# STRUCTURAL CALCULATION NOTES

**PROJECT**: PROPOSED WAREHOUSE

**LOCATION**: RUBAVU

**CLIENT**: ALPHA LOGISTICS RWANDA

JULY,2016

Contents

# INTRODUCTION

This report is about the structure calculation notes of warehouse

# 1. DESIGN CODES AND TOOLS

## 1.1. GENERAL

Design life: 100 years
Function: warehouse

## 1.2. STANDARDS

LOADING
-IBC 2012 International Building Code 2012
-CP3 Chapter V-2:1972 Code of basic data for the design of buildings, Part 2: - Wind loads
-Load combination: BS-EN 1990:2002 NA: 2004

Concrete design:
BS8110, Part-1:2002 Structural use of concrete

NF EN 1992-1-1/NA: 2007 Reincorced concrete wall design

MATERIALS
Concrete: Concrete grade: C25/30

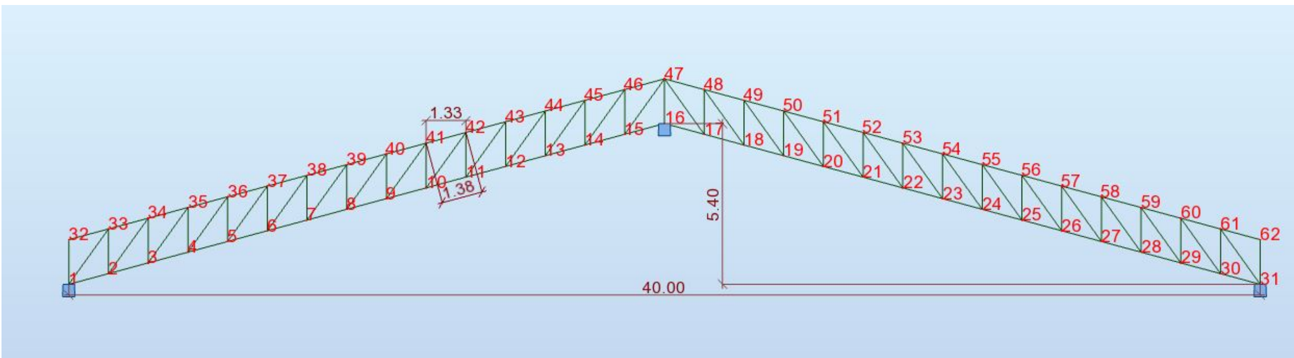
1.3. SOFTWARE
Autodesk Revit Structure 2016: Structure definition and detailing
Autodesk Robot Structural Analysis Professional 2016: Load definition, Analysis and RC members design
CSC Tedds: Individual member analysis and desing or design

# 2. STRUCTURE DEFINITION AND LOADING

## 2.1. STRUCTURE DEFINITION

The structure was defined in Revit; as we define the physical element in Revit, the analytical model was immediately produced to be sent to the structure analysis program.

Below are 3D Views of the Architectural and structural model and Ground floor of the building. The structure frame arrangement and detailed drawings will be provided in the annex of this report.




Picture 1: Structural Framing of the Building

## 2.2. MEMBER SIZING AND ARRANGEMENT

Before analyzing the structure, we defined it. By defining the structure, we arranged the structural members carefully to avoid alteration of the beautiful Architecture of building; we also avoided to interfere with MEP installations.

We used shear walls in the building around stair' cases and elevators; these shear walls are effective for seismic forces.

## 2.3. LOAD DEFINITION

After defining the structure in Revit, we transferred the analytical model of the structure to Robot for Load Definition, Structure Analysis and structural member design and resizing where the initial size was not suitable.

### DEAD LOAD

Self-weight of the structural members will be calculated by computer program automatically.

Unit weight of concrete block masonry: 18.5kN/$m^3$

Concrete unit weight: 25kN/ $m^3$
Roof iron sheets: 0.5kN/$m^2$

### LIVE LOAD

Accessible roof for Repair: 1kN/$m^2$

### SEISMIC LAOD DEFINITION

Code parameters

To complete the seismic analysis according to the rules given in this code, we defined the following parameters in Robot:

- **Site class** (A, B, C, D, E or F) based on the site soil properties, classified according to the table 1613.5.2 (Site Class Classification)
  - Site Class: D
- **Spectral response accelerations,** as specified in Section 1613.5.1, mapped in Figures 1613.5(1) through 1613.5(14)
  - **$S_1$** - spectral acceleration for 1-second period
  - **$S_s$** - spectral acceleration for short periods

For Rubavu: S1=1.24 and Ss=0.56

- **$T_L$** - long-period transition period, specified according to the ASCE 7-05 code, as shown in the Figures 22-15 through 22-20
- **I** - importance factor, as specified in ASCE 7-05, Section 11.5.1.
  - Buildings and other structures that represent asubstantial hazard to human life or represent significant economic loss in the event of failure. **I=1.25**
- **R** - response modification coefficient, as specified in ASCE 7-05, Tables 12.2-1

- Reinforced Concrete structure with shear walls
- R=4

Base shear

Base shear force is calculated according to the formula: $F_x = V * w_x * h^k{}_x / (\Sigma w_i * h_i)$ (eq. 12.8-11 and 12.8-12) where:
$w_x$ and $w_i$ - floor weight

h - height from base level to appropriate floor level

V - base shear force (this value is already calculated in Robot) k - exponent depending on the period value

## WIND LAOD

Dynamic pressure, $q_s$ = 0.613 $V_s$

= 0.613 x $33.86^2$

= 702.80 $N/m^2$

= 0.703 $kN/m^2$

Design wind speed, $V_s$ = V x $S_1$ x $S_2$ x $S_3$(Refer 5.1, CP 3: Chapter V-2:1972)

= 30 x 1.36 x 0.83 x 1

= 33.86 m/s

Basic wind speed, V = 30 m/s

Topography factor, $S_1$ = 1.36 (Conservative for Hilly terrain) Ground roughness, $S_2$ = 0.79 + (0.93 – 0.79) * (6.5 – 5) / (10 – 5)
= 0.83 (Ground roughness – 2, Class – A)

Statistical factor, $S_3$ = 1 (Conservative, Fig 2, CP3: Chapter V-2:1972)

| Wind pressure | | |
|---|---|---|
| For beams and<br>For pipes | = 1.9<br>= 1.2 | (Refer Table 17, CP 3: Chapter V-<br>(Refer Table 18, CP 3: Chapter V- |
| | | 2:1972) |

## 2.4. LOAD COMBINATION

Loads have been combined according to BS-EN 1990:2002 NA: 2004.

Code: BS-EN 1990:2002 NA:2004 Version: 24.0

| | Nature | Subnature | $\gamma_{max}$ | $\gamma_{min}$ | $\gamma_s$ | $\gamma_a$ | $\Psi_{0,1}$ | $\Psi_{0,2}$ | $\Psi_{0,3}$ | $\Psi_{0,n}$ | $\Psi_1$ | $\Psi_{2,1}$ | $\Psi_{2,n}$ | $\Psi_K$ | $\xi_1$ | $\xi_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Dead | STRC | 1.35 | 1 | 1 | 1 | | | | | | | | | 0.925 | 1 |
| 2 | Dead | NSTR | 1.35 | 1 | 1 | 1 | | | | | | | | | 0.925 | 1 |
| 3 | Live | CAT_A | 1.5 | | 1 | | 0.7 | | | | 0.5 | 0.3 | | | | |
| 4 | Live | CAT_B | 1.5 | | 1 | | 0.7 | | | | 0.5 | 0.3 | | | | |
| 5 | Live | CAT_C | 1.5 | | 1 | | 0.7 | | | | 0.7 | 0.6 | | | | |
| 6 | Live | CAT_D | 1.5 | | 1 | | 0.7 | | | | 0.7 | 0.6 | | | | |
| 7 | Live | CAT_E | 1.5 | | 1 | | 1 | | | | 0.9 | 0.8 | | | | |
| 8 | Live | CAT_F | 1.5 | | 1 | | 0.7 | | | | 0.7 | 0.6 | | | | |
| 9 | Live | CAT_G | 1.5 | | 1 | | 0.7 | | | | 0.5 | 0.3 | | | | |
| 10 | Live | CAT_H | 1.5 | | 1 | | 0.7 | | | | | | | | | |
| 11 | Snow | | 1.5 | | 1 | | 0.5 | | | | 0.2 | | | | | |
| 12 | Snow | S_M1000 | 1.5 | | 1 | | 0.5 | | | | 0.2 | | | | | |
| 13 | Snow | S_P1000 | 1.5 | | 1 | | 0.7 | | | | 0.5 | 0.2 | | | | |
| 14 | Wind | | 1.5 | | 1 | | 0.6 | | | | 0.2 | | | | | |
| 15 | Temperature | | 1.5 | | 1 | | 0.6 | | | | 0.5 | | | | | |
| 16 | Accidental | | | | | 1 | | | | | | | | | | |
| 17 | Seismic | | | | | 1 | | | | | | | | | | |
| 18 | | | | | | | | | | | | | | | | |

|  |  | Combination type | User-defined type | Loads |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  |  | Dead | Live | Accidental | Seismic |
| 1 | ULS | USR | STR | (4) $\sum_{i\geq1} G_i \cdot \begin{cases}\gamma^{(i)}_{\max} \\ \gamma^{(i)}_{\min}\end{cases}$ | (19) $Q_i \cdot \gamma_i + \sum_{j\geq1, i\neq j} Q_j \cdot \gamma_j \cdot \Psi_{0,1}$ | (0) ——— | (0) ——— |
| 2 | SLS | RAR |  | (1) $\sum_{i\geq1} G_i \cdot \gamma^{(i)}_S$ | (21) $Q_i + \sum_{j\geq1, i\neq j} Q_j \cdot \Psi_{0,1}$ | (0) ——— | (0) ——— |
| 3 | SLS | FRE |  | (1) $\sum_{i\geq1} G_i \cdot \gamma^{(i)}_S$ | (20) $Q_i \cdot \Psi_1 + \sum_{j\geq1, i\neq j} Q_j \cdot \Psi_{2,1}$ | (0) ——— | (0) ——— |
| 4 | SLS | QPR |  | (1) $\sum_{i\geq1} G_i \cdot \gamma^{(i)}_S$ | (22) $\sum_{i\geq1} Q_i \cdot \Psi^{(i)}_{2,1}$ | (0) ——— | (0) ——— |
| 5 | ACC | ACC |  | (5) $\sum_{i\geq1} G_i \cdot \gamma^{(i)}_a$ | (20) $Q_i \cdot \Psi_1 + \sum_{j\geq1, i\neq j} Q_j \cdot \Psi_{2,1}$ | (18) $\sum_{i\geq1} A_i \cdot \gamma^{(i)}_a$ | (0) ——— |
| 6 | ACC | SEI |  | (5) $\sum_{i\geq1} G_i \cdot \gamma^{(i)}_a$ | (22) $\sum_{i\geq1} Q_i \cdot \Psi^{(i)}_{2,1}$ | (0) ——— | (17) $\sum_{i\geq1} S_i \cdot \begin{cases}\gamma^{(i)}_a \\ -\gamma^{(i)}_a\end{cases}$ |
| 7 | ACC | SEI |  | (5) $\sum_{i\geq1} G_i \cdot \gamma^{(i)}_a$ | (22) $\sum_{i\geq1} Q_i \cdot \Psi^{(i)}_{2,1}$ | (0) ——— | (0) ——— |
| 8 | SEI | USR | FIRE | (5) $\sum_{i\geq1} G_i \cdot \gamma^{(i)}_a$ | (20) $Q_i \cdot \Psi_1 + \sum_{j\geq1, i\neq j} Q_j \cdot \Psi_{2,1}$ | (18) $\sum_{i\geq1} A_i \cdot \gamma^{(i)}_a$ | (0) ——— |
| 9 |  |  |  |  |  |  |  |

## 3. STRUCTURE ANALYSIS

After loading the structure, we used the software (Robot) to analyze and to display the analysis results. The image captions below shows the display of some results after analyzing the structure

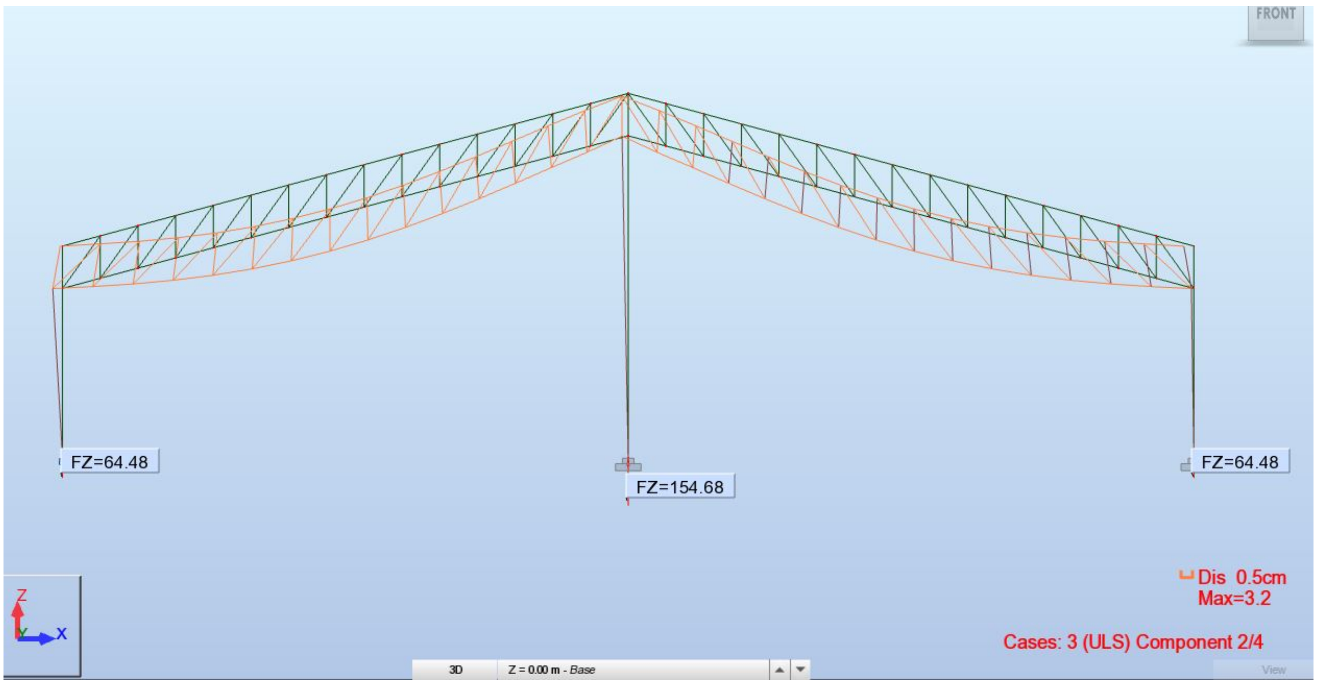



Fig2: Structure deformation due to ULS Load combinations.

### 3.1. STRUCTURE ANALYSIS RESULTS

After the structural analysis, we extracted results in form of values, graphs, diagrams and other. And we used those values to design our members. Here are some graphics of some values

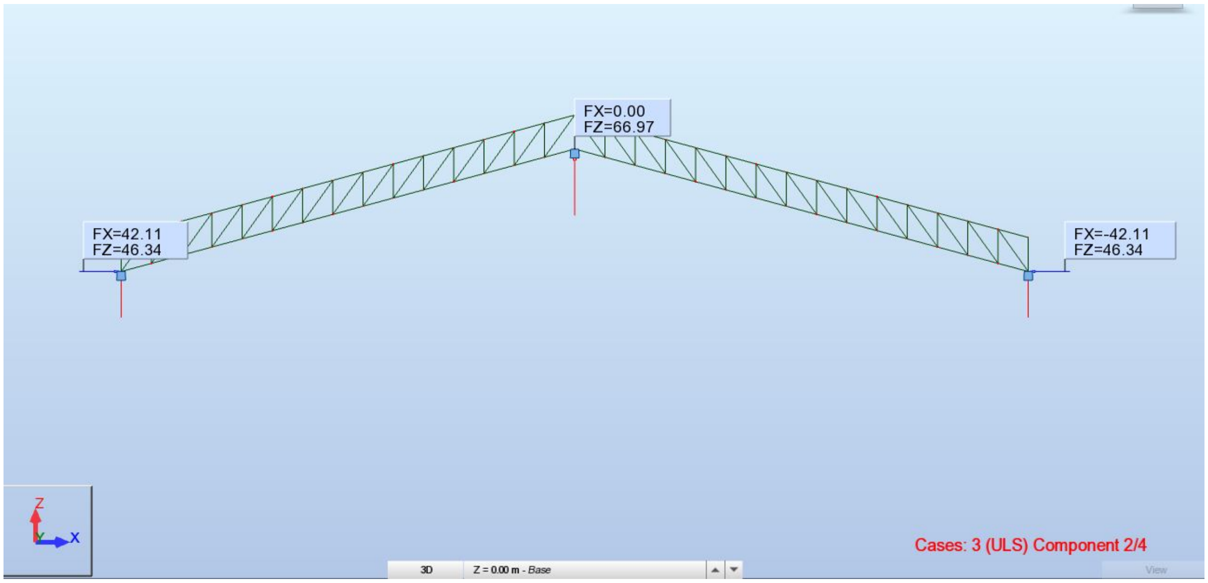


Image: Reactions due to ULS load combination

# 4. STRUCTURAL MEMBER DESIGN

After determining the loads in each structural member, we designed those reinforced concrete members and steel trusses to safely withstand loads imposed upon them. We sized the members to optimize the cost vs. the strength.

Below, there are detailed calculation notes of reinforced concrete members and steel truss members.

## STEEL TRUSS DESIGN

# Bottom Chords

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**CODE:** *EN 1993-1:2005/A1:2014, Eurocode 3: Design of steel structures.*
**ANALYSIS TYPE:** Code Group Verification

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**CODE GROUP:** 1 BottomChords
**MEMBER:** 19 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

---

**LOADS:**
*Governing Load Case:* 3 ULS /1/ 1*1.35 + 2*1.50

---

**MATERIAL:**
Steel ( S235 ) fy = 235.00 MPa

---

**SECTION PARAMETERS: SHSC 70x70x3.6**

| | | | |
|---|---|---|---|
| h=7.0 cm | gM0=1.00 | gM1=1.00 | |
| b=7.0 cm | Ay=4.62 cm2 | Az=4.62 cm2 | Ax=9.23 cm2 |
| tw=0.4 cm | Iy=66.50 cm4 | Iz=66.50 cm4 | Ix=108.00 cm4 |
| tf=0.4 cm | Wply=22.70 cm3 | Wplz=22.70 cm3 | |

---

**INTERNAL FORCES AND CAPACITIES:**
N,Ed = 186.55 kN
Nc,Rd = 216.91 kN
Nb,Rd = 197.10 kN
Class of section = 1

---

**LATERAL BUCKLING PARAMETERS:**

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**BUCKLING PARAMETERS:**

| About y axis: | | About z axis: | |
|---|---|---|---|
| Ly = 1.38 m | Lam_y = 0.55 | Lz = 1.38 m | Lam_z = 0.55 |
| Lcr,y = 1.38 m | Xy = 0.91 | Lcr,z = 1.38 m | Xz = 0.91 |
| Lamy = 51.45 | | Lamz = 51.45 | |

---

**VERIFICATION FORMULAS:**
***Section strength check:***
N,Ed/Nc,Rd = 0.86 < 1.00 (6.2.4.(1))
***Global stability check of member:***
Lambda,y = 51.45 < Lambda,max = 210.00 Lambda,z = 51.45 < Lambda,max = 210.00 STABLE
N,Ed/Nb,Rd = 0.95 < 1.00 (6.3.1.1.(1))

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***Section OK !!!***

# Top Chords

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**CODE:** *EN 1993-1:2005/A1:2014, Eurocode 3: Design of steel structures.*
**ANALYSIS TYPE:** Code Group Verification

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**CODE GROUP:** 2 TopChords
**MEMBER:** 55 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

---

**LOADS:**
*Governing Load Case:* 3 ULS /1/ 1*1.35 + 2*1.50

---

**MATERIAL:**
Steel ( S235 ) fy = 235.00 MPa

---

**SECTION PARAMETERS: SHSC 70x70x3.6**

| | | | |
|---|---|---|---|
| h=7.0 cm | gM0=1.00 | gM1=1.00 | |
| b=7.0 cm | Ay=4.62 cm2 | Az=4.62 cm2 | Ax=9.23 cm2 |
| tw=0.4 cm | Iy=66.50 cm4 | Iz=66.50 cm4 | Ix=108.00 cm4 |
| tf=0.4 cm | Wply=22.70 cm3 | Wplz=22.70 cm3 | |

---

**INTERNAL FORCES AND CAPACITIES:**
N,Ed = 167.62 kN
Nc,Rd = 216.91 kN
Nb,Rd = 197.10 kN
Class of section = 1

---

**LATERAL BUCKLING PARAMETERS:**

---

**BUCKLING PARAMETERS:**

| About y axis: | | About z axis: | |
|---|---|---|---|
| Ly = 1.38 m | Lam_y = 0.55 | Lz = 1.38 m | Lam_z = 0.55 |
| Lcr,y = 1.38 m | Xy = 0.91 | Lcr,z = 1.38 m | Xz = 0.91 |
| Lamy = 51.45 | | Lamz = 51.45 | |

---

**VERIFICATION FORMULAS:**
***Section strength check:***
N,Ed/Nc,Rd = 0.77 < 1.00 (6.2.4.(1))
***Global stability check of member:***
Lambda,y = 51.45 < Lambda,max = 210.00 Lambda,z = 51.45 < Lambda,max = 210.00 STABLE
N,Ed/Nb,Rd = 0.85 < 1.00 (6.3.1.1.(1))

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***Section OK !!!***

# Diagonals

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**CODE:** *EN 1993-1:2005/A1:2014, Eurocode 3: Design of steel structures.*
**ANALYSIS TYPE:** Code Group Verification

---

**CODE GROUP:** 3 Diagonals
**MEMBER:** 76 **POINT:** 1 **COORDINATE:** x = 0.00 L = 0.00 m

---

**LOADS:**
*Governing Load Case:* 3 ULS /1/ 1*1.35 + 2*1.50

---

**MATERIAL:**
Steel ( S235 )  fy = 235.00 MPa

---

**SECTION PARAMETERS: SHSC 60x60x3**

| | | | |
|---|---|---|---|
| h=6.0 cm | gM0=1.00 | gM1=1.00 | |
| b=6.0 cm | Ay=3.31 cm2 | Az=3.31 cm2 | Ax=6.61 cm2 |
| tw=0.3 cm | Iy=35.10 cm4 | Iz=35.10 cm4 | Ix=57.10 cm4 |
| tf=0.3 cm | Wply=14.00 cm3 | Wplz=14.00 cm3 | |

---

**INTERNAL FORCES AND CAPACITIES:**
N,Ed = 94.99 kN
Nc,Rd = 155.34 kN
Nb,Rd = 97.15 kN
Class of section = 1

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**LATERAL BUCKLING PARAMETERS:**

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**BUCKLING PARAMETERS:**

| About y axis: | | About z axis: | |
|---|---|---|---|
| Ly = 2.29 m | Lam_y = 1.06 | Lz = 2.29 m | Lam_z = 1.06 |
| Lcr,y = 2.29 m | Xy = 0.63 | Lcr,z = 2.29 m | Xz = 0.63 |
| Lamy = 99.31 | | Lamz = 99.31 | |

---

**VERIFICATION FORMULAS:**
***Section strength check:***
N,Ed/Nc,Rd = 0.61 < 1.00 (6.2.4.(1))
***Global stability check of member:***
Lambda,y = 99.31 < Lambda,max = 210.00  Lambda,z = 99.31 < Lambda,max = 210.00  STABLE
N,Ed/Nb,Rd = 0.98 < 1.00 (6.3.1.1.(1))

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***Section OK !!!***

# Posts

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**CODE:** *EN 1993-1:2005/A1:2014, Eurocode 3: Design of steel structures.*
**ANALYSIS TYPE:** Code Group Verification

---

**CODE GROUP:** 4 Posts
**MEMBER:** 109  **POINT:** 1  **COORDINATE:** x = 0.00 L = 0.00 m

---

**LOADS:**
*Governing Load Case:* 3 ULS /1/ 1*1.35 + 2*1.50

---

**MATERIAL:**
Steel ( S235 )  fy = 235.00 MPa

---

**SECTION PARAMETERS: SHSC 50x50x3**

| | | |
|---|---|---|
| h=5.0 cm | gM0=1.00 | gM1=1.00 |

| | | | |
|---|---|---|---|
| b=5.0 cm | Ay=2.71 cm2 | Az=2.71 cm2 | Ax=5.41 cm2 |
| tw=0.3 cm | Iy=19.50 cm4 | Iz=19.50 cm4 | Ix=32.10 cm4 |
| tf=0.3 cm | Wply=9.39 cm3 | Wplz=9.39 cm3 | |

---

**INTERNAL FORCES AND CAPACITIES:**

N,Ed = 92.60 kN
Nc,Rd = 127.14 kN
Nb,Rd = 98.06 kN

Class of section = 1

---

**LATERAL BUCKLING PARAMETERS:**

---

**BUCKLING PARAMETERS:**

| About y axis: | | About z axis: | |
|---|---|---|---|
| Ly = 1.50 m | Lam_y = 0.84 | Lz = 1.50 m | Lam_z = 0.84 |
| Lcr,y = 1.50 m | Xy = 0.77 | Lcr,z = 1.50 m | Xz = 0.77 |
| Lamy = 79.01 | | Lamz = 79.01 | |

---

**VERIFICATION FORMULAS:**

***Section strength check:***

N,Ed/Nc,Rd = 0.73 < 1.00   (6.2.4.(1))

***Global stability check of member:***

Lambda,y = 79.01 < Lambda,max = 210.00   Lambda,z = 79.01 < Lambda,max = 210.00   STABLE
N,Ed/Nb,Rd = 0.94 < 1.00   (6.3.1.1.(1))

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***Section OK !!!***

## COLUMN DESIGN

# 1 Level:

- Name : Level +5.40
- Reference level : -6.00 (m)
- Concrete creep coefficient : $\varphi_p$ = 2.77
- Cement class : N
- Environment class : X0
- Structure class : S1

# 2 Column: Column Calculation Notes

## 2.1 Material properties:

- Concrete : C25/30 $f_{ck}$ = 25.00 (MPa)
  Unit weight : 2501.36 (kG/m3)
  Aggregate size : 20.0 (mm)
- Longitudinal reinforcement: : T $f_{yk}$ = 460.00 (MPa)
  Ductility class : -
- Transversal reinforcement: : T $f_{yk}$ = 460.00 (MPa)

## 2.2 Geometry:

2.2.1 Rectangular 40.0 x 40.0 (cm)
2.2.2 Height: L = 11.40 (m)
2.2.3 Slab thickness = 0.00 (m)
2.2.4 Beam height = 0.00 (m)
2.2.5 Cover = 4.0 (cm)

## 2.3 Calculation options:

- Calculations according to : EN 1992-1-1:2004 AC:2008
- Seismic dispositions : No requirements
- Precast column : no
- Pre-design : no
- Slenderness taken into account : yes
- Compression : with bending
- Ties : to slab
- Fire resistance class : No requirements

## 2.4 Loads:

| Case | Nature | Group | $\gamma_f$ | N (kN) | My(s) (kN*m) | My(i) (kN*m) | Mz(s) (kN*m) | Mz(i) (kN*m) |
|---|---|---|---|---|---|---|---|---|
| DL1 | dead load(Structural) | 123 | 1.35 | 92.21 | 0.00 | 0.00 | 0.00 | 0.00 |
| LL1 | live load(Category A) | 123 | 1.50 | 94.48 | 0.00 | 0.00 | 0.00 | 0.00 |

$\gamma_f$ - load factor

## 2.5 Calculation results:

Safety factors Rd/Ed = 2.19 > 1.0

### 2.5.1 ULS/ALS Analysis

Design combination: 1.35DL1+1.50LL1 (C)
Combination type: ULS
Internal forces:
Nsd = 266.20 (kN) Msdy = 0.00 (kN*m) Msdz = 0.00 (kN*m)
Design forces:
Cross-section in the middle of the column
N = 266.20 (kN) N*etotz = 12.34 (kN*m) N*etoty= 5.32 (kN*m)

| Eccentricity: | | ez (My/N) | ey (Mz/N) |
|---|---|---|---|
| Static | eEd: | 0.0 (cm) | 0.0 (cm) |
| Imperfection | ei: | 1.9 (cm) | 0.0 (cm) |
| Initial | e0: | 1.9 (cm) | 0.0 (cm) |
| Minimal | emin: | 2.0 (cm) | 2.0 (cm) |
| Total | etot: | 4.6 (cm) | 2.0 (cm) |

#### 2.5.1.1. Detailed analysis-Direction Y:

##### 2.5.1.1.1 Slenderness analysis

Non-sway structure

| L (m) | Lo (m) | λ | λlim | |
|---|---|---|---|---|
| 11.40 | 11.40 | 98.73 | 41.56 | Slender column |

##### 2.5.1.1.2 Buckling analysis

M2 = 0.00 (kN*m) M1 = 0.00 (kN*m) Mmid = 0.00 (kN*m)
Case: Cross-section in the middle of the column, Slenderness taken into account
M0e = 0.6*M02+0.4*M01 = 0.00 (kN*m)
M0emin = 0.4*M02
M0 = max(M0e, M0emin)

ea = θ1*lo/2 = 1.9 (cm)
θ1 = θo * αh * αm = 0.00
θo = 0.01
αh = 0.67
αm = (0,5(1+1/m))^0.5 = 1.00
m = 1.00

**Method based on nominal stiffness**

$$\left[1+\frac{\beta}{(N_B/N)-1}\right] = 2.44$$

β = 1.23
Nb = (π^2 * EJ)/ lo^2 = 494.38 (kN)
EJ = Kc*Ecd*Jc+Ks*Es*Js = 6509.89 (kN*m2)
φef = 1.26
Jc = 213333.3 (cm4)
Js = 2463.0 (cm4)
Kc = 0.03 ()
Ks = 1.00 ()
MEdmin = 5.32 (kN*m)

$$M_{Ed} = \max\left\{M_{Ed\min};\left[1+\frac{\beta}{(N_B/N)-1}\right]M_{0Ed}\right\} = 12.34 \text{ (kN*m)}$$

#### 2.5.1.2. Detailed analysis-Direction Z:

M2 = 0.00 (kN*m) M1 = 0.00 (kN*m) Mmid = 0.00 (kN*m)
Case: Cross-section in the middle of the column, Slenderness not taken into account
M0e = 0.6*M02+0.4*M01 = 0.00 (kN*m)
M0emin = 0.4*M02
M0 = max(M0e, M0emin)

ea = 0.0 (cm)
Ma = N*ea = 0.00 (kN*m)
MEdmin = 5.32 (kN*m)
M0Ed = max(MEdmin,M0 + Ma) = 5.32 (kN*m)

### 2.5.2 Reinforcement:

Real (provided) area Asr = 12.57 (cm2)
Ratio: $\rho$ = 0.79 %

## 2.6 Reinforcement:

**Main bars (T):**

- 4 $\phi$20 l = 11.36 (m)

**Transversal reinforcement: (T):**

stirrups: 30 $\phi$8 l = 1.36 (m)

# 3 Material survey:

- Concrete volume = 1.82 (m3)
- Formwork = 18.24 (m2)

- Steel T
  - Total weight = 128.16 (kG)
  - Density = 70.26 (kG/m3)
  - Average diameter = 14.3 (mm)
  - Reinforcement survey:

| Diameter | Length (m) | Weight (kG) |
|---|---|---|
| 8 | 40.69 | 16.06 |
| 20 | 45.44 | 112.10 |

# FOUNDATIONS DESIGN

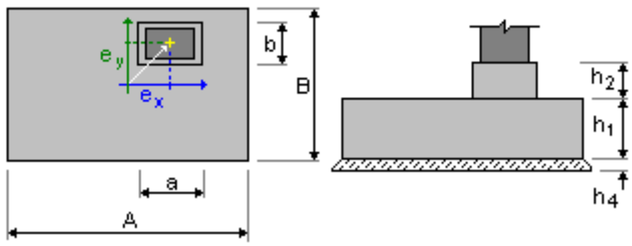
# 1 Spread footing: F1

## 1.1 Basic data

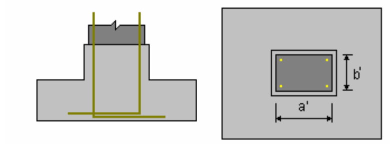
### 1.1.1 Assumptions

- Geotechnic calculations according to : BS 8004
- Concrete calculations according to : EN 1992-1-1:2004 AC:2008
- Shape selection : without limits

### 1.1.2 Geometry:




| | | | |
|---|---|---|---|
| A | = 0.90 (m) | a | = 0.40 (m) |
| B | = 0.90 (m) | b | = 0.40 (m) |
| h1 | = 0.25 (m) | $e_x$ | = 0.00 (m) |
| h2 | = 0.20 (m) | $e_y$ | = 0.00 (m) |
| h4 | = 0.05 (m) | | |




a' = 40.0 (cm)
b' = 40.0 (cm)
cnom1 = 6.0 (cm)
cnom2 = 6.0 (cm)
Cover deviations: Cdev = 1.0(cm), Cdur = 0.0(cm)

### 1.1.3 Materials

- Concrete : C20/25; Characteristic strength = 20.00 MPa
  Unit weight = 2501.36 (kG/m3)
  Rectangular stress distribution [3.1.7(3)]
- Longitudinal reinforcement : type Characteristic strength = 500.00 MPa
  Ductility class: C
  Horizontal branch of the stress-strain diagram
- Transversal reinforcement : type Characteristic strength = 500.00 MPa
- Additional reinforcement: : type Characteristic strength = 500.00

MPa

### 1.1.4 Loads:

**Foundation loads:**

| Case | Nature | Group | N (kN) | Fx (kN) | Fy (kN) | Mx (kN*m) | My (kN*m) |
|---|---|---|---|---|---|---|---|
| DL1 | dead load(Structural) | 64 | 114.58 | 0.00 | 0.00 | 0.00 | 0.00 |
| LL1 | live load(Category A) | 64 | 94.48 | 0.00 | 0.00 | 0.00 | 0.00 |
| DL1 | dead load(Structural) | 65 | 47.76 | 0.00 | 0.00 | 0.00 | 0.00 |
| LL1 | live load(Category A) | 65 | 32.97 | 0.00 | 0.00 | 0.00 | 0.00 |

**Backfill loads:**

| Case | Nature | Q1 (kN/m2) |
|---|---|---|

### 1.1.5 Combination list

| | |
|---|---|
| 1/ | 64_SLS : 1.00DL1+1.00LL1 |
| 2/ | 64_SLS : 1.00DL1 |
| 3/ | 64_SLS : 1.00DL1+0.80LL1 |
| 4/ | 65_SLS : 1.00DL1+1.00LL1 |
| 5/ | 65_SLS : 1.00DL1 |
| 6/ | 65_SLS : 1.00DL1+0.80LL1 |
| 7/* | 64_ULS : 1.35DL1+1.50LL1 |
| 8/* | 64_ULS : 1.35DL1 |
| 9/* | 64_ULS : 1.00DL1+1.50LL1 |
| 10/* | 64_ULS : 1.00DL1 |
| 11/* | 65_ULS : 1.35DL1+1.50LL1 |
| 12/* | 65_ULS : 1.35DL1 |
| 13/* | 65_ULS : 1.00DL1+1.50LL1 |
| 14/* | 65_ULS : 1.00DL1 |
| 15/* | 64_SLS : 1.00DL1+1.00LL1 |
| 16/* | 64_SLS : 1.00DL1 |
| 17/* | 64_SLS : 1.00DL1+0.50LL1 |
| 18/* | 64_SLS : 1.00DL1+0.30LL1 |
| 19/* | 65_SLS : 1.00DL1+1.00LL1 |
| 20/* | 65_SLS : 1.00DL1 |
| 21/* | 65_SLS : 1.00DL1+0.50LL1 |
| 22/* | 65_SLS : 1.00DL1+0.30LL1 |

## 1.2 Geotechnical design

### 1.2.1 Assumptions

Foundation design for:
- Capacity
- Rotation
- Sliding
- Sliding with soil pressure considered: none
- Uplift
- Average settlement

### 1.2.2 Soil:

| | | |
|---|---|---|
| Soil level: | $N_1$ | = 0.00 (m) |
| Column pier level: | $N_a$ | = 0.00 (m) |
| Minimum reference level: | $N_f$ | = -0.50 (m) |

**Clay**

- Soil level: 0.00 (m)
- Unit weight: 2243.38 (kG/m3)
- Unit weight of solid: 2753.23 (kG/m3)
- Internal friction angle: 25.0 (Deg)
- Cohesion: 0.06 (MPa)

### 1.2.3 Limit states

**Stress calculations**

Soil type under foundation: not layered
Design combination **64_SLS : 1.00DL1+1.00LL1**
Load factors: **1.00** * Foundation weight
**1.00** * Soil weight
Calculation results: On the foundation level
Weight of foundation and soil over it: Gr = 8.61 (kN)
Design load:
Nr = 217.67 (kN) Mx = -0.00 (kN*m) My = 0.00 (kN*m)
Soil profile parameters:
C = 0.00 (MPa)
$\phi$ = 0.0
$\gamma$ = 0.00 (kG/m3)
Stress in soil: 0.27 (MPa)
Design soil pressure 0.30 (MPa)
Safety factor: 1.116 > 1

**Uplift**

Uplift in SLS
Design combination: **65_SLS : 1.00DL1**
Load factors: **1.00** * Foundation weight
**1.00** * Soil weight
Contact area: s = 2.25
$s_{lim}$ = 1.00

**Sliding**

Design combination **65_SLS : 1.00DL1**
Load factors: **1.00** * Foundation weight
**1.00** * Soil weight
Weight of foundation and soil over it: Gr = 8.61 (kN)
Design load:
Nr = 56.38 (kN) Mx = -0.00 (kN*m) My = 0.00 (kN*m)
Equivalent foundation dimensions: A_ = 0.90 (m) B_ = 0.90 (m)
Sliding area: 0.81 (m2)
Foundation/soil friction coefficient: tg($\phi$) = 0.47
Cohesion: C = 0.06 (MPa)
Sliding force value F = 0.00 (kN)
Value of force preventing foundation sliding:
- On the foundation level: F(stab) = 74.89 (kN)

Stabilility for sliding: $\infty$

**Average settlement**

Soil type under foundation: not layered
Design combination **64_SLS : 1.00DL1+1.00LL1**
Load factors: **1.00** * Foundation weight
**1.00** * Soil weight
Weight of foundation and soil over it: Gr = 8.61 (kN)
Average stress caused by design load: q = 0.27 (MPa)
Thickness of the actively settling soil: z = 2.70 (m)
Stress on the level z:
- Additional: $\sigma zd$ = 0.01 (MPa)
- Caused by soil weight: $\sigma z\gamma$ = 0.07 (MPa)

Settlement:
- Original s' = 0.2 (cm)
- Secondary s'' = 0.0 (cm)
- TOTAL S = 0.2 (cm) < Sadm = 5.0 (cm)

Safety factor: 21.29 > 1

**Settlement difference**

Design combination **65_SLS : 1.00DL1+0.80LL1**
Load factors: **1.00** * Foundation weight
**1.00** * Soil weight
Settlement difference: S = 0.0 (cm) < Sadm = 5.0 (cm)
Safety factor: ∞

**Rotation**

<u>About OX axis</u>
Design combination **65_SLS : 1.00DL1**
Load factors: **1.00** * Foundation weight
**1.00** * Soil weight
Weight of foundation and soil over it: Gr = 8.61 (kN)
Design load:
Nr = 56.38 (kN) Mx = -0.00 (kN*m) My = 0.00 (kN*m)
Stability moment: $M_{stab}$ = 25.37 (kN*m)
Rotation moment: $M_{renv}$ = 0.00 (kN*m)
Stability for rotation: ∞

<u>About OY axis</u>
Design combination: **65_SLS : 1.00DL1**
Load factors: **1.00** * Foundation weight
**1.00** * Soil weight
Weight of foundation and soil over it: Gr = 8.61 (kN)
Design load:
Nr = 56.38 (kN) Mx = -0.00 (kN*m) My = 0.00 (kN*m)
Stability moment: $M_{stab}$ = 25.37 (kN*m)
Rotation moment: $M_{renv}$ = 0.00 (kN*m)
Stability for rotation: ∞

## 1.3 RC design

### 1.3.1 Assumptions

- Exposure : X0
- Structure class : S1

### 1.3.2 Analysis of punching and shear

**Punching**

Design combination **64_ULS : 1.35DL1+1.50LL1**
Load factors: **1.35** * Foundation weight
**1.35** * Soil weight
Design load:
Nr = 308.03 (kN) Mx = -0.00 (kN*m) My = 0.00 (kN*m)
Length of critical circumference: 2.28 (m)
Punching force: 161.37 (kN)
Section effective height $h_{eff}$ = 0.18 (m)
Reinforcement ratio: $\rho$ = 0.13 %
Shear stress: 0.39 (MPa)
Admissible shear stress: 1.48 (MPa)
Safety factor: 3.751 > 1

### 1.3.3 Required reinforcement

**Spread footing:**

bottom:

64_ULS : 1.35DL1+1.50LL1
My = 15.84 (kN*m) $A_{sx}$ = 2.34 (cm2/m)

64_ULS : 1.35DL1+1.50LL1
Mx = 15.84 (kN*m) $A_{sy}$ = 2.34 (cm2/m)

$A_{s\ min}$ = 2.34 (cm2/m)

top:
$A'_{sx}$ = 0.00 (cm2/m)
$A'_{sy}$ = 0.00 (cm2/m)

$A_{s\ min}$ = 0.00 (cm2/m)

**Column pier:**
Longitudinal reinforcement A = 3.20 (cm2) $A_{min.}$ = 3.20 (cm2)
A = 2 * (Asx + Asy)
Asx = 0.60 (cm2) Asy = 1.00 (cm2)

### 1.3.4 Provided reinforcement

**Spread footing:**
**Bottom:**
Along X axis:
5 8 l = 1.11 (m) e = 1*-0.36 + 4*0.18
Along Y axis:

5 8 l = 1.11 (m) e = 1*-0.36 + 4*0.18

Pier

**Longitudinal reinforcement**

Along X axis:

2 12 l = 1.22 (m) e = 1*-0.11 + 1*0.21

Along Y axis:

2 12 l = 1.27 (m) e = 1*-0.11 + 1*0.21

**Transversal reinforcement**

3 8 l = 1.20 (m) e = 1*0.16 + 2*0.09

# 2 Material survey:

- Concrete volume = 0.23 (m3)
- Formwork = 1.22 (m2)

- Steel
  - Total weight = 10.23 (kG)
  - Density = 43.64 (kG/m3)
  - Average diameter = 9.0 (mm)
  - Survey according to diameters:

| Diameter | Length (m) | Weight (kG) |
|---|---|---|
| 8 | 14.71 | 5.80 |
| 12 | 4.99 | 4.43 |