

A Comprehensive Research Review on Timber Post-Tensioning Technology

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Abstract: Wood also known as timber in the engineering term that is beneficial to all over the world by its contribution as an important construction material. Timber alike to other materials such as steel and concrete, which able to lead to rapid development of construction field in this era of globalization. However, usage of timber is slightly less than steel and concrete in construction field including office and commercial building construction due to the long span length timber beam is easily deflect at the mid-span. From reliable reviews, prestressing of timber element also known timber post-tensioning technology introduced as an advance technology to enhance the tensile strength, bending stiffness and load bearing capacity of the timber in order to reduce the deflection at the mid span of long span timber beam and reduced the thickness of the timber beam as well. This study was conducted to determine the concept of the timber post-tensioning and its development history from past to present. Besides, the design of post-tensioning timber also a great concern, which can design as timber beams or frames under gravity and seismic loading consequently influenced its structural performance. From previous study, it illustrates that the strength and structural performance also influenced by post-tensioning losses in term of long-term behavior. Besides, several advantages are significantly by comparing the timber element with and without post-tensioning technology such as reduce deflection at the mid span, ecofriendly, time and cost saving.

Keywords: Post-Tensioning Timber, Design Method, Post-Tensioning Losses, Advantages

1. Introduction

Prestressing technology are introduced as a technique that applied on the construction materials such as concrete and timber to resist compressive force from the applied load on that exerted on the structural element including beam, slab and frames of a building. Structural behavior of the concrete and timber are enhanced by using prestressed technique to provide benefits in reduced deflection at the mid span of the beam, particularly to the long span beam that experiences maximum deflection at the mid span when gravity load is applied on it. Pre-tensioning and post-tensioning are the common methods that utilized in the prestressing technique [1]. Prestressing of the timber elements are alike to

the prestressing method of the concrete due to their properties, which is good in compression but weak in tension area. In other words, timber and concrete structure normally experiences failure at the tension area that also known as brittle failure of the structures. Prestressed tendons implemented at the tension area of the structure to enhance the bending stiffness and bearing capacity in order to reduce tensile failure and flexural failure of the beam, subsequently failure mode is changed from tension failure to compression failures, which known as ductile failure. Thus, loading capacity of the beams increases as the flexural strength increases. In other words, increase in tensile capacity of the timber structures also fully utilizing the compression capacity of the timber [2]. Increment of the ultimate load bearing capacity and bending stiffness of the timber beam influenced by the location of prestressed tendons. From the reviews of Kliger [3], the bending stiffness increase significantly by distributing the reinforcing element equally to the both sides of top and bottom area of the timber beams. Hence, the maximum ultimate load bearing capacity can only achieved with a range of percentage between 25 and 30 of reinforcement at the top area of timber beam. Meanwhile, prestressed tendons are usually implement at the tension area due to the concrete slab is overlay on the top area with the application of timber concrete composite floor system.

Overall structural performance improved by both prestressing method such as pre-tensioning and post-tensioning (PT) methods. Both methods commonly utilized in concrete but able be utilized in the timber elements as well. Brittle failure mode is the common failure in the tension area of timber beam, which is lower the compressive strength due to the presence of defects. Thus, tensioning system also presented compressive force that may reduce feasibility of brittle failures. Other than that, it presented the bending effect is inversely to the transverse loads while the cross-section of the timber element is utilized by the tensioning force eccentrically. Hence, it will enhance the behavior of the element by limiting the ultimate deformations [4]. Pre-tensioning method usually implement in the concrete element as the prestressed tendons are against the independent anchorages before concrete is placed on it. Prestressed force is generated when prestressed tendons at both end anchorages are cut and transmitted to the entire beam length. For PT system, prestressed tendons remain unbonded and elongation is not required before tensioning of the tendons. Thus, prestressed tendons are tensioned when the elements are set and subsequently tensioning force is generated [5]. Two methods that introduced in the timber (PT) system such as conventional method of prestressing jack that rely on placement of prestressing tendons and forced bending jacking method that obtained from the fundamental of prestressing and bending theory. However, conventional method is more effective than the forced bending jacking method [4].

2. Design Method and Structural Performance of Post-Tensioning Timber

2.1 Post-tensioning timber under Gravity Load Design

Post-tensioning (PT) timber are widely used as PT frames and beams in the development of multi-storey building including residential, office, commercial and hotel buildings which is constructed by using short and long span length at the flooring system of the structures. Longer span length caused the increases of the sizes of beam section in order to withstand the gravity loads that applied on the spans. However, the depth of the beams reduced by using PT frames and beams even it required to withstand larger loads due to the increases of the span length [6]. Gravity loading are the primary system of the frames designed and it can be utilize in any cases and buildings including the structures in the seismic areas with the combination of gravity and lateral loads [7]. Deflection is the main criteria of the timber beam with long span length design and it can be control by using PT timber to achieve reduction of deflection and thickness of timber beam section with the enhancement of the strength of the timber beam. Precamber is added into the engineering wood products such as glued laminated (glulam) and laminated veneer lumber (LVL). Reduction of deflection is achieved by using the PT forces induced in the precamber of the beam, which is similar to the application of PT concrete. The reduction of deformations in serviceability limit state (SLS) design is significant by using the precamber in the beam [8]. In other words, an increase of the PT forces reflect the PT tendons elongated when deflection of the beams and it related with ultimate limit state (ULS) strength of beams [6]. Several studies for design procedures of long span with unbonded PT tendons that only subjected to the gravity load conducted at

the University of Canterbury [9] These studies can be carried out by using any engineering wood products included LVL and glulam. By considering the efficiency of cross section and can be easily PT inside, therefore only hollow core box sections are chosen which tested in different types of beam and tendon profile configuration [6]. The outcomes on straight and draped tendons profiles configuration for the simply supported beam are similar. Draped tendons show greater inclination if compared to the simply supported beam. However, straight tendons profiles are the least feasible alternative to the continuous beam over some supports in the term of structural. Tendon profile configuration with high eccentricity is a greater alternative due to the reduction in total amount of tendons and anchors used [10]. Nevertheless, the several types of tendon profile that illustrate at the figure above are used to create moment resisting connections by anchor the tendons at the both end of columns which connected the columns and beams together [7].

2.1.1 Design procedure

As mentioned above, straight tendons profiles are the least feasible alternative to the continuous beam. Therefore, the design procedure below only considered the design for the simply supported beam with subjected to the gravity load only. Tensile strength of the beam is enhance by the straight and draped tendons to oppose the gravity load that exerted on the beam. Commonly, all dead loads exerted on the beam while the variable load exerted within a range of 40 percentages. The total load in the PT tendon and the PT force expressed as Eq. 1 and Eq. 2 respectively. Total loads that carried by the tendons should be equivalent to the force in precamber as PT force [10].

$$P_{d,pt} = k_{dead} \cdot G + k_{live} \cdot Q \text{ Eq. 1}$$

$$w(P_{d,pt}) = w(F_p) \text{ Eq. 2}$$

Where, $P_{d,pt}$ is total load on PT tendons, G is dead load, Q is live load, k_{dead} is portions of dead load (1.0), k_{live} is portions of live load (0 to 0.4), F_p is PT force

In order to design simply supported beam with satisfactory, unity checks are required including bending and compression design, shear strength design, long and short term deflection design as illustrate in figure 1 below. For bending and compression design, overall capacity of the timber beam expressed as Eq. 3 regarding to AS/NZS3603 (New Zealand Structural Design Action Standard) whereas Eq. 4 and Eq. 5 represented the compression capacity and bending capacity regarding the equations in EC 5 (Eurocode 5) respectively. Bending and compression strength are in term of ULS. Besides, the design checking of the shear expressed in the Eq. 6, which is less than the value one by referring to its shear capacity. Shear capacity of the beam expressed in Eq. 7. Deflection design can assigned into two different categories, which is short term and long-term deflection. Short term is depends on the deflection that caused by the gravity load on the timber beam and the precamber due to PT under certain period of time factor. Meanwhile, long-term deflection for the beam under a long loaded duration also have to consider the PT losses. Equation for short-term deflection expressed as Eq. 8 below. Meanwhile, Eq. 9 and Eq. 10 represented the equations to determine the long-term PT losses and deflection. Figure 1 below illustrates the flow chart of the design procedure of the PT simply supported timber beam [10]

$$\frac{N_c^*}{\phi N_{nc}} + \frac{M_y^*}{\phi M_{ny}} < 1 \text{ Eq. 3}$$

$$N_{nc} = k_1 \times k_8 \times f_c \times A \text{ Eq. 4}$$

$$M_{ny} = k_1 \times k_8 \times f_b \times Z \text{ Eq. 5}$$

Where, N_c^* is compression force, N_{nc} is compression capacity, M_y^* is bending moment, M_{ny} is bending capacity, ϕ is reduction factor for strength, k_1 is factor for load duration, k_8 is stability factor, f_c is compression strength, f_b is bending strength, A is cross sectional area, Z is section modulus

$$\frac{V^*}{\phi V_n} < 1 \text{ Eq. 6}$$

$$V_n = k_1 \times f_s \times \frac{2t_w \times I_z}{S_z} \text{ Eq. 7}$$

Where, V^* is shear force, f_s is shear strength, t_w is thickness web, S_z is section modulus of half section, I_z is second moment of inertia

$$\delta_{NET} = (-\delta_0 + \delta_1) \cdot k_{2,short} \leq \bar{\delta} = \frac{L_{beam}}{250} \text{ Eq. 8}$$

$$\Delta P(t) = F_{p0} \left\{ 1 - \frac{\Omega_p \left[1 - \frac{1 - \Omega_p}{2} \cdot (k_2 - 1) \right]}{1 + \frac{1 - \Omega_p}{2} \cdot (k_2 - 1)} \right\} \text{ Eq. 9}$$

$$\delta_{NET} = (-\delta_0 + \delta_1) \cdot k_{2,long} \leq \bar{\delta} = \frac{L_{beam}}{250} \text{ Eq. 10}$$

Where, δ_{NET} is total deflection, δ_0 is deflection caused by gravity load, δ_1 is deflection of precamber caused by PT, k_2 is duration of load factor, $\bar{\delta}$ is deflection limit (refer NZS 1170), F_{p0} is initial PT force, $\Delta P(t)$ is PT losses, L_{beam} is length of the beam

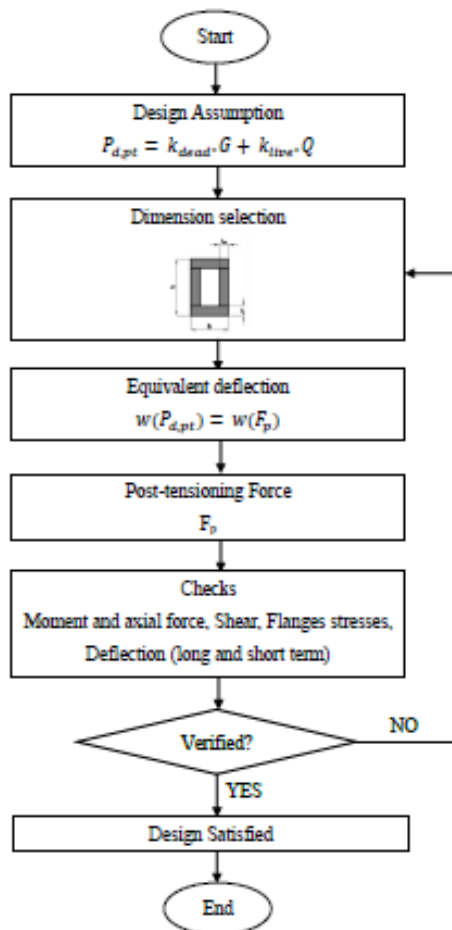


Figure 1: Design procedure of PT timber beam [10]

2.2 Post-tensioning timber under Seismic design

Precast concrete seismic resisting system (PRESSSS) introduced a technique that utilized different types of connections and unbonded tendons to generate moment resisting in order reducing damage

taken and deformation to the structural building after an earthquake. This system not only able to utilize in the concrete structure but same goes to the timber structure and this developed system known as Pres-Lam. Moment-resisting connection introduced by this system with the timber box that has an internal duct to allow the passing of steel tendons. Connections at the foundation and wall or the interface between column and beam generated moment capacity to resist the displacement of lateral motions [11]. Hybrid system and Direct Displacement Based Design (DDBD) are the types of seismic design. Combination of unbonded post-tensioning system and elements for energy dissipaters by implementing on the engineering wood products such as glulam or LVL is the basic concept for this hybrid system to achieve moment-resistant connections. The properties of the unbonded tendons enable the structures return to its original form of geometry after a lateral load displacement. Meanwhile, the energy dissipating elements will allocate adequate energy dissipation to yield in compression and tension in order to achieve flag-shape behavior due to the ductile connections. Hence, the mechanism of the rocking motion happened at the hybrid connection system. Besides, hybrid connection system been tested with different types of connections such as wall to foundation, column to foundation and beam to column connections which are the main components to construct a timber building [12]

DDBD is a simplified design method and procedure in lateral load resistance. In other words, dynamic movement at the superstructure can resist or reduce the damage taken when lateral movement occurred. The fundamental of design procedure by using DDBD is to consider the timber frame as a single degree of freedom system. There are no requirement on iterative design procedure if the ductility of the structure and yield rotation determined. However, the yield rotation of the timber frames cannot determined or predicted easily unlike other materials such as steel and concrete. This is due to yield rotation is only rely on its strength. Therefore, the ductility of the structure had to be estimate and determined accurately in order to achieve its ductility. Yield rotation expressed as the Eq. 11 below. As mentioned above, yield rotation and the ductility of the structures are main factors in the DDBD design procedure. The ductility of the structures able to express in a term of equivalent viscous damping. This term, equivalent viscous damping is a total of hysteretic and elastic damping which only adequate for a maximum 2 percentage as the critical damping at the timber frame buildings. The energy absorbed by inelastic response interpret the component of hysteretic damping in DDBD and the axial stiffness of connection determines the geometry of the hysteric damping system [13].

$$\theta_y = \theta_{b,y} + \theta_{c,y} + \theta_{j,y} + \theta_{imp,y} \text{ Eq. 11}$$

Where, θ_y is yield rotation, $\theta_{b,y}$ is beam elastic deformation, $\theta_{c,y}$ is column elastic deformation, $\theta_{j,y}$ is joint elastic deformation, $\theta_{imp,y}$ is deformation caused by elastic rotation of rocking connections

2.3 Anchorage system

Anchorage system play an important role in PT timber member as provided PT force to increase the tensile strength and bearing capacity to withstand the gravity load on the timber beam. PT force is provided by released the PT tendon that hold it by the anchorage connection at the timber beam or column. However, PT timber beam obtained more benefits if compared to timber column due to the direction of compressive stresses in parallel and perpendicular to the grain respectively. Anchorage disks and single strand anchorages are the types of anchorage system that implemented in the PT timber technology. By taking these advantages, only small jack is required for single strand anchorage meanwhile bigger jack in size is required for anchorage disks in order to hold up multiple strands. Anchorage system not only can be utilized at the external surface of timber beam (mostly at the surface of the timber column in frame structures) but also able to utilize in the internal of the timber beam. Both external and internal anchorages bring advantages to the anchorage system and PT timber element design as well. Convenient manufacture process is one of the advantages that addressed by the external anchorage if compared to internal anchorages. However, timber beam can placed between the timber columns by using internal column. Anchorage is able to implement at the lower part of the flange when straight tendons utilized in the timber beam. Besides, a steel plate at the interface of the anchorage and timber element, it called as steel anchorage plate that required appropriate thickness to transfer PT force to the entire PT timber beam. Other than that, anchorage steel plate played a function of limiting the compressive stresses that transfer to the timber element and this is beneficial to the timber column due

to its fiber orientation is perpendicular to the grain. The high strength of the washer is required due to it located in between the anchorage disk and steel plate and function as to distribute the stresses from the anchorage [10].

2.4 Post-tensioning losses

PT losses has to be consider and analyze during the construction of PT timber structure. This fact is being so long term behavior of the PT timber beam caused losses to influence the PT forces that transfer from the anchorage to the entire timber beam. From experimental tests, 10% of PT long-term losses had gained when the gravity loads subjected to the PT timber beam in the direction of compression stresses parallel to the grain. Besides, from reliable study of W. Van Beerschoten [6], it stated that the total amount of PT applied affected long term losses in a range of 6.5% to 14%. Meanwhile, the PT losses can be greater at the column up to triple times higher when timber beam and column clamped together which caused the compression stresses subjected in the direction of perpendicular to the grain. This fact caused the deformations of the beam due to the reduction in the PT forces. PT long term losses in the direction of compression stresses perpendicular to the grain can be decrease by implementation of fully threaded screws as reinforcement to the PT anchorage and connection zone [7]. The amount of PT losses affected by the ratio of sectional area of the timber member and the PT area. It can be mentioned as the greater of the ratio are, the greater PT losses are which due to the PT losses occurred when there is an action induced by tendon force [14]. PT long term losses can attributed to distinct conditions such as creep, mechano-sorption (MS) creep, shrinkage and swelling in the direction of perpendicular or parallel to the grain for column and beam respectively [15]. Loss in the PT tendon force determined by the equations that derived by Fragiacomio & Davies [16] expressed as Eq. 12 and Eq. 13 for controlled and uncontrolled environmental respectively.

$$\Delta P(t) = \frac{P_0 \times \left\{ \frac{l_{\parallel} \cdot \Phi_{\parallel}(t)}{E_{\parallel} \cdot A_{\parallel}} + \frac{l_{\perp} \cdot \Phi_{\perp}(t)}{E_{\perp} \cdot A_{\perp}} \right\}}{\frac{l_{\parallel} \{1 + \Phi_{\parallel}(t)\}}{E_{\parallel} \cdot A_{\parallel}} + \frac{l_{\perp} \{1 + \Phi_{\perp}(t)\}}{E_{\perp} \cdot A_{\perp}} + \frac{l}{E_p \cdot A_p}} \quad Eq. 12$$

$$\Delta P(t) = \frac{P_0 \times \left\{ \frac{l_{\parallel} \cdot \Phi_{\parallel}(t)}{E_{\parallel} \cdot A_{\parallel}} + \frac{l_{\perp} \cdot \Phi_{\perp}(t)}{E_{\perp} \cdot A_{\perp}} \right\} + \Delta L_{in,beam}(t) + \Delta L_{in,column}(t)}{\frac{l_{\parallel} \{1 + \Phi_{\parallel}(t)\}}{E_{\parallel} \cdot A_{\parallel}} + \frac{l_{\perp} \{1 + \Phi_{\perp}(t)\}}{E_{\perp} \cdot A_{\perp}} + \frac{l}{E_p \cdot A_p}} \quad Eq. 13$$

Where, P_0 is initial tendon force, l is length, E is Young's modulus, A is cross sectional area, Φ is creep coefficient, A_p is tendon cross sectional area, E_p is tendon Young's modulus, \parallel is parallel to the grain, \perp is perpendicular to the grain, $\Delta L_{in,beam}(t)$ is loss in tendon force (beam), $\Delta L_{in,column}(t)$ is loss in tendon force (column)

Creep will take place in the long-term behavior of the PT timber beams and frames as long-term rheological effect. Creep commonly take places in the direction of compressive stresses perpendicular to the grain and it will greater than the direction parallel to the grain. Creep development will shorten the timber sections and caused the reduction of PT force at the PT timber frames. MS creep is the effect that occurred when the speed of creep deformation rises due to alter of moisture content. The change in strength capacity and the durability of the timber also affected by the moisture content [14]. The coefficient of the creep are required in order to determine the loss of PT tendon force, which expressed as Eq. 17 below and substitute by Eq. 14, Eq. 15 and Eq. 16. [15].

$$\epsilon = \frac{u(t) - u_0}{u_0} \quad Eq. 14$$

$$\epsilon_d = \frac{u_d(t) - u_{d0}}{u_{d0}} \quad Eq. 15$$

$$\epsilon_{el} = \frac{u(0) - u_0}{u_0} \quad Eq. 16$$

$$\phi = \frac{\epsilon - \epsilon_d}{\epsilon_{el}} - 1 \text{ Eq. 17}$$

Where, ϕ is coefficient of creep, u is distance between two plates at time t , u_0 is distance between two plates when load compression load employed, u_{d0} is distance between two plates before compression load employed (dummy specimens), u_d is distance at the dummy specimens, $u(0)$ is distance before tendon force employed (loaded specimens)

Moisture content affected by surrounding environment, which will subjected to different conditions. In order to determine the PT losses, creeps and the factors that will affect the results of the PT timber, it divided into two conditions, which is uncontrolled and controlled environmental conditions. Mechanical properties and the PT losses of the PT timber influenced by the moisture content [14]. Thus, shrinkage and swelling of the timber element also influenced the PT losses. Reduction of the moisture content caused by the shrinkage of the timber and consequently influenced the reduction of the PT force. Meanwhile, increment of the moisture content caused by the swelling effect will lead to the recovery of the PT forces [16]. Besides, there are three different types of service classes in the environmental conditions regarding to the Eurocode 5 (EC 5) and have to determine the service classes that suitable to the structure when the pre-design begin. Table 1 illustrates the criteria of the moisture content and the temperature for each classes.

Table 1: Service classes [11]

Service Classes	Moisture Content in Material (°C)	Relative Humidity of Surrounding Air (% for few week/ year)
I	20	> 65
II	20	> 85
III	Climatic condition	Higher than service class II

3. Analysis and Discussion

3.1 Experimental test on gravity beam

An experimental test of PT timber beams that only subjected to the gravity load had carried out by W. A. van Beerschoten [8]. There are four timber beams with difference sections and properties utilized in this experiment. Anchorage system that consists of 7 tendons with diameter of 12.7mm are utilized and initial PT forces of 910kN applied in the timber beam. Four point bending test is carried in these timber beam with a span length of 9.15m. Both end of each beam connected to the flexible connection. Table 2 and table 3 show the sectional properties and results of tested timber beam respectively.

Table 2: Sectional properties of timber beams [8]

Beam	Cross Section Area, A (10 ³ mm ²)	Shear Area, A _s (10 ³ mm ²)	Sectional Modulus, Z (10 ⁶ mm ³)	Second moment of Inertia, I (10 ⁹ mm ⁴)	Tendons Profile
1	150	74.4	28.2	10.7	No
2	130	59.7	19.9	6.07	Straight PT
3	130	59.7	19.9	6.07	Draped PT
4	130	57.2	20.2	6.74	Draped PT

Table 3: Results of tested timber beam[8]

Beam	Tendons Profile	Load to Deflection Limit	Mid-span Bending Moment (kNm)	Stiffness (kN/mm)	Max. PT Force (kN)
1	No	200/30	1083	6.67	-
2	Straight PT	223/30	768	4.46	979
3	Draped PT	267/30	874	5.34	1071

4	Draped PT	307/30	909	6.14	1080
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From the results of previous study, it shows that the PT beam 4 with draped tendon profile has the highest load to deflection limit if compared to other beams, especially timber beam 1 obtained the lowest load to deflection limit due to PT tendon is not implemented in the timber beam. The result of PT timber beam 4 is slightly higher than that of timber beam 3 due to the sizes of the upper flange is double even the cross sectional area are the same for both PT timber beam. Thicker upper flange would have better compressive strength and load bearing capacity to withstand greater load if compared to single thickness of the flange even under the same tendon profiles and same cross sectional area. Besides, PT timber beam 3 has greater load bearing capacity if compared to the PT timber beam 2 is due to the draped PT profiles has greater inclination than that of straight PT profiles. By comparing within these four timber beams, the results illustrate that the timber beam undergo implementation of PT tendons have better bending stiffness by generated negative bending if compared to the timber beam that without PT tendons and subsequently increases the load capacity to withstand more loads. The percentages of deflection limit of PT timber beam 1, 2 and 3 increases 11.5, 33.5 and 53.5 by refer to timber beam 1 that has no PT tendons. By referring to the value of mid-span bending moment in table 2, it shows that the timber beam 1 has the stiffness slope which can addressed that the beam 1 has the largest bending stress and lower mid-span deflection compared to PT beams. Besides, the increase of PT force is depends on the elongation of the PT tendons which can significantly illustrate that PT timber beam 3 and 4 with draped tendon profiles have the better elongation of tendons if compared to beam 2. By compared with the initial PT force, the percentages of maximum PT force that gained in PT timber beam 2, 3 and 4 are 8.68%, 17.69% and 18.68% respectively. The higher the PT force, the stronger the strength to support the gravity load on PT timber beam. It can say that the PT timber beam 4 consists of draped tendon profiles with double thickness of upper flange is the better PT timber beam among the tested beams in order to enhance load bearing capacity and tension strength to withstand gravity load

3.2 Long-term behavior

Table 4: Summary of creeps of reliable studies

References	Fibre Orientation	Phenomenon	1 Year (%)	10 Years (%)	50 Years (%)
Wanninger et al., (2015)	Perpendicular to the grain	Pure Creep	0.9	1.8	3.0
		Ms-Creep	1.0	3.9	9.5
		Total	1.9	5.7	12.5
	Parallel to the grain	Pure Creep	0.2	0.4	0.5
		Ms-Creep	0.4	1.0	1.9
		Total	0.6	1.4	2.4
Davies & Fragiacomio, (2011)	Perpendicular to the grain	Pure Creep	5.3	-	(13-17)
		Ms-Creep	0.2	-	(8-12)
		Total	5.5	-	(21-29)
	Parallel to the grain	Pure Creep	1.4	-	(3-5)
		Ms-Creep	1.5	-	(3-5)
		Total	2.9	-	(6-10)
Gabriele Granello et al., (2017)	Parallel to the grain	Pure Creep	-	1.3	2.4
		Ms-Creep	-	4.8	5.1
		Total	-	6.1	7.6

Table 5: Summary of PT losses of overall studies

References	Material	Environmental Conditions	PT losses (%)	Remark
G Granello et al., (2019)	Glulam	Uncontrolled	3.0 after 1 year 7.1 after 2 years	Block C (frame) erected in the winter
			4.1 after 1 year 6.7 after 2 years	Block D (frame) erected in the summer

Wanninger et al., (2015)	Glulam	Controlled	3 after 1 year 8 after 1 year	Beam Frame
		Uncontrolled	3 after 1 year 8 after 1 year	Beam Frame
Davies & Fragiaco, (2011)	LVL	Controlled	1.4 after 1 year 7 after 1 year	Beam Frame
		Uncontrolled	2 after 1 year 9 after 1 year	Beam Frame
Gabriele Granello et al., (2017)	LVL	Uncontrolled	3.4 after 4 years	Beam

By referring to the results of previous studied, long-term behavior addressed that the long-term losses including the PT losses, moisture content, creeps and tendon relaxation are commonly happen under PT timber and frame under long loaded duration. Table 4 and table 5 illustrate the summary of the creeps and PT losses of overall studies respectively. Creep, it divided into two categories, which is pure creep and MS creep that happened on the timber, reduced the PT effect, and subsequently reduce the tendon force of PT timber beam and frames. Ms-creep is depends on the rate of creep development as it influenced by the change in moisture content which can only considered as under uncontrolled environmental condition. By comparing the results of total creep among the direction of perpendicular and parallel to the grain, it illustrates that the percentage of total creep in the direction of parallel is lower than the direction of perpendicular to the grain. This is because of the timber has weaker resistance on the compression stresses on the direction of perpendicular to the grain if compared to the direction of parallel to the grain. Furthermore, the results of pure creep and Ms-creep predicted over 50 years in order to estimate the PT losses of the timber beams and frames due to the PT losses also influenced by the creep development. The higher the percentage of total creep, the higher the percentage of PT losses and it can be seem that the percentage of creep over 50 years in the direction of perpendicular is much higher than the direction of parallel to the grain. Besides, PT losses are dependent on the moisture content, environmental conditions and creep development. By comparing the results among the controlled and uncontrolled environmental conditions, it significantly presented the uncontrolled condition has a slightly higher percentage of PT losses if compared to the controlled condition after one year duration. This fact is being so when the PT timber beams and frames undergo the change in moisture content, which also need to consider the creep development as well. However, there are some differences of PT losses even in the same environmental conditions, which is due to their geometrical properties, timber beams and timber frames. As mentioned above, timber frames that compressive strength in the direction of perpendicular to the grain is lower, which will experience more losses if compared to the parallel in the grain. On the whole, PT losses are higher in the uncontrolled conditions due to the change in moisture content subsequently additional of strain such as Ms-creep take place and it can said that the strength of the timber frame in the direction of perpendicular to the grain is much lower if compared to the direction of parallel to the grain.

3.3 Advantages

There are several advantages addressed from the experimental tests above. As the experimental tests on the gravity beam can tell that the implementation of the PT timber technology able to reduce deflection of the loaded beam. In other words, PT timber technology able to increase the bending stiffness and load bearing capacity to withstand the gravity load on the PT timber beam. In a meant of reduction of deflection, PT timber technology also able to increase the deflection limit that allow the precamber PT timber to withstand more loads. This effect can seen by the differences between the PT timber elements and non-PT timber elements, which means timber element that without reinforcement (steel tendons). By the implementation of PT timber technology in the construction field, it enlarge the field to the construction of the commercial building and office structures. This is due to the structure of

the office and commercial buildings commonly consists of large floor plans and less in number of internal wall and column to transfer load from the top to foundation unlike the structure of hotel and residential houses. This problem can overcome by using PT timber technology as presented in the experimental tests, which able to enhance tension strength of the bottom part of the timber beam subsequently to reduce the thickness of the timber beam. Besides, brittle failure that occur at the tension zone able to change to ductile failure at the compression zone with fully utilizing the compression capacity of the timber. Other than that, there are several advantages including cost saving, time saving and ecofriendly to the environment. In term of time and cost saving, it can mentioned timber itself has high strength to weight ratio and able to construct easily. Besides, timber structures are unlike concrete structures that need time to set meanwhile timber structures that able to construct directly and subsequently reduces the time for construction and hardening process. Cost saving due to no requirement of heavy machinery for the PT timber element. PT timber will normally prefabricated offsite and transfer to onsite for simple assemble process, unlike cast in-situ concrete structures even precast concrete are widely used nowadays. Since the PT timber elements are prefabricated offsite, it will significantly reduce the waste produce and improve the safety of the workers in order to reduce the risks and injuries occur [2].

4. Conclusion

From the overall reviews, the results indicates that the reduction of mid span deflection of the timber beam is achieved by using timber post-tensioning technology, especially for long span timber beam. It significantly mentioned that the post-tensioning timber beams obtained greater tensile strength and load bearing capacity to withstand greater load if compared to the timber beam without post-tensioning. When the post-tensioning tendon passing through the internal duct and hold up with anchorage system, it will generate post-tensioned force that improve the tensile strength of the post-tensioning beam. Besides, it reduce the deflection of the beam by bending upwards before the beam is loaded and able to reduce the thickness of the timber beam. Thus, it is beneficial to the construction of the office and commercial building due to the long span timber beam not easily deflect and able to support more loads. Due to this technology, post-tensioning timber members are prefabricated that able to reduce the construction time and cost required. Besides, timber structure is constructed by simple assemble post-tensioning element due to its high strength to weight ratio unlike concrete structure have to wait for the hardening process to gain sufficient strength. Since it prefabricated offsite, the number of workers and the risk of injuries can reduced subsequently reduced the waste produced at the project site.

Last but not lease, the structural performance and the design of post-tensioning member is evaluated under gravity load and seismic design as presented with the listed equations and design procedure. Long-term behavior of the post-tensioning timber beams and frames including post-tensioning losses, creep, mechano-sorptive creep and moisture content are generally discuss. It stated that the post-tensioning losses are due to the factors such as creep and moisture content. Mechano-sorptive creep is due to the change in moisture content in uncontrolled conditions consequently influenced the rate of creep development. As a conclusion, objectives of this comprehensive review are achieved.

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