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KEMPAS TIMBER UN-BONDED POST-TENSIONING SOLUTION NEW APPROACH

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ABSTRACT

Post-tensioning technique is a commonly used for concrete structure. This technique had many advantage, it gives thinner section larger span, better cracking resisting sections. For timber material it is a new technique with limited use. in this paper a natural timber (Malaysian Kempas type) is used in post-tensioning solution. Two methods are investigated for post-tensioning solution. The first method is the standard method of post-tensioning which used commonly in concrete pre-stressing that include pump and jack tools. The other method is a new way for post-tensioning that depending on the fundamentals of pre-stressing and bending theory. Two type of threaded rod bar are used. The two methods were deflection control process and the post-tensioning force estimated by stress-strain relation. The limitation of post-tensioning force was depending on the timber, rod bar strength capacity. The results clear that standard method is more effective in post-tensioning process while the post-tensioning by bending is safer for specimens due to avoiding stress concentration at the end face of beam.

Key words: Kempas timber, post-tensioning, bending jacking, pre-stressing jacking

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1. INTRODUCTION

Pre-tensioning and post-tensioning forces are well known in structural elements. This technique used in many systems and with different materials, especially concrete. Its function is by modify the bending stresses which reduce or cancel the tensile stresses. The property of tensioning can be used in wooden structures. The merit of wood that it has a very high tensile strength at defect-free condition. The wood tensile strength in real structures is less than its compressive strength due to the essential nature of presence of defects. wood exhibits ductile failure in compression and brittle failure in tension. Fore that, the introduction of a compressive force via a tensioning system reduces the probability of brittle failures in the material, which are always undesirable in structures.

When tensioning forces are eccentrically applied to the cross-section of a structural element, they also introduce a bending effect opposite to the gravitational loads. This effect helps to limit the final deformations, improving the behavior of structures at their serviceability limit [1]. This feature has been widely used in steel and wooden structures, especially in those with long spans inasmuch as their bigger deformations are what will most condition the design. In the case of wooden structures, these solutions have recently lead to the development of a special field of study because of the wood's low rigidity in comparison with other structural materials.

The simplest system for limiting deformation involves the use of unbonded tendons placed eccentrically on the cross-section. The maximum efficiency is reached by placing tendons externally to the cross-section, as in under-deck cable-stayed beams [2]. Introducing the tensioning components within the cross-section, even though placed as far as possible from its barycenter, enables to use the wooden cross-section as a protective component in the case of fire. Simultaneously, the steel is not visually perceived anymore, so it seems that the structural element is entirely made of a timber piece with a height that appears smaller than it should be. These tendons can be pre-tensioned, as in the panels of the roof of the Richmond Olympic Oval in Vancouver, Canada [3], or post-tensioned, as in the solution proposed by Massey University College of Creative Arts, Wellington, New Zealand [4].

Post-tensioning systems allows the connection of pillars and beams, resulting in an increased rigidity of the joint, thus giving the possibility of transmitting moments. This improves the behavior in comparison to beam-pillar joints made with traditional mechanical components. Buchanan [5] has studied the use of post-tensioning systems that employ unbonded tendons to increase the rigidity of these beam-pillar joints in complete wooden frameworks. Another advantage of these systems is the improved seismic behavior of multi-story buildings entirely built with wooden structural components [6].

Another option that has traditionally been used to improve the bending behavior of wooden elements is reinforcement with bars or bonded tendons, which may be pre-tensioned. Based on the progress in adhesive technologies and their derivatives, many studies have proposed the use of Fiber Reinforced Polymer (FRP) or other fibers that are glued to the wood in the form of bands, sheets, or bars [7]. Initially, these proposals were related to the development of reinforcements for existing structures. These reinforcements resulted in improvements of the strength and rigidity of these elements, although the improvements were heavily dependent on how the reinforcements were executed. In addition, it has been observed that the rigidity also increases when incrementing the span of the components [8]. Reinforcement can also be performed with bonded-in steel, but several authors have noted the problem of possible failure due to delamination caused by the difference in the rigidites of the materials that are to be joined [9] [10].

These solutions have been extrapolated to the design of new structural elements in which the reinforcing component is pre-tensioned before bonding it to the beam. Furthermore, this approach adds a small precamber generated by the pre-tensioning to the advantages of the reinforcement [11] [12]. These studies indicate the possibility of failure by delamination at the extremities of the reinforcement and the necessity of evaluating the long-term behavior. Structural elements with bonded and post-tensioned tendons exhibit greater strength and rigidity than elements in which the reinforcements are bonded, but not post-tensioned [13].

This article presents a practical system produces a post-tensioning force. The advantage of the presented system, and its main difference from other existing systems, is that the post-tensioning force is generated via bending loads that act on the structure. The proposed system can be of great utility when applied to the design of long-span wooden structural systems. It is possible to achieve structures that remain almost horizontal without significant deflections under service loads.

2. POST-TENSIONING SOLUTION

The post-tensioning solution will include two methods for post-tensioning solution. The first method is the standard method of post-tensioning by using pump and jack which is noted as (PJ) .The other method is a new way for post-tensioning was developed for practical matters, which depending on the fundamentals of pre-stressing and bending theory, this method is noted as (BJ). The properties of the material used in the process will define the limitation of the method. The research will conduct the material properties, the theoretical fundamentals, the methods detail, the estimation and limitation of post-tensioning force.

2.1. Material Properties

The supplementary tests concerned the timber beam are (4 point bending test) and the compression test. The 4 bending test specimen size is 40x90x1200 mm and the compression test specimen size is 40x90x240 mm. The bending test results were presented in Table 4.1**.** This results give the collapse load (P), the maximum bending moment (M=P x a/2), maximum bending stress (σ_m =M/Z). Where Z is section modulus which calculating using (Z=bh2/6).

The average value of bending stress for 5 specimens was 86.5 Mpa and modulus of elasticity is 12103.6 Mpa. In same manner for compression test of timber three specimens were tested the results presented in Table 1**.** The average compressive strength is 60.9 Mpa .

The tensile test was done to threaded rod bar using extensometer (50 mm gauge length). The results of tensile test for two type of rod bars black and silver color are shown in Table 1**.** This table presents the results of yield and ultimate tensile strength. It is obvious that black rod had high yield and ultimate tensile strength 480. 506.7Mpa respectively compared with silver rod bar 288.3. 310.8 Mpa. E for black rod bar is 205769.2 Mpa E for silver rod bar is 212579.2 Mpa

Table1: the material property detail

The test	Specimen code	Number of specimens	Size mm	Results	
4 point bending test (Mpa)	T_b1	5	1000x40x90	91.66	
	T_b2			92.71	
	T_b3			88.25	
	T_b4			82.80	
	T_b5			76.9	
Average value		COV%		86.5	7.6%
Compression test (Mpa)	T_c1,	3	40x90x240	51.2	
	T_c2,			65.6	
	T_c3			65.8	

Average value		COV%		60.9		13.7%	
Tensile test (Mpa)				Yield stress		Ultimate stress	
	S1.	2	100x9.4 dia	286		322	
	S2,			310		315	
Average value		COV%		298	4%	318.5	1%
Tensile test (Mpa)	B1,	2	100x8.85dia	526		547	
	B2,			511		529	
Average value		COV%		519	1.5%	538	1.7%

Note: T_b is timber beam for 4 point bending test, T_c is timber sample for compressive test, S is silver color threaded rod bar , B is black color threaded rod bar. All the timber tests are done parallel to grain.

2.2. Post-tensioning Solution (The Concept)

Post-tensioning is a method of reinforcing (strengthening) concrete or other materials with high-strength steel strands or bars, typically referred to as tendons. Post-tensioning applications include office and apartment buildings, parking structures, slabs-on-ground, bridges, sports stadiums, rock and soil anchors, and water-tanks.

The theoretical fundamentals of the conventional pre-stressing jack depending on The pre-stressing tendon place. Commonly it is placed eccentrically below the neutral axis at mid-span. to induce tensile stresses at the top fibers due to pre-stressing. If the tendon is placed at eccentricity *e* from the center of gravity of the concrete. it creates a moment Pe, and compressive stresses as shown in Figure1.

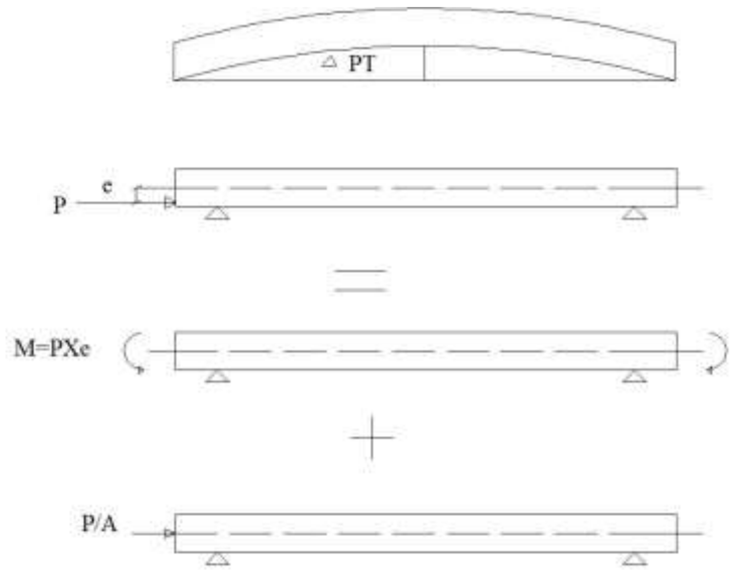


Figure 1: Post-tensioning force components

The second post-tensioning solution is given the name “Forced-bending Jacking Method”. This solution method is novel in that it is derived based on the theoretical concept of bending and combining it with the conventional pre-stressing theoretical concept. The novelty of this solution is found useful when the normal pre-stressing jack is not available. hence this “Forced-bending Jacking Method” is a second option that can be used.

This section presents the basic concept in the case of forced bending post-tensioning method. This concept deepened on the idea that the same vertical deflection in timber beams resulting from various load reflect the same moment causing this similar deflection. Fore that the moment of post-tensioning force can be achieved by bending force give the equivalent moment. Figure 2 which present the bending moment diagram for the two cases of post-tensioning first pure bending result from post-tensioning force and second from 4 point bending force.

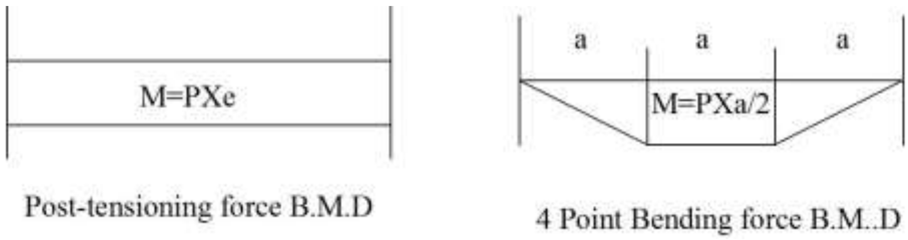
And that concept can be represented by this condition:

(Deflection due post-tensioning = Deflection due forced bending) which mean in another word (Bending moment due post-tensioning = bending moment due forced bending).

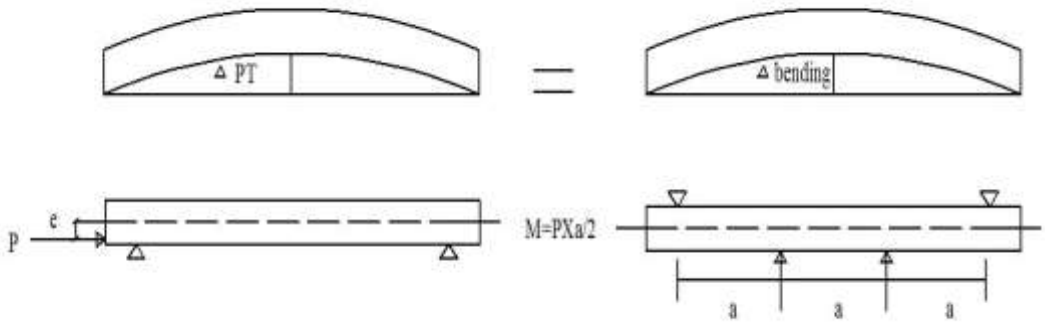
Bending moment due post-tensioning=Pt x e. Pt = post-tensioning force. e = eccentricity of post-tensioning force of neutral axis (at middle case of symmetry) Bending moment due forced bending =P x a/z . P= point force causing bending moment. Eq.1&2 show the equilibrium condition the estimation post-tensioning force equal to the effect of bending force.

$$p_{post\text{-}tensioning} \times e = \frac{p_{bending} \times a}{2} \quad (1)$$

$$p_{post\text{-}tensioning} = \frac{p_{bending} \times a}{2 \times e} \quad (2)$$



a) Bending moment diagram for post-tensioning force and 4 point bending.



b) Similar deflection due post-tensioning force and 4 point bending.

Figure 2: a) bending moment diagram for post-tensioning force and bending force b) Deflection due post-tensioning force and bending force.

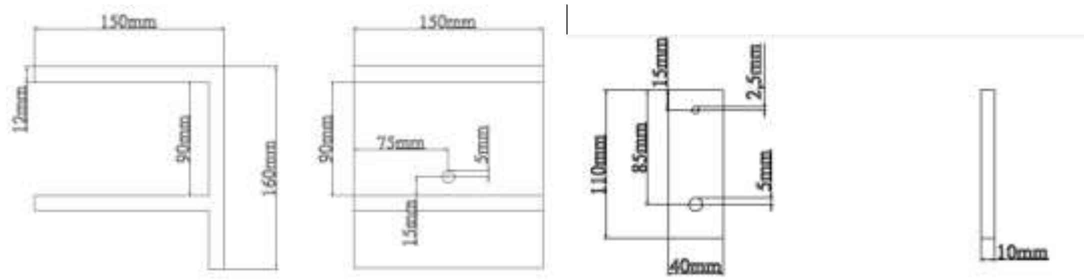
2.3. Post-tensioning by Pre-stressing Jack

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 & 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. The nuts used to keep post-tensioning action as shown in Figure3.

The total components are shown in Figure 4. Chair steel bracket at the timber beam end to transfer the load from the jack to the beam, Figure 5. Show the position of two dial gauges to measure deflection of timber and displacement of rod bar**.**

The screw dimensions detail which used to fix the end plate to timber beam.

Type of connector	Length (mm)	Diagonal (mm)	Head diagonal (mm)
Screw	68.70	5.47	9.48



Chair front view Chair side view end plate front view end plate side view

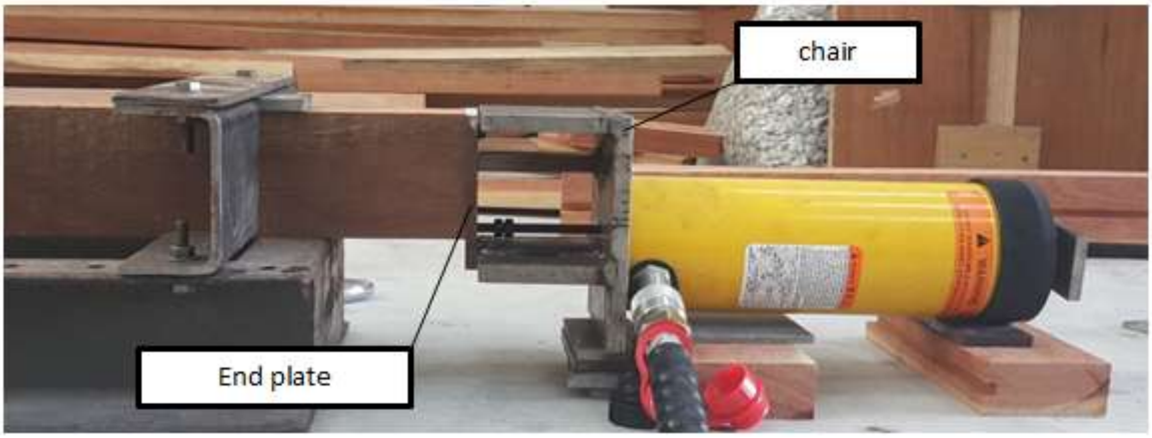
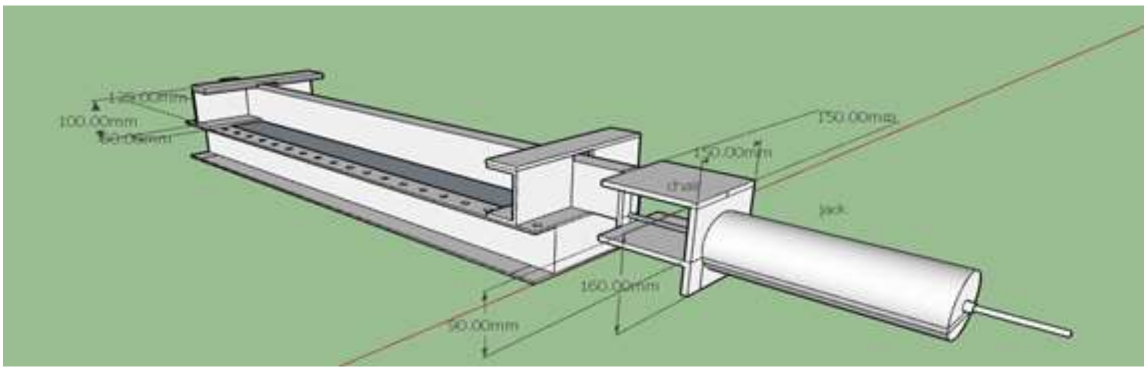


Figure 3: The chair part which used at the end of beam and end plate



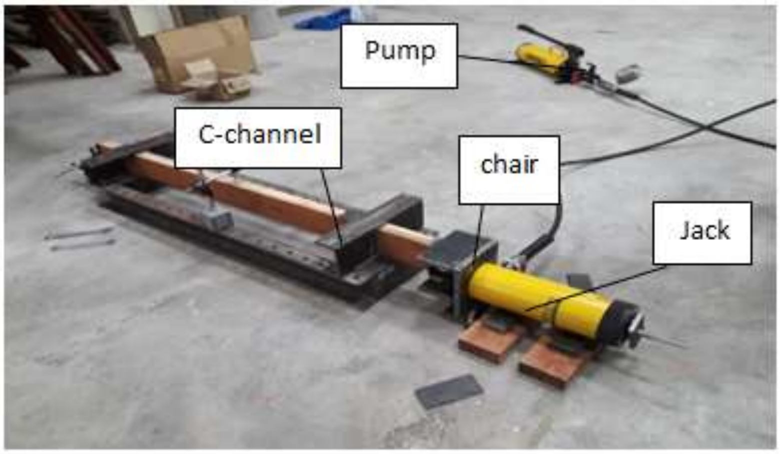


Figure 4: The total system of post-tensioning

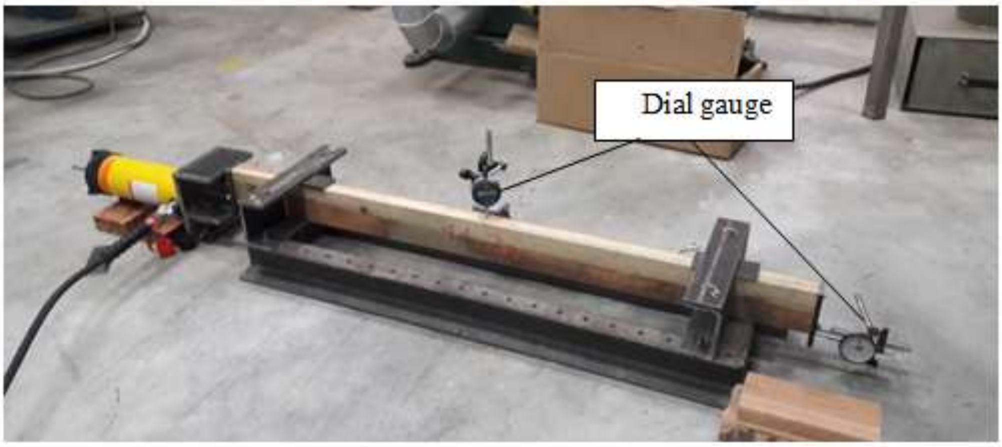


Figure 5: The dial gauge position in total system of post-tensioning

The post-tensioning process includes fixing the specimen on base plate. Put two dial gauges on mid span to read deflection and on end plate at level of rod bar to read rod bar deformation. Start the jacking and record data of dial gauges. Then fix the rod bar by nuts and release the pump and record the final reading, which named residual deflection. Which mean the deflection stored at specimens at end of post-tensioning process.

2.4. Post-tensioning by (Forced-bending) Method

Post-tensioning by (Forced-bending) method is the application of the principle of the equivalent action of bending force to post-tensioning force action. which requires the condition of similar deflection. The process of this method is the same as the bending test process. But with difference that the specimen position at the machine is opposite from the normal position of test as shown in Figure 6.a. It means the top of specimen is the part which included the threaded rod bar. This method required, universal testing machine (1000KN capacity), two dial gauge and reinforced timber beam. The two dial gauge to record vertical deflection and rod bar deformation.

The process of post-tensioning is shown in Figure 6 . This process includes fixing the specimen inside universal testing machine, applying the load to the timber specimen to make downward deflection as shown in Figure 6.a&7. Fixing the nuts to keep post-tensioning force see Figure 6.b&8**.** The two dial gauges to record vertical deflection and deformation of rod bar as shown in Figure 6.c&9. This process gives the residual deflection which means the stored vertical deflection at mid span after fixing rod bars with nuts

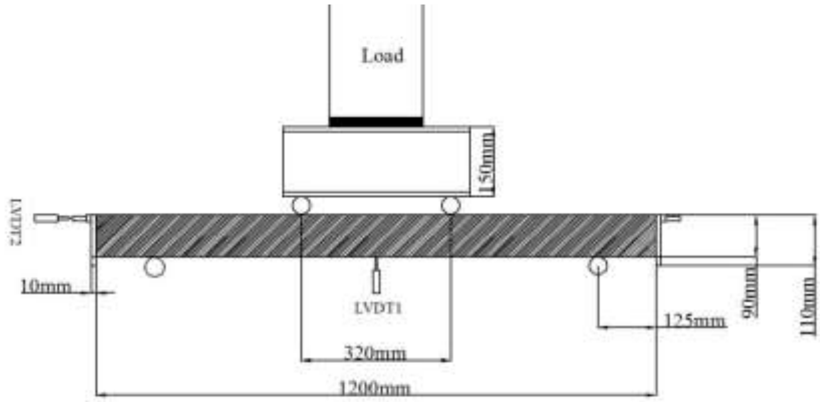


Figure 6 a) First step is putting the beam timber specimen upside down at universal testing machine

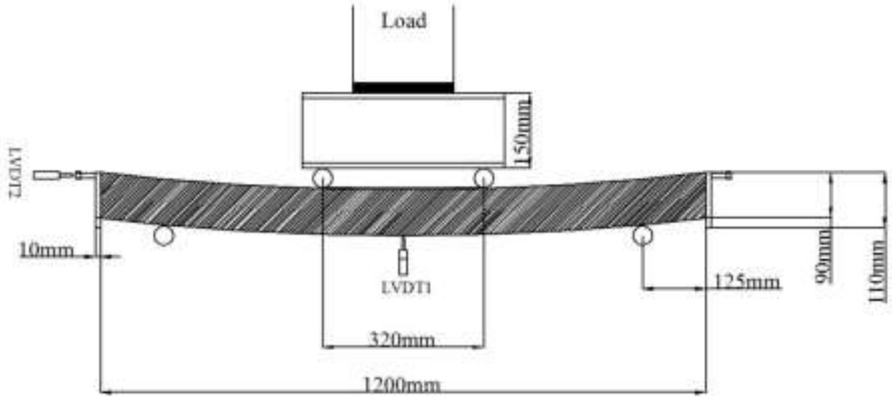


Figure 6 b) Second step is to release the nuts at rod bar then start applying load until the suitable deflection.

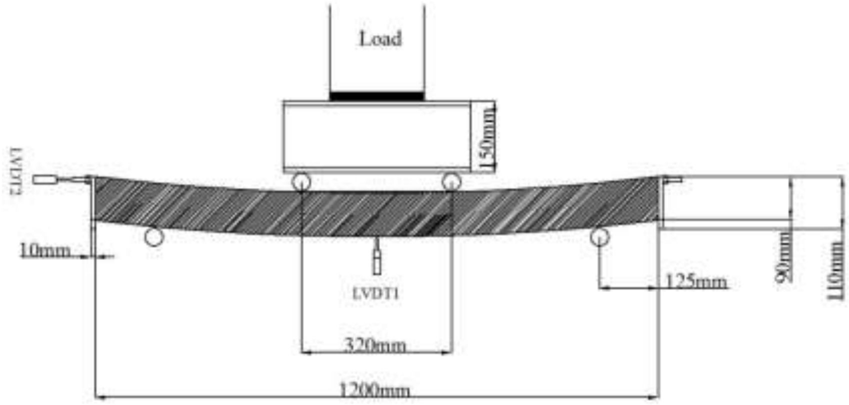


Figure 6 c) Third step is to tight the nuts at ends and releasing the load of universal testing machine.

Figure 6: The process steps of post-tensioning by bending a,b& c.

Figure 7: The process of post-tensioning by bending using universal testing machine

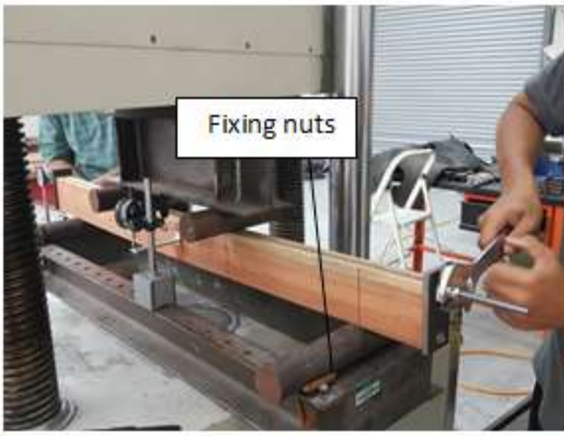


Figure 8: Fixing the post-tensioning force **Figure 9**: Dials gauge

3. THE MAXIMUM SAFE CAMBERING DURING POST-TENSIONING PROCESS

In case of rod bar post-tensioning it is necessary that the rod bar force not exceed elastic region (yield tensile strength). This limitation to rod bar due to the capability of restoring the original length after force removes under elastic region. It is known from rod bar tensile test that the yield strength load is 20 kN for silver rod and 31.8 kN for black rod. So the maximum post-tensioning force can't exceed this load. For that post-tensioning force calculated theoretically from the (equivalent deflection principle) discussed in previous chapter 3 (section 3.4.3) ($P_{post\text{-}tensioning} = P_{bending}$ x a/ (2x e)). The theoretical results for a bending force in range from (1-6KN) and corresponding results presented in Table 4.4. In this table the results listed for bending moment, bending stress, equivalent post-tensioning force and deflection. The post-tensioning force is calculated using the form (PT Force= M/e) and deflection using the form $\Delta=(PxL^3/48EI)$. The eccentricity (e) present the post-tensioning force arm from neutral axis= 45 mm. Δ deflection due bending force. E modulus of elasticity of timber = 12103.6 N/mm^2. L span length. I area moment of inertia $=bh^3/12$ for rectangular. The maximum theoretical cambering is 3.77 mm for silver rod bar and further for black rod bar. It will be assumed in this research that 3.8 mm and 4 mm 100% PT, for silver and black color respectively. The 50% PT will be 2mm as 50% for both rod bar types. In another side the maximum post-tensioned force can be applied should not cause compression force on timber exceed the compressive strength capacity. The maximum compression applied stress should not exceed the ultimate compressive stress strength of timber which is (60.9 Mpa). Two parts of stress applied on compression zone of timber the first part is bending stress due to eccentricity of post-tensioning force. This part bending stress is taken from Table 4.4. The second part is compressive stress calculating from the value of equivalent post-tensioning force given in Table 4.4 which is dividing on the area of cross section .Then the total stress will be the sum of this two parts. The total stress should be less than timber compressive strength 60.9 Mpa as presented in Table 4.5. For that the maximum save deflection is 4 mm for black rod and 3.77 mm for silver rod.

Table 2: The total stress in compression zone and its components.

P point load (bending load) kN	Deflection mm	Part 1 bending stress (Mpa)	eq. pre-stress force kN	Part2 compressive stress (Mpa)	Total stress (Mpa)
3	1.99	8.95	10.74	2.98	11.93
4	2.65	11.92	14.3	3.97	15.89
4.5	2.98	13.4	16.08	4.47	17.87
5	3.31	14.88	17.85	4.96	19.84
5.3	3.51	15.77	18.9	5.25	21.02
5.7	3.77	16.95	20.3	5.64	22.59
6	3.97	17.84	21.41	5.95	23.79

4. POST-TENSIONED METHOD PT JACKING

The recorded results of post-tensioning method are the vertical deflection before and after fixing nuts. In the pre-stressing jacking method the residual deflection (after fixing nuts residual deflection) against the deflection before fixing nut (jacking deflection) are listed in Table 3. Two types of nuts were used to store post-tensioning force, double hex nut and long coupling Figure 11. The residual deflection of jack pre-stressing is 88.8% of jacking deflection for double hex nut, and 98.2% of jacking deflection for coupling nut. Figure 10 shows comparison for residual deflection between two types of nuts.

Table 3: Residual deflection for timber in case of post-tensioning jack device

Sample black rod double hex nut	Jacking deflection (mm)	Residual deflection (mm)	Percent of residual %
T1-B	4.16	3.84	92.3
T2-B	4.10	3.84	93.7
T3-B	3.69	3.0	81.3
T4-B	3.03	2.66	87.8
		average	88.8
Sample silver rod couple	Jacking deflection	Residual deflection	Percent of residual %
T1-S	3	3	100
T2-S	2.32	2.32	100
T3-S	3.4	3.38	99.4
T4-S	3.2	3.07	95.9
T5-S	2.86	2.73	95.5
		average	98.2

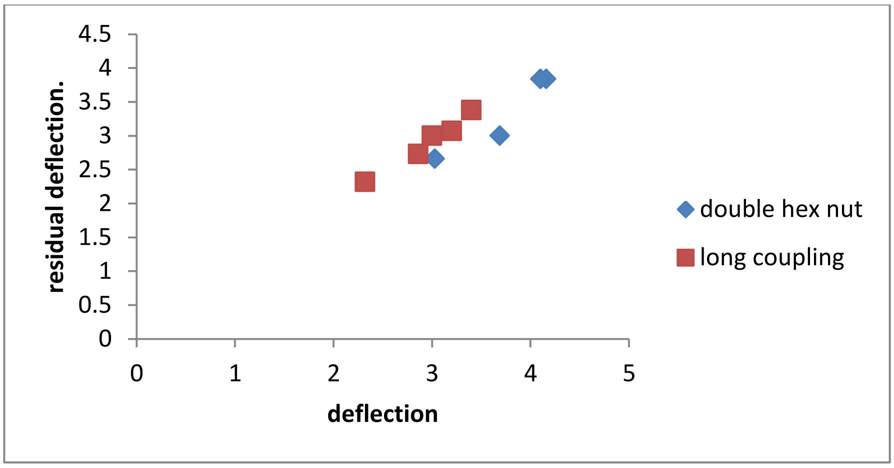


Figure 10: Correlation between deflection and residual deflection for two types of rod bar (silver color with long coupling nut and black color with double hex nut)

Figure 11: Long nuts coupling and double hex nut

5. POST-TENSIONED METHOD FORCED BENDING

This method aim to give the same effect of upward cambering by using forced bending. The results of vertical deflection(jacking deflection) at mid span and corresponding residual deflection for Forced-bending jacking are shown in Table 4. which present the results of residual deflection for different deflection due to Forced-bending of specimen post-tensioned using long coupling.

Table Error! No text of specified style in document.: Residual deflection for bending jacking process at end of beams using long nuts coupling

Specimens long nuts coupling	Jacking deflection (mm)	Residual deflection (mm)	Residual def. percent %
T5-S	5.29	1.93	36.5
T6-S	8	2.8	35
T7-S	5.34	2.14	40.1
T8-S	9.2	2.87	31.2
T8-S	8.6	2.81	32.7
		average	35.1

The residual deflection of pre-stressing using bending jacking for silver rod bar is 35.1%. Figure 12 present the correlation between deflection and residual deflection for silver rod bar using two types of nuts double hex nut and coupling.

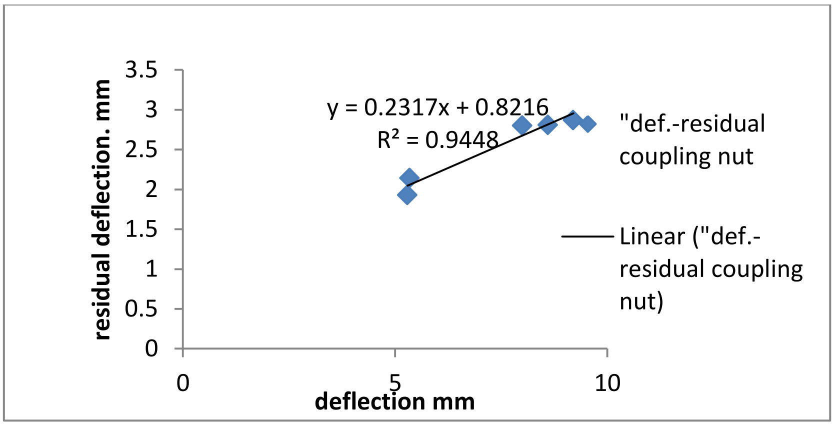


Figure 12 Correlation between deflection and residual deflection for silver rod bar using coupling nut.

6. ESTIMATION OF POST-TENSIONING FORCE

The estimation of post-tensioning force was calculated by three methods. The first method is experimentally calculated through these steps: From rod bar deformation recorded by dial gauge (ΔL) at level of rod bar calculate strain =ΔL/L . ΔL= dial gauge record mm, L= rod bar length =1200 mm. From strain value the force in rod bar can be calculated using formula (F= σ.A =E .ε.A). The results of vertical deflection and corresponding strain recorded through post-tensioning process are shown in Figure 13. Table 5 show post-tensioning force estimation experimentally using this method. The second method is the theoretical estimation. The results of this method listed in Table 5.

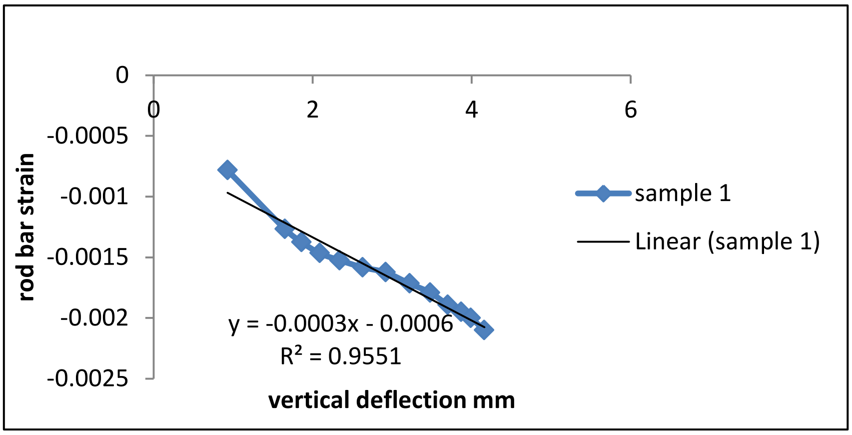


Figure 13: The timber vertical deflection vs. rod bar strain in post-tensioning process

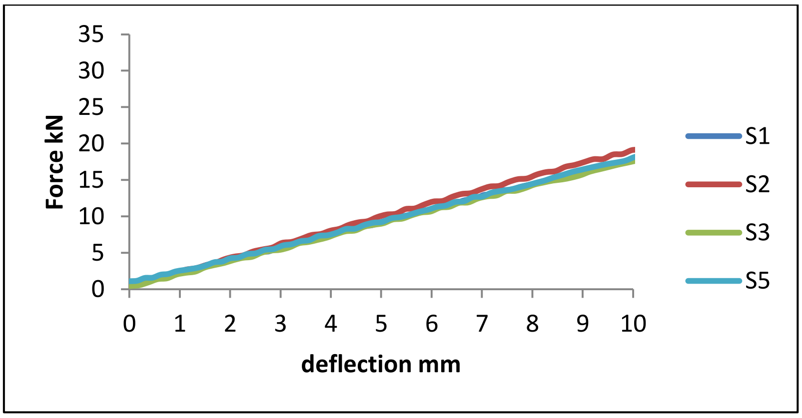


Figure 14: Experimental point load corresponding to deflection at range (10mm) for four samples.

The third method is also experimental method depending on timber bending test results. For four timber specimens bending moment calculated from experimental 4 point bending test at (0-10mm) deflection range is shown in Figure 14. The average value for these graphs results were shown in Table 5. Then the equivalent post-tensioning force is calculated from ($P_{post\text{-}tensioning} = P_{bending}$ x a/(2x e)) as shown in Table 5.

All these results of the three methods listed in Table 5 & Figure 15. It considers that the theoretical estimation is the control value for comparison. It can see that the method 3 (bending experimental) give constant error 20% . method 1 (rod strain method) give high divergent until 2mm deflection then give less error% after 2 mm deflection.

Table 5: the PT force estimation in 3 methods error% equal (PT mehod-PT theoretical)x100/ PT theoretical

Deflection mm	PT rod strain method kN	Error%	PT bending test method kN	Error%	PT theoretical kN
0.66	9.7	89.6	6.1	20.0	5.1
1.32	12.1	41.0	10.3	20.1	8.6
1.99	14.5	20.3	14.5	20.1	12.1
2.65	16.9	8.9	18.6	20.0	15.5
2.98	18.1	5.0	20.7	20.0	17.3
3.31	19.3	1.8	22.8	20.0	19.0
3.51	20.0	0.2	24.0	20.0	20.0
3.64	20.5	-0.9	24.8	19.9	20.7
3.97	21.7	-3.2	26.9	20.0	22.4

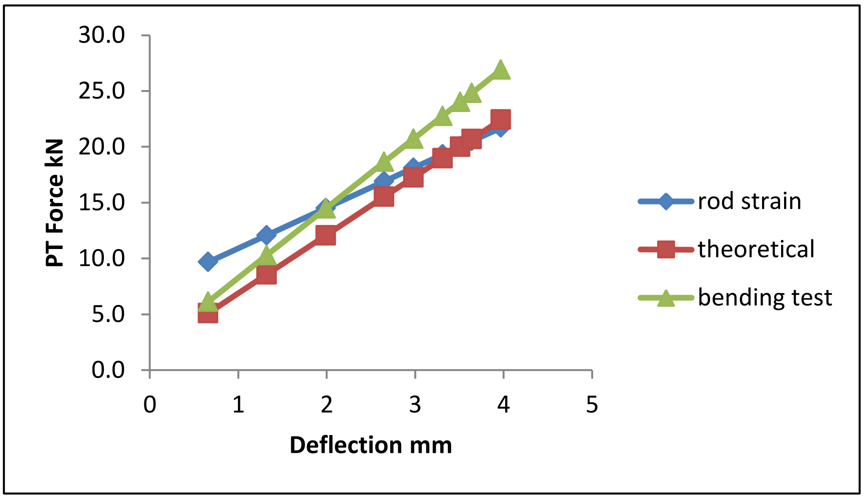


Figure 15: PT estimation in three methods (rod strain. bending test. theoretical)

7. CONCLUSIONS

From the test results for the two methods of pre-stressing. It is clear that pre-stressing Jacking (PJ) give higher residual deflection 98.2% for silver color rod bar, and for black rod bar the residual deflection is (88.8%) . While the Forced bending (BJ) method the residual deflection is 35.1% for silver color rod bar and 27% for black color rod bar. The silver color rod bar gives higher residual deflection. So this type of rod bar (silver color with long nut coupling) is the more efficient in use.

The (P.J) specimens give higher increasing in bending moment 26% compared with (B.J) with percent of increasing in bending moment 22%. The residual deflection of pre-stressing in case of bending jacking is 23% of jacking deflection in case of double hex nut and 35.1% in case of long coupling nut which give higher residual deflection (less anchorage slip losses). The using of (P.J) more effective in post-tensioning it gives high residual deflection and higher maximum deflection than using post-tensioning by bending(BJ). The post-tensioning by bending is safer for specimens because of avoiding stress concentration at the end face of timber beam.

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