



Computational Investigation into the Response of Glue-laminated GFRP Timber Bridge Beams

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Abstract: The paper presents data obtained from the finite element ANSYS program used to study the response of the Douglas fir timber bridge beams under static loading condition. The beams were analyzed under three point bending and were reinforced with the glue-laminated glass fiber-reinforced plastic (GFRP) plates along the bottom surface of the timber beams. The beams analyzed had dimensions of $130 \times 330 \times 4500$ mm. The material properties used in the ANSYS program were obtained from material testing. The failure criteria used for GFRP longitudinal reinforcements were predicted using the maximum stress theory. The second order delaminating equation was used to predict failure in the interface between wood surface and the GFRP reinforcements. The data obtained from the finite element program was compared with the elastic portion of the experimental load versus deflection curves published by Alhayek and Svecova [1] as it was hard to include the small non-linear portion because of the heterogeneity of the timber. The published data obtained from the experimental work agreed very well with the data obtained from the finite element analysis which lead to confirm the accuracy and the validity of the finite element model.

Keywords: Timber; GFRP; Bridge; FEA; ANSYS

I. Introduction

A. Background

There are a total of 575 bridges were built prior to 1980 in the province of Manitoba, Canada. A rough estimate provided by Manitoba infrastructure and highways indicate that rehabilitating these bridges may exceed \$430 million. On other hand a complete replacement of these bridges costs as twice much as having them rehabilitated besides the involvement of complex political issues and decisions related to environmental concerns. Retrofitting timber bridges with GFRP sheets is considered as an effective and economical alternative to the replacement of the bridge components because members are rehabilitated instead of being replaced. It is always expensive to carry out full size of experimental tests on Timber Bridges. As a consequence, a computational investigation using ANSYS finite element software [3] would be considered a good technique to assess the structural enhancement and behaviour to these glue-laminated GFRP timber bridges. It is emphasized that the ANSYS model in this study is a general-purpose finite-element program that will analyze Timber Bridge under the most generalized assumptions. First, it uses the ANSYS program and material mechanical properties from material testing, the prediction of displacements in the vertical direction is determined. Second, the ANSYS program was used to investigate the stresses obtained for GFRP, Epoxy resin and Timber beams in order to locate the failure in structure. Finally, the results obtained from computational analysis will be compared to the actual testing published results. Many studies were reported in literature on the subject of strengthening timber beams in tension side using aluminium, steel strips and steel rebar ([14], [5], [15], and [12]). Other studies were conducted on strengthening laminated timber beams using steel wire bonded with epoxy ([11], [7]). The effects of bonding unidirectional fiberglass/epoxy reinforced plastic to the compression and tension faces of wood cores of various species were conducted by both Wangard[19] and Biblis[4]. They report in their studies increases in the modulus of elasticity (MOE) ranging from 20 to 50 % using only 10 % reinforcement by volume. In the past two decades, there was great demand on the application of FRP for reinforcing timber beams. Dagher et al. [8] studied the effect of FRP reinforcements on low grade eastern Hemlock glulam beams reinforced with FRP on the tension side and three unreinforced controls. In their research, the FRP reinforcement was varied from 0.3% to 3.1%. All of the beams were tested to failure in four-point bending and the results showed a substantial increase in strength up to 56% and an increase in stiffness up to 37% compared to the control beams. Taheri et al.[17] investigated the response of glued-laminated columns reinforced with GFRP. The authors performed a complimentary experimental and computational investigation to describe the response of axially loaded glulam timber columns strengthened with GFRP. The study involved several parameters such as slenderness ratio, boundary conditions, and FRP reinforcement length. Yahyaei and Taheri[18] studied the performance of GFRP reinforced glulam beams. They determined experimentally the creep parameters of aramid fiber-reinforced epoxy (AFRP) and plain

wood. Moreover, a non-linear finite element model was developed to predict the creep response of the AFRP reinforced timber beams based on the creep characteristics of the individual. Alshurafa et al. [16] manufactured a total of 15 glued-laminated curved beams. The beams were partially and fully reinforced with glass fiber-reinforced polymer (GFRP) laminates in tension and in compression zones. The beams were tested to failure in three point bending. The average ultimate load for a glued-laminated curved beam with [0]2 layup (i.e., GFRP reinforcement ratio of 1.05% by volume) applied on the upper and lower surfaces of the beam, along the full-length, showed an increase of 42 percent in strength and a 27 percent increase in stiffness compared to those of the control curved beam, respectively. This remarkable enhancement was achieved by using only 1% by volume of reinforcement. Moreover, a linear NISA finite element model was developed to predict the structural behaviour of the beam. The experimental obtained results showed a good agreement with the finite element results. Alhayek and Svecova[1] tested a total of 20 salvaged creosote-treated Douglas fir timber stringers strengthened with glass fiber-reinforced polymer (GFRP) plates. The beams were reinforced using various GFRP configurations. Some of the beams only reinforced along the bottom and other beams reinforced on top and bottom surface of the beams. The beams were tested to examine the effect of GFRP reinforcement on the stiffness increase of the beams. The beams were tested in three-point bending. Two groups were studied. This study found that the strengthening with GFRP laminates, on average, increased the strength and the stiffness of the beams, respectively, up to 36 and 3.5%.

B. Objectives

The main objective of this paper was to write an ANSYS finite element program to analyse GFRP plates glued-laminated to created grooves along the bottom tension side of the Timber beams. In addition, the paper will compare the data obtained from the computational investigation to the data published experimentally by Alhayek and Svecova[1] to validate the established finite element model. Moreover, it will confirm the fact that the ANSYS program can be used to examine the capability of the use of GFRP to strengthen timber bridges to produce an effective structural material.

II. Finite Element Analysis

A. Finite Element Model

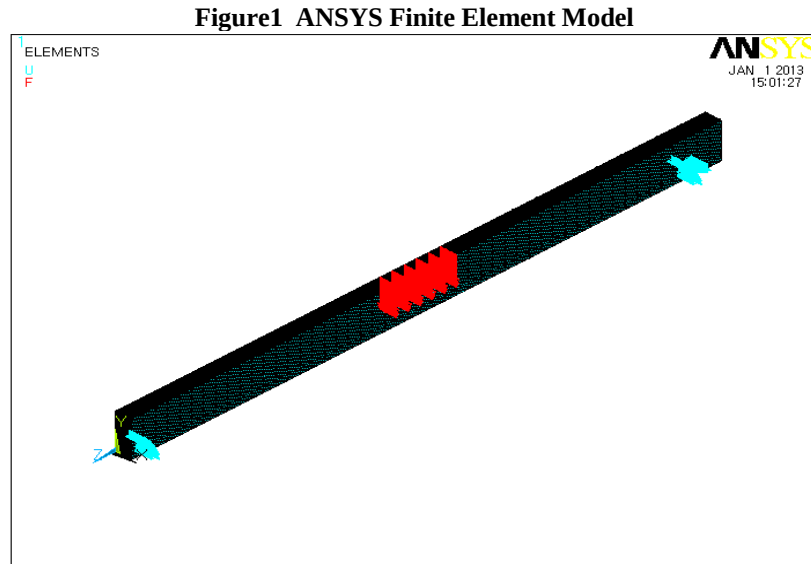
The finite element method is essentially an approximation of the original real problem. The structure under investigation is divided into a number of smaller elements which are interconnected at a finite number of points. If the force/displacement relationships for each of the elements can be formulated then the force/displacement relations for the entire structure can be expressed in the form of a matrix. This matrix relates the stress and strain at any point in the structure using the material properties. These material properties are indicated by the modulus of elasticity and Poisson's ratio. Having defined the element geometry and material properties, the next step is to define the boundary conditions and the applied loads and /or displacement conditions. In matrix formulation the basic equation relating force and displacement for the static analysis in ANSYS is:

$$\{F\}^e = [K]^e \{u\} \quad (1)$$

$$[K]^e = \iiint [B]^T [D] [B] dx dy dz \quad (2)$$

Where F is nodal force vector, u is nodal displacement vector, D is elasticity matrix for orthotropic case and, B is strain matrix. This equation repeats for all elements. When these equations are solved for the known loading and boundary conditions in such a way those at all nodes, the equilibrium and compatibility conditions are satisfied, and displacements, stresses and strains at every point in the structure can be obtained. The ANSYS finite element program was established to analyze a total of 7 Timber beams. Each of these beams has different modulus of elasticity. The modulus of elasticities of the beams were taken from data published by Alhayek and Svecova [1]. The ANSYS program is best defined as an iterative process. The ANSYS line commands code was written in order to find the desired stresses and deflection at any location along the timber beam by running the program simply as many times as needed and changing one or more of the input variable parameters to obtain results that satisfy current Standards. The variable parameters used for the analysis of the glued-laminated timber beams include: the beam cross section; the geometry of the beam; the type of boundary conditions used in the analysis; the mechanical properties; and, the magnitude of the loads applied at the centre point of the top surface of the beam. The finite element program established contained 53200 node and 48951 elements. Figure 1.1 shows the FE model used in the analysis.

The ANSYS Link8 element was chosen to model the GFRP plate. This element is a two-dimensional spar element. The element type used in the analysis of Timber beam was Solid45. This element is used for the 3-D modeling of solid structures. The element is defined by eight nodes having three degrees of freedom at each node: translations in the nodal x , y , and z directions. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.



B. Failure Criteria

The failure in the GFRP/Timber beam interface was determined using the commonly used second order criterion given in equation 3 [13]. Since the normal theoretical stresses obtained usually very small, the first term of the equation will be ignored (S. Alshurafa et al. [16]).

$$\left(\frac{\sigma_n}{\sigma_u} \right)^2 + \left(\frac{\tau_{nt}}{\tau_u} \right)^2 \leq 1 \quad (3)$$

Where:

τ_{nt} : Shear stresses obtained from FEM

τ_u : Epoxy shear strength, taken as 20MPa

The failure in the GFRP plates was determined using the maximum stress theory. Since the GFRP is oriented in the zero direction along the length of the beam, the maximum stress theory short form was used as seen in equation 4.

$$\frac{\sigma_{11}}{S_{LT}} < 1 \quad (4)$$

Where:

σ_{11} : Maximum stress in the principal material direction (FEA)

S_{LT} : Longitudinal tensile strength = 570MPa (Alshurafa and Polyzois [2])

III. Discussion on the Results

As given in Table 1, the maximum difference in deflection between data obtained from the ANSYS finite element and deflection values published by Alhayek and Svecova [1] was in beam # 38 as shown in Figure 1. The present difference was 8.83%. This indicates that the finite element analysis slightly overestimates the deflections. This is understandable, given the fact that the finite element analysis is based on a number of assumptions which underestimate the stiffness of the timber bridge. The summary of deflection values for all 7 beams obtained from ANSYS finite element model along with those obtained from the experimental published data (Alhayek and Svecova[1]) are listed in Table 1.

Figure2 Deflected shape of beam #38

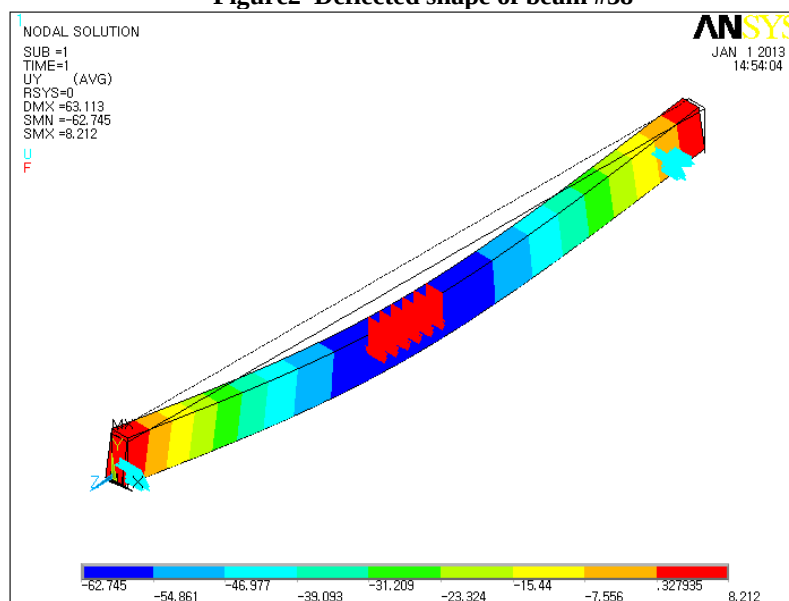


Table 1 Comparison between FE results and (Alhayek and Svecova [1])

Beam #	Load (kN)	Theoretical data from finite element Analysis	Experimental Data obtained from (Alhayek and Svecova [1])		Middle span Deflection Difference in (%)
		Max. Deflection (mm)	Modulus of Elasticity (MPa)	Max. Deflection (mm)	
B38	147	62.74	10769.1	57.20	8.83
B39	117	56.33	10306.1	55.90	0.76
B57	139	49.42	13173.8	47.80	3.27
B34	143	62.22	10615.7	61.04	1.89
B56	100	48.08	10466.6	47.43	1.35
B52	101	46.42	10006.6	46.30	0.25
B53	100	35.31	13272.0	35.20	0.31

The values of the shear and principal stress obtained from finite element are summarized in Table 2. The values obtained from applying the second order delaminating equation and the maximum stress theory were given in Table 3. The values were less than one. This indicates no failure has happened in the epoxy interface or in GFRP plates under the failure loads recorded by (Alhayek and Svecova [1]).

Table 2 Maximum stresses obtained from FE for the reinforced timber beam

Beam #	Load from FEAin (kN)	Maximum stresses obtained from FEAin (MPa)		
		Timber	GFRP	Epoxy
B38	147	61.13/ -63.79	169.65/ -8.62	19.71/ -1.39
B39	117	48.44/ -50.68	140.46/ -7.13	16.31/ -1.15
B57	139	58.85/ -60.78	133.58/ -6.82	15.51/ -1.09
B34	143	59.38/ -62.02	167.17/ -8.49	19.41/ -1.368
B56	100	41.47/ -43.35	118.40/ -6.013	13.75/ -0.97
B52	101	41.69/ -43.69	124.49/ -6.31	14.46/ -1.01
B53	100	42.36/ -43.73	95.45/ -4.87	11.08/ -0.78

Table 3 Values obtained from delaminating equation and maximum stress theory

Beam #	$\left(\frac{\tau_{nt}}{\tau_u}\right)^2$	$\frac{\sigma_{11}}{S_{LT}}$
B38	0.90	0.32
B39	0.66	0.26
B57	0.61	0.25
B34	0.94	0.31
B56	0.47	0.22
B52	0.52	0.23
B53	0.30	0.18

IV. Conclusions

A finite element program was established to analyze bridge timber beams. The small difference of 8.83% of the deflections obtained from the FE model and the tests deflections values reported by (Alhayek and Svecova[1]) confirms the strength of the finite element model as an analysis tool for timber bridges. The comparison of the FEM results with the experimental results indicated that finite element simulation could be effectively used to characterize the response of FRP-reinforced timber beams in an economical manner.

V. References

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