UNIVERSITÉ DE SHERBROOKE

CHLORINATED WATER RESERVOIR WATER TREATMENT PLANT, THETFORD MINES

CALCULATION NOTE

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NSERC RESEARCH CHAIR IN INNOVATIVE FRP REINFORCEMENT FOR CONCRETE INFRASTRUCTURE

Submitted to:

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February 22, 2011

Design of Chlorinated Water Reservoir Water Treatment Plant, Thetford Mines

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INTRODUCTION

Using of FRP bars and implementing them in the field is one of the objectives (technology transfer) of the NSERC research chair in FRP reinforcement for concrete structures (Department of Civil Engineering, University of Sherbrooke).

This calculation note was prepared based on the request of Bernard Drouin, General Manager, and Jassen Pettinella, Sales Manager, Pultrall Inc. to Prof. Brahim Benmokrane (NSERC Research Chair Professor, Department of Civil Engineering, University of Sherbrooke) to investigate the use of V-ROD GFRP reinforcing bars in the design of chlorinated water reservoir, water treatment plant, Thetford Mines and to prepare a design of the top slab, walls and foundation to compare its cost against steel reinforcement.

DESIGN CRITERIA

The structural design of the project is completed in accordance with the relevant Canadian Standard Association Code CSA S806-02 "Design and Construction of Building Components with Fibre-Reinforced Polymers" unless specified.

LOADS

Top slab

- Dead Load
o.w. as calculated

2 kN/m^2

- Live Load

5 kN/m^2

Foundation

The soil bearing capacity is 3000 lbs per square feet (the soil is structural landfill).

MATERIAL MECHANICAL PROPERTIES

Concrete compressive strength = 30 *MPa*

Standard V-ROD GFRP bar No. 15 (nominal cross-sectional area, 199 mm^2)
E_f = 48200 *MPa*, Guaranteed tensile strength (f_{fu}^*) = 683 *MPa*
HM V-ROD GFRP bar No. 15 (nominal cross-sectional area, 199 mm^2)
E_f = 60900 *MPa*, Guaranteed tensile strength (f_{fu}^*) = 1284 *MPa*
HM V-ROD GFRP bar No. 20 (nominal cross-sectional area, 284 mm^2)
E_f = 60500 *MPa*, Guaranteed tensile strength (f_{fu}^*) = 1205 *MPa*

DESIGN PROCEDURE

Design the main reinforcements of the top slab, vertical walls and foundation is performed using HM V-ROD GFRP bars. Standard V-ROD GFRP bars are used as secondary reinforcements for all the members of the tank.

DESIGN OF TOP SLAB

Calculate loads

Thickness of slab (t_s) = 350 *mm*

d = thickness – cover – bar diameter / 2 = 350 – 50 – 15/2=292.5 *mm*

w_{DL} = o.w. slab = 0.35 x 24 = 8.40 kN/m^2
w_{DL} = 2 kN/m^2 (finishing)
w_{LL} = 5 kN/m^2 (live load)
$M_u = 1.25\, M_{DL} + 1.5\, M_{LL}$
$M_{uDesign} = M_u/N_u - 0.5$ x thickness + cover

Bending moments and normal forces on different cross sections were calculated using Program SAP 2000. Table 1 shows the moments and normal forces for different cross section.

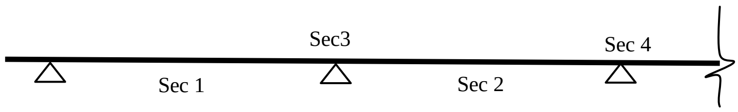


Table 1: Moments and normal forces on the slab

	Ultimate Moment (kN.m)	*Notes*	*Ultimate Normal force (kN)*
Sec.1	*51*	*Positive*	*+46*
Sec. 2	*24*	*Positive*	*+46*
Sec. 3	*71*	*Negative*	*+46*
Sec. 4	*47*	*Negative*	*+46*

Sec.1

Determine area of GFRP bars in the main direction

Reinforcement: HM GFRP No. 15 – 140 mm

Reinforcement ratio

$$\rho_f = \frac{no\, x\, A_f}{b\, d} = \frac{5.55\, x 199}{1000\, x 292.5} = 0.0046$$

Resistance factors

$\Phi_c = 0.6$

$\Phi_f = 0.75$

$\alpha_1 = 0.85 - 0.0015 f_c' = 0.805 \geq 0.67$

$\beta_1 = 0.97 - 0.0025 f_c' = 0.895 \geq 0.67$

INTERNAL FORCES

Compression Force

$$C_c = \alpha_1 \varphi_c f_c' ba = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805 x\ 0.6 x\ 30 x\ 1000 x\ 0.895 xc$$

Tension Force

$$T_F = \varphi_F \varepsilon_f E_F A_F = 0.75 \left[\frac{0.0035}{c} (292.5 - c) \right] x\ 5.5 x\ 199$$

$$C_c = T_c$$

$$Ac^2 + Bc + C = 0$$

A	12968.55
B	227233.1
C	-6.6E+07

c = 63.36 mm

$$\frac{c}{d} = \frac{63.36}{292.5} = 0.21 > \frac{7}{7 + 2000 x \varepsilon_f} = 0.15 \text{ ok Compression Failure}$$

Check the Flexural capacity

$$\therefore C_c = \alpha_1 \varphi_c f_c' ba = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805 x 0.6 x 30 x 1000 x 0.895 x 63.36 = 821726.2N$$

$$\therefore T_F = 0.75 \left[\frac{0.0035}{63.36} (292.5 - 63.36) \right] x 7.1 x 199 = 821726N$$

Check the maximum stress under ULS

$$f_f = T_F / A_f = 517\, MPa < 0.75 f_f^* < 963$$

Resisting Moment

$$M_r = C_c \left(c - \frac{a}{2} \right) + T_F (d - c) = 217 kN.m$$

$$M_{cr} = f_r \frac{I_g}{y_t} = 0.6\sqrt{30} x \frac{bxt^3 / 12}{t / 2} = 67\ kN.m$$

$1.5 M_{cr} = 100\ kN.m < M_r \quad ok$

Check maximum stress under service load

Service moment due to dead and live loads (assume 50% of the live load is sustain)
$M = 28 kN.m$
Normal force
$T = +37 kN$

Stress level in GFRP bars under service loads

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f$$

$$E_c = 4500\sqrt{f_c'} = 4750\sqrt{30} = 24647.52 MPa$$

$$n_f = \frac{E_f}{E_c} = \frac{60900}{24647.52} = 2.42$$

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f = 0.14$$

$$f_f = \frac{M}{no\, A_f\, d(1-k/3)} + \frac{T}{no\, A_f} = 104 MPa \quad \le 0.3 f_{fu}^* = 385 MPa$$

Check crack width

$$w = k_b \frac{E_s}{E_F} f_f \sqrt[3]{d_c A}$$

$$k_b = 0.8$$

$$E_s = 200000$$

Distance from extreme tension fiber of concrete to centerline of flexural reinforcement
$d_c = h - d = 350 - 292.5 = 57.5 mm$

$$A = \frac{57.5x2x1000}{7.14} = 16100$$

$$w = k_b \frac{E_s}{E_F} f_f \sqrt{d_c A}$$

$$= 0.8x \frac{200000}{60900} x104x\ ^3\sqrt{16100x57.5} = 26632 < 38000 N/mm$$

$$A_{f\,min} = \rho_{f\,min}\, b\, d = 0.0025x\ 1000x\ 292.5 = 875 mm^2 < no.A_f$$

Compute crack width

$$h_1 = d - kd = 250 mm$$

$$h_2 = h - kd = 308 mm$$

$$w = 2\frac{f_f}{E_f}\frac{h_2}{h_1} k_b \sqrt{d_c^2 + (0.5s)^2} = 0.3mm$$

Calculate slab top and bottom reinforcements in the secondary direction

d = thickness – cover – bar diameter / 2 = 350 – 50 – 15–15/2=277.5 *mm*

$$A_f = \rho_{f\ min}\, b\, d = 0.0025 x\ 1000 x\ 277.5 = 693 mm^2$$

$$A_f = \frac{400 x E_f}{A_g} = 69\, mm^2$$

Standard V-ROD GFRP No. 15 @ 250 mm

Sec.3

Determine area of GFRP bars in the main direction

Reinforcement: HM GFRP No. 15 – 90 mm

Thickness of slab (t_s) = 350 *mm*

d = thickness – cover – bar diameter / 2 = 350 – 50 – 15/2=292.5 *mm*

Reinforcement ratio

$$\rho_f = \frac{no\ x\ A_f}{b\, d} = \frac{11.11 x\ 199}{1000 x\ 292.5} = 0.00755$$

Resistance factors

$\Phi_c = 0.6$

$\Phi_f = 0.75$

$\alpha_1 = 0.85 - 0.0015 f_c' = 0.805 \geq 0.67$

$\beta_1 = 0.97 - 0.0025 f_c' = 0.895 \geq 0.67$

Internal forces

Compression Force

$$C_c = \alpha_1 \varphi_c f_c' b a = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805 x\ 0.6 x\ 30 x\ 1000 x\ 0.895 x c$$

Tension Force

$$T_F = \varphi_F \varepsilon_f E_F A_F = 0.75 \left[\frac{0.0035}{c} (292.5 - c) \right] x\ 11.11 x\ 199$$

$C_c = T_c$

$Ac^2 + Bc + C = 0$

A	12968.55
B	353473.8
C	-1E+08

c = 76 mm

$$\frac{c}{d} = \frac{76}{292.5} = 0.25 > \frac{7}{7 + 2000 x \varepsilon_f} = 0.15$$ ok Compression Failure

Check the Flexural capacity

$$\therefore C_c = \alpha_1 \varphi_c f'_c ba = \alpha_1 \varphi_c f'_c b(\beta c) = 0.805x\, 0.6x\, 30x\, 1000x\, 0.895 * 76 = 985609.8N$$

$$\therefore T_F = 0.75\left[\frac{0.0035}{76}(292.5-76)\right]x\, 5.5x\, 199 = 1006935N$$

Check the maximum stress under ULS

$$f_f = T_F / A_f = 455MPa < 0.75 f_f^* < 963$$

Resisting Moment

$$M_r = C_c\left(c - \frac{a}{2}\right) + T_F(d-c) = 260kN.m$$

$$M_{cr} = f_r \frac{I_g}{y_t} = 0.6\sqrt{30}x \frac{bxt^3/12}{t/2} = 67\ kN.m$$

$$1.5M_{cr} = 100\ kN.m < M_r \quad ok$$

Check maximum stress under service load

Service moment due to dead and live loads (assume 50% of the live load is sustain)

$M_s = 41kN.m$

Normal force

$T = +37kN$

Stress level in GFRP bars under service loads

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f$$

$$E_c = 4500\sqrt{f'_c} = 4750\sqrt{30} = 24647.52MPa$$

$$n_f = \frac{E_f}{E_c} = \frac{60900}{24647.52} = 2.42$$

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f = 0.175$$

$$f_f = \frac{M}{no\, A_f\, d\,(1-k/3)} + \frac{T}{no\, A_f} = 89MPa \quad \le 0.3 f_{fu}^* = 385MPa$$

Check crack width

$$w = k_b \frac{E_s}{E_F} f_f \sqrt[3]{d_c A}$$

$$k_b = 0.8$$

$$E_s = 200000$$

Distance from extreme tension fiber of concrete to centerline of flexural reinforcement

$$d_c = h - d = 350 - 292.5 = 57.5mm$$

$$A = \frac{57.5x\ 2x\,1000}{11.11} = 10350$$

$$w = k_b\ \frac{E_s}{E_F} f_f\ \sqrt{d_c\ A}$$

$$= 0.8x\ \frac{200000}{60900} x\ 89x\ \sqrt[3]{10350x\ 57.5} = 19777 < 38000\,N\ /\,mm$$

$$A_{f\ min} = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 292.5 = 875\,mm^2 < no.A_f$$

Calculate slab top and bottom reinforcements in the secondary direction

d = thickness – cover – bar diameter / 2 = 350 – 50 – 15–15/2=277.5 *mm*

$$A_f = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 277.5 = 693\,mm^2$$

$$A_f = \frac{400xE_f}{A_g} = 69\,mm^2$$

Standard V-ROD GFRP No. 15 @ 250 mm

Design of walls

Walls on axes A-D-G

Design cross section at the midnight

$M_u = 85$ kN.m $N_u = -60$ kN

$M_{uDesign} = M_u/N_u + 0.5$ x thickness – cover

Determine area of GFRP bars in the main direction

<u>Reinforcement: HM GFRP No. 15 – 120 mm</u>

Thickness of slab (t_s) = 350 *mm*

d = thickness – cover – bar diameter / 2 = 350 – 50 – 15/2=292.5 *mm*

Reinforcement ratio

$$\rho_f = \frac{no\,x\,A_f}{b\,d} = \frac{8.3\,x\,199}{1000\,x\,292.5} = 0.00567$$

Resistance factors

$\Phi_c = 0.6$

$\Phi_f = 0.75$

$\alpha_1 = 0.85 - 0.0015 f_c' = 0.805 \geq 0.67$

$\beta_1 = 0.97 - 0.0025 f_c' = 0.895 \geq 0.67$

Internal forces

Compression Force

$$C_c = \alpha_1 \varphi_c f_c' b a = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805x\ 0.6x\ 30x\ 1000x\ 0.895xc$$

Tension Force

$$T_F = \varphi_F \varepsilon_f E_F A_F = 0.75\left[\frac{0.0035}{c}\left(292.5 - c\right)\right]x8.3x199$$

$C_c = T_c$

$Ac^2 + Bc + C = 0$

A	12968.55
B	265105.3
C	-7.8E+07

c = 67.67 mm

$$\frac{c}{d} = 0.2 > \frac{7}{7 + 2000x\varepsilon_f} = 0.15$$ ok Compression Failure

Check the Flexural capacity

$$\therefore C_c = \alpha_1 \varphi_c f_c' ba = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805x0.6x30x1000x0.895 * 67.67 = 878982.4N$$

$$\therefore T_F = 0.75\left[\frac{0.0035}{67.67}(292.5-62)\right]x8.3x199 = 878972.5\ N$$

Check the maximum stress under ULS

$$f_f = T_F / A_f = 612MPa < 0.75 f_f^* < 963$$

Resisting Moment

$$M_r = C_c\left(c - \frac{a}{2}\right) + T_F\,(d-c) = 230.43\ kN.m$$

$$M_{cr} = f_r \frac{I_g}{y_t} = 0.6\sqrt{30}x\ \frac{bxt^3 / 12}{t/2} = 67\ kN.m$$

$$1.5M_{cr} = 100\ kN.m < M_r \quad ok$$

Check maximum stress under service load

Service moment due to dead and live loads (assume 50% of the live load is sustain)

$M_s = 74kN.m$

Normal force

$T = -48kN$

Stress level in GFRP bars under service loads

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f$$

$$E_c = 4500\sqrt{f_c'} = 4750\sqrt{30} = 24647.52MPa$$

$$n_f = \frac{E_f}{E_c} = \frac{60900}{24647.52} = 2.42$$

$$k = \sqrt{2\rho_f n_f + (\rho_f n_f)^2} - \rho_f n_f = 0.153$$

$$f_f = \frac{M}{no\,A_f\,d\,(1-k/3)} - \frac{T}{no\,A_f} = 131MPa \quad \le 0.3\,f_{fu}^* = 385\,MPa$$

Check crack width

$$w = k_b \frac{E_s}{E_F} f_f \sqrt[3]{d_c\,A}$$

$$k_b = 0.8$$

$$E_s = 200000$$

Distance from extreme tension fiber of concrete to centerline of flexural reinforcement

$d_c = h - d = 350 - 292.5 = 57.5mm$

$$A = \frac{57.5x2x1000}{8.3} = 13800$$

$$w = k_b \frac{E_s}{E_F} f_f \sqrt{d_c\ A}$$

$$= 0.8x \frac{200000}{60900} x131x\ ^3\sqrt{13800x57.5} = 36221 < 32073.78\ N/mm$$

Compute crack width

$$h_1 = d - kd = 250\,mm$$

$$h_2 = h - kd = 308\,mm$$

$$w = 2\frac{f_f}{E_f}\frac{h_2}{h_1}k_b\sqrt{d_c^2 + (0.5s)^2} = 0.35\,mm$$

$$A_{f\ min} = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 302.5 = 875\,mm^2 < no.A_f$$

Calculate reinforcements in the secondary direction

d = thickness – cover – bar diameter / 2 = 350 – 50 – 15–15/2=277.5 *mm*

$$A_f = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 277.5 = 693\,mm^2$$

$$A_f = \frac{400xE_f}{A_g} = 69\,mm^2$$

HM V-ROD GFRP No. 15 @ 250 mm

Horizontal reinforcement

Standard V-ROD GFRP No. 15 @ 250 mm

Walls on axes B-E

d = thickness – cover – bar diameter / 2 = 300 – 50 –15/2=242.5 *mm*

$$A_f = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 242.5 = 606\,mm^2$$

Vertical reinforcements

Standard V-ROD GFRP No. 15 @ 250 mm

Horizontal reinforcement

Standard V-ROD GFRP No. 15 @ 300 mm

DESIGN OF FOUNDATION

Loads

The net uplift pressure on the footing as a result of the salb and walls loads $w_u = 29.35 kN/m^2$

$M_{uDesign} = M_u/N_u - 0.5$ x thickness + cover

Bending moments and normal forces on different cross sections were calculated using Program SAP 2000. Table 2 shows the moments and normal forces for different cross section.

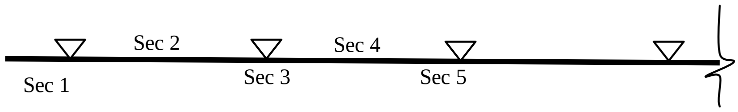


Table 2: Moments and normal forces on the footing

	Ultimate Moment (kN.m)	*Ultimate Normal force (kN)*
Sec.1	*6.41*	*+100*
Sec. 2	*78*	*+100*
Sec. 3	*113*	*+100*
Sec. 4	*36*	*+100*
Sec. 5	*102*	*+100*

Sec.2

Thickness of slab (t_s) = 350 *mm*

d = thickness – cover – bar diameter / 2 = 350 – 50 – 20/2=290 *mm*

$M_u = 78$ kN.m $N_u = + 100$ kN

Determine area of GFRP bars in the main direction

Reinforcement: HM GFRP No. 20 – 130 mm

Reinforcement ratio

$$\rho_f = \frac{no\,x\,A_f}{b\,d} = \frac{7.7\,x\,284}{1000\,x\,290} = 0.007$$

Resistance factors

$$\Phi_c = 0.6$$
$$\Phi_f = 0.75$$
$$\alpha_1 = 0.85 - 0.0015 f_c' = 0.805 \geq 0.67$$
$$\beta_1 = 0.97 - 0.0025 f_c' = 0.895 \geq 0.67$$

Internal forces

Compression Force

$$C_c = \alpha_1 \varphi_c f_c' ba = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805x\ 0.6x\ 30x\ 1000x\ 0.895xc$$

Tension Force

$$T_F = \varphi_F \varepsilon_f E_F A_F = 0.75\left[\frac{0.0035}{c}\left(290 - c\right)\right]x7.7x284$$
$$C_c = T_c$$
$$Ac^2 + Bc + C = 0$$

A	12968.55
B	346944.2
C	-1E+08

c = 75.71 mm

$$\frac{c}{d} = \frac{75.71}{290} = 0.26 > \frac{7}{7 + 2000x\varepsilon_f} = 0.15$$ ok Compression Failure

Check the Flexural capacity

$$\therefore C_c = \alpha_1 \varphi_c f_c' ba = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805x0.6x30x1000x0.895x75.71 = 981913.8N$$
$$\therefore T_F = 0.75\left[\frac{0.0035}{75.71}\left(290 - 75.71\right)\right]x7.7x284 = 981905.1N$$

Check the maximum stress under ULS

$$f_f = T_F / A_f = 449.46\ MPa < 0.75 f_f^* < 963$$

Resisting Moment

$$M_r = C_c\left(c - \frac{a}{2}\right) + T_F\left(d - c\right) = 251.48\ kN.m$$

$$M_{cr} = f_r \frac{I_g}{y_t} = 0.6\sqrt{30}x\ \frac{bxt^3/12}{t/2} = 67\ kN.m$$

$$1.5M_{cr} = 100\ kN.m < M_r \quad ok$$

Check maximum stress under service load

Service moment due to dead and live loads (assume 50% of the live load is sustain)
$M = 44 kN.m$

Normal force

$T = +72\,kN$

Stress level in GFRP bars under service loads

$$k = \sqrt{2\rho_f\, n_f + \left(\rho_f\, n_f\right)^2} - \rho_f\, n_f$$

$$E_c = 4500\sqrt{f_c'} = 4750\sqrt{30} = 24647.52 MPa$$

$$n_f = \frac{E_f}{E_c} = \frac{60500}{24647.52} = 2.45$$

$$k = \sqrt{2\rho_f\, n_f + \left(\rho_f\, n_f\right)^2} - \rho_f\, n_f = 0.174$$

$$f_f = \frac{M}{no\, A_f\, d\left(1 - k/3\right)} + \frac{T}{no\, A_f} = 104.39\ MPa \quad \le 0.3\, f_{fu}^* = 385\,MPa$$

Check crack width

$$w = k_b\, \frac{E_s}{E_F} f_f\, \sqrt[3]{d_c\, A}$$

$k_b = 0.8$

$E_s = 200000$

Distance from extreme tension fiber of concrete to centerline of flexural reinforcement

$d_c = h - d = 350 - 290 = 60\,mm$

$$A = \frac{60x2x1000}{7.7} = 15600$$

$$w = k_b\, \frac{E_s}{E_F}\, f_f \sqrt{d_c\, A}$$

$$= 0.8\,x\,\frac{200000}{60500}\,x104x\ ^3\sqrt{15600x60} = 27006.69 < 38000\,N / mm$$

Compute crack width

$h_1 = d - kd = 250\,mm$

$h_2 = h - kd = 308\,mm$

$$w = 2\,\frac{f_f}{E_f}\,\frac{h_2}{h_1}\,k_b\,\sqrt{d_c^2 + \left(0.5\,s\right)^2} = 0.3\,mm$$

$$A_{f\ min} = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 290 = 875\,mm^2 < no.A_f$$

Calculate slab top and bottom reinforcements in the secondary direction

d = thickness – cover – bar diameter / 2 = 350 – 50 – 15–15/2=277.5 *mm*

$$A_f = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 277.5 = 693\,mm^2$$

$$A_f = \frac{400xE_f}{A_g} = 69\,mm^2$$

Standard V-ROD GFRP No. 15 @ 250 mm

Sec.3

Thickness of slab (t_s) = 350 *mm*

d = thickness – cover – bar diameter / 2 = 350 – 50 – (20+15)/4=291.25 *mm*

M_u = 113 kN.m N_u = + 100 kN

Determine area of GFRP bars in the main direction

Reinforcement: HM GFRP No. 15 @ 130 mm + HM GFRP No. 20 @ 130 mm

Reinforcement ratio

$$\rho_f = \frac{no\,x\,A_f}{b\,d} = \frac{7.7x483}{1000\,x\,291.25} = 0.012$$

Resistance factors

$\Phi_c = 0.6$

$\Phi_f = 0.75$

$\alpha_1 = 0.85 - 0.0015 f_c' = 0.805 \geq 0.67$

$\beta_1 = 0.97 - 0.0025 f_c' = 0.895 \geq 0.67$

Internal forces

Compression Force

$$C_c = \alpha_1 \varphi_c f_c' ba = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805x\ 0.6x\ 30x\ 1000x\ 0.895xc$$

Tension Force

$$T_F = \varphi_F \varepsilon_f E_F A_F = 0.75\left[\frac{0.0035}{c}\left(291.25 - c\right)\right]x7.7x483$$

$C_c = T_c$

$Ac^2 + Bc + C = 0$

A	12968.55
B	591271.2
C	-1.7E+08

c = 94.4 mm

$$\frac{c}{d} = \frac{94.4}{291.25} = 0.35 > \frac{7}{7 + 2000x\varepsilon_f} = 0.15$$ ok Compression Failure

Check the Flexural capacity

$$\therefore C_c = \alpha_1 \varphi_c f_c' ba = \alpha_1 \varphi_c f_c' b(\beta c) = 0.805x0.6x30x1000x0.895x94.4 = 1224594\,N$$

$$\therefore T_F = 0.75\left[\frac{0.0035}{94.4}(291.25-94.4)\right]x7.4x483 = 1224595\,N$$

Check the maximum stress under ULS

$$f_f = T_F / A_f = 328.92\,MPa < 0.75 f_f^* < 963$$

Resisting Moment

$$M_r = C_c\left(c-\frac{a}{2}\right)+T_F\,(d-c) = 303.38\ kN.m$$

$$M_{cr} = f_r\,\frac{I_g}{y_t} = 0.6\sqrt{30}x\,\frac{bxt^3/12}{t/2} = 67\ kN.m$$

$$1.5M_{cr} = 100\ kN.m < M_r \quad ok$$

Check maximum stress under service load

Service moment due to dead and live loads (assume 50% of the live load is sustain)
$M = 65kN.m$
Normal force
$T = +70kN$

Stress level in GFRP bars under service loads

$$k=\sqrt{2\rho_f\,n_f+(\rho_f\,n_f)^2}-\rho_f\,n_f$$

$$E_c = 4500\sqrt{f_c'} = 4750\sqrt{30} = 24647.52MPa$$

$$n_f = \frac{E_f}{E_c} = \frac{60750}{24647.52} = 2.46$$

$$k=\sqrt{2\rho_f\,n_f+(\rho_f\,n_f)^2}-\rho_f\,n_f = 0.22$$

$$f_f = \frac{M}{no\,A_f\,d\,(1-k/3)}+\frac{T}{no\,A_f} = 86.68\ MPa \quad \le 0.3\,f_{fu}^* = 385\,MPa$$

Check crack width

$$w = k_b\,\frac{E_s}{E_F}f_f\,\sqrt[3]{d_c\,A}$$

$$k_b = 0.8$$

$$E_s = 200000$$

Distance from extreme tension fiber of concrete to centerline of flexural reinforcement
$d_c = h-d = 350-291.25 = 58.75mm$

$$A = \frac{58.75x2x1000}{7.7} = 1500$$

$$w = k_b \frac{E_s}{E_F} f_f \sqrt{d_c \, A}$$

$$= 0.8\,x \frac{200000}{60750} x86x \sqrt[3]{15600x58.75} = 22425.34 < 38000\,N/mm$$

Compute crack width

$$h_1 = d - kd = 250\,mm$$

$$h_2 = h - kd = 308\,mm$$

$$w = 2\frac{f_f}{E_f}\frac{h_2}{h_1} k_b \sqrt{d_c^2 + \left(0.5\,s\right)^2} = 0.25\,mm$$

$$A_{f\ min} = \rho_{f\ min}\, b\, d = 0.0025x\ 1000x\ 291.25 = 875\,mm^2 < no.A_f$$

NOTATIONS

The following symbols are used in this report:

A_f = Area of FRP reinforcement (mm^2)

b = Cross section width of beam (mm)

c = Neutral axis depth (mm)

c_b = Neutral axis depth at balanced strain condition (mm)

d = Effective depth of beams (mm)

d_c = Thickness of cover from tension face to center of closest bar (mm)

E_c = Modulus of elasticity of concrete (MPa)

E_f = Modulus of elasticity of FRP (MPa)

f_{fu} = Ultimate tensile strength of FRP (MPa)

f_{fu}^* = Guaranteed tensile strength of FRP (MPa)

f_f = Tensile stress in reinforcement (MPa)

f_c' = Concrete compressive strength (MPa)

f_{cr} = Cracking strength of concrete (MPa)

h_1 = Distance from the centroid of tension reinforcement to the neutral axis (mm)

h_2 = Distance from the extreme flexural tension surface to the neutral axis (mm)

L = Span (mm)

M = Service moment (kN.m)

M_{cr} = Cracking moment (kN.m)

M_f = Factored moment (kN.m)

M_n = Nominal moment (kN.m)

M_r = Resistance moment (kN.m)

M_u = Ultimate moment (kN.m)

n_f = Ratio of modulus of elasticity of FRP bars to modulus of elasticity of concrete

I_g = Gross moment of inertia (mm^4)

I_{cr} = Cracking moment of inertia (mm^4)

I_e = Effective moment of inertia (mm^4)

s = Bar spacing (mm)

V_c = Factored shear resistance provided by concrete kN

w = Crack width (mm)

Δ = Total deflection (mm)

Δ_{DL} = Deflection due to dead load (mm)

Δ_{LL} = Deflection due to live load (mm)

Δ_{LT} = Long term deflection (mm)

ε_{cu} = Maximum concrete compressive strain

ε_f = Maximum tensile strain of FRP bars (%)

ρ_f = Reinforcement ratio

β = Factor used to account for the shear resistance of cracked concrete

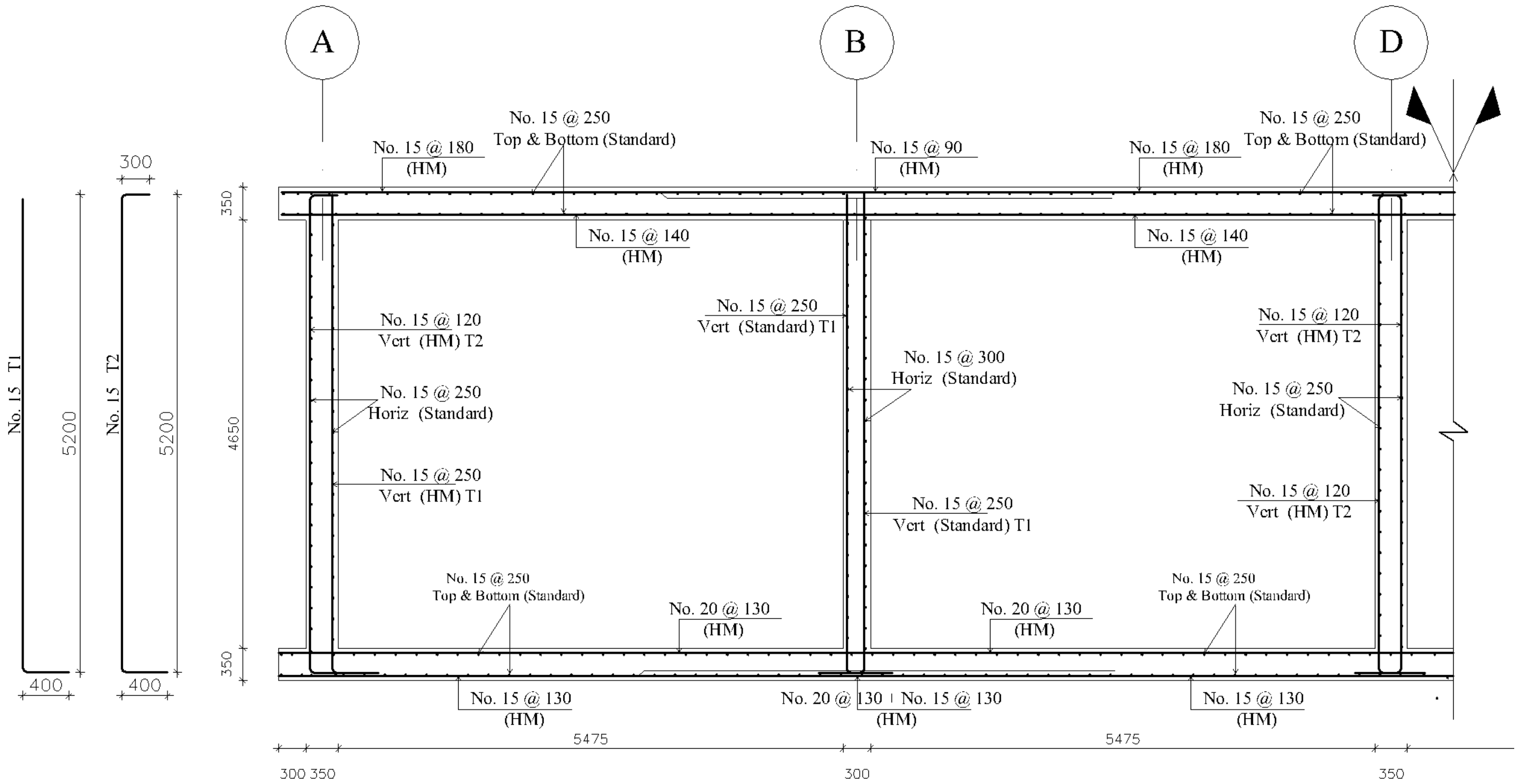
β_1 = is the ratio of depth of equivalent rectangular stress block to depth of the neutral axis

Φ_c = Resistance factor for concrete

REFERENCES

Canadian Standard Association (CSA). (2002). "Design and construction of building components with fibre-reinforced polymers." CSA-S806-02, CSA Rexdale BD, Toronto.

REINFORCEMENT DETAILS



Note: Concrete cover for all members 50 mm

Fig. 1 Details of reinforcements in vertical cross section

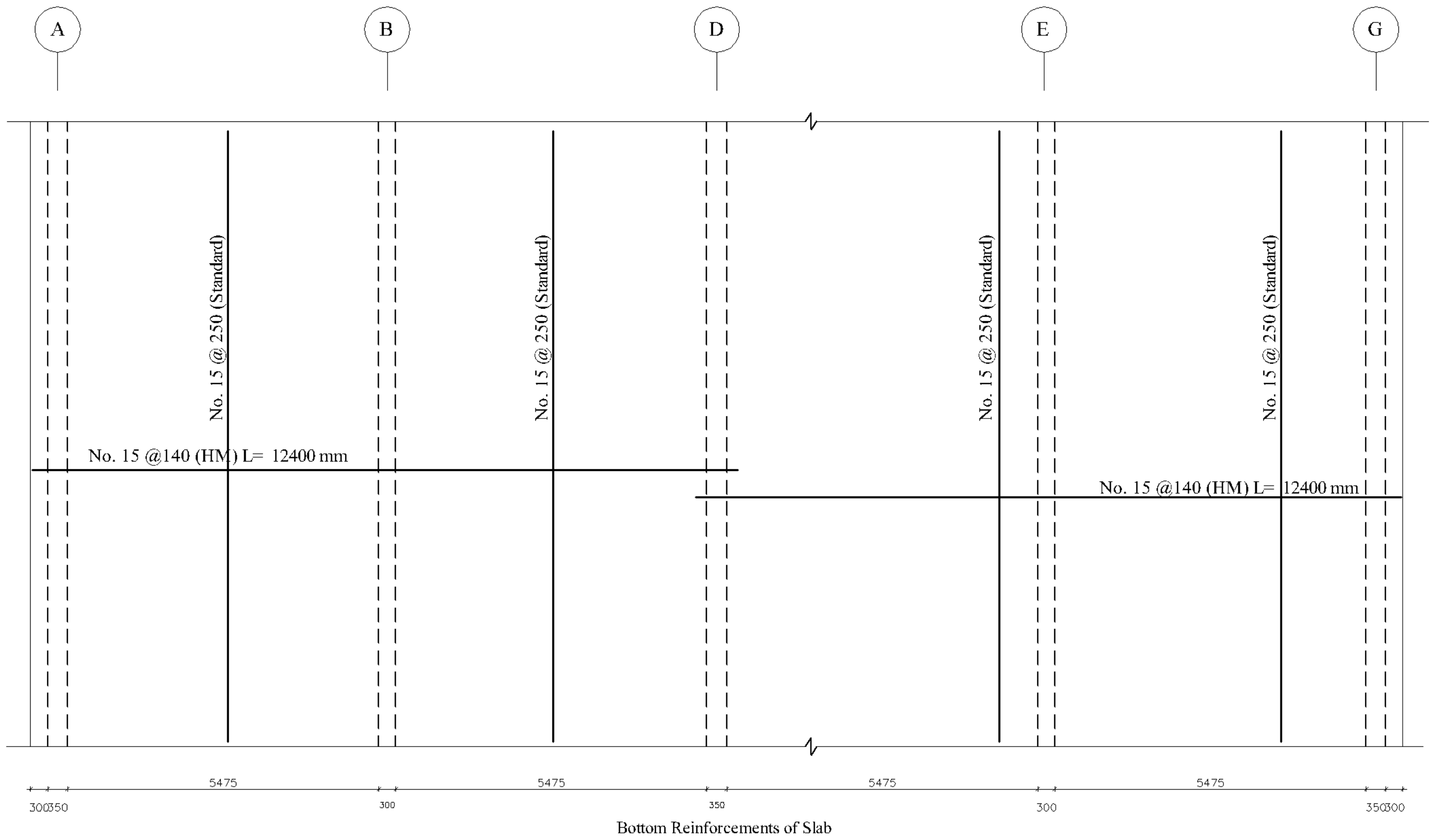


Fig. 2 Details of bottom reinforcements of the slab (Plane)

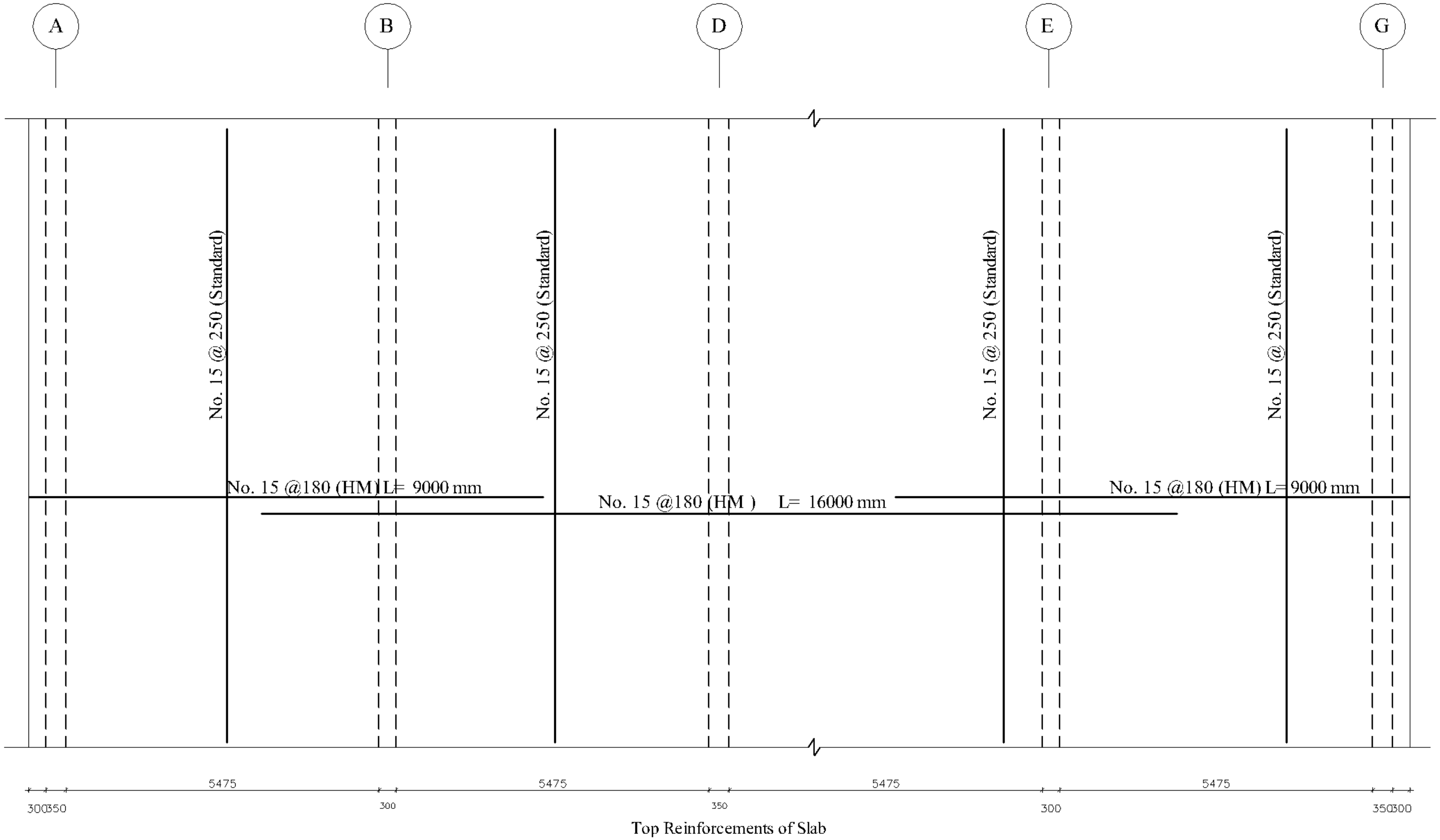


Fig. 3 Details of top reinforcements of the slab (Plane)

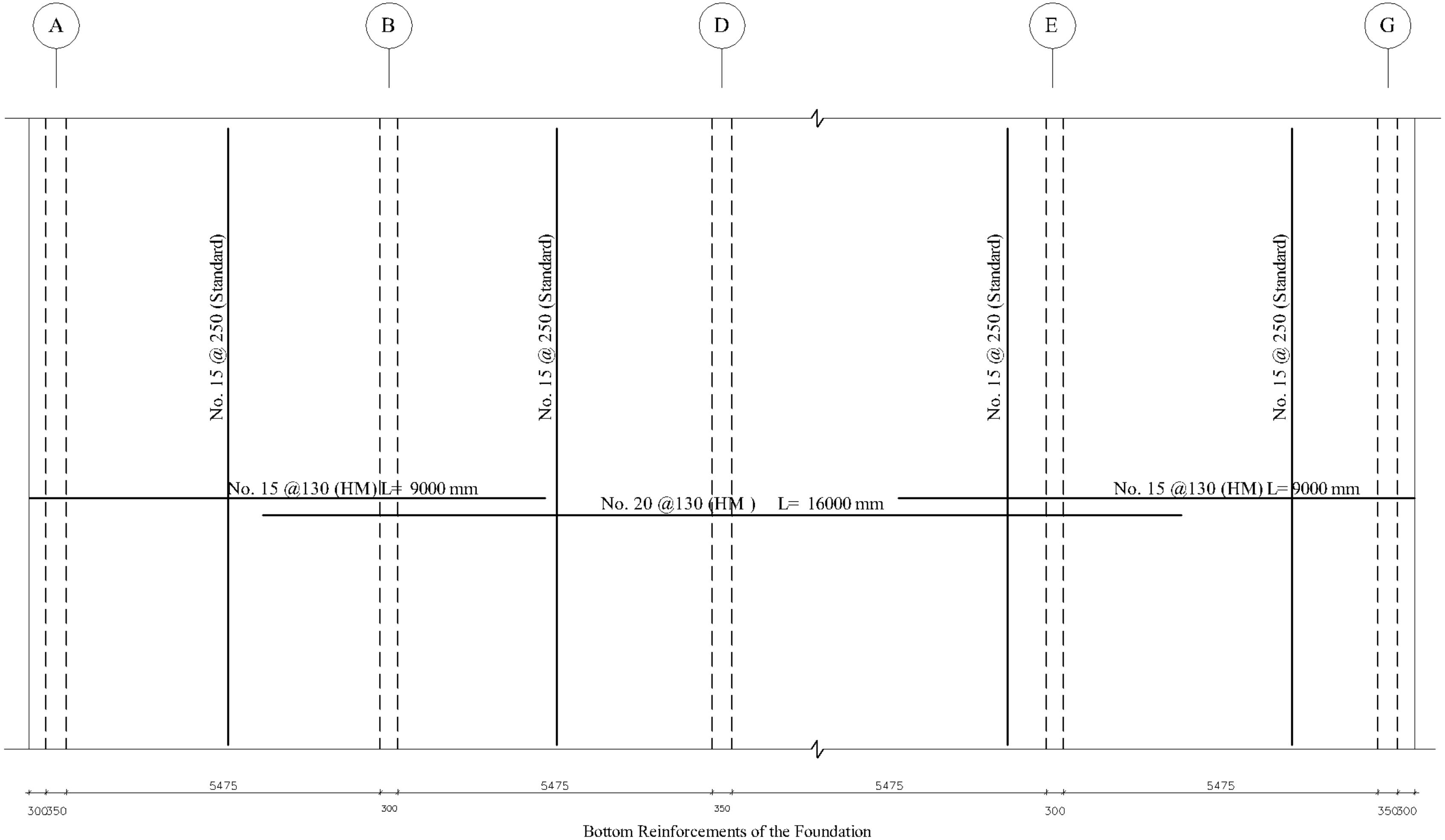


Fig. 4 Details of bottom reinforcements of the foundation (Plane)

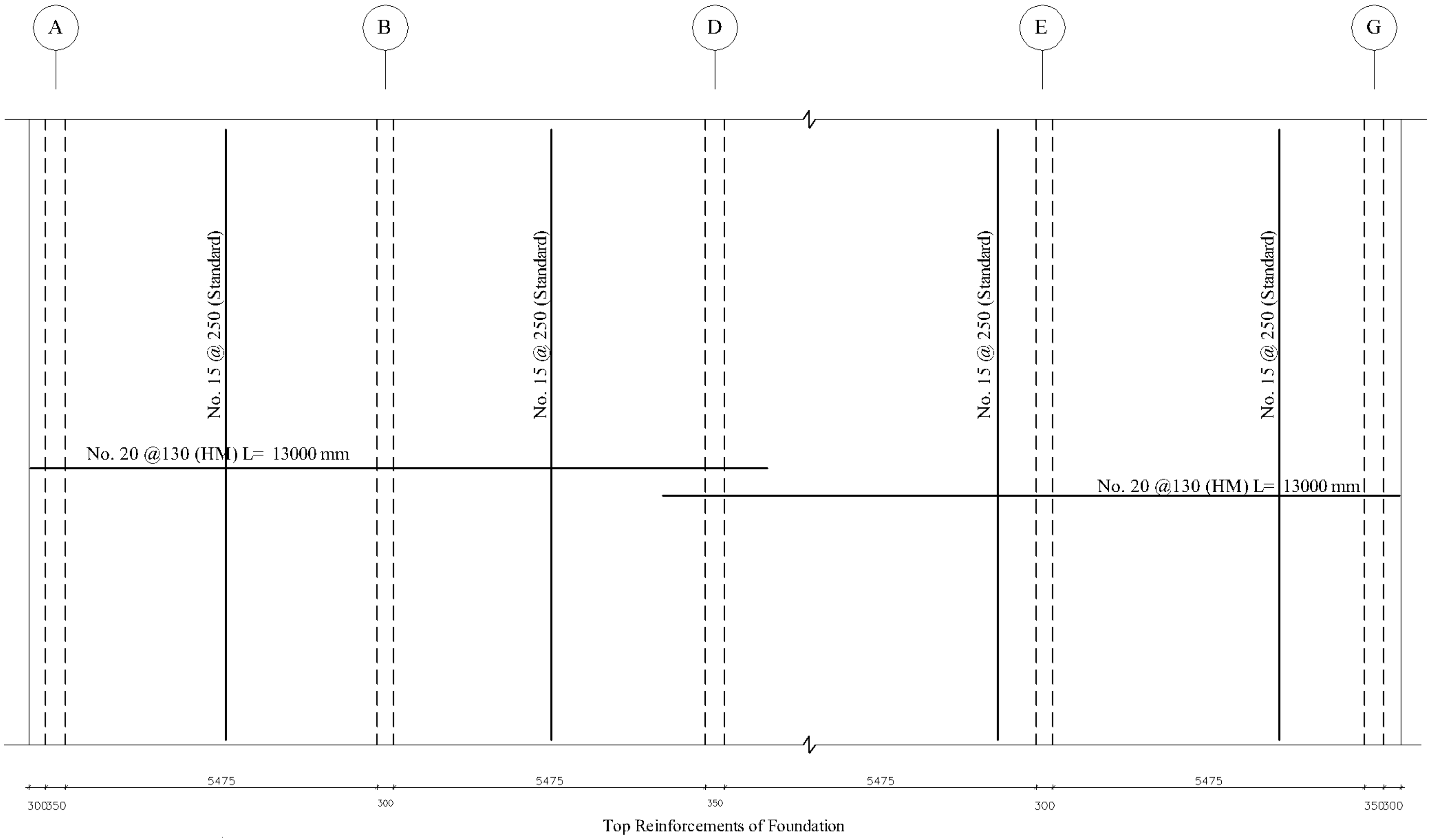


Fig. 5 Details of top reinforcements of the Foundation (Plane)

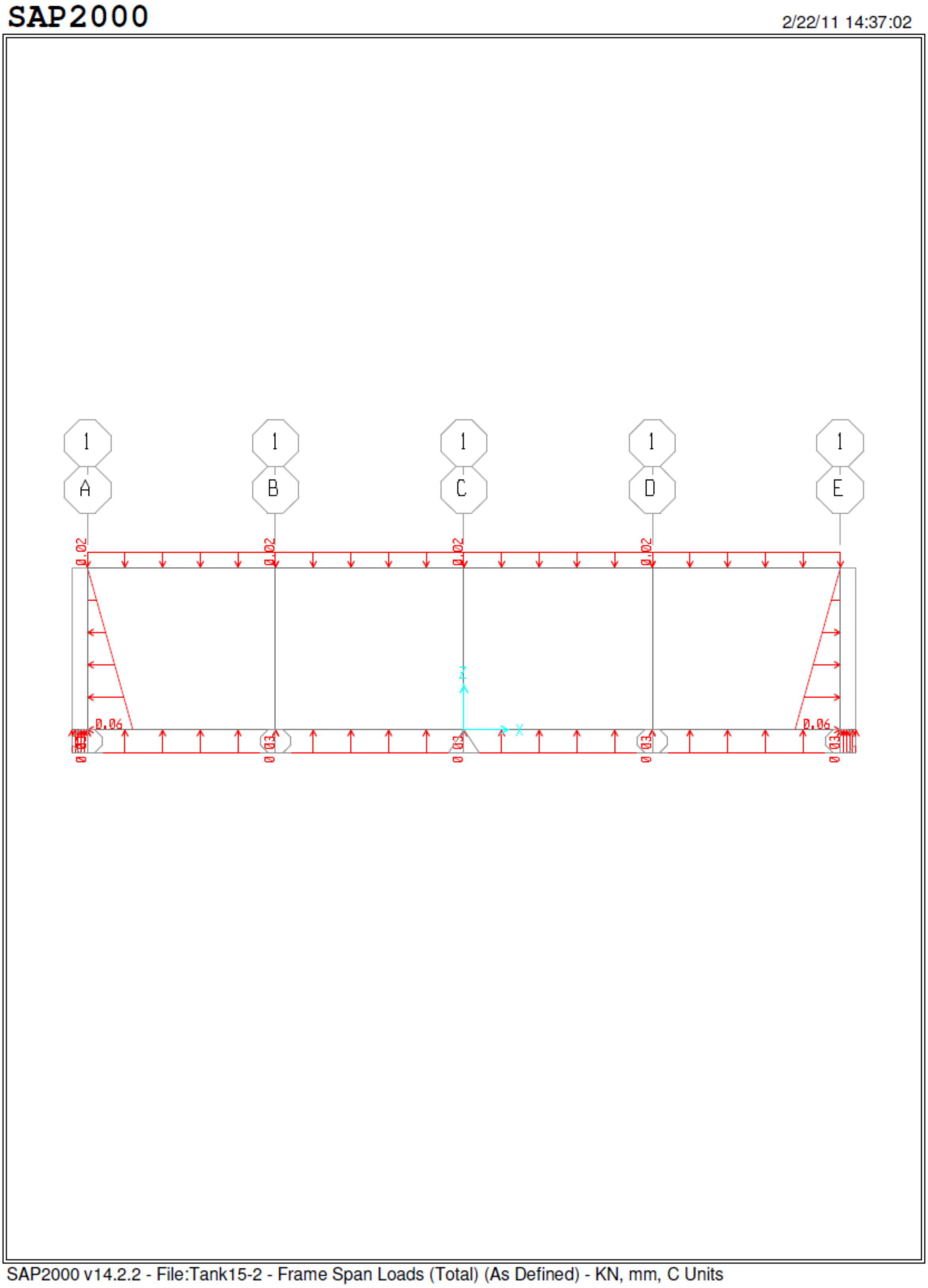


Fig. 6 **Loads on the tank**

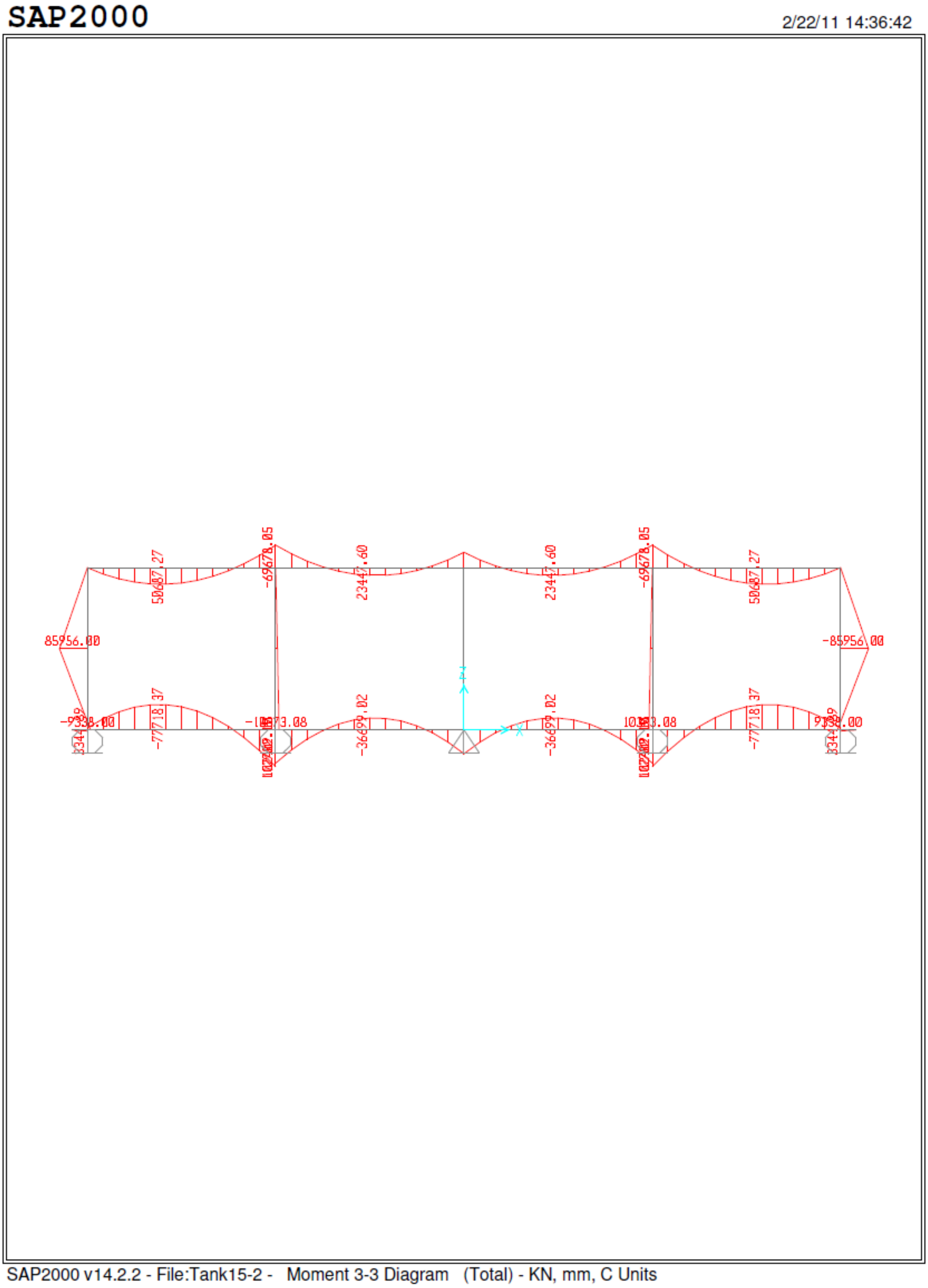


Fig. 7 **Bending moment diagram**

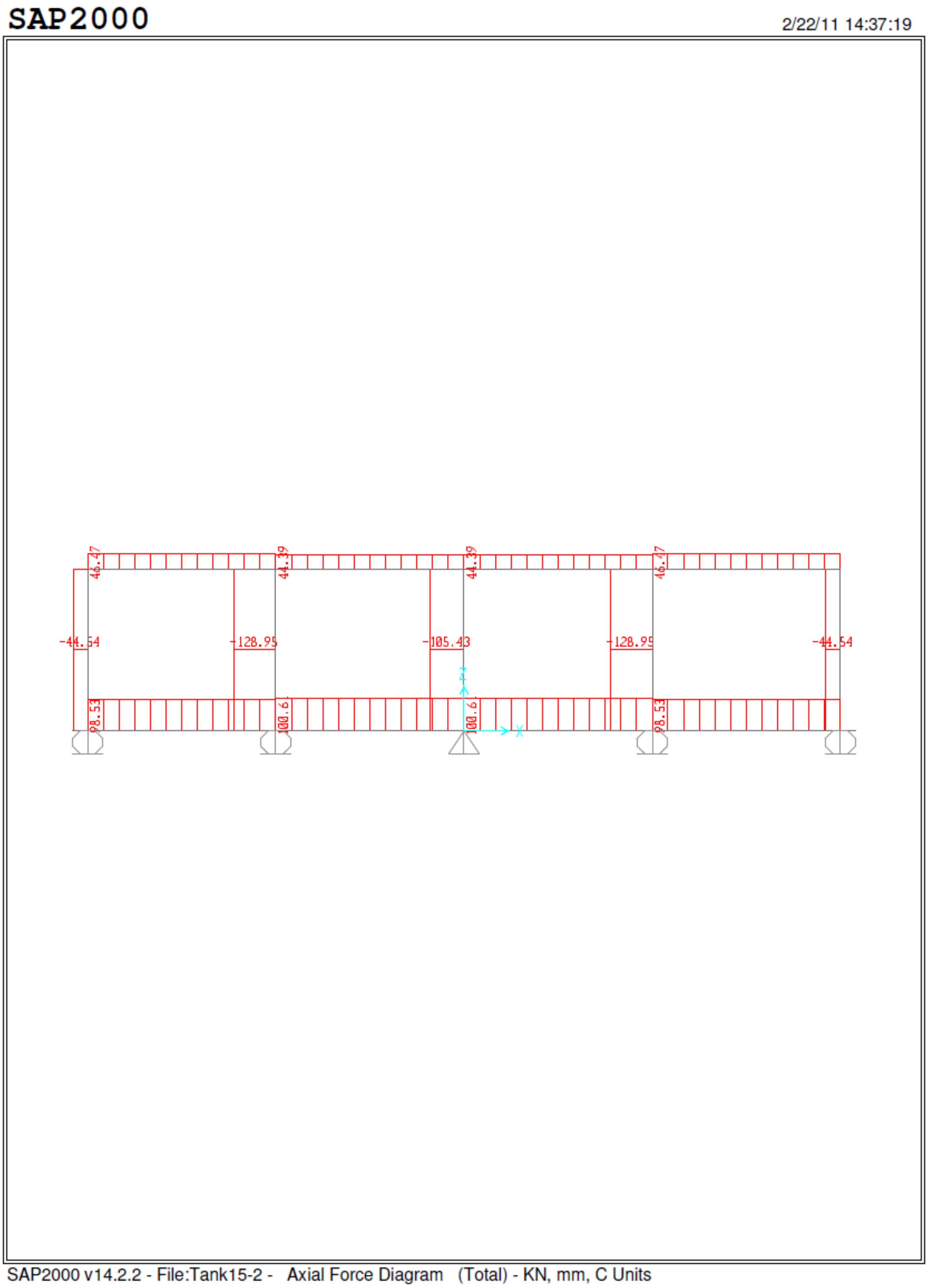


Fig. 8 **Normal force diagram**