Verification

&

Technical integrity

For structural design calculations

on website structolution.com

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Author: Bart van Rhijn

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1. Verification framework

How we ensure the accuracy of structolution.com calculation engines.

At Structolution, we recognize that structural safety depends on the precision of our tools. Our verification process is designed to provide engineers with the confidence that our digital outputs align perfectly with the physical requirements of the Eurocodes (EN 1990 – EN 1999).

1.1. Three tier verification process

There are three tiers of tests in the verification process. In each section the type of test will be noted.

1. **Automated audit.** We use automated suite testing or hand calculations to verify the core logic of a formula.
2. **Independent benchmark.** Results are compared against established industry benchmarks. This includes:
    - Manual hand calculations: Step-by-step verification of long-form equations.
    - Peer software analysis: Comparison with known FEM solutions.
    - Standardized worked examples: Verification against published books, journals and documentation.
3. **Professional review.** Final output reports are audited by a qualified Structural Engineers to ensure the logic follows standard engineering practice and provides conservative, safe results.

1.2. Precision thresholds

Every verification calculation will display the accuracy. While we strive to always stay within the tolerances, we cannot guarantee with one hundred percent certainty that precision will always be met. Structolution.com aims for the following strict tolerances :

- **Primary values:** Variance must be $\leq$ 0.5% for numerical calculations.
- **Empirical/iterative coefficients:** Variance of $\leq$ 2.0% is acceptable for values involving complex iterations (e.g., lateral-torsional buckling curves or soil-structure interaction), provided the results remain conservative.

2. Analysis

2.1. Beam analysis

Route	https://structolution.com/calculations/beam-analysis
Version	1.0.0
Standard/Reference	

Independent benchmarking

Compared with: C. Hartsuijker, H. Welleman. Mechanica: Statisch onbepaalde constructies en bezwijkanalyse. Proceedings of Boom. 2016 2nd edition. Vergeet-mij-nietjes (p405)

For the comparison the following values are used:

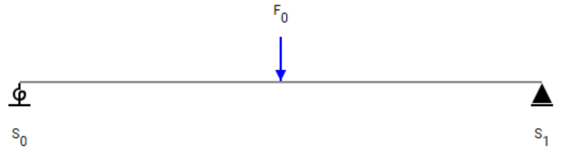
- $T = 7.5\ kNm; F = 7.5kN; q = 7.5kN/m$
- $EI = 210000MPa \times 5538400000\ mm^4$
- $l = 10000mm$

For the comparison with springs the following values are used:

- $F = 80kN$
- $EI = 20MNm^2$
- $l = 10000mm$
- $k = 100kN/m; k_r = 10000kNm/rad$

Test translational spring with Example 2.25, find vertical reaction force at S_1 with $S_{1v} = \frac{Fkl^3}{3EI+kl^3}$:

Test rotational spring, find moment M at support S_0 with $M = \frac{3Fl^3k_r}{16(3EI+k_rl)}$



Parameter	Benchmark case	Reference value	Structolution value	Error	Status
w_2 (mm)	Vergeet-mij-nietjes (1)	18.75	18.76	0.1%	Pass
w_2 (mm)	Vergeet-mij-nietjes (2)	125.0	125.0	0.0%	Pass
w_2 (mm)	Vergeet-mij-nietjes (3)	468.8	468.8	0.0%	Pass
w_3 (mm)	Vergeet-mij-nietjes (5)	7.813	7.808	-0.1%	Pass
S_{1v} (N)	Example 2.25 (E=5727376MPa HEA100)	50.00	50.00	0.0%	Pass
M (kNm)	Example kr (E=5727376MPa HEA100)	93.75	93.75	0.0%	Pass

3. Steel checks

3.1. Axial tension / compression

Route	https://structolution.com/calculations/steel/beam-axial
Version	1.0.0
Standard/Reference	EN1993-1-1:2025

Independent benchmark

Compared with: Silva, L.S. (2013). Eurocode 3: Design of Steel Structures. Part 1-1: General rules and rules for buildings. ECCS Eurocode Design Manuals. Example 3.3 ii (p133)

Structolution value $A_{required} = UC \times A_{applied}$,

Parameter	Benchmark case	Reference value	Structolution value	Error	Status
$A_{required}$ (mm2)	HEA140	2700	2700	0.0%	Pass

3.2. Shear strength

Route	https://structolution.com/calculations/steel/beam-shear
Version	1.0.0
Standard/Reference	EN1993-1-1:2025

Independent benchmark

Compared with: Silva, L.S. (2013). Eurocode 3: Design of Steel Structures. Part 1-1: General rules and rules for buildings. ECCS Eurocode Design Manuals. Example 3.4 iv (p144); Example 3.5 iv (p149)

Parameter	Benchmark case	Reference value	Structolution value	Error	Status
V_pl,Rd (kN)	Example 3.4 HEA220 S235	280.4	280.4	0.0%	Pass
V_pl,Rd (kN)	Example 3.5 HEA360 S275	777.3	777.2	0.0%	Pass

3.3. Bending moment strength

Route	https://structolution.com/calculations/steel/beam-bending
Version	1.0.0
Standard/Reference	EN1993-1-1:2025

Independent benchmark

Compared with: Silva, L.S. (2013). Eurocode 3: Design of Steel Structures. Part 1-1: General rules and rules for buildings. ECCS Eurocode Design Manuals. Example 3.4 ii (p143); Example 3.5 ii (p148)

Structolution value $W_{y,required} = UC \times W_{y,applied}$, hence the +/- 0.5 percent error. The section modulus at Structolution for RHS profiles are a bit smaller than the reference material. Nevertheless it is shown that elastic and plastic bi-axial bending corresponds well with the reference material.

Parameter	Benchmark case	Reference value	Structolution value	Error	Status
$W_{y,applied}$ (cm3)	Example 3.4 HEA220 S23	568.5	568.4	0.0%	Pass
$W_{y,required}$ (cm3)	Example 3.4 HEA220 S235	446.8	449.036	0.5%	Pass
$W_{y,applied}$ (cm3)	Example 3.4 IPE270 S235	484	483.9	0.0%	Pass
$W_{y,required}$ (cm3)	Example 3.4 IPE270 S235	446.8	445.2	-0.4%	Pass
$W_{y,applied}$ (cm3)	Example 3.5 HEA360 S275	2088	2088	0.0%	Pass
$W_{y,required}$ (cm3)	Example 3.5 HEA360 S275	2036.4	2046.24	0.5%	Pass
$W_{Pl,y}$ (cm3)	Example 3.6 RHS200x100x8 (hot finished) S275	286	282	-1.4%	Pass
$W_{Pl,z}$ (cm3)	Example 3.6 RHS200x100x8 (hot finished) S275	174	171.8	-1.3%	Pass
$M_{Pl,Rd,y}$ (kNm)	Example 3.6 RHS200x100x8 (hot finished) S275	78.7	77.55	-1.5%	Pass
$M_{Pl,Rd,z}$ (kNm)	Example 3.6 RHS200x100x8 (hot finished) S275	47.9	47.25	-1.4%	Pass
UC double bending	Example 3.6 RHS200x100x8 (hot finished) S275	0.83	0.85	2.4%	Pass
$W_{El,y}$ (cm3)	Example 3.6 RHS250x150x6.3 (hot finished) S275 CC3	334	331.4	-0.8%	Pass
$W_{El,z}$ (cm3)	Example 3.6 RHS250x150x6.3 (hot finished) S275 CC3	252	249.9	-0.8%	Pass
UC double bending	Example 3.6 RHS250x150x6.3 (hot finished) S275 CC3	0.91	0.92	0.8%	Pass

3.4. Column buckling

Route	https://structolution.com/calculations/steel/beam-flexural-buckling
Version	1.0.0
Standard/Reference	EN1993-1-1:2025

Independent benchmark

Compared with: Silva, L.S. (2013). Eurocode 3: Design of Steel Structures. Part 1-1: General rules and rules for buildings. ECCS Eurocode Design Manuals. Example 3.9 (p188); Example 3.10 (p191)

Parameter	Benchmark case	Reference value	Structolution value	Error	Status
N_b,Rd (kN)	Example 3.9 HEB240 S355	1618	1624	0.4%	Pass
N_b,Rd (kN)	Example 3.10 SHS120x8 (hot finished) S275	835.7	826.6	-1.1%	Pass
N_b,Rd (kN)	Example 3.10 SHS80/6.3 (hot finished) S275	398.2	392	-1.6%	Pass
N_b,Rd (kN)	Example 3.10 HEA180 S275	851.2	852.3	0.1%	Pass

3.5. Lateral torsional buckling

Route	https://structolution.com/calculations/steel/beam-lateral-torsional-buckling
Version	1.0.0
Standard/Reference	EN1993-1-1:2025

Independent benchmark

Compared with: Silva, L.S. (2013). Eurocode 3: Design of Steel Structures. Part 1-1: General rules and rules for buildings. ECCS Eurocode Design Manuals. Example 3.11 (p214);

Structolution value for Example 3.11 received with custom LTB values for the unrestrained loading:

- Free standing load with C2=0.42
- Custom C1 factor C1=1.04

The critical bending moment M_{cr} matches. The used reference uses different α_{LT} values based on the Generation 1 Eurocode, explaining the difference in the moment LTB resistance $M_{b,Rd}$.

Parameter	Benchmark case	Reference value	Structolution value	Error	Status
$M_{b,Rd}$ (kNm)	Example 3.11 HEA240 S235 unrestrained	131.2	129.2	-1.5%	Pass
M_{cr} (kNm)	Example 3.11 HEA240 S235 unrestrained	231.5	232.5	0.4%	Pass
$M_{b,Rd}$ (kNm)	Example 3.11 HEA220 S235 unrestrained using less conservative method	101.5	94.97	-6.4%	Pass
M_{cr} (kNm)	Example 3.11 HEA220 S235 unrestrained using less conservative method	158.8	158.9	0.1%	Pass
$M_{b,Rd}$ (kNm)	Example 3.11 HEA220 S235 restrained	124.2	116.3	-6.4%	Pass
M_{cr} (kNm)	Example 3.11 HEA220 S235 restrained	551.3	551.5	0.0%	Pass

3.6. Fillet weld

Route	https://structolution.com/calculations/fillet-weld-check
Version	1.0.0
Standard/Reference	EN1993-1-8:2008 (material following EN:2025)

Independent benchmark

Comparison with: Gresnigt, A.M. (2014). Design Rules for Fillet Welds in Eurocode 3 and AISC. Proceedings of EUROSTEEL 2014, Naples, Italy.

Each case is checked for $\sigma_x = f_y$ from Table 1 of the compared material. The other selected parameters in the calculations are 'weld length reduction' off, β_{Lw1} and a 'custom material' with $\gamma_{M2} = 1.25$.

All calculations pass except for S420, which has less capacity at Structolution. Table 1 from the reference suggests that a=0.75t. Formula (5) from the reference gives a=0.714t, which the Structolution calculation perfectly matches.

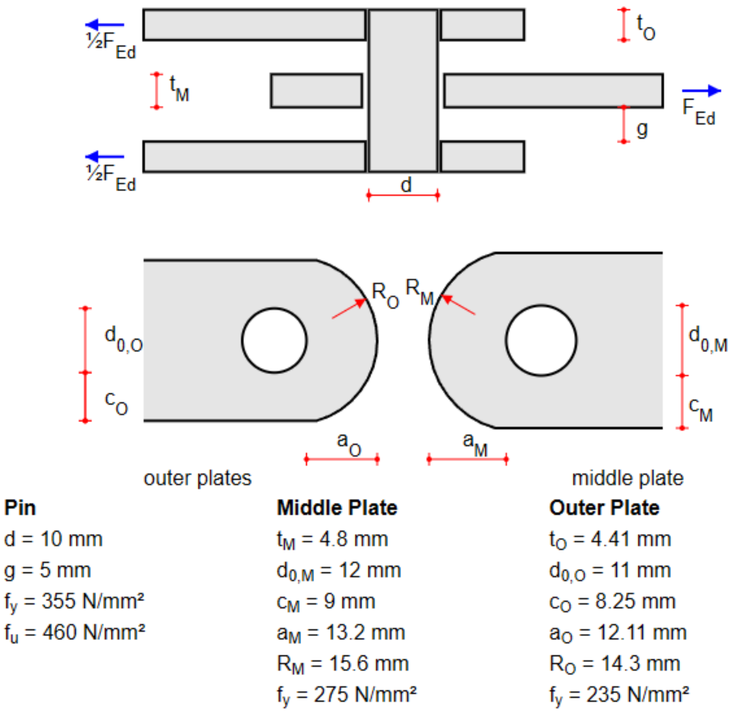
Parameter	Benchmark case	β_W (-)	f_u (MPa)	Reference value	Structolution value	Error	Status
UC_{VM}	S235/S235W, t ≤ 40mm, a=0.461t	0.8	360	1.00	1.00	0%	Pass
UC_{VM}	S355/S355W, t ≤ 40mm, a=0.553t	0.9	510	1.00	1.00	0%	Pass
UC_{VM}	S355 N/NL, t ≤ 40mm, a=0.576t	0.9	490	1.00	1.00	0%	Pass
UC_{VM}	S355 M/ML, t ≤ 40mm, a=0.602t	0.9	470	1.00	1.00	0%	Pass
UC_{VM}	S420 N/NL/M/ML, t ≤ 40mm, a=0.714t	1.0	520	1.05	1.00	-5%	Pass
UC_{VM}	S460 N/NL/M/ML, t ≤ 40mm, a=0.754t,	1.0	540	1.00	1.00	0%	Pass

3.7. Clevis joint

Route	https://structolution.com/calculations/clevis-joint-check
Version	1.0.0
Standard/Reference	EN1993-1-8:2025

Independent benchmark

Comparison with manual hand calculation. The engine results were compared against a step-by-step hand calculation following the Eurocode equations directly.



$F_{Ed} = 10\ kN$
$F_{Ed,ser} = 5\ kN$
$\gamma_{M0} = 0.9$
$\gamma_{M2} = 1.25$
$\gamma_{M6,ser} = 1.11$

Using custom γ_M values. The geometry of the eyes in the middle and outer plate are checked following Table 5.2 Type A. In case of setting 'geometry by the hole diameter' then the distance a and distance c are the smallest of Type A and Type B.

Parameter	Reference value	Structolution value	Error	Status
UC pin shear	0.29	0.29	0%	Pass
UC pin bending	0.72	0.72	0%	Pass
UC pin shear + bending	0.61	0.61	0%	Pass
UC middle plate bearing	0.45	0.45	0%	Pass
UC outer plate bearing	0.29	0.29	0%	Pass
UC geometry middle plate a	0.86	0.86	0%	Pass
UC geometry middle plate c	0.82	0.82	0%	Pass
UC geometry outer plate a	0.78	0.79	0%	Pass
UC geometry outer plate c	0.71	0.71	0%	Pass
UC pin bending SLS	0.84	0.84	0%	Pass
UC middle plate bearing SLS	0.70	0.70	0%	Pass
UC outer plate bearing SLS	0.45	0.45	0%	Pass
UC middle plate hertz stress	2.00	2.00	0%	Pass
UC outer plate hertz stress	1.22	1.22	0%	Pass