Evaluation of the amount of flexural buckling load of the cross-section stiffened with delta sheet beam using ANSYS software

Bahador Marghoub[1], Hasan Ghasemzadeh[2], Siamak Bodaghpour[3]

1- PhD student of geotechnics at KNTU university of technology,
2- Professor in the Department of Civil Engineering at K. N. Toosi University of Technology.
3- Professor in the Department of Civil Engineering at K. N. Toosi University of Technology.

Abstract

The performance of beams causes that the energy received by other structural members is reduced and as a result, they do not undergo much deformation. The reason for this is the strength created in the wing and beam due to their location. On the other hand, the property of increasing resistance against the loads caused by buckling, which causes local destruction in the beam-column, is one of the most desirable features of delta beams, which, in this way, reduces the damage caused by seismic loads in the structures. , minimizes Based on this, the purpose of the current research is to evaluate the amount of bending buckling load of the stiffened section with delta sheet beam. In this research, using the numerical calculations and modeling done in ANSYS software, along with the influence of the cross-section geometrical characteristics on the resistance of sheet beams, to the changes in the height of the sheet beams using MA and moment-moment change charts of longitudinal and delta stiffeners. and then by using elastic and non-linear buckling analysis and economic (flexural strength index) and technical (optimal dimensions of delta and plain beam) analyzes and according to the findings obtained from the analyzes Flexural buckling of delta sheet beam and its comparison with simple sheet beam is discussed. In places where the use of long beams is used and it seems necessary, the use of sheet beams is recommended, because, in cases where the length exceeds five to six meters, the increase in length has a special effect on the critical buckling moment. It will not have; So that its effect can be ignored.

Keywords: flexural, buckling, stiffened, delta, beam, ANSYS

1.Introduction

Depending on the place where they are used, the beams are affected by different loads, which are concentrated, uniformly wide, non-uniformly wide (linear) or a combination of them. On the other hand, thick sheets cannot be made into a profile shape by forming. In such cases, the wing and wing sheets are cut in the desired widths and connected to each other by welding to obtain the desired profile. Such periods are called Tiruq. The amount resulting from the pressure and tension of the horizontal and vertical strands of the beams due to the flexural buckling of the parts, causes many local failures in the structures, which, as the name implies, causes hardship by using stiffening parts or the sheet beams themselves. And the wings are in the beams and columns.

In fact, when a member is placed between two points of the opening, the incoming loads are transferred to the supports through the mechanism of tension and pressure in the horizontal threads of the member. This phenomenon is called bending and it plays an essential role in the load bearing of structural members. Each beam can be assumed to consist of wires parallel to the longitudinal axis of the beam, which are also placed on top of each other in height. The observation of the decrease in the distance of the vertical lines at the top and its increase at the bottom shows that the upper wires are shorter. And the lower strings become longer. while the middle thread remains the same size as before. In this way, it can be said; During bending, when the shape of the beam changes downwards, the upper strands are under pressure and the lower strands are under tension. On the other hand, due to the widespread use of sheet girder in various structures and its special benefits compared to common profiles, it is necessary to have a complete understanding of the behavior of sheet girder. Considering the failure mode of buckling in the sheets, including the sheets in the beam, it is necessary to take measures in this regard. Delta hardeners are used with this approach. Sheet beams are bending members that are made from a suitable combination of steel sheets. In cases where the existing rolled profiles are not able to withstand the loads on the bending member, the use of beams made of sheets (sheet beams) will be inevitable. If the amount of bending moment is so much that the rolled profiles cannot respond to the forces and bending moments, then sheet beams should be used. Of course, there are other methods that are not often used. While complying with the principles and rules of design of these types of beams, by using steel sheets, beams can be designed and implemented as bending members, which, in addition to having proper and optimal performance against incoming loads, are also economical compared to beams with rolled profiles. to be more economical. Girders are widely used as the main members in the construction of bridges and overpasses with relatively large spans, the main carriers of normal building structures with large spans, and the frames of industrial structures. Since 1950, with the expansion of the welding industry, the use of sheet beams to cover openings larger than 15 meters has been welcomed by engineers and designers [1].

The main girder consists of two wing sheets and one girder sheet, which are welded to each other in a suitable way to prepare an I-shaped section. The use of steel sheets with different yield stress in the cross-section and along the length of the beam opening provides the possibility for the designer to design sections with high bending capacity in places of the beam that experience a large bending moment. Sheet beams can be designed and implemented as simple two-headed, all-over on several simple supports, and also as a member of a steel bending frame. Usually, the cross-sections of beams in general beams and also in industrial frames are designed and implemented in a variable manner to optimize its load in front of bending anchors. Basically, the beam of I-shaped sheets for beams with a span between 20 and 50 meters has a suitable and economical performance. In some cases, especially in the implementation of spans above 15 meters, longitudinal stiffeners are placed in the compression area of the sheet to deal with the moment, and transverse stiffeners are basically considered to increase the shear buckling resistance. Sheet beams reinforced by longitudinal stiffeners are often used in bridges to cope with very high bending forces. Now, if the longitudinal stiffener is connected diagonally from the web to the wing, the resulting sheet girder is called a delta girder [2]. But due to the lack of technical knowledge about this type of sheet beam, it is necessary to make the sheet beam technically desirable by finding the appropriate geometrical characteristics of the delta stiffener. In 2015, Khalkifard et al. compared the buckling load of delta sheet beam with sheet beam without stiffener and with longitudinal stiffener by numerical method. In his research, he stated that, based on previous studies, the optimal section in the delta sheet beam is the section where the connection point of the stiffeners on the web should be 20% of the height of the web from the compression wing; In this study, the buckling resistance of the optimal cross-section of the delta sheet beam was investigated and compared with the sheet beam without stiffener and with longitudinal stiffener. By modeling the delta sheet beam, sheet beam without stiffener and sheet beam with longitudinal stiffener in ANSYS finite element software, the results of this research showed that the use of delta stiffener, a relatively high increase in the buckling resistance of the section, when under The effect of pure bending is located, compared to the cross-section without stiffener and also the cross-section reinforced with stiffener creates longitudinal [3]. In 2014, Nizami et al. investigated numerically the effect of local loading on steel beams with delta stiffener. In this research, beams strengthened by delta stiffener under concentrated or local loads without eccentricity have been investigated. The mentioned study was evaluated by means of numerical simulation of the problem with Abaqus 13.1 finite element analysis software, and the result showed favorable compatibility compared to the existing laboratory results [4]. Therefore, according to what was said; In this study, the amount of flexural buckling load of the stiffened section with delta sheet beam has been evaluated using ANSYS software.

2. The importance and necessity of conducting research

The performance of beams causes that the energy received by other structural members is reduced and as a result, they do not undergo much deformation. The reason for this is the strength created in the wing and beam due to their location. On the other hand, the property of increasing the resistance against the loads caused by buckling, which causes local destruction in the beam-column, is one of the very desirable features of delta beams, which, in this way, reduces the damage caused by seismic loads in the structure. It minimizes. So; Considering the seismicity of many areas and localized destructions that are applied to structures against loads caused by lateral buckling, the necessity of conducting such research in order to increase the resistance of structures against incoming loads and their strength is completely obvious and obvious.

3. Sheet beam

Beams are bending members that are made from a suitable combination of steel sheets. In cases where the existing rolled profiles are not able to withstand the loads on the bending member, the use of beams made of sheet (beams) will be unavoidable. If the amount of bending moment is so much that the rolled profiles cannot respond to the forces and bending moments, then sheet beams should be used. Of course, there are other methods that are not often used. While complying with the principles and rules of design of these types of beams, by using steel sheets, beams can be designed and implemented as bending members, which, in addition to having proper and optimal performance against incoming loads, are also economical compared to beams with rolled profiles. to be more economical. Sheet beams are widely used as the main members in the construction of bridges and overpasses with relatively large spans, the main carriers of normal building structures with large spans, and the frames of industrial structures [5].

4. The principles and generalities of sheet beam design

The increase in span length as well as the applied loads on structural systems such as bridges and all types of residential and industrial buildings forces designers to use other bending members such as beams and truss systems or to strengthen the existing rolled profiles. . Boosting profiles is a good solution, but it is limited. Because there is often a need for a cross-section with a higher load-bearing capacity, and in this case, the ease of construction and the development of welding technologies and connection defects in truss systems, and the ability to use composite systems with concrete slabs or decks, as well as the lower height of the cross-section compared to the system Others lead engineers to use beams [6].

In fact, since 1950, with the expansion of the welding industry, the use of sheet beams to cover openings larger than 15 meters has been welcomed by engineers and designers. The main girder consists of two wing sheets and one girder sheet, which are welded to each other in a suitable way to prepare an I-shaped section. The use of steel sheets with different yield stress in the cross-section and along the length of the beam opening provides the possibility for the designer to design sections with high bending capacity in places of the beam that experience a large bending moment [7].

If the ratio of the free height of the beam to the thickness of the beam is greater than $\frac{6370}{\sqrt{F_b}}$ (about 170), it is called a sheet beam.

$$\frac{h}{t_w} > \frac{6370}{\sqrt{F_b}}$$

$\frac{h}{t_w}$ should not exceed 340, so if $170 < \frac{h}{t_w} < 340$, it is called a sheet beam.

5. Flexural buckling in delta beams

As stated before; The increase in span length as well as the applied loads on structural systems such as bridges and types of residential and industrial buildings forces the designers to use other bending members such as beams and truss systems or to strengthen the existing rolled profiles. . There is another type in which two slanted sheets are used to increase torsional strength, which is called a delta sheet beam. The cross section of a delta sheet beam is shown below.

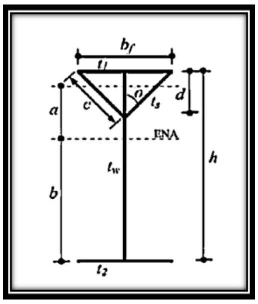


Figure 1 - Delta sheet beam section

I-shaped beams under bending have more hardness and resistance around their main axis than the minor axis. If these members are not properly restrained against lateral and torsional deformations, they will undergo lateral-torsional buckling before reaching their in-plane capacity. Torsional lateral buckling is a structural performance limit state in which before beam failure due to large deformations and yielding, the deformations of the beam change from a mostly planar state to a combination of lateral and torsional deformations [8]. .

The AISC regulation [2] considers the pure bending mode as the basic mode in calculating the buckling moment of beams, because buckling under pure bending is the most critical mode and its calculation is also easier. The buckling moment value of a simple I beam under pure bending is calculated from the following equation [3]:

$$M_{ocr} = \frac{\pi}{L}\sqrt{EI_y GJ}\sqrt{(1+W^2)} \qquad (1)$$

$$W = \frac{\pi}{L}\sqrt{\frac{EC_W}{GJ}} \qquad (2)$$

L: is the unrestrained length. Of course, in practical conditions, beams are subjected to different loadings and consequently non-uniform bending moments along their length. In such a situation, the differential equation governing the buckling behavior of the beam will have non-linear coefficients for which no exact analytical solution has been provided. It is possible to solve such equations and calculate critical loads by numerical methods. The effect of changes in bending moment on frictional moment can be easily applied by considering the uniform moment coefficient equal to Cb. In this case, the nominal anchor of the beam is obtained from the following relationship [9]:

$$M_n = c_b M_{ocr} \qquad (3)$$

AISC has considered the value of the coefficient Cb as a constant value for all non-elastic beams with different slenderness. In the AISC-LRFD code, depending on the beam loading conditions, different values for Cb coefficients are provided. For example, the value of this coefficient of widespread and concentrated loads applied in the center of the beams is equal to 1.13 and 1.35, respectively [3]. In general, beams show buckling behavior in three areas:

1. Plunge behavior where the length of the beam is short enough so that the entire cross-section yields before any buckling occurs.
2. Inelastic buckling in which parts of the beam become unstable after yielding.
3. Resilient buckling that occurs in long unbraced beams.

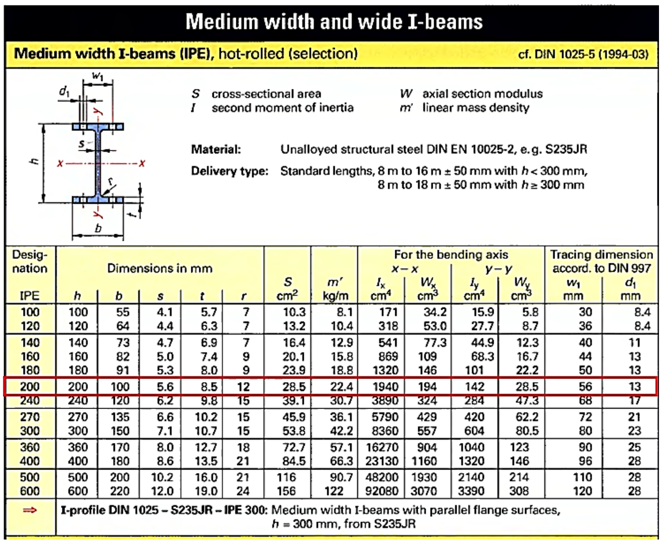
In order to study the flexural buckling behavior of delta sheet beams, laboratory models have been made by Hadley. Other researchers such as Arabzadeh and Kaheh, Arabzadeh and Wormziari, Mohebkhah and Gerjii have investigated this problem using the finite element method. In this research, regarding the evaluation of the bending buckling of the beam of delta sheets with compressed web using ANSYS software, to analyze the nonlinear buckling of the beam of delta sheets with non-compressed and thin web, it was first modeled and then using relations and analysis The relevant studies have been investigated and determined for bending buckling in delta sheet beams.

6. Research method

The method of conducting this study is applied-analytical. In this research, using the numerical calculations and modeling done in ANSYS software, along with the influence of the cross-section geometrical characteristics on the resistance of sheet beams, to the changes in the height of the sheet beams using MA and moment-moment change charts of longitudinal and delta stiffeners. and then using elastic and non-linear buckling analysis and according to the findings obtained from the analysis, the flexural buckling of delta sheet beams and its comparison with simple sheet beams has been investigated.

7. Flexural buckling in the presence and absence of delta beam

To investigate and simulate this report, one of the common beams used in construction and industrial structures was used. The selected beam is considered to be IPE200 beam. Then, in the presence and absence of the delta beam, simulations have been carried out.



Medium width and wide I-beams

Medium width I-beams (IPE), hot-rolled (selection) cf. DIN 1025-5 (1994-03)

S cross-sectional area
I second moment of inertia
W axial section modulus
m' linear mass density

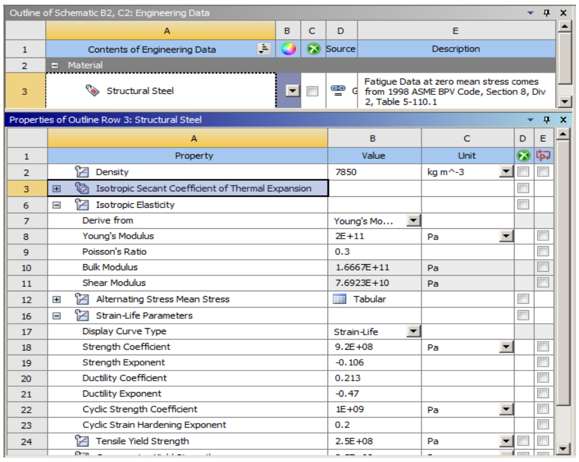
Material: Unalloyed structural steel DIN EN 10025-2, e.g. S235JR

Delivery type: Standard lengths, 8 m to 16 m ± 50 mm with $h < 300$ mm,
8 m to 18 m ± 50 mm with $h \geq 300$ mm

Designation	Dimensions in mm							For the bending axis				Tracing dimension accord. to DIN 997	
								$x-x$		$y-y$			
IPE	h	b	s	t	r	S cm^2	m' kg/m	I_x cm^4	W_x cm^3	I_y cm^4	W_y cm^3	w_1 mm	d_1 mm
100	100	55	4.1	5.7	7	10.3	8.1	171	34.2	15.9	5.8	30	8.4
120	120	64	4.4	6.3	7	13.2	10.4	318	53.0	27.7	8.7	36	8.4
140	140	73	4.7	6.9	7	16.4	12.9	541	77.3	44.9	12.3	40	11
160	160	82	5.0	7.4	9	20.1	15.8	869	109	68.3	16.7	44	13
180	180	91	5.3	8.0	9	23.9	18.8	1320	146	101	22.2	50	13
200	200	100	5.6	8.5	12	28.5	22.4	1940	194	142	28.5	56	13
240	240	120	6.2	9.8	15	39.1	30.7	3890	324	284	47.3	68	17
270	270	135	6.6	10.2	15	45.9	36.1	5790	429	420	62.2	72	21
300	300	150	7.1	10.7	15	53.8	42.2	8360	557	604	80.5	80	23
360	360	170	8.0	12.7	18	72.7	57.1	16270	904	1040	123	90	25
400	400	180	8.6	13.5	21	84.5	66.3	23130	1160	1320	146	96	28
500	500	200	10.2	16.0	21	116	90.7	48200	1930	2140	214	110	28
600	600	220	12.0	19.0	24	156	122	92080	3070	3390	308	120	28

⇒ **I-profile DIN 1025 – S235JR – IPE 300:** Medium width I-beams with parallel flange surfaces,
$h = 300$ mm, from S235JR

Figure 2- Specifications of IPE beam according to the standard of engineering design book



Outline of Schematic B2, C2: Engineering Data

	A	B	C	D	E
1	Contents of Engineering Data			Source	Description
2	⊟ Material				
3	Structural Steel		☐		Fatigue Data at zero mean stress comes from 1998 ASME BPV Code, Section 8, Div 2, Table 5-110.1

Properties of Outline Row 3: Structural Steel

	A	B	C	D	E
1	Property	Value	Unit		
2	Density	7850	kg m^-3	☐	☐
3	⊞ Isotropic Secant Coefficient of Thermal Expansion			☐	
6	⊟ Isotropic Elasticity			☐	
7	Derive from	Young's Mo...			
8	Young's Modulus	2E+11	Pa		☐
9	Poisson's Ratio	0.3			☐
10	Bulk Modulus	1.6667E+11	Pa		☐
11	Shear Modulus	7.6923E+10	Pa		☐
12	⊞ Alternating Stress Mean Stress	Tabular		☐	
16	⊟ Strain-Life Parameters			☐	
17	Display Curve Type	Strain-Life			
18	Strength Coefficient	9.2E+08	Pa		☐
19	Strength Exponent	-0.106			☐
20	Ductility Coefficient	0.213			☐
21	Ductility Exponent	-0.47			☐
22	Cyclic Strength Coefficient	1E+09	Pa		☐
23	Cyclic Strain Hardening Exponent	0.2			☐
24	Tensile Yield Strength	2.5E+08	Pa	☐	☐

Figure 3-Specifications of structural steel in Ansys software

After determining the type and properties of the material, it is time to model the beam. Beam modeling is placed in the Geometry module of the Ansys Workbench software. The modeled beam without delta sheet is shown in the figure below.

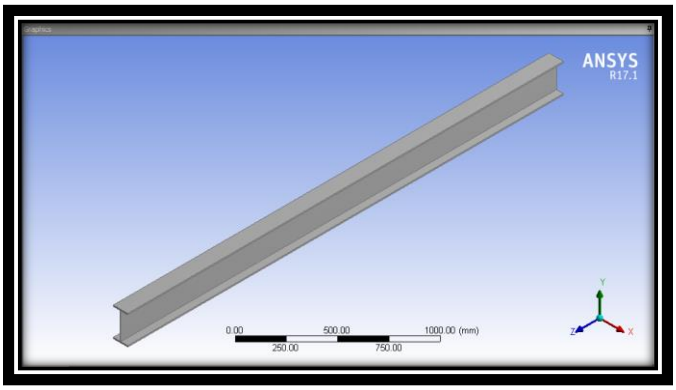


Figure 4- Modeled beam without delta sheet in ANSYS software

As it is clear in the figure, the specifications of the delta sheet beam including the horizontal distance and the vertical distance and its thickness have been determined as a parameter so that its values can be changed and checked.

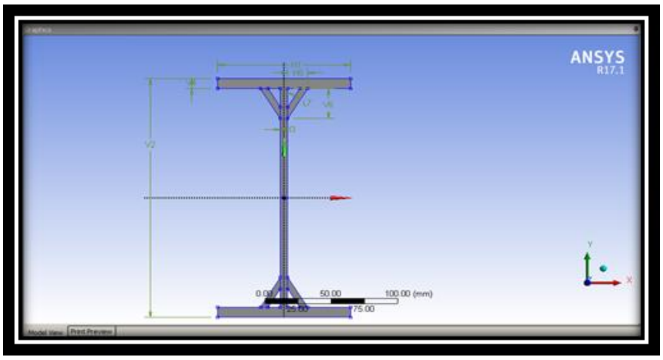


Figure 5- Beam cross-section of the delta sheet beam model along with parametric specifications

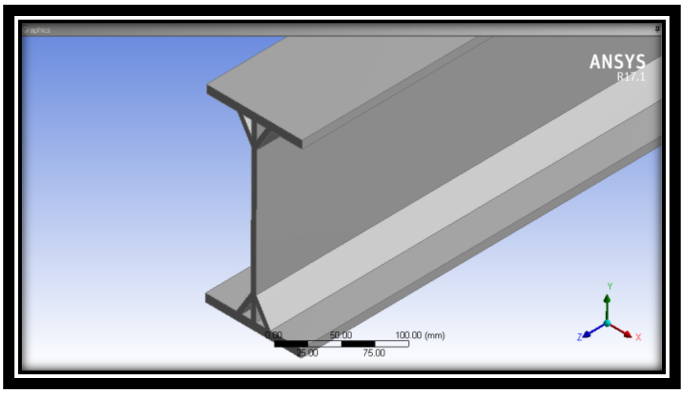
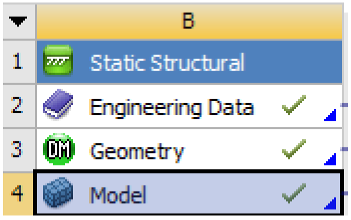


Figure 6- Delta sheet beam model in 3D

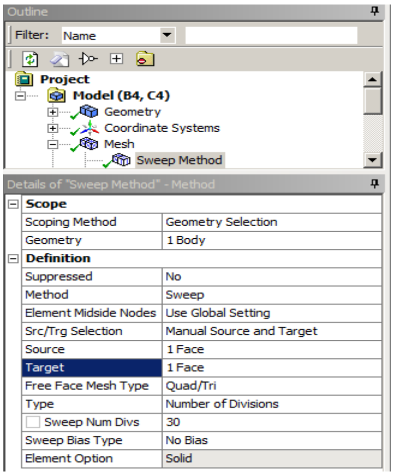
After modeling the structure, it is time to analyze the finite element of the structure. This analysis is done in the Model module.



	B
1	Static Structural
2	Engineering Data ✓
3	Geometry ✓
4	Model ✓

Figure 7- Analysis in the Model module

After modeling, it is time to mesh the structure. It is better to perform sweep type meshing. In the sweep, the source and target are specified and meshing is done between these two desired settings. Since it is a beam, the source and target must be the beginning and the end of it, and the necessary number of divisions must be done between these two. Figure (4-7) shows the sweep mesh settings. The number of divisions between the beginning and the end is set to 30. These divisions can be made smaller, which makes the meshing smaller.



Project
- Model (B4, C4)
  - Geometry
  - Coordinate Systems
  - Mesh
    - Sweep Method

Details of "Sweep Method" - Method

Scope	
Scoping Method	Geometry Selection
Geometry	1 Body
Definition	
Suppressed	No
Method	Sweep
Element Midside Nodes	Use Global Setting
Src/Trg Selection	Manual Source and Target
Source	1 Face
Target	1 Face
Free Face Mesh Type	Quad/Tri
Type	Number of Divisions
☐ Sweep Num Divs	30
Sweep Bias Type	No Bias
Element Option	Solid

Figure 8- Settings related to sweep meshing

After specifying the mesh settings, meshing is done using the Generate mesh option. Beam meshing with delta sheet beam and without delta sheet beam is given below.

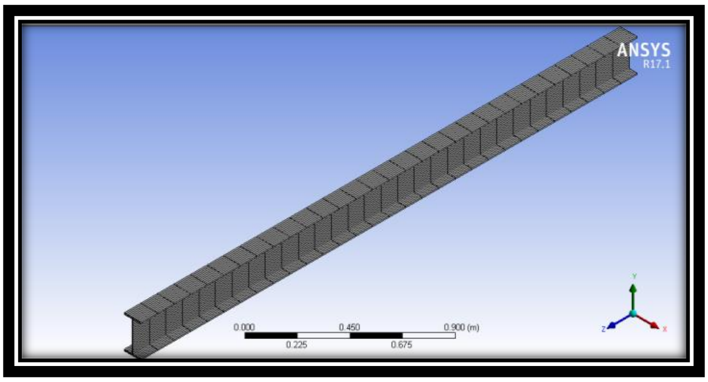


Figure 9- Beam meshing with delta sheet beam and without delta sheet beam

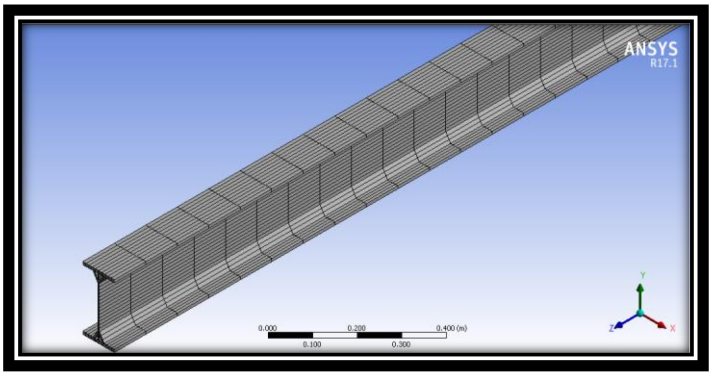
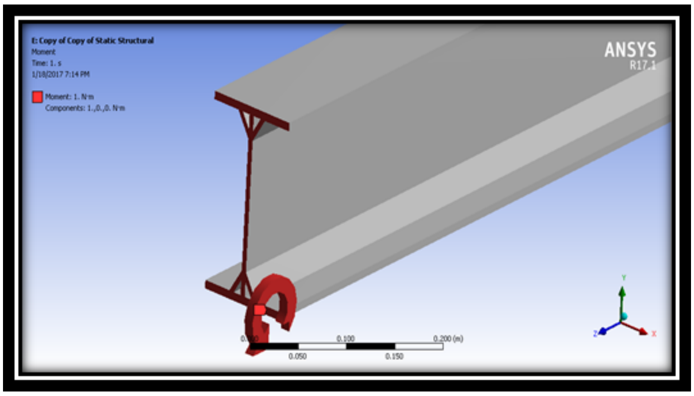


Figure 10- Beam meshing with delta sheet beam and without delta sheet beam

After meshing, it is time to apply support and loading conditions. The only noteworthy point is that when applying force, a bending moment of 1 unit should be considered. In the analysis of buckling issues in Ansys software, whether the analysis is of the buckling load or buckling moment type, a static analysis with a single load must be done first. Then buckling analysis is done. Therefore, the unit load bending moment should be applied. In the following, the applied bending moment is shown as a unit load.


E: Copy of Copy of Static Structural
Moment
Time: 1. s
1/18/2017 7:14 PM

🟥 Moment: 1. N·m
Components: 1.,0.,0. N·m

Figure 11- Bending moment applied as unit load in Ensys software

Static structural module was used up to this point. In this section, the Eigen value buckling module should also be added and all the required values from the static module should be dragged to it. The final shape is as follows.

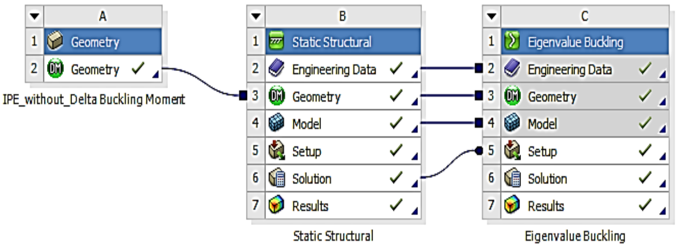
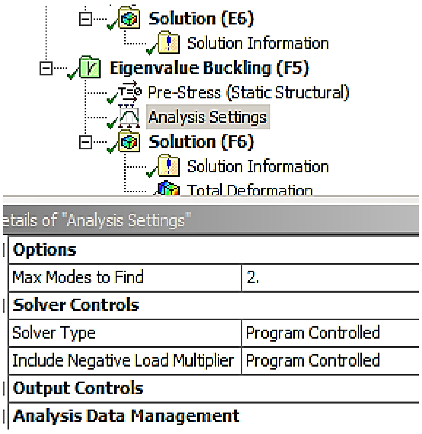


Figure 12- Adding the Eigen value buckling module

Finally, it is the turn of the problem solving settings, for buckling, the number of buckling modes should be specified. Since the aim is to find the buckling moment, the first mode is sufficient, but in this research, two modes were used. In order to obtain the information of other modes, the problem is set based on the first mode.

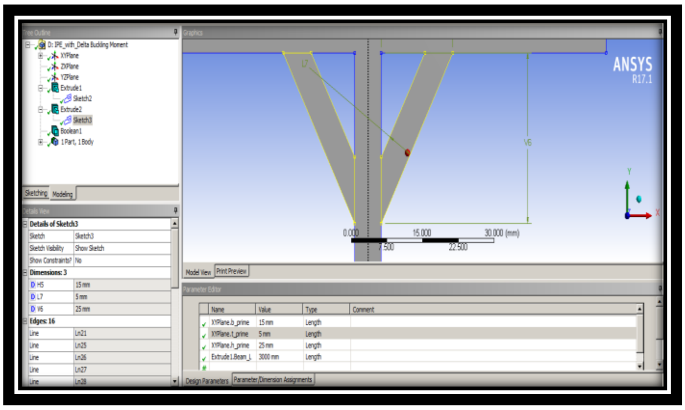


etails of "Analysis Settings"

Options	
Max Modes to Find	2.
Solver Controls	
Solver Type	Program Controlled
Include Negative Load Multiplier	Program Controlled
Output Controls	
Analysis Data Management	

Figure 13- Setting the first mode to analyze beam buckling

After making these settings, it's time to check parameters. The parameters that are going to be changed, just tick the empty square next to them. For example, in the sheet beam problem, horizontal distance, vertical distance, beam thickness, and beam length are considered as parameters.

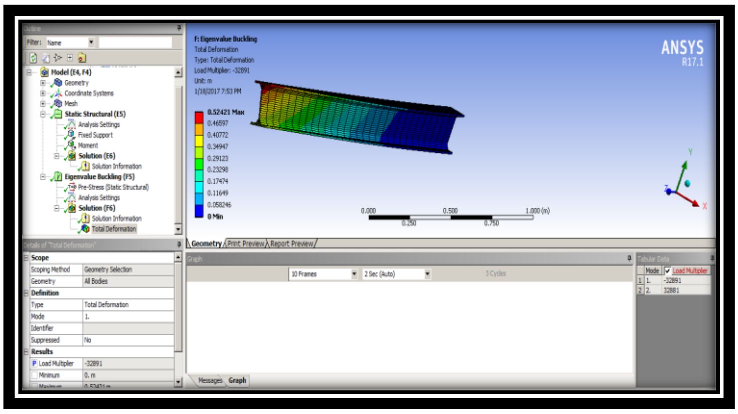


Details of Sketch3	
Sketch	Sketch3
Sketch Visibility	Show Sketch
Show Constraints?	No
Dimensions: 3	
D H5	15 mm
D L7	5 mm
D V6	25 mm
Edges: 16	
Line	Ln21
Line	Ln25
Line	Ln26
Line	Ln27
Line	Ln28

	Name	Value	Type	Comment
✓	XYPlane.b_prime	15 mm	Length	
✓	XYPlane.t_prime	5 mm	Length	
✓	XYPlane.h_prime	25 mm	Length	
✓	Extrude1.Beam_L	3000 mm	Length	

Figure 14- Parametric check settings of the designed beams

Also, the desired outputs, such as buckling load, etc., will be displayed as parameters by activating the option next to the parameter. Before solving the problem, in the Solution section, the output of the system should be set to Deformation, and in its settings, its value should be set to the first model. Then he activated the option next to the load multiplier parameter, which indicates the critical load.



F: Eigenvalue Buckling
Total Deformation
Type: Total Deformation
Load Multiplier: -32891
Unit: m
1/18/2017 7:53 PM

Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	1.
Identifier	
Suppressed	No
Results	
Load Multiplier	-32891
Minimum	0. m
Maximum	0.52421 m

	Mode	☑ Load Multiplier
1	1.	-32891
2	2.	32881

Figure 15- Critical load in a specific state

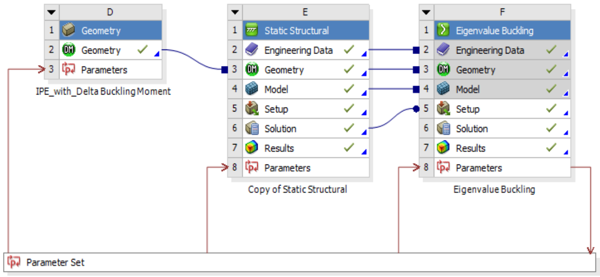
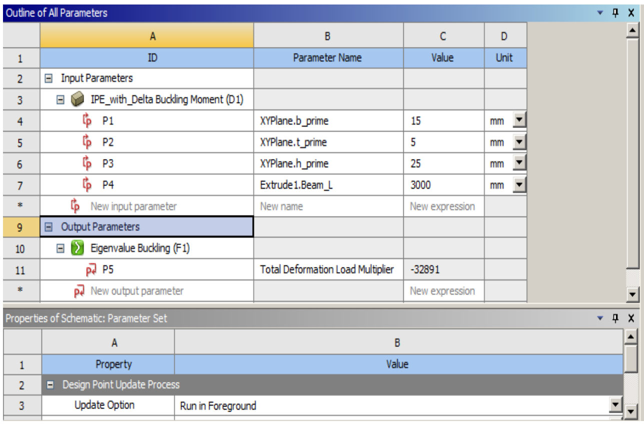


Figure 16- Final model setting steps

And the parameters include four geometrical parameters, including the horizontal and vertical distance and the thickness of the delta beam, as well as the beam length and the output parameter of the critical buckling moment. All the parameters are shown in the figure below.



Outline of All Parameters

	A	B	C	D
1	ID	Parameter Name	Value	Unit
2	Input Parameters			
3	IPE_with_Delta Buckling Moment (D1)			
4	P1	XYPlane.b_prime	15	mm
5	P2	XYPlane.t_prime	5	mm
6	P3	XYPlane.h_prime	25	mm
7	P4	Extrude1.Beam_L	3000	mm
*	New input parameter	New name	New expression	
9	Output Parameters			
10	Eigenvalue Buckling (F1)			
11	P5	Total Deformation Load Multiplier	-32891	
*	New output parameter		New expression	

Properties of Schematic: Parameter Set

	A	B
1	Property	Value
2	Design Point Update Process	
3	Update Option	Run in Foreground

Table 1- Geometrical parameter including horizontal and vertical distance and delta beam thickness and beam length

After specifying each parameter, arbitrary values will be given to check the changes. In the figure below, different values are given to the parameters, and in each case, the problem is run and its output, which is the critical buckling moment, is taken. Finally, after solving the problem for different design points, it is in the form of the following table.

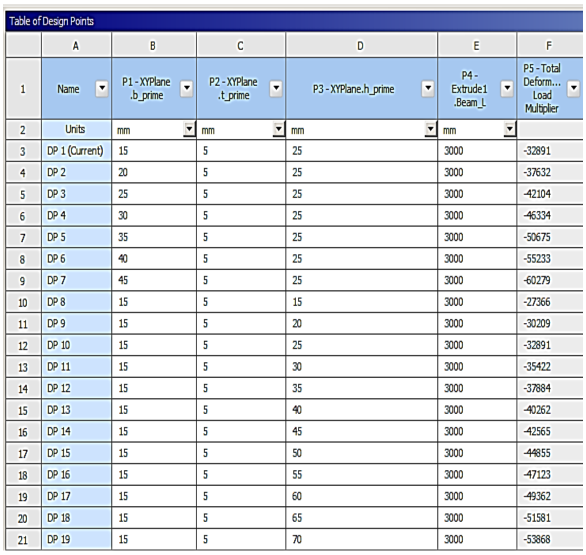


Table of Design Points

	A	B	C	D	E	F
1	Name	P1 - XYPlane .b_prime	P2 - XYPlane .t_prime	P3 - XYPlane.h_prime	P4 - Extrude1 .Beam_L	P5 - Total Deform... Load Multiplier
2	Units	mm	mm	mm	mm	
3	DP 1 (Current)	15	5	25	3000	-32891
4	DP 2	20	5	25	3000	-37632
5	DP 3	25	5	25	3000	-42104
6	DP 4	30	5	25	3000	-46334
7	DP 5	35	5	25	3000	-50675
8	DP 6	40	5	25	3000	-55233
9	DP 7	45	5	25	3000	-60279
10	DP 8	15	5	15	3000	-27366
11	DP 9	15	5	20	3000	-30209
12	DP 10	15	5	25	3000	-32891
13	DP 11	15	5	30	3000	-35422
14	DP 12	15	5	35	3000	-37884
15	DP 13	15	5	40	3000	-40262
16	DP 14	15	5	45	3000	-42565
17	DP 15	15	5	50	3000	-44855
18	DP 16	15	5	55	3000	-47123
19	DP 17	15	5	60	3000	-49362
20	DP 18	15	5	65	3000	-51581
21	DP 19	15	5	70	3000	-53868

Table 2-Critical buckling moment values for different design points

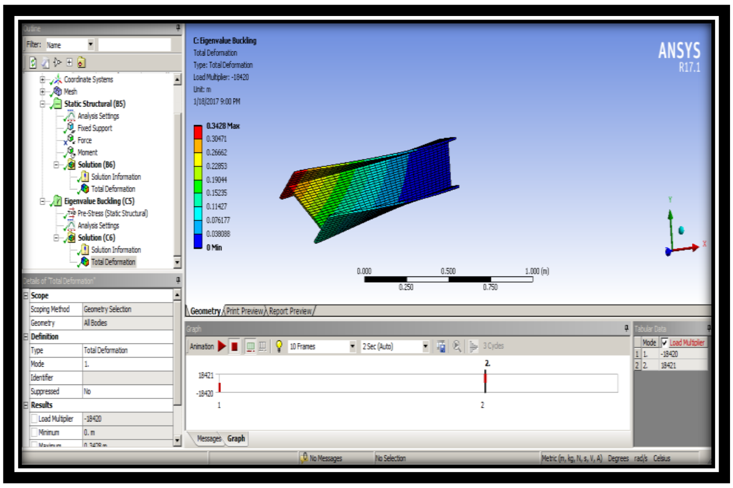
8.Research findings

The comparison of the critical bending moment in the presence and absence of the sheet beam with the specifications is presented in the following table:

Table 3- Comparison of the critical bending moment in the presence and absence of sheet beam with specifications

	پارامترها(mm)	بار بحرانی
تیر معمولیIPE 200	L=3000	18420
تیر با ورق دلتا	L=3000	32891
	b=15	
	H=25	
	T=5	

In the following, the deformation of the beam under the critical bending moment is shown in the case of a simple beam and a delta beam.



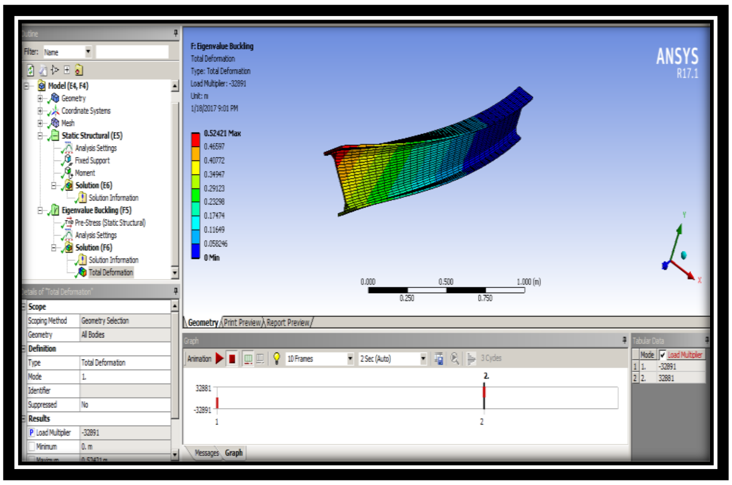
C: Eigenvalue Buckling
Total Deformation
Type: Total Deformation
Load Multiplier: -18420
Unit: m
1/18/2017 9:00 PM

Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	1.
Identifier	
Suppressed	No
Results	
Load Multiplier	-18420
Minimum	0. m

	Mode	☑ Load Multiplier
1	1.	-18420
2	2.	18421

Figure 19- Deformation of the beam under the critical bending moment in the case of a simple beam



F: Eigenvalue Buckling
Total Deformation
Type: Total Deformation
Load Multiplier: -32891
Unit: m
1/18/2017 9:01 PM

Details of "Total Deformation"

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Type	Total Deformation
Mode	1.
Identifier	
Suppressed	No
Results	
P Load Multiplier	-32891
Minimum	0. m

	Mode	☑ Load Multiplier
1	1.	-32891
2	2.	32881

Figure 20- Deformation of the beam under the critical bending moment in the case of the delta beam

As shown in the results. In the presence of delta sheet beam, the buckling moment has increased significantly. Of course, it should be noted that optimization has not been done yet. And this difference can be much more than this.

Investigating the changes of the critical buckling moment with the increase of the distance between the sheet beam and the girder b:

The diagram below shows the effects of the distance between the beam and the beam. The greater the distance between the beam and the beam, the critical moment increases.

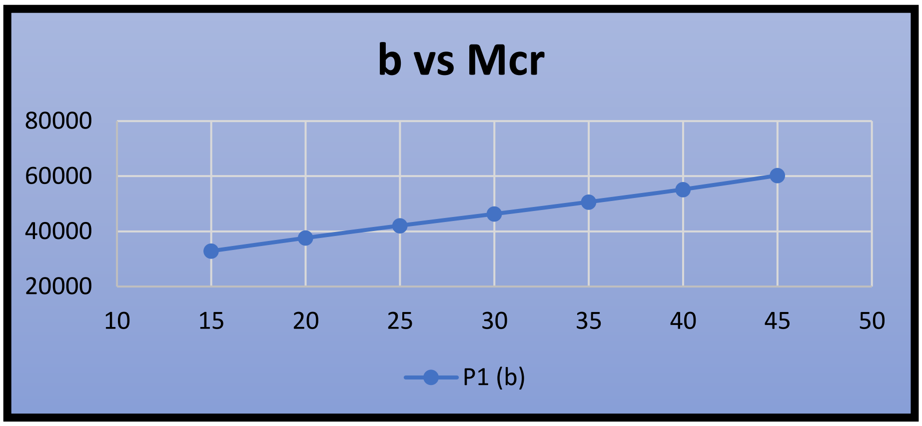


Diagram 1-Diagram of examining the changes of critical buckling moment with increasing distance of sheet beam from beam web

9.Examining the changes of the critical buckling moment by increasing the distance between the sheet beam and the beam h:'

As can be seen, the critical load value increases with the increase of the distance between the sheet beam and the wing of the beam.

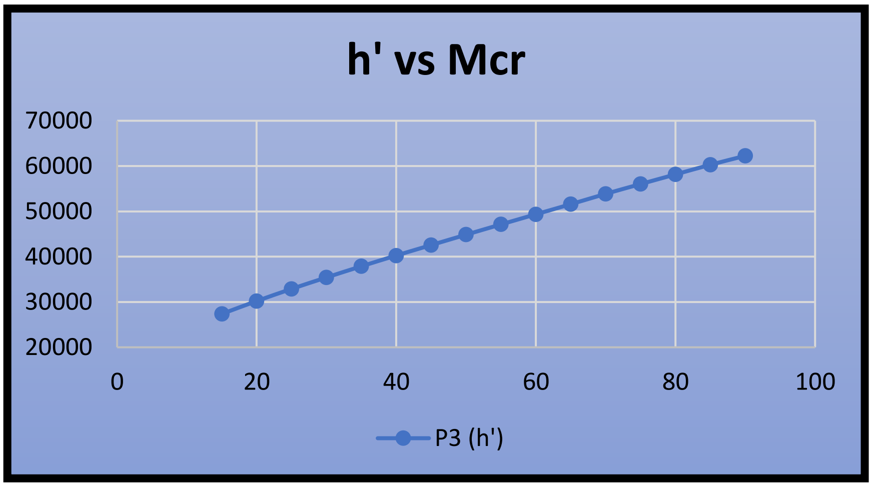


Diagram 2- Examining the changes of the critical buckling moment by increasing the distance of the sheet beam from the beam wing

10. Examining the changes of the critical buckling moment with the increase in the thickness of the plate girder:

As shown in the figure, the value of the critical moment increases with the increase in the thickness of the sheet beam. But this trend is not linear and it shows that when the thickness of the sheet beam reaches 9 mm or more, this value becomes fixed. So it can be concluded that increasing the thickness affects the amount of buckling moment to a certain extent.

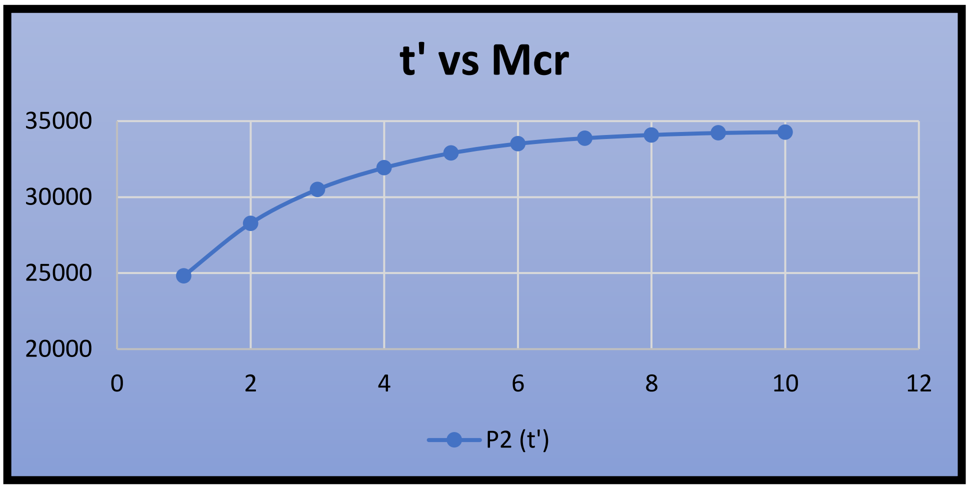


Diagram 3- Examining the changes of the critical buckling moment with the increase in the thickness of the plate girder

Examining the changes of the critical buckling moment with increasing beam length:

As can be seen, the critical buckling moment decreases with increasing beam length. But this process is also not linear and it shows that when the length of the beam exceeds a certain limit, the effect of the length on the critical load is reduced.

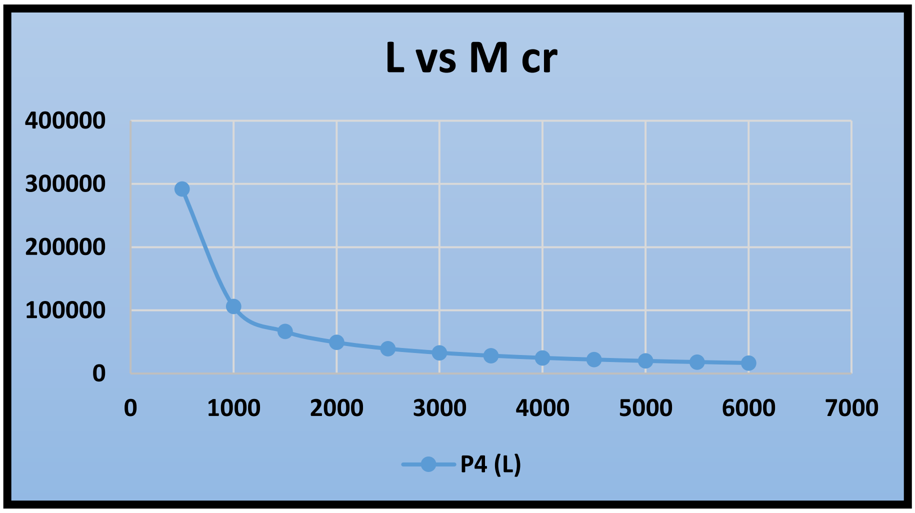


Diagram 4- Examining the changes of the critical buckling moment with increasing beam length

11.Optimization of sheet beam dimensions

The dimensions of sheet girder have been analyzed in Ensys software for 45 different points, based on which it can be checked that for the design of sheet girder, the distance to the girder and also the distance to the wing of the girder should be increased as much as possible. But its thickness is sufficient up to about 8 mm and after that it does not affect the critical load. Also, in places where the use of long beams is used and it seems necessary, the use of sheet beams is recommended, because, in cases where the length increases from five to six meters, the increase in length affects the critical buckling moment. It will not be special; So that its effect can be ignored.

Table 4- Optimization of sheet beam dimensions

Name	**t'**	**b'**	**h'**	**L**	**Mcr**
DP 1	5	15	25	3000	32890.9
DP 2	5	20	25	3000	37632.01
DP 3	5	25	25	3000	42104.27
DP 4	5	30	25	3000	46334.41
DP 5	5	35	25	3000	50675.44
DP 6	5	40	25	3000	55232.76
DP 7	5	45	25	3000	60279.32
DP 8	5	15	15	3000	27365.53
DP 9	5	15	20	3000	30208.77
DP 10	5	15	25	3000	32890.9
DP 11	5	15	30	3000	35421.86
DP 12	5	15	35	3000	37884.24
DP 13	5	15	40	3000	40262.16
DP 14	5	15	45	3000	42565.28
DP 15	5	15	50	3000	44854.75
DP 16	5	15	55	3000	47123
DP 17	5	15	60	3000	49361.63
DP 18	5	15	65	3000	51581.36
DP 19	5	15	70	3000	53867.72
DP 20	5	15	75	3000	56028.76
DP 21	5	15	80	3000	58159.48
DP 22	5	15	85	3000	60287.17
DP 23	5	15	90	3000	62255.73
DP 24	1	15	25	3000	24825.02
DP 25	2	15	25	3000	28278.32
DP 26	3	15	25	3000	30504.32
DP 27	4	15	25	3000	31926.59
DP 28	5	15	25	3000	32890.9
DP 29	6	15	25	3000	33509.39
DP 30	7	15	25	3000	33871.99
DP 31	8	15	25	3000	34086.19
DP 32	9	15	25	3000	34217.44

Name	t'	b'	h'	L	Mcr
DP 33	10	15	25	3000	34274.75
DP 34	5	15	25	500	292134.2
DP 35	5	15	25	1000	106139.8
DP 36	5	15	25	1500	66470.15
DP 37	5	15	25	2000	49229.56
DP 38	5	15	25	2500	39361.39
DP 39	5	15	25	3000	32890.9
DP 40	5	15	25	3500	28287.15
DP 41	5	15	25	4000	24833.11
DP 42	5	15	25	4500	22147.66
DP 43	5	15	25	5000	19990.5

12.Results

In this research, based on what was mentioned, the buckling of delta beams has been investigated. After designing the beams using ANSYS software, the findings were analyzed, according to the assumptions, the results of this research indicated that;

1) In the presence of delta sheet beam, the buckling moment has increased significantly.

2)The greater the distance between the beam and the beam, the critical moment increases.

3)By increasing the distance between the sheet beam and the wing of the beam, the amount of critical load increases.

4) As the thickness of the sheet beam increases, the critical moment value increases. But this trend is not linear and it shows that when the thickness of the sheet beam reaches 9 mm or more, this value is fixed. It can be concluded that increasing the thickness affects the amount of buckling moment to a certain extent. This indicates that the efficiency due to the addition of delta hardener in the sheet beam is related to the thickness of the hardener.

5)As the beam length increases, the critical buckling moment decreases. But this trend is not linear and it shows that when the length of the beam exceeds a certain limit, the effect of the length on the critical load is very low. This indicates that the addition of the delta plate beam increases the buckling strength of the panel stiffened with the longitudinal plate beam.

6) For the design of the sheet beam, the distance to the beam web and also the distance to the wing of the beam should be increased as much as possible. But its thickness is sufficient up to about 8 mm and after that it does not affect the critical load. This indicates that the efficiency due to the addition of delta hardener in the sheet beam is related to the thickness and life. In other words, the performance of the delta sheet beam is related to its placement angle.

7) In places where the use of long beams is used and it seems necessary, the use of sheet beams is recommended, because, in cases where the length increases from five to six meters, the increase in length will exceed the critical buckling moment. It will not have a special effect; So that its effect can be ignored.

8) In general, the addition of delta stiffener in a normal situation due to the optimization of beam dimensions can be very effective in increasing the buckling load.

References:

1- Bakker, M.C.M, Rosmanit, M and Hofmeyer, H, Prediction of the elasto-plastic post-buckling strength of uniformly compressed plates from the fictitious elastic strain at failure, Thin-Walled Structures, Volume 47, Issue 1, January 2009, Pages 1-13.

2- Danielsonand, D. A., Wilmer, A., Buckling of stiffened plates with bulb flat flanges, International Journal of Solids and Structures, Volume 41, Issues 22-23, November 2004, Pages 6407-6427.

3- Khalki Fard, Mehrdad; Respected, Hassan. (2015). Comparison of buckling load of delta plate beam with plate beam without stiffener and with longitudinal stiffener by numerical method. International Conference on Urban Engineering, Civil, Architecture, ID (COI) Article: ICOA01_096.

4- Nizami, Mohammad. Shah Ali, Maitham; (2014), "Numerical investigation of the effect of local loading on steel beams with delta stiffener". The third national conference of new findings in civil engineering.

5- Baker, M. "LRFD Design Example for steel girder superstructures bridge", FHWA/ National highway institute, Washington DC, 2021.

6- Shakri, Mahmoud; Bigelow, Akbar Ali. (2014) Mechanical structures (beams, sheets and shells), Amirkabir University and Industrial Jihad publisher. second edition. P. 317.

7- McCormack, (2021). Design of steel structures, Iranian translator, Fereydoun. Second edition. P. 451.

8- C. M. Wang, Y. Chen and Y. Xiang, Plastic buckling of rectangular plates subjected to intermediate and end in-plane loads, International Journal of Solids and Structures, Volume 41, Issues 16-17, August 2004, Pages 4279-4297

9- Jazayeri, Sayde Pegah; Lover, Amin. (2014), "Bending capacity of delta sheet beams". The second international conference on civil engineering, architecture and urban economic development.