Conference of IASS, Varna, 2006

ADDITIONAL CONSTRUCTIVE SOLUTIONS FOR SINGLE DECK FLOATING ROOFS IN ABOVEGROUND CYLINDRICAL STEEL TANKS WITH LARGE DIAMETER

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The floating roofs of vertical cylindrical steel tanks are most wide-spread constructive solution for decrease of the loss when volatile oil products are stored in the tanks. They can be used in the open on top tanks and also to be situated inside in the tanks with fixed roof (so called internal floating roofs).

1. Introduction

The main advantages of the tanks with floating roof are as follow:

- minimizing losses of the stored product. These losses are due to the product evaporation;
- minimizing the zone occupied by the mixture of vapor and air which decrease the corrosion in the upper courses of the shell [5];
- decrease the fire risk of the tank, which is the result of the decreased evaporation of the volatile stuff, and decreased risk from the creation of the mixture with the air that can explode;
- in the comparison with the tanks with fixed roof, area to foam extinguishing inside the tanks with floating roof is smaller (fig. 2), it allows to put there fire fighting system with smaller capacity and its pipes to be with smaller diameter [4];
- the floating roof do not almost transfer the vertical /axes/ efforts to the shell. The risk of loss of stability is diminished.

The appropriate determination of the type of the roof and its equipment can provide with easy maintenance and quick return of investments. The factors which influence of construction of the tank and the type of the floating roof are:

- characteristics of the stored product;
- climate and constructive conditions on the site;
- volume of the stored product;
- requirements for the tank facility as a storage vessel.

2. Single deck roof

The single deck floating roof is a most wide-spread constructive solution for floating roofs. It is due to well known and tested during the time calculation and construction methodology, (buoyancy is included here) and its easy way to erection.

A principal scheme of this type of floating roofs is showed on fig. 1.

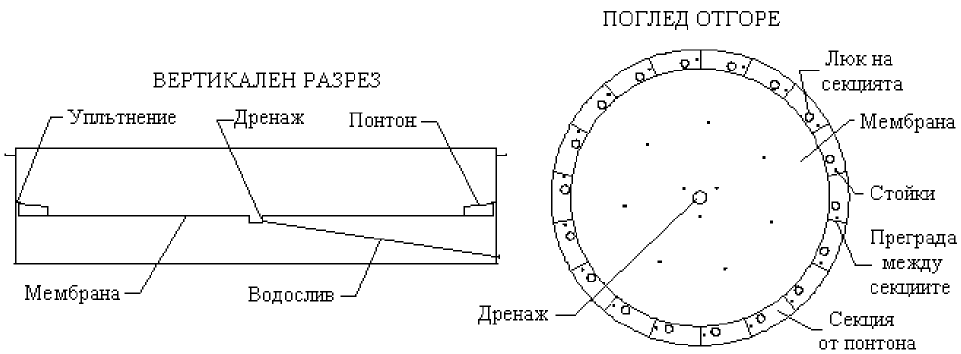

fig. 1 Single deck floating roof with rim of pontoons

2.1 Area of use [1]:

- in sites where wind pressure is small and where it is not possible to tear the membrane from the product;
- when the stored products have small vapor pressure;

- in the region with low sun activity – where the low membrane temperature allows to decrease of product evaporation ;
- more often in the tanks that have a diameter $D \leq 50$ m.

Advantages:
- they are a simple construction which can be easily prefabricated and erected;
- there is a low waste of metal for an unit covered surface;
- they do not need complementary facilities for erection;
-weld joints in space have a small volume.

Disadvantages:
- increased deformation of the membrane which can lead to destruction of weld joints caused by fatigue;
- there are many deviation from the projected shape on the central part which are an obstacle the drain of the water toward the roof drain;
- difficulties in execution of the membrane according to its projected form /inclination toward the roof drain/.

2.2 Determined subordinations

Unfortunately there are many lacks and vacancies in the concrete specificity of the design of floating roofs. The firm's methodology is not published because of the commercial reasons. In the available normative documents (for example [7], [8] u [9]), are mentioned only the most common requirements .

When the program "ELEMAPI" had been elaborated for calculations of AST elements, a successful attempt for ascertaining of several subordinations was done, it concerns especially the main dimensions of the floating roofs. [6].

For convenience two new quantities can be introduced in advance with symbols on fig. 2:

(1) $\Delta P_t = \dfrac{D - D_p}{2}$ $[m]-$ distance between the tank shell and pontoon;

(2) $B_p = \dfrac{D_p - D_m}{2}$ $[m]-$ radial width of the pontoon.

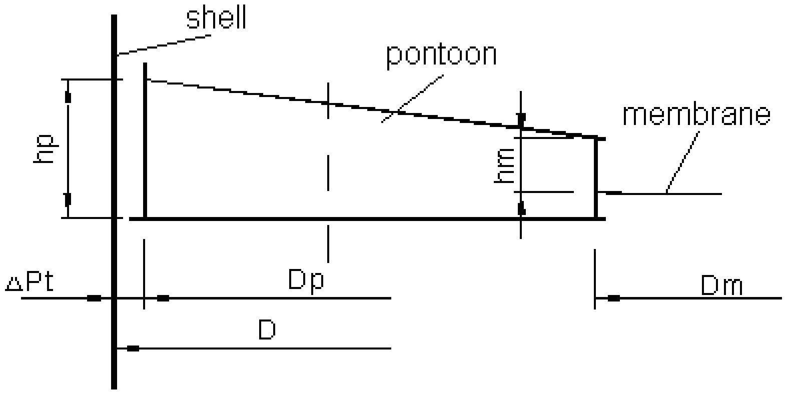

fig. 2 Basic dimensions of shell and pontoon

Due to some normative documents, though they do not consist a lot of information, through the expression (1) and (2), we can find the main dimension of the pontoons. According to [7], the pontoon of the floating roof must has a radius smaller than the tank radius with min 200 mm, $\Delta \boldsymbol{P_t} \geq 0{,}2$ m. In [6] this instruction was complementary differentiated and subordinated by diameter D of the tank. Functional subordination between $\boldsymbol{D}$ and $\Delta \boldsymbol{P_t}$ represented in the table:

Table 1

D [m]	≤ 12	12 ÷ 64	64 ÷ 75	> 75
$\Delta \boldsymbol{P_t}$ [m]	0,15	0,20	0,25	0,30

As far as it is given for each tank (or calculated from its volume V) almost tank diameter ***D***, the calculated approximate subordinations for given parameter ***Z*** are:

(3) $$Z = Z(D)$$

So with ΔPt according to the Table 1 and (1) calculated diameter of the floating roof $\boldsymbol{D_p}$ is:

(1') $$D_p = D - 2.\Delta P_t \; [m]$$

Before to proceed to the concrete relations we will look at the accepted manner of their calculation. Based on one side of many articles for executed floating roofs (for example [1], [3] and [10]), and on the other side – using our own rich and long experience in design and manufacturing in field of tank construction we have enough detailed data base. This data base was considered as completely full and confidential especially in field of single deck floating roofs. In order to avoid the possible deviations, peculiar for the accepted approximation approach, in State owned company "KZU" was elaborated special program for calculation **APROXIMA – N**[*]. It operates with 7 possible approximate relations and classifies automatically the first two of them. It operates at minimum with 3 couples independent variable values entered as entrance information. As a result of the executed statistical data processing with this Program for main parameters of floating roofs was obtained the following relations (3):

(4) $$B_p = \frac{1}{-a+b} \; [m]$$

(5) $$h_p = \frac{B_p}{3} \; [m]$$

(6) $$h_m = \frac{B_p}{6} = \frac{h_p}{2} \; [m]$$

(7) $$D_m = D_p - 2B_p \; [m]$$

Analogical relations were calculated for dimensions and weights of all constructive elements of floating roof – roof supports, foam dam, antirotation device, seal of roof.

3. Stiffening of the membrane

For the conditions in Bulgaria where wind and snow pressures, and sun activity are not so big the main problem with the single deck floating roof is deformation of the membrane. It is considered as main restriction for use of such type of construction in the tanks with a diameter $D > 50$ m. In order to increase their use it is necessary to take additional constructive solutions. The practice is accepted the project solutions as follow:

- additional stiffening girders;
- additional central pontoon;
- combination of the two above mentioned solutions.

3.1 Additional stiffening girders

When the stiffening girders are put double effect could be reach:

- decrease of vibration and deformation of the central part of the roof;
- mounting of enough tall girders which are fully connected with stiff ring in the center , separates the membrane on smaller sections and this prevent the overflow of the product in the whole roof if there is a hole in the membrane. When this solution is used it is necessary that every section has its own water drain which through the pipes under the roof is connected with roof drain pipe the in the center.

a) radial stiffening girders

The roofs with stiffened membrane through radial girders are used in the Netherlands, Germany, Austria and the USA. The kind of all this girders and their connecting depends on diameter of the tank. Type of stiffening girders could be:

[*] Computer specialist eng. B. Чимева, Record of State company KZU

- girders from steel sheets. It can be complementary cold formed for bigger stiffness. It is used for tanks with smaller diameters;
- girders from the hot rolled sections. There could be used angle, channel and wide flange sections there. They can be easy mounted on membrane.
- perforated steel sheets or girders with an hole in the web. They can be made with increased constructive height and corrosion protection became more difficult;
- box girders. They usually are used in the tanks with bigger dimensions. When the box have enough big section it is possible to decrease the dimensions of the pontoons because this box girders assure complementary floatation of the roof when there is some liquid upon it, i.e. they are additional pontoons.

The location of the radial girders upon the roof can be different. Several constructive solutions are shown on fig. 3:

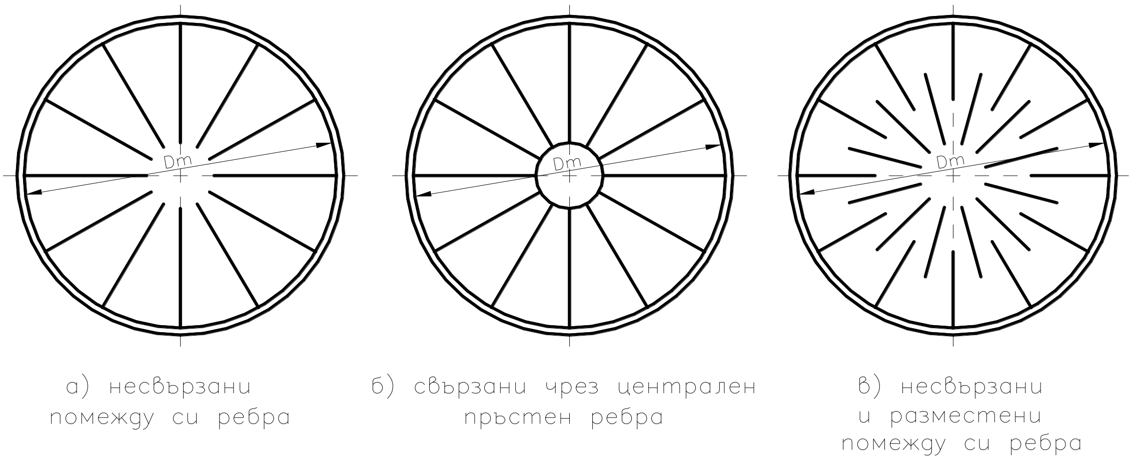

fig. 3 Location of the radial stiffening girders on the membrane

- girders which are not connected between them. It is usually used when the girders are made from steel sheets. They can be connected to the pontoons but can also be at some distance from them;
- girders connected through the central ring. When this solution is used almost always the girders are connected to the pontoons and work together with them. The central ring can be shaped as cylinder toward which the girders are butt connected or to be cut in shape of plate disk that lies upon the girders. If the girders are enough high upon the membrane and central ring is formed as cylinder there can be formed separated sections on membrane;
- unconnected and dislocated between them girders. The stiffening membrane girders are ≈ 0,25.D_m long**.** Due to this construction roof is stiffened but works as free membrane. It is impossible to make separate sections upon the central part;

b) stiffening girders as rings

The ring shaped stiffening girders are put under the membrane according to the scheme (fig. 4):

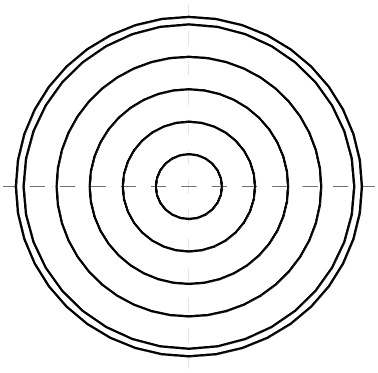

fig. 4 Location of ring shaped stiffening girders under the membrane

In Poland [10] are constructed many tanks with volume V=50 000 m^3, which roofs are stiffened with stiffening rings which dimensions are L100x100x10 mm. During the executed measurements done on site for determining the deflection in the center of membrane, this way of stiffening showed very good effectiveness.

The disadvantage of this way of stiffening is that the girders must be put under the membrane. It causes :

- all weld joints are executed on the ceiling position;
- an impossibility for formation of the smaller sections on the membrane;

c) radial located girders and girders in circular location

When the ring shaped and radial girders are used metal and labor consumption is bigger, but naturally the membrane is most resistant to deformation.

3.2 Additional central pontoon on membrane

The use of this constructive solution aims double effect:

- the weight of the pontoon located in the membrane center (fig. 5) facilitates to put and keep the membrane in its projected position;
- the central pontoon is hollow and assures additional buoyancy of the roof. This allows decreasing of dimensions of the pontoons in the periphery.

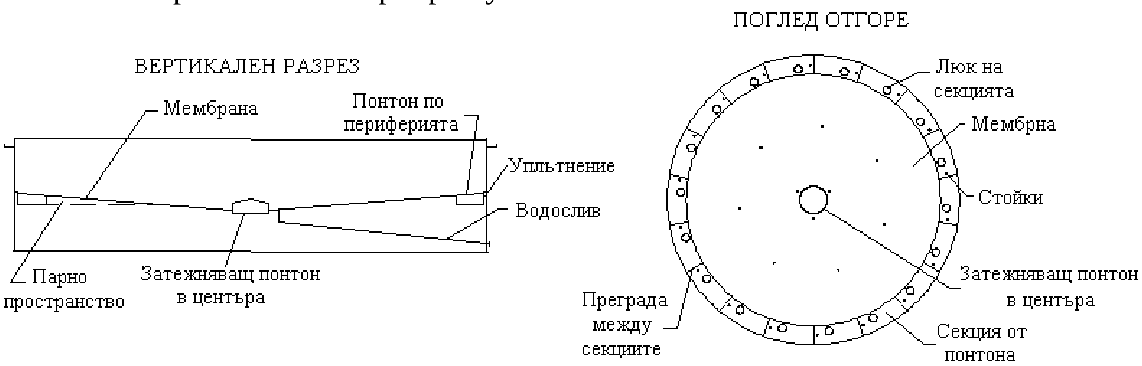

fig. 5 Single deck roof with pontoons in periphery and one central pontoon

Field of use:

- in the regions with high wind pressure, where it is possible to tear the membrane from the pontoon and it must be prevented;
- when the sheet rolls are used in the central part and we want that the central part is stretched;
- most often when the tank has diameter $\boldsymbol{D}$ > 50 m.

Advantages:

- improved geometrical form of the central part;
- higher ability to floatation of the roof in case of membrane cutting;
- simple construction for execution erecting and maintaining;
- relatively small metal consumption for one unit covered surface .

Disadvantages:

-complicated device for water draining.

Design of central pontoon, as additional constructive solution, for single deck floating roof required an adequate research. As a result, using [10], for diameter of the central pontoon $\boldsymbol{D_c}$, we can use these relations:

$$
\begin{aligned}
&D_c = 0{,}3.D && \text{за}\ \ D = 16 \div 30\ \ m \\
&D_c = 0{,}2.D && \text{за}\ \ D = 30 \div 50\ \ m \qquad (8) \\
&D_c = 0{,}1.D && \text{за}\ \ D > 50\ \ m
\end{aligned}
$$

The height of the central pontoon is h_c = 0,5 m = const, and its value does not depend on the pontoon diameter ***D***.

The dimensions of the main pontoons located in the periphery can be decreased in comparison with the dimensions calculated for one deck roof (4) ÷ (7), as follows:

(9) $$B'_p = B_p - \frac{c}{D} \ [m]$$

(10) $$h'_p = \frac{1}{2}\left(d - \frac{c}{D}\right) \ [m]$$

(11) $$h'_m = \frac{2}{3} h'_p \ [m]$$

In formulas (4), (9) and (10) coefficients ***a***, ***b***, ***c***, ***d*** are calculated by APROXIMA-N. In this case for increased membrane diameter $\boldsymbol{D'_m}$, by analogy with (7), but with new radial width of the pontoons according to (9), we have the following expression:

(12) $$D'_m = D_p - 2.B'_p \ [m]$$

All ascertained through statistical research approximate relations (1) ÷ (12), can be compared with the dimensions of the central and periphery pontoons in the tank with nominal volume V = 80000 m^3 and diameter *D* = 73 m, shown on fig. 7. The comparison is represented in Table 2 and there are shown the estimated differences between calculated values with APROXIMA-N and design solution /according to their absolute value in percent/.

TABLE 2

Z [m]	**ΔPt**	**B_p**	**B'_p**	**D_c**	**H'_p**	**H'_m**	**D'_m**
Z_c	0,25	3,95	3,61	7,30	0,9768	0,6512	65,28
( )	table. 1	(4)	(9)	(8)	(10)	(11)	(12)
Z_p	0,25	-	3,80	7,70	0,96	0,65	64,90
Δ [m]	0	-	- 0,19	- 0,40	+0,0168	+0,0012	+ 0,38
Δ [%]	0	-	- 5,000	- 5,195	+ 1,750	+ 0,185	+ 0,585

Note: $\boldsymbol{Z_c}$ is the sign for calculating values according to the relevant formulas, which № is mentioned in the line below ( ). $\boldsymbol{Z_p}$ is the sign for the values accepted in the tank project fig. 7.

On TABLE 2 it is shown that the reduction of the radial width of the periphery pontoon when there is a central one is equal to: Δ = B_p – B'_p = 3,95-3,61=0,34m.

When the tank diameter is big (*D* = 73 m) this reduction together with decreased heights $\boldsymbol{h'_p}$ and $\boldsymbol{h'_m}$, undoubtedly will lead to the considerable safe from the weight of the pontoon which safe exceeds the increased membrane weight.

It is shown that the differences between the calculated values and design values of the relevant parameters do not exceed ± 0,4 t. This differences represented in percent are up to ± 5 %.

4. Executed additional constructive solutions

4.1 Membrane stiffening with radial girders

In 2005 on sites Palogue and Al-Jabalayn, in Sudan, were erected two big group of tanks with different use and volume. Seven of which, with capacity of every one V = 52000 m^3 and diameter *D* = 60 m, have single deck floating roof.

The increased dimensions of the floating roofs imposed the additional membrane stiffening. The idea to put radial girders which are with different length was accepted (fig. 6). One half from these girders reach the center and the rest of them reach one quarter of the membrane diameter $\boldsymbol{D_m}$.

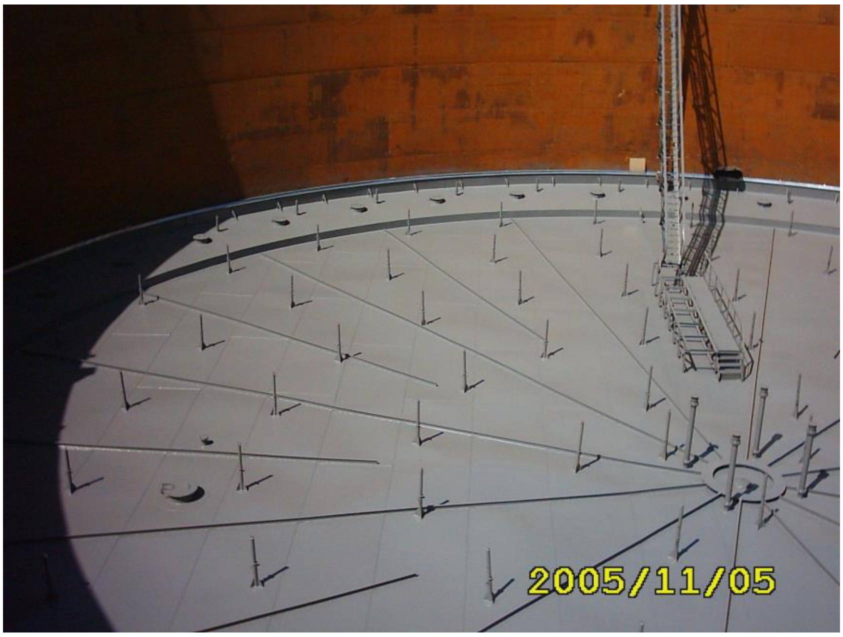

fig. 6 Stiffening of membrane with radial girders, Sudan

4.2 Membrane stiffening with central pontoon

In 1994 year, according to the project of „NOELL" company, „KZU Holding" erected a tank with diameter D = 76 m and volume V = 80000m^3 in Germany. It is a storage vessel with single deck floating roof. Because the tank has large diemeter, the membrane is stiffened with central pontoon. As additional mean to decrease roof deformations, 90 mm high steel girders from sheets were welded to the lap joints of the sheets in the central part, under roof.

fig. 7 Single deck floating roof with central pontoon, Germany

5. Research and results

Membrane of single deck floating roof could be stiffened in some ways. For determination of the effectiveness of every constructive solution were created and analyzed different models.

The research of possibility for deformation of the membrane is carried out under the following conditions:

a) general conditions for all researches:

- different models are 3-dimensioned and were created with software SAP 2000 v.9;
- membrane diameter D_m = 30 ÷ 70 m;
- initial membrane slope $i = 0^0$;
- membrane thickness t = 5 mm;
- material for membrane – steel ВСт3пс $(R_y^n = 225\text{MPa})$;

- tank is filled with water ($\rho = 10\ kN/m^3$);
- pressure upon membrane:

Its own weight of the construction $\boldsymbol{g}$;

Water column upon the membrane which height is $h = 250$ mm, i. e. the pressure is $\boldsymbol{w} = 2{,}5\ kN/m^2$;

Steam pressure upon the membrane $\boldsymbol{p} = 1{,}0\ kN/m^2$.

b) membrane stiffened with radial located girders (fig. 8)

- the girders have section IPE200 and are located between 20^0 ;
- the one end of the girders is at 1 m from the roof pontoon and the other reaches the conditional ring in the center which diameter is $d = 0{,}2.D_m$;

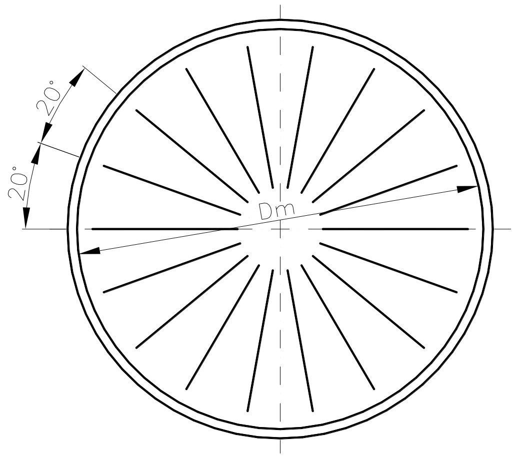

fig. 8 Membrane stiffening with radial girders

c) membrane stiffening with central pontoon (fig. 9)

- central pontoon diameter $d = 0{,}2.D_m$;
- central pontoon height $h_p = 0{,}5$ m;
- thickness of the sheets of the central pontoon $t_p = 5$ mm;
- the central pontoon does not have any holes and there is not water inside it.

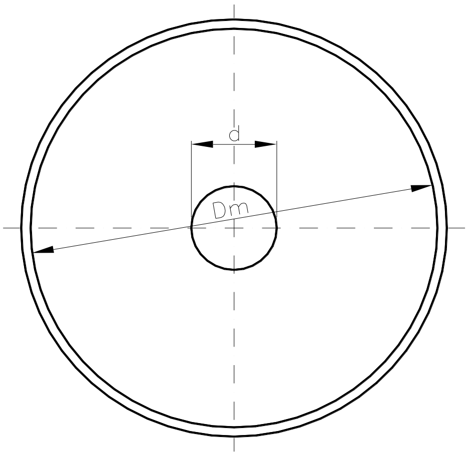

fig. 9 Membrane stiffening with central pontoon

d) membrane stiffened with radial located girders and central pontoon (fig. 10)

The conditions are the same as in b) and c).

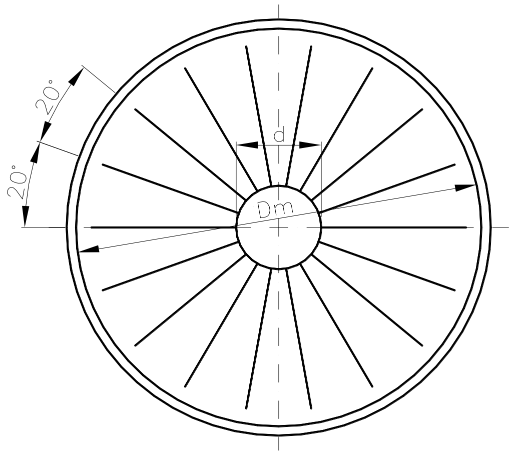

fig. 10 Membrane stiffened with radial located girders and central pontoon

The purpose of the carried out research is to ascertain the deviation of the center of membrane with the different types of stiffening.

The results are shown in Table 3:

TABLE 3

1. Single deck floating roof without reinforcement

	Diameter of membrane, ***D*** [m]				
sinking ***f***, m	30	40	50	60	70
self weight **g**	-0,173	-0,281	-0,379	-0,483	-0,594
water **w + g**	-0,496	-0,807	-1,087	-1,387	-1,703
vapour pressure **p + g**	0,065	0,106	0,143	0,182	0,223
g and water below	-0,041	-0,041	-0,041	-0,041	-0,041
w + g and water below	-0,277	-0,302	-0,302	-0,302	-0,302

2. Single deck floating roof with radial girders

	Diameter of membrane, ***D*** [m]				
sinking ***f***, m	30	40	50	60	70
self weight **g**	-0,197	-0,286	-0,383	-0,488	-0,598
water **w + g**	-0,542	-0,796	-1,072	-1,371	-1,685
vapour pressure **p + g**	0,058	0,090	0,125	0,163	0,203
g and water below	-0,047	-0,041	-0,041	-0,041	-0,041
w + g and water below	-0,283	-0,302	-0,302	-0,302	-0,302

3. Single deck floating roof with central pontoon

	Diameter of membrane, ***D*** [m]				
sinking ***f***, m	30	40	50	60	70
self weight **g**	-0,183	-0,2669	-0,360	-0,457	-0,551
water **w + g**	-0,477	-0,699	-0,941	-1,199	-1,425
vapour pressure **p + g**	0,051	0,076	0,101	0,130	0,153
g and water below	-0,062	-0,064	-0,067	-0,069	-0,072
w + g and water below	-0,218	-0,231	-0,230	-0,224	-0,212

4. Single deck floating roof with central pontoon and radial girders

	Diameter of membrane, ***D*** [m]				
sinking ***f***, m	30	40	50	60	70
self weight **g**	-0,183	-0,267	-0,360	-0,457	-0,547
water **w + g**	-0,469	-0,689	-0,928	-1,184	-1,403
vapour pressure **p + g**	0,040	0,064	0,088	0,115	0,137
g and water below	-0,070	-0,067	-0,068	-0,069	-0,070
w + g and water below	-0,257	-0,254	-0,242	-0,231	-0,217

Relations between deflection of the central part of the membrane and different types of its stiffening is shown on fig. 11 ÷ fig. 13:

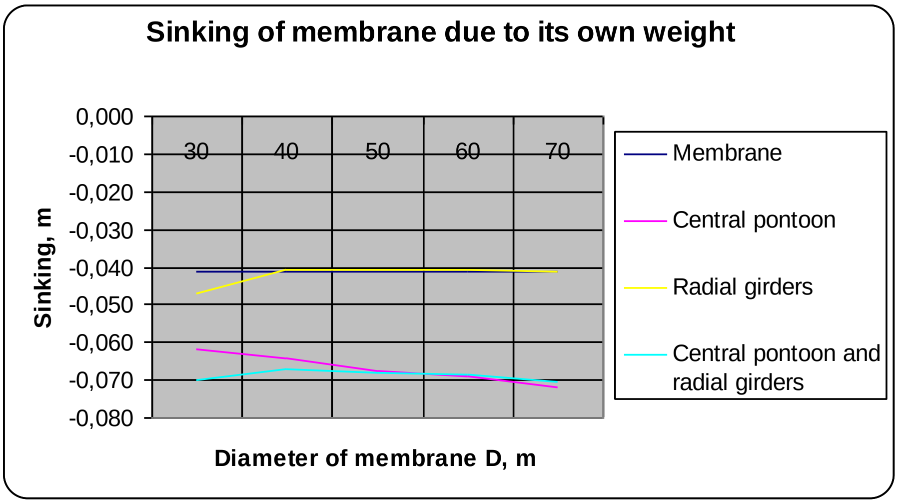

fig. 11 Sinking of the central part of the membrane in the liquid due to its own weight

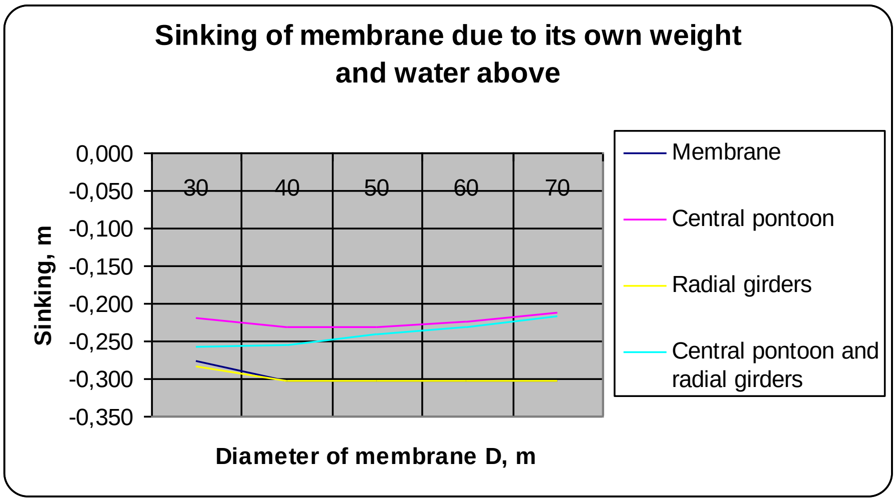

fig. 12 Sinking of the central part of the membrane in the liquid due to its own weight and 250 mm water upon it

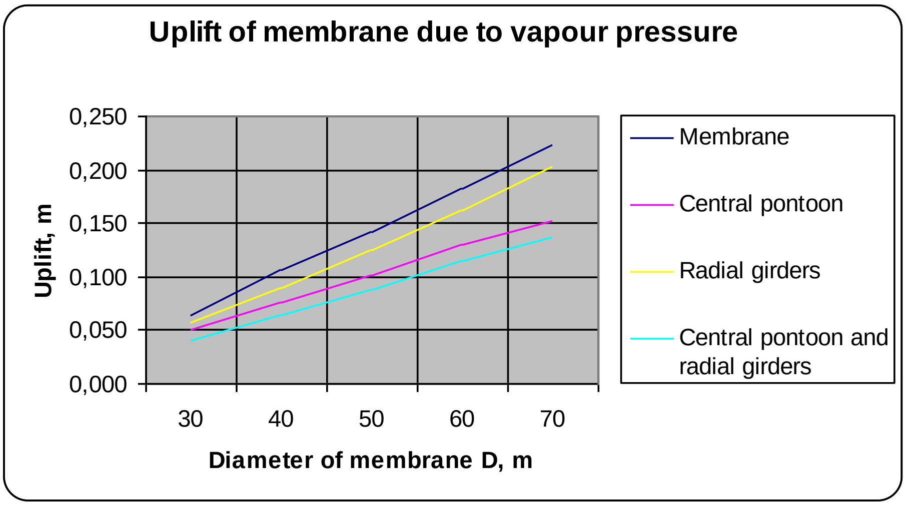

fig. 13 Sinking of the central part of the membrane caused by vapour pressure

6. Conclusions

- the sinking of the unstiffened membrane when loads are its own weight ***g*** and/ or water ***w*** has a constant value;

- the sinking of the membrane stiffened with radial girders IPE 200, when loads are its own weight ***g*** and/or water ***w*** , with diameter D ≥ 40 m, has constant value;

- practically the sinking of the membrane is the same nevertheless it is unstiffened or radial girders are put on it;

- the sinking of the membrane stiffened with central pontoon when loads are its own weight ***g*** and water ***w*** , in comparison with the others constructive solutions, is the smallest. It is due to the smaller quantity of water on the roof;

- the rise of the membrane stiffened with central pontoon and radial girders from load ***p*** is the smallest in comparison with the others constructive solutions;

- unstiffened and stiffened with radial girders membranes have close values of the rise of its central part caused by vapour pressure ***p*** .

References

1. *Бордовский, А. М., Медник, Б. М., и др.* Тенденции в развитии комплексных требований к резервуарам для хранения нефти (зарубежный опыт). Основа, 2000.
2. *Здравков, Л. А.* Увеличаване на сигурността на стоманени резервоари, намиращи се в експлоатация. сп. "Строителство", кн. 5, 2003.
3. *Мельников, Н. П.* Металические конструкции, 1983.
4. Наредба № 2, Противопожарни строително – технически норми, МВР – МТРС, 1994.
5. *Русев, С. С., Захариева, Н.* Върху корозионната устойчивост на стоманените мазутни резервоари. сп. "Строителство", кн. 1, 1977.
6. *Русев, С. С.* Автоматизирано изчисляване, оразмеряване и специфициране на СВР. Програма ELEMAPI, Архив на КЗУ, 2004.
7. Ръководство за проектиране на СВР, БРВ – КЗР, 1988.
8. API Std 650, Welded Steel Tanks for Oil Storage, 2001.
9. BS 2654:1989, Manufacture of vertical steel welded non-refrigerated storage tanks with but – welded shells for the petroleum industry.
10. *Ziolko, J.* Zbiorniki metalowe na cilncze i gazy, Arkady, Warszawa, 1986.