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# Flexural Behaviour of External Reinforced Concrete Beams

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**Abstract**

Most of highway bridge structure elements are constructed using concrete structures such as deck, girders and piers. Especially on girder beams, concrete structural elements that work optimally resist bending is a part of the outermost fibers on the compression side while the concrete on the tensile side is negligible. Therefore it is understandable that the concrete on compression section of a concrete beam should be optimized while the concrete on tension section should be minimized. This may cause the reducing of the self-weight of the concrete structures as well as the using of the concrete materials can be reduced. As an experimental effort to achieve the above consideration, a series of study is being done in reducing the volume of concrete on tension parts. In order to clarify the flexural capacity of beam without concrete on the tension part (External reinforced concrete beam, ERCB), an experimental flexural test was carried out. The specimens are beams with a length of 2700 mm, width of 150 mm and 200 mm high. The beams were supported by a simple supports with span of 2500 mm and it was subjected to monotonic two loading points. The results indicated that the flexural capacity of ERCB decreased to 86%, compared to the control specimens. Additionally, the stiffness of the ERCB also decreased to 60% compared to the normal beams.


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*Keywords:* concrete beams; flexural; external reinforcement; stiffness; moment capacity.

## 1. Introduction

Concrete is a common material which is formed from natural materials consisting of coarse aggregate, fine aggregate and cement with a density of average of 2200 kg/m$^3$. Concrete material is strong in compression but weak in tension. Combining with steel

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reinforcement can become a high durable structures and it has been used commonly in the modern structures. Therefore, high demand of concretes affects to the increasing of the exploitation of natural materials such as sand, stone, gravel that can cause erosion, abrasion and sedimentation. Similarly, the cement production process that requires high energy would result a high $CO_2$ gas, which in turn causes a decrease in environmental quality.

As a flexural element, it is known that the concrete structural elements that work optimally resist bending is part of the outermost fibers on the compression side while the tension side is negligible as illustrated in Figure 1. According to Whitney, equivalent rectangular stress block can be used to calculate the load without losing accuracy. Equivalent compressive stress block holds bending on the compression side while concrete on the tension side is considered not to work because of the tension stress is carried by the steel reinforcement as shown in Figure 2.

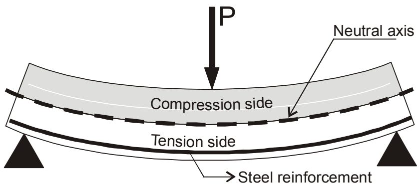



Figure 1. Compression-tension of a flexural beams

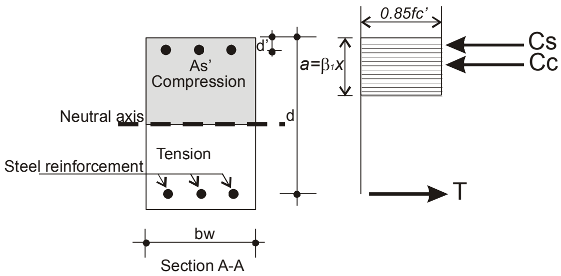
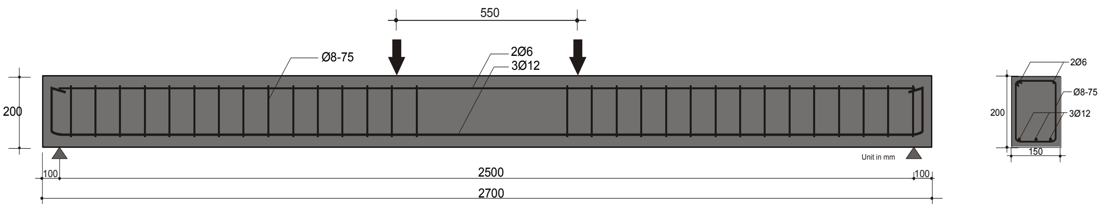



Figure 2. Whitney's rectangular stress blok

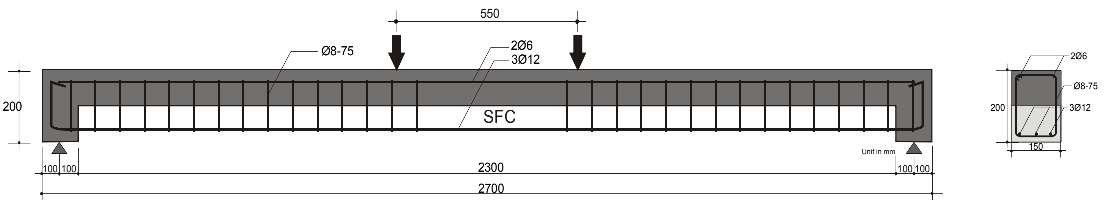
Therefore, concrete part on the tension section is neglected in calculating the capacity of flexural members.

As an experimental effort to achieve the above consideration, a series of study is being done in reducing the volume of concrete on tension parts. In order to clarify the flexural capacity of beam without concrete on the tension parts (External reinforced concrete beam, ERCB), an experimental study of flexural test was carried out.

Flexural beam on simple support that loaded will suffer bending stress and shear stress. Largest bending stress occurs at the top and bottom fibers consisting of compression bending stress and tensile bending stress. Cross section that suffer compression bending stress is resisted by the concrete and the part that suffer tension bending stress resisted by the steel reinforcement while shear stress occurs evenly throughout the cross section.




(a) Normal Beam (BN)




(b) External Reinforcement Beam (ERCB)

Figure 3. Specimens

Nominal bending moment capacity of a reinforced concrete beam section is the ability of the reinforced concrete beam section to resist bending moment, mathematically may be expressed as Eq.(1).

$$M_n = C_C\left(d - \frac{a}{2}\right) + C_S(d - d') \tag{1}$$

## 2. Specimen and Test Setup

Two types of concrete beams with three specimens for each type with span of 2500 mm were tested under flexural test. Tye are a normal beam (BN) and an external reinforced concrete beam (ERCB). The specimen details are presented in Figure 3.

Both of Type BN and ERCB are reinforced with same steel bars contents. On ERCB, a part with the length of 2300 mm at the centre of span with depth of half of beam height was un-casted. A normal concrete was intentionally casted at both end of beam for support purposes. Material properties of the concrete and steel reinforcements used in this study is presented in Table 1. To avoid shear failure, all beams was reinforced with steel stirrups as shear reinforcement.

The specimen was casted using a fresh concrete with design compression strength of 25 MPa. The specimen was tested after curing for 28 days. Cylinder test and flexural test was done to measure the compression strength and tensile strength of concrete.

Table 1. Material Properties

| No. | Material | Compression Strength (MPa) | Tensile Strength (MPa) | Modulus of Elasticity (MPa) |
|---|---|---|---|---|
| 1 | Concrete | 26.3 | 3.47 | 24,800 |
| 2 | Steel Reinforcement | 410 | 410 | 210,000 |

*) Strength for steel is yield stress

Each specimen was subjected to two equal loads at the centre of span as shown in Figure 3. The point loads were placed with distance of 975 mm from both side of support points to have the a\d ratio equal to 5.7. High ratio of a/d was taken to ensure a flexural failure on each specimen. The beams were instrumented with dial gauge at the centre of span to measure the deflection. The load was applied using a hydraulic jacks step by step at a rate 1 kN per step. At the end of each step, the dial of load as well as deflection gauge was read while observed the appearance of cracks. The load was applied until the load decreased.

## 3. Results and Discussion

### *3.1. Load-Deflection Relationship*

Load-Deflection behaviour of the specimens may be observed through Figure 4 as a load-deflection relationship curve. The deflection measured was the centre point of beam span. Initially, all beams are un-cracked and stiff. Further loading caused a crack occurred at approximately at the centre of span as a flexural cracks.

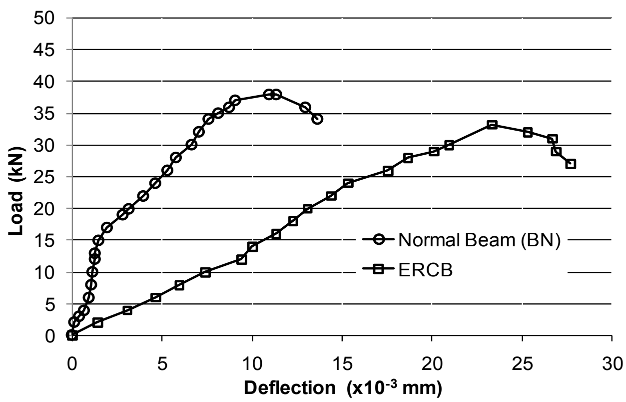
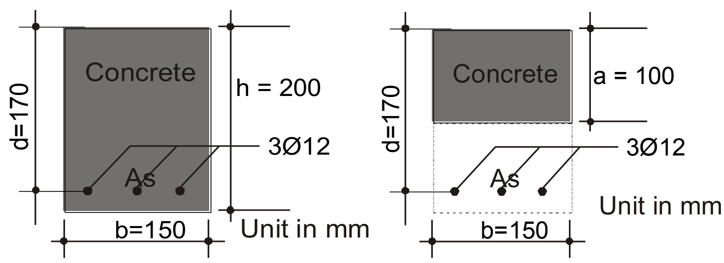



Figure 4. Load – deflection relationship




(a) Normal (b) ERCB

Figure 5. Cross Section of Beams

First crack occurred on the BN (normal beam) when the applied load reached to 13 kN while first crack occurred on the ERCB when the applied load reached to 6 kN. First cracking load on the ECBR is lower than the normal one, but it has bigger fist cracking deflection which are 23.5 mm while on normal beam was 12.6 mm. This indicated that ERCB beams has more ductility during elastic range compared to the normal beam. This may be caused of lower moment of inertia (Ig) of entire beam section as shown in Figure 5. The ratio between moment of inertia of normal beam ($I_N$) and the ERCB beam ($I_{ERCB}$) is about 0.60 or it decreased to the 60% compared to the normal one. This caused to the decreasing of the load-deflection slope.

The occurrence of first crack indicated that the applied moment exceeded the cracking moment capacity of beams. First cracks caused a reducing in stiffness of the normal beams. However, first cracking on the ERCB beam did not cause significantly decreasing on the load-deflection slope as on the normal beam. Some new flexural cracks occurred by increasing the applied load while the previous cracks was still continuo to propagate. At this stage, all types of specimens had approximately same stiffness, although the normal beam has slightly stiffer than the ERCB beam. This may be caused by the effect of the no-bonding between steel reinforcement and concrete on ERCB beam. From Figure 4, it can be observed that, taking-off the concrete on the tension layer of ERCB did not show any significant effect to the load-deflection slope at the cracking stage.

When the applied load on normal beam reached to approximately 38 kN, then the tensile reinforcement entered into plastic range. The yielding of tensile reinforcement was followed by the crushing of the compression concrete. This affects to the decreasing of the flexural capacity of beam. On the ERCB beam the maximum capacity was 32,7 kN which are lower that the normal beam. The maximum capacity of ERCB was initiated by the compression failure due to big deflection rather than the yielding of the tensile reinforcement. Bigger deflection of the ERCB beam was caused by the decreasing the of the beam stiffness due to the changing of the moment arm ($z$) of the tensile force of steel reinforcement to the compression force. Moment arm ($z$) changed due to the geometrical condition of the ERCB which are the steel reinforcement acted as the cable that tended to be straight line during the deformation as illustrated in Figure 6. On the normal beam, the moment arm $z$ between steel reinforcement to the compression fiber of concrete did not change during the deformation. The steel reinforcement was pushed by the concrete to be deflected following the deformation of the beam. While, on the ERCB beam, the moment arm $z$ between steel reinforcement to the compression fiber of concrete changed during the deformation. The steel reinforcement behaved as a cable to be a line during the deformation of the beam.

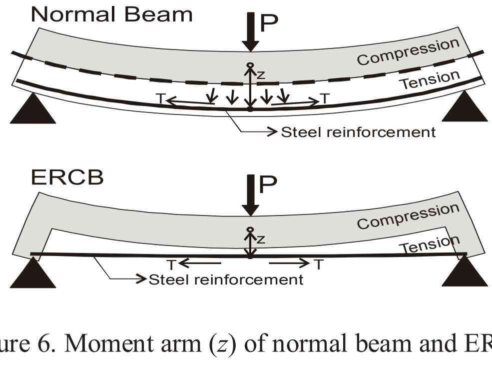



Figure 6. Moment arm ($z$) of normal beam and ERCB

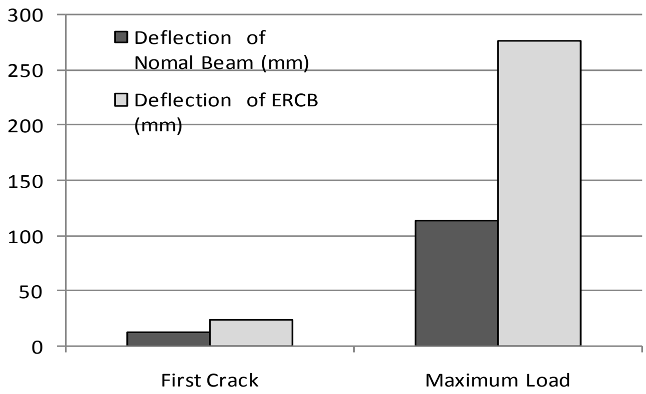



Figure 7. Comparison of the deflection at the span centre of normal beam and ERCB

### 3.2. Ductility

Releasing of the beam energy due to the low stiffness as well as changing of the moment arm ($z$) of the ERCB affected to the increasing of ductility compared to the normal one as shown in the Figure 7. Deflection on the ERCB at first crack was 1.9 times bigger than normal beam. While at the maximum load, the deflection on the ERCB was 2.44 times bigger than normal beam.

### 3.3. Ultimate Flexural Capacity

Taking off the concrete at the tension region of a beam on the ERCB caused the decreasing of beam stiffness. This increased the deformation of the beam. As the result, the occurrence of the first crack was earlier on the ERCB than the normal beam. First crack on ERCB and Normal beam occured when the applied load achieved to 6 kN and 12 kN, respectively.

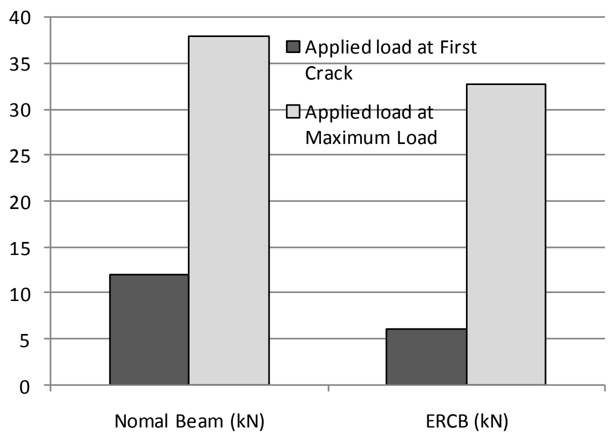
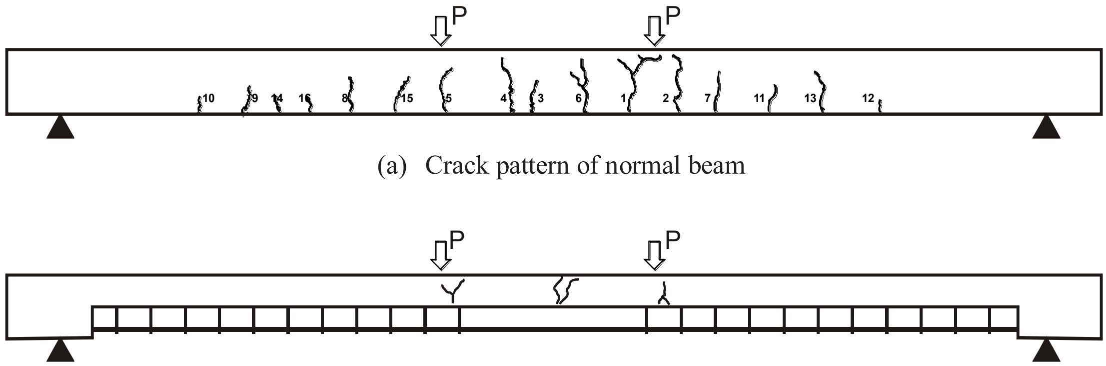



Figure 8. Comparison of loading capacity




(a) Crack pattern of normal beam

(b) Crack pattern of ERCB

Figure 9. Crack pattern of normal beam and ERCB

Ultimate flexural capacity of ERCB was 32.7 kN, while on the normal beam was 38 kN, respectively as presented in Figure 8. Ultimate flexural capacity of ERCB was only 86% compared to the normal beam (BN).

Decreasing of ultimate capacity of the ERCB specimen may be caused by the changing of moment arm *z* between tension force on the steel reinforcement and the compression force on the concrete. This affected to the decreasing of the internal couple moment of the ERCB beam section.

### *3.4. Crack Pattern and Failure Mode*

Figure 9 shows the crack pattern of beam specimens. Flexural first crack found at the middle of beam when the applied load equal to 6 kN and 12 kN, on the ERCB and Normal beam, respectively.

Further loading on specimens, cracks propagated in normal ways typically as on flexural beams. Observation of the cracks shows that the crack propagation was much progressive on the normal beam than on the ERCB beam. The number of cracks was much less on the ERCB compared to the normal one. The crack on the ERCB beam tended to propagate under single cracking because there was no steel reinforcement on the lower side of the concrete region. So, it behaved like an un-reinforced concrete. This crack propagated slowly. Unlike on the normal beam, the cracks propagated followed by the appearance of the new cracks.

All beams failed under compression failure at the range of the loading points. On the normal beam, the failure was initiated by the yielding of the steel reinforcement and followed by the compression failure on the concrete.

## 4. Conclusions

Based on the discussion, then some conclusions may be obtained as follows:

1) First cracking load on the ECBR is lower than the normal one, but it has bigger fist cracking deflection which are 23.5 mm while on normal beam was 12.6 mm. This indicated that ERCB beams have more ductility during elastic range than the normal beam. The ratio between moment of inertia of normal beam ($I_N$) and the ERCB beam ($I_{ERCB}$) at un-crack stage is about 0.60 or it decreased to the 60% compared to the normal one.

2) Maximum capacity of normal beam was approximately 38 kN while on the ERCB beam, the maximum capacity was 32,7 kN which are lower than the normal beam. The maximum capacity of beam was initiated by the compression failure rather than the yielding of the tensile reinforcement.

3) Bigger deflection of the ERCB beam was caused by the decreasing of the beam stiffness due to the decreasing of the moment arm ($z$) of the tension force of steel reinforcement to the compression force of concrete section. Moment arm ($z$) changed due to the geometrical condition of the ERCB which are the steel reinforcement acted as the cable that tended to form a straight line when the beam is deflected.

4) Crack propagation was much progressive on the normal beam than on the ERCB beam. The number of cracks was much less on the ERCB compared to the normal one. The crack on the ERCB beam tended to propagate under single cracking because there was no steel reinforcement on the lower side of the concrete region.

5) On the normal beam, the failure was initiated by the yielding of the steel reinforcement and followed by the compression failure on the concrete while on the ERCB the failure was initiated by compression of concrete.

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