Elastic Behavior of Connection System with the Addition of Wooden Clamp on Bamboo Truss Structure

Astuti Masdar, Noviarti, Bambang Suhendro, Suprapto Siswosukartor, Joko Sulistyo

Abstract: The elastic behavior of structure is very much dependent on the type of material used and the connection applied. Material properties significantly affect the elastic characteristics of the connection system, and hence it's structural behavior. The bamboo connection, which is a connectivity system among bamboo stems, have different elastic characteristics depending on the constituent material and the applied connection method. This paper presents the results of study on the elastic behavior of bamboo connection system with the addition of wooden clamps. Model of bamboo connections was made and loaded under quasi-static load, where loading applied repetitively at static load below the proportional limit. Loading was gradually increased at constant additional load in one loading direction. These quasi-static tests were carried out on several specimens of 45o stem angle's bamboo connection. Two variation loading limits were considered, namely 0,45Pprop and 0,7Pprop. The test results show that the load repetition in quasi-static testing can reduce the connection stiffness by 2.45% and 23.26% respectively. It can be concluded that under repetitive loading, higher load limit might result in larger stiffness reduction. This might be attributed to earlier loss of static friction at higher load limit under loading.

***Index Terms**: Keywords: Elastic Behavior; Connection; Bamboo; Truss Structure; Quasi-Static.*

I. INTRODUCTION

A. Bamboo as a Sutainable Material

Bamboo is well known as an environmentally friendly material, and its renewable characteristic is one of its advantages in construction purposes. Bamboo grows very fast, it can reach a maximum height of 15-18 cm in just 4-6 weeks, while similar rate of growth will take a year for wood (Morisco, 2000). Bamboo's cycle growth of only 3-5 years is another its advantages, hence it will not be too long for bamboo stem can be used as construction materials [4][5].

Bamboo plants do not need special attention during planting period. Bamboo shoots will grow continuously and appear around the bamboo plants. In terms of quantity, bamboo is widely available in every season. Therefore, bamboo is an environmentally friendly construction material suitable to support green construction programs in combating global warming. Bamboo is a such versatile material, has high strength, is relatively light and can be used only by simple tools. In addition, processing of bamboo stem as construction material does not require significant amount of energy as presented in Table I.

Table I: Energy, needed for production, compared with stress when in use (Janssen, 1981)

Mate rial	Energy for Production (MJ/kg)	Density (MJ/m^3)	Energy for production (MJ/m^3)	Stress when in use (N/mm^2)	Ratio Energy per unit stress
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(4)/(5)**
Conc rete	0,8	2400	1920	8	240
steel	30	7800	234000	160	150
wood	1	600	600	7,5	80
bamb oo	0,5	600	300	300	30

Table I shows the energy needed to produce materials such as concrete, steel, wood and bamboo as construction materials. It shows that bamboo requires the least energy compared to other materials. In contrast steel and concrete require large energy derived mostly from earth's energy based resources. Steel requires the greatest energy, while bamboo requires only about 1.67% of that for steel. In terms of strength, however, bamboo strength is comparable to steel material.

B. Bamboo as a Structure Material

Bamboo has great potential to be used as a structural material for various building components such as beams,

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columns, partitions, floors or as a frame structure. In frame structures, bamboo is generally modeled as truss structures. It is generally known that the connection is the weakest part of structure, and it is also the case for bamboo structures. The high strength of bamboo cannot be optimally utilized because of the constraints related to connection system among bamboo stems. The elemental connection system of the truss structure greatly affects the stiffness and strength of the structure.

Some studies of the bamboo connection system include connection system with gusset steel plate and bolted connection (Morisco, 1999), connection system with gusset plate of plywood materials or hard wooden planks and nailed connection (Misra, 1998), connection system with PVC [1][2], connection system with bolts and in-filled cement mortar at the internode of bamboo culms (Trujillo, 2009), and connection system with gusset plate of plywood materials and bolts [3].

Masdar et. al (2015) has been development a connection system without filler material on bamboo culms with wooden gusset plate and wooden clamps used to increase the contribution to the shear at the connection. In the development of connection system on bamboo truss structure, the behavior aspects must be considered, such as elastic behavior between components of connection system that consist of different material. Material properties significantly affect the elastic characteristics of structural behavior on connection system. This paper presents the results of study on the elastic behavior of bamboo connection system with the addition of wooden clamps. Model of bamboo connections was made and loaded under quasi-static load, where loading applied repetitively at static load below the proportional limit with variations of loading limit on quasi-static loading.

II. LITERATURE REVIEW

A. Bamboo Connection System using Wooden Plate and Clamp

Connection system using steel plates and heavy in-filled material is less preferable because its heavy self weight and heavy weight of structures. This heavy self weight of materials greatly affects the construction cost of bamboo structures. The bamboo connection system without fillers with wooden gusset plates and wood clamps is a connection system that uses lightweight materials and relatively cheap cost. In the bamboo connection system without filling material, wooden boards were used as a substitute of steel gusset plates. This bamboo connection system without fillers using wooden gusset plates and wood clamps was developed by21[8] as presented in Fig. 1.

The wooden planks used in this connection system was Keruing Wood (Dipterocarpaceae) that includes E14 quality of wood with quality A according to Indonesian Standard for wood (SNI 7973: 2013). The wooden clamps to be used to uniformly distribute stresses within the connection system by enlarging the connection area among bamboo was made of Mahagony wood[11]. This wooden clamp were also intended to widen-up area for stress distribution at the bolts area. The wooden clamp was introduced to widely distribute transfer of forces from bolts to the wooden plate. The addition of clamp is expected to be able to enlarge the contact plane of the connection as such so that the compression forces resulted from tightening the bolts will not concentrate at the area of bolts hole. The schematic illustration of transfer forces at the connection is presented at the Fig. 2. The stiffness of connection system is affected by many factors, such as connection angel of bamboo stem (Masdar, 2013) and the stiffening forces at he bolts [6][7].

(a) (b)

Fig. 1. The Development connection system (a) Connection system using wooden plate and wooden clamp
(b) connection system components

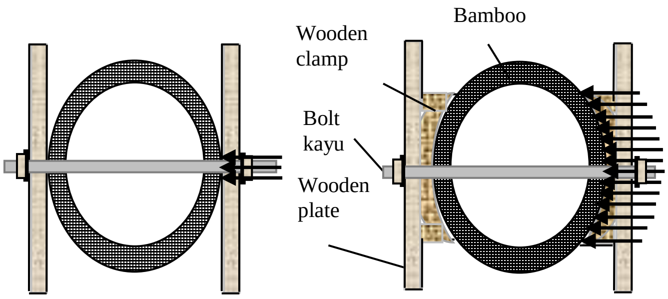

Fig. 2. Forces distribution from bolt and wooden plate to bamboo stem; (a) direct force to bamboo stem (b) forces acting through wooden clamp.

III. METHODOLOGY/MATERIALS

The study was conducted experimentally in two phases of testing. In the early stage of the research preliminary testing on basic properties of the materials used have been conducted. The second phase of the research involved designing and fabricating several types of joint model of bamboo truss structure with full-scale sizes and tested experimentally in the laboratory. The experiment was carried out under quasi-static loading on the bamboo truss connections model. The Quasi static-loading is performed on the connection at an angle of 45° with 2 variations of load below the proportional load limit is 0.45Fprop and 0.7Fprop, respectively[9][10].

A. Material

The material used on the joint model of bamboo truss

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structure is a natural material and a bolt made of steel with a diameter of 12,2 mm. The type of bamboo used as the main structural material in this study was Gigantochloa atroviolacea. The gusset plates ware made of Keruing wood (Dipterocarpaceae), while Mahoni wood *(Swietenia Mahagoni)* was used for the clamps.

B. Test Set-up

The testing method of basic material properties was based on ISO N22157-2 for bamboo and ASTM D 143 for wood. The testing method of bearing strength of bamboo was adopted from ASTM D 5764 standard test method for evaluating dowel bearing strength of wood and wood-based products. Bearing strength test has been carried out on bamboo and wood with deformed bolt diameter of 12.2 mm.

The test set-up for connection system models is shown in Fig. 3. Tests on connection system on bamboo truss structure are carried out in quasi-static loading. Quasi-Static loading is carried out below the proportional limit and observation on deflection that occurs. In this test, the load-displacement relationship is measured with load instrument in the form of load cell capacity 10 Ton and displacement with LVDT capacity of 50 mm. Loading was gradually increased at constant additional load in one loading direction. These quasi-static tests were carried out on several specimens of 45º stem angle's bamboo connection. Two variation loading limits were considered, namely 0,45Pprop and 0,7Pprop with each test object given 20 loading cycles. Based on the loading which is given in stages with the magnitude of the predetermined load, it is known the connection behavior and the relationship between the load and deflection on the connection

Fig. 3. Test set-up for connection system models with quasi-static loading

IV. RESULTS AND FINDINGS

A. Quasi-Static Test Results

Elastic connection behavior was studied under quasi static testing. Elastic behavior can be observed from several conditions including when the stress and strain relationships are below the proportional limit. However, elastic behavior is very dependent on the type of material used, not all elastic behavior is known by the stress relation in the form of a perfect straight line. In this test, the amount of load given to the connection is below the proportional limit. As long as the load applied to the connection is still below the proportional limit, the connection will return to the initial condition. Static quasi testing is performed on the connection at an angle of stem of 45o with 2 variations of load below the proportional load limit. The first loading is given at 0.45Pprop and at the second load is 0.7Pprop as presented by the graph of the load relation to deflection in static testing in Fig. 4.

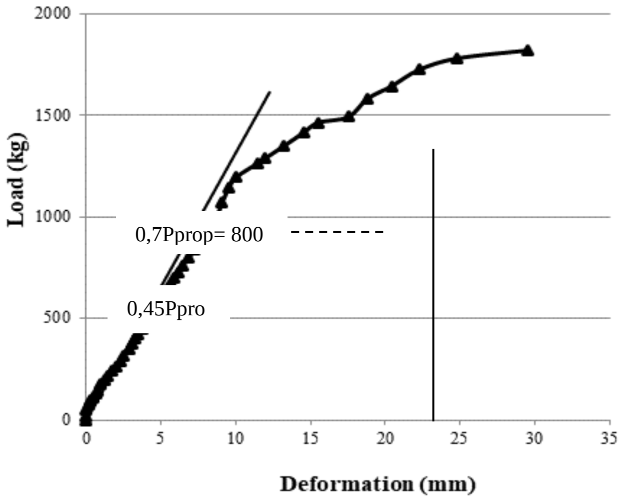
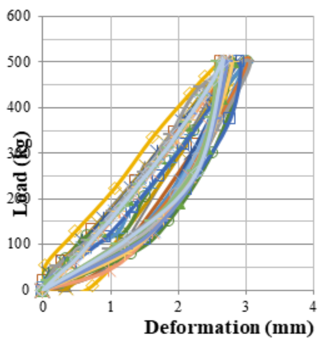
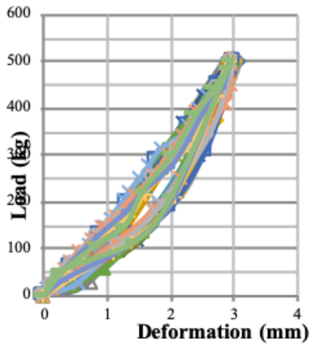


Fig. 4. The amount of load given to the connection in quasi-static testing

Based on Fig. 4, the magnitude of the quasi static load for the first loading is 0.45Pprop and the second load of 0.7Pprop will be given to the connection model, each of 500 kg and 800 kg. Furthermore, each loading variation is given to the connection model asmany as 20 loading cycles. Quasi static test results on the connection model are presented in the following figures.



(b) Specimen 1 (QSA-1)



(a) Specimen 2 (QSA-2)

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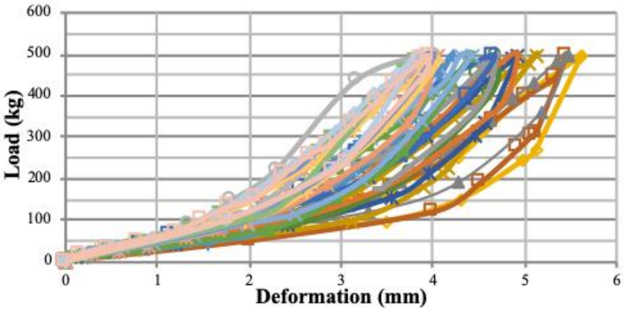
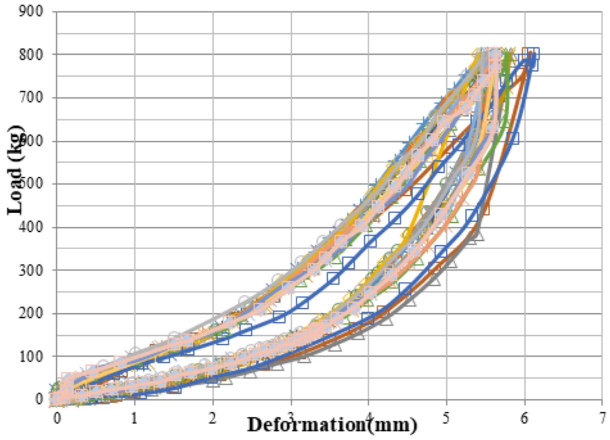
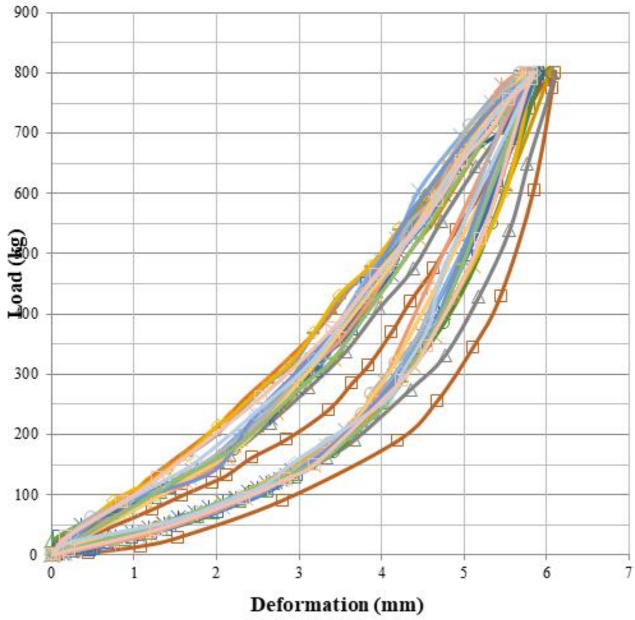


(c) Specimen 3 (QSA-3)

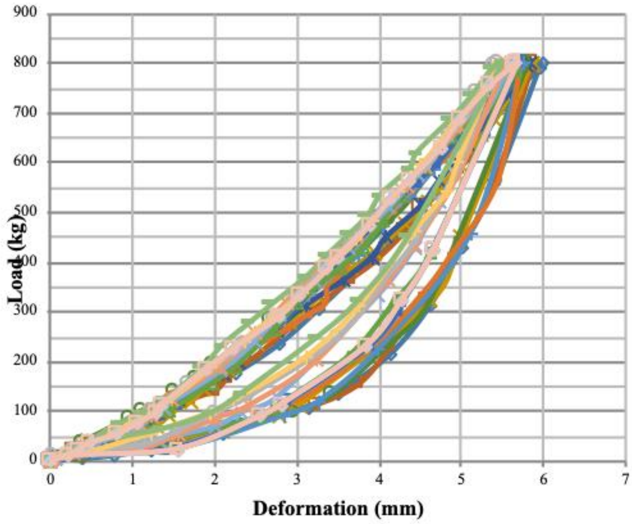
Fig. 5. Graph of the relationship between load (kg) and deflection (mm) on quasi-static loading with P = 0.45 P prop



(a) Specimen 1 (QSB-1)



(b) Specimen 2 (QSB-2)



(c) Specimen 3 (QSB-3)

Fig. 6. Graph of the relationship between load (kg) and deflection (mm) on quasi static loading with P = 0,7 Pprop

Based on the test results presented in Fig. 5 and Fig. 6, it is known that the behavior of the connection in quasi static testing is the value of the load and deflection relationships that occur in the connection. Table II presents the quasi static loading pattern in cycle 1 to cycle 20 on each specimen.

Table II. Deflectiont in each cycle with a maximum load of 0.45 Pprop (QSA) and 0.7 Pprop (QSB)

Siklus	Displacemen (mm)					
	QSA-1 (mm)	**QSA-2 (mm)**	**QS-A3 (mm)**	**QSB-1 (mm)**	**QSB-2 (mm)**	**QSB-3 (mm)**
1	5,62	2,65	3,05	6,06	6,11	5,98
2	5,44	2,63	3,00	5,82	6,08	5,87
3	5,46	2,76	2,85	5,79	6,03	5,85
4	5,12	2,79	2,98	5,61	5,96	5,82
5	4,91	2,85	2,96	5,64	5,92	5,8
6	4,68	3,03	3,03	5,45	5,86	5,75
7	4,21	3,01	3,01	5,50	5,83	5,71
8	4,91	3,04	3,03	5,47	5,80	5,66
9	4,68	3,05	3,09	5,39	5,80	5,68
10	4,65	2,90	3,03	6,12	5,85	5,71
11	4,40	2,80	3,02	6,06	5,81	5,65
12	4,30	2,72	2,99	5,53	5,79	5,60
13	4,04	2,68	2,94	5,58	5,75	5,54
14	4,02	2,68	2,92	5,46	5,68	5,43
15	3,97	2,8	2,96	5,64	5,71	5,45
16	3,89	2,73	2,98	5,66	5,78	5,47
17	3,81	2,58	2,94	5,63	5,82	5,49
18	3,82	2,67	2,94	5,64	5,85	5,53
19	3,95	2,60	2,93	5,66	5,82	5,58
20	3,94	2,60	2,93	5,65	5,82	5,57

(c) Specimen 3

Based on Table II it is seen the deflection in each cycle. Connection behavior is observed in each cycle during testing. The test begins with pre-loading on the connection, it is seen that the deflection in each cycle with a maximum load of

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0.45Pprop and 0.7P prop. The deflection that occurs when pre-loading has a much greater value than the deflection that occurs in the next cycle. This condition is caused because in this condition the components in the connection system have not been in a precise condition. At the time of pre-loading the maximum deflection for the maximum loading of 0.45 P prop is 7.79 mm, 4.9 mm and 5.11 mm respectively with an average deflection at pre-loading of 5.93 mm. At the time of pre-loading the maximum deflection for a maximum loading of 0.7Pprop was 11.75 mm, 10.2 mm and 7.75 mm with an average deflection in cycle 1 of 9.9 mm.

In the first cycle the maximum deflection for maximum loading of 0.7P prop is 6.06 mm, 6.11 mm and 5.98 mm, respectively, with an average deflection in cycle 1 of 6.05 mm. During the test, visual observations were carried out on each specimen. In addition to visual observation, during the test also observed the noise generated on the test object. The test object is a connection with a connection system component consisting of bamboo, wooden clamp, wooden gusset plate and bolts, where during the test sound is heard which indicates that the connection system has to adjust to a stable position. Sound is heard during pre-loading at loading with a maximum load of 0.7Pprop which is around 800 kg. In the first cycle and so on there is no more noise generated on the connection. This behavior shows that on the test object repositioning during pre-loading and in the first cycle and on the behavior of the test object the connection is relatively stable and the contact area between the bolt and the other connection system components is perfect.

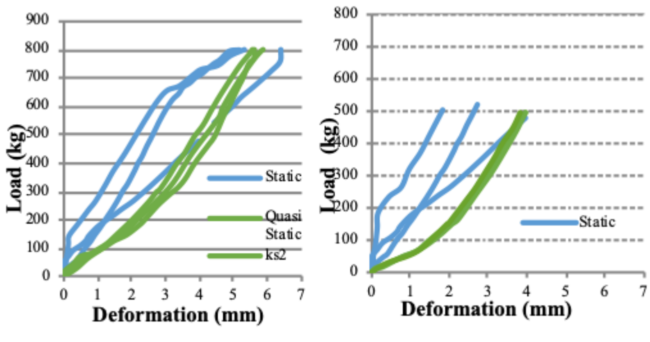
Load repetition in quasi static testing can reduce connection stiffness as presented in Table III. Reduction of connection stiffness for loading 8000N to 5000N load repeatedly (taken in cycle 20) is 14%. This static behavior can be analogous as a repetitive load in one direction such as the load caused by wind force (wind direction in 1 direction). Based on the test results it is known that the load that act continuously even though it is still below the proportional load limit will reduce the stiffness of the connection. The amount of load that is given repeatedly will affect the stiffness of the connection, the closer to the proportional load limit the smaller the stiffness will be.

Table III. Perbandingan kekakuan sambungan kuasi statik

Load (N)	Specimen	Deformation (mm)	Average Deformation (mm)	Stiffness N/mm	Average Stiffness N/mm	Rasio $\frac{QS}{QSA}$
5000	QSA-1	3,94	3,16	1269,04	1632,87	1
	QSA-2	2,60		1923,08		
	QSA-3	2,93		1706,48		
8000	QSB-1	5,65	5,68	1415,93	1408,93	0,86
	QSB-2	5,82		1374,57		
	QSB-3	5,57		1436,27		

B. Comparison of Strength Ratios to Connection Stiffness in Static and Quasi Static Testing

Tests under static loading and static quasi carried out on the bamboo stem connection model produced different strength and stiffness ratios. Static loading was carried out until it reaches the ultimate load or the bamboo culm has large deflection while static quasi loading is carried out by giving successive loads statically but increase continuously or gradually in one direction with the load given at proportional limits and the connection has not reached collapse. To compare these two types of testing, the static loading amount is taken at the proportional limit (before the test object reaches collapse), while in the static quasi testing the comparison cycle is the last cycle, which is the twentieth cycle as presented in Fig. 7.



(a) (b)

Fig. 7. Graph of the relationship between load (kg) and deflection (mm) on static and quasi static loading with (a) P = 0,7 Pprop (b) P = 0,45 Pprop

Based on the results of testing with static and quasi static loading, it is known that repetition of loads on quasi static testing can reduce connection stiffness. Reduction of connection rigidity for 8000N and 5000N repetitions which were repeated (taken in the 20th cycle) were 2.45% and 23.26% respectively. This static behavior can be analogous as a repetitive load in one direction such as the load caused by wind force (wind direction in 1 direction). Based on the test results it is known that the load that continues continuously even though it is still below the proportional load limit will reduce the stiffness of the connection.

V. CONCLUSION

Komponen sistem sambungan yang terdiri dari bambu, klos kayu, plat buhul kayu dan baut, selama pengujian melakukan penyesuaikan pada posisi yang stabil. Perilaku ini menunjukkan bahwa pada sistem sambungan pengalami reposisi pada saat *pre-loading* dan pada siklus ke-1 dan seterusnya perilaku benda uji sambungan relatif stabil dan bidang kontak antara baut dengan komponen sistem sambungan lainnya telah sempurna. Selama beban yang diberikan pada sambungan masih dibawah batas proporsional maka sambungan kembali pada kondisi awal yaitu bentuk dan posisi sambungan sama dengan bentuk dan posisi sebelum dibebani. Pembebanan statik dan kuasi statik dapat menurunkan kekakuan sambungan yaitu untuk pemberian beban secara berulang sebesar 8000N dibandingkan dengan 5000N terjadi pengurangan kekakuan sebesar 14%. Sementara itu apabila dibandingkan dengan pembebanan secara statik, pembebanan secara kuasi statik yang diberikan secara berulang sebanya 20 siklus untuk beban sebesar 0,45 Pprop dan 0,7 Pprop dapat menurunkan kekakuan sambungan masing-masingnya adalah 2,45% dan 23,26%. Berdasarkan pengujian kuasi statik diketahui perilaku sambungan yaitu kekuatan dan kekakuan sambungan sangat dipengaruhi oleh besarnya beban dan penempatan komponen sambungan pada sistem sambungan.

The connection system component consists of bamboo, wood clamp, wood gusset plate and bolt, during the test do adjustments in a stable position. This behavior shows that the repositioning connection system at pre-loading and in the first cycle and so on the behavior of the test object is relatively stable and the contact area between the bolt and the other connection system components is perfect. As long as the load applied to the connection is still below the proportional limit, the connection is returned to the initial condition, ie the shape and position of the connection are the same as the shape and position before being loaded. Static and static quasi loading can reduce connection stiffness, ie for repetitive loading of 8000N compared to 5000N there is a 14% reduction in stiffness. Meanwhile when compared with static loading, the quasi static loading which is given repeatedly is 20 cycles for a load of 0.45 Pprop and 0.7 Pprop can reduce the connection stiffness of 2.45% and 23.26% respectively. Based on the quasi static test, it is known that the connection behavior is the strength and stiffness of the connection which is strongly influenced by the amount of load and placement of the connection components in the connection system

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VI. REFERENCES AND NOTES

All referencing styles are allowed. However,authors must use END NOTE or any other software for Referencing. Preferred Style is APA for Humanities and SocialSciences. **Manual referencing is not allowed**. In case of manual referencing, the process of publication can be delayed.

Note: Tables and Figures should be adjusted within paragraphs text.

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