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Case Report

Temperature Variation on Concrete Structures- A Case Study

Corneliu BOB*

Polytechnic University of Timisoara, Romania

***Corresponding author:** Corneliu BOB, Polytechnic University of Timisoara, Romania.

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Introduction

During steaming of wood log a complex stress and strain state appear in the RC basins. The effect of this state on the behavior of the basins is presented (Figure 1) [1]. The basin structure elements were designed by taking into account the classical analysis which is characterized by next actions: permanent loads, the temperature action due to the difference between interior of basins (80-90°C) and the outdoors temperature (20°C), the earth pressure and wood log pressure. The different temperature action between the RC basin walls and the RC foundation was not taken into account (Figure 1).

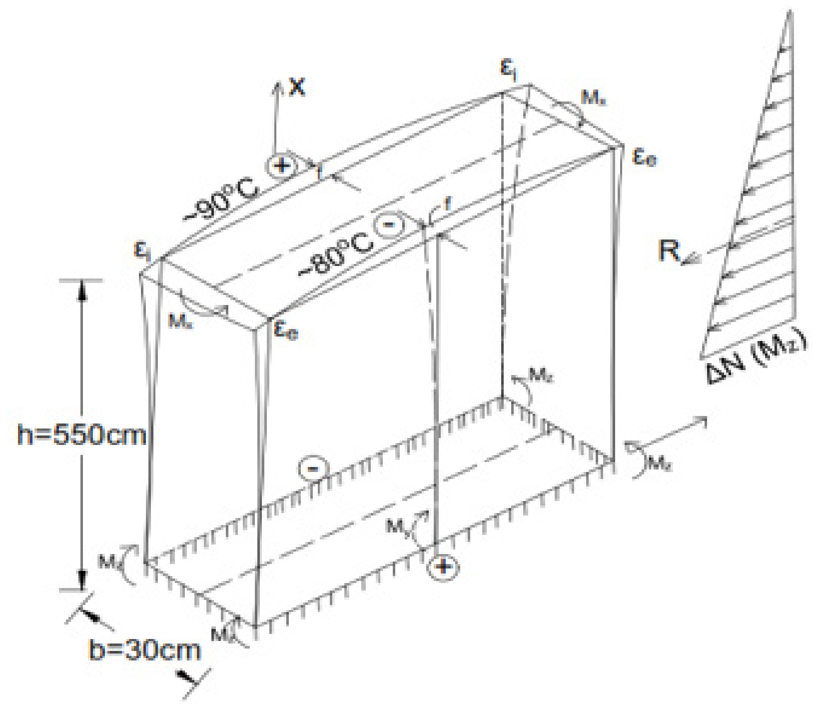

Figure 1: The stress state due to temperature variation.

The Deformations due to Temperature Variation

It was calculated function of temperature on basin walls by using of well know procedure [2].

The temperature on the basin walls

$$Q_k = Q_i - \frac{Q_i - Q_{em}}{R_o} \sum R_{j-1,j} \qquad (1)$$

$$R_i = \frac{d}{b \cdot \lambda}; \quad b = 1; \quad \lambda = 2.03 \frac{W}{m \cdot K} \qquad (2)$$

$$R_{wall} = \frac{0.30}{2.03} = 0.147 \frac{m^2 \cdot K}{W}; \quad Q_{em} = 9.5^0 C$$

$$R_{found} = \frac{0.45}{2.03} = 0.222; \quad Q_m = 15^0 C$$

$$R_o^{wall} = 1.60; \quad R_o^{found} = 1.099$$

(Figure 2)

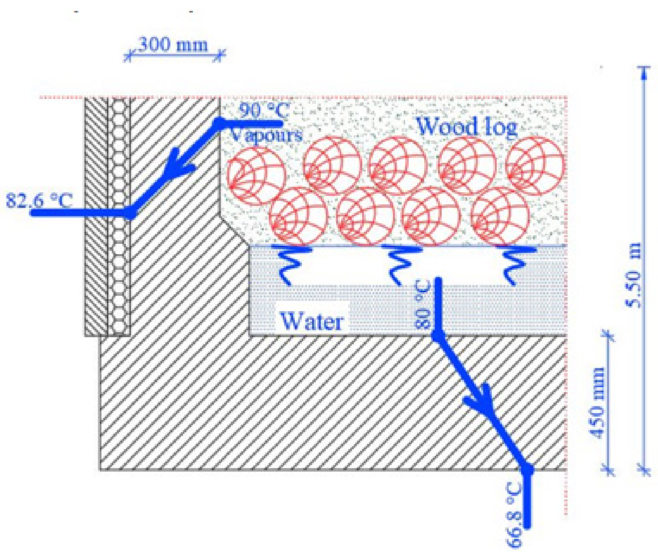

Figure 2: The cross section on the RC basins.

The wall: $Q_k = 90 - \frac{90 - 9.5}{1.6} \cdot 0.147 = 82.6^0 C; \quad T_m = 86.3^0 C$

The foundation: $Q_k = 80 - \frac{80 - 15}{1.099} \cdot 0.222 = 66.76^0 C; \quad T_m = 73.3^0 C$

Stress state from differential strain

The stress state due to different temperature of interior and outdoor of the wall is illustrated in Figure 3 (Figure 3).

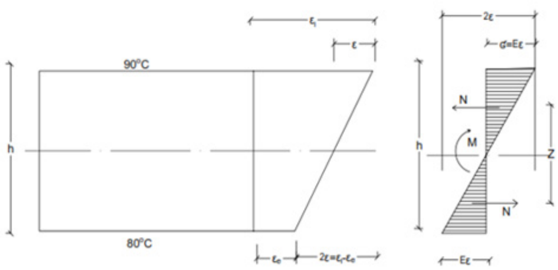

Figure 3: Stress and strain state due to difference of temperature.

$$\Delta l = \alpha \cdot l \cdot \Delta T; \quad \frac{\Delta l}{l} = 2\varepsilon = \alpha \cdot \left(T^{sup} - T^{inf}\right) = \alpha \cdot \Delta T \qquad (3)$$

$$M = N \cdot z \qquad (4)$$

in which: $N = \frac{1}{2} \acute{o} \cdot \frac{h}{2} \cdot b = \frac{1}{4} E \cdot \mathring{a} \cdot h \cdot b$ and $z = \frac{2}{3} h$.

The result is: $M = \frac{\alpha \cdot \Delta T \cdot E \cdot I}{h}$ (5)

The bending moments for temperature difference are:

$\Delta T = 10 \Rightarrow M = 24.1 kNm/m;$

$\Delta T = 12 \Rightarrow M = 29.3 kNm/m$

The differential strain between the wall and the foundation is (Figure 4A, 4B):

$$\delta \Delta T = 86.3 - 73.3 \cong 13^0 C$$

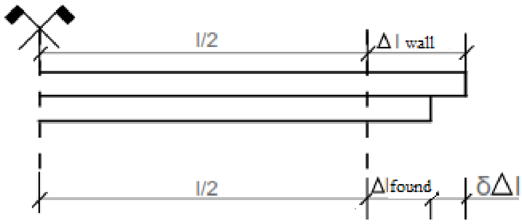

Figure 4: Differential strain between wall and foundation.

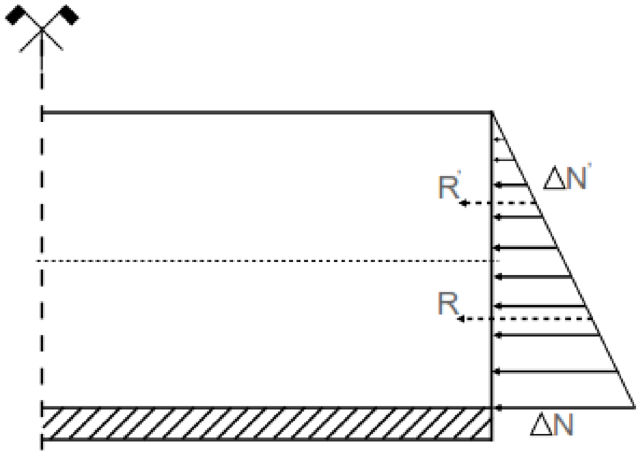

Figure 4B: Stress due to differential strain in the wall.

The different temperature between the foundation and the wall will produce a state of stress in the wall as it is presented in Figure 1 and is calculated:

$$\Delta l = \alpha \cdot l \cdot \Delta T \qquad (6)$$

$$\Delta l = \frac{N \cdot l}{E \cdot A}\ ;\ N = \alpha \cdot E \cdot A \cdot \Delta T\ ;\ \Delta N = \alpha \cdot E \cdot A \cdot \delta\Delta T \qquad (7)$$

The materials characteristics are:

E=325000 daN/cm^2=32500 N/mm^2; C25/30;

A=30x100=3000 cm^2=0.3 m^2;

$I = \frac{100 \times 30^3}{12} = 225000\text{cm}^4 = 0.00225\text{m}^4$; α=10^{-5} m/m.

The efforts are:

$\Delta N = 10^{-5} \times 3.25 \times 10^5 \times 3000 \times 13 = 126750\text{daN/m} = 1267.5\text{kN/m}$;

$R = \frac{1}{2} \times 126750 \times 5.5 = 348562\ \text{daN} = 3486\ \text{kN}$;

$R' = \frac{1}{2} \times 63375 \times 2.75 = 871.41\text{kN}$.

Where: R is the effort for the whole wall and

R' is the effort for superior half of wall.

Critical axial force of the wall

The critical axial force of a wall, according to Timoshenko-Gere, is calculated and compared with the effort from differential deformation between the wall and the foundation [3] (Figure 5).

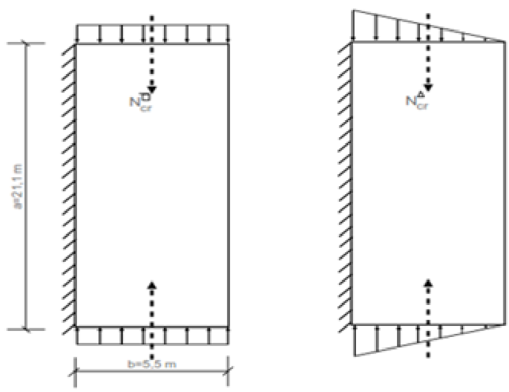

Figure 5: The critical axial force in plate.

For an elastic behaviour, the critical axial force for a simple supported slab N_{cr}^{sr} and for a slab with a restraint side N_{cr}^{inc}, are (Figure 5) :

$$N_{cr} = k\frac{\pi^2 \cdot D}{a^2};\ D = \frac{E \cdot h^3}{12(1-v^2)} \qquad (8, 9)$$

Simple supported plate

For a/b=3.84 (a=21.1 m; b=5.5 m) $\Rightarrow$ k=0.524, and the critical force is:

$$N_{cr}^{sr} = 0.524\frac{\pi^2 \cdot D}{a^2} = 5.16\frac{D}{a^2}\ .$$

Plate with a restraint side

For a/b=3.84 $\Rightarrow$ k_{min}= 1.328, and the critical axial force is:

$$N_{cr}^{inc} = 1.328\frac{\pi^2 \cdot D}{a^2} = 13.1\frac{D}{a^2}\ .$$

$$\frac{N_{cr}^{inc}}{N_{cr}^{sr}} = 2.54$$

According to Romanian Code [4], the critical axial force for a girder is:

$$N_{cr} = \frac{\pi^2 (EI)_{conv}}{l_f^2};\quad (EI)_{conv} \cong \frac{0.15(1+\sqrt{p})}{1+\frac{M_{ld}}{M}} \qquad (10, 11)$$

$$N_{cr} \cong \frac{1.5(1+\sqrt{p})}{1+\frac{M_{ld}}{M}} \cdot \frac{E_b \cdot I_b}{l_f^2} \qquad (12)$$

In the case of a reinforced concrete plate, will result:

$$N_{cr} \cong \frac{1.5(1+\sqrt{p})}{1+\frac{M_{ld}}{M}} \cdot \frac{D}{a^2} \qquad (13)$$

For the basin plate, with a restraint side and uniformly distributed load, for a unity width, result:

$$N_{cr/1} = 2.54 \times \frac{1.5(1+\sqrt{p})}{1+\frac{M_{ld}}{M}} \times \frac{D}{a^2} \qquad (14)$$

$$N_{cr/1} = 2.54 \times \frac{1.5(1+0.38)}{2} \times \frac{7.78\times10^8}{2.11^2\times10^6} = 460\,\text{daN/cm} = 460\,\text{kN/m}$$

$$N_{cr}^{tot} = 46000 \times 5.5 = 253000\text{daN} = 2530\text{kN}$$

For a triangular distributed load, the result is:

$$f = \frac{p \cdot l^4}{8 \cdot E} = \frac{Q \cdot l^3}{8 \cdot E} \qquad (15)$$

$$\Rightarrow \quad f_{\Delta} = 0.53 \cdot f$$

$$f_{\Delta} = \frac{p \cdot l^4}{30 \cdot E} = \frac{Q \cdot l^3}{15 \cdot E} \qquad (16)$$

from which:

$$N_{cr}^{\Delta} = \frac{1}{0.53}N_{cr} = \frac{253000}{0.53} = 477000\text{daN} = 4770\text{kN}\ .$$

The check of detailing and wall reinforcement

The temperature differences on the two sides of the wall

In the case of 10°C temperature differences, the bending moment is:

1. Cracking bending moment:

$$M_f = 0.29 \cdot b \cdot h^2 \cdot R_t + 16 \cdot A_a \cdot h \qquad (17)$$

$$M_f = 0.29 \times 100 \times 30^2 \cdot 12.5 + 16 \times 3.92 \times 30 = 3280\text{daNm/m} = 32.8\text{kNm/m}$$

$$M_f > M_x = 24.1\text{kNm/m}$$

No cracking of the wall is obtaining. Some cracks have to appear due to restrained shrinkage.

2. Necessary reinforcement is:

$$A_a = \frac{M}{R_a \cdot z} \cong \frac{241000}{3000 \times 0.8 \times 30} = 3.34\text{cm}^2 < 3.92\text{cm}^2 \qquad (18)$$

It can be seen that the necessary reinforcement is sufficient.

3. Maximum deflection was calculated taking into account the bending moment M_x, acting on the full length of the wall:

$$f^{sr} = \frac{M_x \cdot l^2}{8 \cdot EI} \qquad (19)$$

On the other hand, for a wall with a restraint side, the ratio from the loads of 2.54 was introduced:

$$f^{inc} = \frac{f^{sr}}{2.54} = \frac{M_x \cdot l^2}{2.54 \cdot 8EI} = \frac{2.41 \times 44.1}{2.54 \times 8 \times 3.25 \times 2.25} = 0.7\,\text{cm} \qquad (20)$$

Combined action

$M_l \cong 30$ kNm/m , for $\Delta T = 12^0 C(K)$;

N_l=63364 daN/m=633.64 kN/m;

$$N_{cr}^{tot} = 477000\text{daN} = 4770\text{kN}\ ;\ N_{cr}^{med} = \frac{477000}{5.5} = 86730\text{daN/m} \cong 867\text{kN/m}$$

1. The case of $\delta_{\Delta T} = 13^0 C$

The analysis to limit state of buckling safety is introduced by multiplication coefficient η eccentricity:

$$\eta = \frac{1}{1-\frac{N}{N_{cr}}} = \frac{1}{1-\frac{634}{867}} = 3.72 \qquad (21)$$

$$e_0 = \frac{M}{N} = \frac{30}{6347} = 0.047\,m = 4.7\,cm\,;\quad e_{0c} = 4.7 + 2 = 6.7\,cm\,;$$

$\eta \cdot e_{0c} = 3.72 \times 6.7 = 24.92\,cm > 0.3\,h_0$=8.1 cm

$$x = \frac{N}{b \cdot R_c} = \frac{63374}{100 \times 160} = 3.52\,cm < 0.55\,h_0 = 15.4\,cm$$

$$e = \eta \cdot e_{0c} + \frac{h}{2} - a' = 24.92 + 15 - 2.5 = 37.42\,cm$$

$$A_a = A_a' = \frac{N \cdot \left(\eta \cdot e_{0c} - \frac{h}{2} + \frac{x}{2}\right)}{R_a\left(h_0 - a'\right)} = \frac{63374 \cdot \left(24.92 - 15 + \frac{3.52}{2}\right)}{3000 \cdot (27 - 3)} = 10.28\,cm^2$$

Such A_a is greater than existing reinforcement.

$$M_* = \eta \cdot (M + e_0 \cdot N) = 3.72(300000 + 2 \times 63374) = 1587500\,daNcm/m = 159\,kNm/m$$

Bending moment from axial force is:

$$M_s = 63374 \times 2 \times 3.72 \cong 470000\,daNcm/m = 47\,kNm/m$$

The maximum deflection will result (Figure 6):

$$f_s^{inc} = \frac{4.7 \times 44.1}{2.54 \times 8 \times 3.25 \times 2.25} \cong 1.63\,cm \text{ şi}$$

$$f_{tot}^{inc} = 0.25(0.7) + 1.63 = 1.88(2.33)\,cm$$

2. The case of

$$N = 195000\,daN/m = 1950\,kN/m\,;\quad R = 536000\,daN = 5360\,kN$$

$$N_I = 97500\,daN/m = 975\,kN/m > N_{cr} = 86730\,daN/m = 867.3\,kN/m$$

In the case of monolith connection, the value of the axial force N which is present in the basin walls is greater than the critical axial force for the loss of stability of the walls and some deformations will appear (Figure 6).

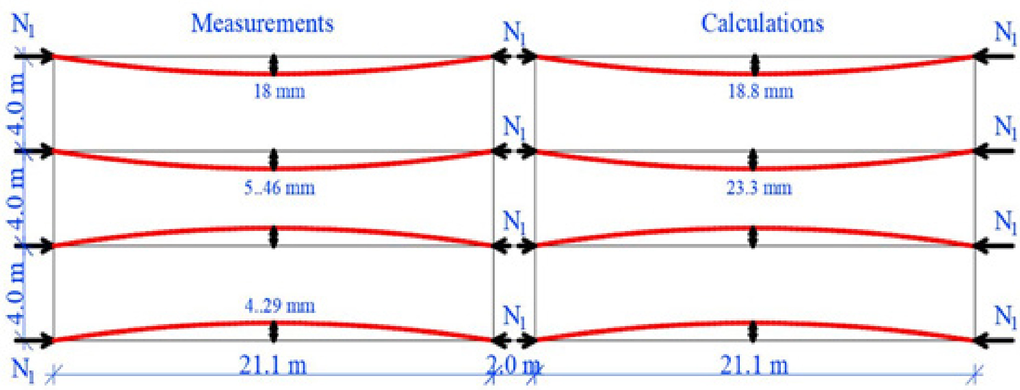

Figure 6: The basin dimensions and the walls deformations.

Conclusion

1. For monolith connections between foundation and the basin wall, the result from calculation was:

N_1=975 kN/m>N_{crit}=867 kN/m

where:

N_1 - the axial force due to the temperature variation between the foundation and the wall.

N_{crit}- the critical axial force of the wall, for loss of stability (buckling).

2. For prefabricated walls of the basin:

$N_1 < N_{crit}$

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Disclosure Statement

No potential conflict of interest was reported by the author.

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