Behaviour of Post-Tensioned Kempas Timber Beam with Two Tendon Types

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Abstract. The post-tensioning technology is commonly used for concrete structures especially bridges. This technology is applied for timber elements in many countries effectively. In Malaysia the timber post-tensioning still not known yet. This research aim to propose the post-tensioning technique for timber beams. The timber type is Malaysian Kempas and the device used to apply the post-tensioning force is hydraulic jack. Three types of specimens were tested using the bending test (four-point bending test) for a simple support beam. Two type of specimens are post-tensioned timber beams with black threaded rod bar (PTBR) and post-tensioned timber beams with silver threaded rod bar (PTSR). All the specimens’ length is 1.2 meter and the dimension of timber is 90mm x 40mm. The increment of moment capacity of post-tension timber beam compared to the timber beam the moment resistance increment is 1.42 times. The moment resistance of the post-tensioned timber beam had average increment is 27.4% - 31.8%. The other finding is the failure mode of specimens it is changed from brittle tension failure to ductile failure (compression failure) the cause of this behavior is the role of the post-tensioning rods.

1. Introduction
Pre-tensioning and post-tensioning forces are well known in structural elements. They are widely used in many systems and with different materials. Especially concrete, as they can modify the bending stresses by reducing the tensile stresses. This property of tensioning is also useful in wooden structures. Although wood has a very high tensile strength when it is defect-free. Its tensile strength in real structures is less than its compressive strength due to the presence of defects intrinsic to this material. The effects of applying a pre-stressing force on timber beams has been studied and analysed several times Lantos [1]. Used a mono-wire cable for pre-stressing with the aim to reinforce low-grade wood. The result was fewer variable failure loads with only a modest increase in strength. Peterson [2] attempted to increase strength and stiffness by using a pre-stressed high-strength steel strip bonded to the beam tensile surface, with moderate success. Reinforcing glulam beams with bonded pre-stressed FRP laminates in the tension zone has recently been proposed as a mean of utilizing low-quality timber by improving its structural performance [3].

Stress-laminated deck plates are typically used in bridge decks. A pre-stressing force is applied perpendicular to the grain and increases the shear friction between the individual pieces of timber [4]. More recently, a pre-stressed LVL-concrete composite beam was constructed and tested by Deam et al [5]. The pre-stressing tendons had little effect on stiffness or strength, but they did reduce the deflection
from the permanent load, particularly when the tendons were draped. New Zealand and Australia recently developed frames of unbounded post-tension timber to construct long-span structures in multi-storey building [6]. The laminated veneer lumber (LVL) and wire strands were the main material for that system. This system can resist the load from earthquake by generating moment–resisting frames [7].

Researchers used steel bars at Italy to glue laminated (glulam) timber beam as pre-stressed tendons. This tendon (steel rod) used in pre-stressing timber beams increased the stiffness, ductility and ultimate load of timber compared to normal timber [8]. The steel or carbon FRP plates used by early researcher to apply pre-stressing in timber beam to increase strength of timber [9]. These researches of the reinforcement systems didn’t success to use as construction market at Italy. The reason of that is the long-term of efficiency and reliability for these systems still do not have enough proven experimental data [8]. McConnell et al. research [10] considers the glulam post-tensioned timber act as reinforced beam with addition eccentric force (post-tensioning force). Figure1 explain the stress diagram that happened in post-tensioned glulam timber, the post-tensioning force could neutralize the tensile stress resulting due the load.

![Figure 1: Stress profiles of unreinforced and tension reinforced glulam timber [10]](image)

This research aim to propose the post-tensioning technique for timber beams. The type of timber is Malaysian Kempas and hydraulic jack used to apply the rod bar force that present the post-tensioning force to the timber beam. Two type of threaded rod bar used as tendons silver color and black color.

2. Materials and methods

2.1. The specimens detail

The details of cross section for the three type of specimens is shown in Figure 2. The timber beam is the first specimen. The post-tensioned timber beam is second specimen. The post-tension timber concrete composite beam is the third specimen. The top layer of concrete is laid on the top of post-tension timber beam.

![Figure 2. Cross section details: (a) Timber only, (b) Post-tensioned Timber](image)

3 series with 4 specimens for each series are prepared with acronym TB as notation for timber beam. For post-tensioned timber beam with black rod the notation is acronym PTBR and for post-tensioned timber beam with silver rod Acronym PTSR as notation.
2.2. Post-tensioning method and preparation for specimens post-tensioned timber beams.

Post-tensioning by Pre-stressing Jack method is the standard method of post-tensioning in concrete structures. Similar method is used in the case of timber post-tensioning. The main difference is that low post-tensioning force required in case of timber post-tensioning. Which lead to use threaded rod bar as tendons. The components used are the device (pump and jack) of capacity 200 KN. extra fittings are required to fix the timber specimen and transfer the load from device to the specimen. These fitting are pair of C channel covered by plate to fix the specimen during the process, two end plates with size (40x110mm. thickness 10mm) fixed with screw. Two type of rod bars black color (8.85 mm) and silver color (9.4mm) with nuts [11].

The total components are shown in Figure 3 and 4. Chair steel bracket at the timber beam end to transfer the load from the jack to the beam, Figure 4. Show the position of two dial gauges to measure deflection of timber and displacement of rod bar.

![Figure 3](image1.png)

(a)

![Figure 3](image2.png)

(b)

![Figure 3](image3.png)

(c)

**Figure 3.** a) the chair position during the post-tensioning process b) black rod bar c) silver rod bar

![Figure 4](image4.png)

**Figure 4.** a) The arrangement of jack and pump during post-tensioning process
2.3. The bending test procedure

All the specimens had been carried out the four-point bending test to determine the bending strength of the specimen, bending modulus of elasticity, the material flexural stress-deflection response. This test usually carried out using Universal Testing Machine (UTM) according to BS EN 408:2010 code [12]. The arrangement of the bending test is shown in Figure 5. The I-beam used at two points over the span to ensure apply symmetrical load in the test, refer Figure 5. The load rate set to 5.0 mm/min until the specimen failure. The maximum deflection occurs at the middle of span. For that the (LVDTs) linear variable differential transformers are located at midpoint of the span to record the specimen deflection.

3. Preliminary tests

The supplementary tests concerned the timber beam are (4 point bending test) and the compression test. The threaded rod bar test is tensile test for the two types black color and silver color. The detail of test specimens and results were presented in Table 1. The modulus of elasticity for black rod bar is 205.769GPa and silver rod bar is 150.133GPa.
Table 1: the preliminary tests results in (MPa)

| The test type                  | Number of specimens | Size mm                     | Results                  | Average value | COV% |
|-------------------------------|---------------------|-----------------------------|--------------------------|---------------|------|
| 4 point bending test          | 5 timber            | 1000x40x90 (l x w x h)      |                          | 86.5          | 7.6% |
| Compression test              | 2 timber            | 40x90x380 (l x w x h)       |                          | 65.8          | 0.1% |
| Tensile test                  | 2 Rod bar silver    | 100x9.4 (l x diameter)      | Yield stress             | 298           | 4%   |
|                               |                     |                             | Ultimate stress          | 318.5         | 1%   |
| Tensile test                  | 2 Rod bar black     | 100x8.85 (l x diameter)     | Yield stress             | 519           | 1.5% |
|                               |                     |                             | Ultimate stress          | 538           | 1.7% |

4. Tensioning force estimation
The theoretical post-tensioning force is obtained from the deflection formula used in case of pure bending moment acting on the end beams. This formula is calculated using moment area method and its value \( \Delta = \frac{M \times L^2}{8EI} \) [13]. The post-tensioned force (PT) is calculated by two methods theoretically and experimentally. The theoretical method using the deflection equation of pure bending moment at the end \( \Delta = \frac{M \times L^2}{8EI} \), where \( M = PT \times x \) then \( \Delta = \frac{PT \times x \times L^2}{8EI} \) and it was related to the PT upward deflection. The experimental method depend on rod bar deformation (\( \Delta_{rod \ bar} \)) and rod bar modulus of elasticity \( E_{rod \ bar} \), the \( PT = E_{rod \ bar} x \varepsilon x A \). The results of the two methods are listed in Table 2.

Table 2: Post-tensioning force estimation theoretically and experimentally

| Series references | Upward Deflection (mm) | Estimated PT Force (kN) \( PT = \frac{\Delta \times 8EI}{eL^2} \) | Estimated PT Force (kN) \( PT = E_{rod \ bar} x \varepsilon x A \) |
|-------------------|------------------------|------------------------------------------------|------------------------------------------------|
| PTBR-1            | 3.84                   | 22.3                                           | 22.2                                           |
| PTBR-2            | 2.66                   | 15.4                                           | 17.7                                           |
| PTBR-3            | 4                      | 23.2                                           | 22.8                                           |
| PTBR-4            | 3                      | 17.4                                           | 19.0                                           |
| PTSR-1            | 2.84                   | 16.5                                           | 15.0                                           |
| PTSR-2            | 2.86                   | 16.6                                           | 15.1                                           |
| PTSR-3            | 3                      | 17.4                                           | 15.5                                           |
| PTSR-4            | 3.38                   | 19.6                                           | 16.7                                           |

5. The Effect of Post-Tensioning Method on Timber Beam Behavior
The behavior of timber beam and post-tensioned beam is presented in Table 4. The \( F_u \) is the ultimate load during the timber beam bending test. The \( M_{exp} \) is the collapse bending moment value which calculated from the equation \( M_{exp} = \frac{F_u x a}{z} \). The timber beam bending strength \( f_b \) that calculated by equation \( f_b = \frac{3F_u a}{2bh^2} \). The equation for modulus elastic, \( E \) is \( E = \frac{F_u a}{4bI \delta_{max}} (3L^2 - 4a^2) \) which depend on the specimen length \( L \), experimental collapse bending load \( F_u \) and the deflection at mid-span in collapse condition, \( \delta_{max} \). The average bending stress of timber beam is 86.5MPa and the average modulus elastic for timber beam is 8961.0MPa. The mode failure of all the specimens for timber beam is tensile crack started at tension edge. For specimens PTBR, the moment improvement had experimental average 27.4% compared to the timber beam bending strength. Next, for specimens PTSR, the bending strength improvement is 31.7%. The failure type of the post-tensioned beam observed after the bending test show
two types. First type is shown in Figure 6(a) display anchorage longitudinal shear failure and the steel end plate is torn out. Second type is shown in Figure 6(b) display the compression with longitudinal shear failure occurs at the mid span.

**Table 3.** Experimental data results with bending strength increment of timber beam and post-tensioned beam.

| Specimen Ref. | $F_u$ (kN) | $M_{exp}$ (kNm) | PT upward def. (mm) | $\Delta_{max}$ (mm) | Increment (%) |
|---------------|------------|-----------------|---------------------|---------------------|---------------|
| TB- Average   | 30.4       | 4.8             |                     | 21.2                |               |
| PTBR-1        | 34.2       | 5.5             | 2.84                | 43.7                | 11.67         |
| PTBR-2        | 38.3       | 6.1             | 2.66                | 37.8                | 25.06         |
| PTBR-3        | 40.1       | 6.4             | 4                   | 22                  | 30.94         |
| PTBR-4        | 43.5       | 7.0             | 3                   | 26.2                | 42.04         |
| Average       | 39.0       | 6.2             |                     | 32.4                | 27.4          |
| Std. Dev.     | 3.9        | 0.6             |                     | 10.1                |               |
| COV %         | 9.9        | 9.9             |                     | 31.0                |               |
| PTSR-1        | 39.2       | 6.3             | 2.84                | 22.3                | 28.00         |
| PTSR-2        | 43.3       | 6.9             | 2.86                | 26.7                | 41.39         |
| PTSR-3        | 40.0       | 6.4             | 3                   | 25.0                | 30.61         |
| PTSR-4        | 39.0       | 6.2             | 3.38                | 26.2                | 27.35         |
| Average       | 40.4       | 6.5             |                     | 25.1                | 31.8          |
| Std. Dev.     | 2.0        | 0.3             |                     | 2.0                 |               |
| COV %         | 4.9        | 4.9             |                     | 7.9                 |               |

**Figure 6.** Typical failure modes of the PT beams silver rod: (a) at the anchorage, (b) at the mid span

A comparison between timber beam and post-tensioned timber beam bending test results are shown in Figure 7. It is obvious that post-tensioned timber show higher bending capacity and more ductility. The data results of all the tests for the two types of rod bars are shown in Figure 8a) and the close results of tests for both types are shown in Figure 8b), the specimens which is close to average value are shown in Figure 8c) it can see that the silver rod bar give small increment than black rod bar.
Figure 7. Comparison between bending test for timber beam and PT beam

Figure 8. A comparison between a) all data results  b) the close results  c) the typical results
6. Conclusions
In term of post-tensioning timber the average increment of moment resistance compared with timber beam capacity is 27.4% for black color rod bar and 31.8% for silver rod bar. The common failure mode of beam after bending test it is observed that a compression with longitudinal shear failure occurs at mid span. The other failure type in less degree is anchorage longitudinal shear failure and the steel end plate is torn out. The bending test results for post-tensioning timber beams show the critical specimens beam is PTBR−4 and PTSR−2. Both of the bending strength increment is 42% compared to timber beam bending capacity, the average experimental bending capacity for silver rod bar is 6.5kNm which is higher than black color type 6.2kNm with variation value 6.1-7.0 kNm depending on the timber properties and defects presence in the timber. The analytical of stress distribution, show reduction in the resultant stress value due to the post-tensioning stress that result from post-tensioning force eccentricity. The maximum negative displacement that can be achieved is 4mm. the post-tensioning fitting parts, end anchorage locking nut, end plate and the timber at the end support were efficient during post-tensioning process.

7. References
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