ISSN No:-2456-2165

The effect of Diameter of Interior Web Members on the behavior of Prefabricated Open Web Steel Joists

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Abstract:- Open web steel joists are truss-type members are proven they are standing strength to weight ratio, flexible and adaptable design characteristics, amazing durability, and economic advantages. Its consists of five components, the top chord, the bottom chord, the end web, Bearing seat, and the interior web member. Open-web steel joists are used extensively in floors and roofs in many types of structures. In this research an experimental investigation was conducted to determine strength and general flexural behavior of prefabricated hybrid open web steel joists (HOWSJS) under central single concentrate static load. The aim of this research was to study the effect of using different diameter of interior web members on flexural behavior based on failure modes, load-deflections curve, and strains in the top, bottom chords and in the interior web members. A Joist (truss-form beam) fabricated in different steel materials has been analyzed in the Finite Element program ABAQUS. The aim was to understand and explain the performance of a loaded steel truss beam and comparing results from analyses performed with Finite Element method vs. experiments. The investigation was done for a four simply supported joists with a span of (1.8m) and a height of (500 mm) meter with welded connections which members directly fastened to each other (without intermediate plates). The results indicated that there was a significant enhancement in the behavior of HOWSJ when the diameter of interior webs increased, where The ultimate load capacity of HOWS increased by (25.4%) when the diameter of interior web increased by about (24.5%).

Keywords:- *Steel Joist, Interior Web members, Open Web.*

I. INTRODUCTION

Open web steel joists (OWSJS) are prefabricated truss like flexural members that are ideal for resisting low levels of load over long spans and its consists from top compression chord , bottom tension chord, and interior web members at specific locations along the joist to connect the top and bottom chord, these interior members vary between tension and compression members and can be fabricated as bars, single angles, double angles or single angles with crimped ends. OWSJS are typically found in floor or roofing support systems. OWS joists are typically designed as simply supported and uniformly loaded flexural members that cover long spans to take advantage of their high strength-to-weight ratio.

The first steel joist was manufactured in 1923. This joist had a truss-type configuration and was consist of round bars for both the top and bottom chords and for interior web used a bent continuous round bar that was bent to form the web [1].

Previous studies [2] and [3] have shown that web openings will cause a significant reduction in the shear capacities of such sections, since primarily webs provide the shear resistance while flanges provide the flexural resistance.

OWS joists are very flexible, and in the past their design has controlled by drift criteria for wind. Their performance during past earthquakes has been satisfactory, with damage limited to brittle façade elements and poorly detailed column bases [4].

This paper presents the results of an experimental investigation conducted to create a new type of HOWS joists having two size of diameter of interior web members. The primary objective of this research is to study the effect of diameter of web members on the behavior of HOWSJ. A nonlinear finite element models were analyzed by using software ABAQUS CAE . The purpose of this study is to compare the results from the developed FE-models with experimental results. To perform the analyses finite element models were created.

II. EXPERIMENTAL TEST AND SPECIMENS SETUP

The experimental investigation included testing Models of simply supported HOWS joist specimens each model consisted of two specimen which they had the same cross section and same prefabricated material. And coupon testing of tensile specimens was done to determine material properties for each part of the steel joist. The span of all joist specimens was (1.8 m) between the supports centerline, with a depth of (0.5 m). All specimens tested were fabricated using (2L50×50×4 mm) double angles for the top and bottom chord members, and steel reinforcement bar for the interior web members.

(Table1) and (Figure 1)showed a typical HOWSJ details with all relevant member sizes and dimensions.

The supports used in this work were manufactured by using steel plate with thickness of (6 mm) to represent a fork simply supported case (roller and hinge) were used with stainless steel shafts with diameter (50 mm) welded to the support at the ends of beam. All steel joist specimens were tested under the effect of static load. A central single concentrate load was applied on the top chord up to failure by using steel shaft with diameter (25 mm) and the mid span deflection was recorded by using Linear Variable

ISSN No:-2456-2165

Displacement Transducer (LVDT). A set of an electrical strain gauge sensors for steel were used, they were fixed at the top and bottom chords of the steel joists, as well as on the interior web members, so that their locations are in the places where the maximum axial tension and compression forces occur, their locations also illustrated in Figure (1). All joist specimens were be tested by using a hydraulic testing machine with capacity 1000 kN. All the strain gauges and LVDTs were connected to data acquisition system to record the readings of them. The output results were then converted to data using Lab VIEW software package. The material properties were experimentally investigated by uniaxial tension tests of coupon samples for the top and bottom chords, and for the interior members according to ASTM A370-14 specifications [5].

The tested results found the average yield strength (Fy =334.9 Mpa) and modulus of elasticity (E=207986 Mpa) for angles, (Fy =554 Mpa), (E=204530 Mpa) for reinforcing bars with diameter (11.97 mm), and (Fy =568.2 Mpa), (E=205114 Mpa) for reinforcing bars with diameter (15.85 mm). The HOWSJ specified material properties were used in the analysis to correlate with the manufacturer's design calculations, and as tested material properties were used in the analysis for comparison and refinement purposes. Details of steel joist setup was shown in Figure (2).

Model	*Specimen No.*	Dimensions (mm)					
		b_f	d	h	L_{db}	L_{vb}	d_b
Model 1	SJ 4-1	100	472.8	500	495	445	11.97
	SJ 4-2						
Model 2	SJ 5-1	100	472.8	500	490	460	15.85
	SJ 5-2						

Table 1: Nominal Cross Section Dimensions of (PHOWSJS).

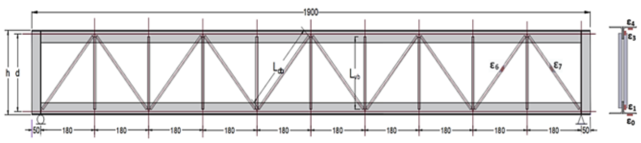

Fig. 1: Prefabricated Hybrid Open Web Steel Joists (all dimensions in mm).

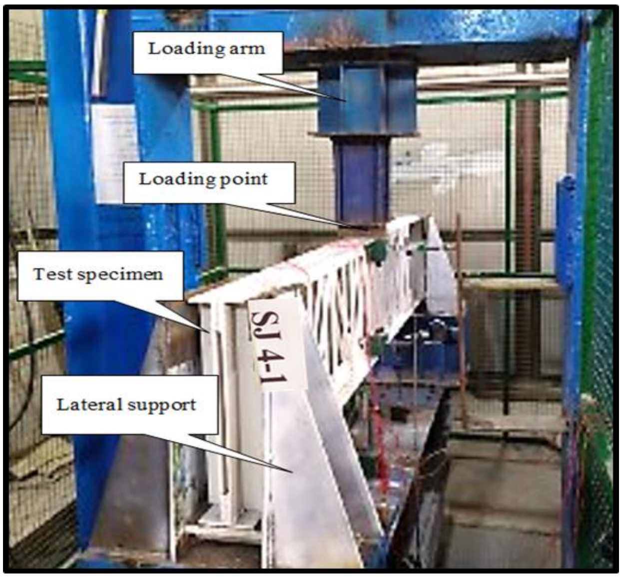

Fig. 2: Details of HOWS Joists Setup.

III. EXPERIMENTAL RESULTS

A. Failure mode of Model 1 and 2 specimens

From the experimental results it can be observed that the mode of failures of each two specimens for the three models were the same. The failure occurred due to the local buckling of the diagonal interior web members near the supports, this failure mode for open web steel joists called a crimped-end web members. Another failure mode was happened due to the top and bottom chords global buckling due to the deflection of the joist, in addition to the local buckling of the vertical leg of the top and bottom chord near the end supports in the regions which was not welded, this buckling occurred because they behave as a vertical connected with the web members. Finally there was welding joint fracture failures between the web members (vertical and diagonal) and the chords at top and bottom of the two HOWSJ specimens were tested in this study. Plates (1) and (2), showed the mode of failures on the two joist specimens tested for each model.

Plate (1): Mode of failures of Model 1 HOWSJ specimens.

Plate (2): Mode of failures of Model 2 HOWSJ specimens.

A. *Load-Deflection Curves*

By observing the results shown Table (2), it can be noted that every two specimens of the same model had very close values of ultimate load, yield strength, maximum deflection and yield deflection. Also Figures (3) and (4) showed that the two specimens for each model have to a large extent the same behavior, and from this it is concluded that the model-prefabricated process was accurate and used materials that have the same properties, so the experimental results were very close for each two specimens.

From experimental results illustrated in Table (2) it can be recognized that ultimate load capacity of the HOWSJS increased when the diameter of interior web members increased, for Model 2 specimens with diameter for interior web of (15.85 mm) the enhancement was about (25.4%) compared with Model1 which had diameter for interior web of (12.97 mm). and the deflection decreased about (6.6%) in Model2 specimens compared with Model 1.

In general, for the mean values for each two specimens for the same model the results indicated that the enhancement in the stiffness (Py δy) of Model2 specimens was significantly higher than Model1 specimens by about (32.3%). Regarding the index of the hardness (Pu/ δu), the results of tests showed that the Model2 specimens also had a highest hardness value rather than Model1 specimens, which was higher about (30%). Finally for the ductility index (δu/ δy)it can be noticed that the Model2 had a higher ductility about 1.25 times the ductility of Model1. Figure (5) showed a comparison between two specimens from each model.

Model	Specimen No.	*Yield strength, Py (kN)*	*Ultimate load, Pu (kN)*	*Def. At yield strength (mm)*	*Def. At ultimate load, (mm)*
Model 1	SJ 4-1	51.34	103.16	4.036	10.785
	SJ 4-2	49.87	102.54	3.394	9.891
Model 2	SJ 5-1	54.43	135.59	2.534	9.438
	SJ 5-2	58.65	140.23	3.084	9.951

Table 2: Experimental results of Models 1, and 2 HOWSJ specimens.

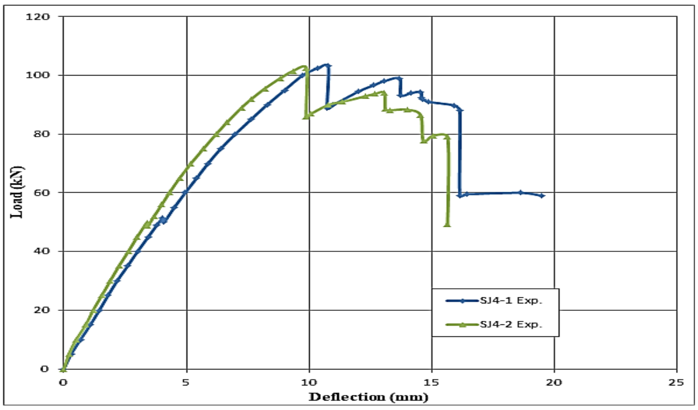

Fig. 3: Experimental load-deflection curve for Model 1 specimens.

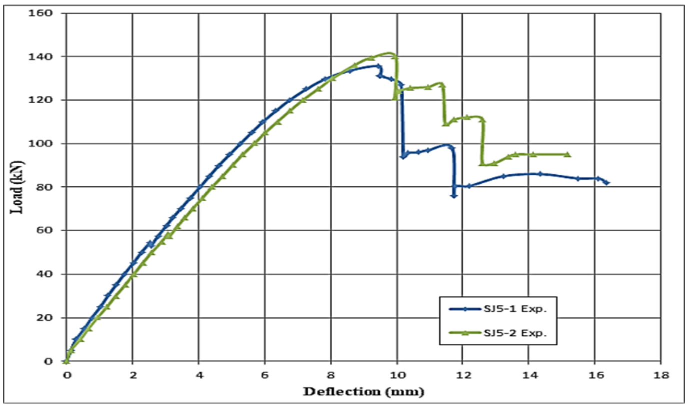

Fig. 4: Experimental load-deflection curve for Model 2 specimens.

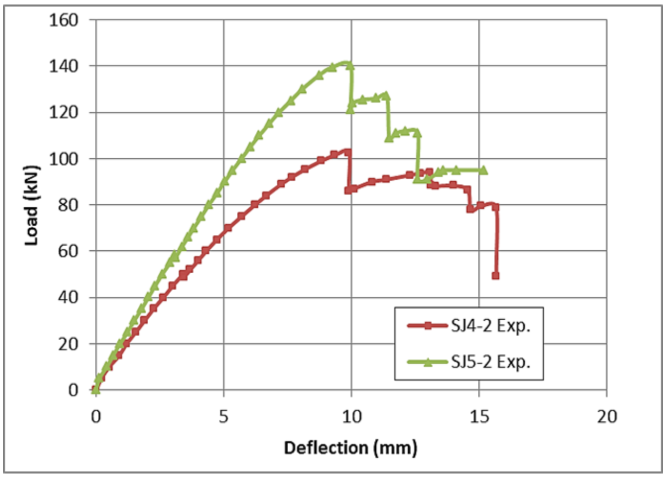

Fig. 5: Load-deflection curve for SJ4-2, and SJ5-2 specimens.

B. *Strain Results*

The strain gauges readings, showed the mean behavior of the HOWSJ Model1 specimens during the test as explained in Figures (6) to (8). Figure (6) illustrated that the strain gauge (ε1) on vertical leg of angle bottom chord exhibited a compression strain up to failure load, that's indicated that the vertical leg of the bottom chord behave as a web with the interior web members which they welded to them, while the behavior of the strain gauge (εO) on the horizontal angle leg of the bottom chord was in tension . And it also can be recognized that the strain at horizontal leg of angle of top chord became very close to the yield limit of the angle, Figure (7). Figure (8) emphasized that the failure of the HOWSJ Model1 specimens was due to the interior web members buckling, because the strain exceed the yield limit, before reaching the top chord to the yield limit.

Regarding, Figures (9) to (11) explained the behavior of strains gauge for the HOWSJ Model2 specimens. It can be recognized that these specimens also had the same behavior of strain gauges readings for the Models1, but the different was the reading of the strain gauge (ε0) on the bottom tension chord which had a value more than for Model 1 by (20.4%). These results proved that the Model2 specimens had a high stiffness and also had high ductility compared to Model1, this was because they was had an interior web members of diameter (15.85 mm) which made their more stable from the Model1 specimens. Finally, the readings of the compressive strain gauges on the end web members (ε7), showed that the strain in Model1 was more than of Model2 by about (63%). And from these results it can be concluded that when the diameter of rebar of the interior webs increased by (24.5%) led to decrease the strain on the interior webs by about (63%). The slenderness ratio (kL/r) of the interior web members were 165.41, and 123.65 for Models1, and 2, respectively. From pervious comparison it can be concluded that when the slenderness ratio of the interior web decreased about (25.2%) the deflection of the HOWSJ also decreased and the ultimate load capacity increased about (25.4%) .

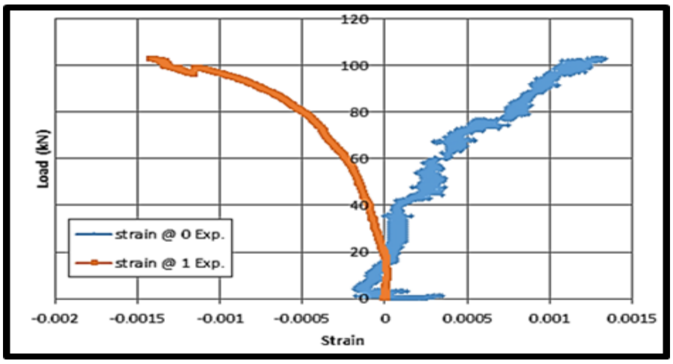

Fig. 6: Load-strain curve of bottom chord of Model 1 HOWSJ specimens.

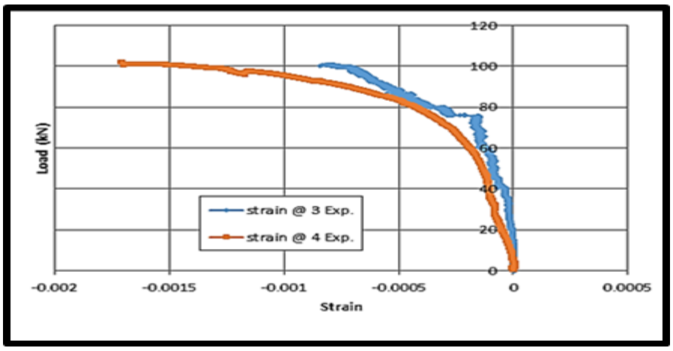

Fig. 7: Load-strain curve of top chord of Model 1 HOWSJ specimens.

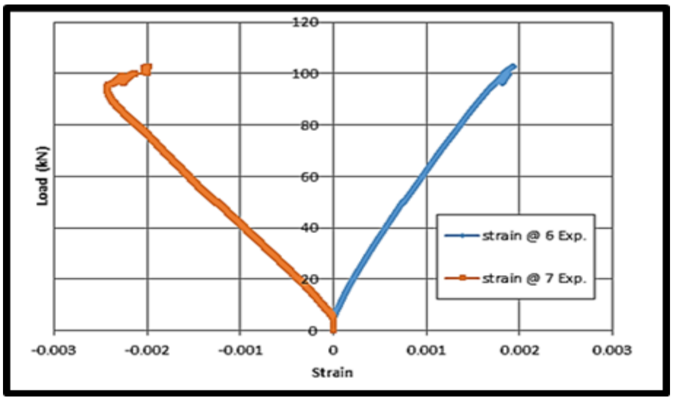

Fig. 8: Load-strain curve of interior diagonal webs near support of Model 1 HOWSJ specimens.

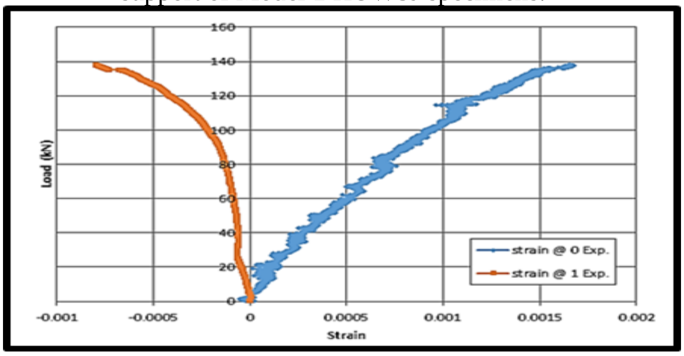

Fig. 9: Load-strain curve of bottom chord of Model 2 HOWSJ specimens.

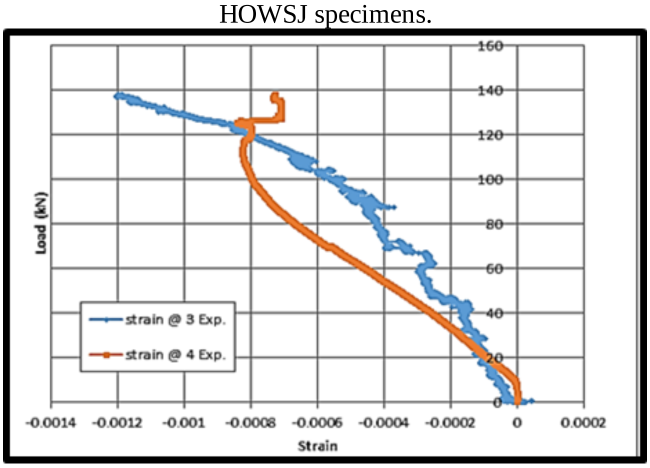

Fig. 10: Load-strain curve of top chord of Model 2 HOWSJ specimens.

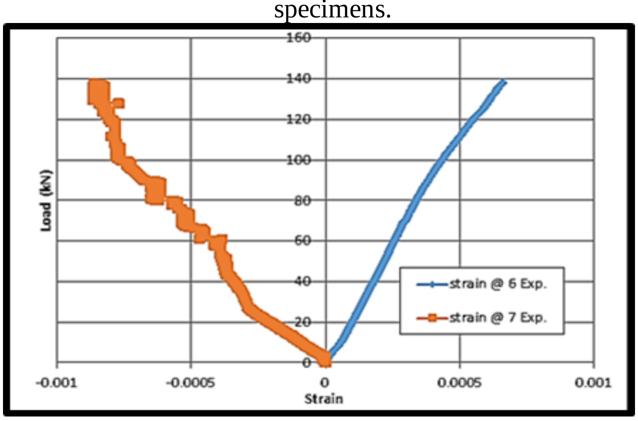

Fig. 11: Load-strain curve of interior diagonal webs near support of Model 2 HOWSJ specimens.

ISSN No:-2456-2165

C. Finite Element Models

In this study the HOWS joists are modeled using ABAQUS CAE finite element software, starting by creating the different parts of the problem. The model consists of three parts:, the chords used shell elements type (S4R) with size (5 mm), welding used shell elements type (S4R) with size (1-2.5 mm) , interior web members used beam elements type (B31) with size (1 mm) to check the risk of interior web buckling , and the cylinder of loading used element type R3D4.

Creating the part means that the geometry of the HOWS joists is drawn. Then the material properties are assigned to each part. After this the parts are assembled, followed by the definition of the analysis type and output requests to be used. Mechanical interactions are defined and loads and boundary conditions are then applied. As an approximation to the geometrical model, an finite element mesh is created. Finally the job is submitted for analysis and the results can then be visualized.

Running the analysis from ABAQUS CAE gives the results. The results consist of a number of eigenvalues from the second step of the analysis, and from the first step the displacements and stresses for the applied reference load are obtained. The eigenvalue obtained from the second step of the analysis gives a load multiplier to calculate the ultimate load capacity of the HOWSJ. The corresponding stresses are similarly obtained by multiplication of the eigen value by the stresses obtained in the first step.

The experimental results were checked with the results from the ABAQUS software and it is seen that the mode of failure, ultimate loads capacity, mid-span deflections, and the strain gauges readings obtained were had a good convergence. And this convergent illustrated in Table (3), Figures (12) and (13) showed the convergence of the load-deflection curve, and Figures from (14) to (19) showed the comparison between experimental and FEM strain readings.

The peak loads for FEM were less than those of the mean of each two specimens experimental results within only (7%). This suggested that the finite element models were able to assess the capacity of HOWS joists with reasonable accuracy.

Model	***Specimen No.***	***FEM Ultimate load, Pu (kN)***	***Exp. Ultimate load, Pu (kN)***	***Relative***	***FEM Ultimate load, Pu (kN)***
Model 1	SJ 4-1	94.65	103.16	8.2	7.9
	SJ 4-2		102.54	7.6	
Model 2	SJ 5-1	128.15	135.59	5.5	7.05
	SJ 5-2		140.23	8.6	

Table 3: Comparison of ultimate loads in between experiments and FEM.

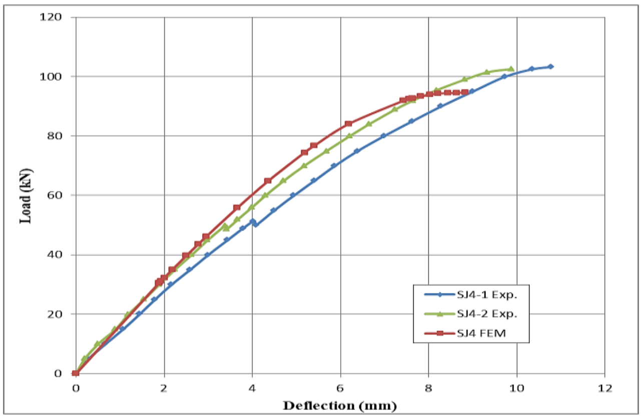

Fig. 13: Comparison of experimental and finite element load-deflection curve for model 1 specimens.

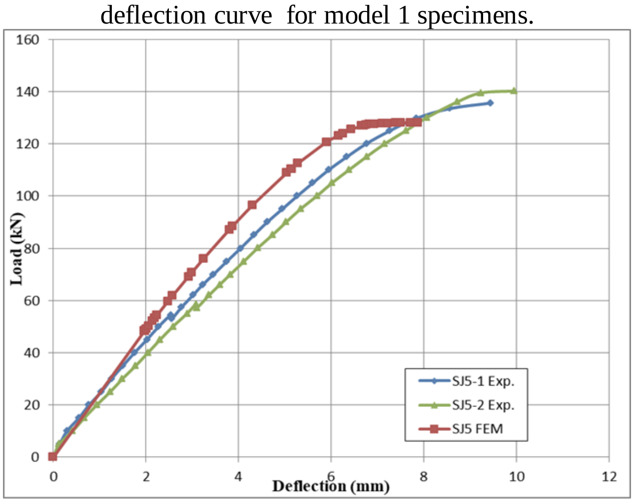

Fig. 14: Comparison of experimental and finite element load-deflection curve for model 2 specimens.

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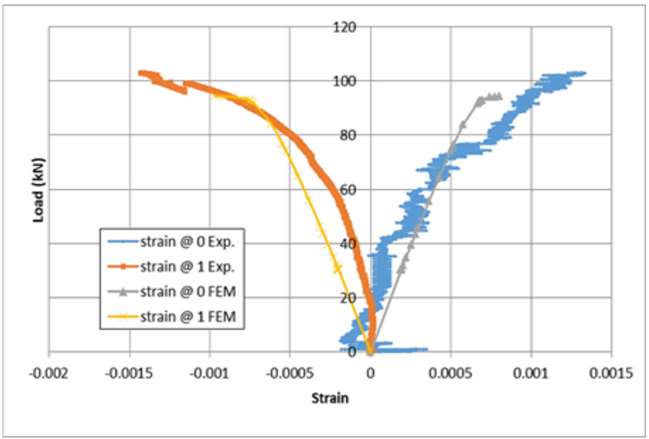

Fig. 15: Comparison of experimental and FEM load-strain curve of bottom chord for Model 1.

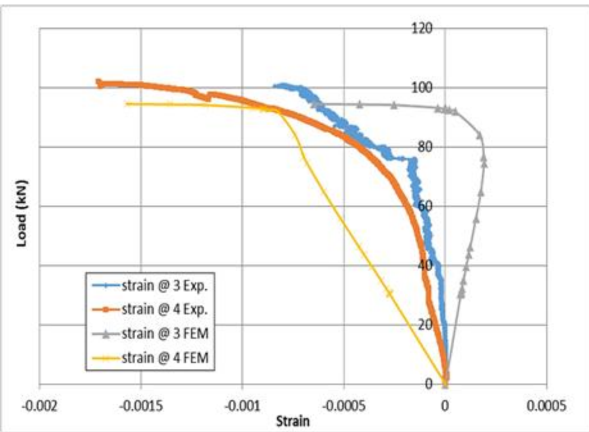

Fig. 16: Comparison of experimental and FEM load-strain curve of top chord for Model 1.

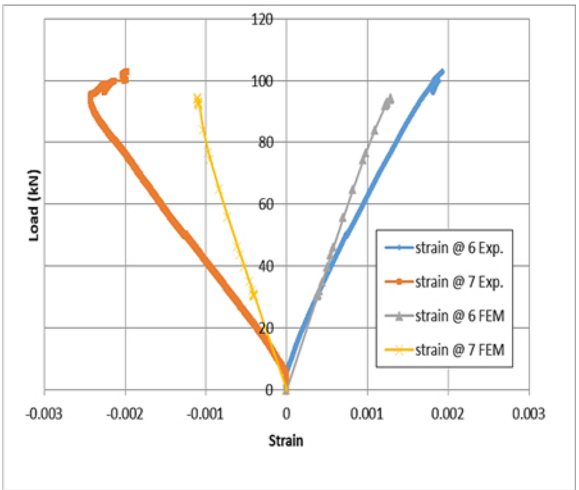

Fig. 17: Comparison of experimental and FEM load-strain curve of interior diagonal webs for Model 1 .

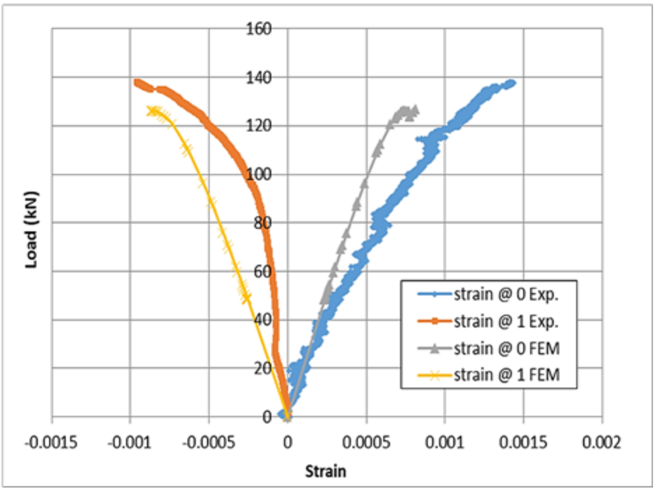

Fig. 18: Comparison of experimental and FEM load-strain curve of bottom chord for Model 2.

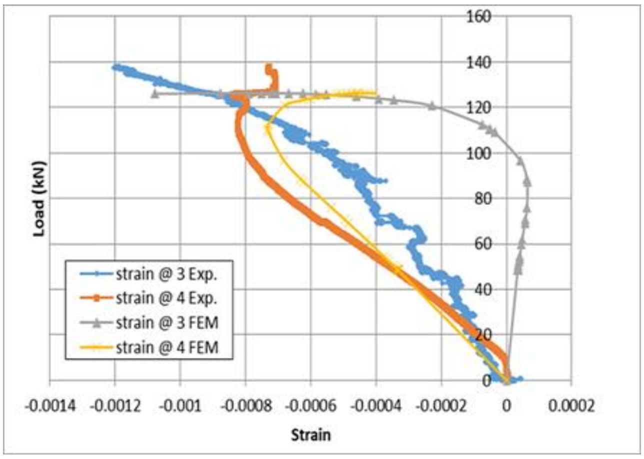

Fig. 19: Comparison of experimental and FEM load-strain curve of top chord for Model 2.

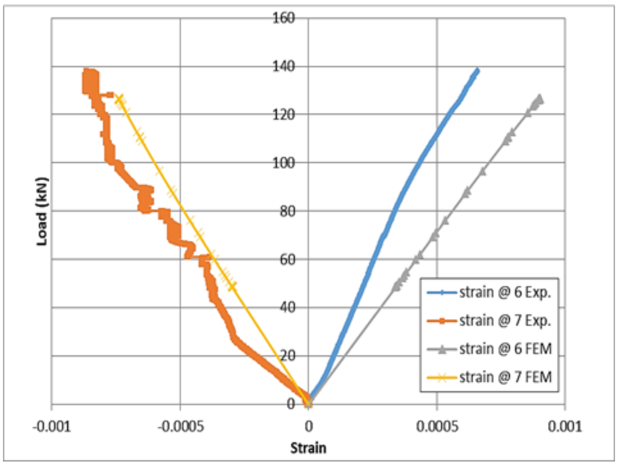

Fig. 20: Comparison of experimental and FEM load-strain curve of interior diagonal webs for Model 2.

IV. CONCLUSION

This study investigated the behavior of simply supported prefabricated hybrid open web steel joist under central single concentrate static load. Based on the experimental and FEM results reported in this paper, the following conclusions can be made:

- The ultimate load capacity of the HOWSJ joists can be estimated by FEM models, although it is difficult to obtain accurate predictions without calibrating the FEM models to experimental data.
- The ultimate strength of HOWS joists with diameter of interior web members with (15.85 mm) increased by (25.4%), as compared to joists with diameter of interior web of (11.97 mm).
- Decreasing the slenderness ratio of the interior web members ratio leads to increase the ultimate capacity and decreased the maximum deflection about (6.2%).
- For the two models a crimped-end web members failure occurred due to the local buckling of the diagonal interior web members near the supports before mid-span, but when increasing the diameter bar of interior webs in Model 2 by about (24.5%), the strain at the compression end web member (ε7) for the two specimen of Model 2 decreased about (63%) compared with Model1 specimens.

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