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EIGENVALUE LINEAR BUCKLING OPTIMIZATION OF MODIFIED OPEN WEB STEEL JOIST

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Abstract: Open web steel joist (OWSJ) is a lightweight beam structural system that is widely used since the 1900s. It generally composed by T section as flanges on top and bottom, and L section as an open web on the centre. However, many modifications of OWSJ is commonly seen in construction sites, one of them is the usage of channel sections as top and bottom flange, and rebar steel as the open web. This configuration is mainly used to reduce cost and ease the material supply. The modified OWSJ have potential to act differently than the regular one, hence scientific study need to performed to know the behaviour of the modified system. In this paper, comparison on analytical and finite element approach is conducted. The analytical method is done by mechanical calculation assuming there are no buckling of the flanges, web rebars are calculated individually. In real structure, buckling may occur and web rebars also work concurrently. Therefore, finite element analysis with LUSAS software is conducted. The purpose of this research is to know the behaviour of OWSJ in FEM analysis. Result displays lateral torsional buckling is happen and to overcome this problem, gradation of web size is tested, resulting maximum of 10.6 % increase in capacity.

Keywords: modified open web joist , finite element analysis

Abstrak: Open web steel joist (OWSJ) adalah struktur balok baja yang digunakan secara luas semenjak abad 1900. OWSJ secara umum tersusun menggunakan profil T sebagai sayap sisi atas dan bawah, dan profil L sebagai badan di sisi tengah. Namun demikian seiring perkembangan, banyak modifikasi dari OWSJ yang ditemukan dan sering digunakan, salah satunya adalah dengan pengunaan profil kanal sebagai sayap, dan profil L sebagai badan di sisi kanan dan kiri. Kombinasi ini memungkinkan OWSJ untuk lebih stabil, namun perlu dilakukan analisis lebih lanjut. Dalam paper ini, analisis secara analistis dan numerik dengan bantuan metode elemen hingga dilakukan. Perhitungan analitis dilakukan dengan asumsi tidak terjadi buckling, sedangkan pada perhitungan numeris, buckling diperhitungkan menggunakan eigenvalue buckling. Tujuan dari penelitian ini adalah untuk mengetahui perilaku dari open web joist saat dimodelkan dalam software elemen hingga. Hasil pemodelan menunjukkan terjadi lateral buckling, dan untuk meminimalkan tekuk, gradasi ukuran web dilakukan, dan menghasilkan kenaikan kapasitas 10.6%.

Kata kunci: : modified open web joist , finite element analysis

INTRODUCTION

Open web steel joist is a lightweight structural system for beams, that are widely used since 1900s. It generally composed by T section as flanges on top and bottom, and L section as open web truss on the centre (see **fig.1**). Many modification of OWSJ can be found. In Indonesia, the most common found modification is using channel section as flanges, and using either rebar or angled section as web truss. In this paper, using angled section as web truss is selected.

Combination of channel section as top and bottom flanges, and 2 sides angled section as open web truss section is preffered because theoritically it gives more stability to the structure, hence bukcling risk will be reduced. Channel and angled section also preffered because of the availibility, and the cost.

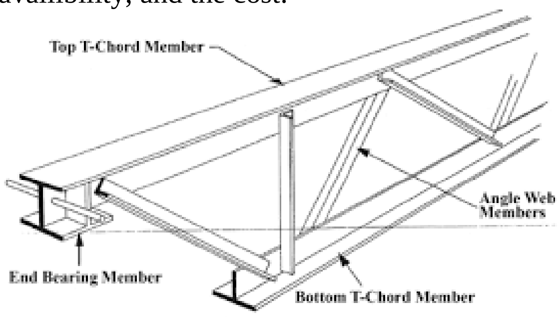

Figure 1. Open web steel joist system
Source : Antiquated structural system series part 9a

To ensure a safe designed structure, the system need to be checked whether analytical method is still suitable or not. This research is conducted to check whether analytical analysis is still capable for calculating the modified joist.

For common shape of open web joist, Steel Joint Institute (SJI) already have standart spesification (SJI 100-2015). For this modified joist, it is not yet specified. Thus for this purpose, research analysis using analytical and finite element method to know behaviour of the structure is carried.

An Eigenvalue Buckling analysis in finite element method can predicts the theoretical buckling strength of an ideal elastic structure. This method corresponds to the elastic buckling analysis. However, imperfections and nonlinearities prevent most real-world structures from achieving their theoretical elastic buckling strength. Therefore, an Eigenvalue Buckling analysis often yields quick but non-conservative results and needs to follow by non-linear analysis or laboratory test.

LITERATURE REVIEW

Research about open web steel joist is already done for many years since 1900s. Many of them is concentrated at laboratory test. Yost et al. (2004) in their jurnal "*strength and design of open web steel joist with crimped end web member"* observe overall flexture behaviour based on failure loads, deflection, and strain of the joist's chords by adding crimp to the ends of the web. Resulting conclusion if the tested web is compact, and no local buckling occur, but rotational rigidity of the joint will be affected by member size and imposed restrain.

Mechanics of material

Analytical calculation can be done by using basic mechanics of material. Assuming web trusses is stable and have no buckling, moment of inertia of the two flanges can be calculated using parallel-axis theorem.

$$I_y = I_{yC} + Ad_2^2 \quad (1)$$

Where I_y = inertia in y axis, I_{yc} = component's inertia in y axis, A = Area, d = distance of component and system's centroid.

With inertia of the structure is known, by inputting bending stress as yielding stress, maximum bending moment of the structure can be calculated using equation (2).

$$\sigma = \frac{M_y}{I} \quad (2)$$

Where σ = bending stress of specimen, M = bending moment, y = position along y-axis on the section area in which the stress σ is calculated.

Specimen is modelled as simple beam structure, with pinned and roller end, and a distributed load, thus maximum load that can be applied, can be calculated with equation (3).

$$m = \frac{1}{8} qL^2 \quad (3)$$

Where m = bending moment, q = distributed loads, L = structure span.

Eigenvalue buckling analysis

A linear buckling analysis is a technique that can be applied to relatively stiff structures to estimate the maximum load that can be supported prior to structural instability or collapse. It is possible to define loads that remain constant and those that can vary for the computation of a load factor to cause buckling. The assumptions used in linear buckling analysis are that the stiffness matrix does not change prior to buckling, and that the stress stiffness matrix is simply a multiple of its initial value. Accordingly, the technique can only be used to predict the load level at which a structure becomes unstable if the pre-buckling displacements and their effects are negligible. As this procedure involves assembly of the stress stiffness matrix, only elements with a geometric nonlinear capability can be used in a linear buckling analysis.

The main objective of an eigenvalue buckling analysis is to obtain the critical buckling load factor, which is achieved by solving the associated eigenvalue problem.

SPECIMEN

Specimen is generated by using 6m span of modified open web steel joist. Height of the specimen is specified as 40cm. 2D and 3D model of the specimen can be seen at **figure 2 and 3.**

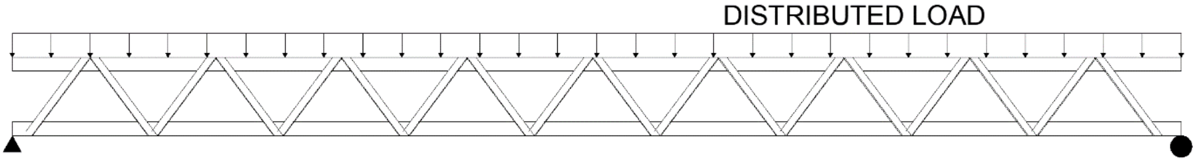

Figure 2. Specimen 2D Model

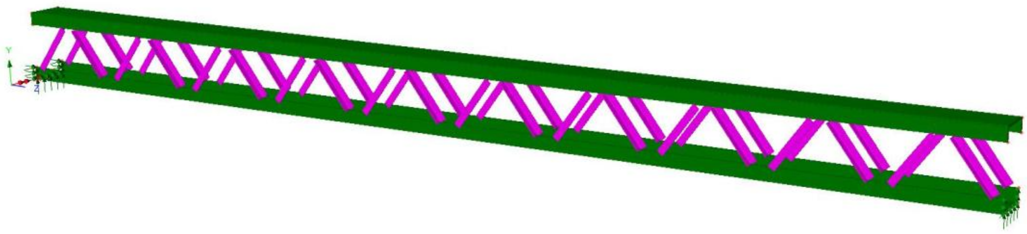

Figure 3. Specimen 3D Model

Each specimen consist of top and bottom channel section of C200.70.7.10, and web angled section variated from L40 to L80mm. Each trusses web is placed 52° to the structure. Steel modulus elasticity is 210.000 MPa, and yield strength f_y of 240 MPa.

Total of 8 model is created in this research as listed in **table 1** below.

Table 1. List of specimens

No.	Specimen Name	Flanges	Web
1	Mod L40.4	C200.70.7.10	2x L40.40.4
2	Mod L45.4	C200.70.7.10	2x L45.45.4
3	Mod L50.5	C200.70.7.10	2x L50.50.5
4	Mod L56.5	C200.70.7.10	2x L56.56.5
5	Mod L60.6	C200.70.7.10	2x L60.60.6
6	Mod L63.6	C200.70.7.10	2x L63.63.6
7	Mod L70.7	C200.70.7.10	2x L70.70.7
8	Mod L80.8	C200.70.7.10	2x L80.80.8

METHODOLOGY

Calculation is separated into two parts, first is analytical calculation, second is finite element modeling.

Part 1. Analytical calculation

In this research, 8 specimens were generated. Each specimen have different web size, starting from 40mm angled to 80mm angled section. However, cosidering there are no buckling on the web, only 1 calculation is conducted.

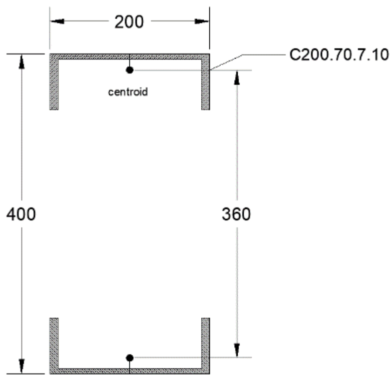

Figure 4. Cross section area of channel

Calculation of moment inertia component :

Shape 1: $1/12 * 10 * 63^3$

Shape 2: $1/12 * 10 * 63^3$

Shape 3: $1/12 * 200 * 7^3$

Total (I_{yc}) = 422461.67 mm^4

shape	I_{yc}	A	d^2	ΣAd^2
1	208372.5	630	20.07	253767.09
2	208372.5	630	20.07	253767.09
3	5716.67	1400	0	0
Total	422461.67	2660		507534.17
Channel Inertia =		929995.84		mm4

Combined Section				
top	929995.84	2660	360	344736000
bot	929995.84	2660	0	0
Total	1859991.68	5320		344736000
Total Inertia =		346595991.68		mm4

Calculation of bending moment

$$240 = \frac{\text{M x 360}}{9346595991.68}$$

M_y = 231.06 kNm

Calculation of maximum loads

$$231.05 = \frac{1}{8} q 6^2$$

q = 51.34 kN/m

From the calculation, the flange will yield when 51.34 kN/m distributed load is applied, however web buckling may occur and needed to calculate with more complex calculation.

Part 2. Finite element model

All of the 8 specimens are modelled using Lusas finite element software (see **fig.5**).

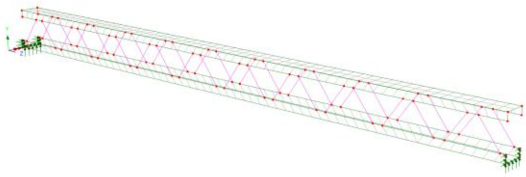

Figure 5. Lusas 3D Model

Thick shell element is used to model channel section, and thick beam material is used to model the open web truss section. Meshing is set to every 0.1m for both, using thick shell - quadratic order. Simple supported structure is generated using pinned and rollec connection in each end. A distributed load of 100N/m2 is given into top of the structure.

RESULT AND ANALYSIS

Modeling result of the 8 specimen are shown on table 2 below. Since analytical result conducted is assumed to have stable web, thus the maximum load that can be carried is same 51.35 kN/m. However, selfweight is not yet applied to the analytical result, applied selfweight displayed on the table.

Eigenvalue buckling result give great different of value compared to analytical. With around 390% of differences. This great difference comes from the buckling that calculated by eigenvalue buckling method. In figure 6 and 7, buckling occur is visualisized. Eigenvalue buckling does not give exact displacement of the nodal, only the buckling shapes. From the shape shown, web is buckled but the structural channel is not yet receiving lot of stresses. This is explain great error from analytical result because web is assumed stable and channel section met its yielding failure. However in FEM analysis, buckling happen first before channel section yield.

Table 2. Maximum load for specimen

No.	Specimen Name	Analytical (kN/m)	FEM (kN/m)	Difference (%)
1	Mod L40.4	50.88	10.29	-394.27372
2	Mod L45.4	50.87	10.71	-375.06392
3	Mod L50.5	50.84	11.17	-355.31487
4	Mod L56.5	50.83	11.33	-348.65125
5	Mod L60.6	50.81	11.38	-346.49209
6	Mod L63.6	50.80	11.39	-346.12256
7	Mod L70.7	50.76	11.24	-351.72909
8	Mod L80.8	50.71	10.90	-365.26963

From table 2 above, result indicating that after the FEM model, it is known if lateral – torsional buckling is happen and make a great difference compared to analytical result.

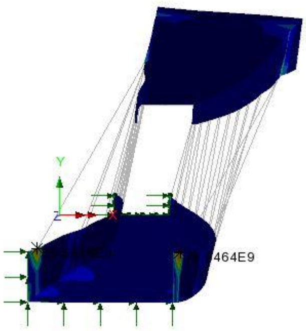

Figure 6. LUSAS result eigenvalue buckling

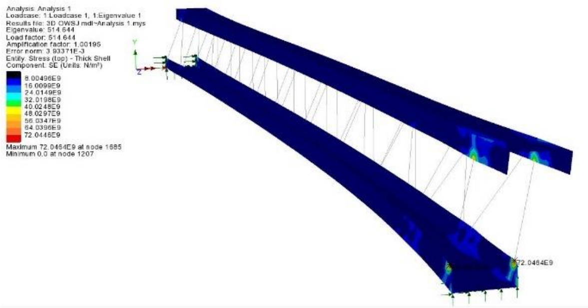

Figure 7. Lateral torsional buckling

Eight specimen are created to see the optimized result by variating the angle web section. Interesting result is happen after specimen 6, which increasing the web dimension, would make the structure's capacity decrease (see **fig 8**).

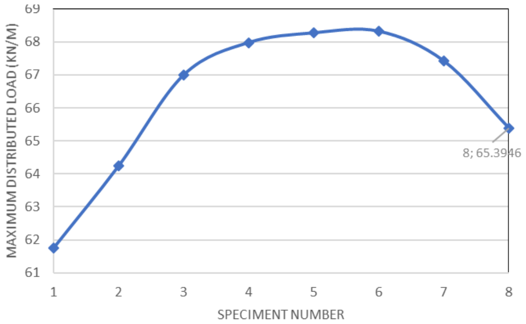

Figure 8. Graph of maximum distributed load and specimen number

Starting from specimen 1 to specimen 6, increasing the web section would make structure's capacity increased, however in specimen 7, by using L70.7 section the capacity is decreased. This anomaly needs to be checked. Increasing web section is not optimum if the flange section is already yielding, but in this case flange is not yet yield, thus further check should be conducted.

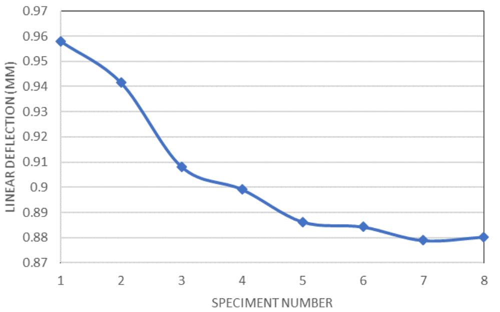

Figure 9. Graph of deflection of 100N/m^2 load and specimen number

Beside checking the behaviour, linear deflection of each section is also checked. 100N/m^2 of pressure loads is applied to each specimen, resulting as graph in figure 9. As the web area section increased, deflection is getting smaller. However the decrease observed is getting not significant starting from specimen 6. With the same case as the structure capacity, the structure is suspected to have optimum condition in specimen 6 with L63.6 section.

Table 3 describe capacity increase which after certain point become not optimum.

CONCLUSION

The purpose of this research is to know behaviour of modified open web joist, by comparing analytical and linear buckling finite element modeling. Result shows that before the structure is yielding, buckling happen and make structural capacity controlled by buckling capacity.

Increasing the size of the web does effect and reduce buckling until certain point, however further increase caused decrease of capacity due to selfweight increase and not optimum web ratio. Eigenvalue buckling analysis gives more conservative result of the strength of system compared to analytical result. However, a laboratory check also non-linear buckling analysis could be done to make more valid result.

RECOMMENDATION

Further non linear and laboratory test should conducted to compare the eigenvalue linear buckling analysis.

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Table 3. Capacity and weight increase of speciment

No.	Speciment Name	Capacity (kN/m)	Weight (kN/m)	Capacity Increase	Weight Increase	Capacity Increase (%)	Weight Increase (%)
1	Mod L40.4	61.76	2.84	0.00	0.00	0.00	0.00
2	Mod L45.4	64.25	2.88	2.49	0.04	4.03	1.45
3	Mod L50.5	67.00	3.02	5.24	0.14	8.49	6.54
4	Mod L56.5	67.98	3.08	6.22	0.06	10.08	8.72
5	Mod L60.6	68.27	3.25	6.52	0.16	10.55	14.53
6	Mod L63.6	68.32	3.28	6.56	0.04	10.63	15.84
7	Mod L70.7	67.42	3.52	5.67	0.23	9.17	23.98
8	Mod L80.8	65.39	3.82	3.64	0.31	5.89	34.87