The Calculation Techniques of Non-Matrix Representation Flexible Joint Stiffness to Improve the Accuracy of Beam Element FEA

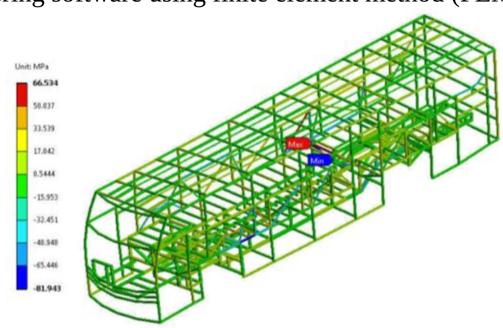
Jakkree Wichairahad*, Sirintra Tan-Intara-Art and Wiparat Nisapai

Abstract— The deformation analysis using finite element method has been widely used to analyze beam structure (e.g. automotive, bus and truck structure). In finite element analysis (FEA), beam element is generally employed as it can simply create CAD model; however, its accuracy is low. The objectives of this study are to examine and provide calculation techniques of non-matrix representation flexible joint stiffness that improves accuracy in measuring the deformation of beam structure by computer-aided engineering software using beam element FEA. The deformation of real T-junction structure is measured by applying 3 linear loads, including linear x, linear y, and linear z. and torsion load- torsion x. Then, compare deformation results between experiment and T-junction rigid joint FEA. The differences of deformation results are further calculated to identify 6-DOF flexible joint stiffness parameters. Next, FEA T-junction structure is re-analyzing with T-junction flexible joint method. By doing so, the subsequent 6 parameters are input to calculate deformation. The results of FEA showed that when analyzing with T-junction flexible joint method, the deformation error was reduced, from 45 % to 1 %, from 46 % to 6 %, and from 16 % to 4 % in the direction of x, y and z axis, respectively.

Keywords— Structural Deformation Analysis, Finite Element Analysis, Accuracy Improvement.

I. Introduction

The deformation analysis of automotive structure, bus structure and truck structure by computer aided engineering software using finite element method (FEM) has recently become common. Generally, three elements- beam, surface and solid are used in FEA. Each element is appropriate for each structure analysis differently. For example, surface element is properly used in FEA of thin wall hollow structure [1], while beam element is suitably used in FEA beam structure due to its computer processing time saving as well as its capability of creating and editing CAD model which is more convenient compared to FEA using surface element. An example of FEA of structure using beam element is FEA bus structure proposed by Gauchia et al. (2010, 2014) [2, 3] as shown in Figure 1(a). An example of FEA of agricultural truck structure is presented in the study of Wichairahad et al. (2016) [4] as shown in Figure 1(b). However, FEA using beam element has an evident drawback: the result accuracy is lower than FEA using surface element. Hence, this study is to provide solutions for the issue. FEA using beam element with flexible joint method can be implemented by two means: non-matrix and matrix representation [5]. The convenient means is non-matrix representation that is calculated by measured the deformation of real structure prior calculating flexible joint stiffness parameters. Then, the identified parameters are input into FEA using beam element with flexible joint method. This paper aims to describe the experiment and calculation process of 6-DOF flexible joint stiffness parameters, including 3-DOF of linear joint stiffness parameters and 3-DOF of torsion joint stiffness parameters based on the recommendations of Alcala et al. (2013) [6]. The contribution of the study is to increase the accuracy of deformation analysis of automotive structure, bus structure and truck structure by computer-aided engineering software using finite element method (FEM).



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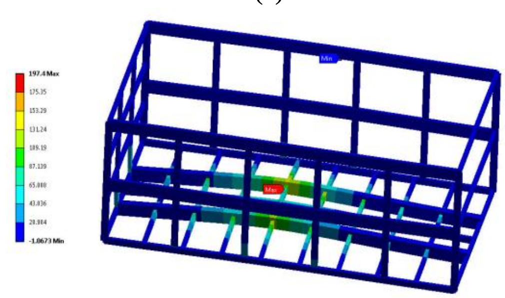

(b)

Fig. 1: FEM structure analysis for; (a) Bus superstructure, (b) Agricultural Pickup Truck structure

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II. Material and Method

A. Fea. T-Junction Rigid Joint

T-junction rigid joint finite element model with 1,000 mm. long and 1,000 mm. wide, 2 fixed supports with equal square hollow cross section and the dimension of 47-mm x 47-mm x 1.8-mm as shown in Figure 2 was considered for FEA to obtain deformation results in order to calculate 6-DOF flexible joint stiffness parameters in equation 1 and 2.

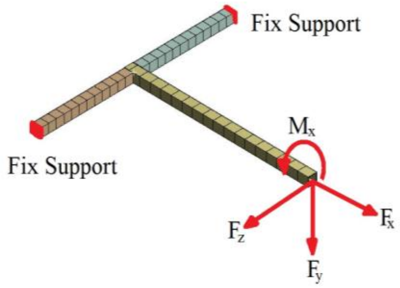


Fig. 2: T-junction FE. Structure with loads

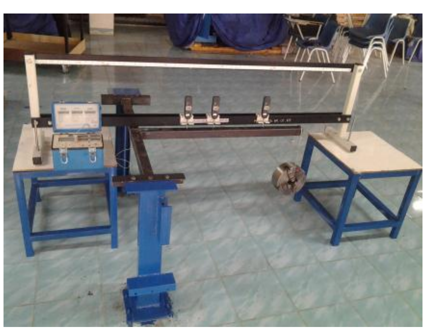
Where F_x, F_y, and F_z are linear loads (N), and M_x is moment or torsion load (N-mm.)

B. Material Properties

Linear elastic homogeneous material behavior assumption was considered, and available material properties were from standard testing. For square channel steel 47x47 mm, yield stress was 245 MPa, Young modulus was 199 GPa, and Poisson ratio was 0.3.

C. Real T-Junction Structure

Real T-junction structure with 1,000 mm. long and 1,000 mm. wide, 2 fixed supports with equal square cross section and the dimension of 47-mm x 47-mm x 1.8-mm as shown in Figure 3 was considered in the experiment to measured deformation results and further calculate 6-DOF flexible joint stiffness parameters in equation 1 and 2 by using F_x, F_y, F_z = 127.53 N (mass 13 kg.), and M_x = 69,925.68 N-mm. (mass 13 kg. span 500 mm.)



(a)

(b)

(c)

(d)

Fig. 3: Real T-junction structure with loads; (a) linear Z-axis, (b) linear Y-axis, (c) linear X-axis and (d) torsion X-axis

D. 6-DOF Flexible Joint Stiffness Equation

To calculate the joint stiffness parameters of T-junction beam member structure, the differences of deformation results between real T-junction structure and FEA T-junction using beam element with rigid joint when applied 3 linear loads and 1 torsion load, respectively, as shown in Figure 3. Applying linear load on X-axis makes T-junction structure correspond to load F_x. Applying torsion load on X-axis makes T-junction structure correspond to load M_x. Applying linear load on Y-axis makes T-junction structure correspond to load F_y and M_z. Finally, applying linear load on Z-axis makes T-junction structure correspond to load F_z and M_y. Then, flexible joint stiffness parameters are calculated in equation 1 and 2.

$$K_{Li} = F_i / d_i \tag{1}$$

$$K_{Ti} = M_i / \theta_i \tag{2}$$

Where:

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K_{Li} – linear joint stiffness parameter corresponding to the x, y and z directions
F_i – elastic element axial force corresponding to the x, y and z directions
d_i – nodal displacement on the x, y and z directions.
K_{Ti} – torsion joint stiffness parameter corresponding to the x, y and z directions
M_i – torsion moment corresponding to the x, y and z directions
θ_i – Twist angle

E. FEA. T-junction flexible joint

After the 6-DOF flexible joint stiffness parameters are identified, FEA. T-junction flexible joint can be created, and 6 parameters can be input as shown in Figure 4.

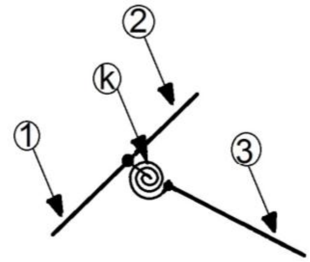

Fig. 4: FEA. T-junction flexible joint

III. Results and Discussions

A. Linear X Joint Stiffness Parameter

Table I presents the deformation results and calculation of linear X joint stiffness parameters. The result showed that K_{Lx} = 1,159 N/mm.

TABLE I:
LINEAR X DEFORMATION AND JOINT STIFFNESS VALUE

	Distance from joint (mm.)	0	150	300	450	600	750	900	1000
Deformation	Experimental (mm.)	0.24							
	FE. rigid joint (mm.)	0.13							
	Difference, d_i (mm.)	0.11							
	Load, F_i (N)	127.53							
	Linear Stiffness X-axis, K_{Lx} (N/mm.)	1,159							

B. Torsion X Joint Stiffness Parameter

Table II illustrates the twist angle and calculation of torsion x joint stiffness parameters. The result showed that K_{Tx} = 588,424 N-mm./degree.

TABLE II:
TORSION X TWIST ANGLE AND JOINT STIFFNESS VALUE

	Distance from joint (mm.)	0	150	300	450	600	750	900	1000
Twist angle	Experimental (degree)								0.42
	FE. rigid joint (degree)								0.30
	Difference, θ_i (degree)								0.12
	Moment, M_i (N-mm.)								69,925.68
	Torsion Stiffness X-axis, K_{Tx} (N-mm./degree)								588,424

C. Linear Z And Torsion Y Joint Stiffness Parameter

Table III presents the deformation results, twist angle, and calculation of linear Z and torsion Y joint stiffness parameters. The results showed that K_{Lz} = 8,502 N/mm., and K_{Ty} = 5,079,292 N-mm./degree.

TABLE III:
LINEAR Z AND TORSION Y JOINT STIFFNESS VALUE

	Distance from joint (mm.)	0	150	300	450	600	750	900	1000
Deformation	Experimental (mm.)	0.080	0.50	1.10	1.77	2.44	3.30	4.02	
	FE. rigid joint (mm.)	0.065	0.37	0.88	1.47	2.14	2.87	3.63	
	Difference, d_i (mm.)	0.015							
	Load, F_i (N)	127.53							
	Linear Stiffness Z-axis, K_{Lz} (N/mm.)	8,502							
Twist angle	Experimental (degree)								0.255
	FE. rigid joint (degree)								0.230
	Difference, θ_i (degree)								0.025
	Moment, M_i (N-mm.)								127,530
	Torsion Stiffness Y-axis, K_{Ty} (N-mm./degree)								5,079,292

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D. Linear Y And Torsion Z Joint Stiffness Parameter

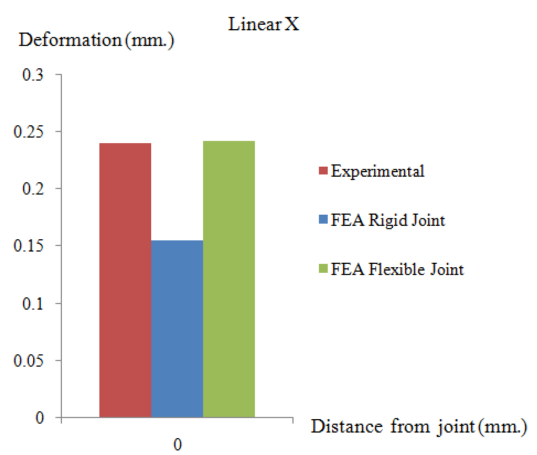
Table IV illustrates the deformation results, twist angle, and calculation of linear Y and torsion Z joint stiffness parameters. The results showed that K_{Ly} = 1,483 N/mm., K_{Tz} = 2,023,486 N-mm./degree.

TABLE IV:
LINEAR Y AND TORSION Z JOINT STIFFNESS VALUE

	Distance from joint (mm.)	0	150	300	450	600	750	900	1000
Deformation	Experimental (mm.)	0.10	0.26	0.67	1.17	1.71	2.34	2.87	
	FE. rigid joint (mm.)	0.01	0.10	0.31	0.61	0.99	1.42	1.88	
	Difference, d_i (mm.)	0.09							
	Load, F_i (N)	127.53							
	Linear Stiffness Y-axis, K_{Ly} (N/mm.)	1,483							
Twist angle	Experimental (degree)								0.182
	FE. rigid joint (degree)								0.119
	Difference, θ_i (degree)								0.063
	Moment, M_i (N-mm.)								127,530
	Torsion Stiffness Z-axis, K_{Tz} (N-mm./degree)								2,023,486

E. Comparison Between Experimental, FEA Rigid Joint And FEA Flexible Joint Deformation Results

In the comparison of the deformation between experimental results and FEA rigid joint, it was found that deformation error on x, y, and z-axis is 45%, 46%, and 16%, respectively. On the other hand, when compare the deformation between experimental results and FEA flexible joint by inputting joint stiffness parameters, it was found that deformation error on x, y, and z-axis reduced to 1%, 6%, and 4%, respectively as shown in Figure 5 which is consistent with the study of Alcala et al. (2013) [6].



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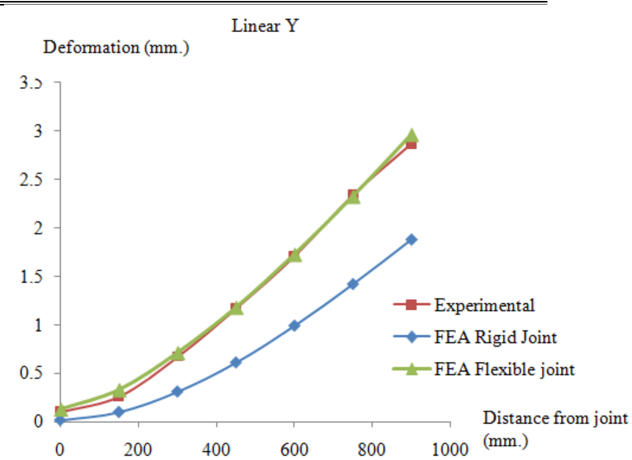

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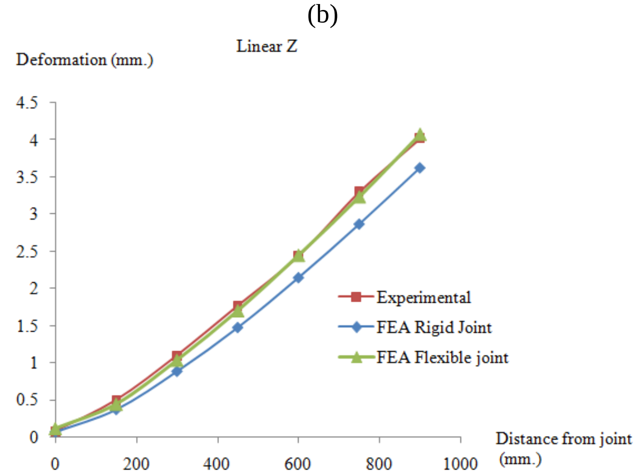

(c)

Fig. 5: Deformation results; (a) linear x, (b) linear y and (c) linear z

IV. CONCLUSIONS

This paper aims to study, analyze, and provide calculation techniques of non-matrix representation flexible joint stiffness which improves accuracy of deformation calculation of beam structure by computer aided engineering software using beam element FEA. To measured deformation of real T-junction structure, 3 linear loads including linear load on X-axis, Y-axis, and Z-axis are applied. Then, a torsion load on X-axis is applied to compare the deformation results between experiment and T-junction rigid joint FEA. Next, the differences of deformation results are used to calculated 6-DOF flexible joint stiffness parameters. FEA T-junction structure is further calculated by analyzing with T-junction flexible joint method and inputting 6 parameters to verify deformation results. The findings showed that analyzing with T-junction flexible joint method reduced deformation error from 45% to 1 %, from 46% to 6%, and from 16% to 4% on X, Y and Z-direction, respectively. This calculation technique is valuable for deformation analysis of beam structure e.g. automotive structure, bus structure, and truck structure.

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