

Comparative Study of Cellular and Hexagonal Castellated Beam Under the Effect of Lateral Distortional Buckling

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Abstract

The study investigates the comparative behavior of cellular and hexagonal castellated beams under the effect of lateral-distortional buckling (LDB) using finite element modeling (ABAQUS) and experimental validation. The structural engineering market extensively uses lightweight castellated beams because they maximize material efficiency. Openings within the web of these beams create buckling issues because of their reduced stiffness characteristics. The examination of LDB resistance between cellular and hexagonal castellated beams from past research has not been studied directly. Research fills this knowledge gap through an evaluation of web opening geometry effects on beam stability as well as stress distribution and failure mechanisms. Logical frameworks within FEA operate by running models of different configurations that account for residual stresses and geometric imperfections and material properties. The numerical results are validated through experimental testing on manufactured specimens. The analysis shows cellular beams perform better in stress distribution and stress concentration reduction which increases their resistance against LDB while hexagonal beams maintain superior load-supporting capacity but show stress concentrations. The paper examines the effects of beam opening size together with their spacing variations on LDB resistance to stress points because proper beam geometry matters. The research adds to the development of design standards for castellated beams by assisting engineers with selecting structural designs that improve stability and reduce costs while being material-efficient. The analysis requires more research to develop hybrid beam structures and AI optimization systems which can optimize performance under challenging loading scenarios.

Keywords: Castellated beams, Cellular beams, Hexagonal beams, Lateral-distortional buckling (LDB), Finite Element Analysis (FEA).

1. Introduction

Professional construction today depends heavily on castellated beams especially cellular and hexagonal configurations which solve the industry requirements for lightweight high-strength cost-effective structural elements. Fabrication of castellated beams starts by re-welding steel I-sections following cutting to create web openings that both boost structural efficiency and minimize material requirement. These beams exhibit structural behavior strongly affected by lateral-distortional buckling (LDB) because it determines the maximum load and overall stability of the beams. [1], [2]. The comparative study of cellular and hexagonal castellated beams under LDB effects is critical for optimizing their design and performance in various structural applications.

1.1 Background on Castellated Beams

The first production of Castellated beams achieved dual functionality of enhanced loading capacity with reduced steel requirements making them preferable to regular I-beams. [1]. Early studies focused on different failure modes such as shear buckling, flexural failure, and web post-buckling [2],[3] and [4]. The author stresses how web stability and buckling behavior function alongside web openings to determine strength characteristics and failure modes. Strong demand exists for castellated beams since they serve in bridges along with buildings and industrial structures and their scope of application has grown through technical improvements in structural analysis [5][6].

Two primary configurations of castellated beams exist:

Cellular Beams: Circular web openings on these beams enhance both distribution of load and buckling resistance.[7]. The circular openings enhance the beam's stiffness, making them preferable in applications where aesthetic considerations and vibration resistance are crucial [8] [9].

Hexagonal Beams: Hexagonally shaped web spaces make up these beams since their simple fabrication method enhances both shear resistance and allows straightforward manufacturing. Stress concentration and web instability happens more frequently in this design when compared to cellular beams[10][11][12].

The buckling resistance of cellular beams exceeds that of hexagonal beams but hexagonal beams demonstrate superior material efficiency for structural applications. [13][14].

1.2 Lateral Distortional Buckling in Castellated Beams

The major mode of instability for castellated beams during bending can be described as lateral-distortional buckling (LDB). Cross-sections affected by LDB experience simultaneous lateral displacement and distortion which results in major reduction of beam load-bearing capability.[15], [16][17].Several factors influence LDB behavior, including:

- The circular shape and dimensions of web openings (cellular beams) result in uniform stress distribution but hexagonal openings with sharp corners tend to increase the probability of LDB. [18][19].
- Beam slenderness ratio: Beams with high slenderness ratios are more prone to LDB, necessitating additional stiffening measures [20].
- The LDB resistance of castellated beams experiences significant effects from residual stresses which arise from welding processes mainly in thin-walled sections. [21].

[22]and [23] Researchers used Finite Element Modeling techniques to study castellated beam LDB stability but found design provisions need improvement for predicting their behavior accurately.

2. Influence of Residual Stresses and Web Buckling on LDB

Residual stresses from welding during beam fabrication contribute to distortional instability. [24]demonstrated that the study proved that remaining stresses modify LDB characteristics which changes the collapsing process and weakens the final strength of castellated beams. Web post-buckling together with local distortions intensify the effects of lack of ductility so predictive models need to be developed precisely. [8], [25].

2.1 Numerical and Experimental Approaches to LDB Analysis

Several analytical and numerical methods have been employed to assess LDB in castellated beams:

- Finite Element Analysis (FEA): [7] and [26] Production research used FEA to simulate nonlinear responses experienced by castellated beams subjected to combined buckling modes. Research practitioners used their findings to demonstrate that including material inelasticity and geometric faults enhances the accuracy of LDB calculations.
- Artificial Neural Networks (ANN): [25] The study employed ANN models to calculate the lateral torsional buckling strength of castellated beams which showed its possible use for reliable strength calculations.
- Empirical Models and Regression Analysis: [10] developed used experimental formulas for estimating the LDB capacity of castellated beams. Additional improvements to these models are necessary for delivering more precise predictions in various beam configurations [27].

2.2 Research Gap and Significance of Study

Limited Comparative Studies on Lateral Distortional Buckling (LDB) in Cellular and Hexagonal Beams:

A limited number of researchers have investigated castellated beam behavior but no direct research exists on comparing cellular and hexagonal beams under LDB conditions. Through the ABAQUS parametric study researchers will obtain valuable information about the relative performance of cellular and hexagonal beams.

Inadequate Experimental Validation for LDB Analysis:

Research in this field heavily depends on computer modeling though it fails to achieve proper experimental validation of its simulation output. The correct prediction of LDB demands experimental testing be applied to finite element results to verify their accuracy.

Optimization of Web Opening Size for LDB Resistance:

The analysis of web configurations has been conducted previously yet an established guideline for determining minimum LDB effects through optimal web sizes remains absent. A research is underway to identify which web opening dimensions create the best results for cellular and hexagonal beams.

4. Effect of Residual Stresses on LDB Behavior:

Current numerical models analyzing stability of castellated beams need to conduct a more comprehensive evaluation of residual stresses because these effects strongly affect system outcomes. The current assessment method needs improvement in order to increase design accuracy.

2.3 Objectives

The primary objective of this study is to compare the lateral-distortional buckling behavior of cellular and hexagonal castellated beams under different loading and boundary conditions. The specific aims include:

To carry out parametric study of cellular beam and hexagonal beam using (ABAQUS) finite element software.

To validate analytical results obtained from software with the experimentation.

To determine optimum size of cellular beam and hexagonal in respect of lateral distortional buckling.

The structural advantages of castellated beams include cellular and hexagonal variants. Design methodologies of these structures require improvement because they remain vulnerable to LDB performance issues. This research analyzes LDB behavior in these two beam types to offer important findings for optimized design protocols in practical projects.

3. Analysis, Fabrication And Experimentation of CSBS

Introduction

The analysis of CSBs appears with circular and hexagonal forms together with the study of openings without stiffeners is presented in this chapter. The research team tested CSBs that lacked stiffeners and validated the software results through these experimental trials.

Selection of Parent Steel I-Beam

The selection of the steel I-beam dimensions along with span length took into account both limitations of UTM testing for longer specimens as well as market availability of steel sections. The entire steel I-beam underwent selection based on dimensions of 150 mm x 50 mm x 5 mm (tw, tf) x 1000 mm. The yield point of 250 MPa together with elastic modulus of 200 GPa defines the properties of the selected steel section.

Parameters Considered

This research utilizes parameters collected from existing literature for conducting the behavioral study of CSB.

Table No. 1 Various Parameters for Study of CSB

Analysis of CSBs

The following section shows the analysis results for CSBs regarding stresses, deflections, and load-carrying capacities when web openings have hexagonal or circular or web shapes.

Analysis with Circular Openings

The CSB provided with circular openings achieved values for Von Mises stress, deflection and LCC measurement at 496.38 N/mm², 2.32 mm, and 58.193 N. Figure 1 displays visualization elements that present Von Mises stresses and deflection values

(a) Von Mises stresses (b) Deflections

Figure 1 (a and b) Visualization modules for CSB with circular opening

Analysis of CSB with Hexagonal Openings

The analysis indicates that the CSB with hexagonal openings reaches 411.69 N/mm² Von Mises stress, 2.14 mm deflection, and provides 59.758 N LCC. The visual presentation from Figure 2 provides observations of both deflection data and Von Mises stress data.

(a) Von Mises stresses (b) Deflections

Figure 2 (a and b) Visualization modules for CSB with hexagonal opening

Fabrication (castellation) Process of CSB with Circular and Hexagonal openings

The fabrication or castellation process of parent steel I-beam involving various steps is explained as given below:

I) Preparation of the '.dxf' file in AutoCAD for Circular openings

A zig-zag cut profile was designed in AutoCAD software by implementing the parameters Do and S and e to create circular-shaped web openings. The prepared cut profile in the AutoCAD exists as a '.dwg' drawing file that requires transformation into a '.dxf' format to enable it as an input for the CNC plasma machine which will cut the parent steel I-beam based on the specified profile cut. The Figure 3 depicts the steel I-beam containing required zig-zag cutting profile.

Figure 3. Circular Openings

Figure 4. Cut profile Circular Openings

II) Preparation of the '.dxf' file in AutoCAD for Hexagonal openings

A zig-zag cut profile was designed in AutoCAD software by implementing the parameters Do and S and e to create hexagon-shaped web openings. The prepared cut profile in the AutoCAD exists as a '.dwg' drawing file that requires transformation into a '.dxf' format to enable it as an input for the CNC plasma machine which will cut the parent steel I-beam based on the specified profile cut. The Figure 5 depicts the steel I-beam containing required zig-zag cutting profile.

Figure 5. Parent steel I-beam with cut profile Hexagonal opening

Figure 6. Hexagonal opening

III) Cutting process of the parent steel I-beam

The ".dxf" file transferred to the plasma CNC machine to perform the castellation process by zig-zag cutting of the parent steel I-beam into separate pieces as shown in Figure 7.

Figure 7. Cutting using CNC plasma machine

IV) Separation and grinding

The steel I-beam received its initial processing through CNC operation for division into two sections according to the zig-zag pattern. Subsequently the two pieces received grinding treatment for achieving flat and smooth borders Shifting and welding process.

The steel I-beam was aligned through opposite movement of its cut sections until it formed a deep beam with hexagonal web opening shape. The weld technicians combined the newly formed section through the welding procedure as illustrated in Figure 8.

Figure 8. Final CSB specimen after welding

Experimental Validation of Software Results for CSB

The results from ABAQUS programming verification occurred through laboratory experimentation of the CSB test specimen. The required setup for testing CSB was ready along with its schematic diagram appearing in Figure 9

Load

250 mm Loading beam

CSB

Support

1000 mm

Dial gauge

Figure 9. The schematic diagram of the test setup

Table No.2 Design Details

4. RESULT AND DISCUSSION

Introduction

The results from ABAQUS software analysis regarding LCC along with deflection levels of CSBs containing Plain, circular and hexagonal openings without stiffeners are presented in this chapter under two-point loading conditions. The analysis results for CSBs being researched have allowed for an effective identification of the most efficient CSB type.

Analytical Results for CSBs

The Research results from ABAQUS indicate that the deflections and carrying capacities from CSB perforations with Plain versus circular versus hexagonal openings demonstrate the following data in Table

Table. No 3. Analytical Results (ABAQUS)

4.3 Cellular Results

Table. No 4. Experimental Results Cellular

4.4 Hexagonal Results

Table. No 5. Experimental Results Hexagonal

Experimental Results for CSBs

The experimental outcomes from the deflections and load-bearing capabilities of CSB Plain along with circular and hexagonal-shaped openings appear in the provided table.

Table. No 6. Experimental Results

Table. No 7 Detailed Results

Fig. No10. Experimental Results for CS

CONCLUSION

The report explores the structural behavior of castellated and cellular beams, with a focus on their lateral distortional buckling (LDB), stress distribution, and deflection characteristics under loading conditions. The findings emphasize the advantages of these beams, including increased load-carrying capacity, material optimization, and cost efficiency, particularly in large-span structures. It compares hexagonal and circular web openings in castellated beams, demonstrating the superior performance of hexagonal openings in terms of stress distribution and load capacity. Moreover, the study highlights the importance of finite element analysis (FEA) and experimental validation in optimizing these beams for practical applications. The results show that cellular beams generally offer better load resistance and stress distribution than hexagonal castellated beams, but both beam types exhibit significant susceptibility to lateral distortional buckling, especially under unbraced conditions. The research also explores the fabrication process, detailing the steps for cutting, grinding, and welding the parent steel I-beams to form the castellated shapes. Overall, the study provides a comprehensive understanding of beam behavior and offers design guidelines for enhanced stability and efficiency in real-world structural applications.

Based on the analysis, hexagonal castellated beams and cellular beams both have distinct advantages depending on the application, but here are the key points to determine which is better:

Load-Carrying Capacity (LCC):

Hexagonal Castellated Beams have a slightly higher load-carrying capacity than circular cellular beams in certain tests. The load capacity for hexagonal beams was recorded at 59.758 kN, compared to 58.193 kN for circular beams.

Cellular Beams (with circular openings) generally exhibit a more uniform stress distribution, improving their long-term structural stability.

Deflection:

Hexagonal Castellated Beams showed slightly lower deflections, indicating better stiffness. For example, at the maximum load, the deflection in hexagonal beams was 2.11 mm, compared to 2.32 mm in circular beams.

Deflection in cellular beams (circular) can be higher under similar load conditions, but they offer better stress distribution, reducing risks of localized failure.

Stress Distribution:

Cellular Beams (with circular openings) offer better stress distribution, reducing the chances of web post buckling and shear-related failures, as noted in the study.

Hexagonal Castellated Beams, while stronger, tend to have more stress concentration at the edges of the openings, which may require additional stiffening or reinforcement to avoid buckling.

Fabrication and Cost:

Hexagonal Castellated Beams are often easier to fabricate and can be cost-effective for larger-scale constructions. However, they require more precise handling during the welding process to avoid geometric imperfections that could lead to distortional buckling.

Cellular Beams (with circular openings) can be more complicated to fabricate but offer advantages when it comes to the integration of mechanical, electrical, and plumbing services due to the uniformity of the openings.

Hexagonal Castellated Beams are more suitable for applications requiring higher load-carrying capacity, but they may need additional reinforcement to prevent lateral distortional buckling.

Cellular Beams, on the other hand, excel in stress distribution and resilience against shear-related failures, making them ideal for applications where uniform load distribution and serviceability are prioritized.

If load capacity and minimized deflection are the primary concerns, hexagonal castellated beams may be the better choice. However, for designs where stress distribution and integration of MEP services are key considerations, cellular beams (with circular openings) would be a more favorable option.

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Web opening	D (mm)	Do (mm)	D/Do	S/Do	S (mm)	e (mm)	End post (mm)
Circular	150	110	1.36	1.4	148	42.5	75
Hexagonal	150	100	1.50	1.4	158	45.33	126

D	X	D0=D/X	e=0.4D O	D0/2	NO.	N	End post	1 End post	S	C/C DIST	0.5D0
130	1.2	108.33	43.33	54.17	6.59	6	133.33	66.67	151.67	151.67	54.17
140	1.2	116.67	46.67	58.33	6.12	5	230.00	115.00	163.33	163.33	58.33
150	1.2	125.00	50.00	62.50	5.71	5	175.00	87.50	175.00	175.00	62.50
160	1.2	133.33	53.33	66.67	5.36	4	306.67	153.33	186.67	186.67	66.67
170	1.2	141.67	56.67	70.83	5.04	4	263.33	131.67	198.33	198.33	70.83
130	1.3	100.00	40.00	50.00	7.14	6	200.00	100.00	140.00	140.00	50.00
140	1.3	107.69	43.08	53.85	6.63	6	138.46	69.23	150.77	150.77	53.85
150	1.3	115.38	46.15	57.69	6.19	5	238.46	119.23	161.54	161.54	57.69
160	1.3	123.08	49.23	61.54	5.80	5	187.69	93.85	172.31	172.31	61.54
170	1.3	130.77	52.31	65.38	5.46	5	136.92	68.46	183.08	183.08	65.38

D	X	D0=D/X	e=0.4D O	D0/2	NO.	N	End post	1 End post	S	C/C DIST	0.5D0
130	1.4	92.86	37.14	46.43	7.69	7	127.14	63.57	130.00	130.00	46.43
140	1.4	100.00	40.00	50.00	7.14	6	200.00	100.00	140.00	140.00	50.00
150	1.4	107.14	42.86	53.57	6.67	6	142.86	71.43	150.00	150.00	53.57
160	1.4	114.29	45.71	57.14	6.25	5	245.71	122.86	160.00	160.00	57.14
170	1.4	121.43	48.57	60.71	5.88	5	198.57	99.29	170.00	170.00	60.71
130	1.5	86.67	34.67	43.33	8.24	7	185.33	92.67	121.33	121.33	43.33
140	1.5	93.33	37.33	46.67	7.65	7	122.67	61.33	130.67	130.67	46.67
150	1.5	100.00	40.00	50.00	7.14	6	200.00	100.00	140.00	140.00	50.00
160	1.5	106.67	42.67	53.33	6.70	6	146.67	73.33	149.33	149.33	53.33
170	1.5	113.33	45.33	56.67	6.30	5	252.00	126.00	158.67	158.67	56.67
130	1.6	81.25	32.50	40.63	8.79	8	122.50	61.25	113.75	113.75	40.63
140	1.6	87.50	35.00	43.75	8.16	7	177.50	88.75	122.50	122.50	43.75
150	1.6	93.75	37.50	46.88	7.62	7	118.75	59.38	131.25	131.25	46.88
160	1.6	100.00	40.00	50.00	7.14	6	200.00	100.00	140.00	140.00	50.00
170	1.6	106.25	42.50	53.13	6.72	6	150.00	75.00	148.75	148.75	53.13

Shape of opening	Results	Analytical (ABAQUS)
Circular	Load carrying capacity (kN)	58.19
Circular	Deflection (mm)	2.32
Hexagonal	Load carrying capacity (kN)	59.78
Hexagonal	Deflection (mm)	2.11

D	X	D0=D/X	Eigen Value	Stress (N/mm ²)	Deflectio n (mm)	Deflectio n (mm)	Deflectio n (mm)	Deflectio n (mm)	Deflectio n (mm)	Deflectio n (mm)
			load (N)		Magnitut e	Magnitut e	Magnitut e	U1	U2	U3
					Left	Centre	Right			
130	1.2	108.33	48539	574.08	5.31	5.56	5.31	0.03	-0.39	-2.53
140	1.2	116.67	51494	580.64	3.63	4.33	3.63	0.05	-0.36	0.44
150	1.2	125.00	52363	838.49	4.26	4.57	4.26	0.08	-0.37	-0.90
160	1.2	133.33	55928	539.46	3.65	3.92	3.65	0.03	-0.32	1.33
170	1.2	141.67	57123	5340.31	37.78	40.22	31.78	0.31	-3.13	18.00
130	1.3	100.00	49714	482.59	3.51	3.82	3.51	0.02	-0.32	0.89
140	1.3	107.69	50782	484.20	3.73	3.97	3.73	0.02	-0.31	1.82
150	1.3	115.38	53751	746.07	2.93	3.49	2.93	0.04	-0.29	0.38
160	1.3	123.08	54923	730.67	4.86	5.00	4.86	0.04	-0.28	4.11
170	1.3	130.77	56004	708.05	3.27	3.48	3.27	0.04	-0.27	-1.03
130	1.4	92.86	49337	602.18	3.31	3.61	3.31	0.03	-0.30	0.84
140	1.4	100.00	51841	445.92	3.00	3.26	3.00	0.02	-0.27	0.84
150	1.4	107.14	52964	460.09	15.53	15.72	15.78	0.02	-0.26	15.75

D	X	D0=D/X	Eigen Value	Stress (N/mm2)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)
160	1.4	114.29	56013	560.99	2.89	2.82	2.59	0.03	-0.23	-0.04
170	1.4	121.43	57249	448.12	2.69	2.87	2.69	0.03	-0.22	-1.44
130	1.5	86.67	50233	559.57	14.11	14.04	13.97	0.03	-0.27	-13.28
140	1.5	93.33	51485	574.74	2.90	3.15	2.90	0.03	-0.26	-0.87
150	1.5	100.00	53961	460.81	2.52	2.91	2.71	0.02	0.23	1.25
160	1.5	106.67	55221	432.01	2.42	2.64	2.42	0.02	-0.22	0.12
170	1.5	113.33	58193	496.39	2.27	2.46	2.26	0.02	-0.21	0.46
130	1.6	81.25	50011	453.69	2.87	3.12	2.87	0.02	-0.26	0.36
140	1.6	87.50	52285	522.72	2.70	2.94	2.70	0.03	-0.24	-0.09
150	1.6	93.75	53523	482.17	2.51	2.74	2.51	0.02	-0.23	0.05
160	1.6	100.00	56005	444.34	2.28	2.48	2.28	0.02	-0.21	0.55
170	1.6	106.25	57963	401.71	2.013	2.19	2.01	0.02	-0.18	0.49

D	X	D0=D/X	Eigen Value	Stress (N/mm2)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)
			load (N)		Magnitude	Magnitude	Magnitude	U1	U2	U3
					Left	Centre	Right			
130	1.2	108.33	51307	428.58	2.52	2.74	2.52	16.77	-227.69	194.27
140	1.2	116.67	53850	441.85	2.54	2.70	2.54	17.47	-205.25	-739.39
150	1.2	125.00	55331	452.04	2.24	2.41	2.24	0.02	-0.19	-0.37
160	1.2	133.33	58048	409.79	1.99	2.16	1.99	0.02	-0.18	-0.14
170	1.2	141.67	59576	408.85	1.91	2.06	1.91	0.02	-0.17	-0.26
130	1.3	100.00	51881	435.07	2.45	2.66	2.45	0.02	-0.22	0.24
140	1.3	107.69	53409	406.91	2.25	2.46	2.25	0.02	-0.20	0.70
150	1.3	115.38	55977	435.35	2.13	2.30	2.13	0.02	-0.19	-0.25
160	1.3	123.08	57531	442.39	1.93	2.09	1.93	0.02	-0.17	0.55
170	1.3	130.77	59107	433.41	1.82	1.97	1.82	0.02	-0.16	0.45
130	1.4	92.86	51706	421.00	2.44	2.66	2.44	0.02	-0.22	0.82
140	1.4	100.00	53963	420.32	3.25	3.36	3.25	0.02	-0.20	2.74
150	1.4	107.14	55539	401.48	2.04	2.22	2.04	0.02	-0.18	0.68
160	1.4	114.29	58065	520.63	1.86	2.02	1.86	0.02	-0.17	0.16
170	1.4	121.43	59722	422.77	1.77	1.91	1.77	0.02	-0.16	0.38
130	1.5	86.67	52209	419.00	19.95	20.02	19.91	0.02	-0.22	-19.25
140	1.5	93.33	53767	415.18	2.18	2.37	2.18	0.02	-0.20	0.24
150	1.5	100.00	56015	402.84	2.25	2.39	2.25	0.02	-0.18	-0.67
160	1.5	106.67	57638	405.99	1.86	2.02	1.86	0.02	-0.17	0.24
170	1.5	113.33	59184	467.04	1.90	2.06	1.90	0.01	-0.18	0.49
130	1.6	81.25	52150	421.16	2.98	3.12	2.98	0.02	-0.22	2.14
140	1.6	87.50	54183	423.66	2.24	2.42	2.24	0.02	-0.20	-0.22

D	X	D0=D/X	Eigen Value	Stress (N/mm ²)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)	Deflection (mm)
150	1.6	93.75	55799	421.04	2.31	2.44	2.31	0.02	-0.18	-0.78
160	1.6	100.00	58095	401.29	1.84	1.99	1.84	0.02	-0.17	0.26
170	1.6	106.25	59758	411.69	2.11	2.22	2.11	0.02	-0.16	1.53

Shape of opening	Results	Experimental
Circular	Load carrying capacity (kN)	61
Circular	Deflection (mm)	2.2
Hexagonal	Load carrying capacity (kN)	66
Hexagonal	Deflection (mm)	2.02

Circular Castellated Beam	Circular Castellated Beam	Hexagonal Castellated Beam	Hexagonal Castellated Beam
Load (KN)	Deflection	Load (KN)	Deflection
5	0.3	5	0.39
10	0.5	10	0.55
15	0.61	15	0.69
20	0.79	20	0.78
25	0.95	25	0.91
30	1.1	30	1.04
35	1.27	35	1.15
40	1.42	40	1.38
45	1.59	45	1.52
50	1.77	50	1.63
55	1.95	55	1.79
60	2.2	60	1.88
61	Failure	65	2.04
		66	failure