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BEHAVIOR OF STEEL BEAMS WITH HOLES IN FLANGES

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ملخص البحث :

الكمرات المعدنية ذات الثقوب في الفلانجات بغرض التربيط بالمسامير. تم التركيز علي تأثيروجود الفتحات في الفلانجات علي سلوك عناصر الكمرة. إن الحكم المتعلق بنطاق الدراسة هذا له تأثير كبير على قوة تحمل الكمرة وخصائص التشوه. دراسة العوامل المختلفة المؤثرة على سلوك هذه الكمرات ألا وهي جسائة الفطاع وقطر الفتحة وموقع الفتحة في القطاع العرضي للحزمة وعلى طول امتداد الكمرة تمت دراستها وعرضها. تم عمل نماذج معايرة للقطاع بواسطة استخدام برنامج العناصر المحددة "الانسيس" للتحقق من تقارب نتائج النماذج مطابقة للدراسات التجريبية او العملية والتأكد منها بالتحليل العددي بهذه العوامل المختلفة.

الكلمات المفتاحية:

الكمرات المعدنية، الثقوب في الفلانجات، القطاعات المدمجة/الجسئة، قطر الفتحة/ الثقب، الانحناء في منتصف بحرالكمرة، حمل الانهيار، الالتواء، التحليل العددي.

ABSTRACT:

The steel beams with holes in flanges are made in structural steel construction for bolting purposes. The influence of flange holes on the behavior of beam members has been the focused. The provision related to this scope of study has a significant effect on the load capacity and deformation characteristics. The different parameters that affected the behavior of these beams including compactness condition, hole diameter, location of hole over the beam cross section and along the beam span length; are presented. Calibration of the finite element model using ANSYS [9] software to capture the previous experimental study on the steel I-beam with holes in flanges is provided for furthermore extended studies. Then, the behavior of steel I- beams with holes in flanges is extremely studied numerically with different parameters.

Key words: Steel Beams, Flange Holes, Compactness, Hole Diameter, Mid-Span Deflection, Failure Load, Buckling, Numerical Analysis.

1. Introduction.

It is not common to have holes in flanges of steel beams that causing the reduction in the effective area that led to reduction in strength and capacity of the beam but sometimes it becomes necessary and should be taken seriously for some reasons such as: installation of fasteners for connections, passages for tie rods, etc. Generally, holes in the flanges should be avoided in high moment but it is not always possible to avoid the placement of holes in flanges in high moment regions. An example of such a situation is bolted flange plate connections in steel building frames.

Recently, many previous studies tended to study the behavior and determine the load capacity for different of steel beams with holes in flanges.**[1]** and **[3]** studied inelastic cyclic behavior of eight full-scale bolted flange plate (BFP) connections analytically and experimentally designed to determine the strength, stiffness, and ductility of BFP connections expressing behavior modes and failure modes. **[2]** presented experimental and analytical studies to estimate the strength and ductility accomplishing and performance of axial tension members with different net area-to-gross area ratios and the tension flange of flexural members made of HPS70W steel (or equivalent to ASTM A709 Grade 70 steel) to examine the applicability of current **[4]** pertinent to the AISC-LRFD (1999) specification code provisions. **[5]** studied experimentally the influence of various ways applied to produce holes [drilling, punching, flame (thermal) cutting, reaming, etc], and explained that the hole-producing process do not effect on connection strength and ductility under static load states, there is no considerable deleterious strength deduction related with punching holes, punching and strain aging holes, or flame cutting holes, there is a luxurious lack of ductility when punched holes applied although, sufficient ductility keep improving the full plastic moment in a beam section before happening the fracture of the flange. **[6]** studying 25 beams experimentally and analytically by using ADINA FE program with various holes diameters were made by drilling, ranging from 0% to 50% of the gross flange area. The holes effects can be ignored on the flexural strength when the gross-section plastic moment is more than the modified net-section fracture moment. **[7]** and **[8]** focused on an experimental study of four-point flexural testing of 25 steel beams with various diameters circular holes ranging from 0% to 50% of the gross flange area to determine the flange holes influence and fasteners holes on the strength and rotation capacity of ASTM A992 steel grade I-beams. These experiments result that the beam specimens having the [Fu*Afn / Fy*Afg] ≥ 1.0 were able to reach the gross-section plastic moment and express and indicate substantial inelastic rotation capacity (R-y of more than 9). If this condition is violated the [Fu*Afn / Fy*Afg] < 1.0 , the beam specimens failed primarily due to rupture of tension flange at the location of the flange holes, which substantially reduced the inelastic rotational capacity.

The aim of this research is to study the effect of presence of holes in flanges on the capacity of different beams having compact, non-compact and slender sections. Different parameters are considered such as different hole diameter sizes, different hole's location in beam cross section either on the top flange, bottom flange or both flanges, also the holes' location through the beam length either at 1/4 of span and 1/3 of span and 1/2 of span. To meet this aim, the numerical analysis by using finite element program **ANSYS** [9] software are conducted to calibrate the numerical model with the previous experimental work for presenting more studies on the various parameters as mentioned previously that affected the behavior of the steel I-beams with holes in flanges.

2. Finite Element Analysis.

The analytical works were constructed using finite element model by ANSYS software[9]. These analytical works were performed to check their validation with the results obtained experimental works. Then, further analytical works were constructed for assisting in exploring effects of various parameters.

2.1. Beam description.

The experimental tests carried by **K.S.Sivakumaran et. Al. (2010)** [7] are modeled analytically with **ANSYS 15.0 APDL**[9] to examine the validity of using finite element modeling to capture the experimental results for further more extended studies.

Seven W200X42 rolled beam specimens were experimentally tested. The beam specimens were simply supported at 75 mm from both ends of the beam specimens: Moreover, at the supporting ends, two bearing plates, each having the dimensions of 160 mm long, 166 mm wide and 15 mm thick, were placed between the test beam flanges and the end supports. The test beams were subjected to two-point loads that were applied to the test beam using a 1000 mm long transfer beam spaced at the center-to-center distance of 750 mm on to the test beam (see Figure 1). The beam specimens used in the experimental tests with the dimensions as listed in table 1.

At the loading locations, two bearing plates each having dimensions of 100 mm long, 166 mm wide and 15 mm thick were used between the supports of the transfer beam and the flange of the test beam. Each beam had double bearing web stiffener plate with dimension (39.7 mm wide*181.4 mm long*6.5mm thick) located at the support and loading locations to prevent web buckling.

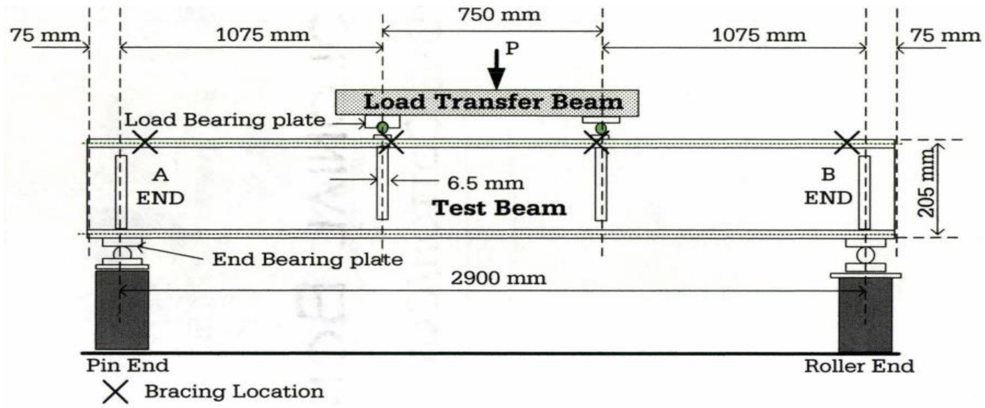


Figure 1 . Detail of beams used in verification by **K.S.Sivakumaran et al** [7]

Table 1 Nominal cross-sectional dimensions of beams tested by **K.S.Sivakumaran et al** [7]

W200X42	Tension flange		Compression flange		Web		Total depth	Beam Length
	bf	tf	bf	tf	h	w	d	L
Dimension (mm)	166	11.8	166	11.8	181.4	7.2	205	3050

Where: bf : Breadth (width) of the flange, tf : Thickness of the flange, h : height of the web, d : the whole depth of the beam, and L : Total beam Length .

The seven tested beams are divided as following: a solid beam (without holes in the flanges) A100 as a series 1; The second group of beams with a pair of open holes in the tension flange A85, A75, A60 with net flange area-to-gross flange area (A_{fn}/A_{fg}) ratios equal 85%, 75% and 60% respectively as a series 2 and the third group of beams with a pair of open holes in both tension and compression flanges A85-B, A75-B, A60-B with A_{fn}/A_{fg} ratios 85%, 75% and 60% respectively as a series 3.

2.2. Element type and Material properties

Twenty nodes solid 186 element is used to model the steel elements. This includes the top and bottom flanges, webs, stiffeners and bearing and loading plates. It has both bending and membrane capabilities. The element has six degrees of freedom at each node; three translations in the nodal x, y, and z directions and three rotations about the nodal x, y, and z-axes.

The Solid186 element requires linear isotropic and nonlinear inelastic multi-linear material properties to properly model steel. The nonlinear inelastic multi-linear material uses the Von Mises failure criterion to define the failure of steel. EX is the modulus of elasticity "Young's Modulus" of steel (Es), and PRXY is the Poisson's ratio (ν). For the Linear Elastic Isotropic, The Poisson's ratio was assumed to be 0.3. Modulus of elasticity of steel (Es) and Nonlinear Inelastic multi-linear stress and strain values as shown in Table 2 and Figure 2 .

Table 2 Section properties of the studied beam by **Author**

Element	Fy (MPa)	Fu (MPa)	Fy / Fu	εy	εu	εy / εu	E (GPa)
Flanges	409	531	0.77	0.0022	0.1554	70	215
Web	409	536	0.7	0.0022	0.1402	64	205

Where: Fy: Yield stress of the element, Fu: Ultimate stress of the element, εy: Yield strain of the element, εu: Ultimate strain of the element, and E : Modulus of elasticity.

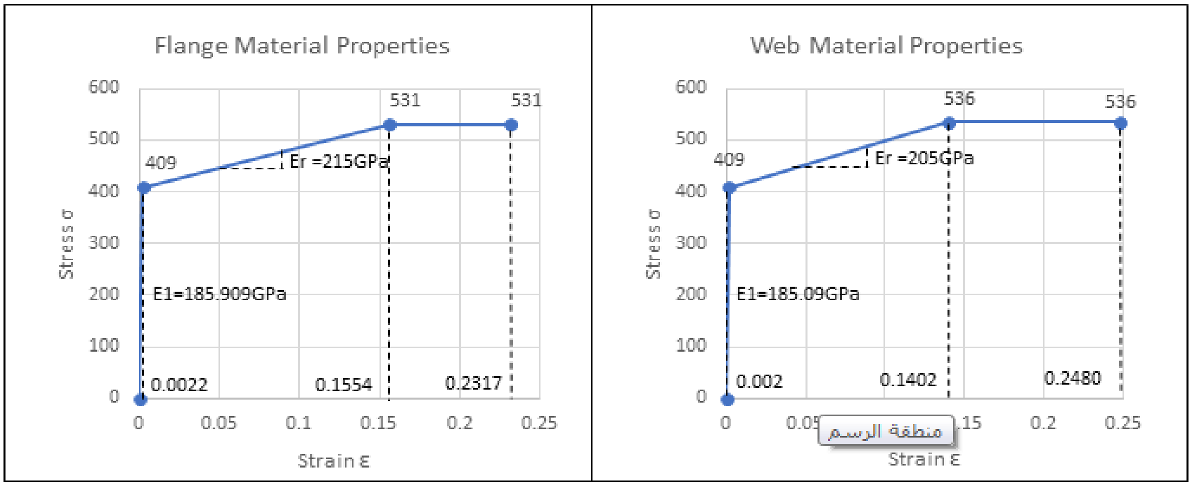
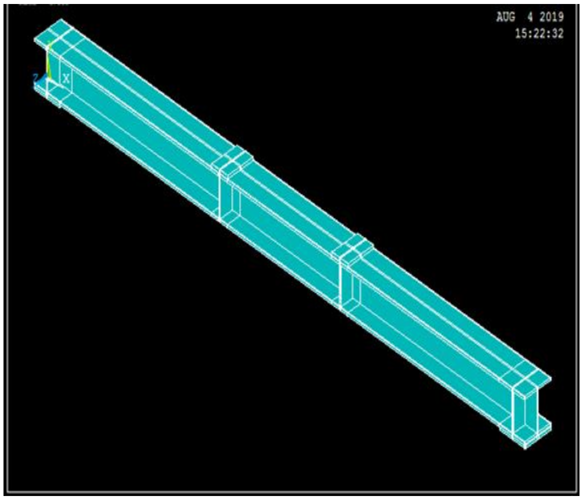


Figure 2 . Stress-Strain curve of the beam elements

2.3. Modeling and meshing and element definition

The steel beam, steel plates, stiffeners and supports were modeled as volumes as shown in figure 3. The mesh was set up such that square or rectangular element were created. And for beams with holes Tet, free is the best selection for meshing the beams. The overall mesh of the steel beam, support bearing plates, loading bearing plates and stiffeners volumes is shown in Figure 4.



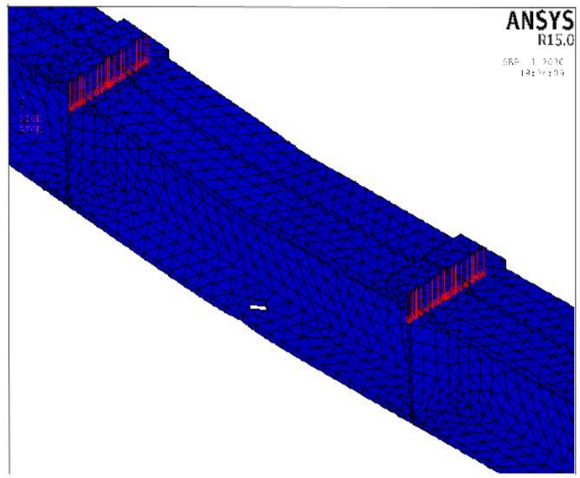


Figure 3 Volumes Created in ANSYS   Figure 4. finite element mesh of steel beam

2.4. Boundary conditions and loading.

The boundary conditions for the beam is shown in Figure 5. One of the supports was modeled in such a way that a roller was created. The lines of nodes on the plate were given constraint in the UY direction and the other support acts as a hinge support, the lines of nodes on the plate were given constraint in the UX, UY, and UZ directions. The force is two-concentrated load applied at centerline of the steel plate.

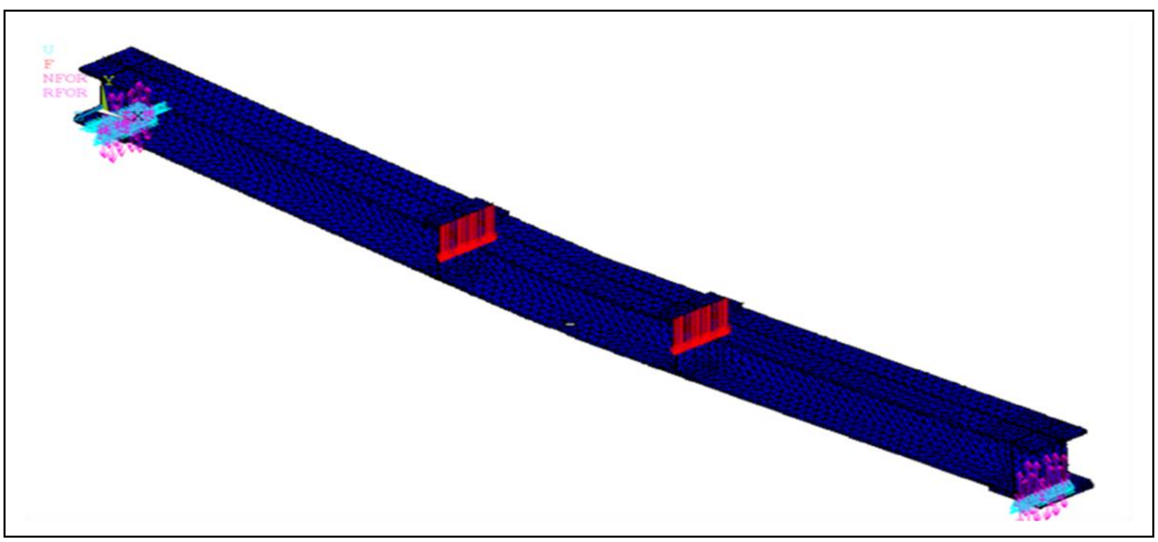


Figure 5 Boundary Conditions for the beam

2.5. Analysis type.

Static analysis type is utilized. The Sol'n Controls command dictates the use of a linear or non-linear solution for the finite element model. Typical commands utilized in a nonlinear large displacement. The values for the convergence criteria are set to defaults except for the tolerances. The tolerances for force and displacement are set as 0.001 as the default values.

3. Verification Results.

Table 4 and Figures 6 and 7 show comparisons between the experimental test results and the numerical **FEM** results by **Author**

Table 2 Analytical data from Ansys models by **Author** compared with tested beams by **K.S.Sivakumaran et al** [7]

	BEAM NAME		Experimental		FEM		Experimental/FEM %	
	Exp. Name	Numerical Name	Load kN	Deformation mm	Load kN	Deformation mm	Load	Deformation
1	**Solid (A100)**	C-A00-2P	400.4	190.75	412	167	97%	114%
2	**A85**	C-A10-2P-0.5L-TF	400.4	185.5	436	185.4	92%	100%
3	**A85B**	C-A10-2P-0.5L-BF	388.96	164.5	430	169.6	90%	97%
4	**A75**	C-A20-2P-0.5L-TF	388.96	157.5	424	162	92%	97%
5	**A75B**	C-A20-2P-0.5L-BF	371.8	134.75	410	139.5	91%	97%
6	**A60**	C-A30-2P-0.5L-TF	366.08	120.75	400	127.7	92%	95%
7	**A60B**	C-A30-2P-0.5L-BF	357.5	113.75	372	117.3	96%	97%

Where: A85 : The net flange area-to-gross flange area (Afn/Afg) ratio is 85%, A75 : The net flange area-to-gross flange area (Afn/Afg) ratio is 75%, A60 : The net flange area-to-gross flange area (Afn/Afg) ratio is 60%, C: Compact , A00: Solid beam (no holes), A10: beam with holes hole diameter 10.4mm+2mm clearance, A20: beam with holes hole diameter 19.9mm+2mm clearance, A30: beams with hole diameter 10.4mm+2mm clearance, 2P: Two-Point Loading Type, 0.5L: Hole Location through the beam span, Tf: Hole Location at

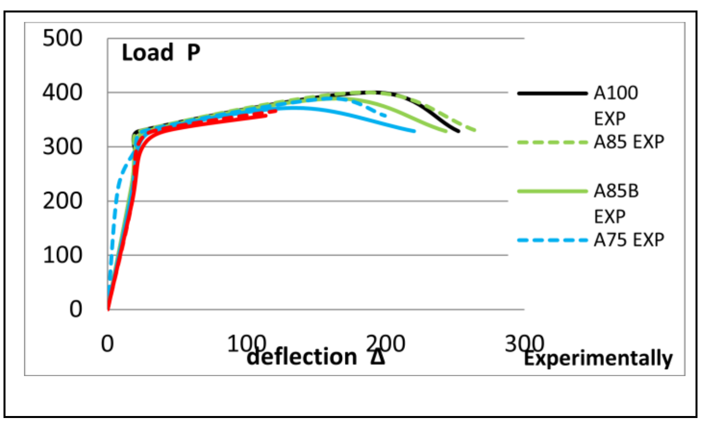


Figure 6 Load- deflection curve for beam Experimentally by **K.S.Sivakumaran**

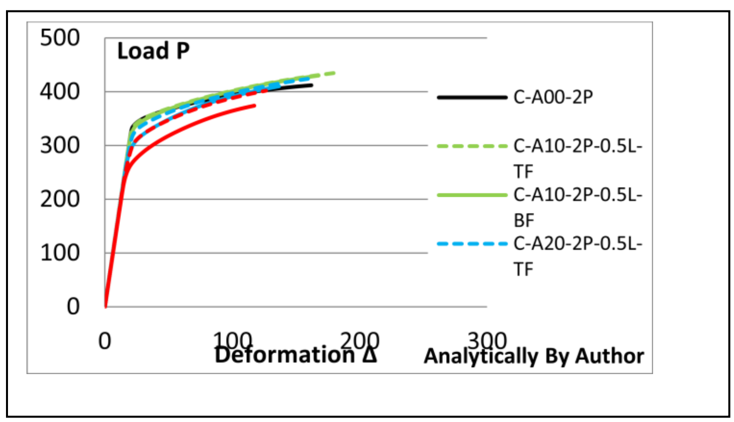


Figure 7 Load- deflection curve for beams tested Analytically by **Author**.

et al [7]

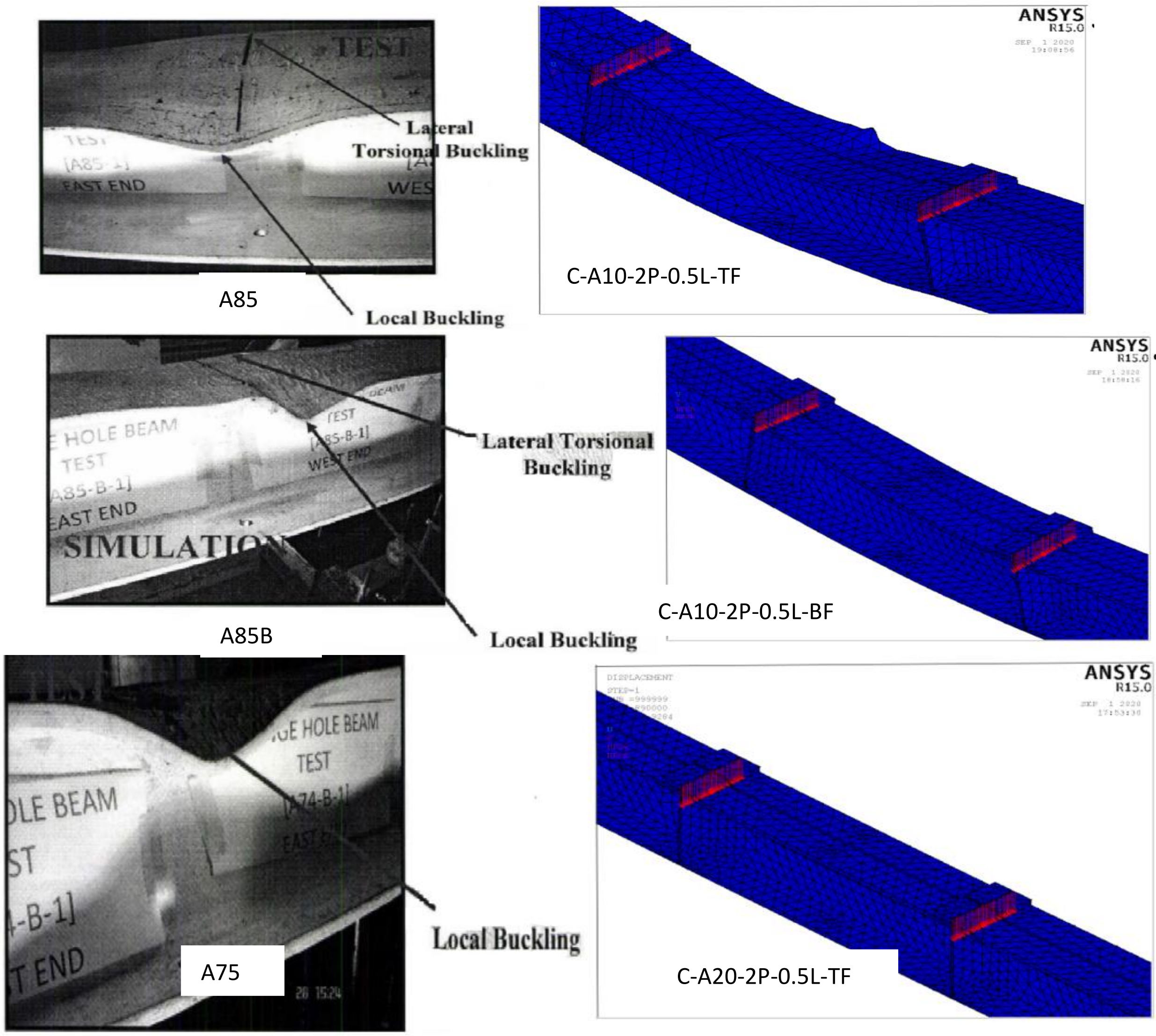


Figure 8 failure mode for beams tested Analytically by **Author** and Experimentally by **K.S.Sivakumaran et al** [7]

4. Parametric Study

The scope of this thesis is studying the effect of the following parameters on the behavior of steel beam specimens with/out holes in flange/s:

- Flange compactness effect [C “Compact”, N “Non-Compact”, S “Slender”].
- Hole diameter [A00 “solid beam”, A10 “... ...eter 10.4mm+2mm clearance”, A2 ... with holes hole d... ...m clearance”, A30 “beams with hole diameter 10.4mm+2mm clearance”].

C-A20-2P A75B

- Hole Location in beam section [CF “Hole Location at Compression flange”, TF “Hole Location at Tension flange”, BF “Hole Location at Both flanges”.
- Hole Location through the beam Length [0.25L “0.25 beam Span”, 0.33L “0.33 beam Span”, and 0.5L “beam mid-span”]
- Loading Type [2P “Two-Point load 750mm in-between located at the beam mid-span”, 1P “One-Point Load at beam mid-span”, and U “the concentrated load result from uniform distributed load”.

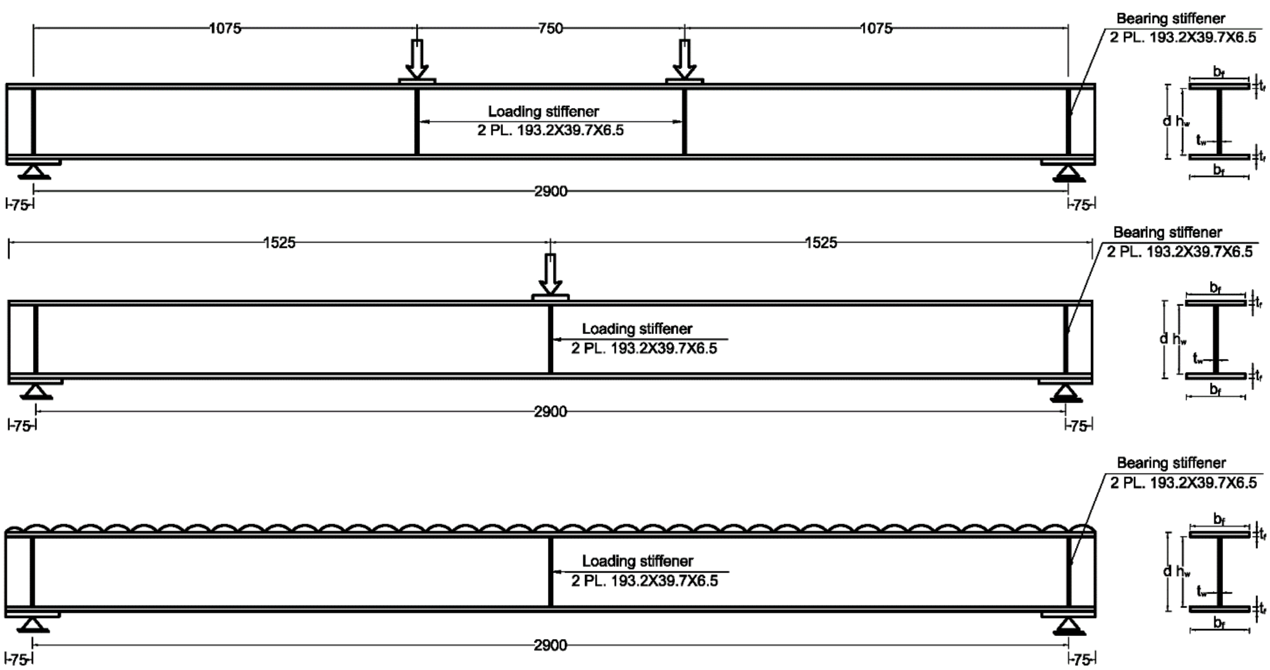


Figure 9 loading configuration by **Author**

Table 3 Cross-sectional dimensions of the beam specimens by Author

Dimension	**Total depth**	**Tension flange**		**Compression flange**		**web**		**Beam Length**
	d	**bft**	**tft**	**bfc**	**tfc**	**hw**	**tw**	**L**
Unit	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**
Compact	205	166	11.8	166	11.8	181.4	7.2	3050
Non-compact	201.4	166	10	166	10	181.4	7.2	3050
Slender	195.24	166	6.92	166	6.92	181.4	7.2	3050

Where: bft, bfc: Breadth “ width” of the tension and compression flanges, tft, tfc: Thickness of the tension and compression flanges, d : Depth of the beam, hw : Height of the web, tw : Thickness of the web, and L : Length of the beam.

4. Results and Analysis

Table 4:Failure load and deflection in case of 2 point load with holes at mid-span (0.5L)

Beam Name	hole locat-ion	P	Δ
C-A100-2P	____	436	241.867
C-A10-2P-0.5L-CF		436	183.881
C-A10-2P-0.5L-TF		436	185.4
C-A10-2P-0.5L-BF		430	169.6
C-A20-2P-0.5L-CF		424	159.121
C-A20-2P-0.5L-TF		424	162
C-A20-2P-0.5L-BF		410	139.5
C-A30-2P-0.5L-CF		402	126.468
C-A30-2P-0.5L-TF		402	127.7
C-A30-2P-0.5L-BF		372	117.3
N-A100-2P		384	180.612
N-A10-2P-0.5L-CF		382	173.392
N-A10-2P-0.5L-TF	0.5L	378	177.503
N-A10-2P-0.5L-BF		374.4	174.333
N-A20-2P-0.5L-CF		369.6	154.78
N-A20-2P-0.5L-TF		369.6	140.562
N-A20-2P-0.5L-BF		357.6	120.033
N-A30-2P-0.5L-CF		350.4	122.431
N-A30-2P-0.5L-TF		352.8	114.449
N-A30-2P-0.5L-BF		333.6	111.268
S-A100-2P		292	171.926
S-A10-2P-0.5L-CF		290.6	170.77
S-A10-2P-0.5L-TF		292	177.06
S-A10-2P-0.5L-BF		289.3	166.88
S-A20-2P-0.5L-CF		284	151.315
S-A20-2P-0.5L-TF		284	151
S-A20-2P-0.5L-BF		273.3	122.509
S-A30-2P-0.5L-CF		272	122.401
S-A30-2P-0.5L-TF		269.3	113.828
S-A30-2P-0.5L-BF		256	108.69

Table 5 : Failure load and deflection in case of 2 point load with holes at 0.25 span (0.25L)

Beam Name	hole locat-ion	P	Δ
C-A100-2P	____	436	241.867
C-A10-2P-0.25L-CF		435	163.862
C-A10-2P-0.25L-TF		435	163.823
C-A10-2P-0.25L-BF		432	155.562
C-A20-2P-0.25L-CF		426	140.459
C-A20-2P-0.25L-TF		426	140.449
C-A20-2P-0.25L-BF		420.	126.9
C-A30-2P-0.25L-CF		411	108.945
C-A30-2P-0.25L-TF		411	108.963
C-A30-2P-0.25L-BF		402	92.712
N-A100-2P		384	180.612
N-A10-2P-0.25L-CF		384	174.747
N-A10-2P-0.25L-TF	0.25L	381.5	175.692
N-A10-2P-0.25L-BF		379	175.427
N-A20-2P-0.25L-CF		381.6	168.233
N-A20-2P-0.25L-TF		376.8	167.034
N-A20-2P-0.25L-BF		374.4	159.698
N-A30-2P-0.25L-CF		369.6	141.702
N-A30-2P-0.25L-TF		366	132.992
N-A30-2P-0.25L-BF		360	117.752
S-A100-2P		292	171.926
S-A10-2P-0.25L-CF		292	171.900
S-A10-2P-0.25L-TF		292	169.802
S-A10-2P-0.25L-BF		289.3	168.478
S-A20-2P-0.25L-CF		290.7	168.346
S-A20-2P-0.25L-TF		290.7	167.953
S-A20-2P-0.25L-BF		288	156.028
S-A30-2P-0.25L-CF		288	156.272
S-A30-2P-0.25L-TF		286.7	150.325
S-A30-2P-0.25L-BF		282.7	134.298

Table 6 : Failure load and deflection in case of 2 point load with holes at 0.33 span (0.33L)

Beam Name	hole locat-ion	P	Δ
C-A100-2P	____	436	241.867
C-A10-2P-0.33L-CF		434	161.180
C-A10-2P-0.33L-TF		434	161.212
C-A10-2P-0.33L-BF		420	127.063
C-A20-2P-0.33L-CF		422	132.049
C-A20-2P-0.33L-TF		422	131.883
C-A20-2P-0.33L-BF		414.	116.197
C-A30-2P-0.33L-CF		408	104.99
C-A30-2P-0.33L-TF		396	83.7764
C-A30-2P-0.33L-BF		390	77.36
N-A100-2P		384	180.612
N-A10-2P-0.33L-CF		381	175.286
N-A10-2P-0.33L-TF		378	171.558
N-A10-2P-0.33L-BF	0.33 L	375	161.097
N-A20-2P-0.33L-CF		378	171.358
N-A20-2P-0.33L-TF		378	173.011
N-A20-2P-0.33L-BF		372	154.445
N-A30-2P-0.33L-CF		363	127.303
N-A30-2P-0.33L-TF		363	127.051
N-A30-2P-0.33L-BF		351	101.664
S-A100-2P		292	171.926
S-A10-2P-0.33L-CF		292	171.705
S-A10-2P-0.33L-TF		292	170.991
S-A10-2P-0.33L-BF		289.3	168.173
S-A20-2P-0.33L-CF		290.7	169.481
S-A20-2P-0.33L-TF		288	156.244
S-A20-2P-0.33L-BF		283.5	139.205
S-A30-2P-0.33L-CF		282	134.002
S-A30-2P-0.33L-TF		282	134.002
S-A30-2P-0.33L-BF		277.5	108.69

Table 7: Failure load and deflection in case of 1 point load with holes at mid-span (0.5L)

Beam Name	hole locat-ion	P	Δ
C-A100-1P	——	387	226.021
C-A10-1P-0.5L-CF		378	189.061
C-A10-1P-0.5L-TF		375	184.227
C-A10-1P-0.5L-BF		360	144.386
C-A20-1P-0.5L-CF		369	158.48
C-A20-1P-0.5L-TF		354	137.27
C-A20-1P-0.5L-BF		348	123.17
C-A30-1P-0.5L-CF		339	136.53
C-A30-1P-0.5L-TF		339	137.91
C-A30-1P-0.5L-BF		336	129.22
N-A100-1P		316	151.040
N-A10-1P-0.5L-CF		314	144.815
N-A10-1P-0.5L-TF		314	150.369
N-A10-1P-0.5L-BF		304	120.548
N-A20-1P-0.5L-CF	0.5L	310	132.57
N-A20-1P-0.5L-TF		294	106.57
N-A20-1P-0.5L-BF		288	93.76
N-A30-1P-0.5L-CF		294	106.57
N-A30-1P-0.5L-TF		290	122.48
N-A30-1P-0.5L-BF		284	106.31
S-A100-1P		240	156.694
S-A10-1P-0.5L-CF		238.5	145.052
S-A10-1P-0.5L-TF		236	140.185
S-A10-1P-0.5L-BF		232	124.117
S-A20-1P-0.5L-CF		234.67	129.38
S-A20-1P-0.5L-TF		230.6	129.46
S-A20-1P-0.5L-BF		225.33	109.89
S-A30-1P-0.5L-CF		229.33	110.02
S-A30-1P-0.5L-TF		218.67	106.299
S-A30-1P-0.5L-BF		216	98.036

Table 8: Failure load and deflection in case of uniform distributed load with holes at mid-span (0.5L)

Beam Name	hole locat-ion	P	Δ
C-A100-1P	——	387	226.021
C-A10-1P-0.5L-CF		378	189.061
C-A10-1P-0.5L-TF		375	184.227
C-A10-1P-0.5L-BF		360	144.386
C-A20-1P-0.5L-CF		369	158.48
C-A20-1P-0.5L-TF		354	137.27
C-A20-1P-0.5L-BF		348	123.17
C-A30-1P-0.5L-CF		339	136.53
C-A30-1P-0.5L-TF		339	137.91
C-A30-1P-0.5L-BF		336	129.22
N-A100-1P		316	151.040
N-A10-1P-0.5L-CF		314	144.815
N-A10-1P-0.5L-TF		314	150.369
N-A10-1P-0.5L-BF		304	120.548
N-A20-1P-0.5L-CF	0.5L	310	132.57
N-A20-1P-0.5L-TF		294	106.57
N-A20-1P-0.5L-BF		288	93.76
N-A30-1P-0.5L-CF		294	106.57
N-A30-1P-0.5L-TF		290	122.48
N-A30-1P-0.5L-BF		284	106.31
S-A100-1P		240	156.694
S-A10-1P-0.5L-CF		238.5	145.052
S-A10-1P-0.5L-TF		236	140.1852
S-A10-1P-0.5L-BF		232	124.117
S-A20-1P-0.5L-CF		234.67	129.38
S-A20-1P-0.5L-TF		230.6	129.46
S-A20-1P-0.5L-BF		225.33	109.89
S-A30-1P-0.5L-CF		229.33	110.02
S-A30-1P-0.5L-TF		218.67	106.299
S-A30-1P-0.5L-BF		216	98.036

Tables 4 to 8 show the relation between failure loads “P” and deflections “Δ” results of compact, non-compact, and slender beam specimens of solid beams and beams having holes in section either in one flange “compression / tension” or both flanges using three diameters of holes. Tables 4, 5 and 6 present beams having holes in mid-span, 0.25 span and 0.33 span respectively under the two-concentrated loading type. While table 7 presents beams having holes with different diameters “10.4+2mm clearance at A10, 19.9+2mm clearance at A20 and

29.6+2mm clearance at A30”in mid-span of the beam under one-point loading type and table 8 shows beams having holes in mid-span of the beam under uniform distributed load.

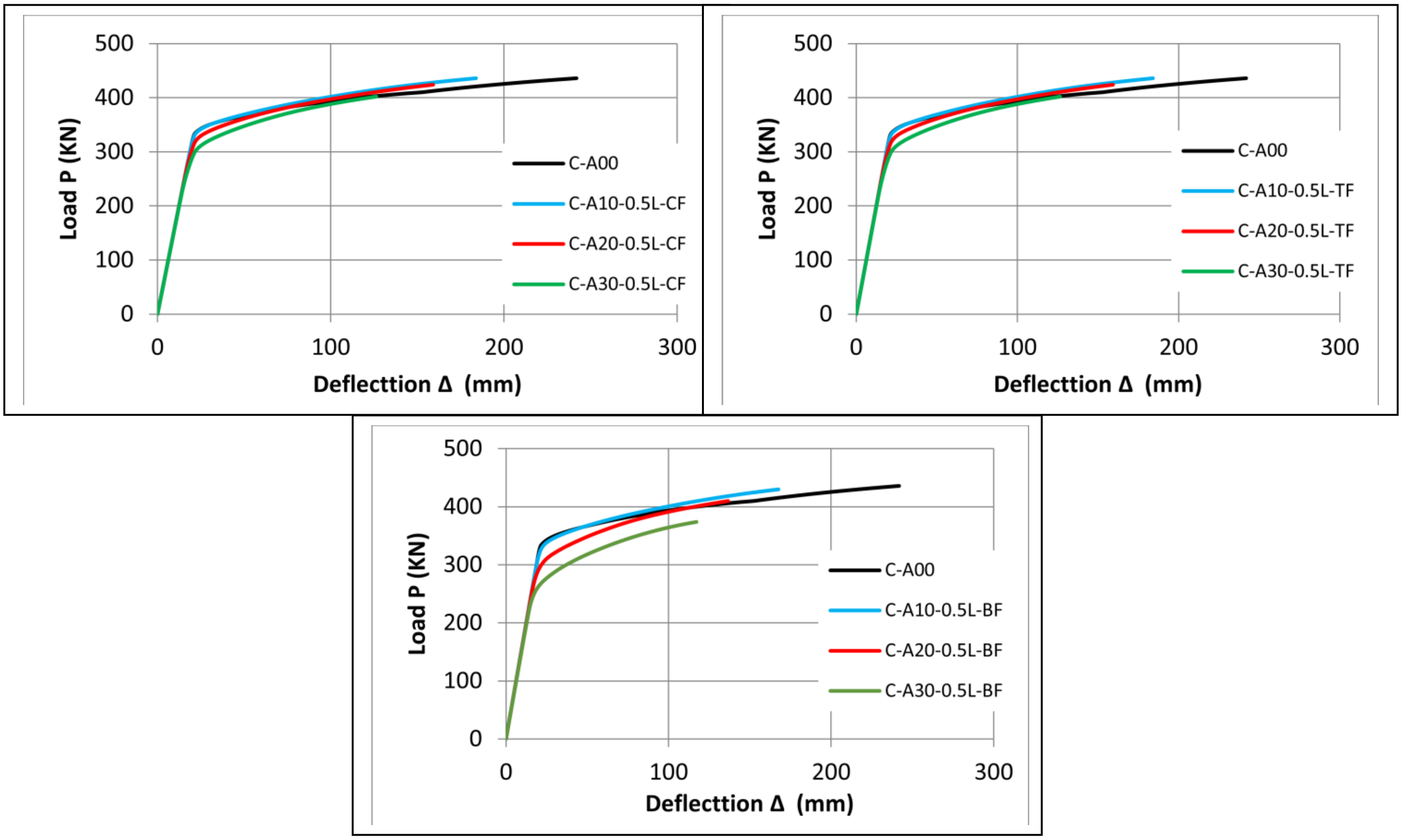


Figure 10 Load versus mid-span deflection for compact beams with hole diameter change in cases of holes in compression flange, tension flange and both flanges

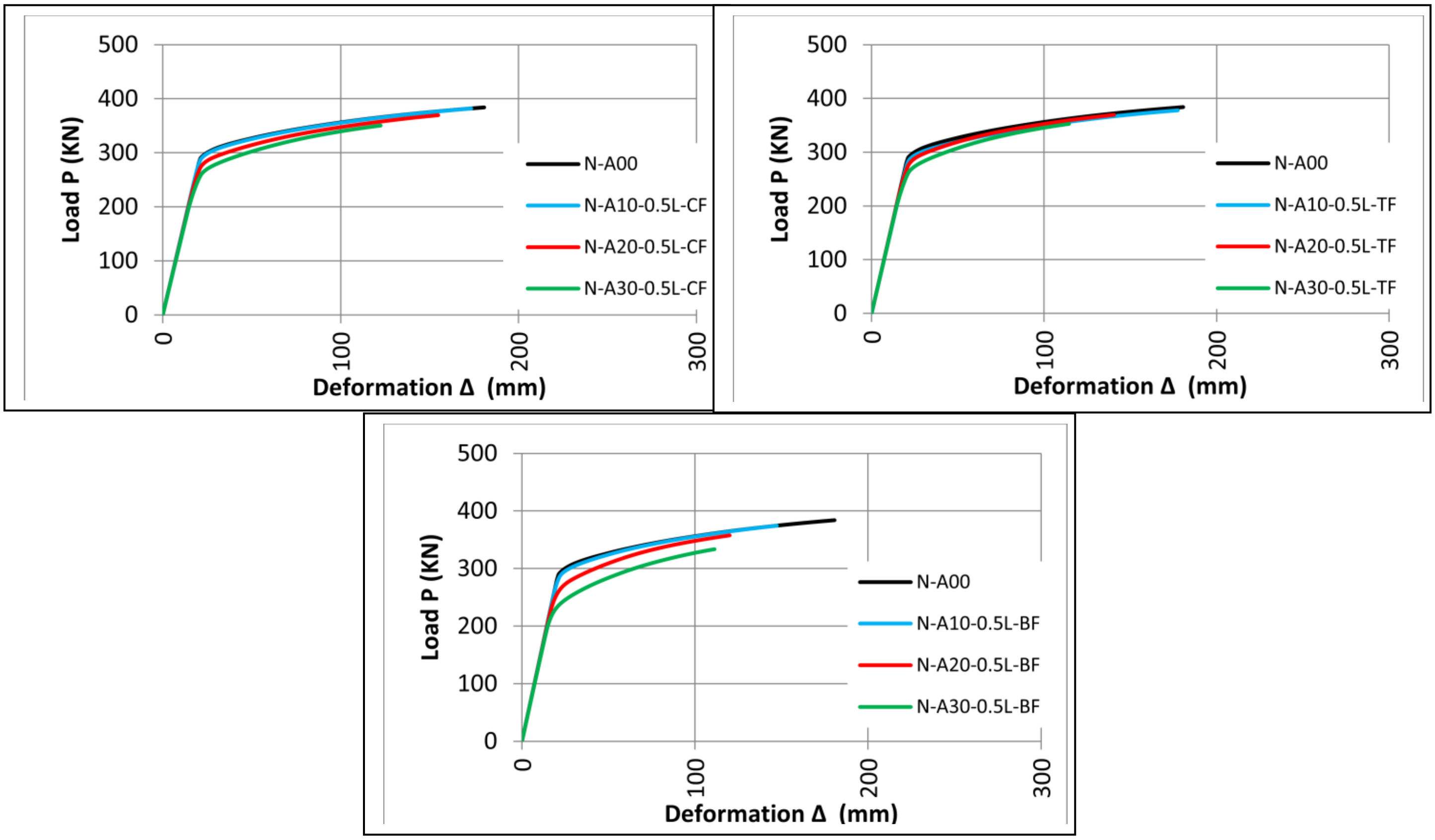


Figure 11 Load versus mid-span deflection for non-compact beams with hole diameter change in cases of holes in compression flange, tension flange and both flanges

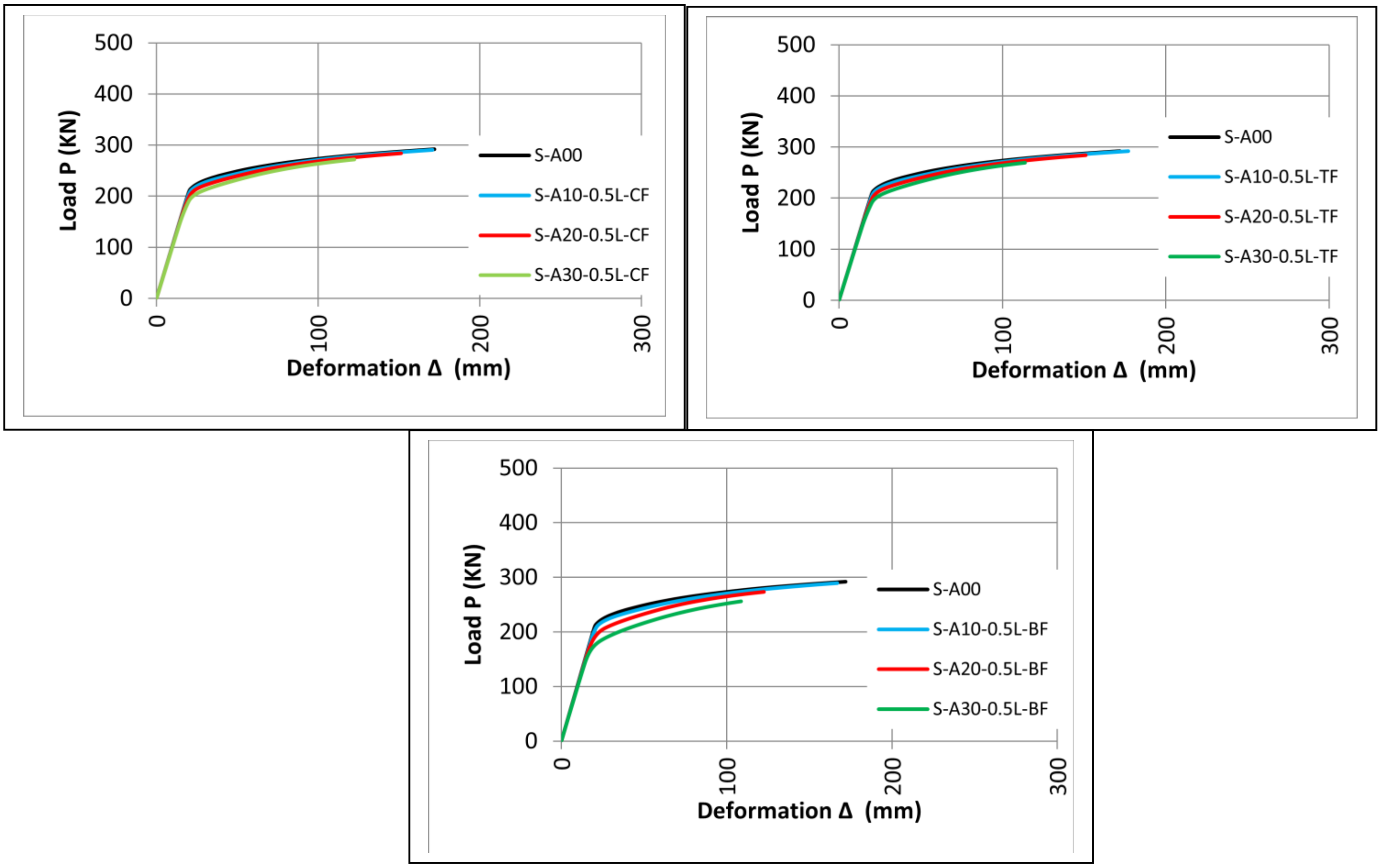


Figure 12 Load versus mid-span deflection for slender beams with hole diameter change in cases of holes in compression flange, tension flange and both flanges

Figures 10 to 12 show the relation between failure loads “P” and deflections “Δ” results of compact, non-compact, and slender beam specimens of solid beams and beams having holes in section either in one flange “compression / tension” or both flanges using three different diameters of holes “10.4+2mm clearance at A10, 19.9+2mm clearance at A20 and 29.6+2mm clearance at A30”for beams having holes in mid-span under the two-concentrated loading type.

5. Conclusion.

1- An analytical model using ANSYS software was presented a reliable prediction of the failure load and deflection and can capture the failure modes.

2- The reduction in load capacity of non-compact section specimens is about 13% with respect to the compact case, while this reduction for slender section is by 33% with respect to the compact case either for beam with hole in flange at top, bottom or both flanges. The slightly effect of section compactness in deflection is slightly (about 3-10% when compared non-compact or slender sections with respect to compact section case) for beam with hole in flange at top, bottom or both flanges.

3- Increasing the hole diameter led to reduction in load capacity and deflection of the beam for beam with hole in flange at top, bottom or both flanges and in all compactness cases with different ratios when compared with solid beam specimen.

4- For sections with different compactness cases, with increasing the hole diameter; the load and deflection reductions in case of hole in compression are approximate similar to case of hole in tension flange. But, the load and deflection reductions in case of hole in either compression or tension flange is less than the beams with holes in both flanges.

5- The effect of increasing hole diameter in reducing the load carrying capacity of beam in cases of compact, non-compact and slender section is slightly different. This means that the increasing hole diameter has the same effect in reducing the load carrying capacity although the compactness condition of beam sections.

6- The effect of increasing hole diameter in beam deflection reduction in case of compact in more remarkable than in the case of non-compact section and this reduction in case of non-compact section is more than the case of slender section.

7- The reduction in load capacity of beam with hole either in tension flange or compression flange is similar for compact, non-compact and slender sections.

8- The reduction in load capacity of beam with hole in both flanges is approximate twice that in beams with hole in one flange for compact, non-compact and slender sections. The deflection reduction due to hole in both flanges in beams with compact, non-compact and slender sections is more than the beams with holes in one flange.

9- The deflection reduction in compact section beams with hole either in tension flange or compression flange is similar. While the reduction for beams with hole in tension flange is more than beams with hole in compression flange for both non-compact and slender sections.

10- The deflection reduction due to hole in flange is remarkable in compact section more than non-compact and the non-compact section is more than slender section either hole in one flange or both.

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