DETERMINATION OF TYPE OF THE FIXED ROOF

Lyubomir A. Zdravkov
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The roofs of steel tanks can be classified in groups as follow:
a) according to the shape of the roof :
- cone roof ;
- dome roof;
- hanging roof;
- floating roof .

b) according to static scheme:
- self supporting – cone and dome ;
- supported roofs – cone and hanging roofs.

c) according to the position of the roof stricture:
- situated under the roof cover plates;
- situated above the roof cover plates.

The most expedient shape of roofs, from the technical end economical point of view, must be determined depending on the geometrical dimensions of AST, the stored product inside, the conditions during the exploitation. Important is the tradition of design and erection of steel tanks:

- in Europe and in particular in Bulgaria most popular are self supporting roofs when the tanks have small diameter and the stored product has slight evaporation;
- in the USA and in the Near East the most used fixed roofs are supported cone roofs.

1. Purpose of the research

It is possible to use different types of roofs – dome, cone, self supporting and supported roofs in the same conditions. Every constructive solution supposes the use of a different quantity of material and a different cost.

The purpose of this research is to determine the borders when it is advisable that one type of fixed roof shall be replaced by another.

2. Conditions in which the research was carried out

The author carried out a series of calculations of fixed roofs in the same tanks and the same conditions. The results, obtained as weights, prove the effectiveness of one or another design scheme.

The research is carried out under the following conditions:
- temperature – t_{max} = 80 ^{0}C ;
- wind – v = 130 km/h ;
- snow – S_n = 150 kg/m^2 ;
- vacuum – p_v = 50 kg/m^2 ;
- overpressure:
  p_0 = 200 kg/m^2 – for self supporting roofs;
  p_0 = 50 kg/m^2 – for supported roofs;
- live load – 100 kg/m^2 ;
- minimal thickness of the roof cover plates – t_r = 5 mm;
- corrosion allowance for roof plates and structure – C_a = 0 mm;
- steel for roof:
  for cover plates – S235;
  for roof structure – S275 for tanks with volume V=10000 m^3 and S235 for all the rest;

3. Results

The roof elevation **f** changes in order to achieve the smallest possible weight of the roof.

The calculated weights of the cover plates, roof structure and top angle in the self supporting roofs are shown on Table 1.

TABLE 1

Tank with capacity V=400 m^3

D = 8530 mm steel **S235**

H = 7450 mm

	Cone roof						Dome roof		
elevation f, m	0.75	1.0	1.5	1.75	2.0	2.25	1	1.25	1.5
Ø central ring, m	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
fields	10	10	10	10	10	10	10	10	10
radial girders, t	0.645	0.655	0.695	0.565	0.58	0.6	0.76	0.77	0.78
rings, t	0.36	0.36	0.32	0.36	0.36	0.36			
cover plates, t	2.329	2.354	2.354	2.479	2.533	2.592	2.41	2.48	2.57
top angle, t	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
total weight of roof and top angle, t	3.434	3.469	3.469	3.504	3.573	3.652	3.27	3.35	3.45

Tank with capacity V=700 m^3

D = 10430 mm steel **S235**

H = 8940 mm

	Cone roof						Dome roof		
elevation f, m	1.0	1.5	1.75	2.0	2.5	1.25	1.5	1.75	2.0
Ø central ring, m	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
fields	12	12	12	12	12	12	12	12	12
radial girders, t	1.2	1.01	1.03	1.05	1.1	1.08	1.1	1.11	1.125
rings, t	0.545	0.475	0.475	0.475	0.475				
cover plates, t	3.521	3.596	3.646	3.7	3.833	3.615	3.7	3.8	3.92
top angle, t	0.62	0.365	0.29	0.24	0.17	0.155	0.125	0.125	0.125
total weight of roof and top angle, t	5.886	5.446	5.441	5.465	5.578	4.85	4.925	5.035	5.17

Tank with capacity V=1000 m^3

D = 12330 mm steel **S235**

H = 8940 mm

	Cone roof						Dome roof				
elevation f, m	1.5	1.75	2.0	2.25	2.5	3.0	1.35	1.5	1.75	2.0	2.25
Ø central ring, m	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
fields	14	14	14	14	14	14	14	14	14	14	14
radial girders, t	1.905	1.93	1.7	1.725	1.76	1.83	1.55	1.555	1.45	1.495	1.515
rings, t	0.665	0.665	0.595	0.665	0.665	0.665					
cover plates, t	4.97	5.021	5.079	5.14	5.188	5.371	5.005	5.06	5.16	5.28	5.41
top angle, t	0.845	0.7	0.595	0.515	0.45	0.355	0.385	0.33	0.26	0.215	0.175
total weight of roof and top angle, t	8.385	8.316	7.969	8.045	8.063	8.221	6.94	6.945	6.87	6.99	7.1

Tank with capacity V=2000 m^3

D = 15180 mm steel **S235**

H = 11920 mm

	Cone roof						Dome roof					
elevation f, m	1.5	2	2.5	2.75	3	3.5	1.75	2	2.25	2.50	2.75	3.00
Ø central ring, m	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
fields	16	16	16	16	16	16	16	16	16	16	16	16
radial girders, t	3.365	3.425	3.505	3.555	3.6	3.71	3.74	3.775	3.81	3.35	3.39	3.435
rings, t	1.145	1.145	1.145	0.98	0.98	0.98						
cover plates, t	7.462	7.571	7.708	7.788	7.871	8.062	7.625	7.74	7.875	8.025	8.19	8.37
top angle, t	2.125	1.53	1.18	1.055	0.95	0.79	0.74	0.615	0.525	0.455	0.395	0.35
total weight of roof and top angle, t	14.097	13.671	13.538	13.378	13.401	13.542	12.105	12.13	12.21	11.83	11.975	12.155

Tank with capacity V=3000 m^3

D = 18980 mm steel **S235**

H = 11920 mm

	Cone roof						Dome roof					
elevation f, m	2.0	2.5	3.0	3.25	3.5	4.0	2.1	2.25	2.50	2.75	3.00	3.25
Ø central ring, m	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
fields	20	20	20	20	20	20	20	20	20	20	20	20
radial girders, t	7.29	7.4	7.525	7.6	7.675	7.845	5.32	5.335	5.375	5.41	4.725	4.765
rings, t	1.83	1.83	1.83	1.83	1.83	1.83						
cover plates, t	14.035	14.208	14.405	14.52	14.64	14.905	14.3	14.395	14.575	14.775	14.995	15.23
top angle, t	4.155	3.28	2.7	2.47	2.29	1.99	1.76	1.625	1.435	1.285	1.16	1.06
total weight of roof and top angle, t	27.31	26.718	26.46	26.42	26.435	26.57	21.38	21.355	21.385	21.47	20.88	21.055

Tank with capacity V=5000 m^3

D = 22800 mm steel **S235**

H = 11920 mm

	Cone roof						Dome roof					
elevation f, m	2.25	2.5	3.0	3.50	3.75	4.0	2.5	2.75	3.00	3.25	3.50	3.75
Ø central ring, m	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
fields	24	24	24	24	24	24	24	24	24	24	24	24
radial girders, t	13.525	13.595	13.765	13.965	14.075	14.19	7.645	7.685	7.725	7.775	7.825	7.88
rings, t	2.29	2.12	2.12	2.29	2.12	2.12						
cover plates, t	20.306	20.29	20.495	20.841	20.8	21.116	20.816	20.815	21.035	21.27	21.525	21.8
top angle, t	8.075	6.91	5.735	5.15	4.8	4.5	3.37	3.045	2.77	2.545	2.355	2.195
total weight of roof and top angle, t	44.196	42.915	42.115	42.246	41.795	41.926	31.831	31.545	31.53	31.59	31.705	31.875

Tank with capacity V=10000 m^3

D = 28500 mm steel **S275**

H = 17900 mm

	Cone roof						Dome roof					
elevation f, m	3.00	3.5	4.0	4.50	5	5.5	3.75	4.00	4.25	4.50	4.75	5.00
Ø central ring, m	7.8	8.1	8.2	8.3	8.3	8.3	2.5	2.5	2.5	2.5	2.5	2.5
fields	30	30	30	30	30	30	36	36	36	36	36	36
radial girders, t	28.735	29	27.785	28.105	28.415	28.865	13.775	13.845	13.915	13.995	14.075	14.165
rings, t	3.47	3.47	3.47	3.47	3.47	3.47						
cover plates, t	31.41	31.65	31.925	32.23	32.575	32.945	32.865	33.155	33.47	33.8	34.15	34.52
top angle, t	15.165	13.045	11.45	10.215	9.235	8.435	5.915	5.55	5.235	4.955	4.71	4.49
total weight of roof and top angle, t	78.8	77.2	74.6	74.0	73.70	73.72	52.555	52.550	52.62	52.75	52.935	53.175

In yellow are colored these values which grant the smallest weight of the roof.

The calculated weights of the cover plates, roof structure and top angle in the supported roofs, type API 650, are shown on Table 2.

TABLE 2

	Supported cone roof						
capacity V, m	400	700	1000	2000	3000	5000	10000
diameter D, m	8,53	10,43	12,33	15,18	18,98	22,8	28,5
height H, m	7,54	8,94	8,94	11,92	11,92	11,92	17,9
elevation f, m	0,27	0,33	0,4	0,48	0,6	0,72	0,89
fields Np	1	1	1	1	2	2	2
radial girders, t	1,085	1,625	2,26	4,355	3,78	7,55	13,35
rings, t	0,335	0,53	0,665	1,035	2,075	2,97	4,205
columns, t	0,32	0,345	0,355	0,505	1,915	2,495	5,065
cover plates, t	2,29	3,425	4,785	7,255	13,35	19,27	30,105
top angle, t	0,1	0,125	0,175	0,215	0,66	0,79	0,99
weight of roof and top angle, t	4,13	6,05	8,24	13,365	21,78	33,075	53,715

Total weight of the roofs, including cover plates, structure and top angle, for tanks with various diameters and roof structures is shown in Table 3:

TABLE 3

Tank capacity, m^3	400	700	1000	2000	3000	5000	10000
Diameter D, m	8,53	10,43	12,33	15,18	18,98	22,8	28,5
Supported cone roof, t	4,13	6,05	8,24	13,365	21,78	33,075	53,715
Self supporting cone roof, t	3,434	5,441	7,969	13,378	26,42	41,795	73,7
Dome roof, t	3,27	4,85	6,87	11,83	20,88	31,53	52,55
Covered area, m^2	57,14	85,44	119,40	180,98	282,92	408,27	637,92
Used steel for unit of covered area, kg/m^2							
Supported cone roof	72,27	70,81	69,01	73,85	76,98	81,01	84,20
Self supporting cone roof	60,09	63,68	66,74	73,92	93,38	102,37	115,53
Dome roof	57,22	56,77	57,54	65,37	73,80	77,23	82,38

The change in the total weight of the cover plates, construction and top angle of the different roof construction is shown on the fig. 1.The smallest weights for the referring diameter are used in this chart.

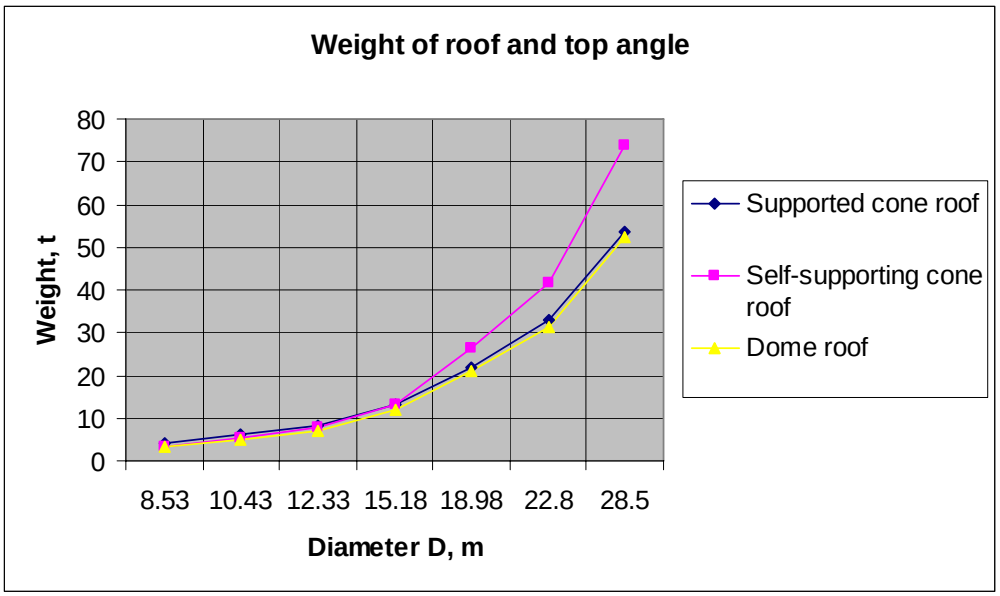

fig. 1 Change of weights of the roofs depending on the diameter ***D***

Change of quantity of the used material in the roof for unit of the roof surface is shown on the fig. 2.

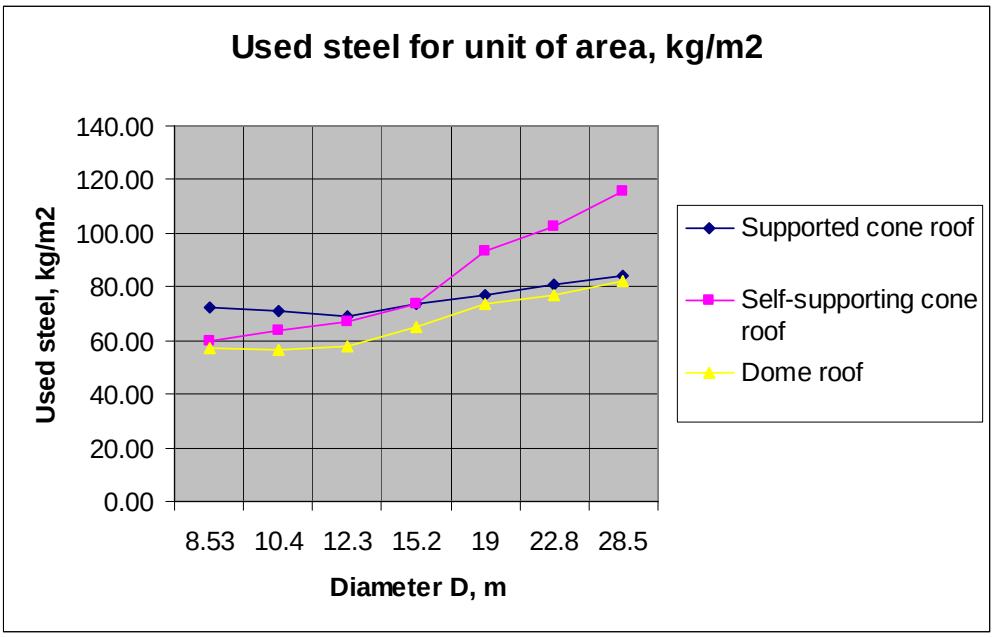

fig. 2 Change of used steel of unit of area depending on diameter ***D***

4. Conclusions from the research

a) the dome roofs are always lighter than cone self supporting or supported roofs. So it is advisable to use dome roofs every time when it is possible;

b) the difference of weight between cone supported roofs and dome roofs is very small. The choice between two design solution must be made considering another parameters as internal super pressure, presence or absence of pontoon in tank, soil characteristics, erection equipment, possibility of bending of radial girders or not;

c) in the smaller tanks the difference in weight of dome roof and self supporting cone roof is not so big, so in order to avoid the bending of the radial girders it is advisable to use cone self supporting roofs. In this case is necessary to compare the prices;

d) the difference between the weight of dome roof and self supporting cone roof is considerable when the tanks volume is $V \geq 2000$ m^3, with the diameter $\boldsymbol{D} > 15$ m. So, the border when cone self supporting roof must be replaced by dome roof is the diameter of the tank $\boldsymbol{D} = 15$ m;

e) the different elevation of roof ***f*** can cause differences in tanks weight. In every individual project it is necessary to calculate and compare several results in order to choice the right one;

f) with the increase of the diameter of the tank, the quantity of the material used in the roof for one unit covered surface increases.