ProtaStructure Design Guide

Castellated Beams

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Publisher

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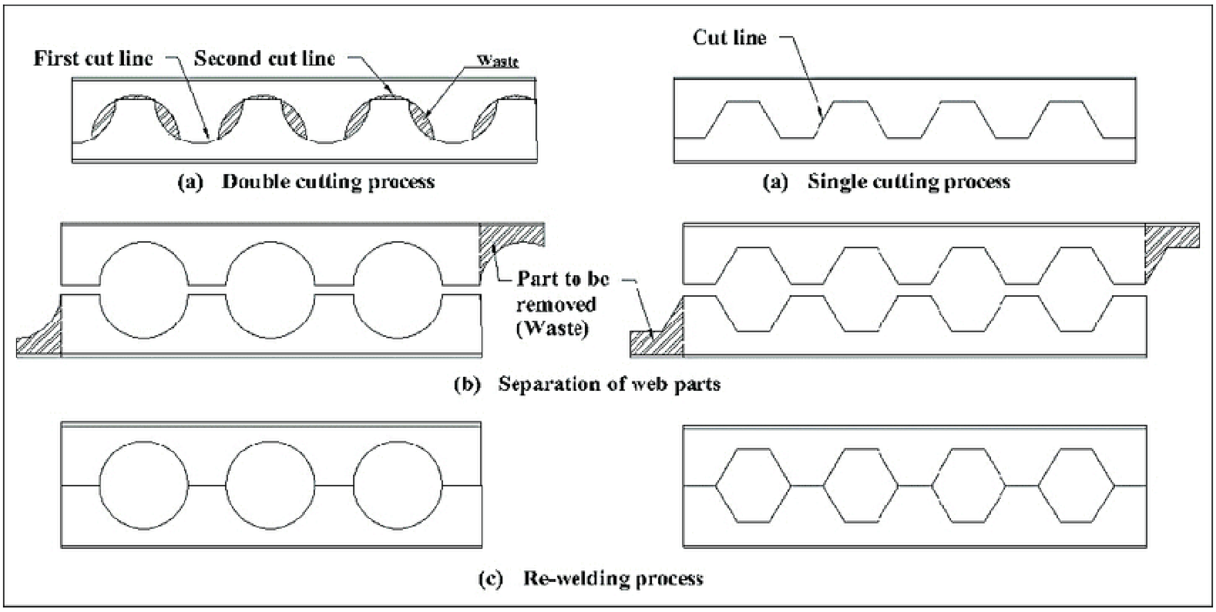
Castellated Beams

A castellated beam is created by slicing an I-beam longitudinally along its web in a specific pattern. The goal is to separate and then rejoin the beam with a deeper web. These beams are categorized based on the shape of the openings in the web section, with common shapes including hexagonal, circular (also known as cellular), octagonal, and diamond.

Castellated beams offer increased depth compared to the original section, while maintaining nearly the same weight. By welding square or rectangular plates between the cut halves, an even deeper castellated beam with octagonal holes can be formed. The key advantage of castellated beams is their ability to increase depth without adding weight, making them highly efficient for enhancing load-bearing capacity. They provide greater moment-carrying capacity without additional steel.

Additionally, castellated beams are useful in situations with height limitations. The openings in the beam web allow for easy passage of piping. However, these benefits come with trade-offs. The web openings introduce additional failure mechanisms, necessitating checks such as Vierendeel, horizontal shear, vertical shear and web post shear buckling. Furthermore, the section properties used in finite element analysis differ from those of conventional solid beams.

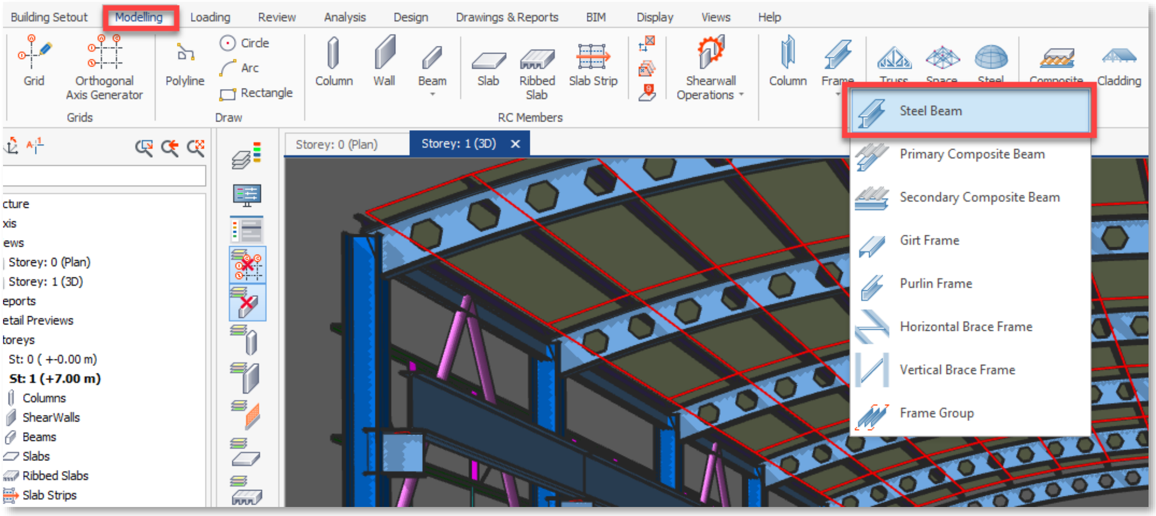


ProtaStructure 2025 now allows you to model, analyze and design castellated steel beams.

Inserting a Castellated Beam

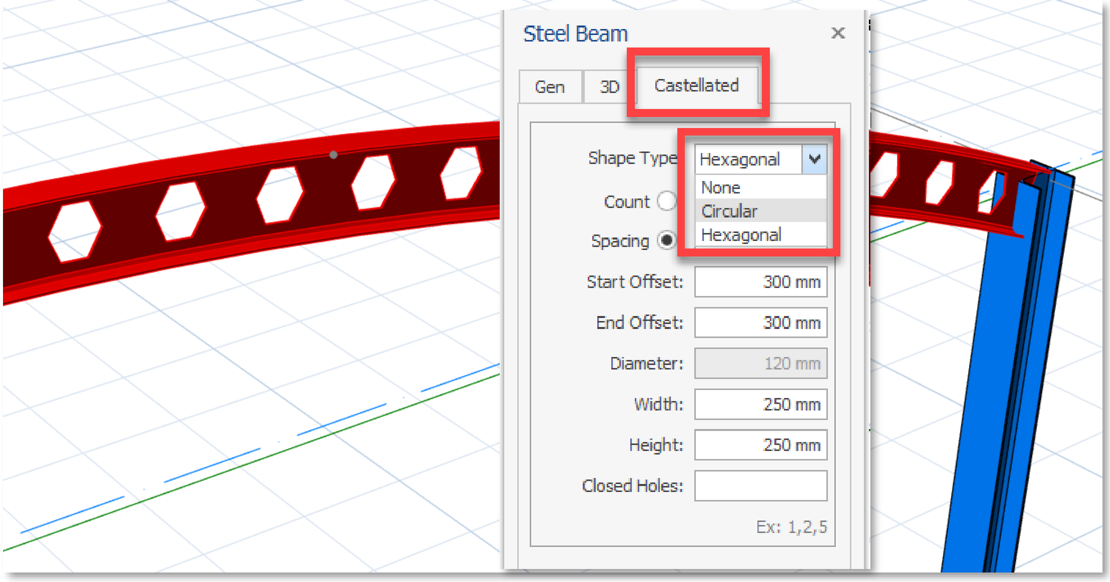
To insert a castellated steel beam:

1. Pick the Steel Beam command on the **Modeling > Frame** ribbon tab.



2. Insert a **linear** or **curved** frame member as usual.

3. On the **Frame Properties** window, switch to **Castellated** tab.



Shape Type: Hexagonal

○ Count

● Spacing

Start Offset: 300 mm

End Offset: 300 mm

Diameter: 120 mm

Width: 250 mm

Height: 250 mm

Closed Holes:

4. You can select a **Hexagonal** or **Circular** Opening.

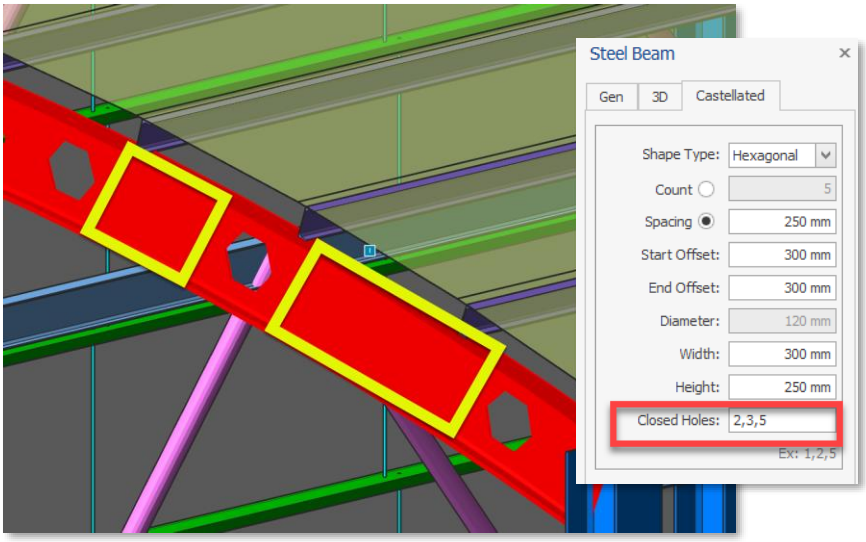
The code design formulations are given for circular (cellular) and hexagonal openings, that's why the rectangular openings are not supported.

5. Place the openings by specifying their **Count** or clear **Spacing**. You can also specify **Start Offset** and **End Offset**.

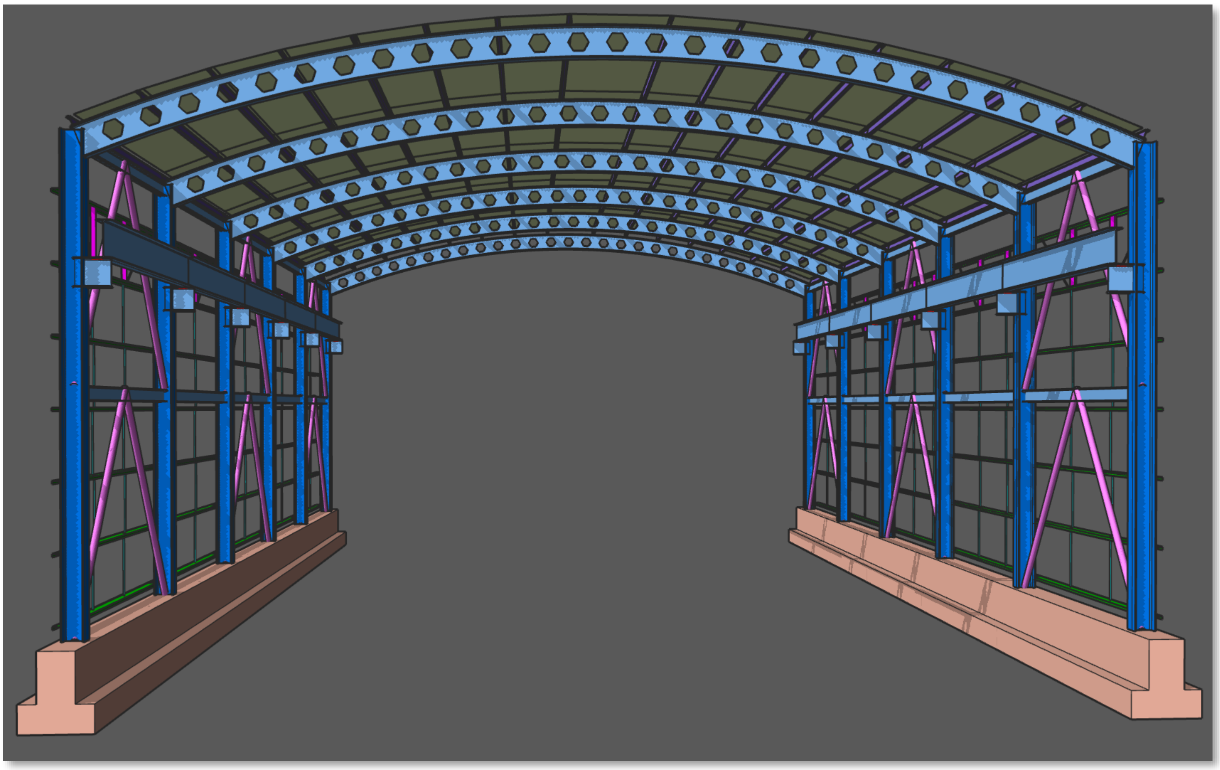
6. Also specify the dimensions of the web openings using the **Width**, **Height** or **Diameter** fields.

Important:
While inserting the castellated steel frame member, choose a **hot-rolled profile** or **built-up profile** that will have the final profile depth. In other words, if the final profile will have 460 mm depth after slicing and welding, you must choose, for example, a W18x46 hot-rolled profile, instead of the original profile before the cut.

7. You may want to infill some of the openings, in this case specify the number of openings to be infilled in respective order. For example, if you want to infill second, third and fifth opening you can enter **2, 3, 5** in the **Closed Holes** field. This does not have any effect on analysis or design. It can be used for detailing purposes.



Shape Type: Hexagonal
Count ○ 5
Spacing ● 250 mm
Start Offset: 300 mm
End Offset: 300 mm
Diameter: 120 mm
Width: 300 mm
Height: 250 mm
Closed Holes: 2,3,5
Ex: 1,2,5



Design of Non-Composite Castellated Beams

Due to the presence of the significant number of web openings, castellated and cellular beams cannot be treated as solid-web members or members with web openings. These structural members are highly indeterminate elements, which do not lend themselves to a simple method of analysis. The presence of web openings introduces many additional failure modes not present in solid web members (Kerdal and Nethercot, 1984). Design checks on the web posts and tee-sections that form the opening are required. Additionally, shear deformations with the top and bottom tees in the beams can be significant, thereby increasing the difficulty of deflection analysis. The re-entrant corners at the openings of castellated beams provide a location of stress concentration that may limit their use in applications where dynamic effects are significant (Dougherty, 1993).

Localized forces develop in open web beams both around the openings and at the web posts; consequently, additional modes of failure must be investigated beyond those which are normal for solid web flexural members. Research has shown that castellated and cellular beams behave similar to Vierendeel trusses. The design theory for castellated beams is based largely on Design of Welded Structures (Blodgett, 1966), and additional research focused on web post buckling (Aglan and Redwood, 1974; Redwood and Shrivastava, 1980). The design theory for cellular beams has been developed by the Steel Construction Institute of the United Kingdom (Ward, 1990). The design procedures have many similarities, but because the procedures were developed by different parties, there are areas where slightly different approaches are used, such as investigation of horizontal and vertical shear. The following limit states should be investigated when designing castellated or cellular beams:

1. Compactness and local buckling
2. Overall beam flexural strength
3. Vierendeel bending of tees
4. Web post buckling
5. Axial tension/compression
6. Horizontal shear
7. Vertical shear
8. Lateral-torsional buckling

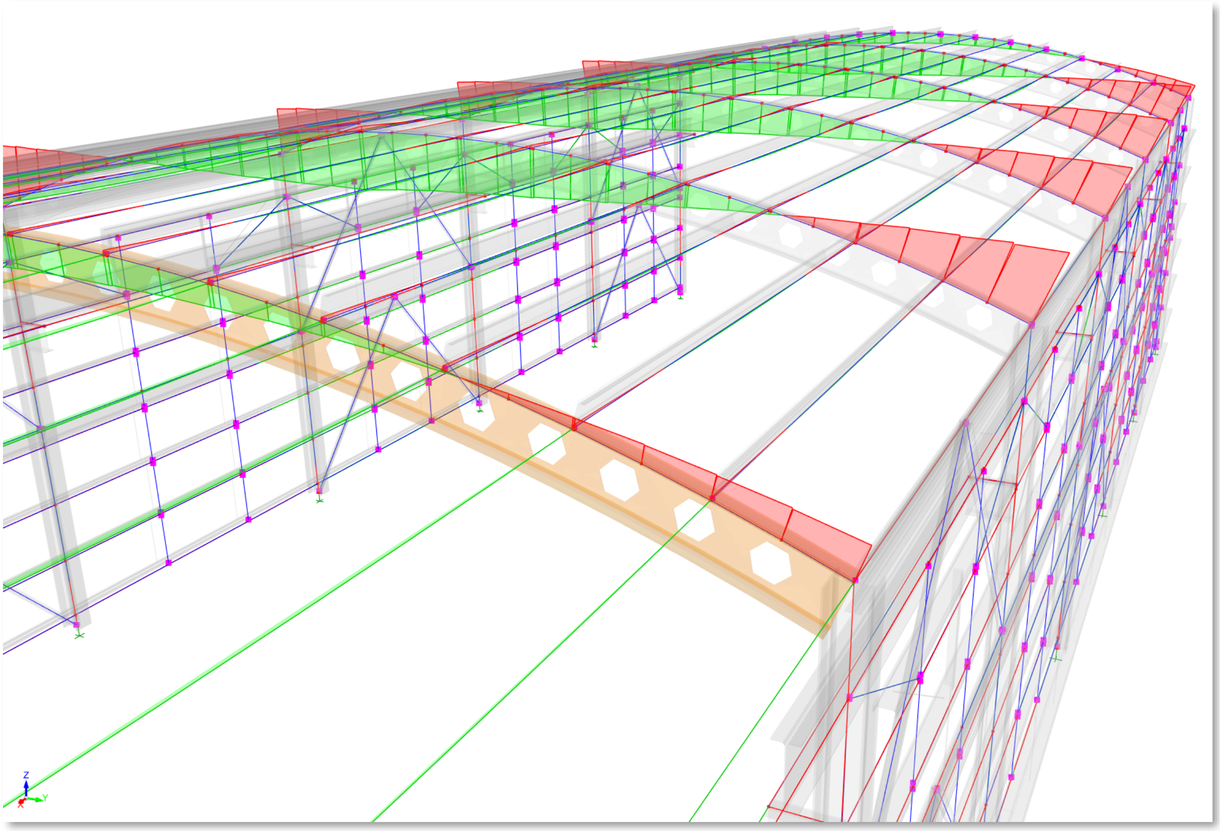
The first step in designing both castellated and cellular beams is to calculate the overall bending moment and shear force at each opening and web post caused by external loads. These forces will be referred to as global forces. The global forces will be used to compute localized forces in the top and bottom tees, the web posts, and the gross section. The components (tees and web posts) of the beams will then be examined for failure under the localized forces.

[*Reference: AISC Design Guide 31 – Castellated and Cellular Beam Design*]

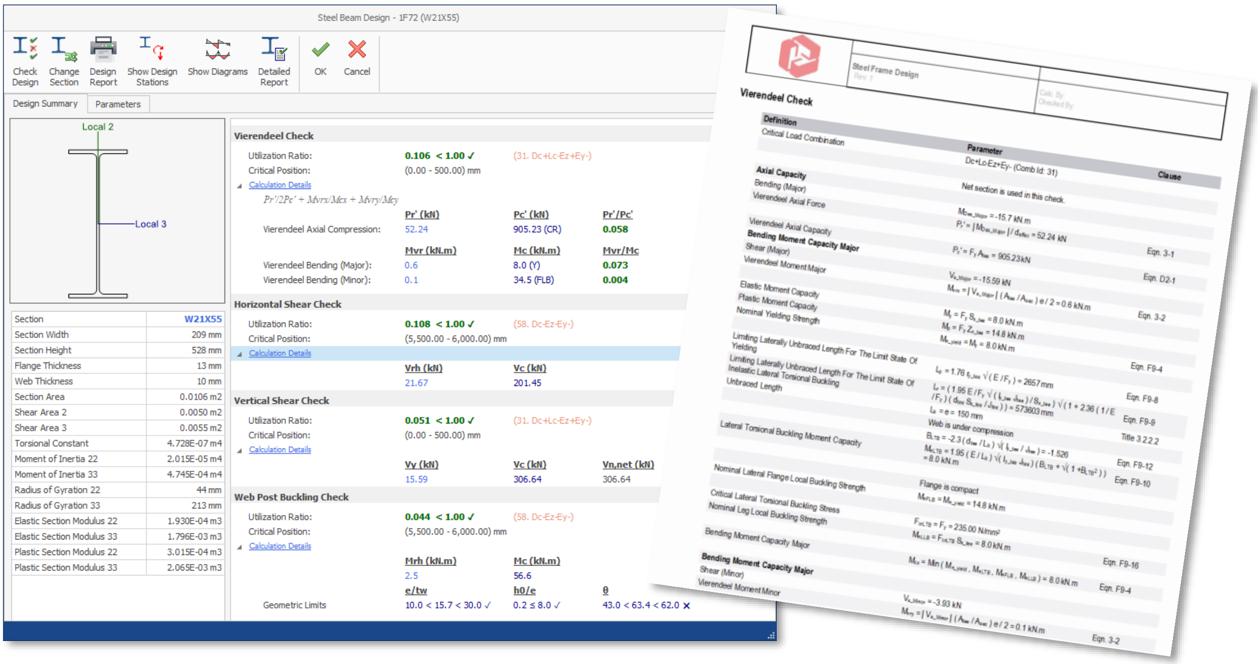
Important
ProtaStructure 2025 performs castellated beam checks according to **AISC360** and **Turkish Steel Design Code**. Eurocode 3 design procedures are work in progress..

ProtaStructure currently supports only the **non-composite castellated beams**. Composite castellated beams are also work in progress.

We are planning to release Eurocode support and composite castellated beam design with ProtaStructure 2025 maintenance releases (with no promises!).



Analysis results shown for a model including castellated non-composite castellated beams



Section	W21X55
Section Width	209 mm
Section Height	528 mm
Flange Thickness	13 mm
Web Thickness	10 mm
Section Area	0.0106 m2
Shear Area 2	0.0050 m2
Shear Area 3	0.0055 m2
Torsional Constant	4.728E-07 m4
Moment of Inertia 22	2.015E-05 m4
Moment of Inertia 33	4.745E-04 m4
Radius of Gyration 22	44 mm
Radius of Gyration 33	213 mm
Elastic Section Modulus 22	1.930E-04 m3
Elastic Section Modulus 33	1.796E-03 m3
Plastic Section Modulus 22	3.015E-04 m3
Plastic Section Modulus 33	2.065E-03 m3

Vierendeel Check

Utilization Ratio: **0.106 < 1.00 ✓** (31. Dc+Lc-Ez+Ey-)

Critical Position: (0.00 - 500.00) mm

Calculation Details

$Pr'/2Pc' + Mvrx/Mcx + Mvry/Mcy$

	Pr' (kN)	Pc' (kN)	Pr'/Pc'
Vierendeel Axial Compression:	52.24	905.23 (CR)	0.058

	Mvr (kN.m)	Mc (kN.m)	Mvr/Mc
Vierendeel Bending (Major):	0.6	8.0 (Y)	0.073
Vierendeel Bending (Minor):	0.1	34.5 (FLB)	0.004

Horizontal Shear Check

Utilization Ratio: **0.108 < 1.00 ✓** (58. Dc-Ez-Ey-)

Critical Position: (5,500.00 - 6,000.00) mm

Calculation Details

Vrh (kN)	Vc (kN)
21.67	201.45

Vertical Shear Check

Utilization Ratio: **0.051 < 1.00 ✓** (31. Dc+Lc-Ez+Ey-)

Critical Position: (0.00 - 500.00) mm

Calculation Details

Vy (kN)	Vc (kN)	Vn,net (kN)
15.59	306.64	306.64

Web Post Buckling Check

Utilization Ratio: **0.044 < 1.00 ✓** (58. Dc-Ez-Ey-)

Critical Position: (5,500.00 - 6,000.00) mm

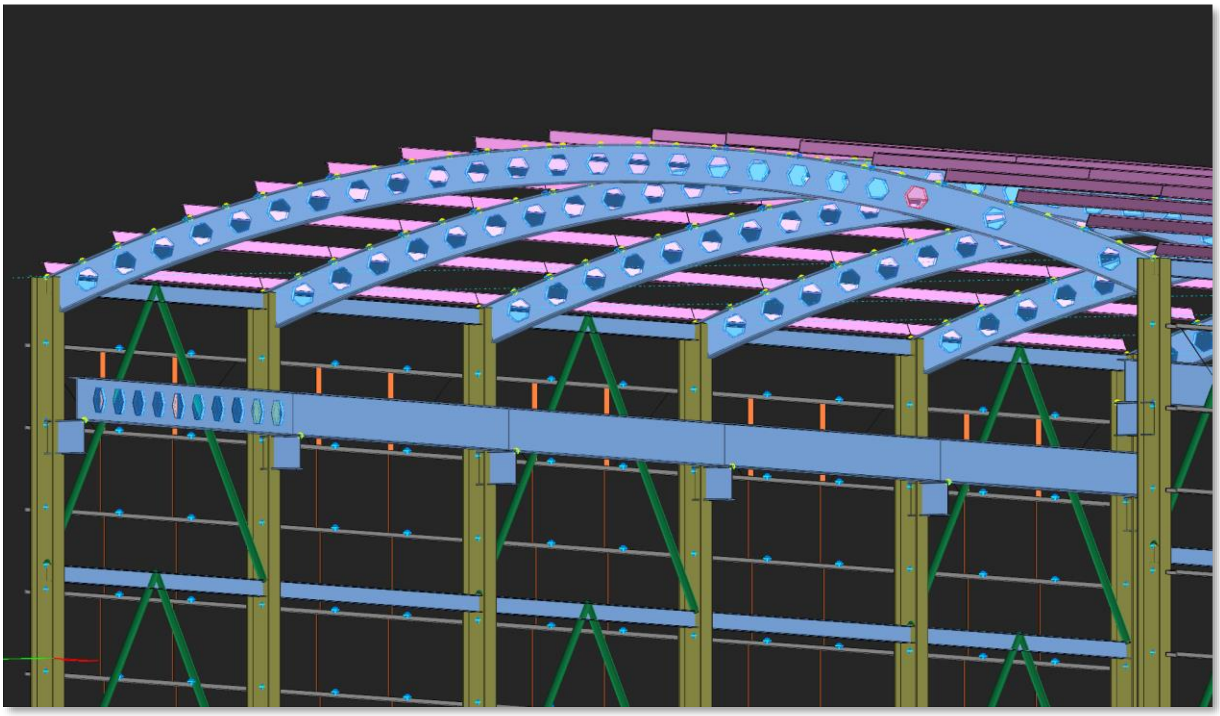
Calculation Details

	Mrh (kN.m)	Mc (kN.m)	
	2.5	56.6	
	e/tw	h0/e	θ
Geometric Limits	10.0 < 15.7 < 30.0 ✓	0.2 ≤ 8.0 ✓	43.0 < 63.4 < 62.0 ✗

Castellated Steel Beam Design UI and Detailed Report in ProtaStructure

Detailing

The web openings are also automatically communicated to ProtaSteel for detailing. Openings are defined by cut object, so you can modify them easily if needed.



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