COMPARATIVE STUDY OF STEEL PRIMARY BEAMS FOR DIFFERENT SPANS

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ABSTRACT

The aim of this study is to perform a comparative analysis of steel primary beams with different cross-sections and truss systems for various spans and roof slopes. The analysis includes six structural solutions: I-section, H-section, rectangular hollow section (☐), circular hollow section (○), constant-depth truss, and variable-depth truss. The research was conducted for spans ranging from 8 m to 44 m and roof slopes from 0° to 20°, using Tower 8 software and S235 structural steel.

The results demonstrated that the I-section is the most efficient among solid profiles in almost all analysed combinations. The H-section achieves similar performance for larger spans, while hollow sections exhibit weaker behaviour as the span increases. Constant-depth trusses provide the lowest deflections and deformations for spans greater than 12 m. Variable-depth trusses show strong dependence on roof slope and become efficient only at higher slope angles.

Keywords: steel beam, cross-section, truss, Tower 8, S235, roof slope

INTRODUCTION

Steel is one of the most important structural materials for large-span buildings, such as industrial halls, warehouses, sports facilities, and agricultural structures. The selection of the primary load-bearing system directly affects the economy of the structure, material consumption, and deformation behaviour.

In roof systems, the primary structural members can be designed either as solid steel sections or as truss systems. The most commonly used profiles are I and H sections, while rectangular and circular hollow sections are used for specific structural and architectural requirements. For large spans, trusses are frequently applied because of their efficient material distribution and reduced structural weight. The objective of this study is to perform a parametric comparison of different steel primary beam systems in order to determine the most efficient structural solution for various spans and roof slope angles.

RESEARCH METHODOLOGY

The analysis was carried out using Tower 8 (Radimpex) structural analysis software based on a linear-elastic model. Structural steel grade S235 was adopted as the construction material.

The following parameters were considered:

• spans: 8 m, 12 m, 16 m, 20 m, 24 m, 28 m, 32 m, 36 m, 40 m, and 44 m,

• roof slopes: 0°, 5°, 10°, 15°, and 20°,
• loading cases: 6 kN/m^2 and 12 kN/m^2,
• boundary conditions: simply supported and fixed-end beams.

Six types of structural systems were analysed:

1. I-section,
2. H-section,
3. rectangular hollow section,
4. circular hollow section,
5. constant-depth truss,
6. variable-depth truss.

For each structural configuration, the following values were calculated:

• normal stresses (σ), $\sigma = M/W + N/A$
• relative deflections (δ), $\delta = k \cdot qL^4/(EI)$

The results were normalised by adopting the I-section as the reference value (σ = 1.000 and δ = 1.000).

Boundary Conditions of Supports

In this topic, two support boundary conditions are analysed: simple (pin/roller) support and fixed (encastre) support. In the case of simple support, the beam is free to rotate at the support, the bending moment at the ends is zero, and the maximum bending moment occurs at mid-span ($M\_max = qL^2/8$, $\delta\_max = 5qL^4/384EI$). In the case of fixed support, rotation at the support is restrained, negative moments are generated at the ends, and the maximum positive moment at mid-span is smaller ($M\_max = qL^2/12$ at the ends, $\delta\_max = qL^4/384EI$ — five times smaller than in the case of simple support).

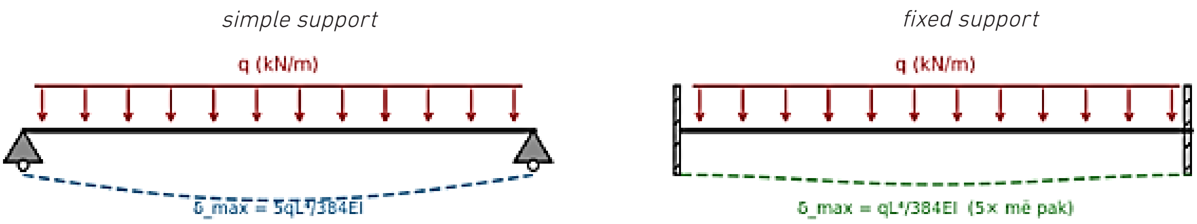

Figure 2.1 *— Beam Under Uniform Load With Free Support (Left) and With Embedment (Right), With the Corresponding Deformation Shapes.*

In practice, boundary conditions are realised through the structural details of the beam connections to columns or other supports. Figure 2.2 shows two types of real structural connections: a simple connection and a rigid connection.

Figure 2.2 — Two Types of Structural Connections: A Simple Connection (Left) With an Angle Plate That Allows Free Rotation and Transmits Only Shear Forces; and a Rigid Connection (Centre, Orange) With Bolted Top and Bottom Plates That Also Transmits Bending Moments. Source: Simpson Strong-Tie.

Types of Cross-Sections for Steel Beams

The industrial production of structural steel offers a wide range of standardised profiles (Figure 2.4). In this topic, four main families of full profiles (I-profile, H-profile, rectangular profile, circular profile/tube) and two types of trusses are compared, which are presented in detail below.

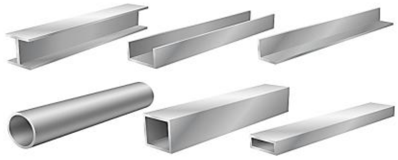

Figure 2.3 *— Common Types of Standardised Steel Profiles. In This Topic, the I-Profile (Top Left) and Circular, Square and Rectangular Profiles (Bottom) are Studied. U and L Profiles are not the Subject of This Paper.*

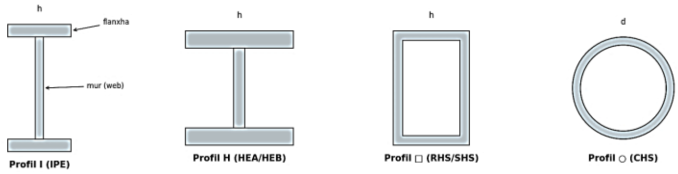

Figure 2.4 *— Schematic of the Four Complete Cross-Sections Analysed: I-Profile, H-Profile, □-Profile (Rectangular) and ○-Profile (Circular/Tube).*

THEORETICAL BACKGROUND

The behaviour of steel beams under vertical loading depends primarily on:

- span length,
- moment of inertia of the cross-section,
- section modulus,
- support conditions,
- roof slope angle.

Beams with higher moments of inertia exhibit smaller deformations, while increasing the span significantly increases beam deflections.

I-sections provide a highly efficient strength-to-weight ratio due to their large moment of inertia in the principal bending direction. H-sections provide greater stability but also higher self-weight. Hollow sections exhibit improved torsional resistance but lower efficiency for large spans.

Truss systems utilise greater structural depth to reduce bending deformations and are therefore suitable for large-span structures.

RESULTS AND ANALYSIS

Horizontal Beams (0°)

For horizontal beams, the I-section provides the best performance among the solid profiles. The H-section exhibits larger deformations, particularly for shorter spans. Hollow sections become significantly less efficient as the span increases.

The constant-depth truss demonstrates the best overall performance in terms of deflections and deformations. For spans greater than 12 m, its deflections are 25–67% lower than those of the I-section.

Roof Slope of 5°

With the introduction of a 5° roof slope, the differences between the I and H sections become smaller. For larger spans, the H-section achieves almost identical results to the I-section.

The variable-depth truss becomes more efficient and shows smaller deformations than the solid profiles for spans greater than 20 m.

Roof Slope of 10°

At a roof slope of 10°, the variable-depth truss exhibits the poorest behaviour. Deflections become significantly larger than those of the I-section due to insufficient structural depth.

The constant-depth truss continues to provide the best overall performance.

Roof Slopes of 15° and 20°

At higher roof slopes, the variable-depth truss becomes considerably more efficient. For spans between 36 m and 44 m, its performance becomes equal to or better than that of the I-section.

The constant-depth truss remains the most efficient system in terms of deformation control, especially for large spans.

DISCUSSION

The results confirm that the selection of the beam type primarily depends on the span length and roof slope.

For small and medium spans, the I-section represents the most rational solution due to its low weight and favourable mechanical properties. The H-section may be applied when additional structural stability is required.

Hollow sections demonstrate acceptable behaviour for smaller spans; however, their efficiency decreases as the span increases.

For large spans, truss systems provide significantly better performance than solid sections. The constant-depth truss exhibits the smallest deformations in almost all analysed combinations. The variable-depth truss becomes justified only at higher roof slopes.

CONCLUSION

Based on the performed analysis, the following conclusions can be drawn:

1. The I-section represents the most efficient solid structural solution in the majority of analysed cases.
2. The H-section achieves performance similar to the I-section for large spans.
3. Hollow sections exhibit weaker performance as the span increases.
4. The constant-depth truss provides the smallest deformations and the best overall results for spans greater than 12 m.
5. The variable-depth truss strongly depends on roof slope and becomes efficient only at roof slopes of 15° and 20°.
6. For small spans, solid sections are more economical than truss systems.

The obtained results may serve as a basis for selecting optimal structural systems in the design of steel halls and large-span buildings.

REFERENCES

1. Timoshenko, S. P., & Gere, J. M. Theory of elastic stability. McGraw-Hill.
2. EN 1993-1-1: Eurocode 3 — Design of steel structures.
3. EN 10025-2: Structural steels.
4. SCI Steel building design — Blue book.
5. Tata Steel Europe — Structural hollow sections.
6. Radimpex software. Tower 8 User Manual.
7. SkyCiv Engineering. Truss vs beam: Structural comparison.
8. Shanmugasundaram, K. Parametric study on structural steel beams.
9. Sulayman, A. Comparative study between wide flange and cellular beams.
10. IRJET. Standardization of industrial steel roof truss sections.

KOMPARATIVNA STUDIJA ČELIČNIH GLAVNIH GREDA ZA RAZLIČITE RASPONE

SAŽETAK

Cilj ove studije je izvršiti komparativnu analizu čeličnih glavnih greda različitih poprečnih presjeka i rešetkastih sistema za različite raspone i nagibe krova. Analiza uključuje šest konstrukcijskih rješenja: I-profil, H-profil, pravokutni šuplji profil (□), kružni šuplji profil (○), rešetka konstantne dubine i rešetka promjenjive dubine. Istraživanje je provedeno za raspone od 8 m do 44 m i nagibe krova od 0° do 20°, korištenjem softvera Tower 8 i konstrukcijskog čelika S235.

Rezultati su pokazali da je I-profil najefikasniji među punim profilima u gotovo svim analiziranim kombinacijama. H-profil postiže slične performanse za veće raspone, dok šuplji profili pokazuju slabije ponašanje s povećanjem raspona. Rešetke konstantne dubine pružaju najmanje otklone i deformacije za raspone veće od 12 m. Rešetke promjenjive dubine pokazuju snažnu ovisnost o nagibu krova i postaju efikasne tek pri većim uglovima nagiba.

Ključne riječi: čelična greda, poprečni presjek, rešetka, Tower 8, S235, nagib krova.

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