

Project: Wall with openings according to EN
 Project no: Project - 08/16/2021
 Author: Jason Smith

Project data

| | |
|----------------|--|
| Project name | Wall with openings according to EN |
| Project number | Project - 08/16/2021 |
| Author | Jason Smith |
| Description | Wall with openings solved by CSFM (Compatible stress field method) |
| Date | 8/16/2021 |
| Design code | EN |

Materials

Concrete

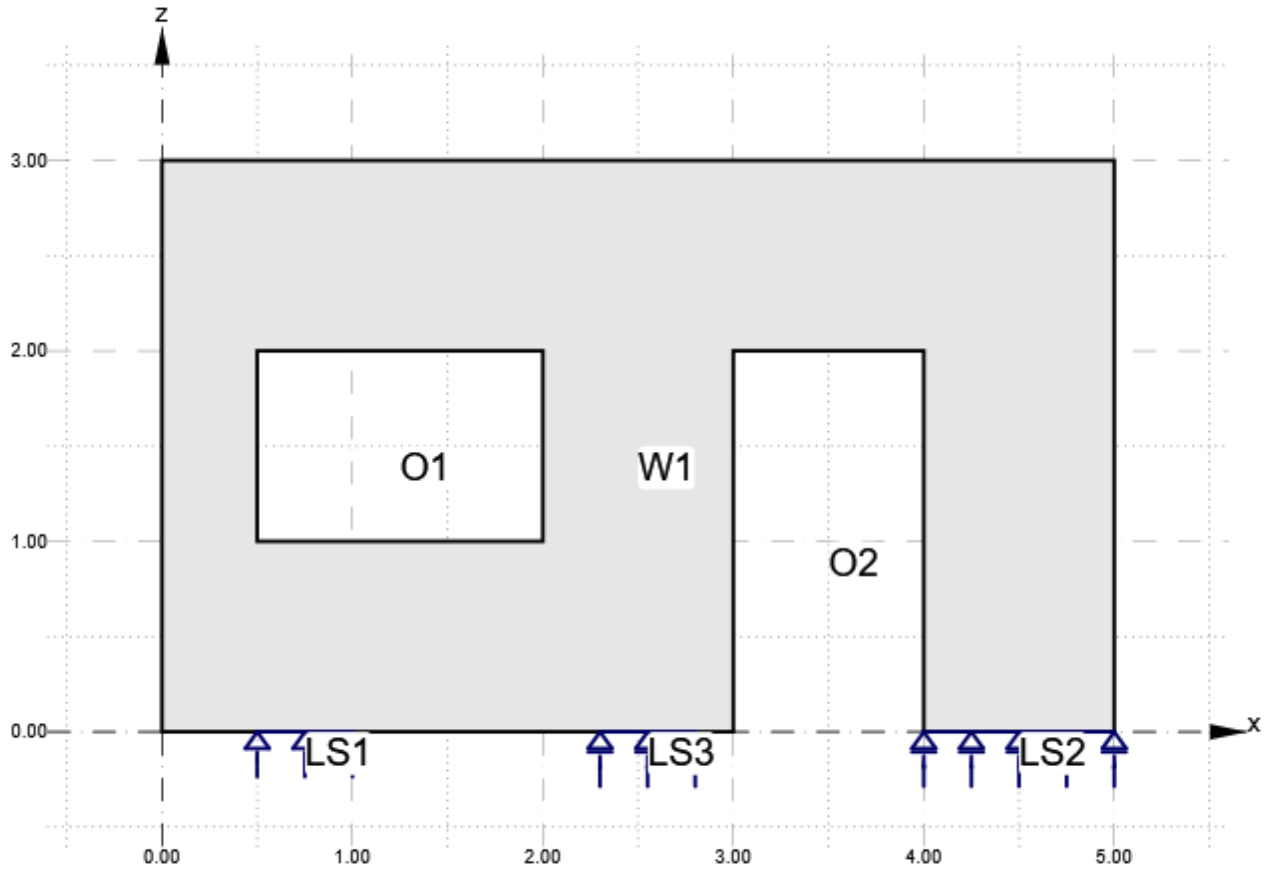
| Name | f_{ck} [MPa] | $f_{ctk,0.05}$ [MPa] | f_{ctm} [MPa] | E_{cm} [MPa] |
|--|-------------------|-------------------------|--------------------|-------------------|
| C30/37 | 30.0 | 2.0 | 2.9 | 32836.6 |
| $\epsilon_{c2} = 20.0 \cdot 10^{-4}$, $\epsilon_{cu2} = 500.0 \cdot 10^{-4}$, Diagram type: Parabolic Creep coefficient: 2.50 | | | | |

Reinforcement

| Name | f_{yk} [MPa] | k [-] | E_s [MPa] | Unit mass [kg/m ³] | ϵ_{uk} [1e-4] | Surface |
|---|-------------------|----------|----------------|-----------------------------------|---------------------------|---------|
| B 500B | 500.0 | 1.08 | 200000.0 | 7850 | 500.0 | Ribbed |
| $\epsilon_{st} = 500.0 \cdot 10^{-4}$, $\epsilon_{sc} = 500.0 \cdot 10^{-4}$, | | | | | | |

DRM1

Geometry

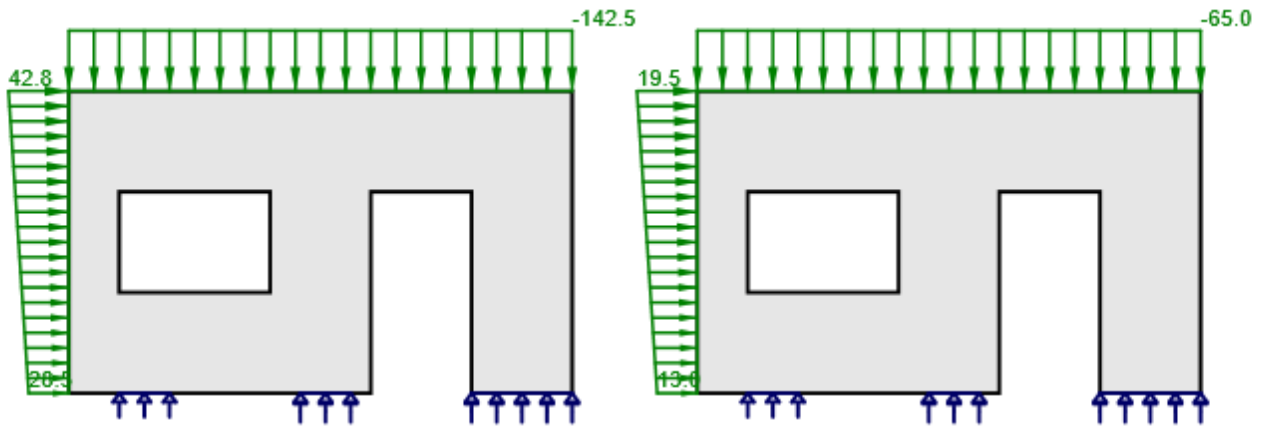


Overview table

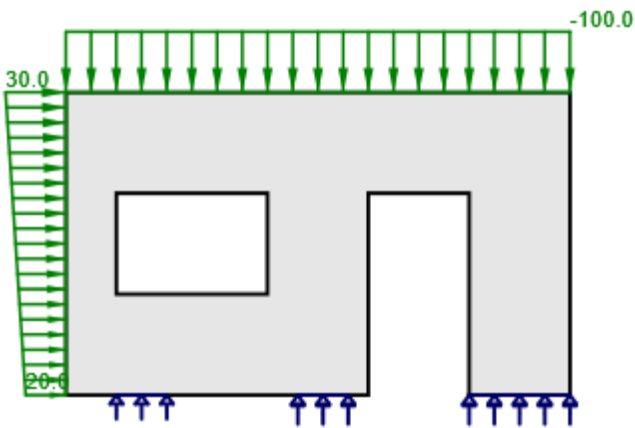
| Name | Type | Properties | Position |
|------|--------------|--|--|
| W1 | Wall | Rectangular; W: 5.00 m; H: 3.00 m; T: 0.20 m; Material: C30/37 | |
| O1 | Opening | Rectangular; W: 1.50 m; H: 1.00 m | M: W1; IP: 1; MP: 1; X: 0.50 m; Z: 1.00 m |
| O2 | Opening | Rectangular; W: 1.00 m; H: 2.00 m | M: W1; IP: 2; MP: 2 |
| LS1 | Line support | X; Z (Pressure only); Local; L: 0.50 m | M: W1, Edge 1; Part of edge; From beginning; X: 0.50 m |
| LS2 | Line support | Z (Pressure only); Local; L: 1.00 m | M: W1, Edge 1; Part of edge; From end; X: 0.00 m |
| LS3 | Line support | Z (Pressure only); Local; L: 0.50 m | M: W1, Edge 1; Part of edge; From end; X: 2.20 m |

Loads

C1, C2



C3

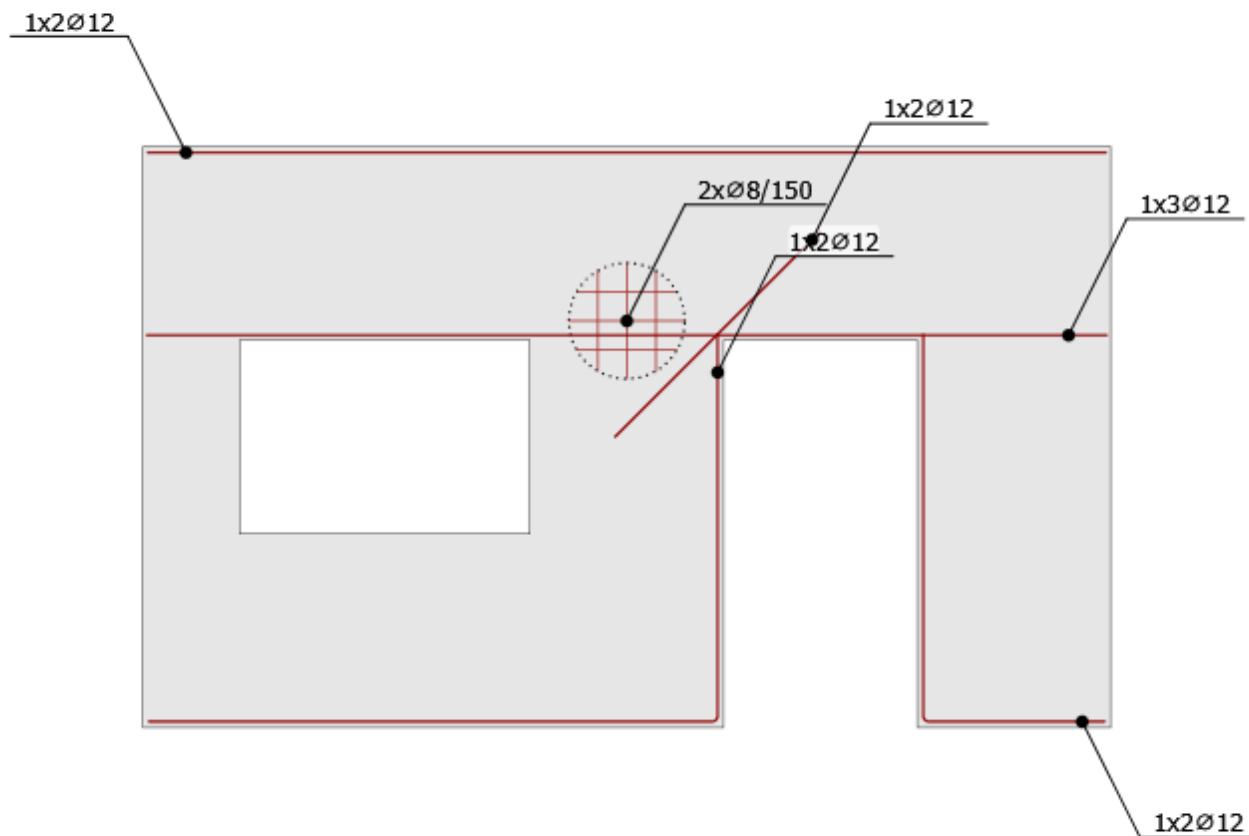


Combination

| Name | Type | Content |
|------|-----------------------|-----------------------------------|
| C1 | ULS | $1.35 \cdot LC1 + 1.50 \cdot LC2$ |
| C2 | SLS - Quasi-permanent | $LC1 + 0.30 \cdot LC2$ |
| C3 | SLS - Characteristic | $LC1 + LC2$ |

Reinforcement

Scheme of reinforcement



Concrete: C30/37; Steel: B 500B

Results

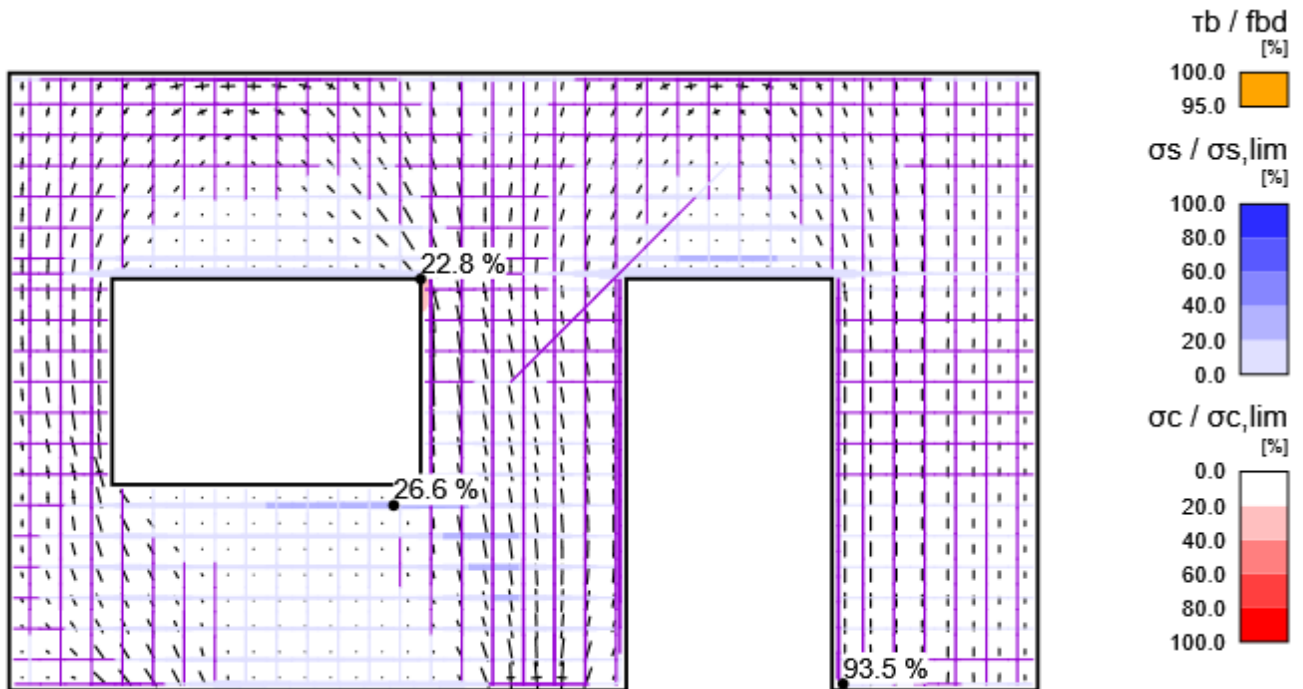
Summary

Overview table

| Check item | Combination | Increment | Item | | | | |
|---------------------------|-------------|------------------|---|------|-------------|---|---|
| ULS | C1 | P100.0%, V100.0% | Strength of reinforcement | | | | ✓ |
| Check item | | Item | Utilization | | | | |
| Strength of concrete | | W1 | $\sigma_c / \sigma_{c,lim}$: 22.8% | | | | ✓ |
| Strength of reinforcement | | WF1 | $\epsilon_s / \epsilon_{s,lim}$: 0.8%, $\sigma_s / \sigma_{s,lim}$: 26.6% | | | | ✓ |
| Anchorage length | | GB3 | t_b / f_{bd} : 93.5% | | | | ✓ |
| SLS | C3 (LT) | P100.0%, V100.0% | Stress limitation | | | | ✓ |
| Check item | Combination | Increment | Critical check | Item | Utilization | | |
| Stress limitation | C3 (LT) | P100.0%, V100.0% | 7.2(5) | WF1 | 22.4% | ✓ | |
| Crack width | C2 (LT) | P100.0%, V100.0% | w/wlim | WF1 | 3.2% | ✓ | |

ULS - Summary

Stress flow



| Above yield | Compression | Explanation |
|-------------|-------------|---------------------------------|
| | | Thickness proportional to force |

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Summary of reactions and applied loads: C1, Load increment: P100.0%, V100.0%

| Type | F _x [kN] | F _z [kNm] | M _y [kNm] |
|-------------------------|------------------------|-------------------------|-------------------------|
| Summary of reactions | -75.0 | 500.0 | 1370.0 |
| Summary of applied load | 75.0 | -500.0 | -1370.0 |
| Check of equilibrium | 0.0 | 0.0 | 0.0 |

ULS - Strength

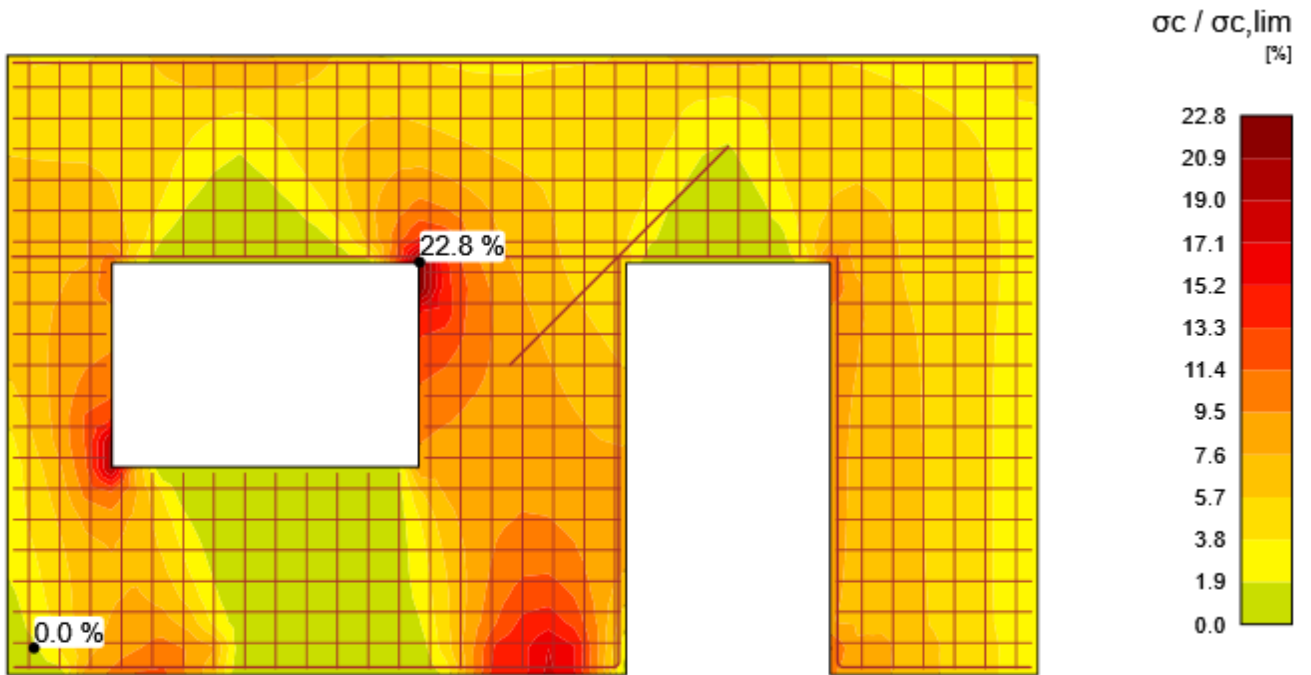
Detailed concrete strength results: C1, Load increment: P100.0%, V100.0%

| Member | X [m] | Z [m] | σ _c [MPa] | ε _c [1e-4] | k _{c2} [-] | σ _c /σ _{c,lim} [%] | |
|--------|----------|----------|-------------------------|--------------------------|------------------------|---|----|
| W1 | 2.00 | 2.00 | -4.6 | -2.4 | 1.00 | 22.8 | OK |
| W1 | 4.00 | 1.88 | -1.7 | -0.9 | 1.00 | 8.6 | OK |

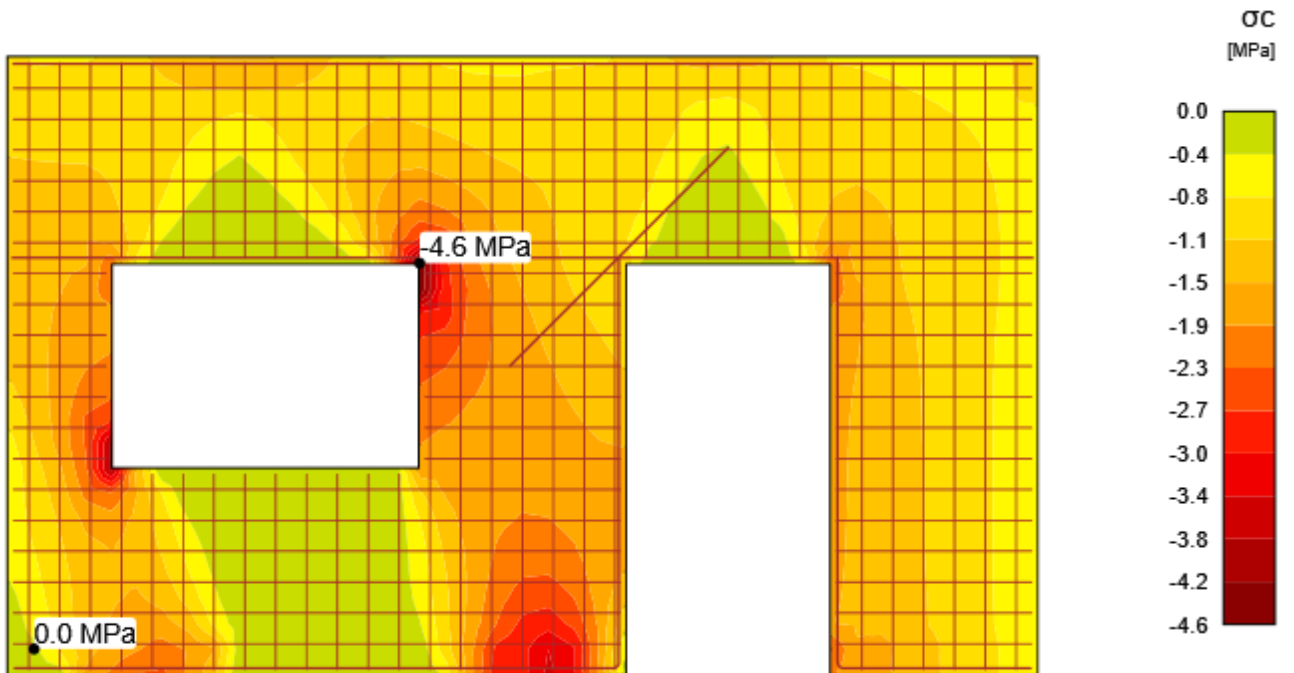
Detailed reinforcement strength results: C1, Load increment: P100.0%, V100.0%

| Member | X [m] | Z [m] | σ _s [MPa] | ε _s [1e-4] | σ _s /σ _{s,lim} [%] | ε _s /ε _{s,lim} [%] | |
|--------|----------|----------|-------------------------|--------------------------|---|---|----|
| WF1 | 1.87 | 0.90 | 125.0 | 0.6 | 26.6 | 0.8 | OK |
| WF1 | 3.00 | 2.10 | 85.4 | 0.9 | 18.2 | 0.7 | OK |
| GB4 | 3.00 | 2.03 | 70.7 | 1.3 | 15.0 | 0.7 | OK |
| GB2 | 1.00 | 0.03 | 51.1 | 0.9 | 10.9 | 0.4 | OK |
| GB3 | 4.03 | 0.18 | -20.3 | -1.0 | 4.3 | 0.2 | OK |
| GB1 | 1.26 | 2.97 | -15.5 | -0.8 | 3.3 | 0.2 | OK |
| GB3 | 4.06 | 0.03 | 41.9 | 0.4 | 8.9 | 0.2 | OK |
| GB1 | 2.38 | 2.97 | 30.3 | 0.2 | 6.5 | 0.1 | OK |
| IB1 | 2.52 | 1.58 | -4.5 | -0.2 | 1.0 | 0.0 | OK |
| IB1 | 3.42 | 2.48 | 0.7 | 0.0 | 0.1 | 0.0 | OK |

Concrete stress/strength ratio

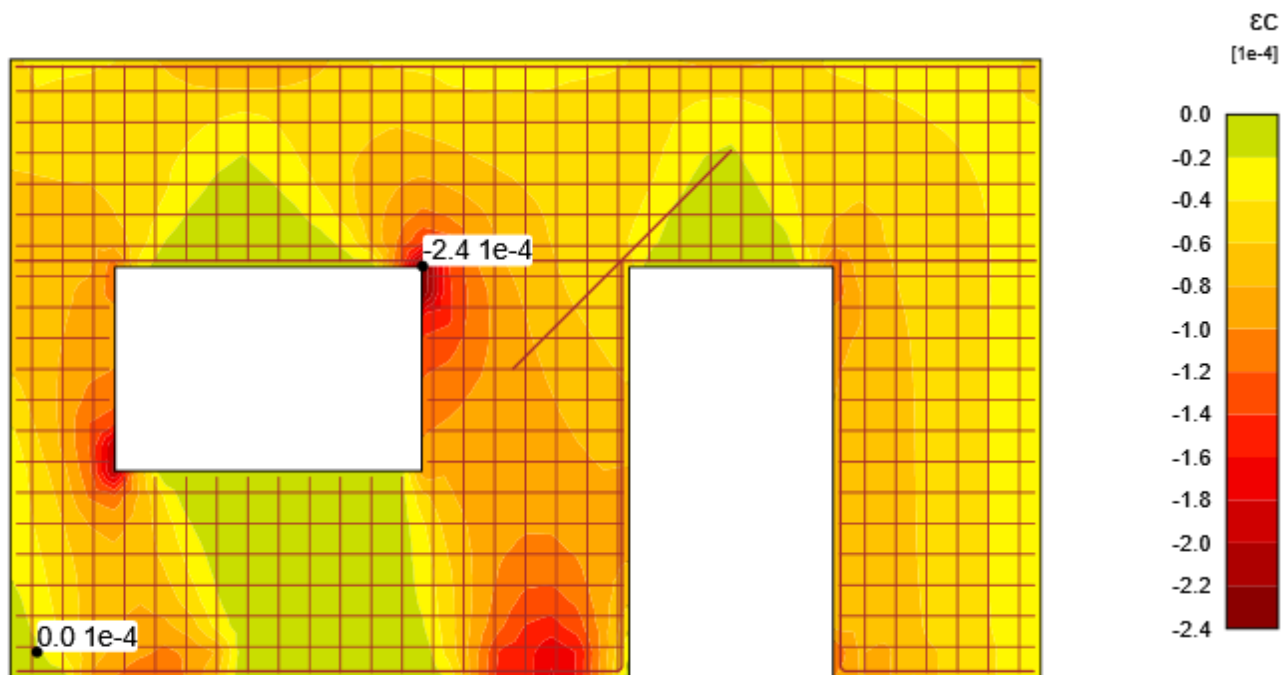


Concrete principal stress σ_c

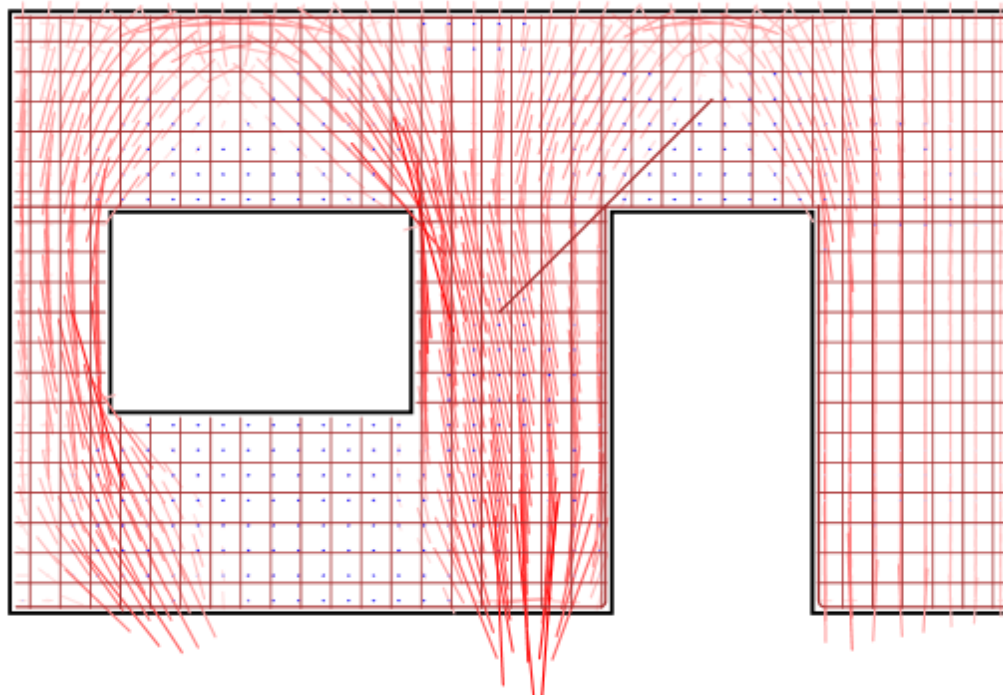


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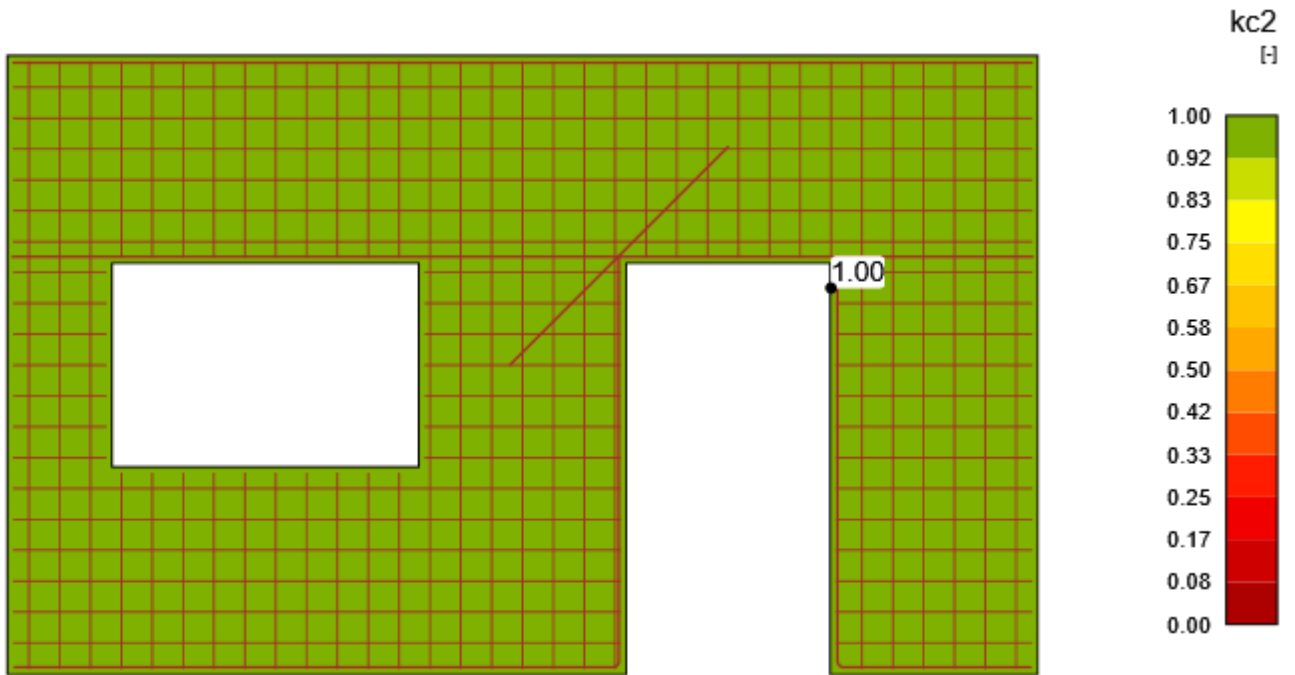
Concrete principal strain ϵ_c



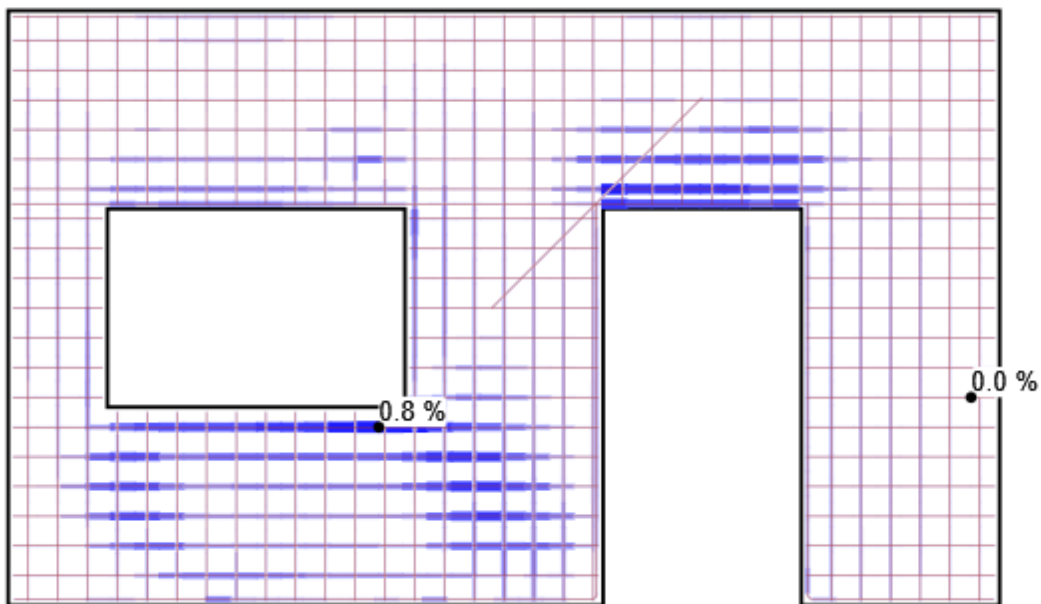
Directions of principal stresses



Compressive strength reduction factor k_{c2}

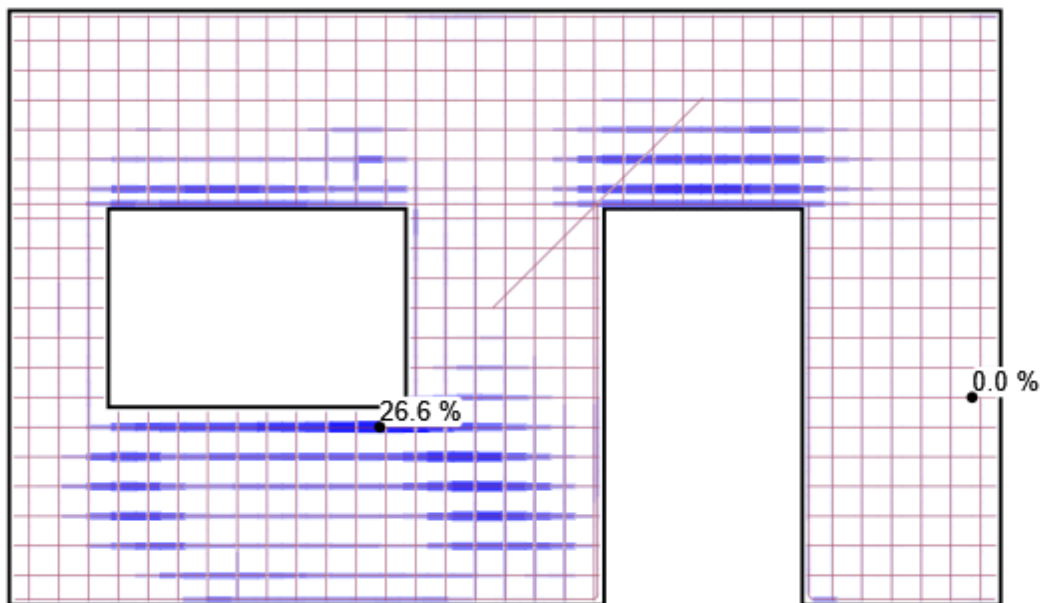


Reinforcement strain/limit strain ratio - $\epsilon_s/\epsilon_{s,lim}$ [%]

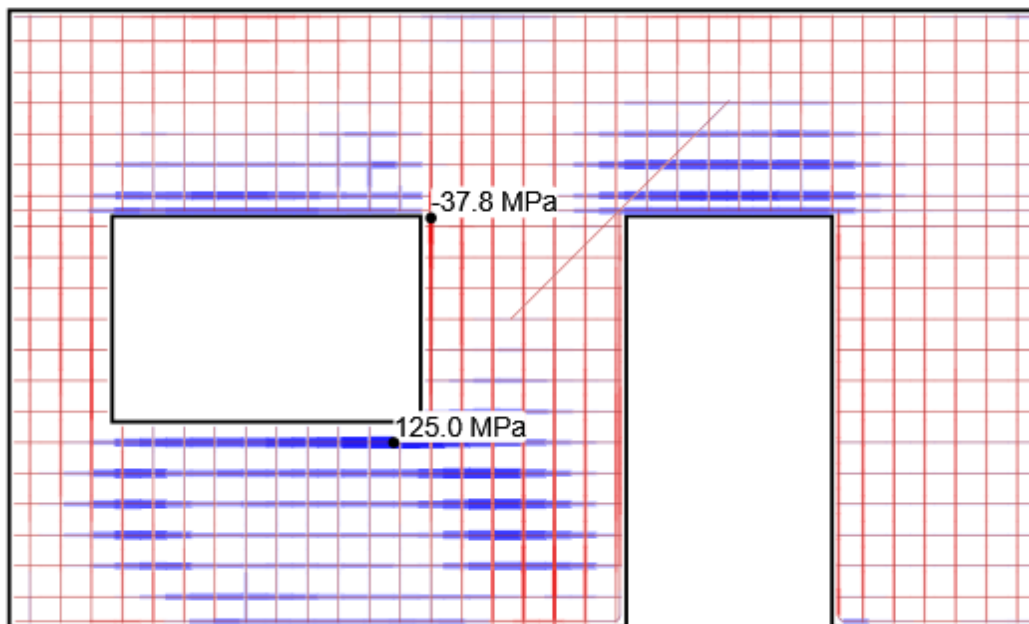


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Reinforcement stress/strength ratio - $\sigma_s/\sigma_{s,lim}$ [%]

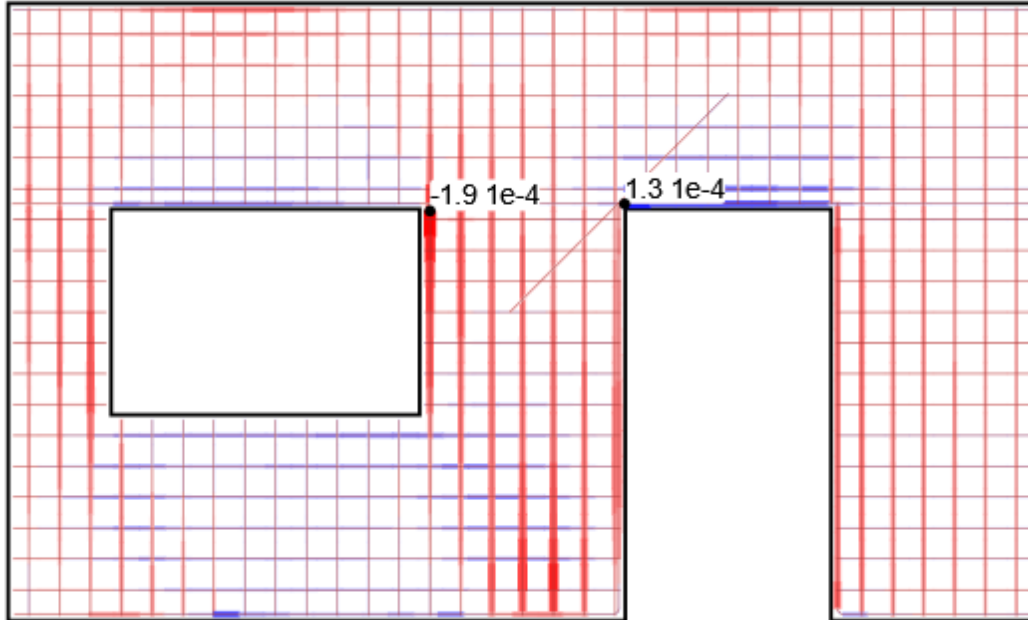


Reinforcement stress - σ_s [MPa]



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Reinforcement strain - ϵ_s [$1e-4$]



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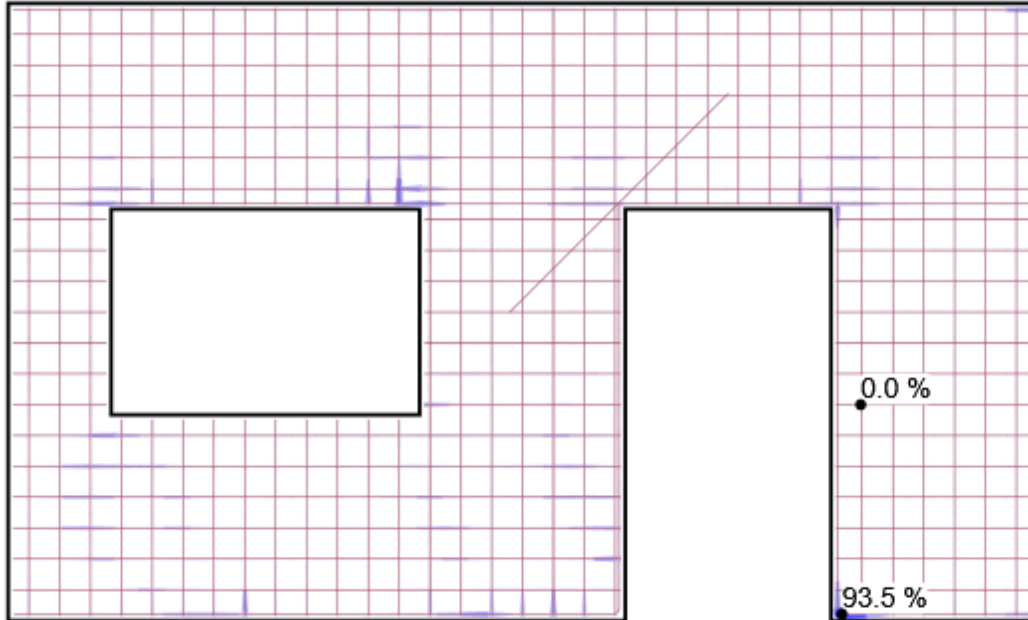
ULS - Anchorage

Detailed anchorage results: C1, Load increment: P100.0%, V100.0%

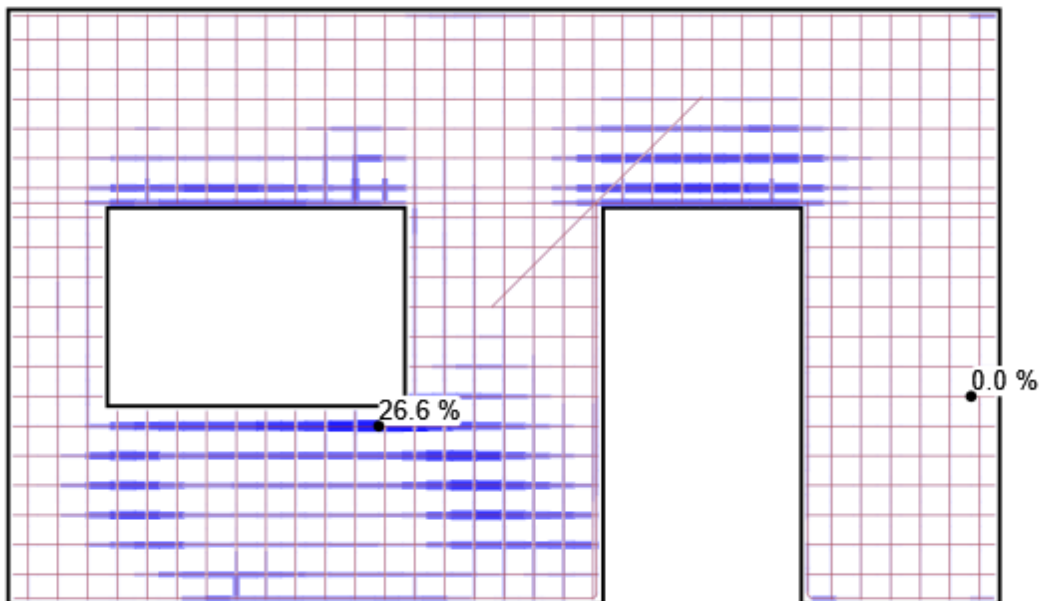
| Member | X [m] | Z [m] | τ_b [MPa] | F_a [kN] | F_{tot} [kN] | F_{tot}/F_{lim} [%] | τ_b/f_{bd} [%] | |
|--------|-------|-------|----------------|------------|----------------|-----------------------|---------------------|----|
| GB3 | 4.05 | 0.03 | 2.8 | 2.0 | 5.0 | 4.7 | 93.5 | OK |
| GB3 | 4.17 | 0.03 | -1.6 | 2.0 | 9.5 | 8.9 | 52.7 | OK |
| GB3 | 4.06 | 0.03 | 2.1 | 2.0 | 9.5 | 8.9 | 70.1 | OK |
| GB3 | 4.03 | 0.18 | -0.4 | 2.0 | -4.6 | 4.3 | 13.4 | OK |
| WF1 | 1.90 | 2.03 | -1.5 | 0.0 | 2.1 | 11.9 | 50.5 | OK |
| WF1 | 2.65 | 0.02 | 1.4 | 0.0 | -2.6 | 5.4 | 44.8 | OK |
| WF1 | 1.87 | 0.90 | 0.1 | 0.0 | 12.6 | 26.6 | 3.3 | OK |
| WF1 | 2.05 | 1.99 | -0.4 | 0.0 | -3.8 | 8.0 | 11.8 | OK |
| GB4 | 2.00 | 2.03 | -1.3 | 0.1 | 12.3 | 7.7 | 43.9 | OK |
| GB4 | 0.52 | 2.03 | 0.9 | 0.1 | 12.2 | 7.7 | 29.5 | OK |
| GB4 | 3.00 | 2.03 | 0.4 | 0.1 | 24.0 | 15.0 | 13.9 | OK |
| GB4 | 2.13 | 2.03 | 0.2 | 0.1 | -1.8 | 1.1 | 5.7 | OK |
| GB2 | 2.33 | 0.03 | -1.0 | 0.0 | 5.8 | 5.5 | 33.5 | OK |
| GB2 | 0.88 | 0.03 | 0.7 | 0.0 | 1.9 | 1.8 | 22.9 | OK |
| GB2 | 1.00 | 0.03 | 0.6 | 0.0 | 11.6 | 10.9 | 20.0 | OK |
| GB2 | 2.97 | 0.68 | 0.0 | 0.0 | -3.8 | 3.6 | 0.6 | OK |
| GB1 | 4.98 | 2.97 | 0.9 | 2.7 | 4.5 | 7.5 | 28.7 | OK |
| GB1 | 4.85 | 2.97 | -0.6 | 2.7 | 4.5 | 7.5 | 18.7 | OK |
| GB1 | 2.38 | 2.97 | 0.1 | 2.7 | 6.9 | 6.5 | 2.6 | OK |
| GB1 | 1.26 | 2.97 | 0.0 | 2.7 | -3.5 | 3.3 | 0.8 | OK |
| IB1 | 2.44 | 1.50 | -0.3 | 0.1 | -0.8 | 0.7 | 9.2 | OK |
| IB1 | 3.01 | 2.07 | 0.1 | 0.1 | -0.6 | 0.6 | 2.4 | OK |
| IB1 | 3.42 | 2.48 | 0.0 | 0.1 | 0.2 | 0.3 | 0.4 | OK |
| IB1 | 2.52 | 1.58 | 0.0 | 0.1 | -1.0 | 1.0 | 1.0 | OK |

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Bond stress check value - τ_b/f_{bd} [%]

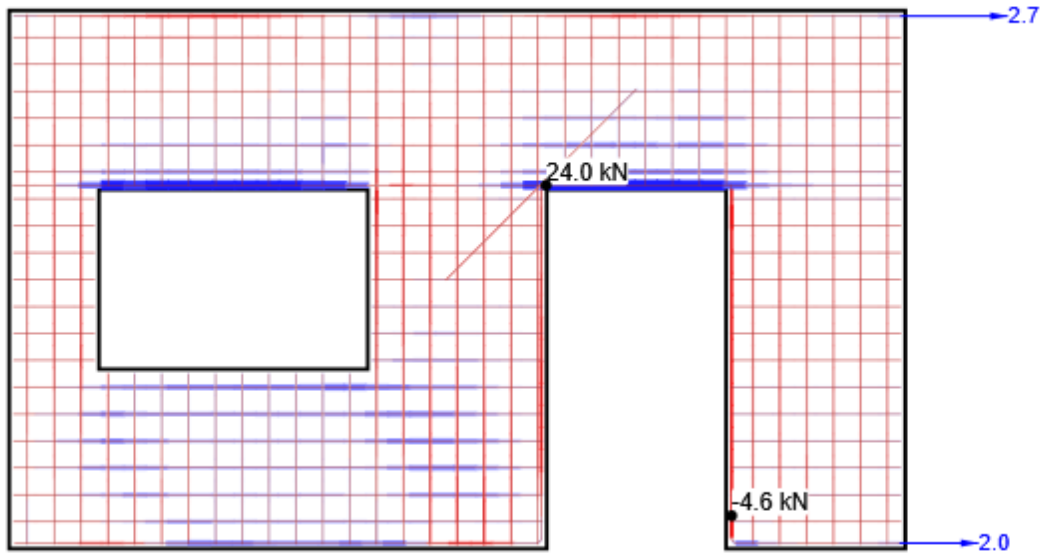


Force check value - F_{tot}/F_{lim} [%]

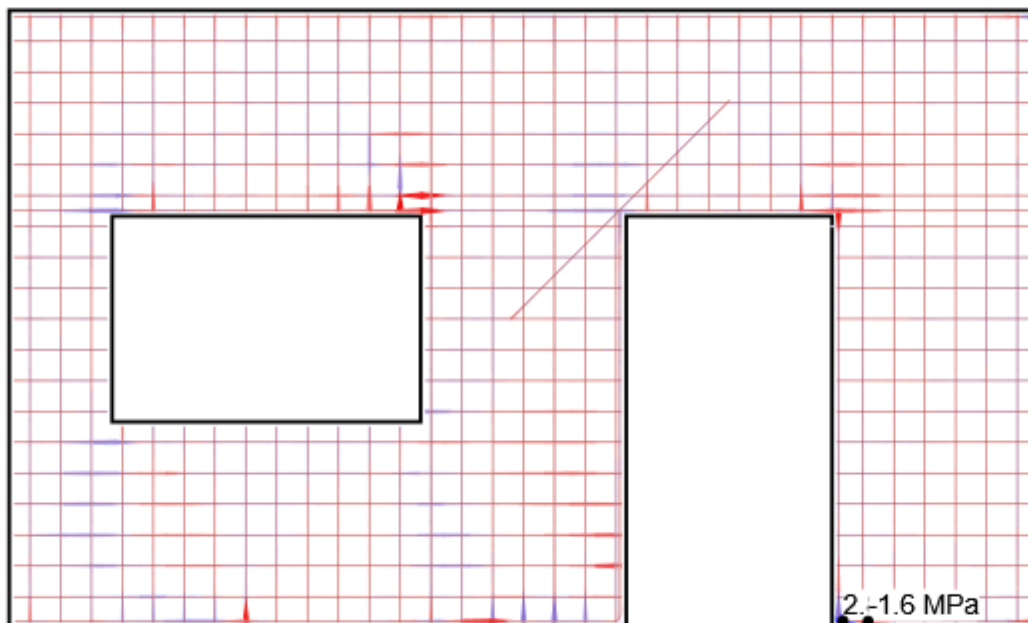


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Total force in the bar - F_{tot} [kN]



Bond stress - τ_b [MPa]



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Settings

Creep coefficient

| Type of input | Creep coefficient |
|---------------|-------------------|
| Input by user | 2.5 |

SLS - Stress

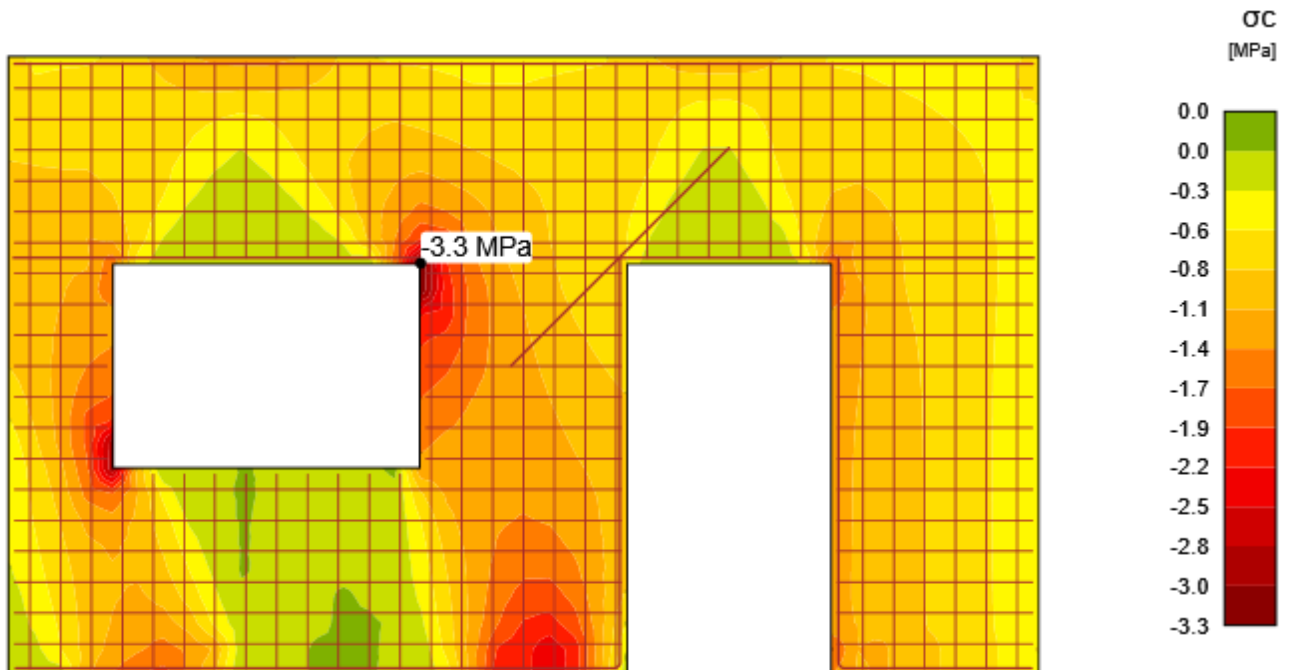
Detailed concrete stress results: C3, Load increment: P100.0%, V100.0%

| Member | X [m] | Z [m] | Critical check | σ_c [MPa] | σ_{lim} [MPa] | σ_c/σ_{lim} [%] | |
|--------|-------|-------|----------------|------------------|----------------------|-----------------------------|----|
| W1 | 2.00 | 2.00 | 7.2(2) | -3.3 | 18.0 | 18.4 | OK |

Detailed reinforcement stress results: C3, Load increment: P100.0%, V100.0%

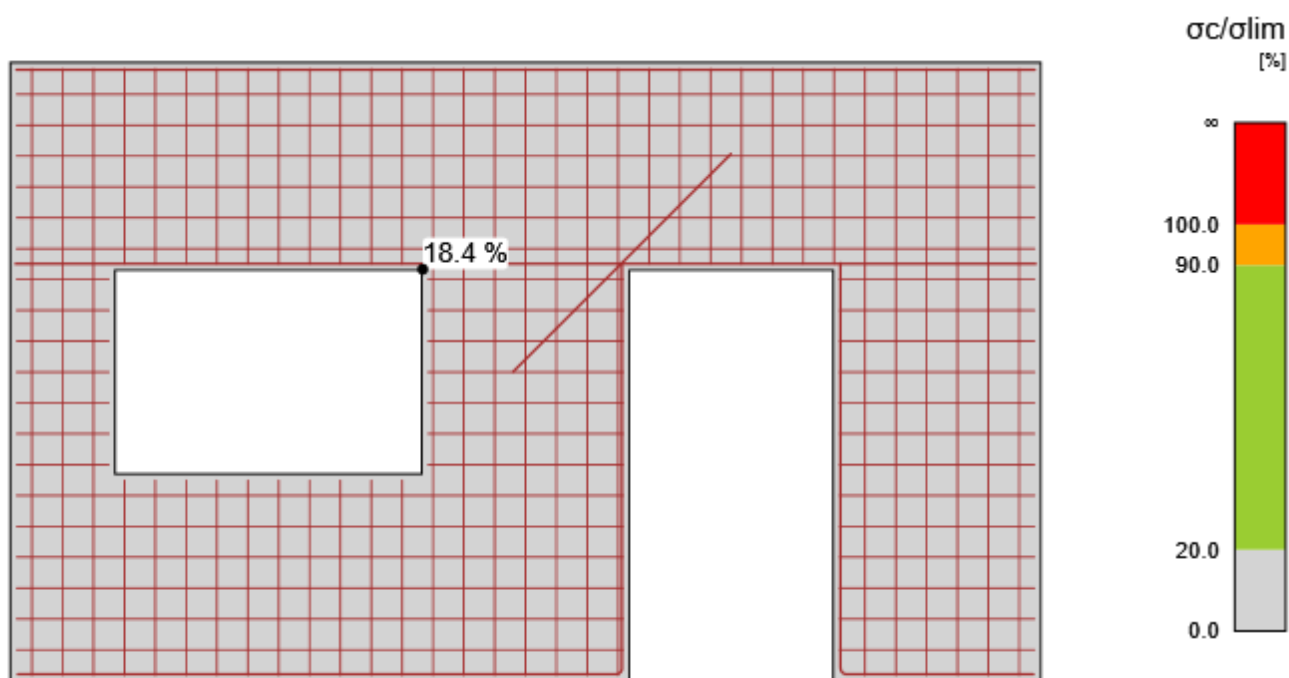
| Reinforcement | X [m] | Z [m] | Critical check | σ_s [MPa] | σ_{lim} [MPa] | σ_s/σ_{lim} [%] | |
|---------------|-------|-------|----------------|------------------|----------------------|-----------------------------|----|
| WF1 | 1.87 | 0.90 | 7.2(5) | 89.7 | 400.0 | 22.4 | OK |
| GB1 | 4.98 | 2.97 | 7.2(5) | 16.1 | 400.0 | 4.0 | OK |
| GB2 | 1.00 | 0.03 | 7.2(5) | 48.4 | 400.0 | 12.1 | OK |
| GB3 | 4.05 | 0.03 | 7.2(5) | 56.7 | 400.0 | 14.2 | OK |
| GB4 | 3.62 | 2.03 | 7.2(5) | 63.1 | 400.0 | 15.8 | OK |
| IB1 | 2.44 | 1.50 | 7.2(5) | -3.9 | 400.0 | 0.0 | OK |

Concrete stress

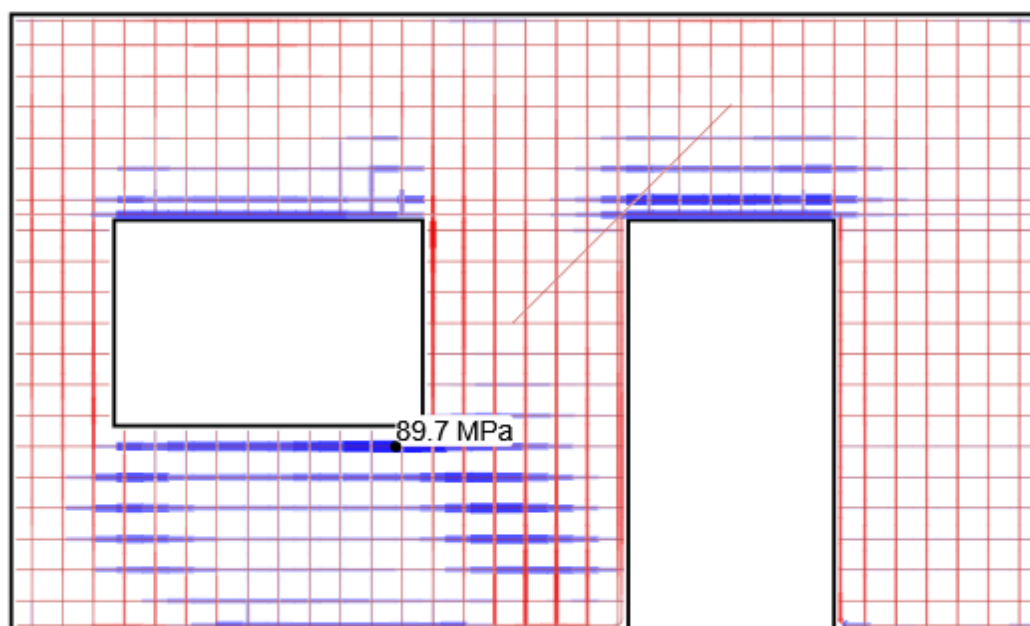


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Concrete stress check

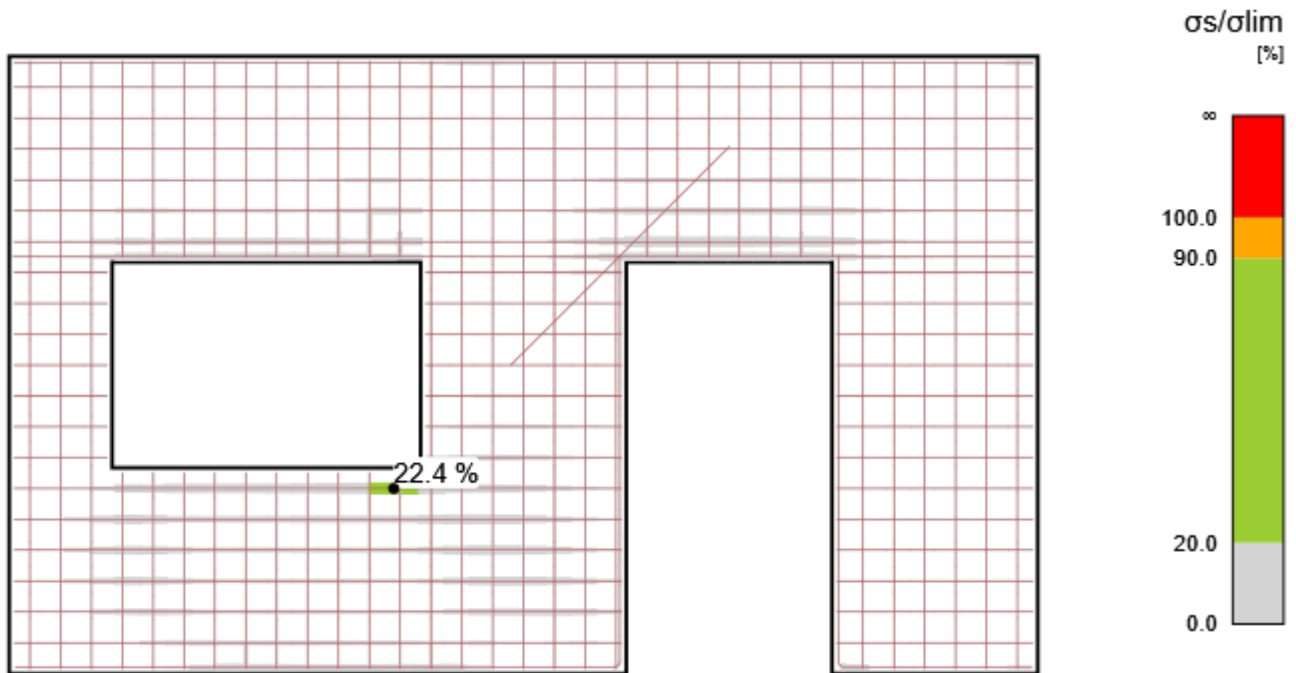


Reinforcement stress - σ_s [MPa]



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Reinforcement stress check



SLS - Crack

Detailed crack results: C2, Load increment: P100.0%, V100.0%, $w_{lim}=0.300$ mm

| Member | X [m] | Z [m] | w [mm] | w/w _{lim} [%] | |
|--------|-------|-------|--------|------------------------|----|
| WF1 | 1.87 | 0.90 | 0.010 | 3.2 | OK |
| WF1 | 1.75 | 0.90 | 0.010 | 3.2 | OK |
| GB4 | 3.00 | 2.03 | 0.005 | 1.8 | OK |
| GB4 | 3.74 | 2.03 | 0.005 | 1.7 | OK |
| GB3 | 4.05 | 0.03 | 0.003 | 1.1 | OK |
| GB2 | 2.09 | 0.03 | 0.002 | 0.8 | OK |
| GB1 | 4.98 | 2.97 | 0.001 | 0.2 | OK |
| IB1 | 2.44 | 1.50 | 0.000 | 0.0 | OK |

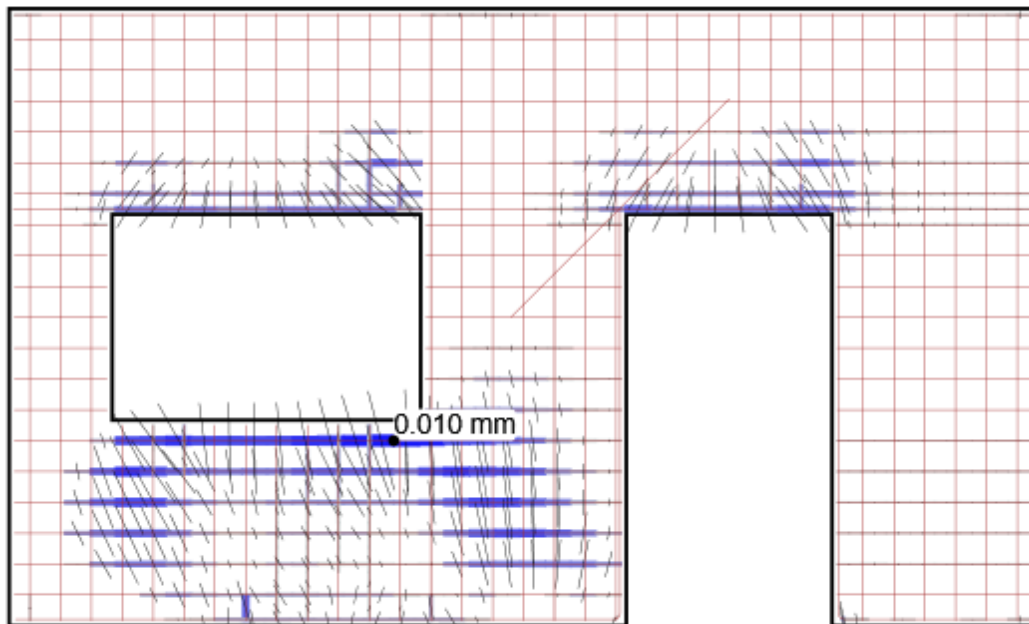
Intermediate crack results

| Member | ϵ_{cm} [1e-4] | ϵ_m [1e-4] | s_r [mm] | Φ [mm] | ρ_{eff} [%] | w_b [mm] | θ_r [-] | θ_b [-] |
|--------|------------------------|---------------------|------------|-------------|------------------|------------|----------------|----------------|
| WF1 | 0.0 | 0.3 | 297 | 8 | 0.67 | 0.010 | 1.60 | 0.00 |
| WF1 | 0.0 | 0.3 | 297 | 8 | 0.67 | 0.009 | 1.83 | 0.00 |
| GB4 | 0.0 | 0.4 | 137 | 12 | 2.15 | 0.005 | 1.14 | 0.00 |
| GB4 | 0.0 | 0.3 | 166 | 12 | 1.77 | 0.004 | 2.18 | 0.00 |
| GB3 | 0.0 | 0.2 | 154 | 12 | 1.91 | 0.003 | 1.79 | -0.13 |
| GB2 | 0.0 | 0.2 | 120 | 12 | 2.44 | 0.002 | 2.11 | 0.00 |
| GB1 | 0.0 | 0.1 | 120 | 12 | 2.44 | 0.001 | 1.69 | 0.00 |
| IB1 | 0.0 | 0.0 | 0 | 0 | 0.00 | 0.000 | 0.00 | 0.00 |

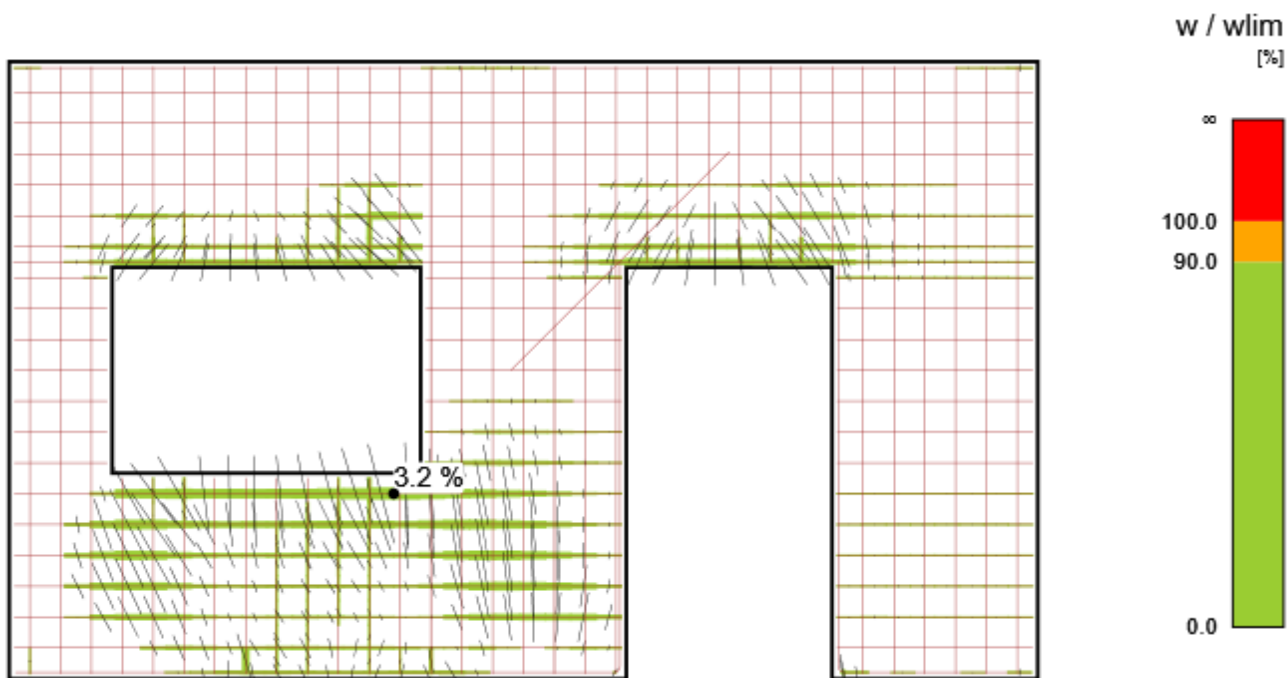
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Note: There are TCM intermediate values displayed in the table above. Adequate POM values are not available in current version of the program.

Crack width - w [mm]



Crack width check



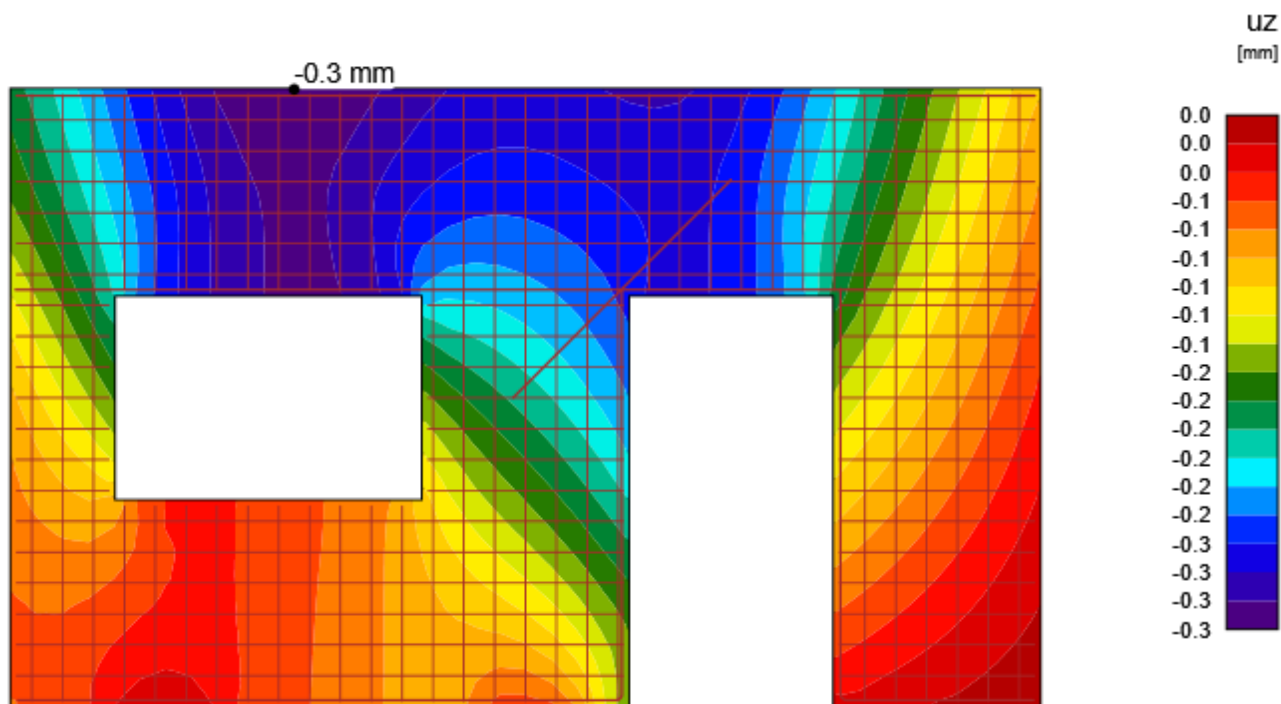
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SLS - Deflection

Detailed deflection results: C3, Load increment: P100.0%, V100.0%

| Member | X [m] | Z [m] | $u_{z,st}$ [mm] | $u_{z,it}$ [mm] | Δu_z [mm] | u_z [mm] | |
|--------|-------|-------|-----------------|-----------------|-------------------|------------|----|
| W1 | 1.38 | 3.00 | -0.2 | -0.2 | -0.1 | -0.3 | OK |
| W1 | 3.25 | 3.00 | -0.2 | -0.2 | -0.1 | -0.3 | OK |

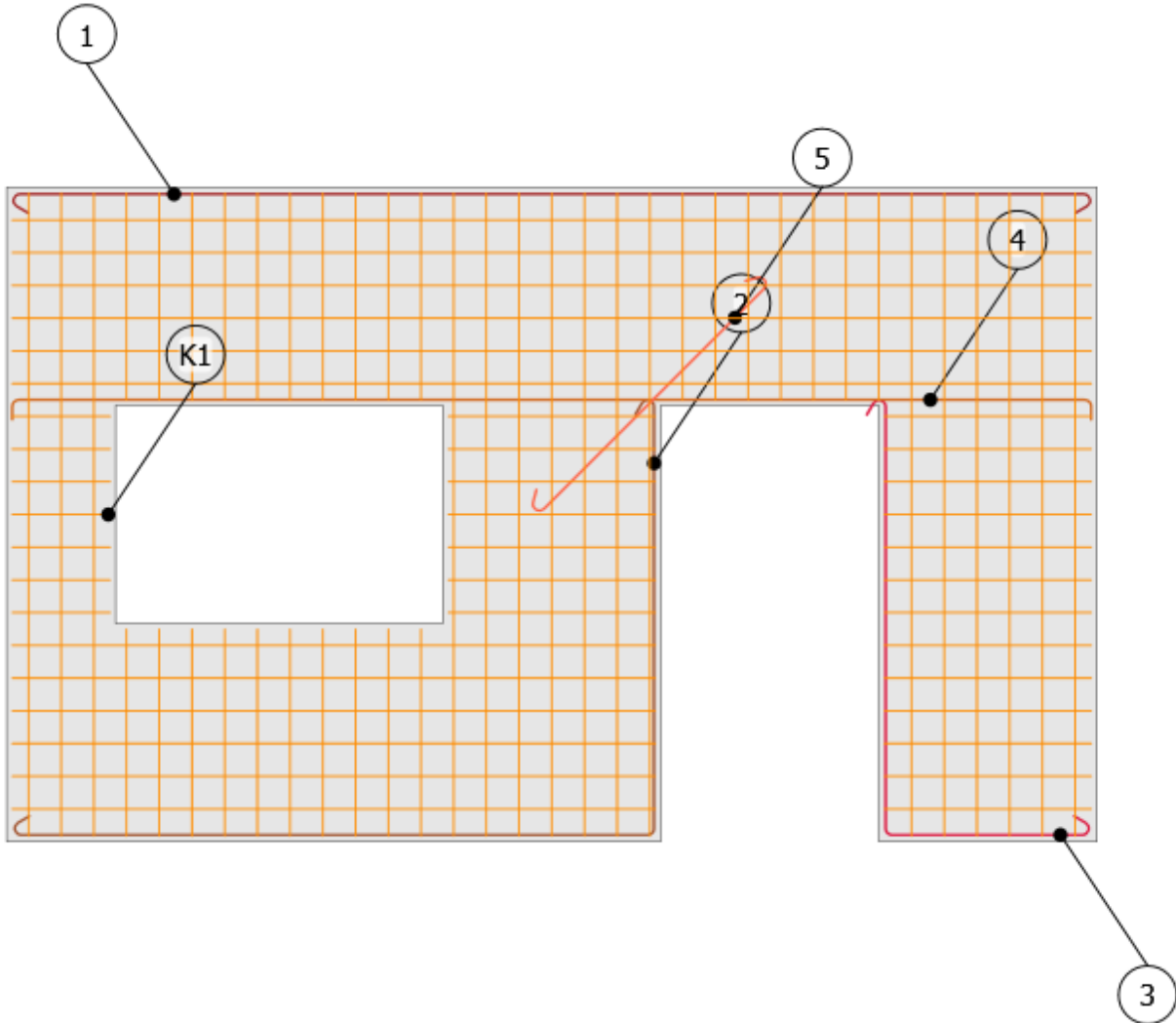
Deflection



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Bill of material

Items numbering



Fabric reinforcement tables

| Parameter | Value |
|-------------------------|-----------|
| Index | K1 |
| Φ X/Y [mm] | 8 / 8 |
| Material | B 500B |
| Number of items | 2 |
| Total area [m2] | 15.00 |
| Bar spacing X/Y [mm] | 150 / 150 |
| Weight of one item [kg] | 79 |
| Assigned to wall | -all- |

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Brief reinforcement bar table

| Index | Φ [mm] | Material | Items | Length [mm] | Weight [kg] | Total length [m] |
|-------|--------|----------|-------|-------------|-------------|------------------|
| 1 | 12 | B 500B | 2 | 5155 | 5 | 10.31 |
| 2 | 12 | B 500B | 2 | 5130 | 5 | 10.26 |
| 3 | 12 | B 500B | 2 | 3130 | 3 | 6.26 |
| 4 | 12 | B 500B | 3 | 5102 | 5 | 15.31 |
| 5 | 12 | B 500B | 2 | 1705 | 2 | 3.41 |

Detailed reinforcement bar tables

| Parameter | Value | Shape |
|------------------|--------|-------|
| Index | 1 | |
| Φ [mm] | 12 | |
| Material | B 500B | |
| Number of items | 2 | |
| Length [mm] | 5155 | |
| Weight [kg] | 5 | |
| Total length [m] | 10.31 | |

| Parameter | Value | Shape |
|------------------|--------|-------|
| Index | 2 | |
| Φ [mm] | 12 | |
| Material | B 500B | |
| Number of items | 2 | |
| Length [mm] | 5130 | |
| Weight [kg] | 5 | |
| Total length [m] | 10.26 | |

| Parameter | Value | Shape |
|------------------|--------|-------|
| Index | 3 | |
| Φ [mm] | 12 | |
| Material | B 500B | |
| Number of items | 2 | |
| Length [mm] | 3130 | |
| Weight [kg] | 3 | |
| Total length [m] | 6.26 | |

| Parameter | Value | Shape |
|------------------|--------|-------|
| Index | 4 | |
| Φ [mm] | 12 | |
| Material | B 500B | |
| Number of items | 3 | |
| Length [mm] | 5102 | |
| Weight [kg] | 5 | |
| Total length [m] | 15.31 | |

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| Parameter | Value | Shape |
|------------------|--------|-------|
| Index | 5 | |
| Φ [mm] | 12 | |
| Material | B 500B | |
| Number of items | 2 | |
| Length [mm] | 1705 | |
| Weight [kg] | 2 | |
| Total length [m] | 3.41 | |

Overview table

| | Φ [mm] | 12 |
|---|-------------|-------|
| Total length of Φ [m] | | 45.55 |
| Weight per meter of Φ [kg/m] | | 1 |
| Total weight of Φ [kg] | | 40 |
| Total weight of bars [kg] | | 40 |
| Total weight of fabric reinforcement [kg] | | 158 |
| Total weight [kg] | | 198 |
| Volume of concrete [m ³] | | 2.30 |
| Reinforcement weight per volume unit of concrete [kg/m ³] | | 86 |

Explanation

| Symbol | Explanation |
|-------------------------------|--|
| f_{ck} | Characteristic compressive cylinder strength of concrete at 28 days |
| $f_{ctk,0.05}$ | Characteristic axial tensile strength of concrete 5% quantile |
| f_{ctm} | Mean value of axial tensile strength of concrete |
| E_{cm} | Secant modulus of elasticity of concrete |
| ϵ_c | Compressive strain in the concrete at the peak stress f_c |
| ϵ_{cu} | Ultimate compressive strain in the concrete |
| f_{yk} | Characteristic yield strength of reinforcement |
| E_s | Modulus of elasticity of reinforcement steel |
| ϵ_{uk} | Characteristic strain of reinforcement or prestressing steel at maximum load |
| Properties | W - Width; H - Height; T - Thickness; L - Length; r - Radius; α - Inclination |
| Position | M - Master; MP - Master point; IP - Insert point |
| σ_c | The extreme value of compressive stress σ_c of concrete of selected subregion. |
| k_{c2} | Compressive strength reduction factor k_{c2} |
| $\sigma_c/\sigma_{c,lim}$ | The ratio of concrete stress and concrete strength. It presents the level of material utilization with respect to concrete strength. |
| σ_s | Maximum stress along the length of reinforcement bar. |
| ϵ_s | Maximum strain along the length of reinforcement bar. |
| $\sigma_s/\sigma_{s,lim}$ | The ratio of stress and strength of the reinforcement. It presents the level of material utilization with respect to reinforcement strength. |
| $\epsilon_s/\epsilon_{s,lim}$ | The ratio of strain and limit strain of the reinforcement. It presents the level of material utilization with respect to limit strain |
| T_b | Bond stress on the surface of reinforcement bar. |

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| Symbol | Explanation |
|-------------------|---|
| F_a | The anchorage force. It is developed at the ends of the bars due to hooked anchorage. |
| F_{tot} | Total force developed along the length of the bar. It consists of the anchorage force due to hooked anchorage and bond force, which integrates bond stresses acting on the surface of the bar. |
| F_{tot}/F_{lim} | The ratio of total force in the bar and limit value of the force. It presents the level of utilization of the rebar. The limit value of the force is calculated as the minimum of two values: (a) the force calculated as the sum of ultimate anchorage force and the force developed from the end of the bar to the point of interest assuming ultimate bond strength, (b) the ultimate strength of the bar. |
| T_b/f_{bd} | The ratio of bond stress and ultimate bond strength for selected (group of) bars and applied portion of the load. It shows the level of utilization with respect to ultimate bond strength between the rebar and adjacent concrete. |
| Creep coefficient | Final value of creep coefficient at time interval ($t_0 = 28$ days, t_{inf} = design working life) |
| w | Total crack width including effect of creep. |
| ϵ_{cm} | the mean strain in the concrete between cracks |
| ϵ_m | the mean strain in the reinforcement under relevant combination of loads, including the effect of imposed deformations and taking into account the effects of tension stiffening. Only the additional tensile strain beyond the state of zero strain of the concrete at the same level is considered |
| s_r | mean value of axial tensile strength of concrete |
| Φ | diameter of reinforcing bar |
| ρ_{eff} | effective reinforcement ratio |
| w_b | calculated crack width |
| θ_r | inclination of the cracks (the angle between the global coordinate system and the crack direction) |
| θ_b | bar inclination (the angle between the global coordinate system and the axis of reinforcement bar) |
| $u_{z,st}$ | Immediate deflection caused by total load, calculated with short-term stiffnesses. |
| $u_{z,lt}$ | Long-term effects of long-term load. |
| Δu_z | Deflection increment caused by variable load. |
| u_z | Total deflection including effect of creep. |

Code settings

| Clause | Name | Value | Description |
|-------------|--|-------|--|
| 2.4.2.4 (1) | γ_c | 1.50 | Partial factor for concrete. |
| 2.4.2.4 (1) | γ_s | 1.15 | Partial factor for reinforcement |
| 3.1.6 (1) | α_{cc} | 1.00 | Coefficient taking into account the long term effect on the compressive strength and the unfavourable from the way the load is applied |
| 3.2.7 (2) | $\epsilon_{ud}/\epsilon_{uk}$ | 0.90 | Ratio of design and characteristic strain limit. |
| 8.3(2) | $\Phi_{m,min} - \Phi_s \leq 16mm$ (4.00 Φ_s) | 4.00 | Minimum mandrel diameter of stirrups as multiple of stirrups diameter. |
| 8.3(2) | $\Phi_{m,min} - \Phi_s > 16mm$ (7.00 Φ_s) | 7.00 | Minimum mandrel diameter of stirrups as multiple of stirrups diameter. |
| 7.2(2) | k1 | 0.60 | Coefficient for calculation of the maximum compressive stress in concrete under SLS characteristic combination |
| 7.2(3) | k2 | 0.45 | Coefficient for calculation of the stress in the concrete under the SLS quasi-permanent combination |
| 7.2(5) | k3 | 0.80 | Coefficient for calculation of maximal tensile stress in the reinforcement under SLS characteristic combination |

Calculation presumptions

- Minimum amount of reinforcement resisting at least the tensile stresses prior cracking has to be provided in cracked zones.

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- It is assumed that a transverse rebar or adequate overlap is provided to enable full anchorage of the stirrups.
- The analysis and code checks are performed for support conditions as specified in the project. No change of supports in construction/service stages is considered.
- The crack width is checked in the vicinity of the reinforcement only. No control of cracking is performed in non-reinforced zones.
- The presentation of crack spacing is schematic only. It does not represent the crack spacing computed for the calculations.