# REHABILITATION OF ROOF STRUCTURE OF CYLINDER TANK ACCORDING TO EUROCODE

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***Summary:*** *During exploitation of the vertical cylindrical tank with spherical roof for kerosene, damages to the some elements of the roof structure were happened. Analysis all reference influences was carried out in order to determine the actual stress and strain states of the structure, in regard to determine the causes that lead to the damage. Analysis of the obtained influences was noted that stresses and deflections of the roof structure of the tank were exceeded. Based on static influences meas of rehabilitation and phases of works were adopted. The newly designed rehabilitated structure of the roof of the tank is designed according to the European standards - Eurocodes.*

***Keywords:*** *Steel cylindrical tank, spherical tank roof, analysis of the influences of the load, Eurocode.*

## 1. INTRODUCTION

Tanks represents hermetically sealed warehouses, that provide storage of liquids - water, chemicals or other dangerous substances in liquid or gas. There are several different types of tanks that depend on the geometric and structural characteristics, the quality of primary steel material from which they are made, place and mode of installation, setup mode, applications and more.
Most widely used tanks are in the form of a sphere, cylinder or rectangular shapes, that were the subject of study earlier works [1], [2], [3].
In this paper, special attention will be paid to the rehabilitation of the roof structure of steel tanks of cylindrical shape, whereas the analysis of the influence of the load and the designing elements of the roof construction was carried out according to European standards [4], [5], [6], [7], [8].

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After performed contol calculation of the existing structures it was determined the need for reinforcement-rehabilitation spherical roof construction of the tank in order to obtain calculated values of maximum stresses in the truss less than allowed. Exceeding the stresses of roof truss appears on the part connecting truss to a cylindrical mantle, and for this reason this part has been reinforcement by the adding new elements to the roof truss.

## 2. DESCRIPTION OF THE STRUCTURE

The tank is above ground, vertical and cylindrical. It is used for storage of kerosene. Diameter of the tank is 10m, height is 7m and the volume is 500m3. It consists of a cylindrical mantle with thickness 8mm, the main roof truss are positioned radially, cross sections HOP50x50x3. The structure of the spherical roof consists of a purlin in the form of annular, cross-section HOP50x30x2 and roofing with thickness of 5 mm (Fig. 1). All sheets and profiles are made of steel quality S235.


*Fig 1. Layout and 3D model of steel tank*

## 3. INSPECTION OF THE CURRENT STATE AND DIAGNOSIS DAMAGE OF STRUCTURE

During visual inspection of the tank it was noted damage to the bearing elements of the roof structure. Visual examination revealed the presence of cracks in zones of the support points of the main roof truss  (Fig. 2), and the need for their rehabilitation. As a result of this damage, there was a change in the geometry of a roof truss (Fig. 3), or to the deflection of the spherical roof of the tank.

*Fig 2.Damages in zones of the support points of the main roof truss*

*Fig 3. Deflection of bearing roof truss*

Deformation of roof sheet metal of the tank (Fig. 4), leads to retention of atmospheric precipitation incurred as a result of those defects.

*Fig 4. Deformation of roofing*

## 4. ANALYSIS OF INFLUENCE OF LOADS AND STATIC CALCULATION

An inspection of the current state of the building damages to the roof structure of the tank were diagnosed, therefore analysis influence of loads and static calculation will be shown only to spherical roof tanks. Analysis of the influence of the load was carried out in accordance with European regulations-standards for the following actions:

- Constant load:

  - Net weight of a structure – calculated by model,
  - Weight of roof covering (vertical load),
- Wind loads [4] with the basic wind speed $v_b=23m/s$ and adopted the terrain category II,
- Influence of the snow [5].

The roof of the tank is modeled spatial Tower model (Fig. 5), whereby the material is modeled as elastic and isotropic for all structural elements, with the Young's modulus E = 210MPa and Poisson's ratio ν=0,3.

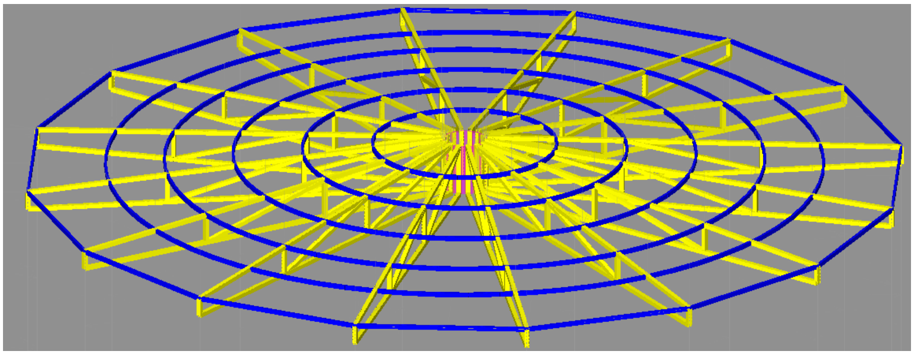

*Fig 5. Structure of roof tank*

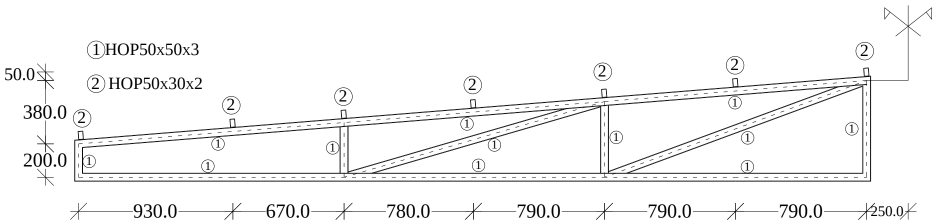


*Fig 6. The main girder of roof strucutre*

## 4.1. ACTION OF CONSTANT LOAD

The effect of construction own weight was entered by the 3D design model, while the weight of the roof covering was presented as the action of vertical concentrated forces on the purlin. Influences on the main girder caused by constant load are given at Fig.7.

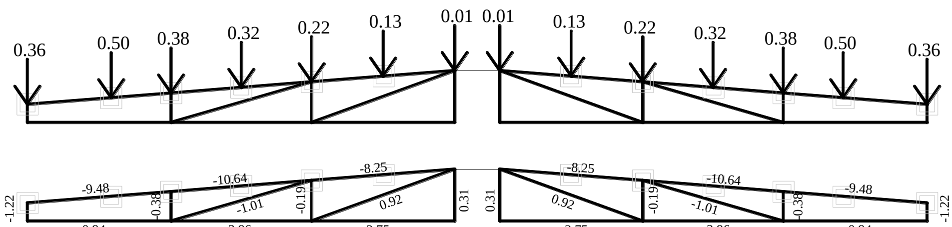


*Fig. 7. Scheme of loads and influences due to the action of constant load Nsr [kN]*

## 4.2. ACTION OF WIND ON SPHERICAL ROOF TANK - EN 1991-1-4

The basic wind speed is $v_b$ =**23,0 м/s**. For the category of the terrain was adopted II - areas with low vegetation such as grass and isolated obstacles (trees, buildings), which are located at least 20 obstacle heights. Minimum height $z_{min} = 2m$, length roughness $z_o = 0.05m$.

The coefficient of external wind pressure $C_{pe,10}$ is constant along the arcs obtained in sections of sphere and plane perpendicular to wind.

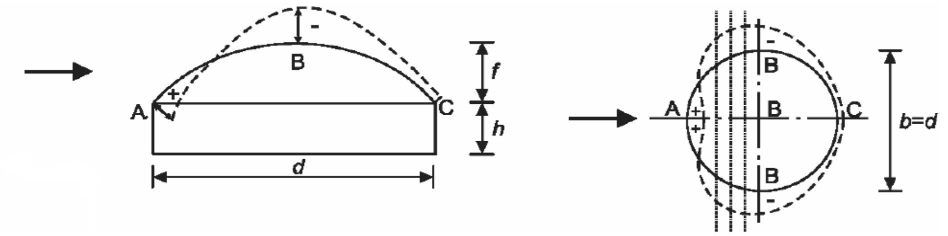


*Fig 8. Schematic representation coefficients of external pressure for the dome on a circular basis [4]*

Arrow *f=0.65m*
Height of the tank*: h=7m*,
Diameter of the tank*: d=10m,*

*h/d=0.7; f/d=0.065*

Coefficients of external pressure for:
$A \rightarrow C_{pe,10} = -1{,}36$
$B \rightarrow C_{pe,10} = -0{,}6$
$C \rightarrow C_{pe,10} = -0{,}5$

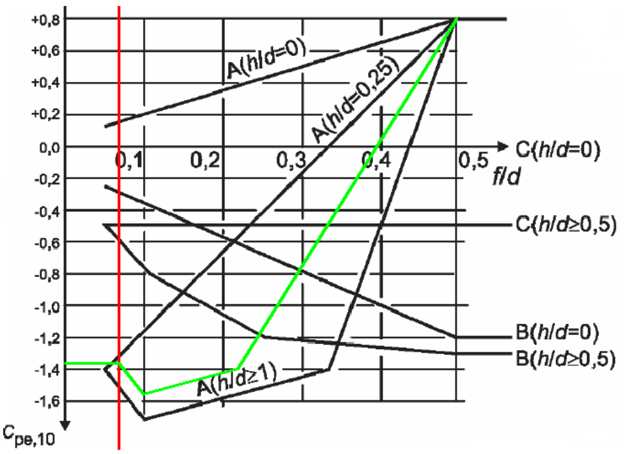


*Fig 9. Coefficients of external wind pressure*

Wind pressure that acts on external surfaces $w_e$ is obtained by expression:

$$w_e = q_p(z_e) \cdot c_{pe}$$

$z_e = 7m$ - reference height for external pressure, equal to the maximum height the observed cross-section above the ground.

Impact of wind pressure, $q_p(z_e)$, at height $z$, which includes medium and short-term fluctuations in speed, should be determined as:

$$q_p(z) = [1 + 7 \cdot I_v(z)]\frac{1}{2} \cdot \rho \cdot v_m^2(z) = [1 + 7 \cdot 0{,}2024]\frac{1}{2} \cdot 1{,}25 \cdot 21{,}59^2 = 0{,}704\ kN/m^2$$

Turbulence intensity Iv($z_e$) at height $z$ is defined as the standard deviation of turbulence, divided by the average wind speed.

$$I_v(z) = \frac{k_I}{c_o(z) \cdot ln(z/z_o)} = \frac{1}{1 \cdot ln(7/0{,}05)} = 0{,}2024 \quad za \quad z_{min} \leq z \leq z_{max}$$

$c_o(z)$ - the coefficient of the topography, adopted as a 1,0;
$k_I$ - the coefficient of turbulence, the recommended value is 1,0

Average wind speed, $v_m(z)$ at height $z$ above the ground, depends on the roughness and topography, as well as the basic wind speed, $\boldsymbol{v}_b$, it should be determined using the expression:

$$v_m(z) = c_r(z) \cdot c_o(z) \cdot v_b = 0{,}9389 \cdot 1 \cdot 23 = 21{,}59\, m/s$$

The recommended method for determining the coefficient of roughness at the height $z$, is given through the expression:

$$c_r(z) = k_t \cdot l_n\left(\frac{z}{z_o}\right) = 0{,}9389 \;\; za \;\; z_{min} \leq z \leq z_{max}$$

$$k_t = 0{,}19\left(\frac{z_o}{z_{o,II}}\right)^{0{,}07} = 0{,}19$$

Wind pressure at roof tank: $w_e = q_p(z_e) \cdot C_{pe,10}$
$A \rightarrow w_e = -0{,}958 \;\; kN/m^2$
$B \rightarrow w_e = -0{,}422 \;\; kN/m^2$
$C \rightarrow w_e = -0{,}352 \;\; kN/m^2$
Wind loads according to Eurocode and caused influences on the roof of the tank are shown at Fig.10.

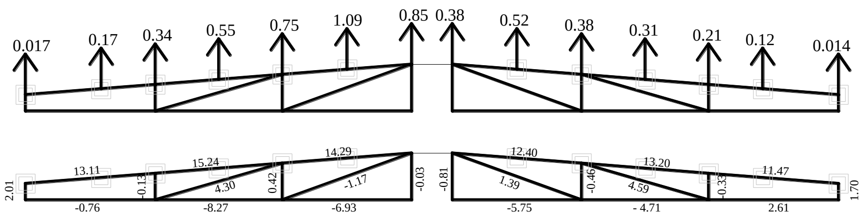


*Fig 10. Scheme of loads and influences due to the action of wind according to Eurocode Nsr [kN]*

## 4.3. ACTION OF SNOW ON SPHERICAL ROOF TANK - EN 1991-1-3

Loads of snow on the roof for permanent / temporary situations must be determined in the following way:

$$s = \mu_i C_e C_t s_k$$

$\mu_i$ -coefficient of shape of snow load;
$c_e$ -coefficient of exposure, the recommended value 1,0;
$c_t$ -the thermal coefficient, the recommended value 1,0;
$c_K$ -characteristic value of snow load on the ground, the recommended value 1,0.

Coefficients form of snow load, which should be used for cylindrical roofs in the absence of snow shield are given by the following expressions:

$$\beta \leq 60^{o}, \quad \mu_3 = 0{,}2 + 10\ h/b = 0{,}85$$

The disposition of the load which should be used in case of snow without drift is illustrated in Fig. 11 in the context of a case (I), while the disposition of the load which should be used in case of snow drifts is shown with the case (II).

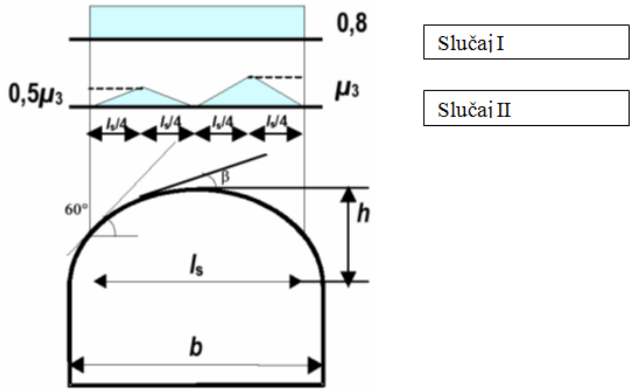


*Fig 11. Coefficients form of snow load for cylindrical roofs [5]*

$$s = \mu_i C_e C_t s_k = 0{,}85\ kN/m^2$$

The influence of snow is presented in the form of vertical concentrated forces on the purlin, whose effects on the main girder are given at the Fig. 12.

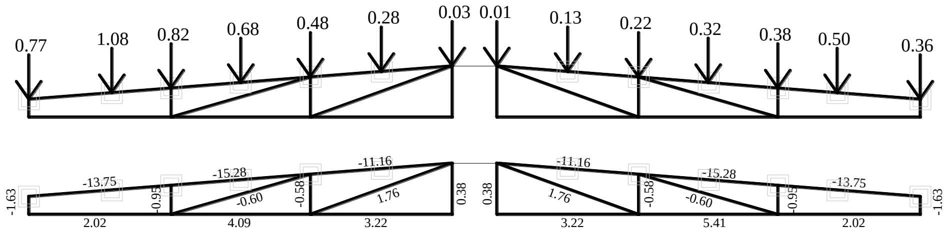


*Fig 12. Scheme of loads and influences due to the action of snow Nsr [kN]*

# 5. CONTROL OF STRESSES AND STABILITY OF EXISTING STRUCTURE

## 5.1 Applicable load

*Table 1. Case of loads*

| No | Case of loads | Type |
|---|---|---|
| 1 | Own weight (g) | constant |
| 2 | Snow | snow |
| 3 | Wind EC | wind |

*Table 2. Combination of loads*

| No | Combination of loads *[6],[8]* |
|---|---|
| 04 | 1.35×I+1.50×II+1.50×0.60×III |
| 05 | 1.35×I+1.50×0.50×II+1.50×III |
| 06 | I+1.50×II+1.50×0.60×III |
| 07 | I+1.50×0.50×II+1.50×III |
| 08 | 1.35×I+1.50×III |
| 09 | 1.35×I+1.50×II |
| 10 | I+1.50×II |
| 11 | I+1.50×III |
| 12 | 1.35×I |
| 13 | I |

## 5.2 Control of stresses

The control of stressews for the main girder of the roof structure of the tank was carried out for load combinations given at Table 2. Exceeding allowable stress occurred in the poles U1 and O1 due to load combinations 9 (Fig. 13).

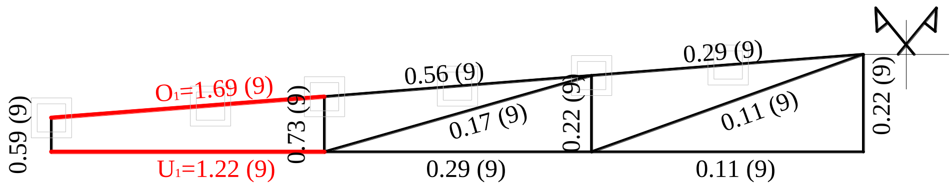


*Fig. 13. The control of dtresses for the main girder of the roof structure of the tank*

## 5.3 Control of stability

Stability control for the main girder of the roof structure of the tank was carried out according to the rules for the design of steel structures - EC3, part 4-2: "Tanks" [7]. Control calculation is analyzed for the capacity of cross sections on the pressure, or tension, and bending. Also, verifying capacity of elements to the buckling and capacity to lateral-torsional buckling was carried out, too. Rod O1 has not fulfilled the criteria of the calculation, which is shown in Fig.14.

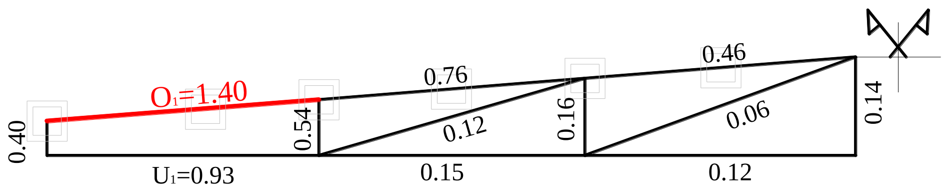


*Fig. 14. Control of stability for the main gireder of the roof structure of the tank*

# 6. NEWLY DESIGNED STATE OF THE STRUCTURE

After performed control of the calculation of the existing structures the need for reinforcement of the roof structure of spherical tanks was identified. Reinforcement is achieved by the addition of new elements of box HOP50x50x3 and cold formed profiles L50x50x5. New elements were added on the part connecting truss to a cylindrical mantle, as shown at Fig. 15

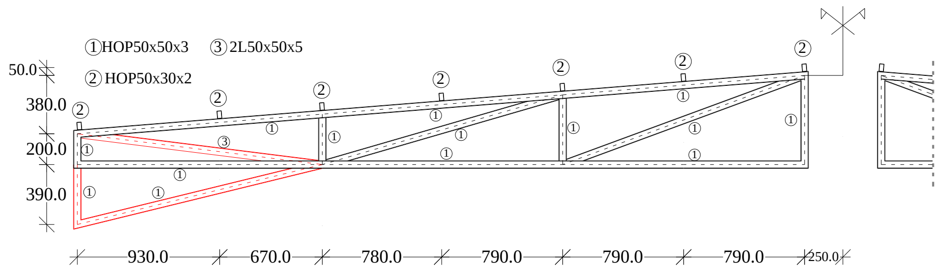


*Fig. 15. Main girder of newly designed roof structure*

## 6.1 CONTROL OF STRESSES AND STABILITY OF NEWLY DESIGNED ROOF STRUCTURE

### 6.1.1 Control of stresses

On the newly designed roof structure control of stresses was repeated due to the same load combinations, Table 2. Fig. 16 shows the stresses of all the rodes of the main girder. It can be concluded that the stresses for steel quality S235 are in acceptable limits.

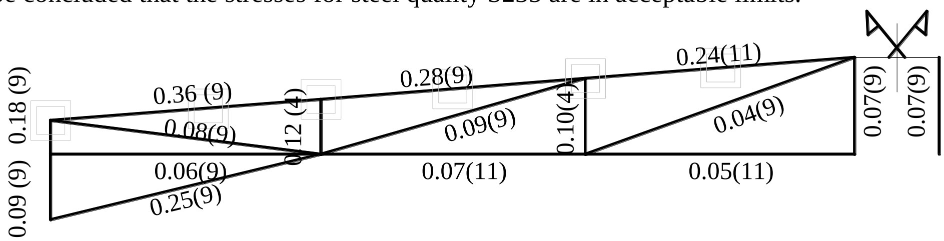


*Fig. 16. The stress control of newly designed main girder of the roof structure of the tank*

### 6.1.2 Control of stability

The results of stability control for the main girder of newly designed roof structure of the tank are shown at Fig. 17. The capacity of cross sections on the pressure, or tension, and bending, as well as the verification of capacity of elements to buckling and lateral-torsional buckling were controlled. All rods of newly designed truss structures satisfy criteria for stability according to the Eurocodes.

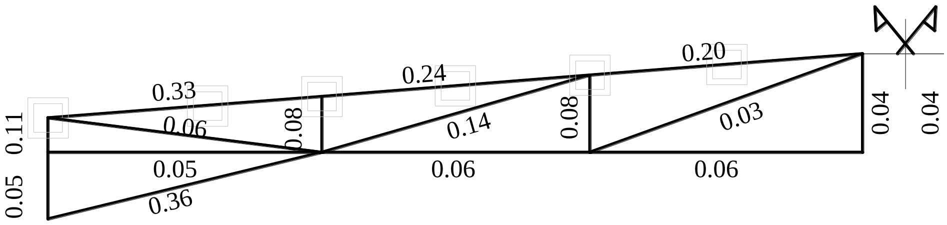


*Fig. 17. Control of stability for the newly designed main girder of the roof structure of the tank*

## 7. MEAS OF REHABILITATION AND PHASES OF WORKS

After the stress and stability control of the newly designed roof structure it was found that adding new elements of box-HOP 50x50x3 and cold formed profiles L50x50x5 regulate the phenomenon of exceeding the permissible stresses at a rehabilitated structure. In addition, the rehabilitation provides removal of deformed metal sheets of spherical roof and replacing them with a new one after setting cold formed L40 × 80 × 3 profiles under the purlins, in order to achieve a corresponding slope of the plane of the roof and remove the influence of deformed structure of the roof.

### Phases of works:

1. Removing the deformed part of the roof covering of the tank to the red line at Fig.18 throughout the volume of the tank.

*Fig. 18. Plan of removing deformed roof covering*

2. The rehabilitation of the supports of the roof structure (Fig. 19) consist of:
- reinforcement mantle with sheets ≠ 450 × 250 × 5 mm below the supports of the truss;
- adding sheets ≠ 300 × 200 × 4mm on the truss;
- setting up of new elements in the main truss of HOP50x50x3 profiles and cold-formed profiles L50x50x5

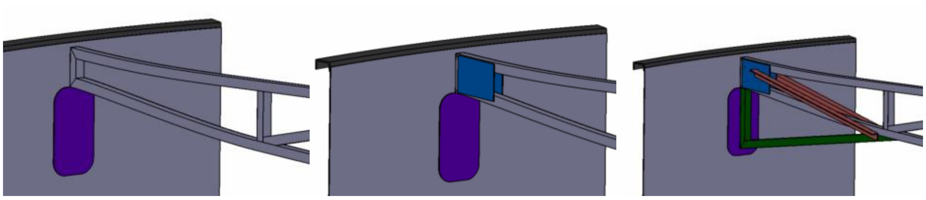

*Fig. 19. The rehabilitation of the supports of the roof structure*

3. Rehabilitation of the roof cover is shown at Fig. 20. Before installing new roofing sheets it is necessary to set the cold-L40 × 80 × 3 profile beneath the purlins, in order to achieve a corresponding slope in the level of the roof and remove the influence of deformed supporting structure of the roof.

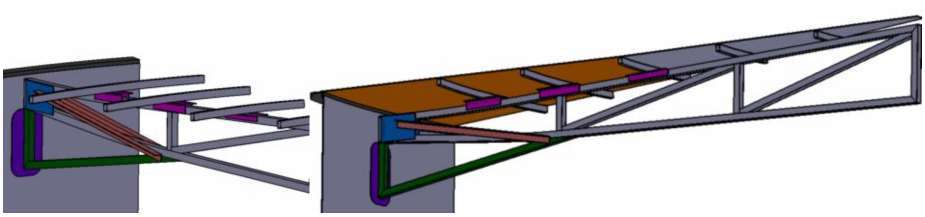

*Fig. 20. Rehabilitation of roof covering*

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# САНАЦИЈА КРОВНЕ КОНСТРУКЦИЈЕ ЦИЛИНДРИЧНОГ РЕЗЕРВОАРА ПРЕМА ЕВРОКОДУ

***Резиме:*** *У току експлоатације вертикаланог цилиндричног резервоара са сфетрноим кровом за керозин, дошло је до оштећења појединих елемената кровне конструкције. Приступило се анализи свих меродавних утицаја како би се утврдила стварна напонска стања и деформације на конструкцији, односно утврдили узроци који су довели до оштећења. Анализом добијених утицаја је констатовано да су прекорачени напони и угиби кровне конструкције резервоара. На основу статичких утицаја усвојене су мере санације као и фазе извођења. Новопројектована санирана конструкција крова резервоара димензионисана је према Европским прописима- Еврокодовима.*

***Кључне речи:*** *Челични цилиндрични резервоар, сферни кров резервоара, анализа утицаја од оптерећења, Еврокод.*