**Program: RFEM 6, Concrete Design**

**Category: Design Check**

**Verification Example: 1000 – Concrete Column with the Nominal Curvature Method**

# 1000 – Concrete Column with the Nominal Curvature Method

## Description

A reinforced concrete column is designed for ULS at normal temperature according to DIN EN 1992-1-1/NA/A1:2015, based on 1990-1-1/NA/A1:2012-08. The design employs the Nenn Curvature Method, see DIN EN 1992-1-1, Section 5.8.8. The addressed column is located at the edge of a 3-span frame structure, which consists of 4 cantiliver columns and 3 individual trusses hinged to them, cf. **Figure 1**. The column is subjected to the vertical force of the precast truss and wind. The results are compared with the literature [1].

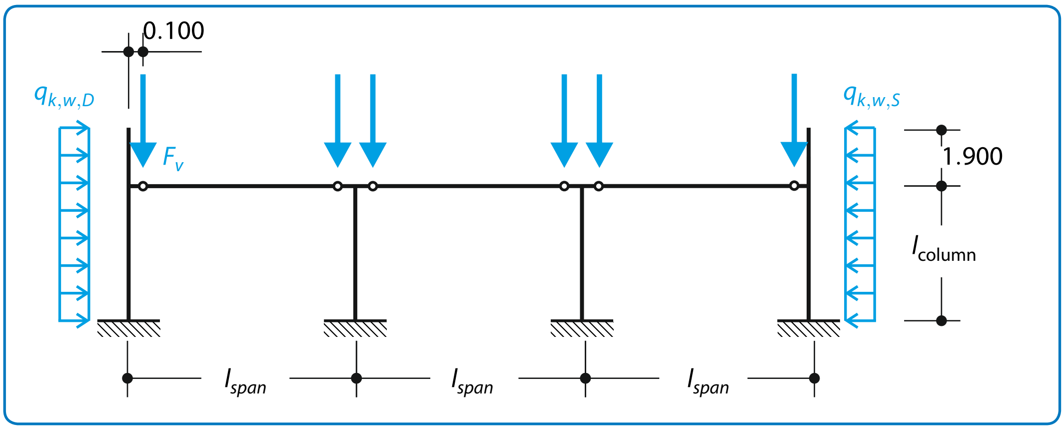


**Figure 1:** Problem sketch

The frame is completely modeled in RFEM. This eliminates the need to manually apply the horizontal coupling force through the trusses. The trusses are modeled as rigid members with quasi-infinite stiffness. For the manual determination of the coupling forces in the reference solution, the stiffnesses of the inner columns were assumed to be 125% of the stiffnesses of the edge columns. To obtain the same coupling forces in RFEM, the bending stiffness of the interior columns is increased by a factor of 1.250. The buckling length coefficients were defined manually according to the reference solution: $\beta_y = 2.100$. The number of effective columns $m$ is set to 4.

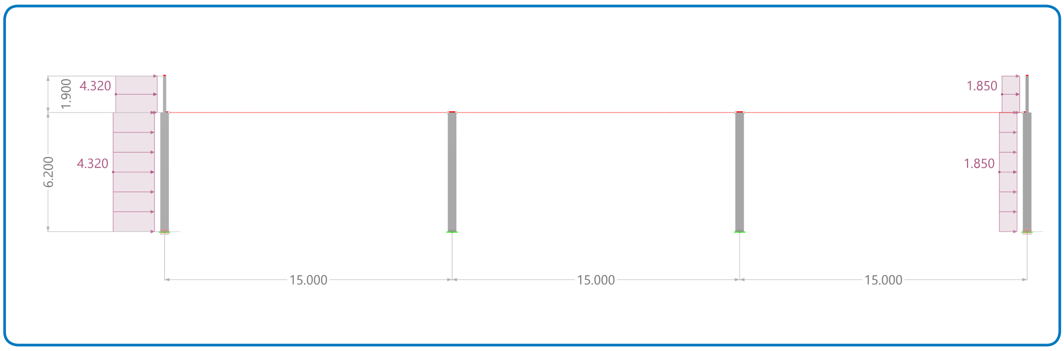


**Figure 2:** RFEM system under load case wind

| | | | | | |
|---|---|---|---|---|---|
| Materials | Concrete | C30/37 | $E_{cm}$ | 33000.000 | $N/mm^2$ |
| | | | $f_{cd}$ | 17.000 | $N/mm^2$ |
| | Reinforcing steel | B500(B) | $f_{yk}$ | 500.000 | $N/mm^2$ |
| | | | $f_{yd}$ | 435.000 | $N/mm^2$ |
| Geometry | Structure | Length | $l$ | 45.000 | m |
| | | Span length | $l_{span}$ | 15.000 | m |
| | | Column Height | $l_{column}$ | 6.200 | m |
| | Column cross-section | Width | $b$ | 0.400 | m |
| | | Height | h | 0.450 | m |
| Load | Permanent loads | Vertical support force of the precast truss | $F_v$ | 400.000 | kN |
| | | Column self-weight | $G$ | 31.210 | kN |
| | Wind | Pressure | $q_{k,w,D}$ | 4.320 | kN/m |
| | | Suction | $q_{k,w,S}$ | 1.850 | kN/m |
| | Snow | Snow force | $Q_{k,s}$ | 68.000 | kN |
| Reinforce-ment | Longitudinal Reinforce-ment | Concrete cover | $c_{nom}$ | 30 | mm |
| | | Rebar parameter | $n_s$ (top) | 4 | – |
| | | | $d_s$ (top) | 16 | mm |
| | | | $n_s$ (lateral) | 1 | – |
| | | | $d_s$ (lateral) | 12 | mm |
| | | | $n_s$ (bottom) | 4 | – |
| | | | $d_s$ (botton) | 16 | mm |
| | | Reinforce-ment area | Top side | 8.040 | $cm^2$ |
| | | | Lateral sides | 2.260 | $cm^2$ |
| | | | Bottom side | 8.040 | $cm^2$ |
| | | | Total | 18.350 | $cm^2$ |

The reinforcement layout is displayed in **Figure 3** and **Figure 4** below:

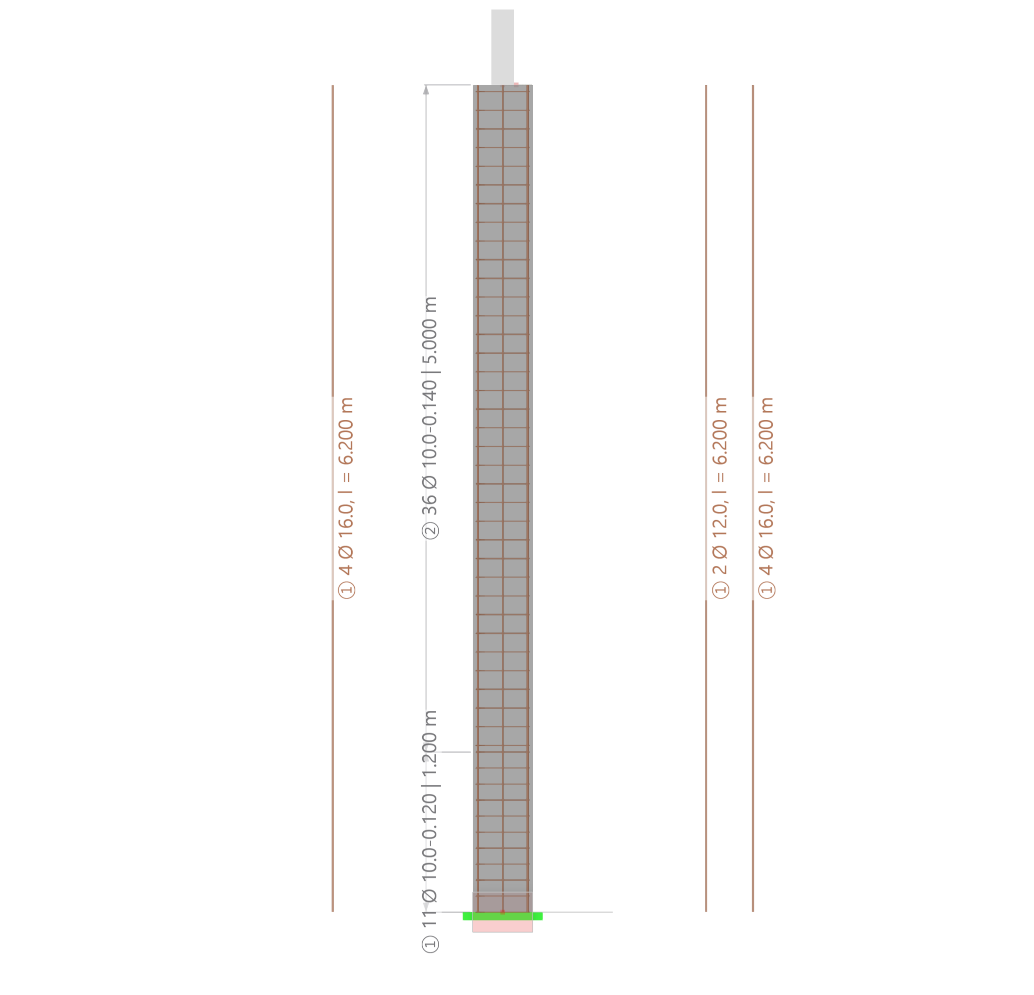


**Figure 3:** Reinforcement layout of the column

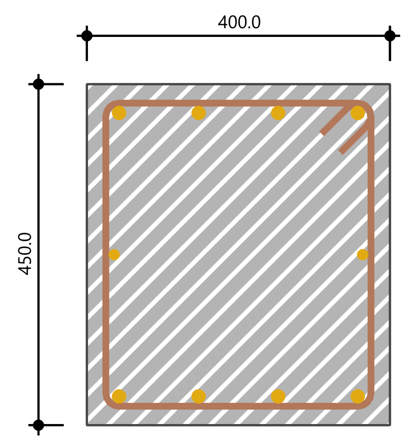


**Figure 4:** Cross-sectional view of the reinforcement

## Results

The relevant column is the one under load case wind suction and snow. The following table sumarizes the RFEM 6 results.

| | | Value | Unit |
|---|---|---|---|
| Normal force | $N_{Ed}$ | 633.020 | $kN$ |
| Relative normal force $N_{Ed}/b \cdot h \cdot f_{cd}$ | $n$ | 0.207 | – |
| Bending Moment | $M_y$ | 99.500 | $kN$ |
| Intended eccentricity | $e_{0,z}$ | 15.720 | $cm$ |
| Eccentricity due to imperfection in z-direction | $e_{i,z}$ | 2.070 | $cm$ |
| Correction factor depending on axial load | $k_r$ | 1.000 | – |
| Factor of taking account of creep | $K_{\phi,y}$ | 1.000 | – |
| Curvature | $1/r_y$ | 0.012 | $m^{-1}$ |
| Additional eccentricity due to second-order theory | $e_{2,z}$ | 19.970 | $cm$ |
| Bending moment acc. to second-order theory | $M_{y,Ed,2}$ | 239.020 | $kNm$ |

## Evaluation

The following table compares the RFEM 6 and the reference results.

| | | RFEM 6 | Reference | Ratio |
|---|---|---|---|---|
| $N_{Ed}$ | kN | -633.000 | -633.000 | 1.000 |
| $M_{Ed}$ | kNm | -99.500 | -100.000 | 0.995 |
| $e_{0,z}$ | cm | 15.720 | 15.800 | 0.994 |
| $e_{i,z}$ | cm | 2.070 | 2.100 | 0.985 |
| $e_{0,z} + e_{i,z}$ | cm | 17.790 | 17.900 | 0.993 |
| $N_{Ed}/b \cdot \mathrm{h} \cdot f_{cd}$ | - | 0.207 | 0.207 | 1.000 |
| $K_r$ | - | 1.000 | 1.000 | 1.000 |
| $K_{\phi,y}$ | - | 1.000 | 1.000 | 1.000 |
| $1/r_y$ | 1/m | 0.012 | 0.012 | 1.000 |
| $e_{2,z}$ | cm | 19.970 | 19.900 | 1.003 |
| $e_{tot}$ | cm | 37.760 | 37.800 | 0,998 |
| $M_{Ed} = N_{Ed} . e_{tot}$ | kNm | 239.020 | 239.000 | 1.000 |
| $A_{s,tot}$ | $\mathrm{cm}^2$ | 15.420 | 16.200 | 0.951 |

Overall, the results of RFEM 6 agree very well with the reference solution [1]. It is important to note that the stiffnesses of the internal columns had to be modified in order to calculate the coupling forces correctly. The consideration of $M_z$ must be switched off for the design. Otherwise, the corresponding moments according to second-order theory will also be included in the calculation. This leads to larger cross-sectional area of reinforcement compared to the reference solution. The required longitudinal reinforcement calculated by RFEM 6 Column module is slightly lower than that of the reference solution. This is because in the reference solution the ω-method is used to determine the reinforcement, which leads to reading inaccuracies. RFEM 6 determines the required reinforcement using a more accurate procedure.

## References

[1] DEUTSCHER BETON- UND BAUTECHNIK-VEREIN E.V., *Beispiele zur Bemessung nach Eurocode 2 Band 1: Hochbau*. Berin: Ernst & Sohn, 2011.