26th International Conference
ENGINEERING MECHANICS 2020
Brno, Czech Republic, November 24 – 25, 2020

INFLUENCE OF TEMPERATURES AND SIZES OF WORK SEQUENCE ON CRACKS FORMATION IN RC WALLS

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Abstract: *The construction of the underground watertight structure is not only conditioned by the watertightness of the foundation slab, but also by the walls. The formation of a crack and thus the amount of reinforcement required to control the occurrence of a crack are dependent on several factors. The amount of tensile stresses occuring in the wall is mainly influenced by the ambient temperature at the time of concreting, the temperature of the foundation slab, which is already hardened, and the ratio of the height of the work sequence of the wall to its length.*

Keywords: Work sequence, Internal restrain, Watertight structure, Time of concreting.

1. Introduction

The watertight function of the underground structure of the so-called "White Tanks" have to be fulfilled not only by the foundation plate, but also by the walls. The wall shall by watertight at least 300 mm above the maximum groundwater level.

The structures constructed as white tanks do not have to be protected by waterproofing insulation based on asphalt or plastics, and that brings several advantages:

– more simple static and construction arrangement of the structure, regardless of the permissible surface load or friction of the surface insulation,
– reduction of the steps of the working procedures (construction and protection of insulation), resulting in reduced construction time and less dependence on weather conditions,
– any leaks can be easily and quickly located and repaired (e.g. by injection),
– greater durability of concrete than in the case of the use of surface insulation.

The concreting procedure must be considered when designing the wall thickness, since the concrete sleeve must fit between the wall reinforcement. The recommended wall thickness is 300 mm and the maximum height should not be more than six meters or fifteen times the wall thickness, respectively (Lohmeyer, 2018). Special measures must be applied to higher walls, or horizontal working joints must be designed.

The design of the watertight concrete wall is affected by the size of the restrained stresses caused by the different time of concreting, when the hardened foundation slab prevents the wall from being free do deform at the time of hydration and subsequent cooling of the concrete wall. Restrained stresses in the walls can be eliminated by concreting the foundation slab and the wall in one work sequence, but this is not a common practice. For this reason, it is important to choose a suitable ratio of the height and the length of the concrete section of the wall, which is related to the quantity and distribution of the reinforcement and the sealing of the joints.

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doi: 10.21495/5896-3-456

2. Crack formation and restrained stresses in the wall

The design risk of the cracking due to the control of the restrained stresses in the walls can be estimated by different methods. Separation crack in the wall occurs when the tensile stresses exceed the mean tensile strength of the concrete. By an appropriate select of the ratio of the wall length to its height, it is possible to reduce the restrained stresses in the wall cross-section. The smaller the ratio, the less the restrained stresses.

In bottom part of the wall, at the joint of the hardened foundation slab and just-concreted wall, no wide cracks can form, but only fine hairline cracks that are watertight. In the longitudinal direction of these capillary cracks, the restrained stresses of the wall develop. In the lower part of the wall (up to the 1/4 of the height) usually no reinforcement is required to control the crack width. In this area, the minimum reinforcement area according to EN 1992-1-1 clause 7.3.2 is sufficient (Lohmeyer, 2018). In the area over a 1/4 of the height it is also possible to save reinforcement, depending on the ratio of the wall length to its height. The amount of the restrained stresses depending on the selected ratio of the wall length to its height is shown in Fig. 1 (Lohmeyer, 2018).

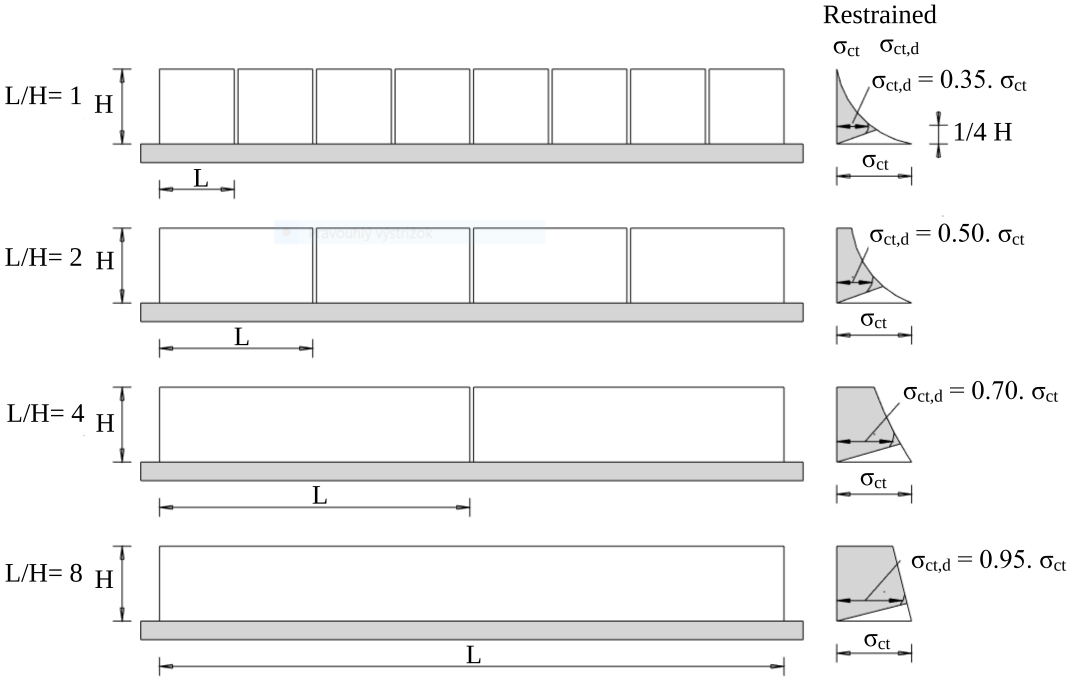

Fig. 1: The course of the restrained stresses in the wall.

The highest restrained stresses (σ_{ct}) arise at the lower edge of the wall, regardless of its length. With increasing wall length, the stresses increase at the upper edge of the wall up to the full value of σ_{ct}. For walls with L/H > 8, the restrained stresses are equal to the whole wall height $\sigma_{ct.d} = 1.0 \cdot \sigma_{ct}$ (Lohmeyer, 2018).

3. Calculation of the cracking stresses

The formulas and assumptions for determining the critical time of cracking, the effective tensile strength of the concrete, as well as the cracking stress were taken from the "Weisse Wannen Einfach und Sicher literature" (Lohmeyer, 2018).

Determination of the critical time, when the first crack is expected as follows:

$$t_{crit} \approx 1.3. t_{maxT} + 24 \ \ [h] \tag{1}$$

t_{crit} is the critical time of separation crack formation according to maximum temperature t_{maxT} [h],

t_{maxT} is the time of the highest wall temperature, it depends on the effective thickness of the element h_0 and the development of concrete strength [h], Tab. 4.4 in Lohmeyer (2018).

Calculating of mean concrete strength at critical time:

$$f_{ct,eff} = k_{ct(t)}. k_j. f_{ctm(28d)} \tag{2}$$

$k_{ct(t)}$ is the time coefficient of tensile strength of concrete for time t_{crit} [-] Tab. 4.18 in Lohmeyer (2018),

k_j is the season factor [-]:

k_j = 1.0 at average daytime temperatures around 10 to 15 °C, e.g. in the spring or autumn,

k_j = 0.9 at lower daytime temperatures, e.g. in the winter,

k_j = 1.1 at daytime temperatures around 20 °C, e.g. in the summer,

k_j = 1.2 at daytime temperatures around 25 °C,

$f_{ctm(28d)}$ is the mean value of concrete tensile strength at 28 days [MPa].

Estimation of the reduced value of the restrained stress at lower edge of the concrete wall:

$$\sigma_{ct,red} = k_{(\varphi+\psi)}.\alpha_{T(t)}.\Delta T_{B,W-F}.E_{c(t)} \quad (3)$$

$k_{(\varphi+\psi)}$ is a factor considering the creep and shrinkage of concrete [-]:

0.55 with early restrained stress for thin in-situ concrete structures with an effective elements thickness of h_0 < 300 mm, e.g. due to draining heat hydration,

0.65 with early restrained stress for thicker in-situ concrete structures with an effective elements thickness of $h_0 \geq$ 300 mm, e.g. due to draining heat hydration,

0.80 with later restrained stress, e.g. shrinkage of concrete,

$\alpha_{T(t)}$ is the coefficient of thermal expansion of young concrete for time t_{crit} [-],

$\Delta T_{B,W-F}$ is the temperature difference between the mean wall element $T_{B,W}$ and the foundation temperature $T_{B,F}$:

$$\Delta T_{B,W-F} = T_{c0} + k_{Tv}.\Delta T_{th} - T_{B,F} \quad (4)$$

$T_{c,0}$ is the temperature of fresh concrete during concreting [°C],

k_{Tv} is the factor considering the course of the temperature within the wall dependent on the effective width of the element, [-], Tab. 4.3 in Lohmeyer (2018),

ΔT_{th} is the increase in wall temperature from hydration heat [K]:

$$\Delta T_{th} = \frac{z.Q_H}{C_{c0}} \quad (5)$$

z is the amount of cement per m^3 of concrete [kg/m^3],

Q_H is the cement hydration heat depending on cement type and time t_{crit}, [kJ/kg], Tab. 3.8 in Lohmeyer, (2018),

C_{c0} is the volume heat capacity of concrete, 2500 kJ/(m^3.K),

$T_{c,0}$ is the temperature of the foundation slab [°C],

$E_{c(t)}$ is the modulus of elasticity of young concrete at time t_{crit} [MPa]:

$$E_{c(t)} = k_{Ec(t)}.\alpha_{(E.g)}.E_c \quad (6)$$

$k_{Ec(t)}$ is the time factor for the development of the modulus of elasticity of the young concrete $E_{c(t)}$ at the age of t days, relative to the mean value of the modulus of elasticity of the concrete $E_{c(28d)}$ at the age of 28 days,

$\alpha_{E,g}$ is the factor taking into account the type and grain size of aggregates, [-], Tab. 3.18 in Lohmeyer, (2018),

E_c is the tangential modulus of elasticity for deformations [MPa].

The calculation of restrained stresses in the wall, taking into account the length and height ratio of the wall:

$$\sigma_{ct,d} = k_{ct,d}.\sigma_{ct,red} \quad (7)$$

$k_{ct.d}$ coefficient to determine the tensile stress at the 1/4 of the wall height (Tab. 1)

The condition for cracks prevention is:

$$f_{ct,eff} > \sigma_{ct,d} \quad (8)$$

3.1. Example

The risk of the cracks due to restrained stresses due to the ambient temperature, the already hardened foundation slab and the ratio of the wall height to length is demonstrated in Fig. 2. The following construction parameters were chosen for the model example:

- unchangeable parameters: concrete strength class C25/30, cement CEM III/B 32.5 R, wall height of 3 m, wall thickness of 0.3 m,
- varying parameters were the wall length from 3 m to 30 m and temperatures.

The crack formation was calculated for three temperature situations:

- summer: temperature of the young concrete of 24 °C and of the foundation slab of 22 °C,
- winter: temperature of the young concrete of 12 °C and of the foundation slab of 15 °C,
- spring/autumn: temperature of the young concrete of 18 °C and of the foundation slab of 20 °C.

Other parameters were calculated based on these inputs.

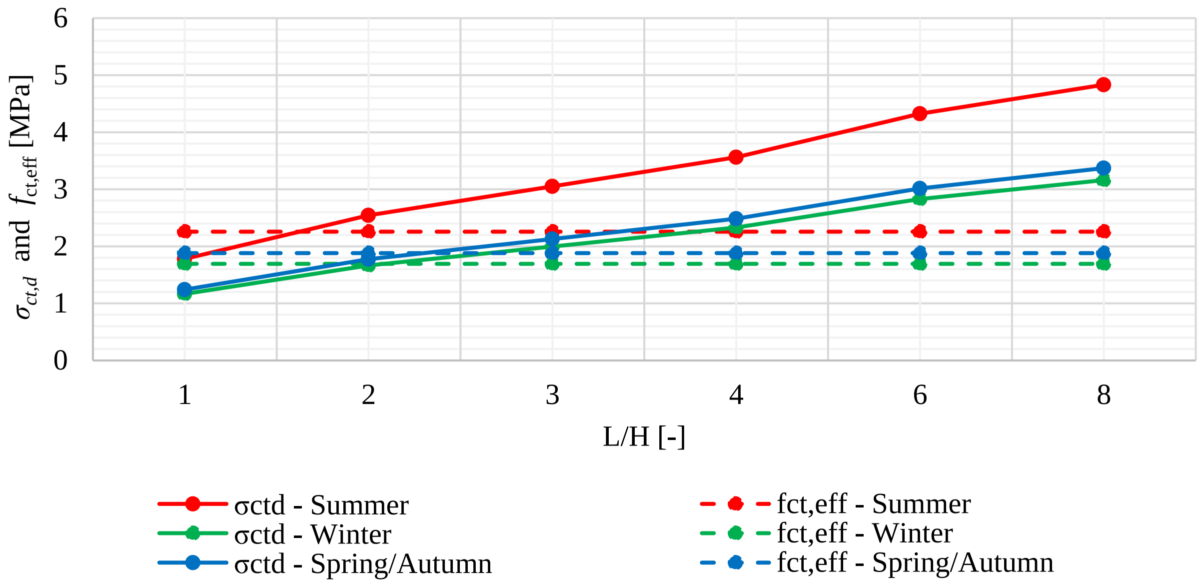

Fig. 2: Comparison of the restrained stresses and tensile strength of concrete in the wall according to the season and the ratio of the wall length to its height.

4. Conclusions

Fig. 2 shows that by choosing a suitable time of concreting and the ratio of the wall length to its height, it is possible to prevent crack formation and thus save on the amount of reinforcement. The dashed line represents the actual tensile strength of the concrete at the critical time for crack formation and the continuous line represents the restrained stresses caused by the hydration of the cement and the restrain of the free deformation of the wall with hardened foundation slab. Concreting of the walls in colder weather leads to the design of a more economical structure even at lager wall length to height ratios, while concreting at high temperatures causes a high risk of cracking. Restrained stresses in summer can be up to 30 % greater than in winter, causing a significant increase in the amount of reinforcement for crack width control.

Acknowledgement

This work was supported by the Slovak Research and Development Agency under the contract No. APVV-15-0658 and by the Scientific Grant Agency VEGA under the contract No. VEGA 1/0522/20.

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