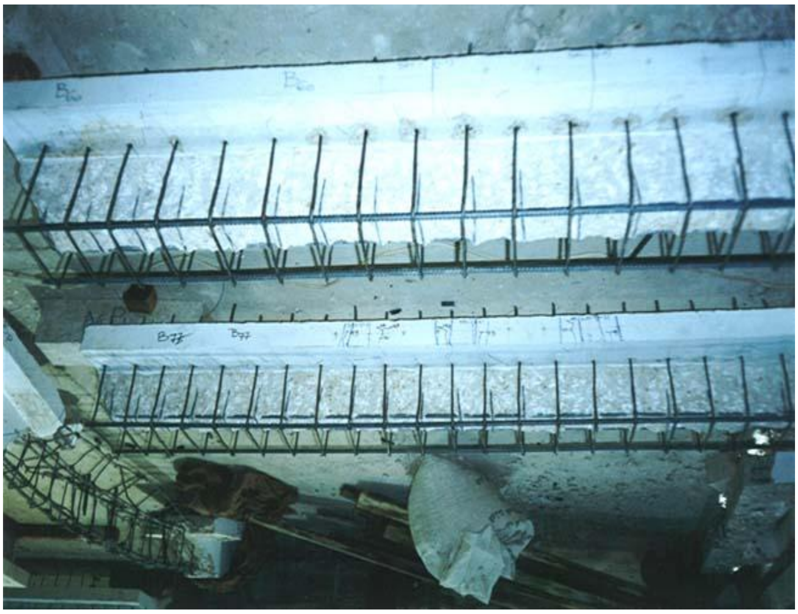

Figure (2) Preparing of beams B60 B77 B100 for jacketing

Concrete

In this research the mix proportion of concrete used was 1 : 2 : 4 by weight (cement : sand : coarse aggregate) with 0.55 w/c ratio.This mix was aimed to obtain about 30N/mm2 cube compressive strength at age 28-days.
The concrete mix used for repairing was same as that used for beams except the w/c ratio was reduced to 0.5 to get the target compressive strength of about 35 N/mm2 at age 28-days. The concrete mix was found to be workable with slump of about 70mm which suitable for casting and repairing of test specimens.

Steel reinforcement

The steel reinforcement used are 6mm, 10mm, 12mm, and 16mm dia. deformed bars which are free from harmful defects, seams, porosity, segregation, non-metallic inclusions.
In this research the samples of steel bars are tested in tension according to BS4449:1988 .The test results are given in Table (2). All samples tested are satisfying the BS4449:1988 standards.
All stirrups used for beams before repair are 6mm diameter. Same diameter are used for beams after repair which are welded by E43 electrode according to BS5950 part 1:1990. The overlap is about 50mm. Tensile tests were carried on this type of welding. Results have shown that the strength of weld is greater than the strength of the original reinforcement.
The yield stress and ultimate stress of bars tested are summarised in Table (2).

Table (2) tensile strength of bars reinforcement

Bar dia. (mm)	6	10	12
Yield stress (N/mm2)	255	287	361
Ultimat stress (N/mm2)	368	431	595

Test procedure

The test procedure was carried out as follows:-
- The sample was put under the test instrument type FM 2750 machine Nr. 613 wolpert
- ch-8232 Merishausen where the hydraulic jack is used to exert load on the specimen
- (See Figure (3).
- The load capacity of the testing machine used is 30 tons and its sensitivity is 0.1 KN
- The specimen was put on supported roller to be simply supported.
- A steel beam with a dimension of 1000 x 240 x 120 mm was used to transfer the single load from the testing machine to two points loads on the tests specimen. The said steel beam would change the concentrated loads in to two equal loads.
- The initial readings were taken before loading, for all deflection points and concrete strain gauges.

The loading was exerted on the specimen at increment which was 4 KN. until the appearance of the first cracking load. All cracks were marked on the concrete surfaces of the specimen during all loading stages. The deflection and concrete strain gauge readings were taken at each stage of the loading until the concrete failure occurs.

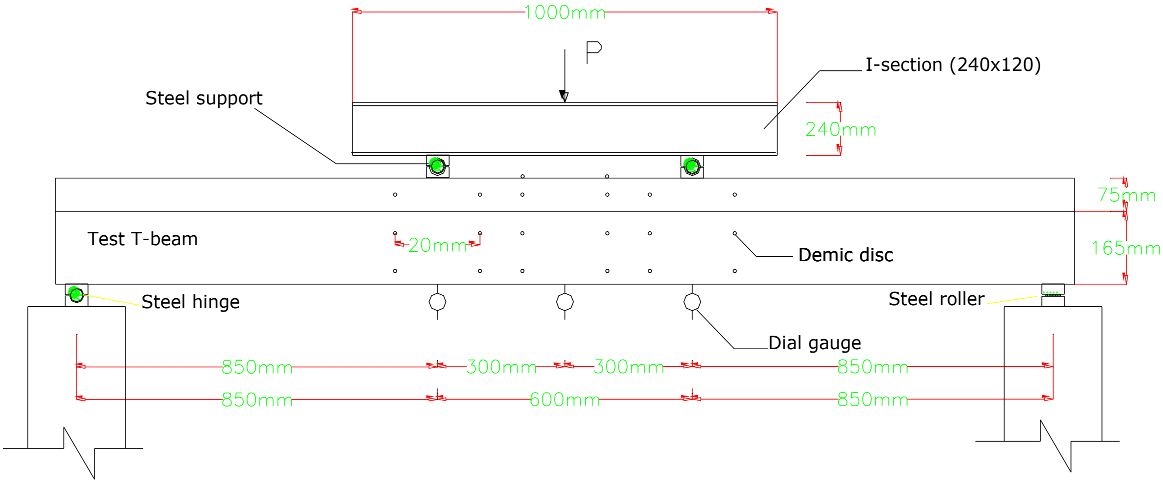

Figure (3) Typical instrumentation of test beams

TEST RESULTS

The behaviour of reinforced concrete beams is well established by research workers but it its behaviour after repair has not yet been fully investigated. However, one of the objective of this study is to investigate the behaviour of repaired beam under flexure.
The beams must be safe and serviceable. A beam is safe if it is able to resist all forces which will act on it during its life time. Serviceability implies that deflections and other distortions under load shall be unobjectionable small.

Load- deflection behaviour

The deflections along the spans of the test beam before and after repair were measured at all stages of loading. The maximum centre deflections for these beams were plotted in Figure (4). as a function of the total applied load. All beams have shown similar behavior before and after repair. These curves are composed of three distinguished regions namely, pre-cracking stage, post cracking stage and post serviceability cracking stage.
At pre-cracking stage, the applied loads are directly proportional to the centre deflections for beams before and after repair. This means that the entire concrete section is effective in resisting deflection, which caused by applied load. The pre-cracking segment of load deflection curve is, therefore, defining full elastic behaviour for all beams tested here. The theoretical deflections shown on the figures, are based on moment of inertia of the un cracked reinforced concrete section which agreed well with those obtained from test results. The theoretical deflections are slightly lower than those observed from tests. This may be due to approximate evaluation of modulus of elasticity by ACI expression:

$$EC = W_c^{1.5} \times 0.043 \sqrt{f_c'}$$

However, the elastic behaviour of beams after repair are similar to those before repair irrespective to the loading condition before repair.

When the load on the test beams is gradually increased beyond the first crack to the service load, the behaviour of beams changed slightly in to a post-cracking stage. Figure (4) showed that the relationship between load and deflection at post-cracking stage are approximately linear defining semi-elastic behaviour.
At post-cracking service load stage, the formation of flexural cracks in beams before repair reduced the flexural stiffness of the beam section making the load-deflection curve less steep in this region than in the pre-cracking stage segment. Similar behaviour was observed for the beams after repairs.The theoretical deflections on these figuress are calculated based on the procedure specified by ACI code,2005, art 9-5-2-2. ACI code methods is slightly underestimated the deflection especially for beams before repairs.This may be due evaluation of cracking moment capacity Mcr in ACI-method which related to approximate value of modulus of rapture

$$(M_{cr} = \frac{f_r \; I_g}{y_t})$$

However, Fig (4) shows that the beams repaired by jacketing gave higher flexural stiffness than their original flexural stiffness, in spite, of the existing cracks in the original concrete. This means the jacketing is significantly increased the flexural stiffness and hence would improve the serviceability.
When the load is further increased beyond the service load, the beams showed substantial loss in their stiffness because of the extensive cracking penetrating to the compression zone. In the region (post serviceability cracking stage), the load deflection curve tend to be flatter. The small increase in the applied load resulted in large amount of deflection.

However, the repaired beams have shown similar or even better load deflection behaviour than the original beams. Jacketing method enhanced the serviceability compared to the original beam. On the other hand, the loading condition and crack condition of the beams before repairs have no significant effect on the load deflection behaviour of the beams after repair. Repair by jacketing resulted in reduction in the deflection under service load to about 40% of the original deflection before repair. The jacketing method has given the best result in improving the load deflection behaviour of beams.

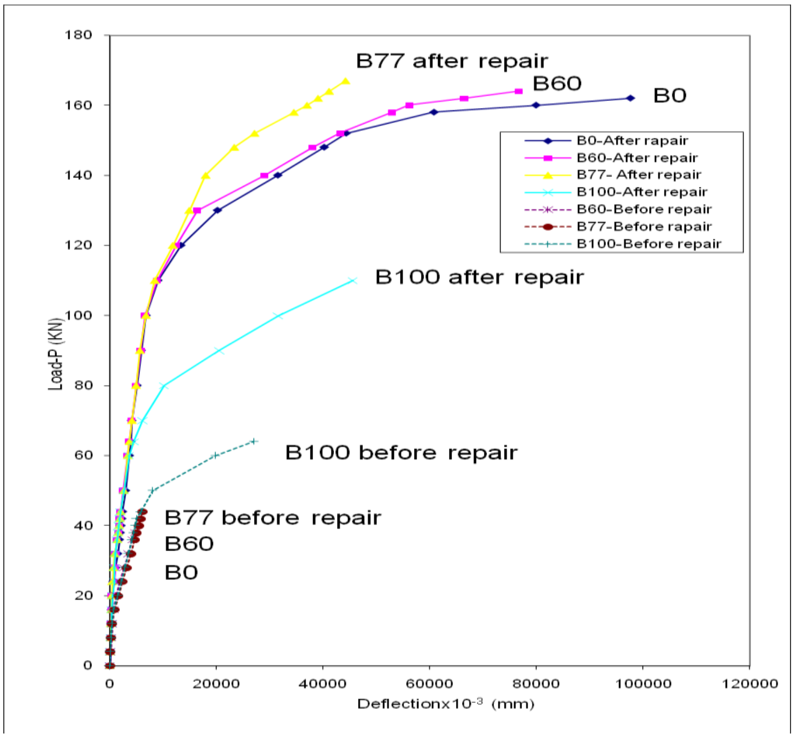

Figure (4) Load-deflection curves of beams before and after jacketing

Load-steel strain curves

The steel strains were measured at three sections along the span (under two points load and at the middle sections). Mechanical strain gauge was used with 200mm gauge length, which measured the concrete surface strain at steel level.
It is assumed that the concrete surface adjacent to the steel will have same strain as the steel. However, this is the best available technique in the laboratory.
The load-tensile steel strain curves at mid-span were plotted for all beams before and after repair as shown in Figure (5). Three different stages of behaviour can be clearly distinguished.
At low load, it can be seen that the steel strain is directly proportional with the applied load following the elastic behaviour (elastic stage). After formation the first crack, the steel strain is changed to be flatter than that before crack. Then it increases steadily and linearly up to the yielding strain.
In the cracking region, the stresses are still proportional to strains. Further increase in the applied load beyond the service load resulted in a large and non-linear increase in the tensile strain of beams before and after repair.
Test results show that the repair by jacketing causes a great decrease in the tensile strain of the original beams. This means that the reinforcement of the jacketing is significantly contributing in resisting the applied load besides the original reinforcement. The percentage of decrease is ranging between about 90% in beam B77 to about 70% in beam B100 at service load.
On the other hand, the top steel plate reduced the steel strain in beams before repairs as shown in Fig. (5).

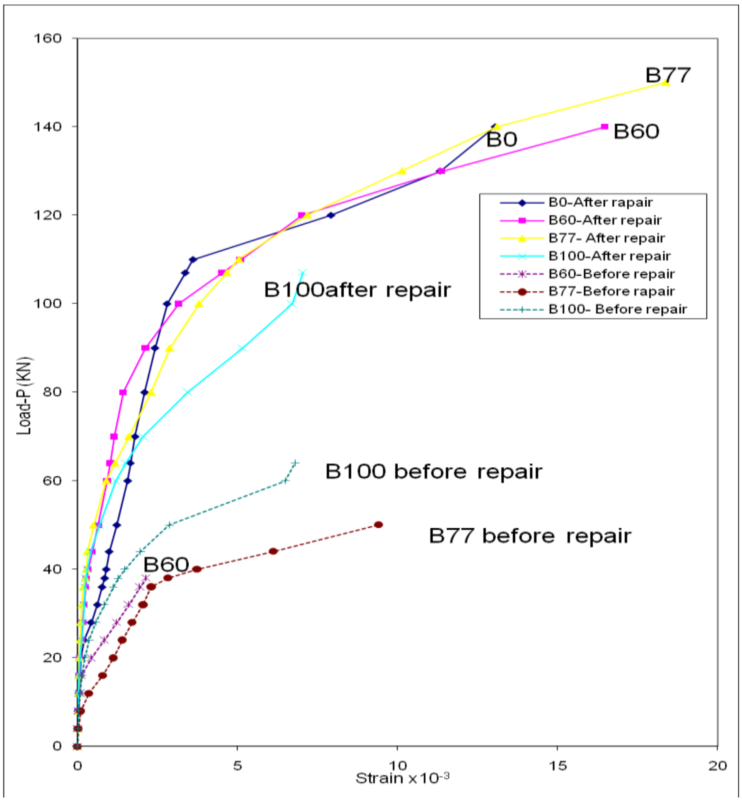

Figure (5) Load-steel stain curves for beams before and after repair by jacketing

Load-Concrete Strain Behaviour

Concrete compressive strains at top fibre of the mid-span section of each beam were measured. Compressive strains under the point loads are also measured. The compressive strains at the mid-span are plotted with applied load for all test beams as shown in Figure(6). The load compressive strain behaviours are similar to the load-tensile strain behaviour discussed elsewhere. Therefore, there is a consistency between the tensile and compressive strain under loading. This should be existing to agree with the rational theory of ultimate bending strength of the beam (strain distribution across any section of the beam is assumed to be linear).

Reinforced jacket acted to redistribute the compressive strain between the original and new concrete. Therefore, the compressive strains are reduced in compression zone of repaired concrete compared to the original strains as shown in Figure (6). The percentage of reduction was observed to be between about 30% in beam B60, Fig. (5.35) to 60% in B100 Fig. (5.39). This behaviour is consistent with the original behaviour . All repaired beams have reached to the specified yield strain of concrete or slightly higher than that. The observed yield strain was ranging between about 0.0035 to 0.0060. The concrete strain in the original beam has reached to about 0.003. This indicates that the jacketing increased the ductility of concrete.

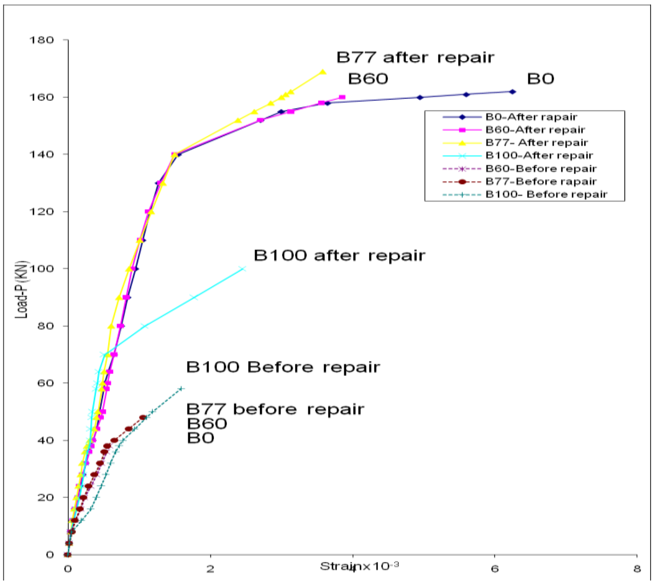

Figure (6) Load-compressive stain curves for beams before and after repair by jacketing

CRACKING BEHAVIOUR

The formation of cracks at every stage of loading is marked on the test beams as shown in Figures (7) and (8). Concrete cracks at an early stage of its loading history will crack first because its weak in tension. Consequently, it is necessary to study its cracking behaviour and control the width of the flexural cracks. Cracking contributes to the corrosion of the reinforcement, surface deterioration and its long-term deterioration effects. The problem of cracking becomes much more important in retrofitting the deteriorated beams, because, the existing uncontrolled cracks may reduce the load carrying capacity of the beams and will increase the deflections beyond the permitted limits.
Hence, the prediction and control of cracking and crack widths are essential for reliable serviceability performance under long-term loading.
As a beam is subjected to bending moment resulting from applied loads, tension stresses will occur in one side of neutral axis and compression stresses developed in the other side. When the tension stress exceeds the modulus of rapture, cracks form. If the concrete compression stress is less than approximately half compressive concrete strength and the steel stress has not yet reached the yield point, both materials continue to behave elastically or very nearly so. At this stage, it is assumed that tension cracks have progressed all the way to the neutral axis, and that sections plane before bending are plane in the bent member.

Beams before repair

The initial flexural cracks have first developed in all beams tested except beams B0, which was not loaded before repair. The typical cracking condition of B100 is shown in Figure (7). All beams have shown that the first crackform at about same load, which was about 16 KN because these beams were identical. The flexural cracks developed at bottom fibre in the region of maximum bending moment (between points loads). These cracks penetrated upward as the load increased and new cracks spread toward the points load. Then, the load was removed when it reached to 60% of the ultimate load (B60) whereas the applied load continued, untill 77% of the ultimate load in beam B77 . In this beam, the flexural cracks penetrate deeper in the flange of the beam (compression zone) and some cracks separated

into two branches. Beam B100 has nearly similar cracking behaviour at this stage (77% Pu). Then, the loading continued for beam B100 up to failure.
As the loaded increases above 77% of the ultimate load in beam B100, the cracks, under the left point load have deeply penetrated to the compression zone resulting in complete failure by crushing the flange under the point load resulting a complete flexural failure.

Beams after repair

The objective of B0 was to investigate the possibility of increasing the ultimate capacity of non-cracked section by jacketing method. Beams B60, B77 were tested to investigate the strengthening of cracked sections using jacketing method. To retrofit the failed beam by jacketing, B100 was investigated. The cracking behaviour of B0 after strengthening, is similar to the cracking behaviour of beams B60, B77, B100 before repair. This means, the strengthening by jacketing would result in similar cracking behaviour to that of the original beams.
Therefore, same principle of the original beam may be used to predict crack width of the beams strengthened by jacketing. The mode of failure of beam B0 is a pure flexural failure which crushed the compression zone, (top flange) between points load. So, the ultimate strength theory can also be used to predict the moment carrying capacity of strengthened beam by jacketing.
After repairing beams B60, B77, B100 by jacketing, the cracking behaviour were approximately similar to those observed before repair . A typical cracking condition of beam after repair is shown in Figure(8). Then, the mode of failure of beam B100 after repair Figure (10) was exactly in similar type and in same location as that of the original beam before repair Figure (9). Beams B60, B77 showed similar mode of failure after repair as in beam B100 but with improved ductility (large deflection before failure). This indicates that the behaviour of strengthened beams (B77, B60) are more ductile than the retrofitted beam (B100).

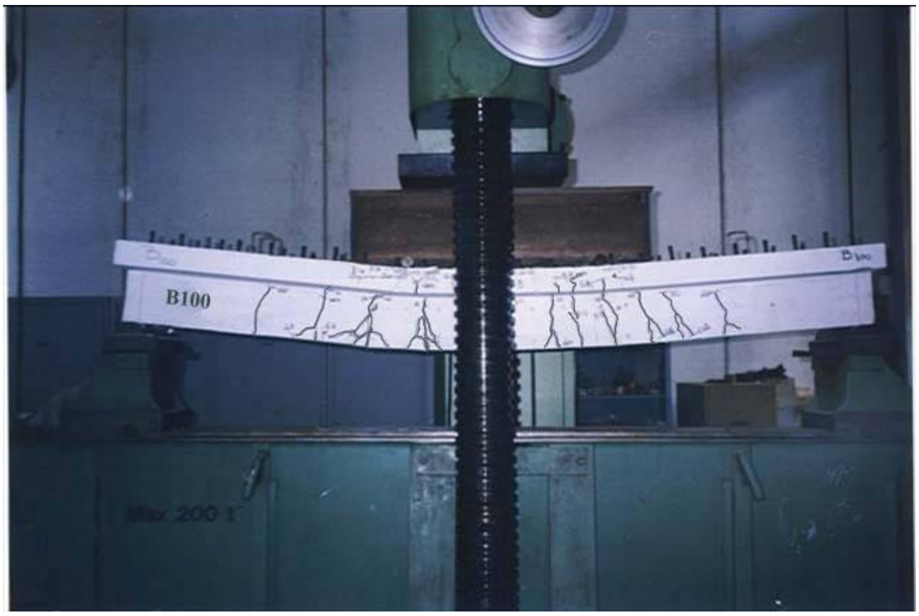

Figure (7) Cracking of Beam B100 (before repair)

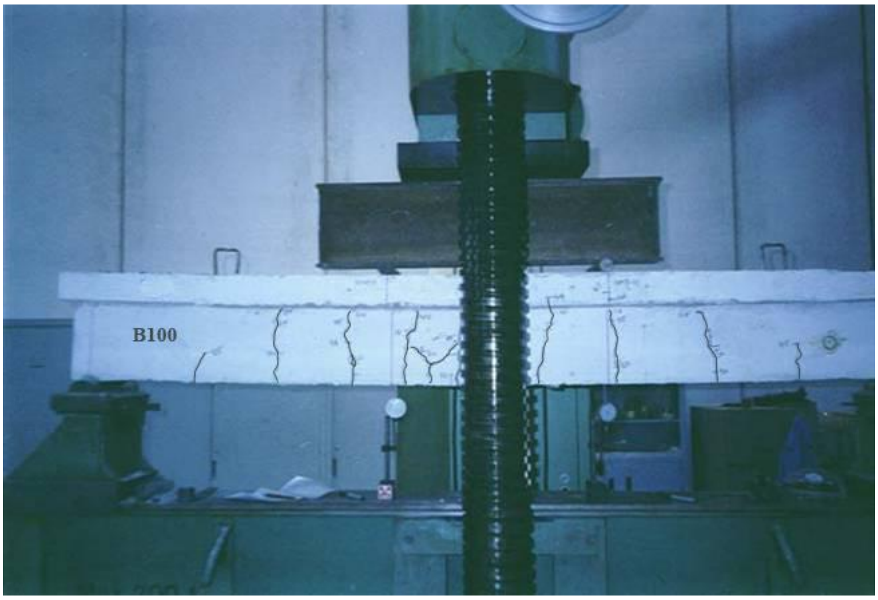

Figure (8) Cracking of Beam B100 (after repair)

FAILURE LOAD OF TEST BEAMS

Experimental and theoretical failure loads are given in Table (3). Based on this table, the strength and the efficiency of repair are presented here.
As mensioned elswhere,all beams have same steel reinforcement, size and concrete properties. They were designed to have flexural failure before repair at ultimate load of about 38KN according to ACI method.
Beam B0 was strengthened by reinforced jacket without any flexural cracks in the original concrete, (unloaded before repair). To show the efficiency of jacketing method in non-cracked section.
Beams B60 , B77 were loaded to 60% and 77% of the failure load obtained from test. Such loading produced flexural cracks with intensity related to the applied load .In fact, the higher the load the more cracks will produce. Then, these beams were repaired by reinforced jacket as mentioned elsewhere. After curing, the beams were tested again to gradually up to failure. Observations were made for surface strain and deflection during the loading. Cracks were also marked on concrete surfaces. Beam B100 was first loaded to flexural failure. then, the crushed concrete was removed and replaced by new concrete in addition to the reinforced jacket. The main aim of this beam was to investigate the possibility of restoring the flexural strength of failed beam using reinforced jacket.

Referring to Table (3), the use reinforced jacket with (2ϕ12) increased the failure load of beam B0, B60, B77 from 64KN to about 165KN. This means the failure load after strengthening increased to about 150% as much as the original failure load irrespective to the condition of cracks before repair. Therefore, the existing flexural cracks have no significant effect on the flexural strength after repair.
The high flexural strength of beams may be attributed to the confinment of cracked beam by new jacket with very high bond strength between the original and jacket concrete,These will make the beam to act as one unit. In fact, the removing of the concrete cover of these beams before jacketing provided a very rough surface for good bond between cracked concrete and new concrete. The ratio between theoretical failure load to the experimental value is about 0.82. The theoretical procedure followed here has taken in consideration the increase in

effective deth after jacketing as weel as the exiting reinforcement in the original beam. On the other hand, the theoretical failure load is very closed to the experimental failure load of the original beam (before jacketing). The ratio between the theoretical to the experimental is about 0.91.

For beam B100, the jacketing was restored about 167% of the original ultimate capacity of the beam. The original reinforcement in this beam was useless since it was ruptured by the first test before jacketing. The ratio between the theoretical and the experimental failure load was about 0.73. this means, that the existing reptured steel contribute in resisting applied load. However, the yield reinforcement may carried about 27% of the failure load in the second test (after jacketing).

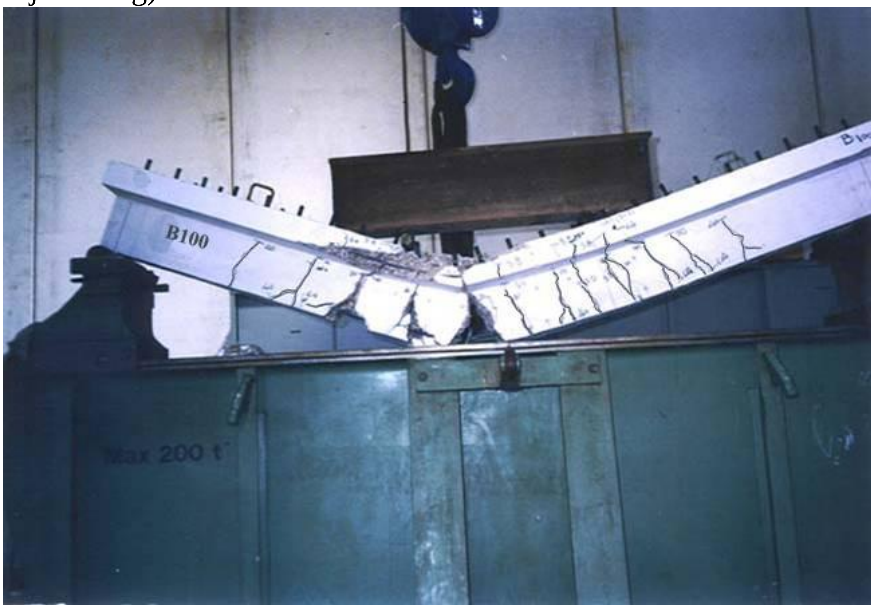

Figure (9) Flexural failure mode of Beam B100 (before repair)

Figure (10) Failure mode of Beam B100 (after repair)

Table (3) Ultimate experimental loads of beams repaired by jacketing

Beam	1st cracking load				Failure load (Pu)				Mode of failure
	Original beam		After repair		Original beam		After repair		
	Exp. (KN)	Theo. (KN)	Exp. (KN)	Theo. (KN)	Exp. (KN)	Theo. (KN)	Exp. (KN)	Theo. (KN)	
B0	16	18.5	20	41.6	64	62	162	135	Flexure
B60	16	18.30	22	33.9	64	62	164	135	Flexure
B77	16	18.30	20	34.2	64	62	169	135	Flexure
B100	18	18.50	22	41.6	64	62	107	78	Flexure

EFFECT OF LOADING ON THE STRENGTH OF REPAIRED BEAM

The failure loads of beams B0, B60, B77, B100 were plotted against the first load test $(P/P_u \times 100)$, which corresponded to crack condition of the original beams before repair as shown in Figure (11). All beams have same failure load because they are identical. The conditions of cracks at the original beams were marked on the axis.
Figure (11) shows that, the existing flexural cracks in the original beam up to load level of 77% has no significant effect on the strength after jacketing. The strength of beams after jacketing is mainly affected by the amount both the existing reinforcement and the reinforcement of jacketing. The reduction in the strength of beam failed in flexural before jacketing, (Beam B100) compared to other, (B0, B60 and B77), was mainly due to lost of original reinforcement by rupture during the first test.

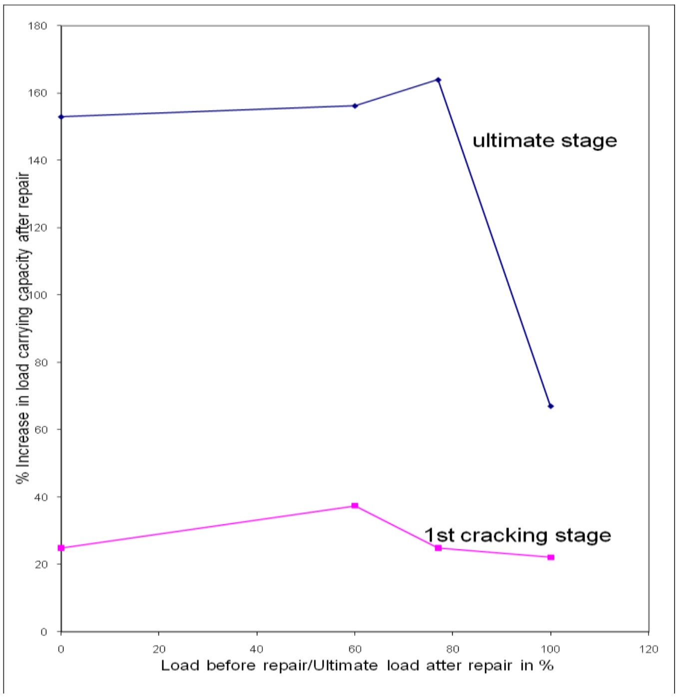

Fig. (11) Effect of loadig before repair on the strength of beams repaired by jacketing

THEORETICAL FAILURE LOAD

Based on ACI-318M-2005 the ultimate moment capacity of the beam (B0, B60, B77, B100), were calculated using the actual dimensions in Figures (1),(3) and material strengths Table (2).The notations used here are same as that given in ACI Code.

<u>Beam before repair</u>

F_{cu} = 35.6 N/mm2 , $f_{c'}$ = 30 N/mm2 , f_{su} = 595 N/mm2 ,

Main reinforcement 2 Ø 12

A_s = 113X2 =226 mm2

Effective depth = 240 - (25 + 12) = 203 mm

As $_{min}$ = 0.005 x b x d

As $_{min}$ = 0.005 x 150 x 203 =152.25 mm2

$$a = \frac{As \times f_y}{0.85 \times , f_{c'} \times b} = \frac{226 \times 595}{o.85 \times 30 \times 400} = 13.2 \text{ mm} < t \text{ (Sec. rectangular with b =400)}$$

$$\rho_b = \frac{0.85B \times f_c'}{f_y}(\frac{600}{600 \times f_y})$$

$$B_1 = 0.85, \; f_y = 361 N/mm^2, \; f_c' = 30 N/mm^2$$

$$\rho_b = \frac{0.85 \times 0.85 \times 30}{361}(\frac{600}{600 \times 361}) = 0.037487$$

$$A_{s_{max}} = 0.75 \rho_b bd$$

$$= 0.75 \times 0.037487 \times 150 \times 203 = 856.106 mm^2$$

As prov.< As max. O.K. $\therefore$ beam under reinforced.

Mu = A_s f_u (d – a/2) Ø = 1 (actual moment capacity without factor of safety)

Mu = 226 x 595 (203 – 13.2/2) = 26409908 N.mm = 26.4 kN.m

Total failure load (P_u) = 2 x 26.4/.85 = 62 kN.m

<u>Beam with jacket B 100</u>

F_{cu} = 35.6 N/mm2 , $f_{c'}$ = 30 N/mm2 , f_{su} = 595 N/mm2 ,

Main reinforcement 2 Ø 12

A_s = 113X2 =226 mm2

Effective depth = 240 + 50 - (25 + 12) = 253 mm

As $_{min}$ = 0.005 x b x d

As $_{min}$ = 0.005 x 150 x 253 =189.75 mm2

$$a = \frac{As \times f_y}{0.85 \times ,\ f_{c'} \times b} = \frac{226 \times 595}{o.85 \times 30 \times 400} = 13.2 \text{ mm} < t \quad \text{(Sec. rectangular with b =400)}$$

$$\rho_b = \frac{0.85B \times f_c'}{f_y} \left(\frac{600}{600 \times f_y} \right)$$

$$B_1 = 0.85,\ f_y = 361 N/mm^2,\ f_c' = 30 N/mm^2$$

$$\rho_b = \frac{0.85 \times 0.85 \times 30}{361} \left(\frac{600}{600 \times 361} \right) = 0.037487$$

$$A_{s_{max}} = 0.75 \rho_b bd$$

$$= 0.75 \times 0.037487 \times 150 \times 203 = 856.106 mm^2$$

As prov.< As max. O.K. $\therefore$ beam under reinforced.

Mu = $A_s f_u$ (d – a/2) Ø = 1 (actual moment capacity without factor of safety)

Mu = 226 x 595 (253 – 13.2/2) = 33133408 N.mm = 33.13 kN.m

Total failure load (P_u) = 2 x 33.13/.85 = 78 kN.m

CONCLUSIONS

The main factor considered here is the effect of the level of loading in percentage of ultimate load before repair on the strength and behaviours of the beam after repair. However, this investigation can not be considered to have given a complete study of problems related to repairing and retrofitting of T-beams but it is hoped that the present investigation show the effectiveness of jacketing method in restoring the flexural strength of T-beams. The test results have led to make some useful contribution towards better understanding of strength and behaviour of reinforced concrete T-beams repaired by jacketing method. The major overall conclusions drawn from the test results are summarized as follows:

- Reinforced concrete jacket has greatly increased the flexural capacity of beams cracked in flexural. The flexural capacity of jacketed beams was about 2.5 times its capacity before jacketing.
- Reinforced jacket was very effective in restoring the flexural capacity of beam failing in flexure. The repairing by reinforced jacketing resulted in increase in the capacity of failed beam into about 167% of the original strength of the beam.
- It was observed that the effect of loading condition of the beam before repair has only slight influence on the flexural capacity of beam after repair by jacketing. That effect

becomes very significant when there is a a complete flexural failure in the beam before repair.

- First flexural cracking load of beams strengthening by jacketing is increased by amount of 25% resulting in an improvement in workability.
- Test results showed that the yielded reinforcement before repair contribute in increasing the flexural capacity of beam after jacketing by amount of 27% of the failure load.
- Reinforced jacket increased, significantly, the flexural stiffness of the original beams resulting in less deflection under service load. The percentage of reduction in deflection was about 40%.
- Tensile steel strain was, considerably, reduced by reinforced jacketing. The percentage of decrease was ranging between 70% to 90% .
- Reinforced jacketing has led to considerable increase in concrete compressive strain at ultimate stage of loading in a very ductile mode of failure.
- Reinforced concrete jacketing has greatly improved the cracking behaviour of beams irrespetive to cracking condition before repair.
- Test results showed that the addition of steel reinforcement at the compression zone increased both the ultimate capacity (22%) and ductility.
- A safe and reliable prediction of failure load of beams repaired by reinforced jacket can be obtained using stress-strain relationship of steel reinforcement. Neglecting the existing yield reinforcement, the average ratio of predicted failure load to that obtained from test beam was about 0.75.

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