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MASE
MACEDONIAN ASSOCIATION OF STRUCTURAL ENGINEERS

12 МЕЃУНАРОДЕН СИМПОЗИУМ
INTERNATIONAL SYMPOSIUM

СТРУГА, МАКЕДОНИЈА
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Вујадин АЛЕКСИЌ[1] , Миодраг АРСИЌ[2], Зоран ОДАНОВИЌ[3]

АНАЛИЗА НА ЧЕЛИЧНА ВОДНА КУЛА ВО ФУНКЦИЈА ОД ЕКСПЛОАТАЦИОНИ ПАРАМЕТРИ

РЕЗИМЕ

Водните кули можат да се изведат од различни материјали како: армиран бетон, цигла, челик и комабинација од овие материјали. Во светските тенденции за проектирање водните кули се посебно интересни бидејќи се карактеризираат со едноставна конструкција па можат да се проектираат со различни облици зависно од конструктивниот интегритет, заштедата на материјал и полесното одржување во фаза на експлоатација. Во трудот е презентиран алгоритам за пресметување на челични водни кули за водоснабдителни технолошки системи, земајќи ги во предвид позитивните и негативните аспекти на експлоатационите ограничувања. Посебно е аспектирана безбедноста на конструкцијата.

Клучни зборови: челична водна кула, оптимизација,конструктивен интегритет

Vujadin ALEKSIĆ[1] , Miodrag ARSIĆ [2], Zoran ODANOVIĆ [3]

AN ANALISIS OF THE STEEL WATER TOWER SELECTION IN FUNCTION OF THE EXPLOATATION PARAMETERS

SUMMARY

Water towers are produced from different materials as: ferro concrete, brick, steel and combination of these materials. In world designer trends the steel water towers are specially interesting, as they are characterized with simple construction, it is possible to design it in different shapes in function of structure integrity, material saving and easier construction maintenance in the in exploitation. This paper presents an algorithm for steel water tower selection in water supply technological chain, taking into consideration positive and negative aspects of exploitation limitations. Structure safety aspects are emphasized.

Keywords: steel water tower, optimization, structure integrity

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1. INTRODUCTION

One of the most important facilities in water supply technological system (technical or drinking water) is water reservoir or water tower. There are used for accumulation of the reserve water and homogenization of the working cycle for the water pump station. Beside that, these facilities regulate pressure and water consumption in water supply system. Contrary to the water tanks, water tower has supporting construction (supporting column) and could be situated on the flat or on the elevated basement. Most frequently water towers are used in flat ground areas with an aim of obtaining satisfactorily pressure in the water supply system for some technological process of drinking water supply system.

2. STEEL WATER TOWER AS A PART OF THE WATER SUPPLY SISTEM

Water towers are produced from different materials as: ferro concrete, brick, steel and combination of these materials. In world designer trends the steel water towers are especially interesting, as they are characterized with simple construction, it is possible to design it in different shapes in function of structure integrity, material saving and easier construction maintenance in the in exploitation. Different combinations of tank shapes and supporting column a water accumulation from 10 to 500 m^3 and higher are enabled. In figure 1, a water tower in technological array of water supply system is presented.

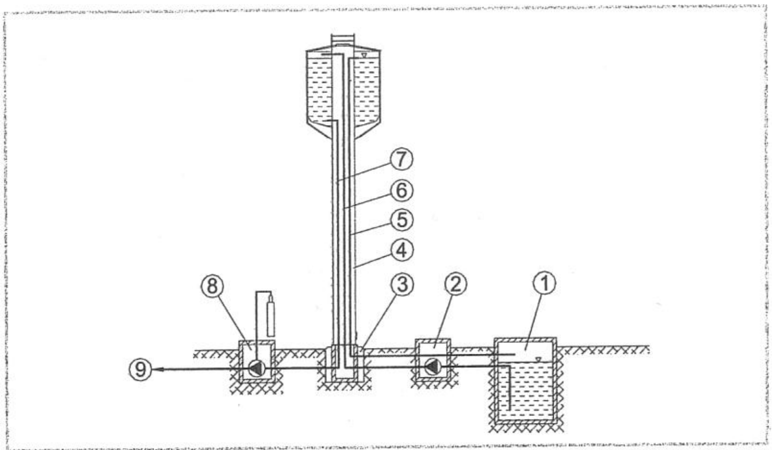

Figure 1. 1. - well, 2. - pumping station, 3.- water tower basement, 4.- water tower, 5. - over flow pipe, 6. - riser pipe, 7. - outlet, 8. - chlorination and filtration unit, 9. - water outlet to distributor.

Supporting units of the water tower are:

- Well situated near the water tower with corresponding capacity,
- Pump station with corresponding number of pumps (at least two, one is main and another is in reserve) with corresponding capacity which is in accordance with capacity of the tank to provide reliable water supply,
- Electric supply necessary for the pump station and other consumers from water tower.

3. BASE ELEMENTS OF THE STEEL WATER TOWER

Steel water tower is consisted from the spheral or cylindrical tank. Sphere diameter and diameter and height of the cylinder and thickness of the shell are in function of the tank capacity. Supporting column could be in different shapes (as pipe, cone or frame) a height from 30 to 50 m, in dependence of designed water pressure in water supply system. Basements are in shape of the flange or joint, in dependence of the type of the water tower, with or without a cable. Supporting devices are also a pipes (riser pipe, delivery pipe, and overflow pipe), connecting units for electric power, lighting installation, signalization, water level regulation and lighting conductor installation.

Water tank, shape and dimensions of the tank are in dependence of the reservoir capacity. It consisted of welded steel plate segments of suitable thickness and thermally isolated with ceramic insulation and covered with Zn plated sheet.

Supporting column, with a water tank is produced by welding of seal pipes with appropriate diameter and wall thickness, or welded frame support. Bottom part of the column is in shape of the cone (in case of the water tower with cable) or flange (in case of the water tower without cable). Inside of the supporting column are pipes, electric installations and ladder.

Basement, is circle plate with basement's knee cup in the middle, where column ball is reposed (in case of the water tower with cable) or a flange fixed at basement plate.

Pipes, (riser pipe, delivery pipe, and overflow pipe) are made of plastic or steel.

In Figure 2 some different design solutions of the water towers with different shape and construction are presented.

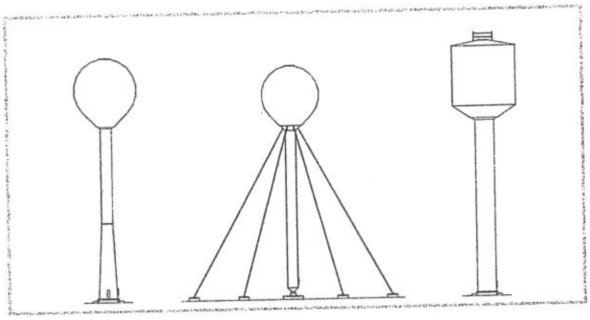

Figure 2. Different design type of the steel water towers

4. ANALISIS OF THE SHAPE SOLUTION OF THE STEEL WATER TANKS

Tanks shapes could be different, in dependence of the: tank's strength and stability of water tower at wind power, production technology, transports and assemblage and also of the tanks capacity. All possible tanks shapes have reinforcements at the joint of the tank and supporting column. Water weight in tank cause hydrostatical pressure with highest intensity at the bottom of the tank. Tank's bottom could be also in different shapes (flat bottom, sphere, or combination of torus and sphere) as presented in Figure 3. In tanks designing, attention have to be devoted to bottom shape (with frame, flat, sphere, with or without collar etc.) to avoid excessive pressure.

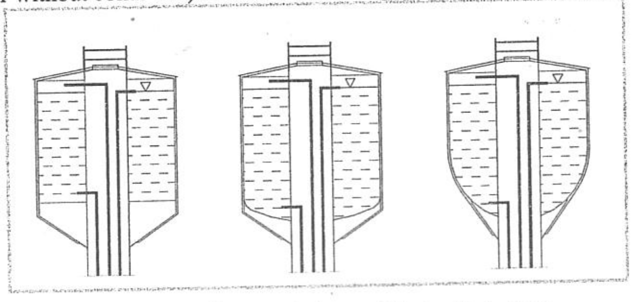

Figure 3 Different solutions of the tank's bottom

Also the other tank's elements, as roof and body of the reservoir, could be in different shapes, as presented in Figure 4.

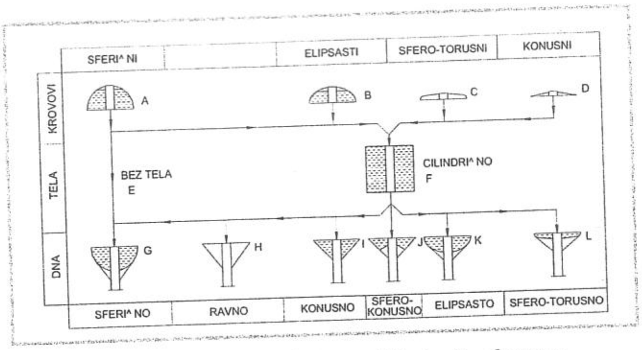

Figure 4. Possible solutions of the tank's elements

Tanks are calculated based on pressure, in accordance with existed standards as JUS M.E2 [1]. It is assumed that pressure of the tank's weight and water weight at supporting column is higher than the calculated pressure inside and possibility of vessel accidence due to their influence are existed, and these facts have to be involved in pressure calculations (item 4.5 JUS M.E2.250).

5. ANALISIS OF THE POSSIBLE SUPPORTING COLUMS SOLUTIONS OF THE STEEL WATER TANKS

As different shapes of the tanks, different shapes of the supporting columns are existed. Supporting columns have to provide to whole system corresponding portability and stability in all situations, as wind impacts, rain, earthquake assumed for the proposed area of exploitation etc. Some of the shapes are: self supported column or the column supported by the cable with constant cross section, self supported column with variable cross section, with a few columns (three and more), frame of constant or variable dimensions, and radialy welded plates with constant or variable cross section, as presented in Figure 5. As a variant could be solutions with three or more vertical or angled columns, as presented in Figure 6.

In designing of the column shape, it is necessary to make analysis of the maintenance. It is also necessary to make detailed analysis of the water tower maintenance in the view of applied accessories manipulation.

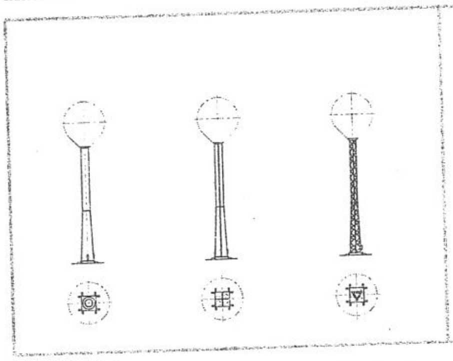

Figure 5. Possible solutions with single column

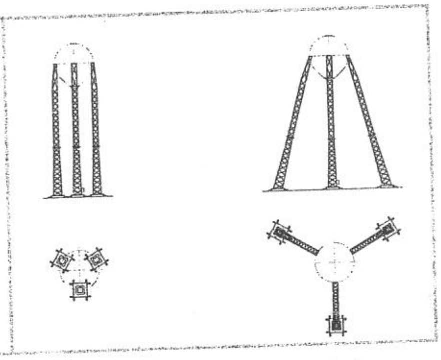

Figure 6. Possible solutions with three or more columns

Water tower column which is exposed to pressure stresses, have to satisfy conditions of stability. Same conditions exist for the other elements exposed to pressure stresses. Results of the stability calculation of the spherical water tower column, with the capacity from 200 to 500 m^3 at increasing of 50 m^3, are presented in the Table 1 [3].

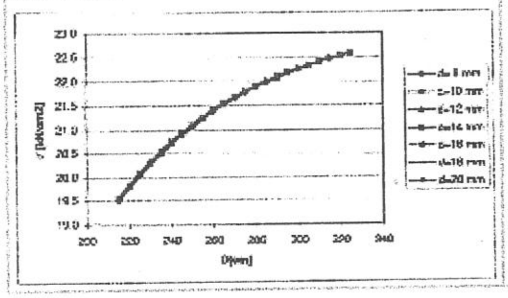

Figure 8. Critical stresses in dependence of the diameter and plate thickness

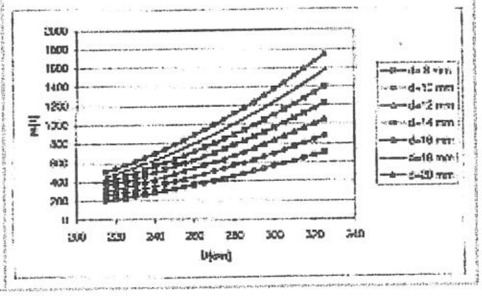

Figure 9. Allowable load in dependence of the diameter and plate thickness

Authoritative critical stresses are signed by shadowing in the Table. In the Figures 8, 9 and 10 the results of the calculations of the supported column, based on the data from Table 1 for different plate thickness, are presented.

Table 1. Results of the column stability for 8 mm plate thickness

D [cm]	d [cm]	comb. No	l [cm]	I_{min} [cm^4]	A [cm^2]	λ	σ_{krO} [kN/cm^2]	V	σ_{kr} [kN/cm^2]	F_{kr} [kN]	F [kN]	mass. spher. [t]	R sf. [cm]
100	98.4	1	4000.0	306544.1	249.2	228.092	3.98	5.917	6.21	992	198	20	169.0
105	103.4	2	4000.0	355269.9	261.8	217.147	4.39	5.363	6.93	1149	230	23	177.5
110	108.4	3	4000.0	408903.5	274.3	207.205	4.82	4.883	7.67	1323	265	27	186.1
115	113.4	4	4000.0	467680.5	286.9	198.134	5.27	4.465	8.42	1513	303	31	194.6
120	118.4	5	4000.0	531836.3	299.4	189.823	5.75	4.098	9.18	1721	344	35	203.1
125	123.4	6	4000.0	601606.4	312.0	182.182	6.24	3.775	9.94	1946	389	40	211.6
130	128.4	7	4000.0	677226.3	324.6	175.131	6.75	3.489	10.69	2191	438	45	220.1
135	133.4	8	4000.0	758931.6	337.1	168.607	7.28	3.233	11.43	2455	491	50	228.7
140	138.4	9	4000.0	846957.7	349.7	162.551	7.84	3.005	12.16	2740	548	56	237.2
145	143.4	10	4000.0	941540.0	362.2	156.914	8.41	2.801	12.86	3046	609	62	245.7
150	148.4	11	4000.0	1042914.3	374.8	151.656	9.00	2.616	13.54	3374	675	69	254.2
155	153.4	12	4000.0	1151315.8	387.4	146.739	9.62	2.449	14.18	3725	745	76	262.7
160	158.4	13	4000.0	1266980.1	399.9	142.130	10.25	2.298	14.80	4099	820	84	271.3
165	163.4	14	4000.0	1390142.8	412.5	137.802	10.90	2.160	15.39	4497	899	92	279.8
170	168.4	15	4000.0	1521039.3	425.0	133.730	11.58	2.034	15.94	4921	984	100	288.3
175	173.4	17	4000.0	1659905.1	437.6	129.892	12.27	1.919	16.46	5370	1074	109	296.8
180	178.4	18	4000.0	1806975.7	450.2	126.268	12.99	1.813	16.95	5846	1169	119	305.3
185	183.4	19	4000.0	1962486.7	462.7	122.840	13.72	1.716	17.41	6349	1270	129	313.9
190	188.4	20	4000.0	2126673.4	475.3	119.594	14.48	1.627	17.84	6880	1376	140	322.4
195	193.4	21	4000.0	2299771.5	487.8	116.515	15.25	1.544	18.23	7440	1488	152	330.9
200	198.4	22	4000.0	2482016.4	500.4	113.591	16.05	1.468	18.60	8030	1606	164	339.4
205	203.4	23	4000.0	2673643.7	513.0	110.809	16.86	1.397	18.95	8650	1730	176	347.9
210	208.4	24	4000.0	2874888.7	525.5	108.161	17.70	1.331	19.27	9301	1860	190	356.5
215	213.4	25	4000.0	3085987.1	538.1	105.636	18.55	1.269	19.56	9984	1997	204	365.0
220	218.4	26	4000.0	3307174.3	550.6	103.227	19.43	1.212	19.84	10699	2140	218	373.5
225	223.4	27	4000.0	3538685.8	563.2	100.925	20.33	1.159	20.09	11448	2290	233	382.0
230	228.4	28	4000.0	3780757.1	575.8	98.723	21.24	1.109	20.32	12231	2446	249	390.5
235	233.4	28	4000.0	4033623.8	588.3	96.615	22.18	1.062	20.54	13050	2610	266	399.1
240	238.4	28	4000.0	4297521.2	600.9	94.596	23.14	1.018	20.74	13903	2781	283	407.6
245	243.4	28	4000.0	4572685.0	613.4	92.659	24.12	0.977	20.93	14793	2959	302	416.1
250	248.4	28	4000.0	4859350.6	626.0	90.800	25.11	0.938	21.10	15721	3144	321	424.6
255	253.4	28	4000.0	5157753.6	638.6	89.014	26.13	0.901	21.26	16686	3337	340	433.1
260	258.4	28	4000.0	5468129.3	651.1	87.297	27.17	0.867	21.41	17690	3538	361	441.6
265	263.4	28	4000.0	5790713.4	663.7	85.645	28.23	0.834	21.54	18734	3747	382	450.2
270	268.4	28	4000.0	6125741.3	676.2	84.054	29.31	0.804	21.67	19818	3964	404	458.7
275	273.4	28	4000.0	6473448.5	688.8	82.521	30.41	0.775	21.79	20943	4189	427	467.2
280	278.4	28	4000.0	6834070.5	701.4	81.043	31.52	0.747	21.89	22109	4422	451	475.7
285	283.4	28	4000.0	7207842.9	713.9	79.618	32.66	0.721	22.00	23319	4664	475	484.2
290	288.4	28	4000.0	7595001.0	726.5	78.241	33.82	0.696	22.09	24571	4914	501	492.8
295	293.4	28	4000.0	7995780.5	739.0	76.911	35.00	0.673	22.18	25868	5174	527	501.3
300	298.4	28	4000.0	8410416.8	751.6	75.626	36.20	0.651	22.26	27209	5442	555	509.8
305	303.4	28	4000.0	8839145.5	764.2	74.383	37.42	0.629	22.33	28596	5719	583	518.3
310	308.4	28	4000.0	9282201.9	776.7	73.180	38.66	0.609	22.40	30030	6006	612	526.8
315	313.4	28	4000.0	9739821.7	789.3	72.016	39.92	0.590	22.47	31510	6302	642	535.4
320	318.4	28	4000.0	10212240.3	801.8	70.888	41.20	0.572	22.53	33038	6608	674	543.9
325	323.4	28	4000.0	10699693.2	814.4	69.794	42.50	0.554	22.59	34615	6923	706	552.4

6. EXPLOATATION PARAMETERS

Exploatation parameters which directly influence construction strength and water tower price are:

- quantity of the building material;
- effect of wind arrangement, earth quake possibilities and rain;
- maintenance conditions;
- vicinity of the settlement.

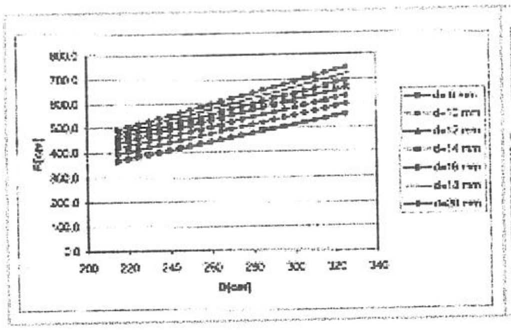

Figure 10. Sphere radius in dependence of the column diameter and thickness

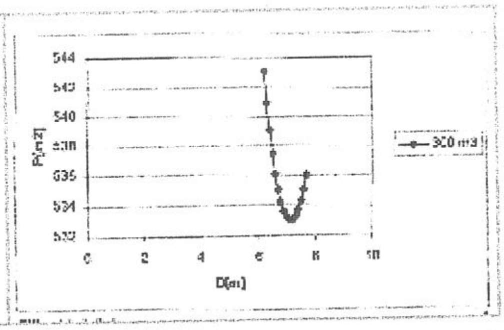

Figure 11. Minimum of the water tower material spends for the 300 m^3 capacity

7. MATERIAL OPTIMISATION

For calculation of the optimal quantity of the building materials, calculation software is adapted for EXCEL. Based on the calculation results for water tower with cylindrical tank of diameter D and volume of 300 m^3 and supported by cylindrical column with diameter of the 1.62 m, a graphical presentation of the function of the minimum used building material in dependence of the steel plate surface P_t is presented in Figure 11.

After dimensional calculations, calculations of the tank's wall thickness, water tower stability and calculation of the building material quantity, it is necessary to perform staticall and dynamical calculations of stresses distribution by the finite element method. This calculation is necessary to obtain stresses distribution in dependence of the all present loads in exploitation conditions.

8. CONCLUSIONS

Effects of the static pressure on the tank's walls and tank's pressure on the column are lower in comparison to the wind influence at total portability. It means that most important calculation have to be in dependence of the wind effects for real exploitation conditions. Also, important decision is determination of the hole for the doors at the column for real exploitation conditions. Due to different friction coefficients, a shape design of the column and tank are important. Designed shapes affect production technology and total water tower price.

Having in mind investment and necessity of the water tower exploitation for few decades, a detailed study with rationale design answers is required, and then is rationale to design, model, calculate and project definite version of the water tower.

LITTERATURE

[1] Standard JUS M.E2.250...
[2] *Report on project "Water tower with cable of 200-500 m^3 volume"* Institute GOŠA, Belgrade, 2000.
[3] *Report on project "Water tower without cable of 200-500 m^3 volume"*, Institute GOŠA, Belgrade, 2001.