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Static Stress Analysis Of Girder Cross Section For Mobile Forest Bridge

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Abstract - **Forest bridge is one of the most important components in forest road network. Good forest road network allows implementation of sustainable forest management by carrying out post-harvesting activities. The bridges were needed when route without stream crossing could not being avoided. The permanent bridge structure would be easily collapsed due to storm and high velocity of water during the monsoon season. Numbers of permanent bridges are to be built along the route to the deep in the forest and high installation cost would be incurred. Therefore, a concept of modular and mobile would be the solution for the accessibility to the remote area in the forest. This proposed concept of forest bridge need a lightweight material and modular design for easy installation and handling. Design of modular and mobile forest bridge needs an optimum timber beam cross-section to be the girder in the bridge system. This cross section was the first parameter to be determined the modular design of forest bridge could be proposed. This study applied finite element method to determine the structural shape of timber beam for the forest bridge girder. The simulation was carried out with 3-point bending test under five load cases for Rectangular-shaped, I-shaped and T-shaped cross-section. Analysis of stress-strain, displacement, and volume have been carried out and recommended I-shaped cross section to be the structural shape of the timber beam.**

Index Terms— Forest Bridge, Modular, FEA, Girder, Cross Section.

I. INTRODUCTION

Forest harvesting in Malaysia is currently being carried out deep inside the forest where accessibility is the main problem. This is particularly true when bridge is needed for stream or river crossing. Under the current logging road specification, temporary log stringer bridges are built for temporary usage which are removed or left to deteriorate at the end of the use period (Taylor et al., 1995). Almost any species of wood would allow usage less than three years. With a proper of culvert design and hardwood species for sill log, the service life could be extended (Chow, 2013). But this condition is subjected to site-specific soil and climatic conditions (Walbridge, Frankin, Griffiths, & Jarck, 1984). This situation leads into a problem to whoever needs to cross the stream for official or personal purposes such as Forestry Department (FD). This poses many problems when inspecting bridge timbers since often the damage is internal, leaving no visible signs of decay on the surface (Morison et al., 2002). Practically, FD will run forest and soil treatment in the logged over area for post harvesting activities in order maintains the forest health and treats the disturbed forest and soil. Most of the time upon completion of logging activities these temporary bridges are not maintained and will deteriorate and collapse due to high velocity of water flow, erosion and sedimentation (Leete, 2008).

Thus, post harvesting activities in the logged-over forests and other research activities inside the logged-over forest could not be carried out unless the bridge is repaired. As such there is a need to have a suitable cost-effective and easy to handle but durable bridge that can be used to access logged-over forest to carry out post-harvesting activities. Taylor et al., (1995) suggest for portable bridge which could be easily transported, installed, and removed for reuse at multiple sites. The ability to serve multiple installations could possible to reduce the construction cost compared to permanent structure besides of reducing potential water quality problems (Brinker & Taylor, 1997). Nowadays, there are numbers of portable bridges that have been developed in reducing the environmental impacts, but heavy machinery is needed to install and dismantle. Besides, those portable bridges are designed with limited span length and could only be applied in certain stream.

Current practice of forest road construction use native log as main structure especially as a stringer. The capability of the structure to sustain the applied loading depends on the design and material applied on it. Forest road network is generally constructed with a single lane and unpaved and exposed to the light vehicle at the early of the forest opening. However these roads exposed to extensive usage during logging operation where the heavy vehicles are used for logs transportation and may excess legal highway load. This road normally used only for a short period with a long

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usage cycle and this lead the management to close these roads whenever there is no logging activities (Taylor, Ritter, & Murphy, 1995).

However the disadvantages of current bridges are these bridges are designed for super heavy loads and activities which designed to use steel beam or solid timber as a stringer or girder. These structures need heavy machinery for installation and removal. Because of high installation and maintenance cost of current bridge, there is a requirement to design a suitable and cost effective modular and mobile forest bridge that can be used to access logged-over forest for post-logging activities in this country.

This study propose the modular concept in designing the mobile forest bridge in order to solve the limitation of bridge length span and the maximum imposed loading. For normal bridge construction, size of bridge girder or deck already being earlier designed for on-site installation. These kinds of bridges are normally for permanent installation or portable bridge but with fixed bridge span. This span would not allow this bridge to be installed at other site for crossing. The expandable span of mobile bridge would give the forest manager better option of route selection for accessibility. However the design of this mobile bridge with expandable bridge span was focused on this study.

The design of modular and mobile forest bridge with lightweight material found to produce a reliable, low-maintenance bridge with capability to deliver high performance over the life of a bridge structure (Kannankutty & Flemming, 2000). The proposed bridge concept is expected to help forest manager to manage execute the post harvesting activities. The proposed bridge is installed at the stream site for crossing and the same the same bridge will be used for the next stream crossing. In this study, the span of the specimen was limited tosub-low volume category of bridges which is less than 10 m bridge span.

II. MATERIALS AND METHODS

Shape and material were the most significance factor that affected the result of the structure especially under bending. This selection was focus on cross section of the main girder which is the most important parts before further the analyses. Focus of this analysis was to select the structural shape of the beam which to be used in the next analysis. Abdollah & Hassan (2013) in the different study also use FEA to determine the suitable cross section for side door impact beam. In their study, four shape was analysed which are circular hollow, square hollow, I-type and C-type. However, only three shapes had been finalized for this study which were Rectangular-shaped, I-shaped and T-shaped (Figure 1). Analysis using finite element method had been carried out toevaluate the best cross section to be applied for timber beam.

The analysis was carried out using Autodesk Mechanical Simulation under Static Stress analysis in comparing result of stress, stain, deformations and deflections. In the Autodesk Mechanical Simulation, static stress analyses need to be defined at the beginning of setting when the program was started. The 3D model was automatically displayed with different colour to differentiate the loose parts in the model. All parts displayed in the simulation desktop should be renamed in order to ease the pre-processing process. The next activity was to mesh all parts in the model in order to create the elements and nodes. Defining the type of contact between parts would allow type of elements and nodes to be assigned for the type of connection. All parts of the specimen were set to be under surface type contact which means the models were separated and allowed to slide.

Three major steps in the simulation session were pre-processing, simulation processing and post-processing. In pre-processing, the first activities that were to be completed modelling of the geometry. In this case, 3D geometry modelling was completed using AutoCAD program before the simulation could be run. These models developed with solid modelling and assembled into a single layer. Unwanted objects in AutoCAD layer were erased and cleaned to avoid disruption during pre-processing of Finite Element Analysis (FEA). Volume intersection of 3D models checking were also being carried in AutoCAD program in order to display the intersection occur among 3D models. Final 3D models were transferred to simulation program with DWG format.

Meshing 3D models was the next activity and it should be approximate to the actual model. In processing part the process involved were mesh adaptation, numerical method and problem solver. The input required at this stage was the bounded error and the maximum iteration steps. However, for standardization in processing the iteration steps and error bounded were set to automatic which the best for that certain process. For post-processing, the result of simulation program was normally expresses in diagram, colour plots and etc. In this study the simulation result was expressed in stress, strain, deformation and displacement. These results of simulation were compiled and compare for further analysis.

Element Type

The element types that used in modelling the bridge affect the calculation of the flexural bending moment in all girders (Mabsout, Tarhini, Frederick, & Tayar, 1997). Finite element analysis program had offered options on element types, material behaviour and numerical solution controls. Besides, the program also offered an auto-meshers with graphic user interfaces, and sophisticated postprocessors and graphics to speed the analyses (Queiroz, Vellasco, & Nethercot, 2007). (Queiroz et al., 2007) in their study had used solid type of elements for the steel section and the concrete slab. The solid element is used for 3D dimensional modelling of solids. The nodes in solid element could vary from four-node tetrahedron to the 27-node brick element and eight-nodes brick element is the most common version

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(Tore, Hopperstad, & Langseth, 2001). This type of element has eight-nodes and three degrees of freedom (translations) at each node. A suitable elements and appropriate solution techniques are important to obtain reliable results up to failure. In this study, solid type of brick element was used to be the main element type as (Minalu, 2010) who modelled girder flanges were as space frame elements, and flange-to-deck eccentricity as modelled by imposing a rigid link with isotropic, eight-nodes brick type of elements while (Jawad & Mohamad-ali, 2010) had modelled using a combination of eight-nodes shell elements and 3-node beam elements. (Uddin, Abro, & Vaidya, 2007), (R. M. Lin, 2011) and (Cheng, Zhao, Karbhari, Hegemier, & Seible, 2005) also in their study used eight-nodes brick type of elements.

The basic output generated from finite element analysis is the displacements which depended on the type of the element. The displacements which are translations and rotations are varied for each element and these referred as ‘degrees of freedom” (Modjeski & Masters, 2003) which were longitudinal displacement, transverse displacement, vertical movement, rotation about the longitudinal axis, rotation about the transverse axis, and rotation about the vertical axis (Alper, 2005).

Element Definition

Beside of element type, element definition also had to be setting up to those 3D models transferred from AutoCAD program. Both timber and aluminium had different grain structure and different material properties. For connector the element of aluminium was defined as isotropic and homogeneous as assumed by Aslam, (2009). This is because of this material properties were identical in all direction. This material model will only experience deflections in the elastic region of the stress-strain curve. A single modulus of elasticity and Poisson's ratio will be the requested material properties. While for timber beam the element was defined as orthotropic where the material properties are not same in all direction. This material model will only experience deflections in the elastic region of the stress-strain curve. The part may have different material properties in certain directions. Specifically, the material properties may be different in one or more of the three orthogonal directions in a rectangular coordinate system. The element properties for both aluminium and timber are as in Table 1.

Table 1: Element properties for simulation (Eugene Kim & Andrawes, 2017).

Component	Material	Element type	Element Definition
Connector	Aluminium 6160-O	Brick	Isotropic
I-Beam	Timber	Brick	Orthotropic

After the meshing process completed the nodes and elemental propertiescould be calculated. Those generated elements and nodes was assigned and used in calculating the applied analyses. By meshing activity also the elements and nodes between connected parts could be defined. These elements and nodes would allow for setting up support condition and loading conditions at the individual element positions. The material properties could then be specified.

Material Properties

Most of analyses carried out in this study used timber as the main material for segmented beam. Western White Pine was selected to be the main material for the finite element analysis because the bending test for this species had been carried out earlier in a separate study. Material properties of timber that were used in the simulation are as in Table 2.

Table 2: Material Properties for Western White Pine (Maloney et al., 2016)

Mass Density (kg/m^3)		425.338
Modulus of Elasticity (MPa)	Local Axis 1	11100.559
	Local Axis 2	868.739
	Local Axis 3	420.580
Shear Modulus of Elasticity (MPa)	Local Plane 12	577.091
	Local Plane 13	532.965
	Local Plane 23	55.848
Poisson's Ratio	Local Plane 12 (Major)	0.329
	Local Plane 13	0.344
	Local Plane 23	0.41
Thermal Coefficient of Expansion (1/℃)	Local Axis 1	3.06E-06
	Local Axis 2	2.21E-05
	Local Axis 3	3.06E-05

Second local axis of modulus of elasticity was applied for the calculation of allowable deflection. The result calculated for only comparison purposes.

Specimen description

In order to start the analysis, a few common structural shapes were finalized such as Rectangular, I and T shape. Dimensions of the beam were modelled with a standard size using AutoCAD program. The outer dimension cross sections were 80mm x 240mm which was the cross section geometry for the first 3D model. The other two models for I and T cross section, the geometry was based on the outer dimension of rectangular cross section (Figure 1).

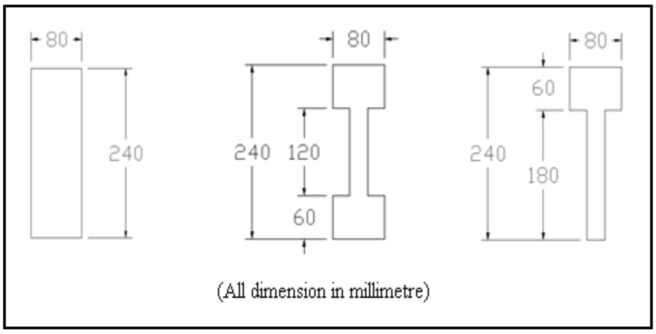

Figure 1: Rectangular, I and T cross section.

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Three unit of 3D model specimen with different cross section with 10m beam span built using AutoCAD are as Figure 2. The unwanted objects in the AutoCAD desktop to finalize the 3D model before transferred to simulation program. These models would undergo the simulation of bending test under static stress analysis in Autodesk Mechanical Simulation program.

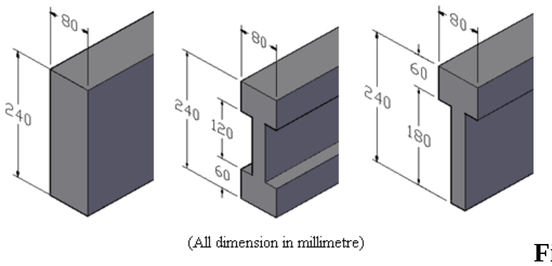

Figure 2: 3D model of Rectangular, I and T shape.

Element details

The clean model transferred to simulation program for meshing process and setting up the boundary condition. One of the most important parts dealing simulation was the meshing process. Meshing created element throughout the 3D CAD model which to be used in simulation process. These elements were bounded by number of nodes which interconnected with in the elements. Table 3 shows the information of the model for different cross section after the meshing process completed.

Table 3: Detail information of the elements

Criteria	REC	I	T
Total nodes	3623	9379	5994
Volume (m^3)	0.192028	0.129619	0.098414
Total elements	2000	17006	8620

Test setup and loading

Three specimens were prepared in AutoCAD program with different cross sections which were Rectangular-shaped, I-shaped and T-shaped with 10 beam span. The model was exported into Autodesk Mechanical Simulation program under static stress analysis for the simulation of bending test. Loading was applied at the mid-span of the specimen as a nodal point force with downward direction. The simulation was repeated with 5 different load case started with 10.301kN, 20.602kN, 30.903kN, 41.204kN and ended with 51.503 kN. The result of stress, strain, deflection from the analysis with different load cases was recorded. Besides, volume parameter was also being analysed to compare the specimen with the different cross section. Schematic diagram for the static stress analysis in this section is as shown in Figure 3.

Beside of material selection, assignment of loading is one of the important steps in pre-processing. In this study, the assignment of loading is based on the 3-points bending test(Foster et al., 2017); (Ghazijahani, Jiao, & Holloway, 2017). Static load(Zheng & Fox, 2017) was assigned at the desired nodes on top of the specimen as nodal force with downward direction.Based on forest road and terrain condition from the main road to deep inside the forest, four-wheel drive vehicle is the best selection for transporting modular and mobile forest bridge for installation and dismantling for each stream crossing. The load design is based on four-wheel drive Toyota Hiluxwith double cabin which the Gross Vehicle Weight is approximately 3000 kg.

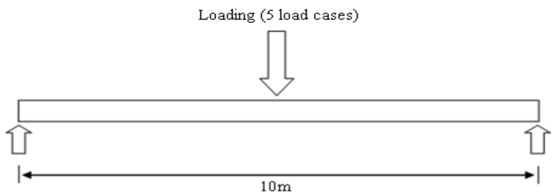

Figure 3: 3-point bending test on static stress analysis

For live load factor in load design is referred to ASSHTO HS20 which is 1.75 (Liu, 2007). The imposed load for the simulation is 51.503 kN (3000kg x 1.75 x 9.81 m/s^2). From Autodesk Mechanical Simulation, the maximum result of stress, strain and deflection could be extracted. Thus, in order to project the trend of the result five different load cases had been tabulated for simulation purposes. Those five load cases are 10.301 kN, 20.602 kN, 30.903 kN,41.204 kN and 51.503 kN were tested on the specimen in each section of the analysis. From these different load cases, the result of stress, strain and deflection were analysed.

The elements were bounded by nodes that were assigned to the boundary condition. Nodal point of loading is set at the mid-span of the beam. In this particular analysis, the selected support is at the surface of the beam end where these surfaces were set as fixed during the bending simulation. A setting of this boundary condition is standardized for all cross section. Different number of nodes in which assigned for support caused by the different cross-section of the beam and meshing processing completed with automatic mode (Figure 4).

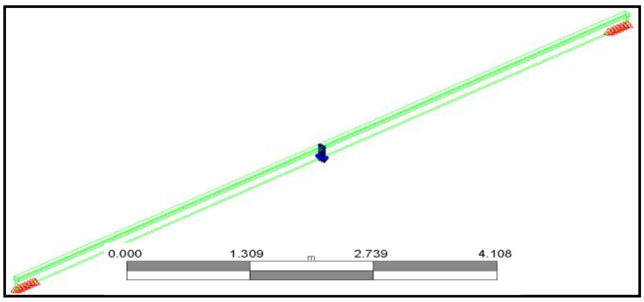

Figure 4: Boundary condition set up for the simulation.

However in completing the simulation a few assumptions were made, namely (i) the 3D models developed are assumed to be geometrically linear and responds to the system with linear elasticity (Minalu, 2010; Weaver,

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Davids, & Dagher, 2004;Bhashyam, 2002), (ii) the reinforcement between timber and CFRP laminates are perfectly bonded (Almusallam, Elsanadedy, & Salloum, 2015;Lin & Zhang, 2013;Park et al., 2010) and the results generated by the Static Stress analysis is not sensitively dependant on the selected mesh size (Park et al., 2010).

III. RESULT AND DISCUSSION

This study was to evaluate the respond of flexural bending on the beam with different cross sections. The analyses were completed finite element method under static stress analysis using Autodesk Mechanical Simulation program. The parametersevaluated were stress, strain, displacement and volume. The selected cross section for timber beam was determined for modelling the specimen. Three cross sections had been identified and the specimens were prepared with 10m beam span.

Stress strain analysis

Selection of timber beam cross section was based on the simulation result which was modelled with 10m beam span. Results of stress and strain were recorded with 5 different load cases. The results for Rectangular-shaped, I-shaped and T-shaped cross section were summarized into stress-strain graph as in Figure 5.

The result shows that the specimen with T-shaped cross section recorded the highest stress and strain vale among all cross section at 51.503 kN loading and followed by I-shaped and then Rectangular-shaped cross-section.

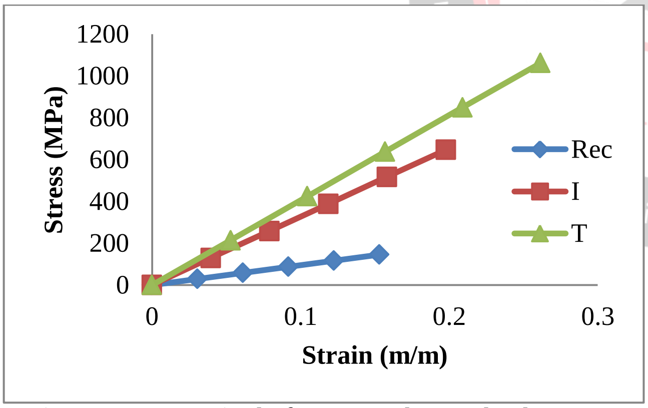

Figure 5: Stress-strain plot for Rectangular, I and T shape cross section.

Rectangular-shaped cross section recorded the lowest value of stress and strain among all of cross section. The simulation result also showed that stress distribution of a loaded beam that the greatest stress occurs at the top and bottom edges of the beam. Abdollah & Hassan (2013) has selected square hollow cross-section because of the capability of the specimen to sustain at the highest bending load before yielding. Amany & Pasini (2009) mentioned that the strain response of a beam strongly depends on the type of applied load. This led to the improvement on a rectangular section by introducing the I-section in which the large flanges were situated at a distance from the neutral axis. Therefore, I-shaped was preferred for the timber beam cross section.

Displacement analysis

Deflection analysis was the second evaluation to justify the selection the cross section for timber beam Rectangular-shaped, I-shaped or T-shaped. The simulation was based on 3-point bending set up to considered a centrally loaded and simply supported beam undergoing small and linear-elastic deformation (Amany & Pasini, 2009). Due to material and geometry, the slender of beam cross-section causes the deformation to be under non-uniform bending. In this analysis, the zero value of deflection was recorded at the support location on the 3D model. Therefore, only the maximum values of deflection which occur at the center of beam span were compared for cross section selection.

Figure 6 shows the deflection results from the simulation program and the allowable deflection calculated for reference purposes. The result showed that the highest deflection from T-shaped cross-section followed by I-shaped and then the Rectangular-shaped of the specimen. The deflection resulted from the simulation for51.503 kN loading was 0.3211m, 1.1521m and 1.7465m for Rectangular-shaped, I-shaped T-shaped cross-section consecutively. The allowable deflection recorded for Rectangular-shaped, I-shaped T-shaped cross-section was 1.6752, 1.8234, 3.0602m consecutively. It is found that, all simulated deflections are within the allowable deflection. The beam cross-section is assumed to be uniform along its length with a homogeneous and orthotropic material.

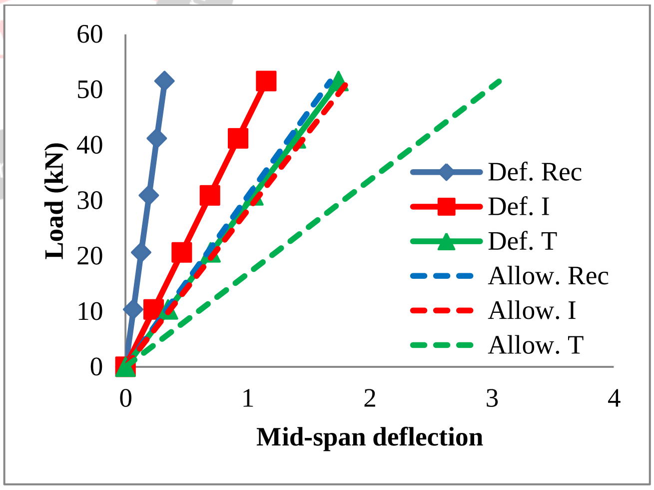

Figure 6: Total load vs displacement for different type of cross section.

The deflection result for I-shaped cross-section shows in the range between Rectangular-shaped and T-shaped cross section. In order to meet required stiffness, the minimum mass of a beam that yielded from cross-section size and shape, beam slenderness, and material govern were considered. The selection of the slenderness, shape and material is optimized the lightweight structure design(Amany & Pasini, 2009). Therefore, I-shaped cross section was suggested to be the structural shape for timber beam.

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Volume analysis

As the study mainly to propose a modular and mobile concept of forest bridge, volume of timber beam is one of the main criteria should be considered during design stage because of linear relationship to the weight. The heavier structure would need number of manpower for installation of forest bridgeat the stream crossing site. Structural geometry and material are factors that would affect deformation and mass efficiency.Megson(2005)mentioned in that the yield lines are assumed to be plane and therefore the cross-section of the structure must possess a geometric compatibility. Abdollah & Hassan(2013)also choose the higher strength to weight ratio of material selection for their study. Therefore, the lighter weight of the parts in bridge structure would be prioritized.

Figure 7 shows the volume comparison of specimen for all different cross-sections. Rectangular-shapedcross section recorded the highest volume of timber beam followed by I-shaped and then T-shaped cross section T-shaped cross section contributes the lightest wright of timber beam among all cross section however, T-shaped cross section is not recommended based on stress-strain and deflection analysis. Thus, I-shaped cross section which the second choice in this volume analysisis recommended for girder cross section to ease in handling and installation processes.

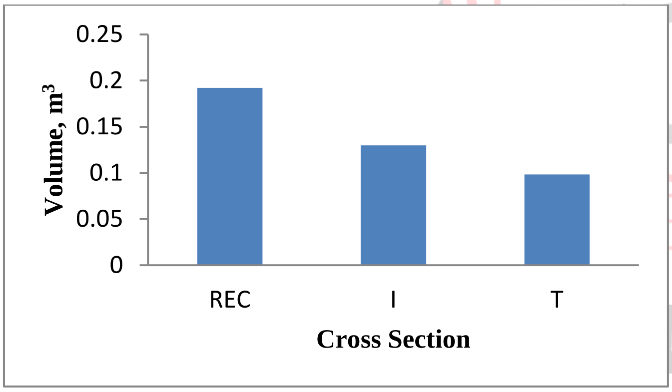

Figure 7: Volume comparisons for different cross section.

IV. CONCLUSION

In conclusion, selection of structural shape for timber beam could affect the structural strength of the proposed modular and mobile bridge. Three different structural shapes had been analysed which are Rectangular-shaped, I-shaped and T-shaped cross section. The analysis shows that the specimens with different cross sections differently behave during the applied loading. Generally the Rectangular-shaped cross section show the strongest and the stiffest compared to other cross section. However, in order to implement the modular and mobile concept for forest bridge, I-shaped cross section was selected because of reasonable result of strength and stiffness result with lighter weight of the structure. This proposed modular mobile forest bridge is expected to solve accessibility problem and allow the forest manager to carry out post harvesting activities such as replanting activities and research activities after logging operation completed.

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