INVESTIGATING THE BEHAVIOR OF STEEL BEAM WITH WEB OPENINGS USING SAP2000 SOFTWARE IN STEEL STRUCTURE WORKS

Pham Nguyen Hoang[1], Nguyen Quang Phu[1]
1. Thuyloi University

Abstract: *In this article, we investigate experimentally and numerically the performance of beams with web openings when subjected to two concentrated loads acting on the upper flange of the beam. Indicators such as: deflection between beams, stress at the edge of the hole, stress at the upper flange of the beam, etc. were measured during the experiment campaign. At the same time, numerical simulation of the experiment was performed using SAP2000 software. The numerical simulation analysis using SAP2000 software and experiment show very similar results. It can be concluded that numerical simulations using SAP2000 software can predict with high reliability and anticipate dangerous locations when designing with less cost than surveying by experiment.*
Keywords: *Steel beam with web openings, SAP2000.*

1. CONTEXT

With the increasingly modern development of the construction industry as well as meeting the actual needs of people, projects using steel structures are increasingly used because of their efficiency and outstanding advantages as well as their suitability. It is more suitable for conventional reinforced concrete structures. Currently, shaped steel beams are manufactured in a variety of shapes and sizes to meet the requirements of each type of project.

However, because the cross-sectional size is pre-determined, prefabricated steel beams have some disadvantages such as not taking full advantage of the material's working ability, large web thickness leading to waste of steel, large volume, not able to span large spans, inconvenient in arranging technical pipes, not achieving high architectural efficiency, etc. These disadvantages have posed the problem for experts and designers to find a more reasonable way to use steel materials for prefabricated steel beams. One of the measures to overcome these disadvantages is to manufacture hollow beams and steel beams with web openings. However, the web openings boring process affects the structural properties and durability of the beam. Therefore, to ensure the safety and structural durability of construction works, research is necessary. Studies on beams with web openings focus on analyzing and determining the dangerous position of the beam when subjected to impact loads.

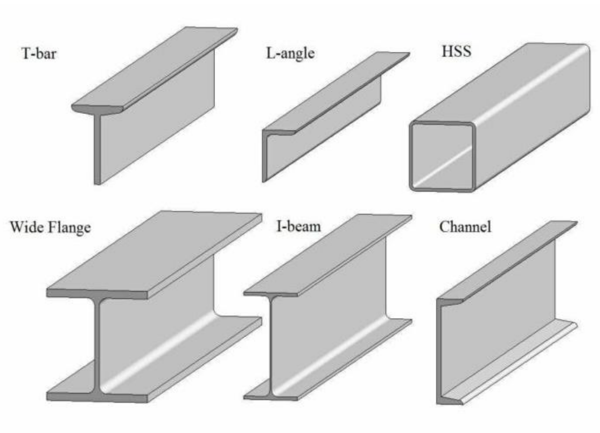

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Figure 1: Some types of shaped steel

Steel beams can be improved, machined from shaped beams, cut along the web along a trapezoidal sawtooth line, then welded over the two halves of the beam but offset by half a pitch, creating a new type of beam, with hollow cells. The 6 edges on the beam's belly are as shown in Figures 2, 3. As a result, the beam has increased height and bending capacity, while creating many spaces (openings), making it easy to arrange technical pipes within the area. beam height. If you want to create higher-height beams with larger hollow cells, you can insert small rectangular steel plates, welded head-on with saw-toothed tips.

Thanks to the increased beam height, beams with web openings have a higher bending capacity than shaped steel beams. This is an outstanding advantage. Thanks to that, beams with web openings are especially suitable when needing to span large spans with small loads. To prevent buckling and overall instability, other materials can be used to weld to fill the openings in the beam (in case necessary).

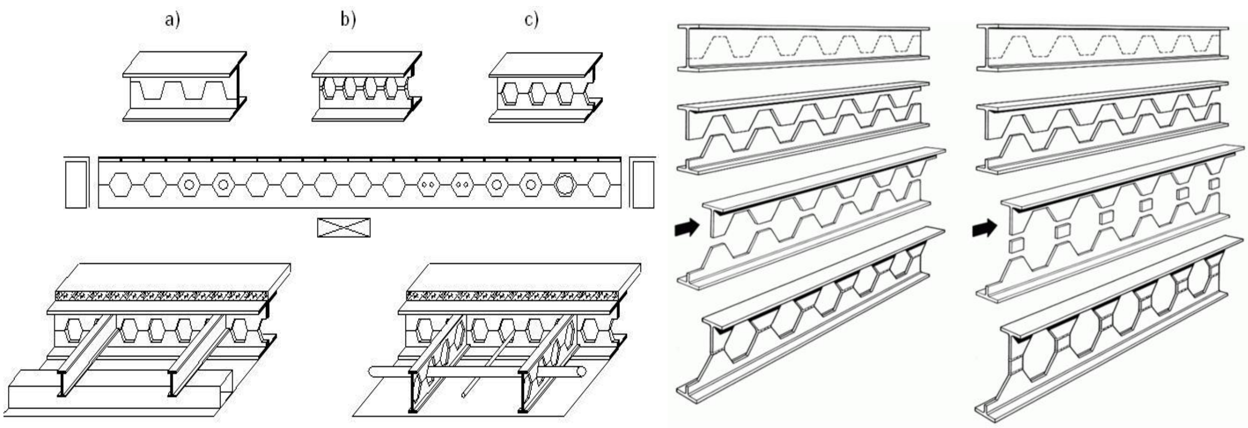


Figure 2: Processing steel beams with hexagonal and octagonal openings

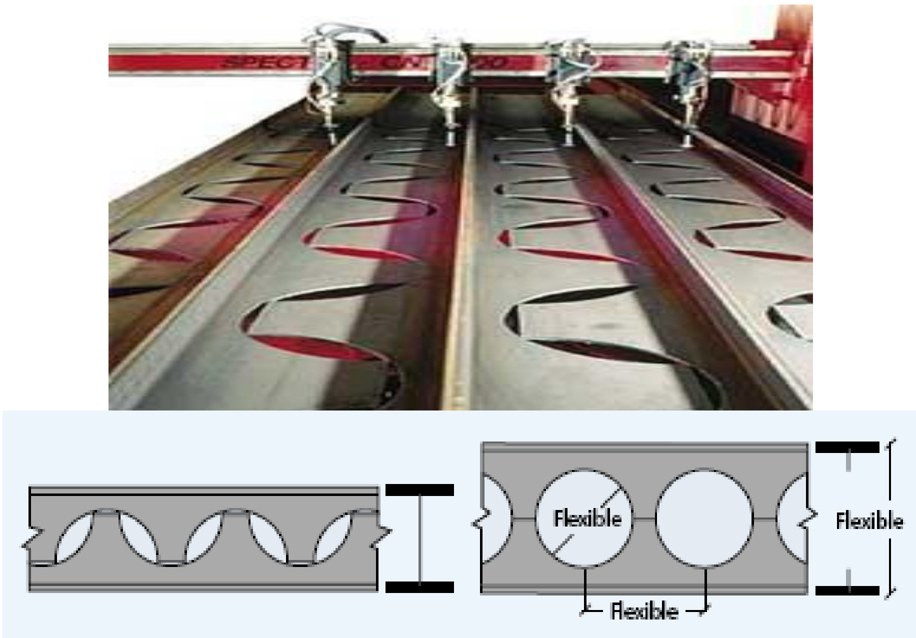
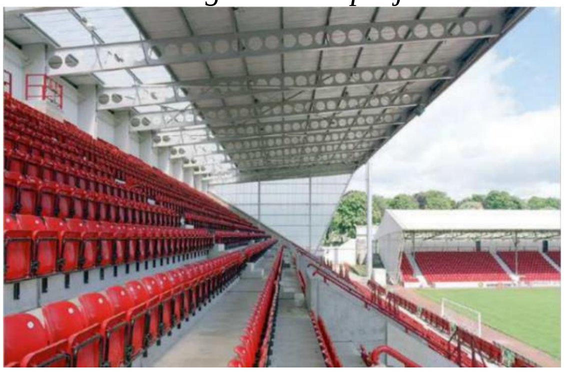


Figure 3: Processing steel beams with circular openings

Compared with traditional steel beams, the beam height is increased, leading to geometric characteristics of bending resistance such as moment of inertia, moment of bending resistance, and radius of inertia also increasing significantly. Therefore, the ability to span a larger span than the original beam reduces the number of columns and foundations in the building and increases the usable space. Therefore, perforated beams are especially suitable when needing to span a large span with load. small . Furthermore, the holes in the beam web allow technical systems to pass through the beam web, allowing the ceiling to be installed right under the surface of the steel beam, increasing the clear height of each floor. There are many projects in the world that have used perforated beams (Figure 4).

a) The beam with span of 11.8m at the Wellington Place project

b) Moorgate Exchange office building, England



c) Cantilever beam with holes in the web at Dumferline stadium

d) Beams in the sports hall in Manchester

Figure 4: Some applications of beams with web openings around the world

In this study, steel beams with regular hexagonal web openings were investigated by numerical simulation analysis using SAP2000 software. The survey results are compared with experimental results to verify the reliability of the numerical simulation method.

2. EXPERIMENT ON THE BEHAVIOR OF STEEL BEAM WITH OPENINGS

a. Experimental beam parameters

The steel beam with web openings has a length of 2.5m, the material used is SS400 steel grade, the cross-sectional dimensions are as shown in Figure 5 and the physical and mechanical characteristics of the material are as follows:

- Elastic modulus: $E = 2{,}06 \times 10^6$ daN/cm^2
- Density: 77 kN/m^3
- Horizontal expansion coefficient $\mu = 0{,}3$.

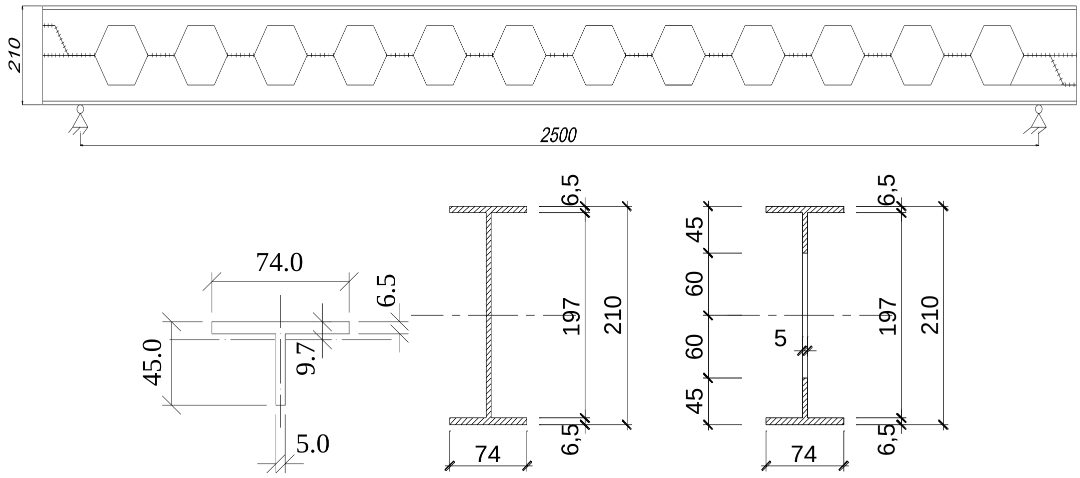


Figure 5: Overall shape and cross-sectional size of the beam without and with openings (mm)

Figure 6: Image of fabrication of two experimental beam samples

Using 2 steel beams of the same size to perform the experiment, the manufacturing process is shown in Figure 6.

b. Experimental diagram

Concentrated load P gradually increases with 5 load levels applied at 2 locations on the beam as shown in Figure 7. Joint connection at both ends of the beam.

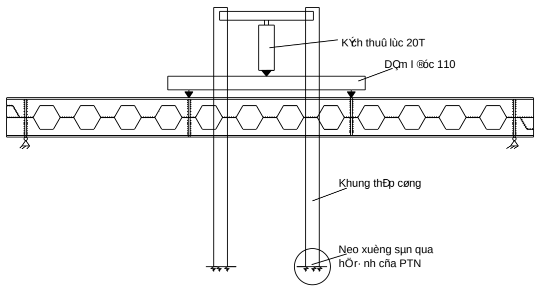


Figure 7: Experimental loading diagram

Displacements and stresses at some locations marked in Figure 8 were recorded during the experiment.

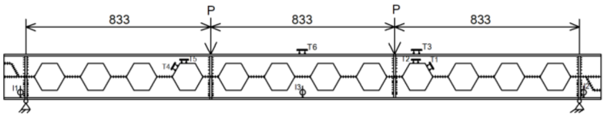


Figure 8: Load location and measuring heads in the experiment (unit: mm)

Loading equipment: Using American hydraulic jack system and SPX Power Team oil pump. Maximum force of jack: 20T (~200kN). Displacement measuring device: Mitutoyo electronic Indicato from Japan. Stress measuring device: Tenzomet. In the experiment, place stress measurement points T1, T2 and T4, T5 at the edge of the hole right next to the position of force application and offset to both ends. The stress measurement point T3 is at the upper flange of the beam, near the position of force P and offset to the right of the beam. Stress measurement point T6, located at the upper flange, in the middle of the beam. Displacement measuring point I3 is located at the lower wing, in the middle of the beam.

Load data: load placed at 2 locations with maximum magnitude Pmax = 28 kN, divided into 5 load levels as Table 1.

Table 1: Experimental load levels

Load levels	1	2	3	4	5
P (kN)	10	15	20	24	28

Figure 9: Some images of actual experiments

c. Experimental results

The experiment was performed on two steel beams with web openings (same size). The experimental diagram is shown in Figure 9. The experimental results are shown in Table 2.

Table 2: Actual test results of two beams with web openings according to experimental load levels

Experimental sample number 1							
Load levels	**Deflection (mm)**	**Stress (daN/cm^2)**					
		T1	**T2**	**T3**	**T4**	**T5**	**T6**
0	0,0	0	0	0	0	0	0
1	2,5	140	182	185	168	282	249
2	3,5	355	480	478	465	780	706
3	4,8	550	860	865	866	1430	1328
4	6,0	785	1163	1092	1227	2020	1786
5	7,4	965	1325	1260	1380	2116	2025

Experimental sample number 2							
Load levels	**Deflection (mm)**	**Stress (daN/cm^2)**					
		T1	**T2**	**T3**	**T4**	**T5**	**T6**
0	0,0	0	0	0	0	0	0
1	2,5	132	186	169	142	296	236
2	3,8	350	489	464	405	759	615
3	4,9	647	882	836	783	1385	1156
4	5,9	885	1250	1053	1064	1886	1663
5	7,0	1050	1522	1442	1225	2315	1990

3. INVESTIGATION THE WORKING OF BEAMS USING SAP2000 SOFTWARE

a. Build models in software

The material used for the model is SS400 with typical parameters as shown in Figure 10.

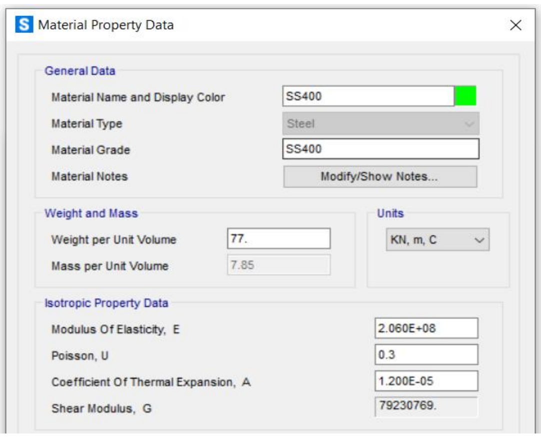


Figure 10: Definition of beam material

The steel beam with web openings is modeled with plate elements (Shell) for the flanges with a thickness of 6.5mm, a width of 74mm, a length of 2500mm and a web with a thickness of 5.0mm, a height of 203, 5mm, length is 2500mm. On the web, openings will be punched in regular hexagons with sides of 69.3mm, the distance between the two corners in the two closest holes is 69.3mm. Shell panels parameters are shown in Figure 13. The 3D modeled beam image and element meshing are shown in Figure 11.

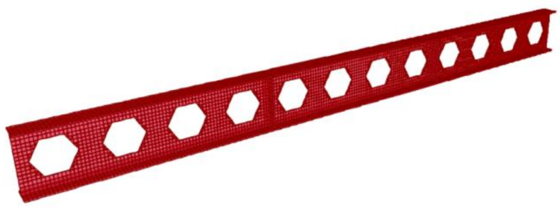


Figure 11: 3D model of perforated beam on Sap2000 software

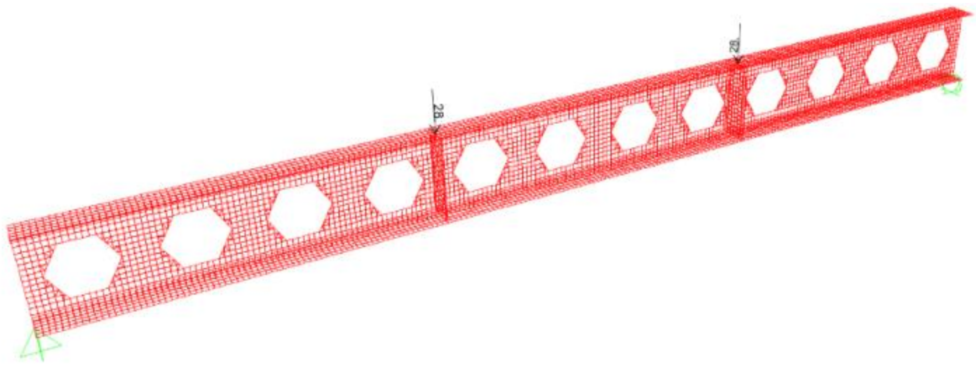
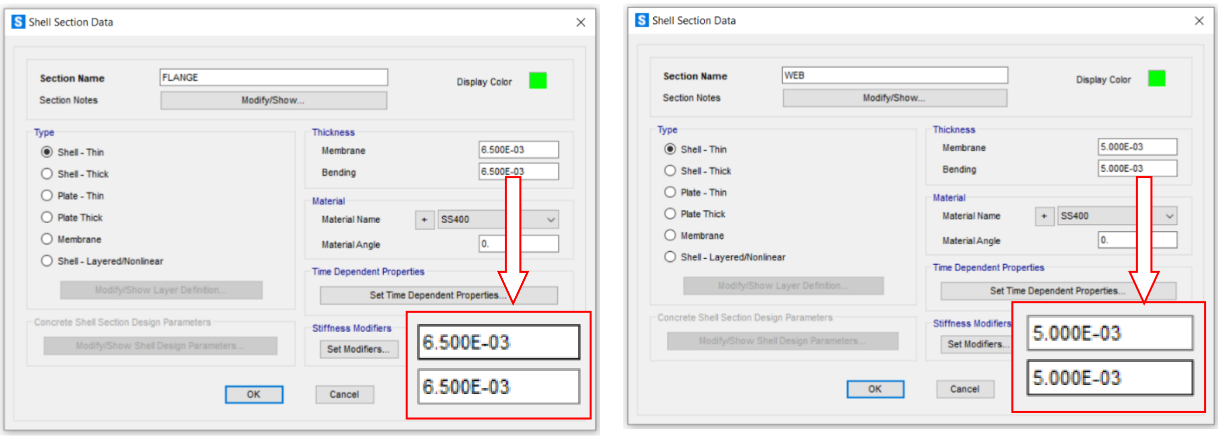


Figure 12: Model of hollow beam subjected to two concentrated forces using SAP2000 software (kN)



a) Beam wings *b) Beam web*

Figure 13: Definition of beam cross-section

The load applied to the beam is kept the same as the load in the experiment above (corresponding to 5 load levels). The load assignment model corresponding to load level 5, which is the largest load level P = 28 kN, is shown in Figure 12.

b. Results of numerical model analysis

The results taken in the model are the displacement and stress results in the beam caused by the two concentrated loads P.

The largest displacement at the mid-span of the beam corresponding to the load level P = 28(kN) (equivalent to the 5th load level in the actual experiment) is u3=6.97666mm (Figure 14). From the experimental results in table 2, the deflections of the two test samples are: 7.4mm and 7mm, respectively, corresponding to the deviation from the model compared to the experiment: 6% and 0%. The deviation from the average deflection of the two test samples is 3%.

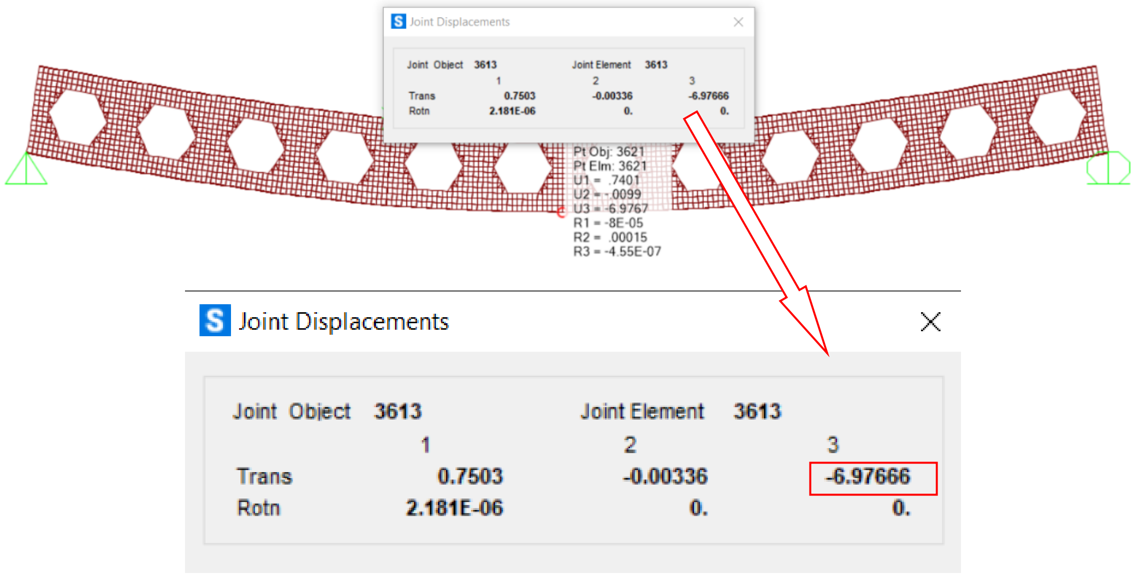


Figure 14: Maximum displacement at the mid-span position of the beam

The stress in the beam when subjected to a load level of P = 28 (kN) is shown in Figure 15.

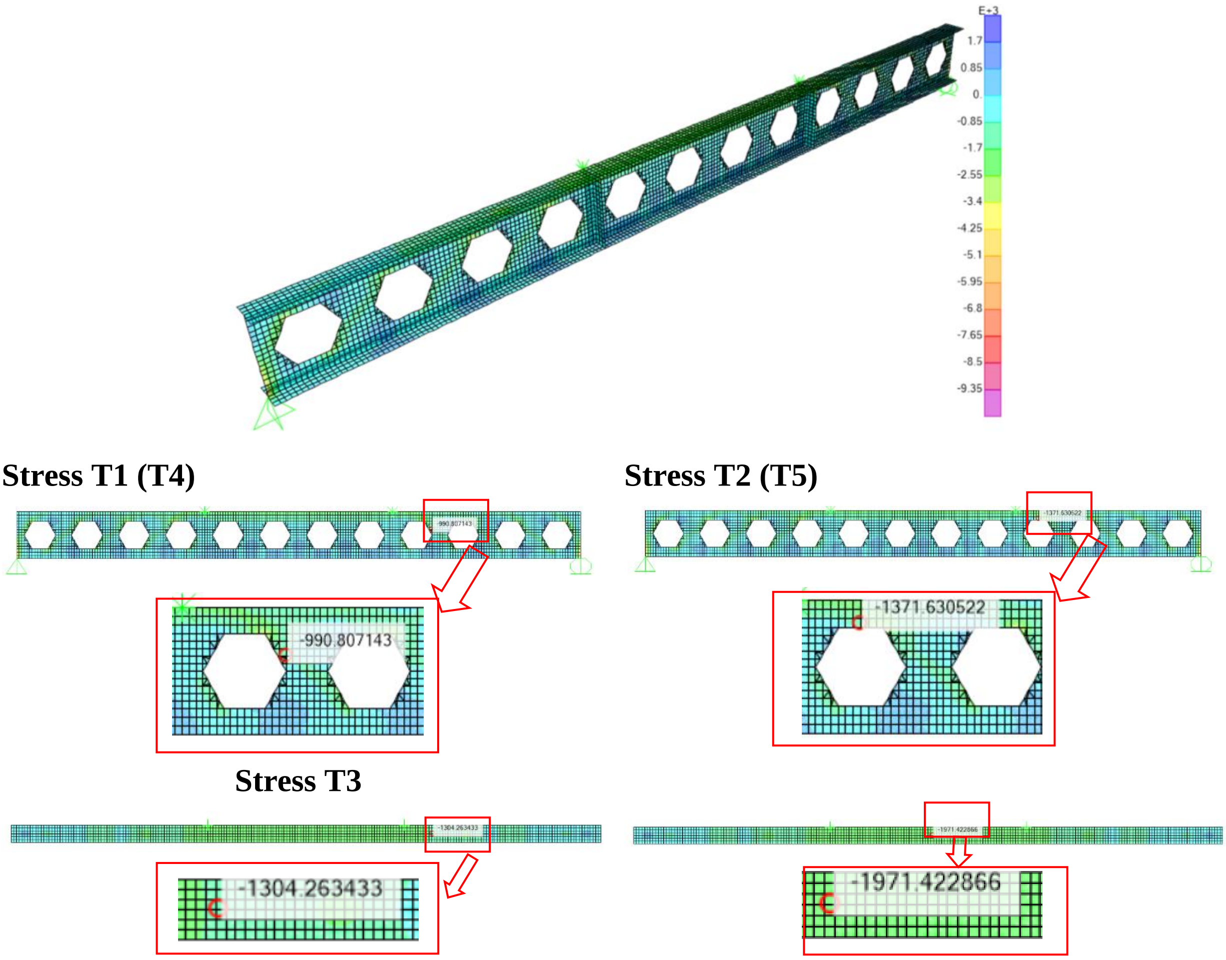


Figure 15: Principal stress in beam (unit: daN/cm^2)

A summary table of stresses on the model corresponding to the measuring head positions in the experiment is shown in Table 3.

Table 3: Stresses on SAP2000 model

Measuring equipment	Stress on the model (daN/cm^2)	Deviation from the average results of 2 test samples
T1	990	1%
T2	1371	-6%
T3	1304	-3%
T4	1312	1%
T5	2138	-3%
T6	1971	-2%

Doing the same model on SAP2000 software with other load levels, the results are obtained in Table 4.

Table 4: Stress deviation between the SAP2000 model and the average value of two experimental samples

Load levels	Model and experimental stress deviation						
	I3	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**
0	0	0	0	0	0	0	0
1	1%	15%	13%	14%	1%	13%	5%
2	4%	8%	7%	9%	1%	9%	2%
3	4%	1%	4%	6%	3%	7%	3%
4	2%	2%	3%	4%	2%	6%	2%
5	3%	2%	4%	3%	1%	3%	2%

4. CONCLUSION

Based on the results of the survey on the performance of steel beams with web openings by numerical model analysis using SAP2000 software above, some conclusions can be drawn as follows:

+ The performance of beams with holes in the web surveyed using SAP2000 software is relatively consistent with the results from the experiment in terms of both displacement values and stress values in the beams at the surveyed locations.

+ The results between numerical simulation analysis and experimental results have some small differences, not too large. The causes of this error may be that the sample manufacturing is not absolutely accurate, the sample is skewed, or somewhat warped when cutting and manufacturing.

+ From the survey results, we can completely survey the working of steel beams with holes in the web by numerical modeling using SAP2000 software with high reliability. Software surveys can predict and anticipate dangerous locations during design at less cost than experimental surveys.

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