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Orthotropic Material as an Alternative Replacement for the end Plate of the Steel Structure Connection

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ABSTRACT

Steel structure (especially beam-column) with a moment connection type has a higher risk of fatigue failure owing to the vibrating component. Reliable material and convenient installation methods are the main concerns for this connection type. To seek a deeper perspective on the alternative use of orthogonal-anisotropic (orthotropic) material, this paper proposed a numeric comparative study between isotropic and orthotropic material. The deformation value of both conditions showed that the lamina plate enhanced the strain rate value.

KEYWORDS: *moment connection, vibrating, steel plate, orthotropic, numeric.*

1. Introduction

The most common materials of industrial use are isotropic, like aluminum, steel, etc. Isotropic materials have an infinite number of planes of symmetry, meaning that the properties are independent of the orientation (Wang, 2007). Due to the variation in manufacturing processes, the same materials could exhibit different behavior. If the properties of the material change in three directions, then the material is considered an orthotropic material (Deev, 2016).

The numerical simulations have been carried out using the finite element program ABAQUS. It has been enhanced by an orthotropic subroutine of the proposed steel plate model. The use of this parameter is necessary for analytical and numerical stress analysis. Poisson's ratio (ν), Young's modulus (E), and shear modulus (G) will calculate iteratively as changing variables.

2. Matrices and Modeling for analysis

Extended end-plate connections are usually regarded as rigid connections, in the previous study of steel connections stated that the steady vibration of the beam can be reduced by 81% by using moment connections instead of the traditional shear connection (Ehab G. 2019). To expand it further, one simple model has been created to resist vibrating components as described in Figure (1)

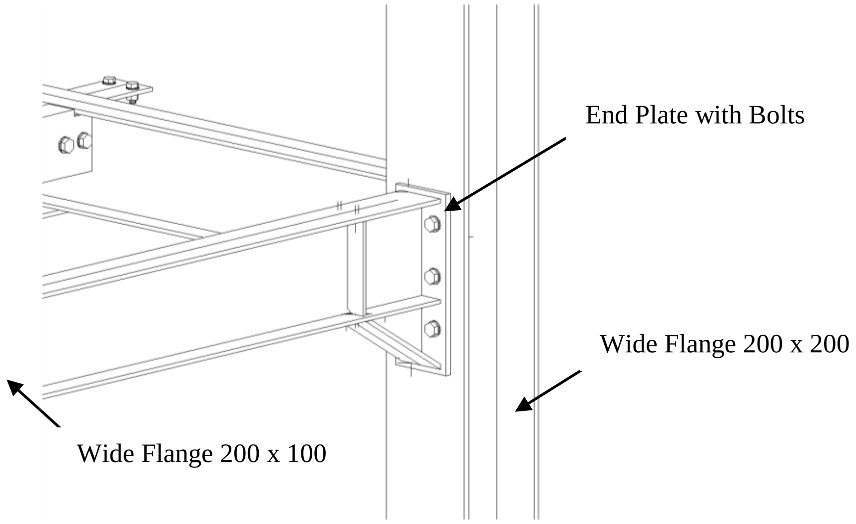

Figure 1. Beam-Column Joint using End-Plate connection

The simulation shall be focusing on the alteration of the end-plate parts, first simulation would be a plate with standard SS 400 material, and a carbon lamina plate for the second simulation. The material property of carbon lamina will follow to table (1) (Lecheb 2018)

Tabel 1. Orthotropic Lamina Property

	Steel
E_1 (GPa)	204
E_2 (GPa)	9
υ_{12}	0.23
G_{12} (GPa)	5
G_{23} (GPa)	5
G_{13} (Gpa)	8

The write of engineering constants for orthotropic materials is in the lamina coordinate system, where the 1-direction is aligned with the fiber direction and the 3-direction is normal to the plane of the lamina.

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix}=\begin{bmatrix}C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16}\\ C_{12} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26}\\ C_{13} & C_{23} & C_{33} & C_{34} & C_{35} & C_{36}\\ C_{14} & C_{24} & C_{34} & C_{44} & C_{45} & C_{46}\\ C_{15} & C_{25} & C_{35} & C_{45} & C_{55} & C_{56}\\ C_{15} & C_{26} & C_{36} & C_{46} & C_{56} & C_{66}\end{bmatrix}\begin{bmatrix}\epsilon_1\\ \epsilon_2\\ \epsilon_3\\ \gamma_4\\ \gamma_5\\ \gamma_6\end{bmatrix} \tag{1}$$

Equation (1) represents the stress stiffness matrix for fully anisotropic material, such material has properties that change with orientation. While equation (2), (3) and (4) represent the inverse of the stiffness matrix or may called the compliance matrix $[S]=[C]^{-1}$

$$\begin{bmatrix}\epsilon_1\\ \epsilon_2\\ \epsilon_3\\ \gamma_4\\ \gamma_5\\ \gamma_6\end{bmatrix}=\begin{bmatrix}S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16}\\ S_{12} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26}\\ S_{13} & S_{23} & S_{33} & S_{34} & S_{35} & S_{36}\\ S_{14} & S_{24} & S_{34} & S_{44} & S_{45} & S_{46}\\ S_{15} & S_{25} & S_{35} & S_{45} & S_{55} & S_{56}\\ S_{15} & S_{26} & S_{36} & S_{46} & S_{56} & S_{66}\end{bmatrix}\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \sigma_4\\ \sigma_5\\ \sigma_6\end{bmatrix} \tag{2}$$

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$$[C'] = \begin{bmatrix} \frac{1-\nu_{23}\nu_{32}}{E_2E_3\Delta} & \frac{\nu_{21}+\nu_{23}\nu_{31}}{E_2E_3\Delta} & \frac{\nu_{31}+\nu_{21}\nu_{32}}{E_2E_3\Delta} & 0 & 0 & 0 \\ \frac{\nu_{21}+\nu_{23}\nu_{31}}{E_2E_3\Delta} & \frac{1-\nu_{13}\nu_{31}}{E_1E_3\Delta} & \frac{\nu_{32}+\nu_{12}\nu_{31}}{E_1E_3\Delta} & 0 & 0 & 0 \\ \frac{\nu_{31}+\nu_{21}\nu_{32}}{E_2E_3\Delta} & \frac{\nu_{32}+\nu_{12}\nu_{31}}{E_1E_3\Delta} & \frac{1-\nu_{12}\nu_{21}}{E_1E_2\Delta} & 0 & 0 & 0 \\ 0 & 0 & 0 & G_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & G_{13} & 0 \\ 0 & 0 & 0 & 0 & 0 & G_{12} \end{bmatrix} \tag{3}$$

$$\Delta = \frac{1-\nu_{12}\nu_{21}-\nu_{23}\nu_{32}-\nu_{13}\nu_{31}-2\nu_{21}\nu_{32}\nu_{13}}{E_1E_2E_3} \tag{4}$$

Setup of solid modeling in ABAQUS shall be follow Figure (2), using 16mm thick plate with six rounded bolt holes on it. To reduce the mesh elements, the model of steel beam would represented with tensile and compressing force as moment force act on end-plate surface as described from Figure (1) configuration.

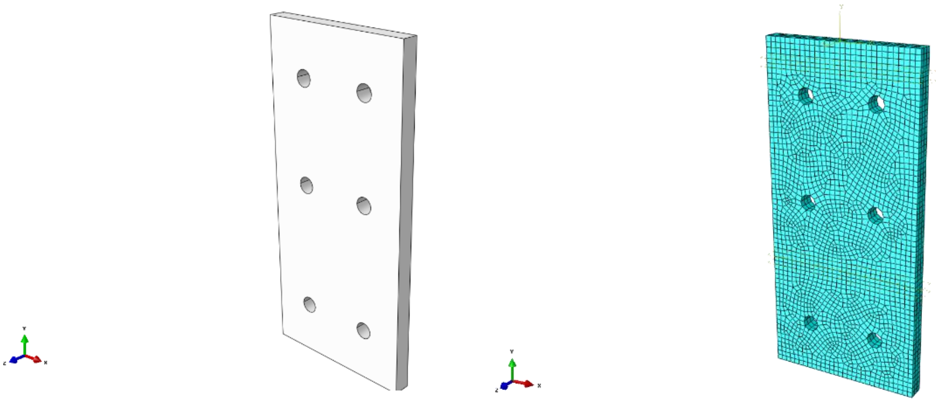
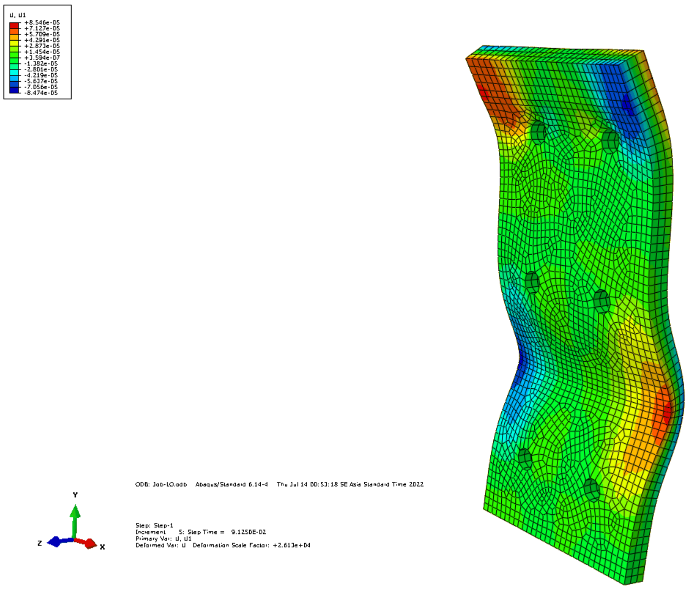


Figure 2. End-plate modeling, and mesh refinement

3. Results and Discussion

The result of the finite element procedure is given in Figure (3), which shown how the deformed shape of endplate perform against moment force.



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ODB: Job-LO.odb    Abaqus/Standard 6.14-4    Thu Jul 14 00:53:18 SE Asia Standard Time 2022

Step: Step-1
Increment      5: Step Time =   9.1250E-02
Primary Var: U, U1
Deformed Var: U   Deformation Scale Factor: +2.613e+04
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Figure 3. ABAQUS output of end-plate's deformed shape

3.1 Deflection value

Herewith below is the resume of deflection value at all corners of endplate, with indicative direction x (parallel to plate surface), y (parallel to plate surface), and z (perpendicular axis to plate face)

Table 2. Deflection at corners of both materials

Experiment Load (Mpa)		Isotropic Steel Deform (mm)				Orthotropic Steel Deform (mm)			
		Point 1	Point 2	Point 3	Point 4	Point 1	Point 2	Point 3	Point 4
1	x	0	0	0	0	0.0006	0.0001	0	-0.0001
	y	-8.63E-05	-8.612E-05	0	0	-0.0008575	-0.0003507	0	0
	z	0.0006219	0.0006199	9.204E-05	9.17E-05	0.0072148	0.0023218	0.0006489	0.0004874
1.5	x	0.0001	0	0	0	0.0008	0.0001	0	-0.0001
	y	-0.0001294	-0.0001292	0	0	-0.0012863	-0.000526	0	0
	z	0.0009328	0.0009299	0.0001381	0.0001375	0.0108221	0.0034827	0.0009733	0.000731
2	x	0.0001	-0.0001	0	0	0.0011	0.0002	-0.0001	-0.0002
	y	-0.0001726	-0.0001722	0	0	-0.001715	-0.0007013	0	0
	z	0.0012438	0.0012398	0.0001841	0.0001834	0.0144295	0.0046436	0.0012978	0.0009747

3.2 Load-Deflection plot

One of the nearest perspectives related to Table (2) is the increasing value of deflection at z-direction. From the load addition in each steps, the orthotropic material seems to expand faster as given at Table (3) , Table (4) and both plotted at Figure (4).

Tabel 3. Isotropic Material Result

	Deflection Slope (mm/Mpa)			
dir-1	0.020%	0.000%	0.000%	0.000%
dir-2	0.009%	0.009%	0.000%	0.000%
dir-3	0.062%	0.062%	0.009%	0.009%

Tabel 4. Orthotropic Material Result

	Deflection Slope (mm/Mpa)			
dir-1	0.040%	0.0000%	0.0000%	0.0000%
dir-2	0.086%	0.0351%	0.0000%	0.0000%
dir-3	0.721%	0.2322%	0.0649%	0.0487%

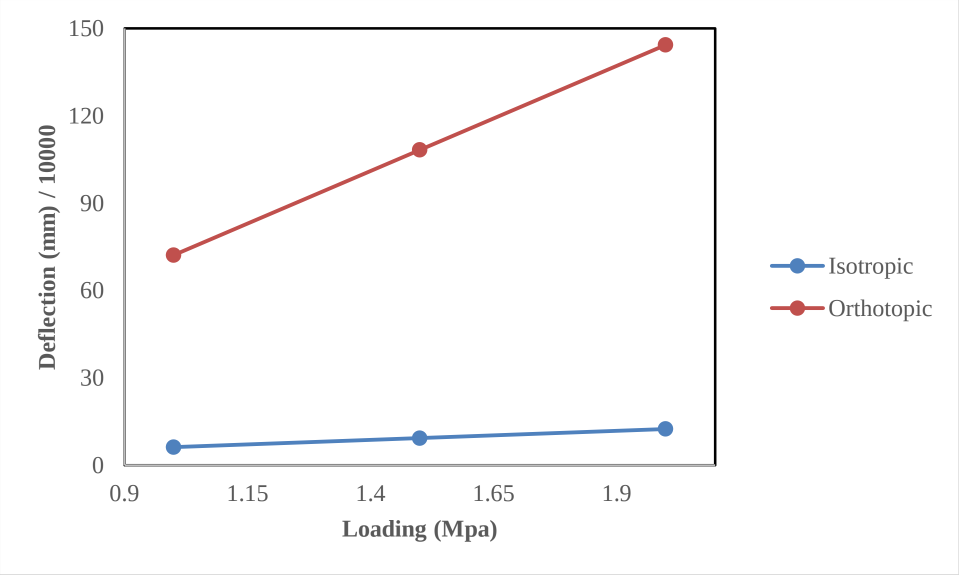

Figure 4. Load-deflection plot

4. Conclusions

The conclusion should be brief and outline the finding discussed in the result and discussion.

Acknowledgments

Acknowledgements are collated in a separate section before the references.

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