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# STRENGTH AND DUCTILITY OF REINFORCED CONCRETE T-BEAMS STRENGTHENED IN THE NEGATIVE MOMENT REGION WITH WIRE ROPE AND MORTAR COMPOSITE

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*ABSTRACT*

The loss due to collapsing structure includes not only materials but also lives. In the case of a change in structure function that may cause increasing loads, it is required to put efforts in strengthening the structure elements in order to increase the capacity and hence to avoid the possibility of collapsing. The objective of this research is to find out the behavior of T-sectional reinforced concrete beam strengthened in the negative moment region with wire rope and mortar composite. The test was carried out on three T-sectional beams: without wire rope reinforcement (BK), with 2 wire rope reinforcements (BP1), and with 4 wire rope (BP2) reinforcements. The type of wire rope was Independent Wire rope Core (IWRC) with a 10 mm diameter. The testing method used was two points static loading with flens positions below (the flens part experienced tensile stress). Results showed that the maximum load carrying capacity of BP1 and BP2 specimens increased by ratios of 1.59 and 2.03 to the BK specimen, respectively. However, the increase was achieved after the development and propagation of high cracking. Ductility of BP1 and BP2 specimens decreased with a ratio of 0.62 to 0.36 to the BK specimen, respectively. The initial stiffness of BP1 and BP2 increased with a ratio of 1.09 to 1.08 to the BK specimen, respectively. The effective stiffness of BP1 and BP2 specimens decreased with a ratio of 0.88 to 0.92 to the BK specimen, respectively. Stress occurred in the wire rope based on the analysis results of Response-2000 and the layer method did not reach 50% of the ultimate stress resulting from the preliminary test. In general, unless improvement was made to the stiffness characteristics of the wire rope, its contribution would not become optimum.

Keyword: Wire rope, mortar, flexural behaviour.

## 1 INTRODUCTION

The loss due to collapsing structure includes not only materials but also lives. In the case of a change in structure function that may cause increasing loads, it is required to put efforts in strengthening the structure elements in order to increase the capacity and hence to avoid the possibility of collapsing. An illustration of collapsing structure resulting from change in function without the strengthening of structural elements can be seen in Figure 1.

Namboorimadathil et al. (2001) stated that a negative moment region of continuous reinforced concrete beams is a critical region because it has maximum value both for moment and shear strength. Moreover, both column element and non-structural components such as mechanical and electrical components make the strengthening at the region have a relatively higher rate of difficulty.

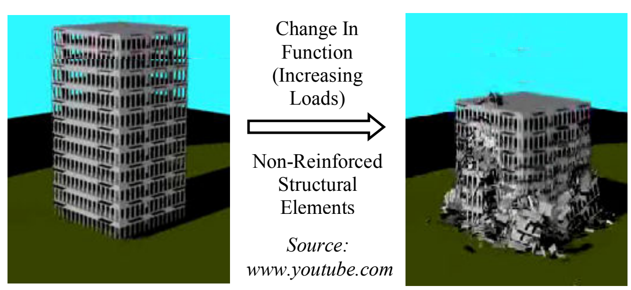


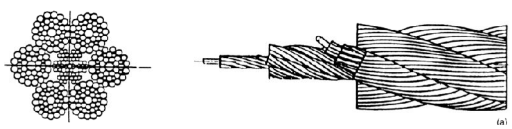

Figure 1. The illustration of collapsing structure resulting from the change in function without the strengthening of structural elements

Avak and Wille (2005) mentioned that the potential of use the of wire rope as reinforcement at concrete structure is based on the idea of the utilization of advantages of wire rope materials such as high flexibility and tensile strength. The high flexibility of wire rope allows it to be brought by coiling up, facilitating the strengthening of structure in a building with multiple floors. Mortar is used because it has high flowability, so the obstacles of concrete pouring with limited dimension and dense reinforcement can be handled.

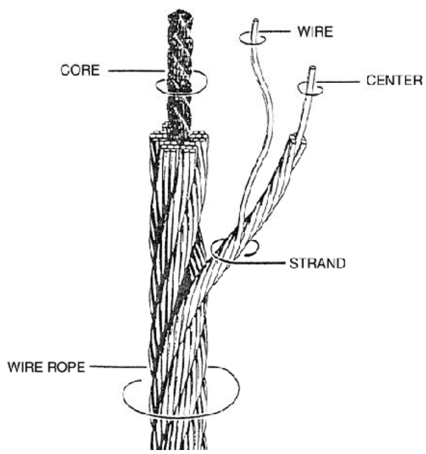
## 2 REVIEW OF LITERATURE

### 2.1 The Characteristics of Wire Rope

According to SNI 0076-2008, steel wire rope consists of six or more twined steel wires (strands), either with or without zinc coating. Generally, the twined steel wires (strands) have tensile strength larger than ordinary reinforced steel but it has not well-defined yielding point. The characteristics of wire rope, including the geometry and diagram of stress-tensile relationship typical for the wire rope, are presented in Figure 2 and Figure 3.



a. *Independent Wire Rope Core (IWRC)*




b. Wire rope with fiber core

Figure 2. Typical geometry of wire rope (Raoof and Davies, 2001)

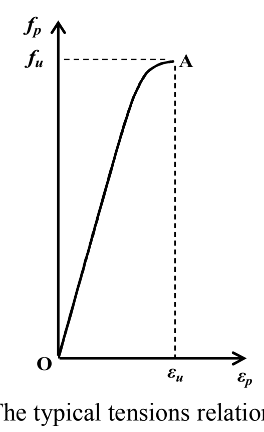



Figure 3. The typical tensions relationship of wire rope

### 2.2 Ductility and Stiffness

Ductility index is determined on the base of equivalency of the diagram of force and deformation relationship with adjusted notation as seen in Figure 4 (El Tawil and Deierlein, 1999). Based on Figure 4, the effective stiffness could also be determined. The initial stiffness was determined at a full elastic condition.

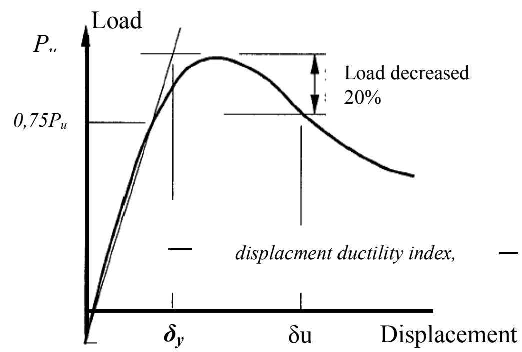



Figure 4. The determination of ductility index (El Tawil and Deierlein, 1999)

## 3 METHODOLOGY

The testing was done on three T-section beams where 1 beam was without reinforcement (BK), 1 beam with reinforcement by 2 wire ropes (BP1), and 1 beam with reinforcement by 4 wire ropes (BP2). The types of wire rope used were Independent Wire rope Core (IWRC) with a diameter of 10 mm. The testing was done by using static loads at two points with flens being positioned below (part of flens with tensile stress). The section of the tested object could be seen in Figure 5 and the setup of the testing could be seen Figure 6.

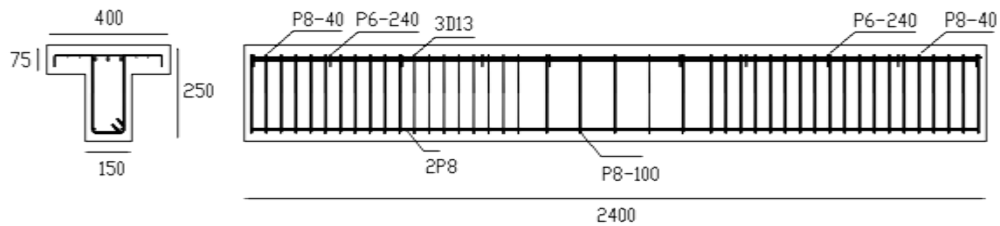
## 4 RESULT AND DISCUSSION

Load-displacement relationship for each specimen could be seen in Figure 7.

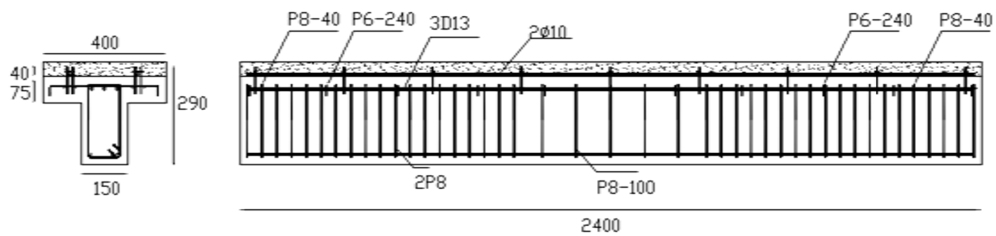
### 4.1 Load Capacity

Based on result of the testing, it can be indicated that the load capacities of both specimens BP1 and BP2 increased toward the specimen BK with ratios of 1.59 and 2.03, respectively. The comparison of load capacities among the results of testing, the *Response-2000* program analysis, and layer method analysis could be seen in Table 1 and Figure 8.

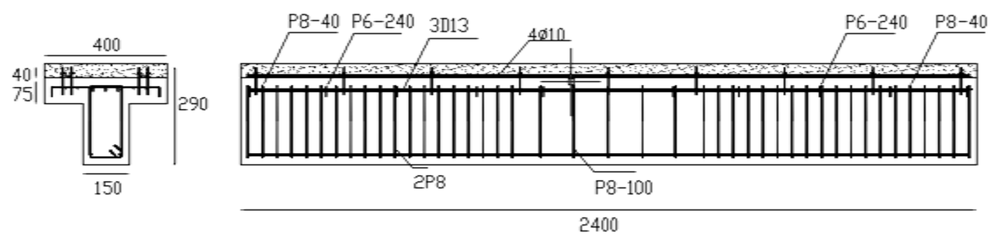
The increase of load capacity was caused by additional reinforcement using wire rope in tensile region resulting in the increase of tensile strength components on beam section. The additional tensile




a. The tested object of control beam (BK)




b. The tested object of the reinforced beam of type 1 (BP1)




c. The tested object of the reinforced beam of type 2 (BP2)

Figure 5. The section of tested object

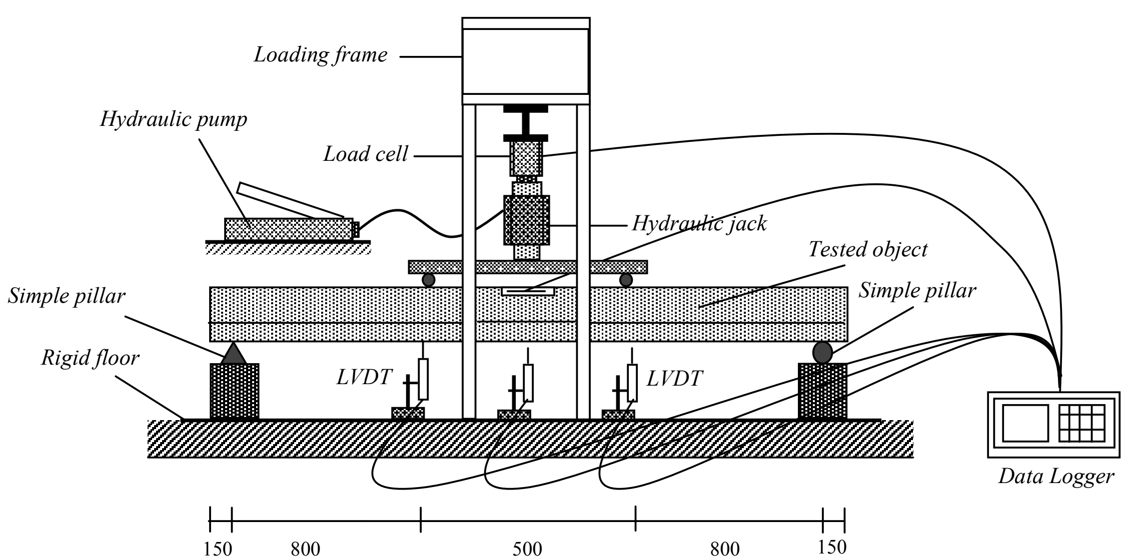



Figure 6. Testing setup

strength component with adjustable hand strength caused the increase of beam section capacity. However, the increase of load carrying capacity was achieved after specimens had undergone high propagation and cracking development. The setup of wire rope without initial pre-tension force caused the constantly high flexibility of wire rope. It caused the possibility of slip, and the contribution of wire rope to retain the stress resulting from loading became suboptimum.

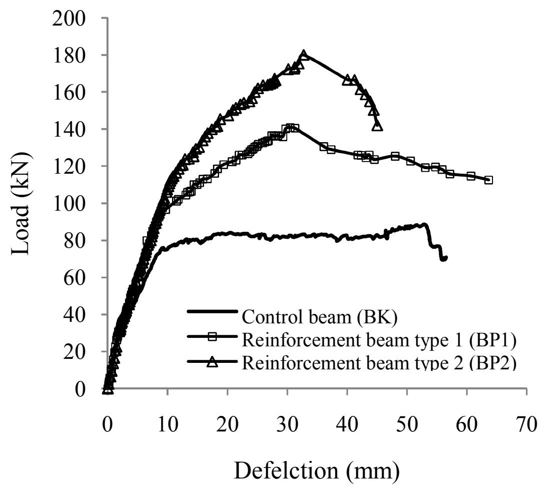



Figure 7. The load-displacement relationship of each of the tested objects

Table 1. Load capacity

| Tested Object | Maximum Load (kN) | | | | |
|---|---|---|---|---|---|
| | Result of Testing | Theoretical Analysis | | | |
| | | *Response -2000* | *Ratio | Pias Method | *Ratio |
| BK | 88.5 | 92.82 | 1.05 | 93.27 | 1.05 |
| BP1 | 140.8 | 134.07 | 0.95 | 120.63 | 0.85 |
| BP2 | 180.0 | 156.45 | 0.89 | 137.49 | 0.76 |

Information: *It was calculated toward the result of testing

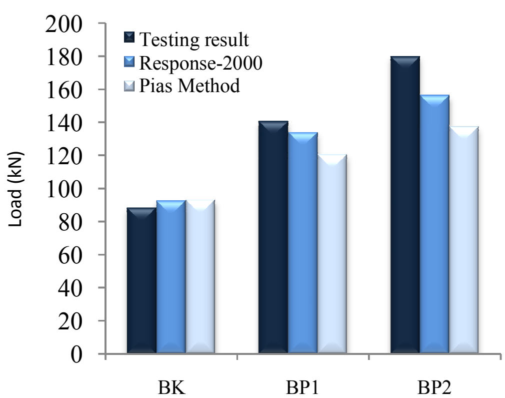



Figure 8. Comparison of load capacity

4.2 Ductility and Stiffness

Ductility index, initial stiffness and effective stiffness for each specimen were presented in Table 2, Table 3, and Table 4. The relationship of wire rope reinforcement ratio and ductility could be seen in Figure 9.

Table 2. Ductility index

| Tested Object | $\delta_y$ (mm) | $\delta_u$ (mm) | Ductility ($\mu = \delta_u / \delta_y$) | Ratio |
|---|---|---|---|---|
| BK | 9.79 | 56.51 | 5.77 | - |
| BP1 | 17.68 | 63.61 | 3.60 | 0.62 |
| BP2 | 21.56 | 45.00 | 2.10 | 0.36 |

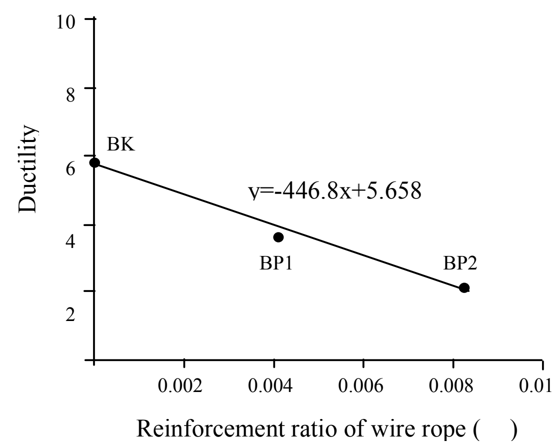



Figure 9. The relationship of wire rope reinforcement and ductility ratio

Table 3. Initial stiffness

| Tested Object | $P_{cr}$ (N) | $\delta_{cr}$ (mm) | Initial Stiffness (N/mm) | Ratio |
|---|---|---|---|---|
| BK | 28600 | 2.00 | 14300.00 | - |
| BP1 | 31800 | 2.05 | 15512.20 | 1.08 |
| BP2 | 31800 | 2.03 | 15665.02 | 1.09 |

Table 4. Effective stiffness

| Tested Object | $P_y = P_u$ (N) | $\delta_y$ (mm) | Effective Stiffness (N/mm) | Ratio |
|---|---|---|---|---|
| BK | 88500 | 9.79 | 9039.84 | - |
| BP1 | 140800 | 17.68 | 7963.80 | 0.88 |
| BP2 | 180000 | 21.56 | 8348.79 | 0.92 |

Table 2 indicates that Ductility index for specimens BP1 and BP2 decreased toward the specimen BK with ratios of 0.62 and 0.36, respectively. The decrease of ductility index resulted from additional wire rope reinforcement in tensile region. By using the equation in Figure 9, it can be found out that in this research, the maximum ratio of wire rope ($\rho_w$) reinforcement that will result in the ductility index of 3.0 as the minimum requirement of ductility index for the reinforced concrete beam (Rashid and Mansur, 2005) was 0.006.

From Table 3, it can be known that initial stiffness increased, both for the specimens BP1 and BP2 toward the specimen BK with ratios of 1.08 and 1.09, respectively. It can be concluded that the increase of initial stiffness was not significant (the ratio came near 1) because at full elastic phase, the stiffness of specimen was influenced only by concrete and mortar materials.

From Table 4, it can be shown that effective stiffness decreased for the specimens BP1 and BP2 toward the specimen BK with ratios of 0.88 and 0.92, respectively. The decrease of effective stiffness was caused by wire rope as the reinforcing material, where it has a high level of flexibility.

### 4.3 Cracking and Collapsing Patterns

The control beam (BK) specimen underwent the first flexural collapse when the load reached 28.6 kN in the flexural region with displacement of 2.0 mm. With the load increased, cracks that occur at the tested objects were increasingly wide and developed toward stressed region. It was followed by new cracks propagating to pillar. Until the loads of *0.75Pu* or 65.7 kN load-displacement relationship came near linear and then the displacement continuously occurred at an almost constant load. The maximum load achieved 88.5 kN with the displacement of 52.72 mm. The last step of collapsing was characterized by the damage of mostly outer tension fiber concrete, signifying that concrete lost the capacity of retaining tension strength that occurred. It can be concluded that the type of collapsing occurred for the control beam (BK) was flexural collapsing. The pattern of cracking in the control beam (BK) could be seen in

Figure 10.

The reinforced beam of type 1 (BP1) underwent the first crack when the load reached 31,8 kN at absolutely flexural region with displacement of 2.05 mm and increasingly developed and propagated with the increased load. The cracks between mortar layer and old concrete began to occur when the load achieved 102.1 kN that came to be near the load of *0.75Pu* or 105.9 kN with the load-displacement relationship coming to be linear. Moreover, the slope of the diagram for load-displacement relationship changed, indicating the decrease of beam stiffness. The outer tension fiber underwent damage at the region of the loading point. The maximum load achieved was 140,8 kN with displacement of 30.44, which was characterized by the spalling of mortar materials at the reinforced segment. The pattern of cracking in the reinforced beam of type 1 (BP1) could be seen in Figure 11.

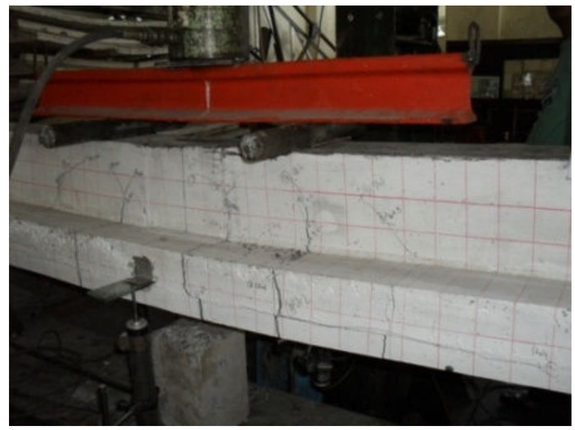


Figure 10. The pattern of crack in control beam

Figure 11. The pattern of crack in the reinforced beam of type 1

The reinforced beam of type 2 (BP2) underwent the first crack when the load achieved 31.8 kN at the absolutely flexural region with displacement of 2.03 mm. Cracks increasingly developed and propagated with the increased load. The hair crack between mortar layer and old concrete occurred at a low load of 39.0 kN, which continuously prolonged, but the load still showed an increase. When the load was

*0.75Pu* or 136.0 kN kN, the slope of the diagram for the load-displacement slope relationship changed, indicating the decrease of beam stiffness. The outer tension fiber at the reinforced beam of type 2 (BP2) also underwent damage at the region of the loading point. The maximum load achieved 180.0 kN with displacement of 32.72 mm. The pattern of cracks for the reinforced beam of type 2 (BP2) could be seen in Figure 12.

Figure 12. The pattern of crack in the reinforced beam of type 2

### 4.4 Tension of Wire rope

Tension at the wire rope did not reach 50% of the ultimate stress, indicating that the contribution of wire rope as the reinforcing material was not optimum. The stress resulting from the *Response-2000* analysis and the layer method analysis is presented in Table 5.

Table 5. Tension of wire rope

| Reinforcement | Tension (MPa) | Information |
|---|---|---|
| Control Beam (BK) | | |
| Tul. P8 | 186.8 | Not melting |
| Tul. D13 | 479.71 | Melting |
| The Reinforced Beam of Type 1 (BP1) | | |
| Tul. P8 | 373.85 | Melting |
| Tul. D13 | 479.71 | Melting |
| Wire rope D10 | 281.12 | *37.80% |
| The Reinforced Beam of Type 2 (BP2) | | |
| Tul. P8 | 373.85 | Melting |
| Tul. D13 | 479.71 | Melting |
| Wire rope D10 | 215.88 | *29.03% |

## 5 CONCLUSIONS

a) Load capacity increased for the specimens BP1 and BP2 toward to specimen BK with ratios of 1.59 and 2.03, respectively.
b) Ductility index of the specimens BP1 and BP2 decreased toward specimen BK with ratios of 0.62 and 0.36, respectively.
c) Initial stiffness of the specimens BP1 and BP2 decreased toward specimen BK with ratios coming near 1, i.e 1.09 and 1.08, respectively, so that although the increase occurred, it was not significant.
d) Effective stiffness of the specimens BP1 and BP2 decreased toward specimen BK with ratios of 0.88 and 0.92, respectively.
e) The specimen BK underwent a flexural collapse where the damage of mostly outer stress fiber concrete began to occur when the load came near the maximum. For the specimen BP1, the spalling occurred when the maximum load was achieved, and for the specimen BP2 the hairline cracking between mortar and old concrete began to form at a low level of load achievement.
f) Stress of the wire rope did not reach 50% of the ultimate stress.
g) In general, if the improvement was not carried out for the wire rope material stiffness, its contribution as the reinforcing material was not optimum.

## 6 RECOMMENDATIONS

a) The setup instrument of measuring the wire rope tensile should be installed when the testing of reinforced concrete beam is in progress.
b) Further research should be done by taking into account the improvement of wire rope material stiffness, such as by giving initial pre-stress force in order that the effectiveness of wire rope as the reinforcing material in the negative moment region can be found out.

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