

# Thermal Analysis of Reinforced Concrete Tank for Conditioning Wood by FEM Method

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**Abstract.** The article introduces the analysis of a RC tank for conditioning wood carried out using the FEM (Finite Element Method). A temperature gradient distribution increase resulting from the influence of hot liquid filling the tank was defined. Values of gradients in border sections of the tank walls and the bottom were defined on the basis of the isotherm method. The obtained results were compared with empirical formulas from literature. Strength analyses were also carried out. Additionally, the problematic aspects of elongated monolithic tanks for liquids were introduced, especially regarding large temperature gradients and the means of necessary technical solutions. The use of the FEM method for designing engineering objects is, nowadays, an irreplaceable solution. In the case of the discussed tank, a spatial model of the construction mapping its actual performance was constructed in order to correctly estimate the necessary dimensions of wall and bottom sections, as well as reinforcement.

## 1. Introduction

The influence of high temperature lowers the stiffness of structural elements threatens building stability and can lead to the building disaster. Greatest destructions follow in fire-temperatures [1-3]. However lower temperatures are also dangerous, especially in case of open objects with considerable dimensions. If this is the case meanings gather rheology phenomena. Such effects must be foreseen also on the stage of the designing. In such situation in the designing process is necessary the regard of the influence of temperature gradients on the formation of inner forces in RC structure specially in transitory phase, that is in progress of the tank filling of hot water and in the exploitive phase. An important problem is also the formation of expansion joints.

## 2. Information about the Object

The described object is a free-standing reinforced concrete tank, not covered by a roof, used to condition wood. The outside dimensions of the tank are as follows: length – 67.70, width – 16.88 m, depth of chamber – 2.4 m, height of tank above ground level – 1.10 m. Inside the tank, four independent chambers extending down the entire length of the tank were isolated. The chamber is set directly on the ground, on a reinforced concrete foundation slab, 50 cm in thickness. The foundation slab serves the function of the tank bottom. The outside (longitudinal and lateral) and inside walls were designed as reinforced concrete, 50 cm in thickness. The tank was divided into 4 segments, separated by expansion joints. Pictures of the structure – plan and cross-sections (lateral and longitudinal) have been presented below (Figure 1 - Figure 3). For technological reasons, the tank was



equipped with numerous steel elements to which technological devices serving to process and transport wooden logs were mounted.

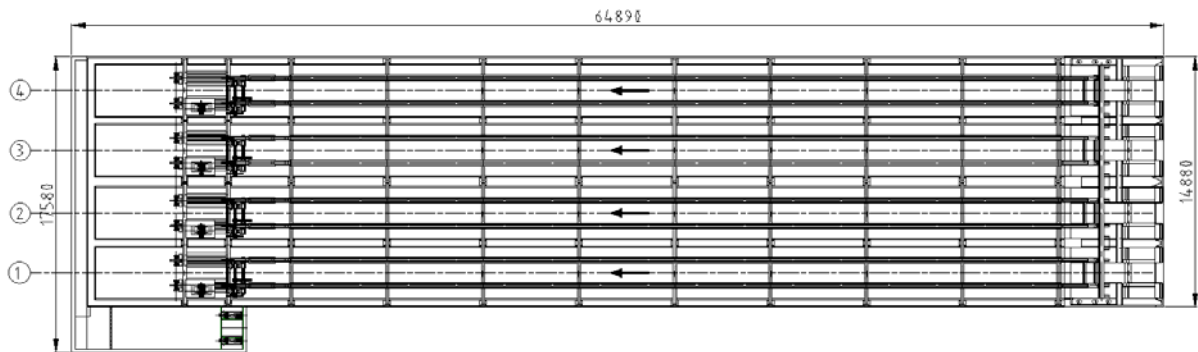


Figure 1. Tank for conditioning wood – plan along with technological devices

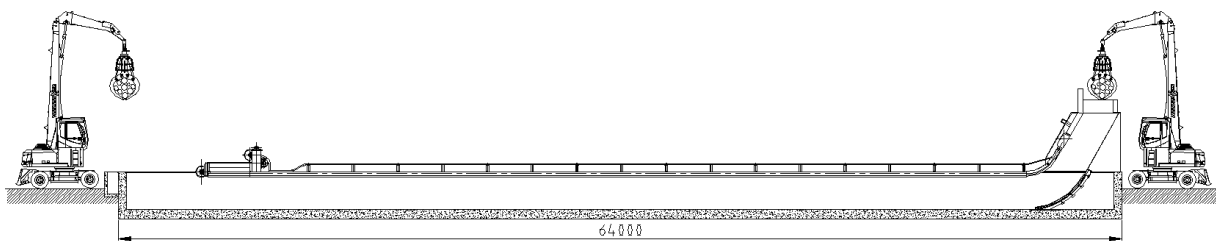


Figure 2. Tank for conditioning wood – longitudinal -section along with technological devices

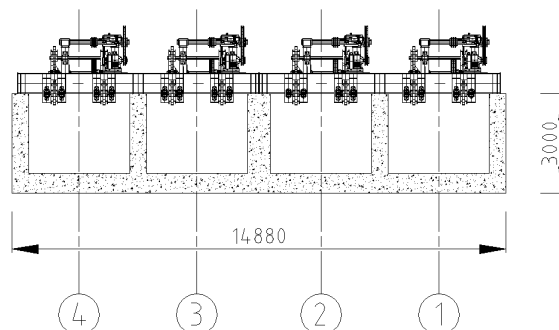


Figure 3. Tank for conditioning wood – lateral section along with technological devices

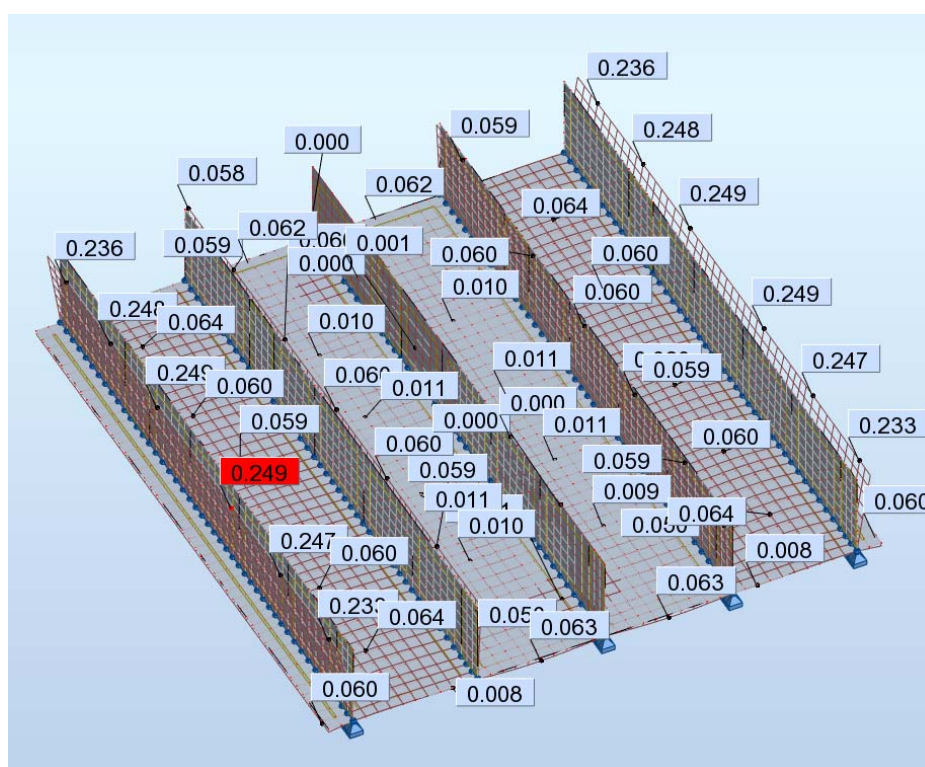
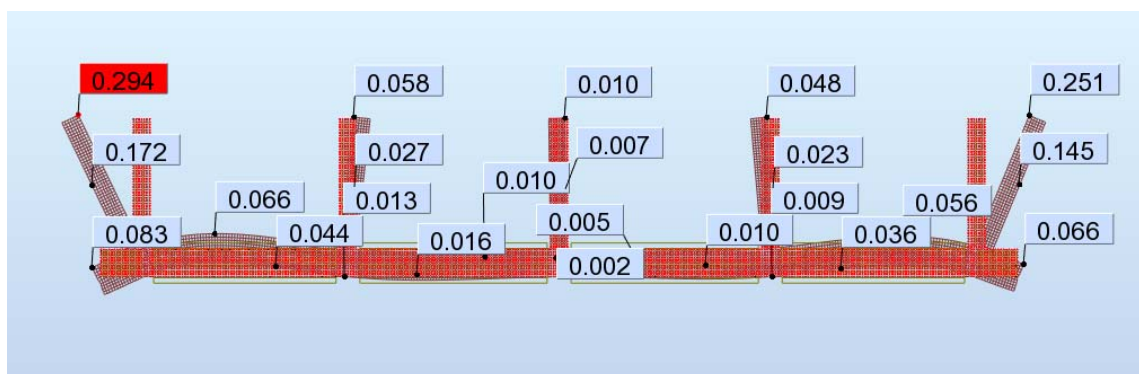
### 3. Loads and Operational Conditions of Tanks for Conditioning Wood

The described structure is used as a tank for conditioning wood – steaming wood logs in technological water. Water used to soften the wood has a negative effect on the construction – it is characterized by a high temperature (approx. 70°C) as well as an acidic pH ( $\text{pH} \leq 3$ ). In accordance with the technological requirements, water is alternately poured into and out of the tank chambers through the entire year, regardless of the atmospheric conditions (air temperature). Due to the high temperature of the liquid, the structure of the tank undergoes cyclic thermal stress. Pouring and draining water leads to the occurrence of temperature gradients in the structural elements of the tank. During numerical analysis, two phases of tank operation were distinguished, i.e. the transitional phase connected with the filling of chambers with hot water, and the operational phase connected with the activity of structural elements at a given temperature. The most unfavourable to concrete strength is the transitional phase, during which the tank is suddenly heated up upon being filled with hot water. The winter period is the least favourable case, as the temperature of an unfilled tank can be, on average, -30°C. At this phase, gradients of temperatures which change over time, characterized by very high

values, occur at wall and bottom section height. This process is very difficult to describe; thus an attempt was made to determine alternative temperature gradients describing this phase of tank operation. On the basis of numeric analysis, an alternative gradient, which is  $\Delta t=35^{\circ}\text{C}$  for the bottom and walls, was indicated. The effect of even heating up connected with the elongating and widening of the tank can be minimalized by introducing structural solutions which allow for the free deformation of the tank, such as articulate lateral expansion joints of walls and flexible expansion joints of walls, as well as a decrease of friction between the bottom of the tank and the ground surface. The following phase of the tank is that of its operation, during which the temperature of the walls and bottom stabilize. Temperature gradients are minimal, and even heating up by values of up to  $70^{\circ}\text{C}$  prevails, referring to temperatures during assembly. As mentioned above, structural tanks can be prepared for such types of impact, but due to the friction forces between the bottom and ground surface, longitudinal forces in the bottom slab and reinforcement of expansion joints ought to be assessed. It should be kept in mind that the heating up and cooling off of the tank takes place in a cyclic manner and, due to its elongated shape, the separation of segments may occur at the expansion joints. Thus, horizontal expansion joints cannot be shaped in a flexible manner but must possess structural (articulated) elements which ensure a constant distance of the tank segments in regards to one another. The values of temperature gradients in the transitional phase can be compared to the guidelines for gradients of outside floors [4] exposed to heating from solar radiation. In this case, the change in temperature is determined for a floor thickness of  $0.9^{\circ}\text{C}/\text{cm}$ . In the case of such an approach, the gradient (difference of temperatures between the surface and bottom of the floor) will be  $\Delta t=0.9 \cdot 50=45^{\circ}\text{C}$ , which is an overestimated value in relations to numerical analysis, but can serve as a good reference for comparison. The temperature of the surface of a floor heated by solar radiation is approximately  $60^{\circ}\text{C}$ , which is comparable to the temperature of the heated liquid in the tank. In addition to the effects of temperature, operational and technological loads (according to the guidelines of machine suppliers), caused by the impact of wooden logs, and the load caused by water pressure and the own weight of the structure were accounted for in the calculations [5]. Structural elements of the tank are under the extremely unfavourable impact of caustic fluids and temperature. Water used in the technological process, due to low pH and a high temperature, can lead to the dissolving of concrete components and severe, uncontrolled corrosion of steel. Sulphate ions contained in the water can react with calcium hydroxide. Because of this, specific guidelines regarding the quality and composition of concrete were provided at the design stage.

#### 4. Describing Temperature Gradients in the Transitional Phase

The most unfavourable, as far as the dimensioning of reinforced concrete tank wall and bottom sections is concerned, is the transitional phase of operation. This is the initial phase, connected with filling a cool tank with hot water at a temperature of  $70^{\circ}\text{C}$ . During this process, the change in temperature gradients occurs gradually, which leads to the significant bending of the coating elements of the walls and bottom. It is very difficult to assess alternative temperature gradients, which will later allow for designing the necessary reinforcement in reinforced concrete sections. The work proposes an effective means of approaching this problem. The basis for the analysis is a set out section of the tank and its modelling in a shield manner with defined bands at depths. The individual bands subsequently undergo even heating by a temperature of  $70^{\circ}\text{C}$  in accordance with the increase in temperature over time inside the sections, and deformations of the system are analysed. Next, the activity of the distinguished segment of the tank modelled in a coating manner was compared and gradients  $\Delta t$  selected so that the deformations were similar to the shield model. On this basis, an appropriate alternative temperature gradient can be accepted for the entire tank system in the transition phase. In Figures 4 and 5, deformations for the shield and coating models have been presented. Figure 4 shows deformations where the inside shield layer is subject to the heating by  $70^{\circ}\text{C}$ , thus it is the first phase of the heating of the bottom and wall layers of the tank. In Figure 5, equivalent deformations for the coating model at a temperature gradient of  $\Delta t = 35^{\circ}\text{C}$  have been shown. Further calculations were carried out for such a temperature gradient.



## 5. Static Calculations of Tank

with points on the opposite edge contour. This intersection point of each pair of horizontal and vertical lines signifies the end of node location within a region, as shown in Figure 6.

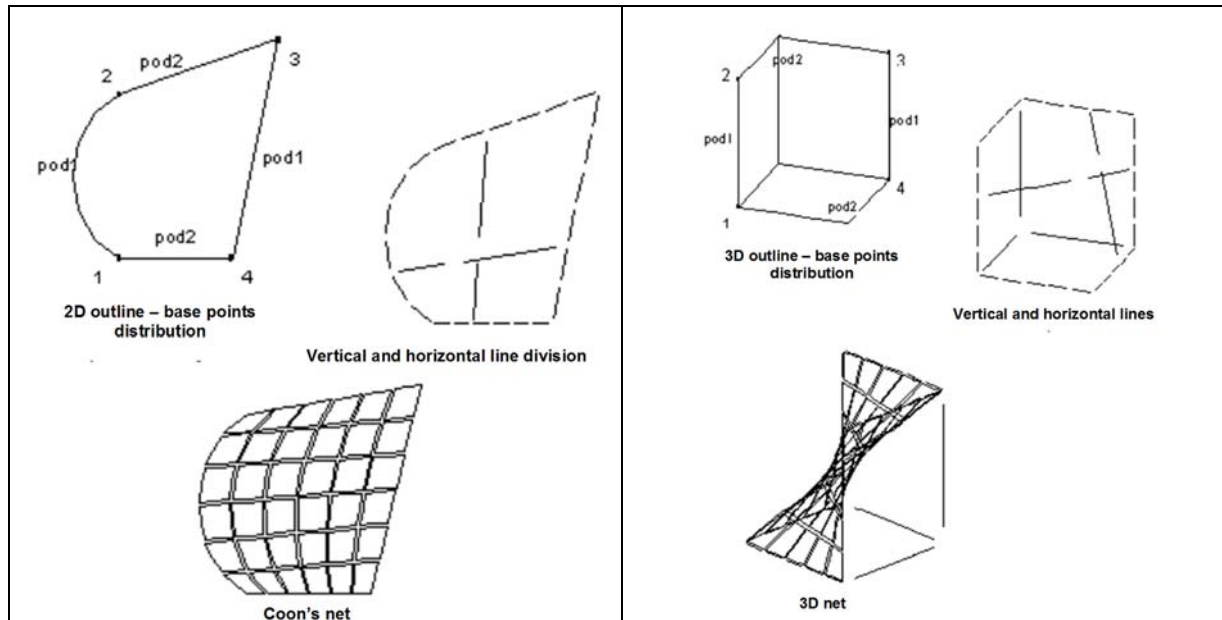


Figure 6. Location of points in Coon's surfaces

Coons meshing for a flat (2D) domain in which the contours are defined in planes (see Figure 6), as well as in 3-D surfaces in which the contours are defined in space were applied in the model. The calculation model accounted for all elements necessary to properly describe the operation of the tank. The walls and bottom were modelled by a coating manner, accounting for all changes in the thickness of the sections and materials. Due to the thermal effects of gradients and even heating up, the tank was placed on an elastic foundation with the possibility of pulling off, with adequate rigidities of the ground surface, both vertical and horizontal, accounting for the rigidity conditions of the ground surface and friction force between the tank bottom and the ground. Articulated expansion joints were introduced in the bottom between the individual segments in order to determine the forces existing in the actual connection. Walls in the expansion joints were completely separated, and flexible sealers were applied in this case.

The calculations were divided into two phases. The first of them was connected with the transitional phase for which the main loading was the temperature gradient determined in pt. 4. (Figure 7) and water pressure. We can observe distinct bending of the tank walls and bottom. The main reinforcement of the tank results from such a state. The second phase of operation is a completely heated tank, operating only under even distribution of temperatures (Figure 8). Technological loads and water pressure comprise additional loading. Deformations of the tank are mainly longitudinal and lateral. Disturbances in the internal forces occur at the joints of wall and bottom components.



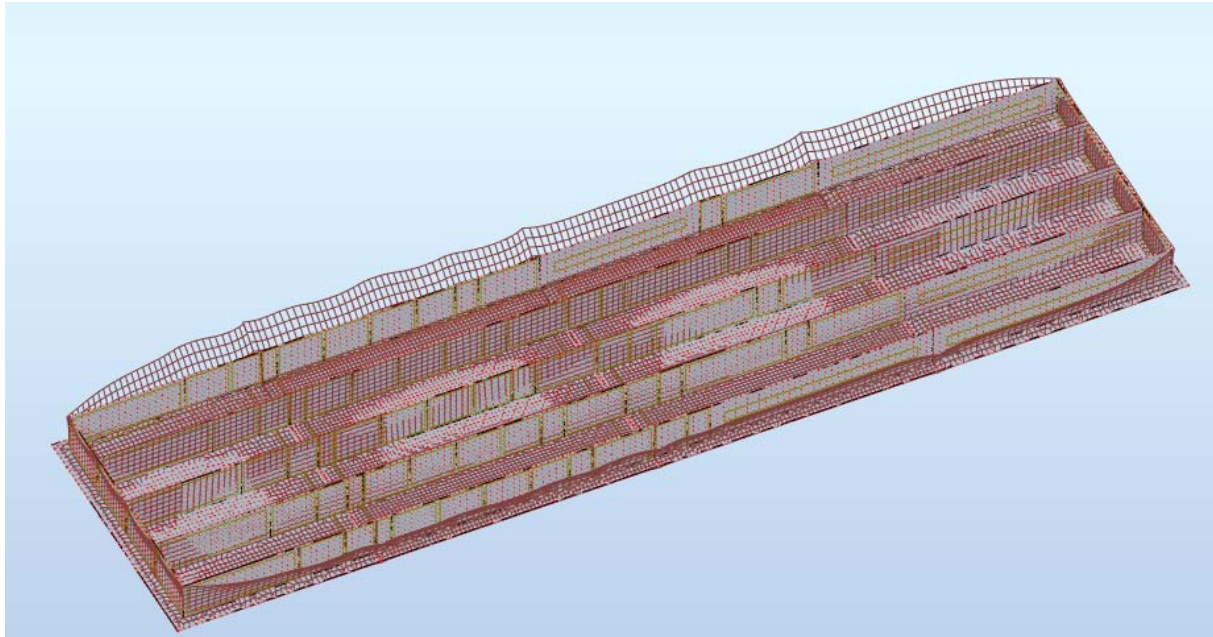


Figure 7. Structure deformations for the transitional phase (influence of temperature gradients on tank deformations)

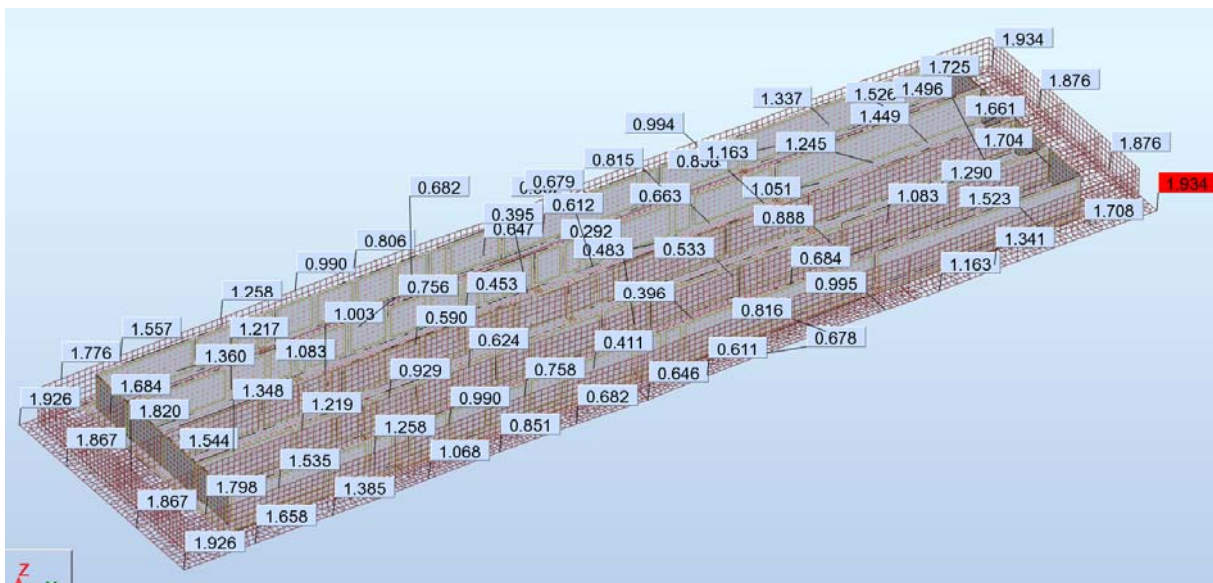


Figure 8. Structural deformations for the second phase of tank operation (influence of even distribution of temperatures)

## 6. Important Aspects of Designing Long Tanks for Liquids

The main problem connected with designing long, reinforced concrete tanks for liquids is their thermal expandability and, in consequence, the issue of properly solving expansion gaps. The analysis of the results of static calculations of the described tank has confirmed this. The influence of temperature gradients is visible in graphs of tensile stresses and deformations of the tank. Sudden heating up of the pool leads to significant thermal expandability of the structure, since outside walls of the tank simultaneously lean outwards and increase in length due to the thermal expandability of concrete, individual segments separated by expansion joints begin to push against each other, and significant tightening of the expansion joints takes place. The cyclic effects of temperature and lack of ballast

elements limiting the possibilities free movement of the tank lead to progressing separation of individual segments of the tank and spreading of expansion gaps. This is visible when inspecting old tanks which had not been used for a long time. The cyclic impact of temperature gradients leads to thermal expandability of the structure and problems with expansion joints.

The problem of slow, long-term expansion of expansion gaps in tanks lies in their construction. In accordance with their definition, expansion joints, due to the thermal expansion of the structure, are gaps in the continuity of a building, allowing for its free deformation, working in response to the contraction or lengthening of structural elements. Their role is to secure the building against the effects of stress occurring as a result of thermal deformations [6-11]. The lack of their compensation leads to cracking of the structure, and in extreme cases, its destruction. Traditional solutions for expansion joints are carried out by completely (100%) breaking the continuity of the structure – concrete and reinforcement – flexible expansion joint. Such solutions do not restrict the movement of the structure in any way, which over time leads to the spreading out of expansion gaps and their leakage.

An expansion joint solution in which thermal expansion is compensated by adequate widths of gaps in the concrete layer was proposed. Appropriately chosen reinforcement located around the flexible element in the expansion joint of the bottom slab restricts the slow, constant spreading of the expansion joint. In the case of cyclic cooling and heating up of the tank, the reinforcement maintains a constant distance of individual segments separated by articulated expansion joints.

At this point, attention should be drawn to the fact that introducing such a solution requires calculating the elongated tank as a whole, that is all segments together, because, due to the friction between the bottom and ground surface, additional tensile or compressive stress is generated in the bottom. Significant forces also occur in the actual rods of expansion joint, which ought to be precisely dimensioned due to the durability of the rod itself and anchoring in the concrete. The applied solution of an articulated expansion joint in the bottom slab has been presented in Figure 9.

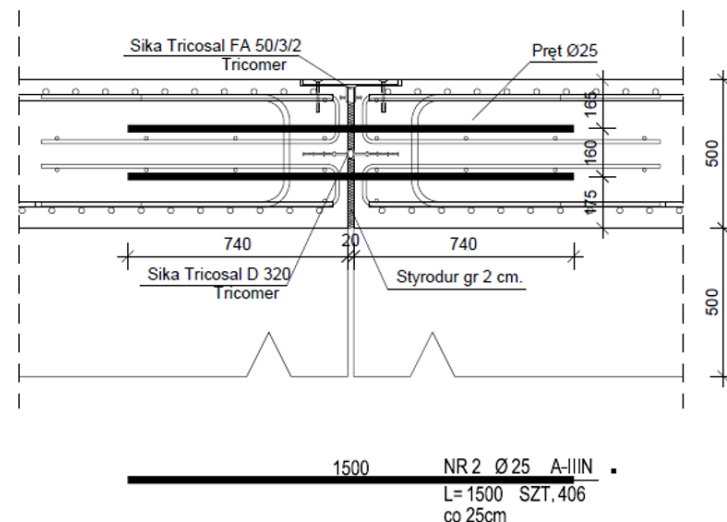


Figure 9. Detail of original solution for articulated expansion gap

Structural elements of the tank are subject to the extremely harmful effects of corrosive liquids and temperature. For this reason, specific guideline regarding the quality and composition of concrete are given at the design stage. Based on standards [12], the minimum concrete grade (C35/45) and exposure class of structures (XF1, XF3, XC4, XA3 – concrete resistant to the effects of: water, acids and wear) are specified. External steel elements (metal plates, culverts, etc.) are made of stainless steel. In the design, recommendations are given regarding the conditions of curing fresh concrete, which should mature in humid (min 60%) and warm (+20°C) air for at least 7 days. In order to obtain

high durability and water-tightness of concrete, it is recommended that chipped basalt aggregate and the addition of silica dust be used to prepare it.

## 7. Summary and Conclusions

Applying the FEM method for designing engineering structures is an irreplaceable solution in current items. It enables the majority of effects on structural elements which may occur in the technological process to be accounted for. In the case of the discussed tank, in order to properly assess the necessary dimensions of wall and bottom sections as well as reinforcement, a spatial model of the structure reflecting its actual activity had to be made. For this purpose, articulated lateral expansion joints between the segments were anticipated in the numeric model, rigidity of the ground surface, both vertical as well as horizontal (frictional force), assumed, the possibility of ground surface pulling off accounted for and alternative temperature gradients for the transitional phase determined. The main achievement of the work was determining these gradients on the basis of numerical analyses. Technological load (applied in the axis of the tank walls), as well as the pressure exerted by liquid, caused significantly lower structural strain. A very important aspect of designing tanks is the proper carrying out and placement of expansion joints. Traditional solutions of breaks in the structure cannot be successfully applied to long tanks. The lack of continuity in reinforcement confining the segments separated by expansion joints leads to their slow, long-term expansion.

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