

A COMPARATIVE STUDY OF BS 449, BS 5950 AND EUROCODE 3 FOR STRUCTURAL STEEL DESIGN

BSc Civil Engineering

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Abstract

The structural integrity of existing steel structures is increasingly under scrutiny as modern design codes evolve to reflect advances in engineering knowledge and safety expectations.

This dissertation investigates the progression of the structural steel design standards and the effects of current design codes on existing structures. It aims to assess how these changes influence the compliance & load-bearing capacity of structures. The study explores contemporary reinforcement methods to evaluate their effectiveness in bridging the gap between old designs and modern requirements. A comparative analysis is conducted using selected member types to highlight discrepancies between historical and current code compliance.

Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the regulations of UWTSD. The work is original except where indicated by special references in the text and no part of the dissertation has been submitted for any other degree.

Any views expressed in the dissertation are those of the author and in no way represent those of the UWTSD.

The dissertation has not been presented to any other University for examination either in the United Kingdom or overseas.

I hereby give permission for my work, if accepted, to be available for photocopying and inter-library loan, and for the title and summary to be made available to outside organizations.

Signed: *J. G. MALLS*

Date: 06/05/2026

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1. Introduction

1.1. Background

The design standards of steel structures have been improved over the decades from having greater engineering practise, increased safety measures and improved material science. Having improved engineering techniques has allowed for design codes to be more detailed and allowing structural engineers to design to utilise the strength of steel sections more effectively and economically.

Steel structures have been a fundamental construction material given its unique properties of providing high strength to weight ratio, durability and adaptability, thus giving flexibility in structural design. The production of steel began in the United Kingdom between 1856-1858, but structural design standards were not established during that period. The advances in engineering means there is a continuous refinement of design standards, including how to approach to the structural design & improvement in safety factors. With these improvements introduces challenges in assessing and evaluating existing structures, which may not comply with current design codes.

With steel structure warranty commonly being 50 years, it's imperative to assess any existing structures pre-1975 to check the integrity and stability of the structure aligns with current regulations. The understanding of how existing standards were implemented on a structure can aid in future structural improvements.

An important factor when undertaking structural analysis to the existing design standards is the evolution and advancement of steel manufacturing processes. Improvements in steel production have led to steels with more reliable higher strength grades, material properties and improved ductility and toughness. The advancements in steel manufacturing have enabled modern structural design to be more economical by adopting higher characteristic strengths.

1.2. Aim and Objection

This dissertation aims to investigate the impact of evolving structural steel design standards by undertaking a comparative study of BS 449, BS 5950 & Eurocodes 3 (EC3). As safety requirements and structural design philosophy have been developed over time, it is essential to understand the differences between the standards to gain a greater understanding in how existing structures have been designed and how modern design standards influence the design, performance and safety of steel structure.

The primary objective of this research is to assess the transition through the design standards has resulted in economical improvements, increase safety in structural design to gain the understanding of how structural analysis has been undertaken throughout each design standard so future analysis can be done with a greater understanding. From this providing suitable reinforcement techniques will give a wider understanding on how to resolve any potential failures from occurring.

To achieve this, the research will involve a comparative analysis of selected structural steel elements in accordance with each of the three design codes, from this based on previous research and knowledge of reinforcement techniques an option will be established to best strengthen the member in the relevant category. The results will be compared to identify variations in member selection, utilisation of members and suitable reinforcement technique to ensure the existing design can align with current design codes. This approach will help provide practical and technical insights of applying different steel design codes in both new designs and the assessment of existing structures.

The specific objectives of the dissertation are to:

1. Understand historic and modern steel production improvements and its effects on the structural analysis through the structural design standards.
2. Identify and analyse key differences between structural design standards BS449 / BS 5950 & Eurocodes 3.
3. Conduct a detailed structural analysis of structural members to BS 449 / BS 5950 & Eurocodes 3.
4. Review the analysis and critically evaluate to most suitable reinforcement technique to ensure it complies with current design codes.

1.3. Research Questions

- What are the main changes between BS 449 / BS 5950 & Eurocodes?
- How do the three standards compare in terms of design economy & material utilisation?
- Which specific changes in the design standards have the greatest impact on structural steel design?
- How can reinforcement aid in bringing existing structures to meet modern design codes?

1.4. Research Limitations

The following research is subject to available standards that can be accessed, for the research it will focus on the following British Standards: -

BS 449-2:1969 - Specification for the use of structural steel in building.

BS 5950-1:2000 - Structural use of steelwork in building

BS EN 1993-1-1-2005 - Eurocode 3. Design of steel structures

Access to additional research papers, a request has been made to acquire 3 additional research papers to aid in this study, unfortunately they have not been provided so limited research can be reviewed and undertaken.

1.5. Structure of Dissertation

The following dissertation will be structured as follows:

- Chapter 1 – Introduction including the aims & objectives of the research paper.
- Chapter 2 – Literature review of the history of steelwork in the UK and design Standards.
- Chapter 3 – Methodology of differences between codes and analytical studies.
- Chapter 4 – Findings methodology & analytical studies.
- Chapter 5 – Discussion around implications of the findings.
- Chapter 6 – Conclude

2. Literature Review

2.1. Use of Structural Mild Steel in the UK

The use of structural mild steel has been used in the UK since 1885, by using the Bessemer and siemens open hearth process to roll steel sections for major bridge constructions. Prior this period (pre-1855) Cast iron and wrought iron was the primary structural framing used. The use of structural mild steel was then incorporated into the buildings in 1900 where the mild steel members were used to transfer vertical load to load bearing walls. (A,Johnson, 2006)

In 1909 it was permitted to then use Structural Steel as a buildings skeleton to withstand both vertical and horizontal loads, although permitted to use as a buildings skeleton some engineers used this method prior, an exam of this is the Midland Hotel in Manchester (Refer to Figure 1) where it was completed in 1903 and constructed from 2,000 tons of steel. (A,Johnson, 2006)



Figure 1 - Midland Hotel Manchester (Bamford, T, 2025)

During both WW1 (1914-1918) & WW2 (1939-1945) Steel construction was prominent for its speed of construction and its efficiency, where it was used to construct defences, bridges, aircraft hangers and temporary structures. Following the WW2 there was a push for increasing the scale on production of steel to be used for industrial buildings and infrastructure projects during the reconstruction of the damaged infrastructure during this period. (A,Johnson, 2006).

Figure 2 shows the rapid increase of Steel manufacturing in the UK following WW2 until the 1970's where industrial relations causing frequent strikes, global competition making it cheaper to import steel and lack of funding to improve outdated infrastructure.



Figure 2 - Steel Production in Great Britain, 1900-2015 (Office for National Statistics, 2016)

Understanding the history and implementation of steel production is essential for comparing construction practices with the corresponding introduction of design codes.

2.2. History of design standards used within the UK

With the increase in use of structural mild steel over a wide range of industries, advancement in material science and structural analysis. The earliest formal standard issued from the British Standard Institute was BS 449: *The Use of Structural Steel in Building*, this document was first issued in 1932. (BSI,1959).

Table 1 - Overview of UK steel structure design standards

Date Issued	Document Reference	Description
1932	BS 449	First UK national steel design code. Basis of design to permissible stress.
1982	BS 5950	Introduced modern Limit State Design for steel buildings
2010	Eurocodes	Eurocodes become UK steel design code to standardise across of Europe.

2.2.1. BS 449

Why was the introduction of the BS 449 a major milestone in the construction industry, because it provided design principles for engineers to standardise structural analysis by giving guidance on material strength, member dimensions and connection detailing. BS449 is based on permissible stress (working stress) design principles, which when introduced gave engineers a standardised method in steel construction during the rapid increase in growth of the use of structural steel. (BSI,1959)

Following BS 449, the British Standard Institute released an updated standard due to the limitations that permissible stress design had. The limitations of BS 449 were the uneconomical approach, by not utilising the elastic material behaviour of the structural steel properties and only applying a single overall factor of safety, which does not distinguish primary load cases and its effects on the different material properties, such as collapse or buckling. (BSI,1959).

2.2.2. BS 5950

So, in response to the limitations, BS 5950: *Structural Use of Steelwork in Buildings* was introduced in 1982 which was a major change in the approach to the structural design philosophy in the UK by adopting the limit state design principle. This design approach considers both ultimate and serviceability limit states, by this means improving structural efficiency and safety. (BSI, 1985)

The standard was published in several parts covering different forms of steel construction, including simple and continuous construction, composite structures, and cold-formed sections. BS 5950 reflected advances in reliability theory, load modelling, and computational analysis, and it remained the principal design standard for steel buildings in the UK for over two decades. (Mac Ginley, T.J. 1981)

2.2.3. Eurocodes

The introduction of the Eurocodes came in 2010, where it became mandatory code within the UK to ensure that there is consistency in structural design across Europe. Although the naming of the design codes changed from British Standards to Eurocode, the British Standard Institute was a part of the European committee for standardisation who created Eurocodes.

The structural Eurocodes comprises of a number of parts; this comprises of the following: -

Table 2 - List of Eurocode Parts (BSI, 2014)

EN 1990	-	Eurocode	Basis of structural design
EN 1991	-	Eurocode 1	Actions on structures
EN 1992	-	Eurocode 2	Design of concrete structures
EN 1993	-	Eurocode 3	Design of steel structures
EN 1994	-	Eurocode 4	Design of composite steel and concrete structures
EN 1995	-	Eurocode 5	Design of timber structures
EN 1996	-	Eurocode 6	Design of masonry structures
EN 1997	-	Eurocode 7	Geotechnical design
EN 1998	-	Eurocode 8	Design of structures for earthquake resistance
EN 1999	-	Eurocode 9	Design of aluminium structures

Figure 3 gives a visual overview of the Eurocodes and how the consideration of the organized hierarchically on how to undertake design of buildings and civil engineering structures to consider the safety and serviceability of structures.

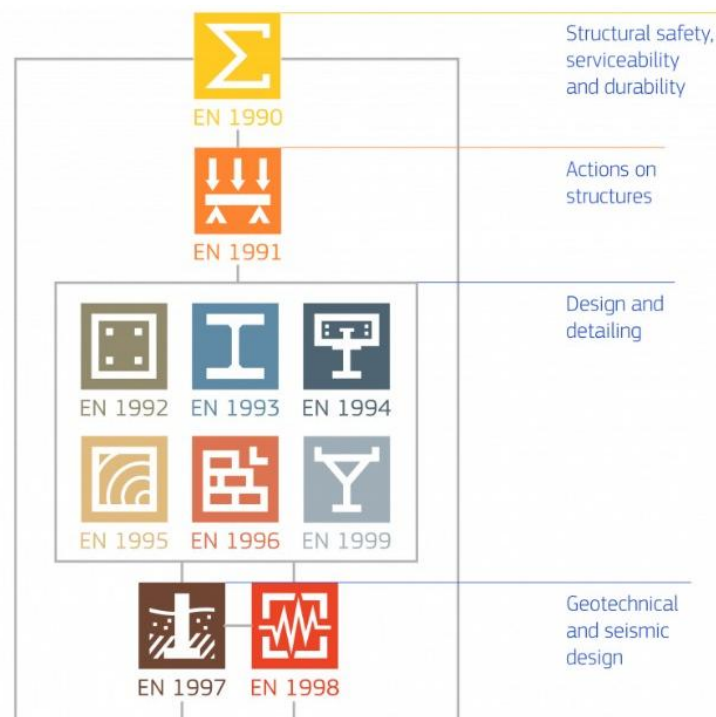


Figure 3 - Breakdown of Eurocodes Sections (Eurocodes at a glance, 2021)

EN 1993: Eurocode 3 covers the design of steel structures, with Eurocodes being a European standard it provides a unified technical framework around civil engineering projects while allowing for national variations through National Annexes.

The basis of design remains the same approach as BS 5950 by using limit state design principle, the Eurocode has been adapted to have a more robust designing method enabling more sophisticated design models for stability, member resistance, and connections. (BSI, 2014)

2.3. Elastic & Plastic Design

During the early development of structural design, the principles leading structural behaviour were not well understood. In 1826, Claude-Louis Navier published “the theory of elasticity”, this enables structural engineers to prevent structures from failing. The elastic modulus allows the ability of the material to withstand elastic deformation in response to applied stress. Within the elastic region the material follows Hooks’s Law, which highlights the stress is directly proportional to the strain, given by the following formula:- (Ryu, J. 2024)

$$E = \frac{\sigma}{e}$$

Where: σ = stress / e = strain / E = Young’s Modulus

This is shown in Figure 4 as the elastic region, it shows the linear nature between the stress and strain line to point A. Point B is the Elastic limit, this is the maximum beyond this point with the increase in stress, the material does not have the ability to reform back into its original form, this is where the plastic region begins. Mane, V. (2024)

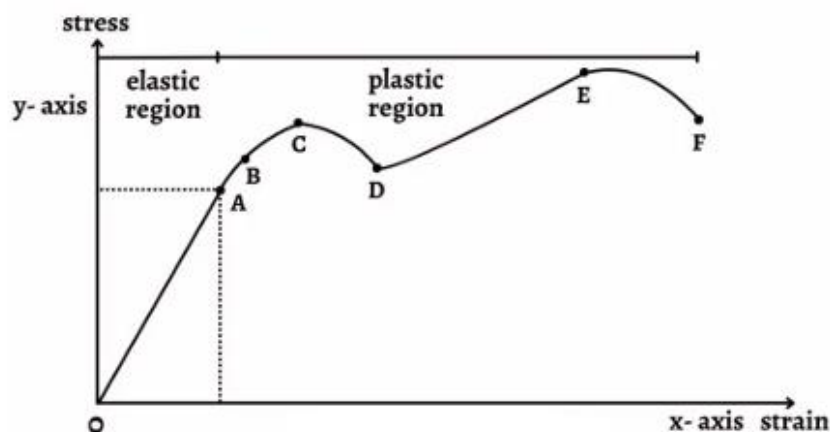


Figure 4 - Stress Strain Diagram (Mane, V. 2024)

Plastic analysis was first established by Sir John Baker at the university of Cambridge from the 1930s. By 1956, Baker, Horne and Heyman released “The Steel Skeleton” which are now regarded as the design principles for plastic design. This was then incorporated into the BS 5950 first issue in 1985 (Chigozirim and Afolabi, 2025, p. 189)

Figure 4 shows the extent of the plastic region with 4 main points. Plastic design allows parts of the structure to yield and permanent deformation occurs. At point C is when the section hits its upper yield point where requires the maximum stress to begin plastic deformation. At point D is when the section hits its lower yield point, this is where the material starts to deform with an increase in strain with a lower increase in stress.

The ultimate stress of the material is represented by point E; this is when the material undergoes plastic deformation reaching its maximum stress prior to failure. At point F the material is at its breaking point/failure point. (Mane, V. 2024)

2.4. Difference in analysis between BS449, BS5950 & Eurocode 3

Design Philosophy

BS449	=	Permissible Stress Design
BS5950	=	Limit State Design
Eurocodes 3	=	Limit State Design

2.4.1. Structural analysis for unrestrained beam members

Available Material Properties

BS449	=	Based on Minimum Tensile Strength (43A = 430N/mm ²) Use of Elastic Modulus
BS5950	=	Based on Yield Strength, N/mm ² (Available = S275 / S355 / S460) Use of Plastic Modulus
Eurocodes 3	=	Based on Yield Strength, N/mm ² (Available = S235 / S275 / S355 / S420 / S460 / S500 / S550 / S690) Use of Plastic Modulus

Characteristic Loads

BS449	=	Dead Load (DL) = Self Weight & Permanent Fixtures Imposed Loads (IL) = CP3 Chapter V-1:1967 - <i>Code of basic data for the design of buildings. Loading - Dead and imposed loads</i> Wind & Snow Loads (WL/SL) = CP 3:Chapter V-2:1972 - <i>Code of basic data for the design of buildings. Loading - Wind loads</i>
BS5950	=	Dead Load(G) = Self Weight & Permanent fixtures / equipment Imposed Loads(Q) = BS 6399-1:1996 - <i>Loading for buildings – Code of practice for dead and imposed loads</i> Wind & Snow Loads = CP 3:Chapter V-2:1972 - <i>Code of basic data for the design of buildings. Loading - Wind loads</i>

Eurocodes 3 = **Dead Load (G)** = Self Weight & Permanent fixtures / equipment
Imposed Loads(Q) = BS EN 1991-1-1:2002 - *UK National Annex to Eurocode 1. Actions on structures - General actions. Densities, self-weight, imposed loads for buildings*
Wind / Snow / Environmental / Accidental / Seismic Loads

Applied Load Combinations

BS449 = Unfactored service loads = 1.0G, 1.6Q
 BS5950 = Factor Loads = 1.4G, 1.6Q
 Eurocodes 3 = Serviceability Limit State (SLS) = 1.0G, 1.0Q, ψ factors
 Ultimate Limit State (ULS) = 1.35G, 1.5Q, 1.5 ψ factors

Calculation for Maximum Bending Moment & Maximum Shear

There is no change in analysis between BS449 / BS5950 & EC3 for calculation Maximum Bending Moment & Maximum Shear:-

$$\text{Maximum Moment} = M_{max} = \frac{w_d L^2}{8}$$

$$\text{Maximum Shear} = V_{max} = \frac{w_d L}{2}$$

Maximum Moment Capacity Checks

$$\text{BS449} = \frac{M_{max}}{Z} \leq f_y$$

$$\text{BS5950} = \text{Calculate moment capacity} = M_{RD} = \frac{f_y Z}{\gamma M 0}$$

$$\text{BS5950 Moment Check} = M_{max} \leq M_{RD}$$

$$\text{Eurocodes 3} = \text{Calculate moment capacity} = M_{RD} = \frac{f_y Z}{\gamma M 0}$$

$$\text{Eurocodes 3 Moment Check} = M_{max} \leq M_{RD}$$

Maximum Shear Resistance Checks

BS449 = Shear Stress Check = $\tau = \frac{V}{A_v}$

Calculate Shear Area (Web) = $A_v = dt_w$

Calculate Allowable Shear = $\tau_{allow} = 0.4f_y$

Allowable Stress = $\tau \leq \tau_{allow}$

Calculate Design Shear Capacity = $V_{allow} \leq \tau_{allow}A_v$

BS449 Shear Check = $V \leq V_{allow}$

BS5950 = Calculate Shear Area = $A_v = dt_w$

Calculate Design Shear Capacity = $P_v = 0.6p_yA_v$

BS5950 Shear Check = $V \leq P_v$

Eurocodes 3 = Calculate Shear Area = $A_v = dt_w$

Calculate Design Shear Capacity = $V_{pl,Rd} = \frac{A_v f_y}{\sqrt{3}\gamma_{M0}}$

Eurocodes Shear Check = $V_{Ed} \leq V_{pl,Rd}$

Member Buckling Checks

BS449 = Section Properties = Z_p, r_y & f_y

Determine Effective Length = $L_e \leq KL$

Calculate Slenderness Ratio = $\lambda = \frac{L_e}{r_y}$

Calculate Allowable Bending Stress = Table 3 in BS449 = p_{bc}

Calculate Actual Bending Stress = $\sigma_b = \frac{M}{Z}$

BS449 LTB Check = $\sigma_b \leq p_{bc}$

BS5950 = Determine M_x Including all loads (Dead, Live and Self Weight)

Determine ϵ from Table 11, BS5950

Section Properties = E

Determine Effective Length = L_E from Table 13, BS5950

Determine bending strength for the section p_b = Using

slenderness value $\sqrt{\beta_w(L E r_y)}$ and D/T.

Calculate buckling resistance moment M_b =

Class 1&2 = $M_b = p_b S_x$ & Class 3 = $M_b = p_b Z_x$

BS5950 Final Check = $M_x \leq M_b$

Eurocodes 3 = Determine M_{ED} = Design ultimate bending moment (ULS)

Determine section classification from Table 5.2, BS EN 1993-1-1

Section Properties = I_z, I_t, I_w

Determine Section Modulus = Class 1/2 = $W_{pl,y}$ / Class3 = $W_{el,y}$

Determine Effective Length = L_{LT}

Elastic Critical Moment = $M_{cr} = C_1 \frac{\pi^2 E I_z}{L_{LT}^2} \sqrt{\frac{I_w}{I_z} + \frac{L_{LT}^2 G I_t}{\pi^2 E I_z}} + C_2 Z_g^2$

Utilise Blue Book of steel for M_{cr} value.

Calculate non-dimensional slenderness = $\lambda_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}}$

From Table 6.3 BS EN 1993-1-1 Establish α_{LT}

Calculate Reduction Factor = $\chi_{LT} = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_{LT}^2}}$

Design Buckling Resistance Moment = $M_{b,Rd} = \chi_{LT} W_y \frac{f_y}{\gamma_{M1}}$

Eurocode 3 Final Check = $M_{Ed} \leq M_{b,Rd}$

Total & Live Load Deflection Limits for Beams & Floors

BS449 = $\Delta_{total} \leq \frac{L}{300}$ $\Delta_{Live} = \text{Not Specified Engineering Judgement}$

BS5950 = $\Delta_{total} \leq \frac{L}{360}$ $\Delta_{Live} \leq \frac{L}{360}$

Eurocodes 3 = $\Delta_{total} \leq \frac{L}{250}$ $\Delta_{Live} \leq \frac{L}{360}$

2.4.2. Structural analysis for column members

Applied Axial load & Reactions Loads

BS449	=	Service Loads = $G + Q (+W)$ Axial Load = $P = \Sigma(\text{Beam Reactions from Above}) + \text{Self Weight} + \text{Vertical Loads}$
BS5950	=	Axial Load = $P = \gamma_f G + \gamma_f Q + \gamma_f W$ γ_f = Partial load factors, Refer to Table 2 in BS5950
Eurocodes 3	=	Axial Load = N_{Ed} = <i>Design Axial Compression Force</i> Moments = $M_{y,Ed}$, $M_{y,Ed}$ = <i>Design Moment about the main axis</i>

Effective Length & Slenderness Ratio

BS449	=	Effective Length = l = Clause 31 of BS449 Slenderness Ratio = $\frac{l}{r}$
BS5950	=	Effective Length = L_E = Table 22 of BS5950 Calculate for both directions = L_{Ex} , L_{Ey} Slenderness Ratio = $\lambda_x = \frac{L_{Ex}}{r_x}$, $\lambda_y = \frac{L_{Ey}}{r_y}$
Eurocodes 3	=	Effective Length = $L_{cr} = \kappa L$ Calculate Euler Buckling Load = $N_{cr} = \frac{\pi^2 EI}{L_{cr}^2}$ Non-Dimensional Slenderness = $\bar{\lambda} = \sqrt{\frac{A \frac{f_y}{\gamma_{m1}}}{N_{cr}}}$

Compressive Strength

BS449	=	Determine Section Axial Compression Strength = p_c = Determine from Table 17 of BS449 Calculate Axial Stress = $f_c = \frac{P}{A}$
BS449 Check	=	$\frac{f_c}{p_c} < 1$

BS5950 = **Determine Section Axial Compression Strength =**
 p_c = Determine from Table 24 of BS5950

Calculate Member Capacity = $P_c = A p_c$

BS5950 Check = $\frac{P}{P_c} < 1$

Eurocodes 3 = **Calculate Reduction Factor =** $\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}}$ with ($\chi \leq 1.0$)

Where $\bar{\lambda} = \sqrt{\frac{A f_y}{N_{cr}}}$

Imperfection factor α = from Table 6.2 of BS EN 1993

Determine $\Phi = \frac{1}{2} [1 + \alpha(\bar{\lambda} - 0.2) + \bar{\lambda}^2]$

Calculate Buckling Resistance = $N_{b,Rd} = \chi A f_y$

Eurocodes 3 Check = $\frac{N_{Ed}}{N_{b,Rd}} < 1$

2.4.3. Mechanical properties of steel under BS449 / BS5950 / Eurocodes 3

Table 3 - BS449 – Universal Beam – Dimensions – APPENDIX B

Serial size	Weight kg/m	Depth D (mm)	Width b (mm)	Web t (mm)	Flange T (mm)	Root radius r (mm)	Depth between Filletts d (mm)	Area of Section cm ²
21 × 8½	122	545	212	12.8	21.3	12.7	473	155.6
	109	539	211	11.6	18.8	12.7	473	138.4
	101	537	210	10.9	17.4	12.7	473	129.1
	92	533	209	10.2	15.6	12.7	473	117.6
18 × 7½	98	467	193	11.4	19.6	10.2	404	125.2
	89	464	192	10.6	17.7	10.2	404	113.8
	82	460	191	9.9	16	10.2	404	104.4
	74	457	190.5	9.1	14.5	10.2	404	94.9
16 × 7	74	413	180	9.7	16	10.2	357	94.9
	67	409	179	8.8	14.3	10.2	357	85.4
	60	406	178	7.8	12.8	10.2	357	75.9
	54	403	178	7.6	10.9	10.2	357	68.3
14 × 6¾	67	364	173	9.1	15.7	10.2	309	85.3
	57	359	172	8	13	10.2	309	72.1
	51	356	171.5	7.3	11.5	10.2	309	64.5
	45	352	171	6.9	9.7	10.2	309	56.9
12 × 6½	54	311	167	7.7	13.7	8.9	263	68.3
	46	307	166	6.7	11.8	8.9	263	58.8
	40	304	165	6.1	10.2	8.9	263	51.4
10 × 5¾	43	260	147	7.3	12.7	7.6	216	55
	37	256	146.4	6.4	10.9	7.6	216	47.4
	31	251	146	6.1	8.6	7.6	216	39.9
8 × 5¾	30	207	134	6.3	9.6	7.6	170	38
	25	203	133	5.8	7.8	7.6	170	32.3

Table 4 - BS449 – Universal Beam - Properties – APPENDIX B

Serial size	Moment of Inertia			Radius of Gyration		Elastic Modulus		Plastic Modulus	
	Gross	Net	I _{yy} cm ⁴	r _{xx} cm	r _{yy} cm	Z _{xx} cm ³	Z _{yy} cm ³	S _{xx} - cm ³	S _{yy} - cm ³
	I _{xx} cm ⁴	I _{xx} net cm ⁴							
21 × 8½	76078	69119	3208	22.1	4.54	2794	303	3198	484
	66610	60541	2755	21.9	4.46	2469	262	2820	419
	61531	55942	2512	21.8	4.41	2293	239	2616	383
	55225	50243	2212	21.7	4.34	2072	211	2362	340
18 × 7½	45653	40978	2216	19.1	4.21	1954	230	2229	366
	40957	36774	1960	19	4.15	1767	204	2012	325
	37039	33278	1746	18.8	4.09	1610	183	1830	292
	33324	29944	1547	18.7	4.04	1458	162	1654	260
16 × 7	27279	24287	1448	17	3.91	1322	161	1502	257
	24279	21619	1269	16.9	3.86	1186	142	1343	226
	21458	19101	1104	16.8	3.81	1056	124	1191	198
	18576	16591	922	16.5	3.67	923	104	1046	167
14 × 6¾	19483	17215	1278	15.1	3.87	1071	148	1210	234
	16038	14185	1026	14.9	3.78	894	119	1007	190
	14118	12495	885	14.8	3.71	794	103	893	165
	12052	10697	730	14.6	3.58	685	85.4	772	137
12 × 6½	11686	10243	988	13.1	3.81	752	119	843	187
	9924	8695	825	13	3.73	646	99.5	721	157
	8500	7455	691	12.9	3.66	560	83.7	623	133
10 × 5¾	6546	5748	633	10.9	3.4	504	86	567	135
	5544	4866	528	10.8	3.33	433	72.1	484	114
	4427	3900	406	10.5	3.18	352	55.5	395	88.8
8 × 5¼	2880	2493	354	8.71	3.05	279	52.9	313	83.7
	2348	2040	280	8.53	2.95	231	41.9	259	67

Table 5 - BS449 – Universal Column - Dimensions – APPENDIX C

Serial size	Weight kg/m	Depth D (mm)	Width B (mm)	Web t (mm)	Flange T (mm)	Root radius r (mm)	Depth between Filletts d (mm)	Area of Section cm ²
Column Core	476	427	424	48.00	53.20	15.20	290	607.20
14 × 14½	202	375	374	16.80	27.00	15.20	290	257.90
	177	368	372	14.50	23.80	15.20	290	225.70
	153	362	370	12.60	20.70	15.20	290	195.20
	129	356	368	10.70	17.50	15.20	290	164.90
12 × 12	283	365	322	26.90	44.10	15.20	247	360.40
	240	353	318	23.00	37.70	15.20	247	305.60
	198	340	314	19.20	31.40	15.20	247	252.30
	158	327	311	15.70	25.00	15.20	247	201.20
	137	321	309	13.80	21.70	15.20	247	174.60
	117	314	307	11.90	18.70	15.20	247	149.80
	97	308	305	9.90	15.40	15.20	247	123.30
10 × 10	167	289	265	19.20	31.70	12.70	200	212.40
	133	276	261	15.60	25.30	12.70	200	168.90
	107	267	258	13.00	20.50	12.70	200	136.60
	89	260	256	10.50	17.30	12.70	200	114.00
	73	254	254	8.60	14.20	12.70	200	92.90
8 × 8	71	216	206	10.30	17.30	10.20	161	91.10
	59	210	205	9.30	14.20	10.20	161	75.80
	52	206	204	8.00	12.50	10.20	161	66.40
	46	203	203	7.30	11.00	10.20	161	58.80
6 × 6	37	162	154	8.10	11.50	7.60	124	47.40
	30	157	153	6.60	9.40	7.60	124	38.20
	23	152	152	6.10	6.80	7.60	124	29.80

Table 6 - BS449 – Universal Column - Properties – APPENDIX C

Serial size	Moment of Inertia			Radius of Gyration		Elastic Modulus		Plastic Modulus	
	Gross	Net	I _{yy} cm ⁴	r _{xx} cm	r _{yy} cm	Z _{xx} cm ³	Z _{yy} cm ³	S _{xx} - cm ³	S _{yy} - cm ³
	I _{xx} cm ⁴	I _{xx} net cm ⁴							
Column Core	172391	154580	68057	16.8	10.60	8075	3207.0	9700	4979.0
14 × 14½	66307	58518	23632	16.0	9.58	3540	1262.0	3976	1917.0
	57153	50410	20470	15.9	9.53	3104	1100.0	3457	1668.0
	48525	42789	17470	15.8	9.45	2681	944.0	2964	1430.0
	40246	35484	14555	15.6	9.40	2264	790.0	2482	1196.0
12 × 12	78777	67879	24545	14.8	8.26	4314	1525.0	5101	2337.0
	64177	55230	20239	14.5	8.13	3641	1273.0	4245	1947.0
	50832	43696	16230	14.2	8.03	2991	1034.0	3436	1576.0
	38740	33282	12524	13.9	7.90	2368	806.0	2680	1228.0
	32838	28204	10673	13.7	7.82	2049	691.0	2298	1052.0
	27601	23700	9006	13.6	7.75	1756	587.0	1953	892.0
	22202	19063	7268	13.4	7.67	1442	477.0	1589	723.0
10 × 10	29914	27401	9796	11.9	6.78	2070	741.0	2417	1132.0
	22575	20670	7519	11.6	6.68	1634	576.0	1875	879.0
	17510	16025	5901	11.3	6.58	1313	457.0	1485	695.0
	14307	13082	4849	11.2	6.53	1099	379.0	1228	575.0
	11360	10389	3873	11.05	6.45	895	305.0	989	462.0
8 × 8	7647	6830	2536	9.17	5.28	708	246.0	802	374.0
	6088	5444	2041	8.97	5.18	581	199.0	652	303.0
	5263	4703	1770	8.89	5.16	510	174.0	568	264.0
	4564	4083	1539	8.81	5.11	449	151.0	497	230.0
6 × 6	2218	1948	709	6.83	3.86	274	91.8	310	140.0
	1742	1532	558	6.76	3.81	221	73.1	247	111.0
	1263	1113	403	6.5	3.68	166	52.9	184	80.9

Table 7 - BS5950 – Universal Beam - Member Dimensions – (Bluebook of Steel, 2026)

Section Designation	Member Dimension														
	Mass per metre	Depth of section	Width of section	Thickness	Root radius	Depth between fillets	Depth between fillets	Ratios for local buckling		Dimensions for detailing			Surface area		
				Web	Flange			Web	Flange	End clearance C	Notch		Per metre	Per tonne	
				t	T						r	d			d / t
kg/m	D mm	B mm	mm	mm	mm	mm	mm			mm					
305 x 165 x 54	54.0	310.4	166.9	7.9	13.7	8.9	265.2	33.6	6.09	6	90	24	1.26	23.3	
	x 46	46.1	306.6	165.7	6.7	11.8	8.9	265.2	39.6	7.02	5	90	22	1.25	27.1
	x 40	40.3	303.4	165.0	6.0	10.2	8.9	265.2	44.2	8.09	5	90	20	1.24	30.8
254 x 146 x 43	43.0	259.6	147.3	7.2	12.7	7.6	219.0	30.4	5.80	6	82	22	1.08	25.1	
	x 37	37.0	256.0	146.4	6.3	10.9	7.6	219.0	34.8	6.72	5	82	20	1.07	28.9
	x 31	31.1	251.4	146.1	6.0	8.6	7.6	219.0	36.5	8.49	5	82	18	1.06	34.1
254 x 102 x 28	28.3	260.4	102.2	6.3	10.0	7.6	225.2	35.7	5.11	5	58	18	0.904	31.9	
	x 25	25.2	257.2	101.9	6.0	8.4	7.6	225.2	37.5	6.07	5	58	16	0.897	35.6
	x 22	22.0	254.0	101.6	5.7	6.8	7.6	225.2	39.5	7.47	5	58	16	0.890	40.5
203 x 133 x 30	30.0	206.8	133.9	6.4	9.6	7.6	172.4	26.9	6.97	5	74	18	0.923	30.8	
	x 25	25.1	203.2	133.2	5.7	7.8	7.6	172.4	30.2	8.54	5	74	16	0.915	36.5
203 x 102 x 23	23.1	203.2	101.8	5.4	9.3	7.6	169.4	31.4	5.47	5	60	18	0.790	34.2	
178 x 102 x 19	19.0	177.8	101.2	4.8	7.9	7.6	146.8	30.6	6.41	4	60	16	0.738	38.8	
152 x 89 x 16	16.0	152.4	88.7	4.5	7.7	7.6	121.8	27.1	5.76	4	54	16	0.638	39.9	
127 x 76 x 13	13.0	127.0	76.0	4.0	7.6	7.6	96.6	24.2	5.00	4	46	16	0.537	41.3	

Table 8 - BS5950 – Universal Beam - Member Properties – (Bluebook of Steel, 2026)

Section Designation	Member Properties													
	Second moment of area		Radius of gyration		Elastic modulus		Plastic modulus		Buckling parameter	Torsional index	Warping constant	Torsional constant	Area of section	
	Axis x-x cm ⁴	Axis y-y cm ⁴	Axis x-x cm	Axis y-y cm	Axis x-x cm ³	Axis y-y cm ³	Axis x-x cm ³	Axis y-y cm ³	<i>U</i>	<i>X</i>	<i>I_w</i> dm ⁶	<i>I_T</i> cm ⁴	<i>A</i> cm ²	
305 x 165	x 54	11700	1060	13.0	3.93	754	127	846	196	0.888	23.6	0.234	34.8	68.8
	x 46	9900	896	13.0	3.90	646	108	720	166	0.890	27.1	0.195	22.2	58.7
	x 40	8500	764	12.9	3.86	560	92.6	623	142	0.889	31.0	0.164	14.7	51.3
254 x 146	x 43	6540	677	10.9	3.52	504	92	566	141	0.890	21.1	0.103	23.9	54.8
	x 37	5540	571	10.8	3.48	433	78	483	119	0.889	24.3	0.0857	15.3	47.2
	x 31	4410	448	10.5	3.36	351	61.3	393	94.1	0.879	29.6	0.0660	8.55	39.7
254 x 102	x 28	4000	179	10.5	2.22	308	34.9	353	54.8	0.874	27.5	0.0280	9.57	36.1
	x 25	3410	149	10.3	2.15	266	29.2	306	46	0.868	31.4	0.0230	6.42	32.0
	x 22	2840	119	10.1	2.06	224	23.5	259	37.3	0.856	36.3	0.0182	4.15	28.0
203 x 133	x 30	2900	385	8.71	3.17	280	57.5	314	88.2	0.881	21.5	0.0374	10.3	38.2
	x 25	2340	308	8.56	3.10	230	46.2	258	70.9	0.877	25.6	0.0294	5.96	32.0
203 x 102	x 23	2100	164	8.46	2.36	207	32.2	234	49.7	0.888	22.4	0.0154	7.02	29.4
178 x 102	x 19	1360	137	7.48	2.37	153	27	171	41.6	0.886	22.6	0.00990	4.41	24.3
152 x 89	x 16	834	89.8	6.41	2.10	109	20.2	123	31.2	0.889	19.5	0.00470	3.56	20.3
127 x 76	x 13	473	55.7	5.35	1.84	74.6	14.7	84.2	22.6	0.894	16.3	0.00200	2.85	16.5

Table 9 - BS5950 – Universal Column - Member Dimensions – (Bluebook of Steel, 2026)

Section Designation		Member Dimension													
		Mass per metre	Depth of section	Width of section	Thickness	Root radius	Depth between fillets	Depth between fillets	Ratios for local buckling		Dimensions for detailing			Surface area	
					Web	Flange			Web	Flange	End clearance	Notch		Per metre	Per tonne
			h	b	t _w	t _f	r	d	c _w /t _w	c _f /t _f	C	N	n		
		kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m ²	m ²
254 x 254	x 167	167.1	289.1	265.2	19.2	31.7	12.7	200.3	10.4	4.18	12	134	46	1.58	9.46
	x 132	132.0	276.3	261.3	15.3	25.3	12.7	200.3	13.1	5.16	10	134	38	1.55	11.7
	x 107	107.1	266.7	258.8	12.8	20.5	12.7	200.3	15.6	6.31	8	134	34	1.52	14.2
	x 89	88.9	260.3	256.3	10.3	17.3	12.7	200.3	19.4	7.41	7	134	30	1.50	16.9
	x 73	73.1	254.1	254.6	8.6	14.2	12.7	200.3	23.3	8.96	6	134	28	1.49	20.4
203 x 203	x 127	127.5	241.4	213.9	18.1	30.1	10.2	160.8	8.88	3.55	11	108	42	1.28	10.0
	x 113	113.5	235.0	212.1	16.3	26.9	10.2	160.8	9.87	3.94	10	108	38	1.27	11.2
	x 100	99.6	228.6	210.3	14.5	23.7	10.2	160.8	11.1	4.44	9	108	34	1.25	12.6
	x 86	86.1	222.2	209.1	12.7	20.5	10.2	160.8	12.7	5.10	8	110	32	1.24	14.4
	x 71	71.0	215.8	206.4	10.0	17.3	10.2	160.8	16.1	5.97	7	110	28	1.22	17.2
	x 60	60.0	209.6	205.8	9.4	14.2	10.2	160.8	17.1	7.25	7	110	26	1.21	20.2
	x 52	52.0	206.2	204.3	7.9	12.5	10.2	160.8	20.4	8.17	6	110	24	1.20	23.1
	x 46	46.1	203.2	203.6	7.2	11.0	10.2	160.8	22.3	9.25	6	110	22	1.19	25.8
152 x 152	x 51	51.2	170.2	157.4	11.0	15.7	7.6	123.6	11.2	5.01	8	84	24	0.935	18.3
	x 44	44.0	166.0	155.9	9.5	13.6	7.6	123.6	13.0	5.73	7	84	22	0.924	21.0
	x 37	37.0	161.8	154.4	8.0	11.5	7.6	123.6	15.5	6.71	6	84	20	0.912	24.6
	x 30	30.0	157.6	152.9	6.5	9.4	7.6	123.6	19.0	8.13	5	84	18	0.901	30.0
	x 23	23.0	152.4	152.2	5.8	6.8	7.6	123.6	21.3	11.19	5	84	16	0.889	38.7

Table 10 - BS5950 – Universal Column - Member Properties – (Bluebook of Steel, 2026)

Section Designation	Member Properties													
	Second moment of area		Radius of gyration		Elastic modulus		Plastic modulus		Buckling parameter	Torsional index	Warping constant	Torsional constant	Area of section	
	Axis x-x cm ⁴	Axis y-y cm ⁴	Axis x-x cm	Axis y-y cm	Axis x-x cm ³	Axis y-y cm ³	Axis x-x cm ³	Axis y-y cm ³	<i>U</i>	<i>X</i>	<i>I_w</i> dm ⁶	<i>I_T</i> cm ⁴	<i>A</i> cm ²	
254 x 254	x 167	30000	9870	11.9	6.81	2080	744	2420	1140	0.851	8.48	1.63	626	213
	x 132	22500	7530	11.6	6.69	1630	576	1870	878	0.850	10.3	1.19	319	168
	x 107	17500	5930	11.3	6.59	1310	458	1480	697	0.848	12.4	0.898	172	136
	x 89	14300	4860	11.2	6.55	1100	379	1220	575	0.850	14.5	0.717	102	113
	x 73	11400	3910	11.1	6.48	898	307	992	465	0.849	17.2	0.562	57.6	93.1
203 x 203	x 127	15400	4920	9.75	5.50	1280	460	1520	704	0.856	7.36	0.549	427	162
	x 113	13300	4290	9.59	5.45	1130	404	1330	618	0.852	8.11	0.464	305	145
	x 100	11300	3680	9.44	5.39	988	350	1150	534	0.852	9.01	0.386	210	127
	x 86	9450	3130	9.28	5.34	850	299	977	456	0.849	10.2	0.318	137	110
	x 71	7620	2540	9.18	5.30	706	246	799	374	0.853	11.9	0.250	80.2	90.4
	x 60	6120	2060	8.96	5.20	584	201	656	305	0.846	14.1	0.197	47.2	76.4
	x 52	5260	1780	8.91	5.18	510	174	567	264	0.847	15.8	0.167	31.8	66.3
	x 46	4570	1550	8.82	5.13	450	152	497	231	0.847	17.7	0.143	22.2	58.7
152 x 152	x 51	3230	1020	7.04	3.96	379	130	438	199	0.848	10.1	0.0610	48.8	65.2
	x 44	2700	860	6.94	3.92	326	110	372	169	0.847	11.5	0.0500	31.7	56.1
	x 37	2210	706	6.85	3.87	273	91.5	309	140	0.848	13.3	0.0400	19.2	47.1
	x 30	1750	560	6.76	3.83	222	73.3	248	112	0.847	16.1	0.0310	10.5	38.3
	x 23	1250	400	6.54	3.70	164	52.6	182	80.1	0.842	20.6	0.0210	4.63	29.2

Table 11 - Eurocodes 3 – Member Dimensions – (Bluebook of Steel, 2026)

Section Designation	Member Dimension														
	Mass per metre	Depth of section	Width of section	Thickness	Root radius	Depth between fillets	Depth between fillets	Ratios for local buckling		Dimensions for detailing			Surface area		
				Web	Flange			Web	Flange	End clearance	Notch		Per metre	Per tonne	
				t _w	t _f						C	N			n
kg/m	h	b	t _w	t _f	r	d	c _w /t _w	c _f /t _f	C	N	n	m ²	m ²		
305 x 165	x 54	54.0	310.4	166.9	7.9	13.7	8.9	265.2	33.6	5.15	6	90	24	1.26	23.3
	x 46	46.1	306.6	165.7	6.7	11.8	8.9	265.2	39.6	5.98	5	90	22	1.25	27.1
	x 40	40.3	303.4	165.0	6.0	10.2	8.9	265.2	44.2	6.92	5	90	20	1.24	30.8
254 x 146	x 43	43.0	259.6	147.3	7.2	12.7	7.6	219.0	30.4	4.92	6	82	22	1.08	25.1
	x 37	37.0	256.0	146.4	6.3	10.9	7.6	219.0	34.8	5.73	5	82	20	1.07	28.9
	x 31	31.1	251.4	146.1	6.0	8.6	7.6	219.0	36.5	7.26	5	82	18	1.06	34.1
254 x 102	x 28	28.3	260.4	102.2	6.3	10.0	7.6	225.2	35.7	4.04	5	58	18	0.904	31.9
	x 25	25.2	257.2	101.9	6.0	8.4	7.6	225.2	37.5	4.80	5	58	16	0.897	35.6
	x 22	22.0	254.0	101.6	5.7	6.8	7.6	225.2	39.5	5.93	5	58	16	0.890	40.5
203 x 133	x 30	30.0	206.8	133.9	6.4	9.6	7.6	172.4	26.9	5.85	5	74	18	0.923	30.8
	x 25	25.1	203.2	133.2	5.7	7.8	7.6	172.4	30.2	7.20	5	74	16	0.915	36.5
203 x 102	x 23	23.1	203.2	101.8	5.4	9.3	7.6	169.4	31.4	4.37	5	60	18	0.790	34.2
178 x 102	x 19	19.0	177.8	101.2	4.8	7.9	7.6	146.8	30.6	5.14	4	60	16	0.738	38.8
152 x 89	x 16	16.0	152.4	88.7	4.5	7.7	7.6	121.8	27.1	4.48	4	54	16	0.638	39.9
127 x 76	x 13	13.0	127.0	76.0	4.0	7.6	7.6	96.6	24.2	3.74	4	46	16	0.537	41.3

Table 12 - Eurocodes 3 – Member Properties – (Bluebook of Steel, 2026)

Section Designation	Member Properties													
	Second moment of area		Radius of gyration		Elastic modulus		Plastic modulus		Buckling parameter	Torsional index	Warping constant	Torsional constant	Area of section	
	Axis y-y cm ⁴	Axis z-z cm ⁴	Axis y-y cm	Axis z-z cm	Axis y-y cm ³	Axis z-z cm ³	Axis y-y cm ³	Axis z-z cm ³	<i>U</i>	<i>X</i>	<i>I_w</i> dm ⁶	<i>I_T</i> cm ⁴	<i>A</i> cm ²	
305 x 165 x 54 x 46 x 40	11700	1060	13.0	3.93	754	127	846	196	0.888	23.6	0.234	34.8	68.8	
	9900	896	13.0	3.90	646	108	720	166	0.890	27.1	0.195	22.2	58.7	
	8500	764	12.9	3.86	560	92.6	623	142	0.889	31.0	0.164	14.7	51.3	
254 x 146 x 43 x 37 x 31	6540	677	10.9	3.52	504	92	566	141	0.890	21.1	0.103	23.9	54.8	
	5540	571	10.8	3.48	433	78	483	119	0.889	24.3	0.0857	15.3	47.2	
	4410	448	10.5	3.36	351	61.3	393	94.1	0.879	29.6	0.0660	8.55	39.7	
254 x 102 x 28 x 25 x 22	4000	179	10.5	2.22	308	34.9	353	54.8	0.874	27.5	0.0280	9.57	36.1	
	3410	149	10.3	2.15	266	29.2	306	46	0.868	31.4	0.0230	6.42	32.0	
	2840	119	10.1	2.06	224	23.5	259	37.3	0.856	36.3	0.0182	4.15	28.0	
203 x 133 x 30 x 25	2900	385	8.71	3.17	280	57.5	314	88.2	0.881	21.5	0.0374	10.3	38.2	
	2340	308	8.56	3.10	230	46.2	258	70.9	0.877	25.6	0.0294	5.96	32.0	
203 x 102 x 23	2100	164	8.46	2.36	207	32.2	234	49.7	0.888	22.4	0.0154	7.02	29.4	
178 x 102 x 19	1360	137	7.48	2.37	153	27	171	41.6	0.886	22.6	0.00990	4.41	24.3	
152 x 89 x 16	834	89.8	6.41	2.10	109	20.2	123	31.2	0.889	19.5	0.00470	3.56	20.3	
127 x 76 x 13	473	55.7	5.35	1.84	74.6	14.7	84.2	22.6	0.894	16.3	0.00200	2.85	16.5	

Table 13 - Eurocodes 3 – Universal Column - Member Dimensions – (Bluebook of Steel, 2026)

Section Designation		Member Dimension													
		Mass per metre	Depth of section	Width of section	Thickness	Root radius	Depth between fillets	Depth between fillets	Ratios for local buckling		Dimensions for detailing			Surface area	
					Web	Flange			Web	Flange	End clearance	Notch		Per metre	Per tonne
			h	b	t _w	t _f	r	d	c _w /t _w	c _f /t _f	C	N	n		
		kg/m	mm	mm	mm	mm	mm	mm			mm	mm	mm	m ²	m ²
254 x 254	x 167	167.1	289.1	265.2	19.2	31.7	12.7	200.3	10.4	3.48	12	134	46	1.58	9.46
	x 132	132.0	276.3	261.3	15.3	25.3	12.7	200.3	13.1	4.36	10	134	38	1.55	11.7
	x 107	107.1	266.7	258.8	12.8	20.5	12.7	200.3	15.6	5.38	8	134	34	1.52	14.2
	x 89	88.9	260.3	256.3	10.3	17.3	12.7	200.3	19.4	6.38	7	134	30	1.50	16.9
	x 73	73.1	254.1	254.6	8.6	14.2	12.7	200.3	23.3	7.77	6	134	28	1.49	20.4
203 x 203	x 127	127.5	241.4	213.9	18.1	30.1	10.2	160.8	8.88	2.91	11	108	42	1.28	10.0
	x 113	113.5	235.0	212.1	16.3	26.9	10.2	160.8	9.87	3.26	10	108	38	1.27	11.2
	x 100	99.6	228.6	210.3	14.5	23.7	10.2	160.8	11.1	3.70	9	108	34	1.25	12.6
	x 86	86.1	222.2	209.1	12.7	20.5	10.2	160.8	12.7	4.29	8	110	32	1.24	14.4
	x 71	71.0	215.8	206.4	10.0	17.3	10.2	160.8	16.1	5.09	7	110	28	1.22	17.2
	x 60	60.0	209.6	205.8	9.4	14.2	10.2	160.8	17.1	6.20	7	110	26	1.21	20.2
	x 52	52.0	206.2	204.3	7.9	12.5	10.2	160.8	20.4	7.04	6	110	24	1.20	23.1
	x 46	46.1	203.2	203.6	7.2	11.0	10.2	160.8	22.3	8.00	6	110	22	1.19	25.8
152 x 152	x 51	51.2	170.2	157.4	11.0	15.7	7.6	123.6	11.2	4.18	8	84	24	0.935	18.3
	x 44	44.0	166.0	155.9	9.5	13.6	7.6	123.6	13.0	4.82	7	84	22	0.924	21.0
	x 37	37.0	161.8	154.4	8.0	11.5	7.6	123.6	15.5	5.70	6	84	20	0.912	24.6
	x 30	30.0	157.6	152.9	6.5	9.4	7.6	123.6	19.0	6.98	5	84	18	0.901	30.0
	x 23	23.0	152.4	152.2	5.8	6.8	7.6	123.6	21.3	9.65	5	84	16	0.889	38.7

Table 14 - Eurocodes 3 – Universal Column - Member Properties – (Bluebook of Steel, 2026)

Section Designation		Member Properties												
		Second moment of area		Radius of gyration		Elastic modulus		Plastic modulus		Buckling parameter	Torsional index	Warping constant	Torsional constant	Area of section
		Axis y-y cm ⁴	Axis z-z cm ⁴	Axis y-y cm	Axis z-z cm	Axis y-y cm ³	Axis z-z cm ³	Axis y-y cm ³	Axis z-z cm ³	<i>U</i>	<i>X</i>	<i>I_w</i> dm ⁶	<i>I_T</i> cm ⁴	<i>A</i> cm ²
254 x 254	x 167	30000	9870	11.9	6.81	2080	744	2420	1140	0.851	8.48	1.63	626	213
	x 132	22500	7530	11.6	6.69	1630	576	1870	878	0.850	10.3	1.19	319	168
	x 107	17500	5930	11.3	6.59	1310	458	1480	697	0.848	12.4	0.898	172	136
	x 89	14300	4860	11.2	6.55	1100	379	1220	575	0.850	14.5	0.717	102	113
	x 73	11400	3910	11.1	6.48	898	307	992	465	0.849	17.2	0.562	57.6	93.1
203 x 203	x 127	15400	4920	9.75	5.50	1280	460	1520	704	0.856	7.36	0.549	427	162
	x 113	13300	4290	9.59	5.45	1130	404	1330	618	0.852	8.11	0.464	305	145
	x 100	11300	3680	9.44	5.39	988	350	1150	534	0.852	9.01	0.386	210	127
	x 86	9450	3130	9.28	5.34	850	299	977	456	0.849	10.2	0.318	137	110
	x 71	7620	2540	9.18	5.30	706	246	799	374	0.853	11.9	0.250	80.2	90.4
	x 60	6120	2060	8.96	5.20	584	201	656	305	0.846	14.1	0.197	47.2	76.4
	x 52	5260	1780	8.91	5.18	510	174	567	264	0.847	15.8	0.167	31.8	66.3
	x 46	4570	1550	8.82	5.13	450	152	497	231	0.847	17.7	0.143	22.2	58.7
152 x 152	x 51	3230	1020	7.04	3.96	379	130	438	199	0.848	10.1	0.0610	48.8	65.2
	x 44	2700	860	6.94	3.92	326	110	372	169	0.847	11.5	0.0500	31.7	56.1
	x 37	2210	706	6.85	3.87	273	91.5	309	140	0.848	13.3	0.0400	19.2	47.1
	x 30	1750	560	6.76	3.83	222	73.3	248	112	0.847	16.1	0.0310	10.5	38.3
	x 23	1250	400	6.54	3.70	164	52.6	182	80.1	0.842	20.6	0.0210	4.63	29.2

2.5. Known Reinforcement Methods

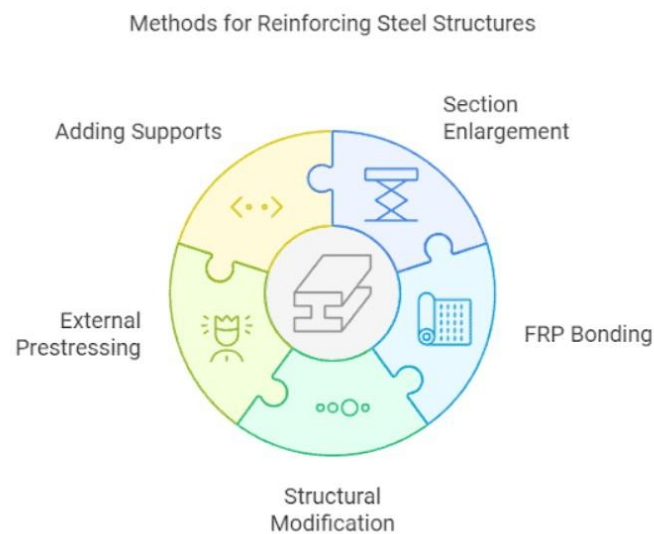


Figure 5 - - Method of Reinforcing Steel Structures (SteelPRO PEB, 2025)

2.5.1 Section Enlargement

Section Enlargement is one of the most common methods to reinforce existing structures, this is where steel plates or sections are welded or bolted to the existing structure to increase its cross-sectional area. By doing this it enhances the load-bearing capacity and stiffness of the existing members.

Section enlargement is commonly applied to columns that may be experiencing overstressing due to increased loading requirements & material degradation. This causes the columns to show signs of local buckling, corrosion loss, or insufficient capacity.

2.5.2 FRP Bonding

Fiber-reinforced polymer (FRP) sheets are externally bonded to the surface of existing steel structures using specialized epoxy adhesives. This technique is used in structural retrofitting and strengthening because the FRP sheets have exceptional tensile strength and corrosion resistance.

When bonded to steel members, the FRP acts as an additional load-bearing layer, increasing the structure's overall tensile capacity, stiffness, and ductility. The adhesive allows for the stresses to transfer between the steel and the FRP, while the fibres help distribute loads uniformly, reduce stress concentrations and prevent crack expansion. This method is effective for strengthening beams, columns, and connections without increasing the structure's weight or altering the cross-sectional dimensions significantly, this making it a practical solution for extending the service life of aging steel structures.

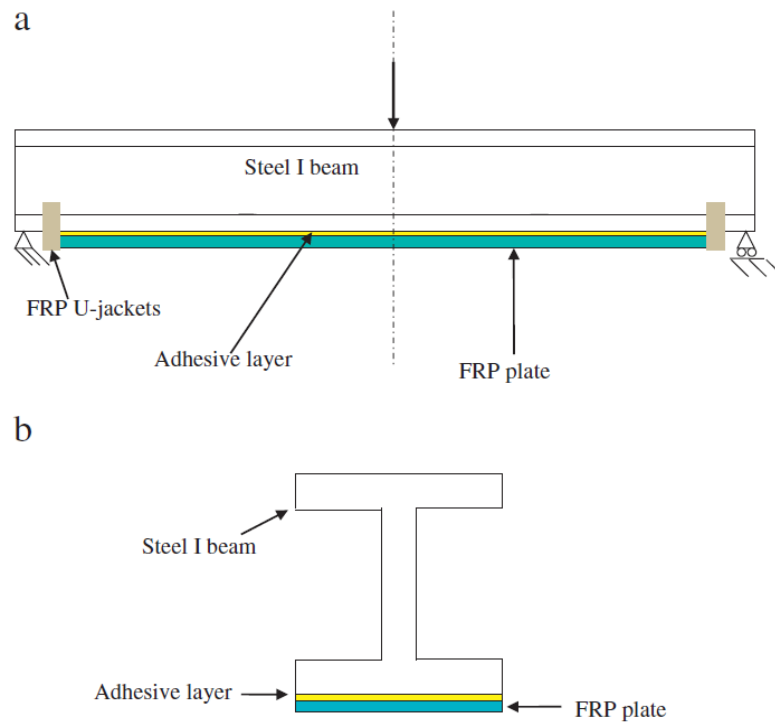


Figure 6 - - (a) Side View. (b) Cross-Sectional View (Teng, Yu and Fernando, 2012)

2.5.3 Structural Modification

Structural Modification includes any change in the structural system itself, such as altering its geometry, replacing and upgrading members, removing or adding structural elements. This method is commonly a second option to adding supports within industries, this is because of the construction required to remove and replace current members, the additional works required to add additional columns such as digging foundations, propping existing steelwork and other temporary works.

Structural modification can involve altering connection types, such as converting pinned connections into fixed connections. This change increases the stiffness of the system and redistributes bending moments, typically reducing bending moments at midspan and allowing loads to be more evenly distributed along the member. As a result, the load-carrying capacity of the member is increased although these moments are then transferred to the connecting member, these members would require further assessment.

2.5.4 External Prestressing

External prestressing is a retrofit technique which uses high-strength steel tendons or cables which are installed outside the existing structural members and then tensioned using hydraulic jacks to introduce a controlled prestressing force. This force generates compressive stresses in critical regions of the structure, which act to counterbalance

existing tensile stresses caused by applied loads. By implementing this method, the technique reduces stress demand in the original steel members, limits crack initiation and expansion and decreases deflections at the midspan.

The externally applied tendons effectively modify the internal force distribution and can introduce beneficial moments that oppose those induced by service loads. This results in an increase in overall load-carrying capacity, stiffness, and fatigue performance of the structure. With the tendons being installed externally, this makes them accessible for inspection, maintenance, and re-tensioning, making the method particularly advantageous for strengthening beams, girders, and bridge structures without significant disruption or added weight to the system.

This installation is common in bridge design because of the fatigue caused by the variable loads being transferred through the structure. This is also an expensive solution with regular maintenance required for inspection and restressing.

2.5.5 Adding Supports

Adding supports is a widely adopted method for the retrofit and strengthening of existing steel structures. This approach involves altering the original load path by introducing additional structural elements to create a bracing system. By redistributing the way loads are transferred through the structure, this can reduce the demand on overstressed members and enhance overall structural performance.

This method is commonly utilised within all industries due to its ease of implementation, and its reduction of on-site construction works. It is particularly effective for horizontal steel members, where the introduction of additional braces can reduce effective span lengths and decrease the bending moments. By doing this it can turn a simply supported beam into a continuous beam, resulting in a more efficient distribution of internal forces. Additional members may also be introduced to improve lateral stability, thereby reducing structural sway and reduce the risk of buckling.

Adding supports is commonly required in all industries due to the response to increased loading conditions, this may arise from changes in building use, the addition of new equipment with greater loads or expansion to the structure.

However, it is important to recognise that such modifications will transfer additional forces to other elements of the structure such as columns and foundations. Therefore, additional assessments on other structural elements are necessary to ensure that all components can safely accommodate the revised load distribution.

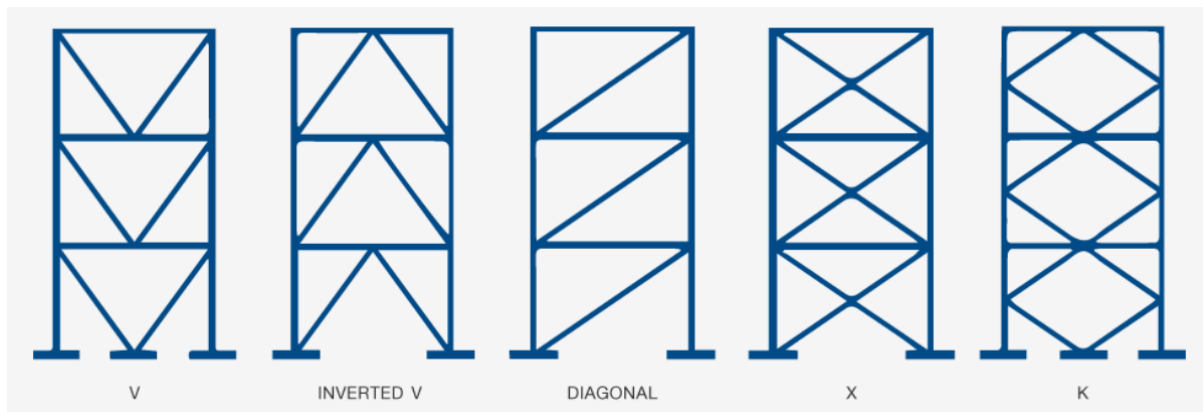


Figure 7 - Common types of bracing (Recal Global, 2026)

2.6. Previous Research between BS449 / BS5950 & EC3

Celikag & Ocal (2006) Although this research does not evaluate BS449 it provides a direct comparison of frame performance between BS 5950 and Eurocode 3, by focusing on frame weights and load-carrying capacity. The key takeaway from the research paper is that designs in accordance with EC3 were up to 55% in comparison to the BS5950, although if additional load applies then BS5950 could sustain more loads than EC3, giving the result that BS5950 allows for future development on the structure acceptable.

“When the weights of both moment and braced frames are considered, generally, the ones designed by EC3 are lighter than those designed by BS 5950 by up to 55 percent, except the applied load increment case of the moment frames, where the frames designed by each code have equal weights despite the fact that they are made of different member sizes. On the other hand, when the same frames were subjected to additional loading then the frames designed by BS 5950 are found to be able to carry more loads than those of the EC3.” (Celikag & Ocal. 2006)

Issa (2010), Similar to Celikag & Ocal, the thesis offers a comprehensive technical breakdown and comparing the specific equations and cross-section classifications used in BS 5950 and Eurocode 3. This thesis highlights how the loads applied can differ between standards based on the load factors and load combinations, this highlighted that the method applied in EC3 indicated that the factored loads applied to the structure will be less than BS 5950.

Loading	Factor γ_f
Dead Load	1.4
Dead Load restraining uplift or overturning	1.0
Dead Load acting with Wind and Imposed loads combined	1.2
Imposed Loads	1.6
Imposed Load acting with Wind Load	1.2
Wind Load	1.4
Wind Load acting with Imposed or Crane Load	1.2
Forces due to temperature effects	1.2
Vertical Crane Load	1.6
Vertical Crane Load acting with Horizontal Crane Loads (crabbing or surge)	1.4
Horizontal Crane Load	1.6
Horizontal Crane Load acting with Vertical	1.4
Crane acting with Wind Load	1.2

Figure 8 - BS 5950 Load Factors (Issa, H. K., 2010, P 69)

Load combination 1: Dead load and imposed load (gravity loads);

Load combination 2: Dead load and wind load;

Load combination 3: Dead load, imposed load and wind load.

Figure 9 - BS 5950 Load combinations (Issa, H. K., 2010, P 70)

Action combination 1: 1.15 Permanent + 1.50 Variable + 0.75 Wind + NHL

Action combination 2: 1.15 Permanent + 0.75 Variable + 1.50 Wind + NHL

Action combination 3: 1.35 Permanent + 0.75 Variable + 0.75 Wind + NHL

Action combination 4: 1.15 Permanent + 1.50 Variable + NHL

Figure 10 - Eurocodes 3 Load Combinations (Issa, H. K., 2010, P 84)

3. Methodology

The following analysis will be undertaken to enable a clear side-by-side comparison of the relevant standards. This approach will give a greater understanding of the differences between each standard and allow the differences to be identified and assessed.

BS 499 is the earliest of the standards being considered, it will be used as the baseline for the initial analysis. The results obtained from the BS 499 assessment will then provide a reference point against both BS5950 & Eurocodes 3. Using this baseline comparison will support a clearer understanding of how each standard influences the final utilisation outcome and will help identify the key drivers behind any differences observed between the assessments.

The analysis that will be undertaken will be of a “Unrestrained Simply Supported Beam” & a “Column in a simple construction” These 2 types of analysis are common within a wide range of industries so will give a greater understanding...

The analysis undertaken will be of an “Unrestrained Simply Supported Beam” and a “Column in A Simple Construction”. These two analysis types are commonly used across a wide range of industries and structural applications.

3.1. Unrestrained Simply Supported Beam Analysis

The first analysis to be undertaken will focus on an unrestrained simply supported beam. To make the comparison representative of how the analysis would have been carried out when each standard was issued, several key considerations will be included: -

- Material Properties will be done in relevance with the available materials at the time.
- General live/imposed loads will be taken from the relevant standards.

The analysis for all standards will be based on the following information: -

Purpose of member	=	Supporting a single spanning flooring for “General duty walkways”
Member length	=	4m Length

Steel Grade	=	Relevant to the availability at the time of the Standard. S235 – BS499 S275 – BS5950 S355 – Eurocodes 3
Area applied to Member	=	4m length x 3m wide (12m ²)
Permeant Load	=	Self Weight (Assumed no permanent equipment)
Variable Load	=	Access Loads = 5Kn/m ² - General duty walkways Wind Load & Snow Load = Not Applicable as the member will be internal members only Assumed an additional maintenance load = 1kN/m ² Open mesh flooring installed on top of steel = 1.5kN/m ² (No Lateral restraint.)

The following analysis will be undertaken (Refer to Appendix for full Analysis): -

- 1) Analysis 1 - BS449 – Basis of comparison (Appendix D)
- 2) Analysis 2 - BS5950 - Same member size as BS449 analysis (Appendix E)
- 3) Analysis 3 - BS5950 – Utilised Member (Appendix F)
- 4) Analysis 4 - Eurocodes 3 – Same member size as BS449 analysis (Appendix G)
- 5) Analysis 5 - Eurocodes 3 – Utilised Member (Appendix H)

3.2. Column Analysis

The analysis will be done by transferring loads applied from section “3.1. *Simply Supported Beam*” and applying loads in both directions at a 6m height. Key considerations are as follows: -

- Material Properties will be done in relevance with the available materials at the time.
- Loads transferred from beam analysis in one direction for both X & Y axis. With the same load applied in the opposing direction with 5Kn less to allow for eccentricity.

The analysis for all standards will be based on the following information: -

Purpose of member	=	Internal column with reactions from all 4 directions at the top of column”
Column length	=	6m Length
Steel Grade	=	Relevant to the availability at the time of the Standard. S235 – BS499 S275 – BS5950 S355 – Eurocodes 3
Reaction Breakdown	=	R1x = Transferred Beam Load R2y = Transferred Beam Load R3x = Transferred Beam Load – 5kN R4y = Transferred Beam Load – 5kN

The following analysis will be undertaken (Refer to Appendix for full Analysis): -

- 1) Analysis 6 - BS449 – Basis of comparison (Appendix I)
- 2) Analysis 7 - BS5950 - Same member size as BS449 analysis (Appendix J)
- 3) Analysis 8 - BS5950 Column Analysis To BS5950 Beam Loads Transferred & Same Member as BS449 (Appendix K)
- 4) Analysis 9 - BS5950 Column Analysis To BS5950 Beam Loads Transferred (Appendix L)
- 5) Analysis 10 - Eurocodes 3 Column Analysis to BS449 Beam Loads Transferred & Same Member (Appendix M)

- 6) Eurocodes 3 Column Analysis to BS449 Beam Loads Transferred – Utilised Member (Appendix N)
- 7) Eurocodes 3 Column Analysis to Eurocodes 3 Beam Loads Transferred – Same Member as BS449 (Appendix O)
- 8) Analysis 13 - Eurocodes 3 Column Analysis to Eurocodes 3 Beam Loads Transferred – Utilised Member (Appendix P)

4. Result / findings

4.3. Simply Supported Beam Results

The following results show the Summary Tables from each of the analysis:-

Table 15 - Analysis 1:- BS449 – Basis of comparison (Appendix D)

Summary Table			
Category	Design Limit	Provided	Utilisation
Bending Stress Utilisation	81.79	180.00	45.44%
Lateral Torsional Buckling	81.79	123.58	66.18%
Web Shear Stress Check	28.55	125.00	22.84%
Combined Bending And Shear	95.57	250.00	38.23%
Deflection Check	2.87	11.11	25.82%

Table 16 - Analysis 2:- BS5950 - Same member size as BS449 analysis (Appendix G)

Summary Table			
Category	Design Limit	Provided	Utilisation
Moment Capacity	71.32	171.33	41.63%
Shear Utilisation	71.32	180.22	39.57%
Lateral Torsional Buckling	71.32	103.51	68.90%
Deflection Check	4.70	11.11	42.28%

Table 17 - Analysis 3:- BS5950 – Utilised Member (Appendix H)

Summary Table			
Category	Design Limit	Provided	Utilisation
Moment Capacity	71.07	132.83	53.50%
Shear Utilisation	71.07	159.67	44.51%
Lateral Torsional Buckling	71.07	81.05	87.68%
Deflection Check	7.17	11.11	64.54%

Table 18 - Analysis 4:- Eurocodes 3 – Same member size as BS449 analysis (Appendix I)

Summary Table			
Category	Design Limit	Provided	Utilisation
Bending Resistance	63.31	221.17	28.63%
Shear Resistance	63.31	326.13	19.41%
Lateral Torsional Buckling	0.45	1.00	44.90%
Deflection Check	4.19	11.11	37.72%

Table 19 - Analysis 5 - Eurocodes 3 – Utilised Member (Appendix J)

Summary Table			
Category	Design Limit	Provided	Utilisation
Bending Resistance	63.31	221.17	28.63%
Shear Resistance	63.31	326.13	19.41%
Lateral Torsional Buckling	0.45	1.00	44.90%
Deflection Check	4.19	11.11	37.72%

4.3. Column Results

Table 20 - Analysis 6 - BS449 – Basis of comparison (Appendix K)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression	1.00	1.00	26.88%
Bending Moment	0.70	1.00	69.85%
Combined Axial Compression and Bending	0.97	1.00	96.73%

Table 21 - Analysis 7 - BS5950 Column Analysis To BS449 Beam Loads Transferred & Same Member (Appendix L)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression	349.93	956.18	36.60%
Bending Moment	0.52	1.00	52.40%
Combined Axial Compression and Bending	0.89	1.00	88.99%

There is no utilisation of BS5950 compared to BS449 due to no member suitable.

Table 22 - Analysis 8 - BS5950 Column Analysis To BS5950 Beam Loads Transferred & Same Member as BS449 (Appendix M)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression	554.09	956.18	57.95%
Bending Moment	0.52	1.00	52.40%
Combined Axial Compression and Bending	1.10	1.00	110.35%

Table 23 - Analysis 9 - BS5950 Column Analysis To BS5950 Beam Loads Transferred (Appendix N)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression	554.74	1142.11	48.57%
Bending Moment	0.43	1.00	42.82%
Combined Axial Compression and Bending	0.91	1.00	91.39%

Table 24 - Analysis 10 - Eurocodes 3 – Same member size as BS449 analysis (Appendix O)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	349.93	2712.2	12.90%
Buckling Resistance	349.93	1667.93	20.98%
Bending Moment	0.41	1.00	40.59%
Combined Axial & Bending	0.62	1.00	61.57%

Table 25 - Analysis 11 - Eurocodes 3 Column Analysis to BS449 Beam Loads Transferred – Utilised Member (Appendix P)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	349.11	2083.85	16.75%
Buckling Resistance	349.11	1271.05	27.47%
Bending Moment	0.54	1.00	53.59%
Combined Axial & Bending	0.81	1.00	81.05%

Table 26 - Analysis 12 - Eurocodes 3 Column Analysis to Eurocodes 3 Beam Loads Transferred – Same Member as BS449 (Appendix O)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	490.01	2712.2	18.07%
Buckling Resistance	490.01	1667.93	29.38%
Bending Moment	0.41	1.00	40.59%
Combined Axial & Bending	0.70	1.00	69.97%

Table 27 - Analysis 13 - Eurocodes 3 Column Analysis to Eurocodes 3 Beam Loads Transferred – Utilised Member (Appendix P)

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	489.19	2083.85	23.48%
Buckling Resistance	489.19	1271.05	38.49%
Bending Moment	0.54	1.00	53.59%
Combined Axial & Bending	0.92	1.00	92.07%

5. Discussion

When analysing the unrestrained simply supported beam, the initial stage across all design standards involves determining the total applied load through the appropriate load factors and load combinations. Of the three standards considered, BS 449 (22.90kN/m) produces the lowest applied load on the member, while BS 5950 results in the highest (35.66kN/m). Eurocode 3 (31.66kN/m) adopts a more rigorous approach in comparison to BS5950 with the application of load factors dependant on different load combinations, resulting in applied loads that are greater than those obtained using BS 449, but lower than those determined using BS 5950.

Table 28 - Applied Loads - Difference (%)

Applied Loads - Difference (%)			
Standard	Load Applied	Difference to BS449	Difference to BS5950
BS449	22.90 kN/m	-	-
BS5950	35.66 kN/m	43.58%	-
EC3	31.66 kN/m	32.11%	11.88%

An additional key factor influencing the analysis is the design philosophy for each standard. BS 449 is based on Permissible Stress Design, whereas BS 5950 and Eurocode 3 adopt a Limit State Design approach. This distinction affects the use of the section properties, particularly the elastic and plastic section modulus. The chosen design philosophy has a significant influence on the determination of moment capacity and the assessment of lateral torsional buckling resistance. The below table shows the difference in the section properties for the member that is suitable for BS449 – UB305x165x40.

Table 29 - Section Modulus for UB305x165x40 – Differences (%)

Section Modulus for UB305x165x40 – Differences (%)		
Standard	Load Applied	Difference to BS449
BS449 – Elastic Modulus	560 cm ³	-
BS5950 – Plastic Modulus	623 cm ³	10.65%
EC3 – Plastic Modulus	623 cm ³	10.65%

For column analysis in simple construction, the governing category is typically the combined effect of axial compression and bending moment. The eccentricity of the applied load is a critical factor in determining the column response across all design standards. This is significant when the eccentricity occurs about the member's minor axis, where the reduced stiffness and lower bending resistance can have an influence on the overall capacity.

The calculation of the column's axial compression resistance also varies between the design standards, primarily due to differences in how the compressive strength parameter, p_c , or equivalent resistance value, is determined. In BS 449, p_c is obtained from Table 17a, while in BS 5950 it is derived from Table 24(b,c). In Eurocode 3, the axial resistance is determined using $N_{c,Rd} = \frac{A f_y}{\gamma_{M0}}$.

For the column analysed, BS 449 gives a p_c value of 85 N/mm², which is considerably lower than the value of 125.15 N/mm² obtained using BS 5950. Eurocode 3 uses a yield strength, f_y , of 355 N/mm² in the determination of the axial resistance. This shows the progressive development in the calculated axial capacity of the member across the standards.

From the results of the analysis, it was interesting to find that for the column design for BS5950 passed the analysis with the BS449 loads transferred (Appendix J) and had a less utilisation than the original BS449 analysis (Appendix I) but when undertaking the loads transferred from the BS5950 analysis (Appendix K) it fails under Combined Axial and bending, Which means the same design fails during a more modern standard, this is the result in the larger loads created by the load factors in the beam design being transferred to the column. The column design would need to be increased to withstand the larger loads.

One aspect that has not been addressed in the analysis is the influence of different connection conditions on member behaviour. In particular, the comparative effects of fixed-fixed, fixed-pinned, and pinned-pinned end conditions. These connection types can significantly affect the member's effective length, stiffness, bending moment distribution, and overall structural capacity.

6. Conclusion and Recommendations

The comparative study undertaken has reviewed the structural design standards BS 449, BS 5950 and Eurocode 3. The research has considered previous studies, the historical development of structural steel, changes in mechanical properties, and the analytical differences between the standards. This has provided a broader understanding of how steel design has progressed from permissible stress design to modern limit state design. The following outcomes were established at the beginning of the study, and these will now be reviewed in relation to the findings of the research.

- 1) Understand historic and modern steel production improvements and its effects on the structural analysis through the structural design standards.

From BS449 to Eurocodes 3 have mainly improved due to the steel production and improvement in material testing. Within BS449, the steel production was commonly based on Grade 40 & 43 (S235 & S2375 modern steel grade equivalent) with current steel grades ranging from S235 TO S460, with S355 being the most common available grade. Also the advancement in testing has enabled the structural design transfer from permissible stress design being constrained to the elastic behaviour to limit state design utilising the member properties to its maximum. Thus showing the conservative approach when designing members and not utilising the member to its maximum capability.

- 2) Identify and analyse key differences between structural design standards BS449 / BS 5950 & Eurocodes 3.

One of the most significant differences identified within the analysis is the increase in applied load resulting from the different load combinations used by each design standard. The applied load increases by 43.58% from BS 449 to BS 5950 and by 32.11% from BS 449 to Eurocode 3. When considered alongside the change in design philosophy from elastic permissible stress design to plastic limit state design, this has an important effect on the assessment of existing structures. Although BS 5950 and Eurocode 3 allow the use of the plastic section modulus, the increase in section capacity for the same member is only 10.65% when compared with the elastic section modulus used under BS 449. The increase in applied design load is considerably greater than the increase in available section modulus, which may result in existing members becoming over-utilised when reassessed using modern design standards.

The use of load combinations within Eurocode 3 also has a significant influence on the outcome of the analysis. Compared with BS 5950, Eurocode 3 provides a more refined approach using partial factors and combination factors, allowing the applied loads to be reviewed more accurately for different design situations. Eurocode 3 produce utilisation ratios that are more compatible with BS 449 in some cases. BS 5950 can

produce higher applied design loads, which may lead to members being more highly utilised or failing when compared with the original BS 449 assessment.

- 3) Conduct a detailed structural analysis of structural members to BS 449 / BS 5950 & Eurocodes 3.

Analysis was undertaken in accordance with BS 449, BS 5950 and Eurocode 3, using the same structural member and considering the transfer of loads into the modern design standards. The results show that BS 449 adopts a more conservative design approach, which is largely due to its permissible stress design philosophy and reliance on elastic behaviour. When the same member was assessed using BS 5950, the column required an increase in member size compared with the original BS 449 design, due to the use of factored loads and limit state design principles. By comparison, Eurocode 3 provided a more refined method of design, allowing a more economical overall design through the use of refined load combinations.

If additional loads were applied to the structural members, the BS 449 design may appear to provide greater reserve capacity because the member was originally designed within elastic stress limits and had not fully utilised its plastic capacity. Members designed to BS 5950 and Eurocode 3 are generally assessed closer to their ultimate resistance, meaning that the available spare capacity may be lower if the members are already highly utilised. Therefore, while modern standards can produce more efficient and economical designs, they may also result in less flexibility / future proof with potential load increase.

- 4) Review the analysis and critically evaluate to most suitable reinforcement technique to ensure it complies with current design codes.

As identified within the discussion, each design code adopts a different method for determining the loads applied to structural members. This has a significant influence on the analysis, as variations in load factors and load combinations can increase the uniformly distributed loads on beams or the axial loads transferred into columns. Where a beam fails due to deflection, several reinforcement techniques can be considered. One of the most common and practical solutions is the addition of supports, as this can reduce the effective span of the member and redistribute the load. An example of this is where bracing may be introduced between the beam and column to provide additional restraint and reduce deflection in the affected member. Structural modification may also be suitable, although replacing an existing member with a larger section can be difficult during construction due to access requirements for installation, temporary works required and disruption to the existing structure. FRP bonding may provide an alternative strengthening solution, but it is generally considered less

practical for this application and may be more expensive than traditional steelwork reinforcement methods.

For column design, where failure occurs due to the combined effects of axial compression and bending, the most suitable strengthening method is often to increase the member's stiffness and lateral stability. This can be achieved by welding plates between the flanges to form a boxed column section. By converting the original open section into a closed or partially closed section, the column's torsional stiffness is increased, reducing the likelihood to twist under load and improving its overall resistance to combined axial and bending effects. This method can also increase the member's load-carrying capacity. The main limitation of this technique is the difficulty of installation, with steel columns may be up to 15 metres in length and can include connections at several different elevations, making continuous plate welding challenging.

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9. Appendix A – BS5950 – Effective Length

26 Effective length of compression flanges for beams and girders

a) For simply supported beams and girders where no lateral restraint of the compression flange is provided but where each end of the beam is restrained against *torsion*, the effective length l of the compression flange to be used in Clauses 19, 20 and 21, shall be taken as follows:

- 1) with ends of compression flanges unrestrained against lateral bending (i.e. free to rotate in plan at the bearings)

$$l = \text{span}$$

- 2) with ends of compression flanges partially restrained against lateral bending (i.e. cleated flange connections)

$$l = 0.85 \times \text{span}$$

- 3) with ends of compression flanges fully restrained against lateral bending (i.e. not free to rotate in plan at the bearings)

$$l = 0.7 \times \text{span}$$

Figure 11 - BS449-2:1969 - Clause 26

10. Appendix B – Universal Beam Properties (BS449)

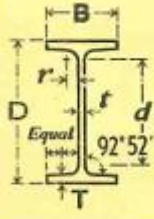
68 DORMAN LONG									
 UNIVERSAL BEAMS TAPER FLANGES Dimensions and Properties METRIC									
Serial Size	Weight		Depth of Section D	Width of Section B	Thickness		Root Radius r	Depth between Fillet d	Area of Section
	per foot	per metre			Web t	Flange T			
ins	lbs	Kg	mm	mm	mm	mm	mm	mm	cm ²
21 × 8½	82	122	545	212	12·8	21·3	12·7	473	155·6
	73	109	539	211	11·6	18·8	12·7	473	138·4
	68	101	537	210	10·9	17·4	12·7	473	129·1
	62	92	533	209	10·2	15·6	12·7	473	117·6
18 × 7½	66	98	467	193	11·4	19·6	10·2	404	125·2
	60	89	464	192	10·6	17·7	10·2	404	113·8
	55	82	460	191	9·9	16·0	10·2	404	104·4
	50	74	457	190·5	9·1	14·5	10·2	404	94·9
16 × 7	50	74	413	180	9·7	16·0	10·2	357	94·9
	45	67	409	179	8·8	14·3	10·2	357	85·4
	40	60	406	178	7·8	12·8	10·2	357	75·9
	36	54	403	178	7·6	10·9	10·2	357	68·3
14 × 6½	45	67	364	173	9·1	15·7	10·2	309	85·3
	38	57	359	172	8·0	13·0	10·2	309	72·1
	34	51	356	171·5	7·3	11·5	10·2	309	64·5
	30	45	352	171	6·9	9·7	10·2	309	56·9
12 × 6½	36	54	311	167	7·7	13·7	8·9	263	68·3
	31	46	307	166	6·7	11·8	8·9	263	58·8
	27	40	304	165	6·1	10·2	8·9	263	51·4
10 × 5½	29	43	260	147	7·3	12·7	7·6	216	55·0
	25	37	256	146·4	6·4	10·9	7·6	216	47·4
	21	31	251	146	6·1	8·6	7·6	216	39·9
8 × 5½	20	30	207	134	6·3	9·6	7·6	170	38·0
	17	25	203	133	5·8	7·8	7·6	170	32·3

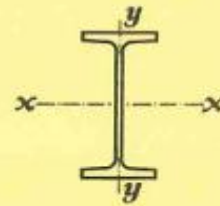
Figure 12 - BS449 - Universal Beam Dimensions (Dorman Long (Steel) Ltd, 1960)

UNIVERSAL BEAMS

TAPER FLANGES

Dimensions and Properties

METRIC



Moment of Inertia			Radius of Gyration		Elastic Modulus		Plastic Modulus	
Axis x-x		Axis	Axis	Axis	Axis	Axis	Axis	Axis
Gross	Net	y-y	x-x	y-y	x-x	y-y	x-x	y-y
cm ⁴	cm ⁴	cm ⁴	cm	cm	cm ³	cm ³	cm ³	cm ³
76078	69119	3208	22.1	4.54	2794	303	3198	484
66610	60541	2755	21.9	4.46	2469	262	2820	419
61531	55942	2512	21.8	4.41	2293	239	2616	383
55225	50243	2212	21.7	4.34	2072	211	2362	340
45653	40978	2216	19.1	4.21	1954	230	2229	366
40957	36774	1960	19.0	4.15	1767	204	2012	325
37039	33278	1746	18.8	4.09	1610	183	1830	292
33324	29944	1547	18.7	4.04	1458	162	1654	260
27279	24287	1448	17.0	3.91	1322	161	1502	257
24279	21619	1269	16.9	3.86	1186	142	1343	226
21458	19101	1104	16.8	3.81	1056	124	1191	198
18576	16591	922	16.5	3.67	923	104	1046	167
19483	17215	1278	15.1	3.87	1071	148	1210	234
16038	14185	1026	14.9	3.78	894	119	1007	190
14118	12495	885	14.8	3.71	794	103	893	165
12052	10697	730	14.6	3.58	685	85.4	772	137
11686	10243	988	13.1	3.81	752	119	843	187
9924	8695	825	13.0	3.73	646	99.5	721	157
8500	7455	691	12.9	3.66	560	83.7	623	133
6546	5748	633	10.9	3.40	504	86.0	567	135
5544	4866	528	10.8	3.33	433	72.1	484	114
4427	3900	406	10.5	3.18	352	55.5	395	88.8
2880	2493	354	8.71	3.05	279	52.9	313	83.7
2348	2040	280	8.53	2.95	231	41.9	259	67.0

In calculating the Net Moment of Inertia about x-x, holes have been deducted from each flange in accordance with the table on page 56.

Figure 13 - BS449 - Universal Beam Properties (Dorman Long (Steel) Ltd, 1960)

11. Appendix C – Universal Column Properties (BS449)

70 DORMAN LONG UNIVERSAL COLUMNS PARALLEL FLANGES Dimensions and Properties METRIC									
Serial Size	Weight		Depth of Section D	Width of Section B	Thickness		Root Radius r	Depth between Filletts d	Area of Section
	per foot	per metre			Web t	Flange T			
<i>ins</i>	<i>lbs</i>	<i>Kg</i>	<i>mm</i>	<i>mm</i>	<i>mm</i>	<i>mm</i>	<i>mm</i>	<i>mm</i>	<i>cm²</i>
14 × 16	426	634	475	424	47.6	77.0	15.2	290	808.1
	264	393	419	407	30.6	49.2	15.2	290	500.9
	202	301	397	400	23.6	38.2	15.2	290	383.2
	158	235	381	395	18.5	30.2	15.2	290	299.8
Column Core	320	476	427	424	48.0	53.2	15.2	290	607.2
14 × 14½	136	202	375	374	16.8	27.0	15.2	290	257.9
	119	177	368	372	14.5	23.8	15.2	290	225.7
	103	153	362	370	12.6	20.7	15.2	290	195.2
	87	129	356	368	10.7	17.5	15.2	290	164.9
12 × 12	190	283	365	322	26.9	44.1	15.2	247	360.4
	161	240	353	318	23.0	37.7	15.2	247	305.6
	133	198	340	314	19.2	31.4	15.2	247	252.3
	106	158	327	311	15.7	25.0	15.2	247	201.2
	92	137	321	309	13.8	21.7	15.2	247	174.6
	79	117	314	307	11.9	18.7	15.2	247	149.8
	65	97	308	305	9.9	15.4	15.2	247	123.3
10 × 10	112	167	289	265	19.2	31.7	12.7	200	212.4
	89	133	276	261	15.6	25.3	12.7	200	168.9
	72	107	267	258	13.0	20.5	12.7	200	136.6
	60	89	260	256	10.5	17.3	12.7	200	114.0
	49	73	254	254	8.6	14.2	12.7	200	92.9
8 × 8	48	71	216	206	10.3	17.3	10.2	161	91.1
	40	59	210	205	9.3	14.2	10.2	161	75.8
	35	52	206	204	8.0	12.5	10.2	161	66.4
	31	46	203	203	7.3	11.0	10.2	161	58.8
6 × 6	25	37	162	154	8.1	11.5	7.6	123.5	47.4
	20	30	157	153	6.6	9.4	7.6	123.5	38.2
	15.7	23	152	152	6.1	6.8	7.6	123.5	29.8

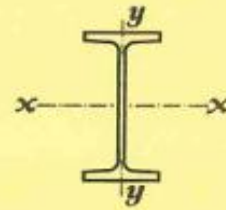
Figure 14 - BS449 - Universal Column Dimensions (Dorman Long (Steel) Ltd, 1960)

UNIVERSAL BEAMS

TAPER FLANGES

Dimensions and Properties

METRIC



Moment of Inertia			Radius of Gyration		Elastic Modulus		Plastic Modulus	
Axis x-x		Axis	Axis	Axis	Axis	Axis	Axis	Axis
Gross	Net	y-y	x-x	y-y	x-x	y-y	x-x	y-y
cm4	cm4	cm4	cm	cm	cm3	cm3	cm3	cm3
76078	69119	3208	22'1	4'54	2794	303	3198	484
66610	60541	2755	21'9	4'46	2469	262	2820	419
61531	55942	2512	21'8	4'41	2293	239	2616	383
55225	50243	2212	21'7	4'34	2072	211	2362	340
45653	40978	2216	19'1	4'21	1954	230	2229	366
40957	36774	1960	19'0	4'15	1767	204	2012	325
37039	33278	1746	18'8	4'09	1610	183	1830	292
33324	29944	1547	18'7	4'04	1458	162	1654	260
27279	24287	1448	17'0	3'91	1322	161	1502	257
24279	21619	1269	16'9	3'86	1186	142	1343	226
21458	19101	1104	16'8	3'81	1056	124	1191	198
18576	16591	922	16'5	3'67	923	104	1046	167
19483	17215	1278	15'1	3'87	1071	148	1210	234
16038	14185	1026	14'9	3'78	894	119	1007	190
14118	12495	885	14'8	3'71	794	103	893	165
12052	10697	730	14'6	3'58	685	85'4	772	137
11686	10243	988	13'1	3'81	752	119	843	187
9924	8695	825	13'0	3'73	646	99'5	721	157
8500	7455	691	12'9	3'66	560	83'7	623	133
6546	5748	633	10'9	3'40	504	86'0	567	135
5544	4866	528	10'8	3'33	433	72'1	484	114
4427	3900	406	10'5	3'18	352	55'5	395	88'8
2880	2493	354	8'71	3'05	279	52'9	313	83'7
2348	2040	280	8'53	2'95	231	41'9	259	67'0

In calculating the Net Moment of Inertia about x-x, holes have been deducted from each flange in accordance with the table on page 56.

Figure 15 - BS449 - Universal Column Properties (Dorman Long (Steel) Ltd, 1960)

12. Appendix D – BS449 Simply Supported Beam Analysis

Member Size

12 x 6½ x 40

D =	304	mm
b	165	mm
d =	263	mm
T =	10.2	mm
t =	6.1	mm
b/T =	16.18	
d/t =	43.11	
ry (Radius of Gyration) =	3.66	cm
Zx (Elastic Modulus) =	560	cm ³
Ix (Second Moment of Area) =	8500	cm ⁴
Effective Length (l)	1	Taken from Clause 26 of BS 449
Beam Length	4	m
Permenant Load - Self Weight	0.40	kN/m
Permenant Load - Open Mesh	4.50	kN/m
Imposed Load - General Duty	15	kN/m
Imposed Load - Service Loads	3.0	kN

Load Combination (wu)

$$w_u = G_k + Q_k$$

Maximum Shear at Ra & Rb

Maximum Shear (Vmax) = 45.80 kNm

Maximum Bending Moment at Mid Point

Maximum Bending Moment (Mmax) = 45.80 kN

Bending Stress Check (fb)

fb = Mmax/Zx 81.79 N/mm²

Allowable Bending Stress (pb) = 180.00 N/mm² For Grade 43

Check fb ≤ pb = 81.79 ≤ 180.00 PASS

Lateral Torsional Buckling Check (fb)

l/ry = 109.29

$$D/T = 29.80$$

From Table 3a, BS449

$$P_{bc,allow} = 123.58 \text{ N/mm}^2 \quad \text{Interpolate if needed See Next Tab "Table 3a, BS 449"}$$

$$\text{Check } f_b \leq p_{bc,allow} = 81.79 \leq 123.58 \quad \text{PASS}$$

Web Shear Stress Check (fq)

$$A_v = \text{clear web depth (d)} \times \text{web thickness (t)} = 1604.30$$

$$\text{Web Shear Stress (fq)} = \frac{V_{max}}{A_v} = \frac{45800}{1604.30} = 28.55 \text{ N/mm}^2$$

$$p_q \text{ from Table 10 in BS449} = 125 \text{ N/mm}^2$$

$$\text{Check } f_q \leq p_q = 28.55 \leq 125.00 \quad \text{PASS}$$

Combined Bending And Shear (fe)

$$\text{Calculate } f_e = \sqrt{f_b^2 + 3f_q^2} = 95.57 \text{ N/mm}^2$$

$$p_e \text{ from Table 1 in BS449} = 250 \text{ N/mm}^2$$

$$\text{Check } f_e \leq p_e = 95.57 \leq 250.00 \quad \text{PASS}$$

Deflection Check (δ)

$$\text{Maximum Deflection } (\delta_{max}) = \frac{5wL^4}{384EI_x} = \frac{1.92E+16}{6.69E+15} = 2.87 \text{ mm}$$

$$\text{Allowable Deflection } (\delta_{Allow}) = \frac{L}{360} = \frac{4000}{360} = 11.11 \text{ mm}$$

$$\text{Check } \delta_{max} \leq \delta_{Allow} = 2.87 \leq 11.11 \quad \text{PASS}$$

Summary Table			
Category	Design Limit	Provided	Utilisation
Bending Stress Utilisation	81.79	180.00	45.44%
Lateral Torsional Buckling	81.79	123.58	66.18%
Web Shear Stress Check	28.55	125.00	22.84%
Combined Bending And Shear	95.57	250.00	38.23%
Deflection Check	2.87	11.11	25.82%

13. Appendix E – BS5950 Analysis to Same Member as BS449

BS5950

Member Size

305 x 165 x 40

D =	303.4	mm
b =	165	
d =	265.2	
T =	10.2	mm
t =	6.0	mm
b/T =	8.09	From Blue Book of Steel
d/t =	44.20	From Blue Book of Steel
ry (Radius of Gyration) =	3.86	
Sx (Plastic Modulus) =	623	cm ³
Ix (Second Moment of Area) =	8500	cm ⁴
Proposed Steel Grade (py)	275	N/mm ²

Beam Length	4	m	Factored Load	
Permanent Load - Self Weight	0.40	kN/m	0.56	kN/m Gk
Permanent Load - Open Mesh	4.50	kN/m	6.30	kN/m Gk
Imposed Load - General Duty	15	kN/m	24	kN/m Qk
Imposed Load - Service Loads	3.0	kN	4.8	kN/m Qk

Load Combination (wu)

$$w_u = 1.4 G_k + 1.6 Q_k$$

Maximum Shear (Fv)

Maximum Shear (Fv) =

71.32 kNm

Maximum Bending Moment (M)

Maximum Bending Moment (M) =

71.32 kN

Material Strength (py)

From Table 9, BS5950 determine py

$$T < 16\text{MM } p_y = 275$$

$$T = 16 - 40\text{MM } p_y = 265$$

$$\epsilon = \sqrt{G_{rde}/P_y}$$

$$1.00$$

Member Classification

From Table 9, BS5950

b/T < 9ε =	8.09	<	9.00
d/t < 80ε =	44.20	<	80.00

Flange is plastic

Web is plastic

Shear Strength

$$d/t < 70\epsilon = 10.20 < 70.00$$

Shear Buckling is not considered

Section Moment Capacity (Mc)

$$\text{For Class 1 Plastic \& Class 2 Compact Section } M_c = p_y S_x = 171.33 \text{ kNm}$$

$$\text{Check } M \leq M_c \quad 71.32 \leq 171.33$$

PASS

Shear capacity of Section (Pv)

$$P_v = 0.6 P_y t D = 300.37 \text{ kN}$$

$$\text{Check } F_v < 0.6 P_v \quad 71.32 \leq 180.22$$

Low Shear Load

Lateral Torsional Buckling (Mx)

Effective Length From Table 13, BS5950 - Both Flanges free to rotate on plan
 $LE = 1.0LLT = 4 \text{ m}$

Determine lateral torsional buckling slenderness (λ_{LT})

$$M_b = p_b S_x \quad \text{For Plastic Section}$$

Obtain p_b from Table 20, BS 5950:-

$$\sqrt{b_w} (LE/ry) = 103.63$$

$$D/T = 29.75$$

$$p_b = 166.16 \text{ N/mm}^2$$

Interpolate if needed See Next Tab
 "Table 20, BS 5950"

$$M_b = p_b S_x = 103.51 \text{ kNm}$$

$$\text{Check } M \leq M_b \quad 71.32 \leq 103.51$$

PASS

Deflection Check (δ)

$$\text{Maximum Deflection } (\delta_{\max}) = \frac{5wL^4}{384EI_x} = \frac{3.14368E+16}{6.6912E+15} = 4.70 \text{ mm}$$

$$\text{Allowable Deflection } (\delta_{\text{Allow}}) = \frac{L}{360} = \frac{4000}{360} = 11.11 \text{ mm}$$

$$\text{Check } \delta_{\max} \leq \delta_{\text{Allow}} = 4.70 \leq 11.11$$

PASS

Summary Table			
Category	Design Limit	Provided	Utilisation
Moment Capacity	71.32	171.33	41.63%
Shear Utilisation	71.32	180.22	39.57%
Lateral Torsional Buckling	71.32	103.51	68.90%
Deflection Check	4.70	11.11	42.28%

14. Appendix F – BS5950 Analysis Utilised Member

BS5950

Member Size

254 x 146 x

31

D =	256	mm
b =	146.4	
d =	219	
T =	10.9	mm
t =	6.3	mm
b/T =	6.72	From Blue Book of Steel
d/t =	34.80	From Blue Book of Steel
ry (Radius of Gyration) =	3.48	
Sx (Plastic Modulus) =	483	cm ³
Ix (Second Moment of Area) =	5540	cm ⁴
Proposed Steel Grade (py)	275	N/mm ²

Beam Length	4	m	Factored Load		
Permanent Load - Self Weight	0.31	kN/m	0.43	kN/m	Gk
Permanent Load - Open Mesh	4.50	kN/m	6.30	kN/m	Gk
Imposed Load - General Duty	15	kN/m	24	kN/m	Qk
Imposed Load - Service Loads	3.0	kN	4.8	kN/m	Qk

Load Combination (wu)

$$w_u = 1.4 G_k + 1.6 Q_k$$

Maximum Shear (Fv)

Maximum Shear (Fv) =

71.07 kNm

Maximum Bending Moment (M)

Maximum Bending Moment (M) =

71.07 kN

Material Strength (py)

From Table 9, BS5950 determine py

T = <16MM py = 275

T = 16 - 40MM py = 265

$$\epsilon = \sqrt{\text{Grade}/P_y}$$

1.00

Member Classification

From Table 9, BS5950

b/T < 9ε =	6.72	<	9.00
d/t < 80ε =	34.80	<	80.00

Flange is plastic

Web is plastic

Shear Strength

d/t < 70ε =	10.90	<	70.00
-------------	-------	---	-------

Shear Buckling is not considered

Section Moment Capacity (Mc)

For Class 1 Plastic & Class 2 Compact Section $M_c = p_y S_x$ = 132.83 kNm

Check $M \leq M_c$ 71.07 ≤ 132.83

PASS

Shear capacity of Section (Pv)

$P_v = 0.6 P_y t D$ 266.11 kN

Check $F_v < 0.6 P_v$ 71.07 ≤ 159.67

Low Shear Load

Lateral Torsional Buckling (Mx)

Effective Length From Table 13, BS5950 - Both Flanges free to rotate on plan

$LE = 1.0 L_{LT}$ 4 m

Determine lateral torsional buckling slenderness (λ_{LT})

$M_b = p_b S_x$ For Plastic Section

Obtain p_b from Table 20, BS 5950:-

$\sqrt{B_w (LE/ry)}$ = 114.94

D/T = 23.49

$P_b =$ 167.80 N/mm²

Interpolate if needed See Next Tab
"Table 20, BS 5950"

$M_b = p_b S_x$ = 81.05 kNm

Check $M \leq M_b$ 71.07 ≤ 81.05

PASS

Deflection Check (δ)

Maximum Deflection (δ_{max}) = $\frac{5wL^4}{384EI_x}$ = $\frac{3.12755E+16}{4.36109E+15}$ = 7.17 mm

Allowable Deflection (δ_{Allow}) = $\frac{L}{360}$ = $\frac{4000}{360}$ = 11.11 mm

Check $\delta_{max} \leq \delta_{Allow}$ = 7.17 ≤ 11.11

PASS

Summary Table			
Category	Design Limit	Provided	Utilisation
Moment Capacity	71.07	132.83	53.50%
Shear Utilisation	71.07	159.67	44.51%
Lateral Torsional Buckling	71.07	81.05	87.68%
Deflection Check	7.17	11.11	64.54%

15. Appendix G – Eurocodes Analysis to Same Member as BS449

Eurocodes

Member Size

305 x 165 x 40

D =	303.4	mm
b =	165	mm
d =	265.2	mm
T =	10.2	mm
t =	6	mm
c/tf =	6.92	From Blue Book of Steel
d/tw =	44.2	From Blue Book of Steel
ry (Radius of Gyration) =	12.9	
Wpl,y (Plastic Section Modulus) =	623	cm ³
Iy (Second Moment of Area) =	8500	cm ⁴
LTB Resistance (Mb,Rd)	141	From Blue Book of Steel
Proposed Steel Grade (py)	355	

Beam Length	4	m
Permanent Load - Self Weight	0.40	kN/m
Permanent Load - Open Mesh	4.5	kN/m
Imposed Load - General Duty	15.00	kN/m
Imposed Load - Service Loads	3.00	kN/m

Applied Load Combination

ULS Load Combination 1 - Both Variable Load Factored (Expression 6.10a)

$$1.35G_k + 1.5\psi_0Q_{k,1} + 1.5\psi_0Q_{k,2} = 25.52 \text{ kN/m}$$

ULS Load Combination 2 - Access Load Leading (Expression 6.10b)

$$1.35G_k + 1.5Q_{k,1} + 1.5\psi_0Q_{k,2} = 31.77 \text{ kN/m}$$

ULS Load Combination 3 - Services Load Leading (Expression 6.10b)

$$1.35G_k + 1.5Q_{k,2} + 1.5\psi_0Q_{k,1} = 26.37 \text{ kN/m}$$

SLS Load Combination 4 - Services Load Leading (Expression 6.10b)

$$G_k + Q_{k,access} + \psi_0Q_{k,services} = 22.00 \text{ kN/m}$$

Design Shear Force (Ved)

$$\text{Maximum Shear (Ved)} = \frac{W_{ed}L}{2} = \frac{127.08}{2} = 63.54 \text{ kNm}$$

Design Bending Moment (Med)

$$\text{Design Bending Moment (Med)} = \frac{W_{ed}L^2}{8} = \frac{508.30}{8} = 63.54 \text{ kNm}$$

Material Strength (fy)

From Table 3.1, BS EN 1993 determine fy

$$T < 16\text{MM } f_y = 355$$

$$T = 16 - 40\text{MM } f_y = 335$$

$$T < 16\text{MM } f_u = 490$$

$$T = 16 - 40\text{MM } f_u = 470$$

$$\varepsilon = \sqrt{235/f_y}$$

$$0.81$$

Member Cross-Section Classification

From Table 9, BS5950

Flange = $c/t_f < 9\epsilon$

6.92 < 7.32

Flange is Class 1 plastic

Web = $d/t_w < 72\epsilon$

44.20 < 58.58

Web is Class 1 Plastic

Bending Resistance (M_c, R_d)

$$\text{Calculate Buckling Resistance} = \frac{W_{pl,y} f_y}{\gamma_{M0}} = \frac{221165000}{1000000} = 221.17 \text{ kN}$$

$$\text{Check } M_{ed} \leq M_c, R_d = 63.54 \leq 221.17 \quad \text{PASS}$$

Shear Resistance (V_{pl}, R_d)

$$\text{Calculate Shear Area } (A_v) = h_w t_w = 1591.20$$

$$\text{Calculate Shear Resistance} = \frac{A_v f_y}{\sqrt{3} \gamma_{M0}} = \frac{564876.00}{1732.05} = 326.13 \text{ kNm}$$

$$\text{Check } V_{ed} \leq V_{pl}, R_d = 63.54 \leq 326.13 \quad \text{PASS}$$

Lateral Torsional Buckling (M_b, R_d)

$$\text{LTB Resistance } (M_b, R_d) = 141 \text{ kNm} \quad \text{Aquired from "Blue Book of Steel"}$$

$$\text{Check } M_{ed}/M_b, R_d \leq 1.0 = \frac{63.54}{141.00} \leq 1.00$$

$$0.45 \leq 1.00 \quad \text{PASS}$$

Deflection Check (δ)

$$\text{Maximum Deflection } (\delta_{\max}) = \frac{5 w_{sls} L^4}{384 E I_y} = \frac{2.816E+16}{6.6912E+15} = 4.21 \text{ mm}$$

$$\text{Allowable Deflection } (\delta_{\text{Allow}}) = \frac{L}{360} = \frac{4000}{360} = 11.11 \text{ mm}$$

$$\text{Check } \delta_{\max} \leq \delta_{\text{Allow}} = 4.21 \leq 11.11 \quad \text{PASS}$$

Summary Table			
Category	Design Limit	Provided	Utilisation
Bending Resistance	63.54	221.17	28.73%
Shear Resistance	63.54	326.13	19.48%
Lateral Torsional Buckling	0.45	1.00	45.06%
Deflection Check	4.21	11.11	37.88%

16. Appendix H – Eurocodes Analysis Utilised Member

Eurocodes

Member Size 254 x 146 x 31

D =	251.4	mm
b =	146.1	mm
d =	219	mm
T =	8.6	mm
t =	6	mm
c/tf =	7.26	From Blue Book of Steel
d/tw =	36.5	From Blue Book of Steel
Wpl,y (Plastic Section Modulus) =	393	cm ³
Iy (Second Moment of Area) =	4410	cm ⁴
LTB Resistance (Mb,Rd)	79.7	From Blue Book of Steel
Proposed Steel Grade (py)	355	

Beam Length	4	m
Permanent Load - Self Weight	0.31	kN/m
Permanent Load - Open Mesh	4.5	kN/m
Imposed Load - General Duty	15.00	kN/m
Imposed Load - Service Loads	3.00	kN/m

Applied Load Combination

ULS Load Combination 1 - Both Vairable Load Facored (Expression 6.10a)

$$1.35G_k + 1.5\psi_0Q_{k,1} + 1.5\psi_0Q_{k,2} = 25.39 \text{ kN/m}$$

ULS Load Combination 2 - Access Load Leading (Expression 6.10b)

$$1.35G_k + 1.5Q_{k,1} + 1.5\psi_0Q_{k,2} = 31.66 \text{ kN/m}$$

ULS Load Combination 3 - Services Load Leading (Expression 6.10b)

$$1.35G_k + 1.5Q_{k,2} + 1.5\psi_0Q_{k,1} = 26.26 \text{ kN/m}$$

SLS Load Combination 4 - Services Load Leading (Expression 6.10b)

$$G_k + Q_{k,access} + \psi_0Q_{k,services} = 21.91 \text{ kN/m}$$

Design Shear Force (Ved)

$$\text{Maximum Shear (Ved)} = \frac{W_{ed}L}{2} = \frac{126.63}{2} = \boxed{63.31} \text{ kNm}$$

Design Bending Moment (Med)

$$\text{Design Bending Moment (Med)} = \frac{W_{ed}L^2}{8} = \frac{506.50}{8} = \boxed{63.31} \text{ kNm}$$

Material Strength (fy)

From Table 3.1, BS EN 1993 determine fy

T = <16MM fy = 355

T = 16 - 40MM fy = 335

T = <16MM fu = 490

T = 16 - 40MM fu = 470

$$\varepsilon = \sqrt{235/f_y}$$

$$\boxed{0.81}$$

17. Appendix I – BS449 Column Analysis

Member Size

8x8

D =	210	mm
d =	205	mm
T =	14.2	mm
t =	9.3	mm
b/T =	14.8	mm
d/t =	22.0	mm
rx =	8.97	cm
ry =	5.18	cm
Zx (Elastic modulus) =	581	cm ³
Zy (Elastic modulus) =	199	cm ³
Ag (Area of Section) =	75.8	cm ²
E =	205	kN/mm ²
Column Length	6	m
Total Reaction on (x-x)	86.6	kN
Total Reaction on (y-y)	86.6	kN
Total Axial Load from Above Level (P)	173.2	kN

Refer to Beam Design	
Reaction 1 (x-x) =	45.8
Reaction 2 (y-y) =	45.8
Reaction 3 (x-x) =	40.8
Reaction 4 (y-y) =	40.8

Calculate Total Axial Compression Stress (fc)

Transferred Loads (P) = 173.20 kN
 Self Weight = 3.47 kN
 Total Axial Load from Above Levels = 173.20 kN

Total Axial load (P) = kN

Effective Length (l) - From Clause 31, BS 449

About x-x axis: Lex = 0.85L = 5100 mm
 About y-y axis: Ley = 0.85L = 5100 mm

Slenderness Ratio

$\lambda_x = L_{ex}/r_x = 56.86$
 $\lambda_y = L_{ey}/r_y = 98.46$

Check Clause 33 for Maximum slenderness = 180

Axial Compression (pc)

$l/r = 98.46$
 From table 17a in BS449, pc = N/mm²

Calculate Axial resistance = Pallow = pc Ag = 644.3 kN

Axial Compression Check = $\frac{P}{P_{allow}} \leq 1.0 = \frac{173.2}{644.3} \leq 1.0 = 0.269$ PASS

Eccentricity at top of Column from Connecting ractions

$$\begin{aligned} M_x &= R1_{ex} - R3_{ex} = 17.54 \text{ kNm} \\ M_y &= R2_{ey} - R4_{ey} = 17.54 \text{ kNm} \end{aligned}$$

Bending Stresses in the Column

$$\begin{aligned} f_{bcx} &= M_x / Z_x = 30.18 \text{ N/mm}^2 \\ f_{bcy} &= M_y / Z_y = 88.12 \text{ N/mm}^2 \end{aligned}$$

$$f_c = P / A_g = \frac{173200}{7580} = 22.85 \text{ N/mm}^2$$

$$p_{bcx} \text{ \& } p_{bcy} \text{ (From Table 4a)} = 169.37 \text{ N/mm}^2$$

$$\text{Check} = \frac{30.18}{169.37} + \frac{88.12}{169.37} = 0.70 < 1$$

PASS

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$$\frac{f_c}{p_c} + \frac{f_{bcx}}{p_{bcx}} + \frac{f_{bcy}}{p_{bcy}} \leq 1.00$$

$$\frac{22.85}{85} + \frac{30.18}{169.37} + \frac{88.12}{169.37} \leq 1.00$$

$$0.27 + 0.18 + 0.52 \leq 1.00$$

$$0.967 \leq 1.00$$

PASS

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression	0.27	1.000	26.88%
Bending Moment	0.70	1.000	69.85%
Combined Axial Compression and Bending	0.97	1.000	96.73%

18. Appendix J – BS5950 Column Analysis To BS449 Beam Loads Transferred & Same Member

Member Size 203 x 203 x

D =	209.60	mm
d =	205.80	mm
T =	14.20	mm
t =	9.40	mm
b/T =	7.25	mm
d/t =	17.10	mm
rx =	8.96	cm
ry =	5.20	cm
Zx (Plastic modulus) =	656.00	cm ³
Zy (Plastic modulus) =	305.00	cm ³
Sx (Elastic modulus) =	584.00	cm ³
Ag (Area of Section) =	76.40	cm ²
E =	205.00	kN/mm ²
Column Length Below	6.00	m
Total Reaction on (x-x)	86.60	kN
Total Reaction on (y-y)	86.60	kN
Total Axial Load from Above Levels	173.20	kN

Refer To Beam Design	
Reaction 1 (x-x) =	45.80
Reaction 2 (y-y) =	45.80
Reaction 3 (x-x) =	40.80
Reaction 4 (y-y) =	40.80

Calculate Total Axial Compression Stres (fc)

Transferred Loads	=	173.20 kN
Self Weight	=	3.53 kN
Total Axial Load from Above Levels	=	173.20 kN
Total Axial Load (Ned)	=	349.93 kN

Scross Sectional Classification - Table 11, BS 5950 = $\varepsilon = \sqrt{275/P_y}$

	T = <16MM Py = 275		T = 16 - 40MM Py = 265	
$\varepsilon =$	1.00			
				10 $\varepsilon =$ 10.00
b/T < 9 ε =	7.25	<	9.00	Flange is plastic
d/t < 80 ε /1+r1=	17.10	<	48.26	Flange is plastic
r1 = Fc/ d t Pyw	=	0.66	If r1 >1 then use =	1

Effective Length (Le) - From Table 22, BS 5950

About x-x axis:	Lex = 0.85L	=	5100	mm
About y-y axis:	Ley = 0.85L	=	5100	mm

Compressive Strength (Pc) - From Table 24, BS 5950

$\lambda = Lex/rx$	=	56.92	Pcx =	225.38 N/mm ²
$\lambda = Ley/ry$	=	98.08	Pcy =	125.15 N/mm ²

Critical Compressive Strength (p_c) =

125.15 N/mm²

Axial compression check = $P_c = A_g p_c$

=

956.18

Check Compressive Resistance = $F_c \leq P_c$

$N_{ed} \leq P_c$

349.93

<

956.18

Compressive Resistance is adequate

Nominal Moment due to Eccentricity

M_x

=

30 kNm

M_y

=

30 kNm

$M_{cx} = P_y Z_x$

=

180.40 kNm

$M_{cy} = P_y Z_y$

=

83.88 kNm

Check

$\frac{30.00}{180.40}$

+

$\frac{30.00}{83.88}$

=

0.52

<

1

PASS

Buckling Resistance

$\lambda_{LT} = 0.5L/r_y =$

57.69

$P_b =$

220.00

N/mm²

Refer to Table 16, BS 5950

$M_{bs} = P_b S_x =$

128.48

kNm

$P_y Z_y =$

83.88

kNm

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$\frac{N_{ed}}{P_c}$	+	$\frac{M_x}{M_{bs}}$	+	$\frac{M_y}{P_y Z_y}$	$\leq$	1.00
$\frac{349.93}{956.18}$	+	$\frac{30.00}{180.40}$	+	$\frac{30.00}{83.88}$	$\leq$	1.00
0.37	+	0.17	+	0.36	$\leq$	1.00
		0.89	$\leq$	1.00		

PASS

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression Resistance	349.93	956.18	36.60%
Bending Moment	0.52	1.00	52.40%
Combined Axial Compression and Bending	0.89	1.00	88.99%

19. Appendix K – BS5950 Column Analysis To BS5950 Beam Loads Transferred & Same Member as BS449

Member Size	203	x 203 x	60
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D =	309.60	mm
d =	205.80	mm
T =	14.20	mm
t =	9.40	mm
b/T =	7.25	mm
d/t =	17.10	mm
rx =	8.96	cm
ry =	5.20	cm
Zx (Plastic modulus) =	656.00	cm ³
Zy (Plastic modulus) =	305.00	cm ³
Sx (Elastic modulus) =	584.00	cm ³
Ag (Area of Section) =	76.40	cm ²
E =	205.00	kN/mm ²
Coulnrn Length Below	6.00	m
Total Reaction on (x-x)	137.64	kN
Total Reaction on (y-y)	137.64	kN
Total Axial Load from Above Levels	275.28	kN

Refer To Beam Design	
Reaction 1 (x-x) =	71.32
Reaction 2 (y-y) =	71.32
Reaction 3 (x-x) =	66.32
Reaction 4 (y-y) =	66.32

Calculate Total Axial Compression Stres (fc)

Transferred Loads	=	275.28 kN
Self Weight	=	3.53 kN
Total Axial Load from Above Levels	=	275.28 kN
Total Axial Load (Ned)	=	554.09 kN

Scross Sectional Classification - Table 11, BS 5950 = $\varepsilon = \sqrt{275/P_y}$

	$T = < 16\text{MM}$	$P_y = 275$	$T = 16 - 40\text{MM}$	$P_y = 265$	
$\varepsilon =$	1.00				$10\varepsilon = 10.00$
$b/T < 9\varepsilon =$	7.25	<	9.00		Flange is plastic
$d/t < 80\varepsilon/1+r1 =$	17.10	<	40.00		Flange is plastic
$r1 = F_c / d \ t \ P_{yw}$	=	1.04	If $r1 > 1$ then use =	1	

Effective Length (Le) - From Table 22, BS 5950

About x-x axis:	$I_{xx} = 0.85I$	=	5100	mm ⁴
About y-y axis:	$I_{yy} = 0.85I$	=	5100	mm ⁴

Compressive Strength (P_c) - From Table 24, BS 5950

$\lambda = \text{Lex/rx}$	=	56.92	Pcx =	225.38	N/mm ²
$\lambda = \text{Ley/ry}$	=	98.08	Pcy =	125.15	N/mm ²

Critical Compressive Strength (p_c) =

125.15 N/mm²

Axial compression check = $P_c = A_g p_c$

=

956.18

Check Compressive Resistance = $F_c \leq P_c$

$N_{ed} \leq P_c$

554.09

<

956.18

Compressive Resistance is adequate

Nominal Moment due to Eccentricity

M_x

=

30 kNm

M_y

=

30 kNm

$M_{cx} = P_y Z_x$

=

180.40 kNm

$M_{cy} = P_y Z_y$

=

83.88 kNm

Check

$\frac{30.00}{180.40}$

+

$\frac{30.00}{83.88}$

=

0.52

<

1

PASS

Buckling Resistance

$\lambda_{LT} = 0.5L/r_y =$

57.69

$P_b =$

220.00 N/mm²

Refer to Table 16, BS 5950

$M_{bs} = P_b S_x =$

128.48 kNm

$P_y Z_y =$

83.88 kNm

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$\frac{N_{ed}}{P_c}$	+	$\frac{M_x}{M_{bs}}$	+	$\frac{M_y}{P_y Z_y}$	$\leq$	1.00
$\frac{554.09}{956.18}$	+	$\frac{30.00}{180.40}$	+	$\frac{30.00}{83.88}$	$\leq$	1.00
0.58	+	0.17	+	0.36	$\leq$	1.00
		1.10	$\leq$	1.00		

FAILS Under Combined Axial
Compression & Bending

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression Resistance	554.09	956.18	57.95%
Bending Moment	0.52	1.00	52.40%
Combined Axial Compression and Bending	1.10	1.00	110.35%

20. Appendix L – BS5950 Column Analysis To BS5950 Beam Loads Transferred

Member Size 203 x 203 x 71

D =	215.80	mm
d =	206.40	mm
T =	17.30	mm
t =	10.00	mm
b/T =	5.97	mm
d/t =	16.10	mm
rx =	9.18	cm
ry =	5.30	cm
Zx (Plastic modulus) =	799.00	cm ³
Zy (Plastic modulus) =	374.00	cm ³
Sx (Elastic modulus) =	706.00	cm ³
Ag (Area of Section) =	90.40	cm ²
E =	205.00	kN/mm ²
Column Length Below	6.00	m
Total Reaction on (x-x)	137.64	kN
Total Reaction on (y-y)	137.64	kN
Total Axial Load from Above Levels	275.28	kN

Refer To Beam Design	
Reaction 1 (x-x) =	71.32
Reaction 2 (y-y) =	71.32
Reaction 3 (x-x) =	66.32
Reaction 4 (y-y) =	66.32

Calculate Total Axial Compression Stres (fc)

Transferred Loads	=	275.28	kN
Self Weight	=	4.18	kN
Total Axial Load from Above Levels	=	275.28	kN
Total Axial Load (Ned)	=	554.74	kN

Scross Sectional Classification - Table 11, BS 5950 = $\epsilon = \sqrt{275/P_y}$

	T = <16MM Py = 275	T = 16 - 40MM Py = 265	
$\epsilon =$	1.02		
			10 $\epsilon =$ 10.19
b/T < 9 $\epsilon =$	5.97	< 9.17	Flange is plastic
d/t < 80 $\epsilon/1+r1=$	16.10	< 40.75	Flange is plastic
r1 = Fc/ d t Pyw	=	1.01	If r1 >1 then use = 1

Effective Length (Le) - From Table 22, BS 5950

About x-x axis:	Lex = 0.85L	=	5100	mm
About y-y axis:	Ley = 0.85L	=	5100	mm

Compressive Strength (Pc) - From Table 24, BS 5950

$\lambda = Lex/rx$	=	55.56	Pcx =	219.33	N/mm ²
$\lambda = Ley/ry$	=	96.23	Pcy =	126.34	N/mm ²

Critical Compressive Strength (p_c) =

126.34 N/mm²

Axial compression check = $P_c = A_g p_c$

=

1142.11

Check Compressive Resistance = $F_c \leq P_c$

$N_{ed} \leq P_c$

554.74

<

1142.11

Compressive Resistance is adequate

Nominal Moment due to Eccentricity

M_x

=

30 kNm

M_y

=

30 kNm

$M_{cx} = P_y Z_x$

=

219.73 kNm

$M_{cy} = P_y Z_y$

=

102.85 kNm

Check

$\frac{30.00}{219.73}$

+

$\frac{30.00}{102.85}$

=

0.43

<

1

PASS

Buckling Resistance

$\lambda_{LT} = 0.5L/r_y =$

56.60

$P_b =$

217.17

N/mm²

Refer to Table 16, BS 5950

$M_{bs} = P_b S_x =$

153.32

kNm

$P_y Z_y =$

102.85

kNm

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$\frac{N_{ed}}{P_c}$	+	$\frac{M_x}{M_{bs}}$	+	$\frac{M_y}{P_y Z_y}$	$\leq$	1.00
$\frac{554.74}{1142.11}$	+	$\frac{30.00}{219.73}$	+	$\frac{30.00}{102.85}$	$\leq$	1.00
0.49	+	0.14	+	0.29	$\leq$	1.00
		0.91	$\leq$	1.00		

PASS

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compression Resistance	554.74	1142.11	48.57%
Bending Moment	0.43	1.00	42.82%
Combined Axial Compression and Bending	0.91	1.00	91.39%

21. Appendix M – Eurocodes 3 Column Analysis to BS449 Beam Loads Transferred & Same Member

Member Size 203 x 203 x

D =	209.6	mm
d =	205.8	mm
T =	14.2	mm
t =	9.4	mm
b/T =	6.2	mm
d/t =	17.1	mm
ry =	8.96	cm
rz =	5.2	cm
Zy (Plastic modulus) =	656	cm ³
Zz (Plastic modulus) =	305	cm ³
Iy =	6120	cm ⁴
Iz =	2060	cm ⁴
Sx (Elastic modulus) =	584	cm ³
Ag (Area of Section) =	76.4	cm ²
E =	205	kN/mm ²
Steel Grade (fy)	355	N/mm ²
Column Length	6	m
Total Reaction on (x-x)	86.6	kN
Total Reaction on (y-y)	86.6	kN
Total Axial Load (Ned)	173.2	kN

Reaction 1 (y-y) =	45.8
Reaction 2 (z-z) =	45.8
Reaction 3 (y-y) =	40.8
Reaction 4 (z-z) =	40.8

Calculate Total Axial Compression Stres (fc)

Transferred Loads = 173.20 kN
 Self Weight = 3.53 kN
 Total Axial Load from Above Levels = 173.20 kN

Total Axial Load (Ned) = kN

Cross Sectional Compression Resistance (Nc,Rd)

$$N_{c,Rd} = \frac{A f_y}{\gamma_{M0}} = \frac{2712200}{1000} = \text{2712.2 kN}$$

Check Ned ≤ Nc,Rd 349.93 ≤ 2712.2

Compressive Resistance is adequate

Effective Length (Lcr)

Fixed base, top laterally restrained and rotationally restrained
 Effective Length Factor (K) = 0.5
 Buckling Length (Lcr) = Lcr = KL 3000 mm

Elastic Critical Buckling Load (Ncr,y / Ncr,z)

$$N_{cr,y} = \frac{\pi^2 E I_y}{L_{cr,y}^2} = \frac{1.26845E+14}{9000000} = 14093.86 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 E I_z}{L_{cr,z}^2} = \frac{4.2696E+13}{9000000} = 4744.01 \text{ kN}$$

Non-Dimensional Slenderness (λ)

$$\lambda_y = \sqrt{A f_y / N_{cr,y}}$$

$$\lambda_y = 0.44$$

$$\lambda_z = \sqrt{A f_y / N_{cr,z}}$$

$$\lambda_z = 0.76$$

Determine Buckling Imperfection Factor - Determine from Table 6.2 & Figure 6.4

λ_y = Transfer to Figure 6.4

$$\alpha = 0.91$$

λ_z = Transfer to Figure 6.4

$$\alpha = 0.73$$

Member Buckling (Nb,Rd)

$$\phi_y = 0.5 [1 + \alpha_y (\lambda_y - 0.2) + \lambda_y^2] = 0.705$$

$$\phi_z = 0.5 [1 + \alpha_z (\lambda_z - 0.2) + \lambda_z^2] = 0.989$$

$$X_y = 1 / \phi_y + \sqrt{\phi_y^2 - \lambda_y^2} = 0.796$$

$$X_z = 1 / \phi_z + \sqrt{\phi_z^2 - \lambda_z^2} = 0.615$$

$$N_{b,Rd,y} = X_y A f_y / \gamma_{M1} = 2158.57 \text{ kN}$$

$$N_{b,Rd,z} = X_z A f_y / \gamma_{M2} = 1667.93 \text{ kN}$$

$$\text{Check } N_{ed} / N_{b,Rd} = 349.93 < 1667.93 \quad \text{PASS}$$

Nominal Moment due to Eccentricity

$$M_{y,ed} = 30 \text{ kNm}$$

$$M_{z,ed} = 30 \text{ kNm}$$

$$M_{y,Rd} = 232.88 \text{ kNm}$$

$$M_{z,Rd} = 108.28 \text{ kNm}$$

$$\text{Check } \frac{30.00}{232.88} + \frac{30.00}{108.28} = 0.41 < 1$$

PASS

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$\frac{N_{ed}}{P_c}$	+	$\frac{M_{y,ed}}{M_{y,Rd}}$	+	$\frac{M_{z,ed}}{M_{z,Rd}}$	$\leq$	1.00
$\frac{349.93}{1667.93}$	+	$\frac{30.00}{232.88}$	+	$\frac{30.00}{108.28}$	$\leq$	1.00
0.21	+	0.13	+	0.28	$\leq$	1.00
		0.62	$\leq$	1.00	PASS	

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	349.93	2712.2	12.90%
Buckling Resistance	349.93	1667.93	20.98%
Bending Moment	0.41	1.00	40.59%
Combined Axial & Bending	0.62	1.00	61.57%

22. Appendix N – Eurocodes 3 Column Analysis to BS449 Beam Loads Transferred – Utilised Member

Member Size 203 x 203 x 46

D =	203.2	mm
d =	203.6	mm
T =	11	mm
t =	7.2	mm
b/T =	8	mm
d/t =	22.3	mm
ry =	8.82	cm
rz =	5.13	cm
Zy (Plastic modulus) =	497	cm ³
Zz (Plastic modulus) =	231	cm ³
Iy =	4570	cm ⁴
Iz =	1550	cm ⁴
Sx (Elastic modulus) =	450	cm ³
Ag (Area of Section) =	58.7	cm ²
E =	205	kN/mm ²
Steel Grade (fy)	355	N/mm ²
Column Length	6	m
Total Reaction on (x-x)	86.6	kN
Total Reaction on (y-y)	86.6	kN
Total Axial Load (Ned)	173.2	kN

Reaction 1 (y-y) =	45.8
Reaction 2 (z-z) =	45.8
Reaction 3 (y-y) =	40.8
Reaction 4 (z-z) =	40.8

Calculate Total Axial Compression Stres (fc)

Transferred Loads = 173.20 kN
 Self Weight = 2.71 kN
 Total Axial Load from Above Levels = 173.20 kN

Total Axial Load (Ned) = 349.11 kN

Cross Sectional Compression Resistance (Nc,Rd)

$$N_{c,Rd} = \frac{A f_y}{\gamma_{M0}} = \frac{2083850}{1000} = \span style="border: 1px solid black; padding: 2px;">2083.85 kN$$

Check $N_{ed} \leq N_{c,Rd}$ 349.11 ≤ 2083.85

Compressive Resistance is adequate

Effective Length (Lcr)

Fixed base, top laterally restrained and rotationally restrained
 Effective Length Factor (K) = 0.5
 Buckling Length (Lcr) = Lcr = KL 3000 mm

Elastic Critical Buckling Load (Ncr,y / Ncr,z)

$$N_{cr,y} = \frac{\pi^2 E I_y}{L^2_{cr,y}} = \frac{9.4719E+13}{9000000} = 10524.34 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 E I_z}{L^2_{cr,z}} = \frac{3.2126E+13}{9000000} = 3569.52 \text{ kN}$$

Non-Dimensional Slenderness (λ)

$$\lambda_y = \sqrt{A f_y / N_{cr,y}} \quad \lambda_y = 0.44$$

$$\lambda_z = \sqrt{A f_y / N_{cr,z}} \quad \lambda_z = 0.76$$

Determine Buckling Imperfection Factor - Determine from Table 6.2 & Figure 6.4

$$\lambda_y = \text{Transfer to Figure 6.4} \quad \alpha = 0.91$$

$$\lambda_z = \text{Transfer to Figure 6.4} \quad \alpha = 0.73$$

Member Buckling ($N_{b,Rd}$)

$$\phi_y = 0.5 [1 + \alpha_y (\lambda_y - 0.2) + \lambda_y^2] = 0.710$$

$$\phi_z = 0.5 [1 + \alpha_z (\lambda_z - 0.2) + \lambda_z^2] = 0.998$$

$$\chi_y = 1 / \phi_y + \sqrt{\phi_y^2 - \lambda_y^2} = 0.791$$

$$\chi_z = 1 / \phi_z + \sqrt{\phi_z^2 - \lambda_z^2} = 0.610$$

$$N_{b,Rd,y} = \chi_y A f_y / \gamma_{M1} = 1648.20 \text{ kN}$$

$$N_{b,Rd,z} = \chi_z A f_y / \gamma_{M2} = 1271.05 \text{ kN}$$

$$\text{Check } N_{ed} / N_{b,Rd} \quad 349.11 < 1271.05 \quad \text{PASS}$$

Nominal Moment due to Eccentricity

$$M_{y,ed} = 30 \text{ kNm}$$

$$M_{z,ed} = 30 \text{ kNm}$$

$$M_{y,Rd} = 176.44 \text{ kNm}$$

$$M_{z,Rd} = 82.01 \text{ kNm}$$

$$\text{Check} \quad \frac{30.00}{176.44} + \frac{30.00}{82.01} = 0.54 < 1 \quad \text{PASS}$$

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$$\frac{N_{ed}}{P_c} + \frac{M_{y,ed}}{M_{y,Rd}} + \frac{M_{z,ed}}{M_{z,Rd}} \leq 1.00$$

$\frac{349.11}{1271.05}$	+	$\frac{30.00}{176.44}$	+	$\frac{30.00}{82.01}$	$\leq$	1.00
0.27	+	0.17	+	0.37	$\leq$	1.00
		0.81	$\leq$	1.00	PASS	

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	349.11	2083.85	16.75%
Buckling Resistance	349.11	1271.05	27.47%
Bending Moment	0.54	1.00	53.59%
Combined Axial & Bending	0.81	1.00	81.05%

23. Appendix O – Eurocodes 3 Column Analysis to Eurocodes 3 Beam Loads Transferred – Same Member as BS449

Member Size 203 x 203 x

D =	209.6	mm
d =	205.8	mm
T =	14.2	mm
t =	9.4	mm
b/T =	6.2	mm
d/t =	17.1	mm
ry =	8.96	cm
rz =	5.2	cm
Zy (Plastic modulus) =	656	cm ³
Zz (Plastic modulus) =	305	cm ³
Iy =	6120	cm ⁴
Iz =	2060	cm ⁴
Sx (Elastic modulus) =	584	cm ³
Ag (Area of Section) =	76.4	cm ²
E =	205	kN/mm ²
Steel Grade (fy)	355	N/mm ²
Column Length	6	m
Total Reaction on (x-x)	121.62	kN
Total Reaction on (y-y)	121.62	kN
Total Axial Load (Ned)	243.24	kN

Reaction 1 (y-y) =	63.31
Reaction 2 (z-z) =	63.31
Reaction 3 (y-y) =	58.31
Reaction 4 (z-z) =	58.31

Calculate Total Axial Compression Stres (fc)

Transferred Loads	=	243.24 kN
Self Weight	=	3.53 kN
Total Axial Load from Above Levels	=	243.24 kN
Total Axial Load (Ned)	=	490.01 kN

Cross Sectional Compression Resistance (Nc,Rd)

$$N_{c,Rd} = \frac{A f_y}{\gamma_{M0}} = \frac{2712200}{1000} = \text{2712.2 kN}$$

$$\text{Check } N_{ed} \leq N_{c,Rd} \quad 490.01 \leq 2712.2$$

Compressive Resistance is adequate

Effective Length (Lcr)

Fixed base, top laterally restrained and rotationally restrained
 Effective Length Factor (K) = 0.5
 Buckling Length (Lcr) = Lcr = KL 3000 mm

Elastic Critical Buckling Load (Ncr,y / Ncr,z)

$$N_{cr,y} = \frac{\pi^2 E I_y}{L_{cr,y}^2} = \frac{1.26845E+14}{9000000} = 14093.86 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 E I_z}{L_{cr,z}^2} = \frac{4.2696E+13}{9000000} = 4744.01 \text{ kN}$$

Non-Dimensional Slenderness (λ)

$$\lambda_y = \sqrt{A f_y / N_{cr,y}} \quad \lambda_y = 0.44$$

$$\lambda_z = \sqrt{A f_y / N_{cr,z}} \quad \lambda_z = 0.76$$

Determine Buckling Imperfection Factor - Determine from Table 6.2 & Figure 6.4

$$\lambda_y = \text{Transfer to Figure 6.4} \quad \alpha = 0.91$$

$$\lambda_z = \text{Transfer to Figure 6.4} \quad \alpha = 0.73$$

Member Buckling (Nb,Rd)

$$\phi_y = 0.5 [1 + \alpha_y (\lambda_y - 0.2) + \lambda_y^2] = 0.705$$

$$\phi_z = 0.5 [1 + \alpha_z (\lambda_z - 0.2) + \lambda_z^2] = 0.989$$

$$\chi_y = 1 / (\phi_y + \sqrt{\phi_y^2 - \lambda_y^2}) = 0.796$$

$$\chi_z = 1 / (\phi_z + \sqrt{\phi_z^2 - \lambda_z^2}) = 0.615$$

$$N_{b,Rd,y} = \chi_y A f_y / \gamma_{M1} = 2158.57 \text{ kN}$$

$$N_{b,Rd,z} = \chi_z A f_y / \gamma_{M2} = 1667.93 \text{ kN}$$

$$\text{Check } N_{ed} / N_{b,Rd} \quad 490.01 < 1667.93 \quad \text{PASS}$$

Nominal Moment due to Eccentricity

$$M_{y,ed} = 30 \text{ kNm}$$

$$M_{z,ed} = 30 \text{ kNm}$$

$$M_{y,Rd} = 232.88 \text{ kNm}$$

$$M_{z,Rd} = 108.28 \text{ kNm}$$

$$\text{Check} \quad \frac{30.00}{232.88} + \frac{30.00}{108.28} = 0.41 < 1$$

PASS

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$\frac{N_{ed}}{P_c}$	+	$\frac{M_{y,ed}}{M_{y,Rd}}$	+	$\frac{M_{z,ed}}{M_{z,Rd}}$	$\leq$	1.00
$\frac{490.01}{1667.93}$	+	$\frac{30.00}{232.88}$	+	$\frac{30.00}{108.28}$	$\leq$	1.00
0.29	+	0.13	+	0.28	$\leq$	1.00
		0.70	$\leq$	1.00	PASS	

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	490.01	2712.2	18.07%
Buckling Resistance	490.01	1667.93	29.38%
Bending Moment	0.41	1.00	40.59%
Combined Axial & Bending	0.70	1.00	69.97%

24. Appendix P – Eurocodes 3 Column Analysis to Eurocodes 3 Beam Loads Transferred – Utilised Member

Member Size 203 x 203 x

D =	203.2	mm
d =	203.6	mm
T =	11	mm
t =	7.2	mm
b/T =	8	mm
d/t =	22.3	mm
ry =	8.82	cm
rz =	5.13	cm
Zy (Plastic modulus) =	497	cm ³
Zz (Plastic modulus) =	231	cm ³
Iy =	4570	cm ⁴
Iz =	1550	cm ⁴
Sx (Elastic modulus) =	450	cm ³
Ag (Area of Section) =	58.7	cm ²
E =	205	kN/mm ²
Steel Grade (fy)	355	N/mm ²
Column Length	6	m
Total Reaction on (x-x)	121.62	kN
Total Reaction on (y-y)	121.62	kN
Total Axial Load (Ned)	243.24	kN

Reaction 1 (y-y) =	63.31
Reaction 2 (z-z) =	63.31
Reaction 3 (y-y) =	58.31
Reaction 4 (z-z) =	58.31

Calculate Total Axial Compression Stres (fc)

Transferred Loads	=	243.24 kN
Self Weight	=	2.71 kN
Total Axial Load from Above Levels	=	243.24 kN
Total Axial Load (Ned)	=	489.19 kN

Cross Sectional Compression Resistance (Nc,Rd)

$$N_{c,Rd} = \frac{A f_y}{\gamma_{M0}} = \frac{2083850}{1000} = \text{2083.85 kN}$$

Check $N_{ed} \leq N_{c,Rd}$ 489.19 ≤ 2083.85

Compressive Resistance is
adequate

Effective Length (Lcr)

Fixed base, top laterally restrained and rotationally restrained
Effective Length Factor (K) = 0.5
Buckling Length (Lcr) = Lcr = KL 3000 mm

Elastic Critical Buckling Load (Ncr,y / Ncr,z)

$$N_{cr,y} = \frac{\pi^2 E I_y}{L^2_{cr,y}} = \frac{9.4719E+13}{9000000} = 10524.34 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 E I_z}{L^2_{cr,z}} = \frac{3.2126E+13}{9000000} = 3569.52 \text{ kN}$$

Non-Dimensional Slenderness (λ)

$$\lambda_y = \sqrt{A f_y / N_{cr,y}} \quad \lambda_y = 0.44$$

$$\lambda_z = \sqrt{A f_y / N_{cr,x}} \quad \lambda_z = 0.76$$

Determine Buckling Imperfection Factor - Dertmine from Table 6.2 & Figure 6.4

$$\lambda_y = \text{Transfer to Figure 6.4} \quad \alpha = 0.91$$

$$\lambda_z = \text{Transfer to Figure 6.4} \quad \alpha = 0.73$$

Member Buckling (Nb,Rd)

$$\phi_y = 0.5 [1 + \alpha_y (\lambda_y - 0.2) + \lambda_y^2] = 0.710$$

$$\phi_z = 0.5 [1 + \alpha_z (\lambda_z - 0.2) + \lambda_z^2] = 0.998$$

$$X_y = 1 / \phi_y + \sqrt{\phi_y^2 - \lambda_y^2} = 0.791$$

$$X_z = 1 / \phi_z + \sqrt{\phi_z^2 - \lambda_z^2} = 0.610$$

$$N_{b,Rd,y} = X_y A f_y / \gamma_{M1} = 1648.20 \text{ kN}$$

$$N_{b,Rd,z} = X_z A f_y / \gamma_{M2} = 1271.05 \text{ kN}$$

$$\text{Check } N_{ed} / N_{b,Rd} \quad 489.19 < 1271.05 \quad \text{PASS}$$

Nominal Moment due to Eccentricity

$$M_{y,ed} = 30 \text{ kNm}$$

$$M_{z,ed} = 30 \text{ kNm}$$

$$M_{y,Rd} = 176.44 \text{ kNm}$$

$$M_{z,Rd} = 82.01 \text{ kNm}$$

$$\text{Check} \quad \frac{30.00}{176.44} + \frac{30.00}{82.01} = 0.54 < 1 \quad \text{PASS}$$

Check Buckling = Combined Axial Compression and Bending - Clause 14(a)

$\frac{N_{ed}}{P_c}$	+	$\frac{M_{y,ed}}{M_{y,Rd}}$	+	$\frac{M_{z,ed}}{M_{z,Rd}}$	$\leq$	1.00
$\frac{489.19}{1271.05}$	+	$\frac{30.00}{176.44}$	+	$\frac{30.00}{82.01}$	$\leq$	1.00
0.38	+	0.17	+	0.37	$\leq$	1.00
		0.92	$\leq$	1.00	PASS	

Summary Table			
Category	Design Limit	Provided	Utilisation
Axial Compressive Resistance	489.19	2083.85	23.48%
Buckling Resistance	489.19	1271.05	38.49%
Bending Moment	0.54	1.00	53.59%
Combined Axial & Bending	0.92	1.00	92.07%