USING OF GENERAL METHOD FOR DETERMINING BEARING CAPACITY OF DOMES WITH RADIAL GIRDERS AND CIRCULAR ELEMENTS ON CIRCULAR BASE, WITH DIFFERENT STIFFENING

Lyubomir A. Zdravkov[1]

University of Architecture, Civil Engineering and Geodesy

***Abstract**: When a building structure is spatial (3D), all elements work together. They influence and support each other. On that situation is very difficult to determine who is supporting and who is supported member. It is impossible to calculate directly their effective lengths. These lengths are used in classic equations of standards to check elements for loss of stability. On that reason is reasonably to use General method, described in European standard EN 1993-1-1 [1]. This method is convenient to use, but unfortunately it could not be used without good computer skills and specialised structural software possessing Buckling Analysis module.*

***Key words**: General method, loss of stability, joints, braces*

1. General method for examination of compressed and bended structural elements for loss of stability. General principles.

Overall resistance to out-of-plane buckling for any structural component conforming to the scope of General method can be verified by ensuring that:

(1.1) $$\frac{\chi_{op} . \alpha_{ult,k}}{\gamma_{M1}} \geq 1,0$$

where :

$\alpha_{ult,k}$ is minimum load amplifier of the design loads to reach the characteristic resistance of the most critical cross section of the structural component considering its in plane behaviour without taking into account lateral or lateral - torsional buckling;

χ_{op} - the reduction factor for the non-dimensional slenderness $\bar{\lambda}_{op}$, to take account of lateral and lateral torsional buckling;

γ_{M1} - partial factor for resistance to buckling.

Minimum load amplifier $\alpha_{ult,k}$ of the design loads to reach the characteristic resistance should be calculated using formulae:

(1.2) $$\alpha_{ult,k} \cdot \left(\frac{M_{y,Ed}}{W_{el,y}} + \frac{N_{Ed}}{A} \right) = f_y$$

The global non-dimensional slenderness $\bar{\lambda}_{op}$ for the structural component should be determined by:

[1] Lyubomir Zdravkov, PhD, associate professor, civil engineer, UACEG, Sofia 1046, №1 „Hristo Smirnensky" str., floor 7, office 733, e-mail: zdravkov_fce@uacg.bg

$$\bar{\lambda}_{op} = \sqrt{\frac{\alpha_{ult,k}}{\alpha_{cr,op}}} \quad (1.3)$$

where:

$\alpha_{cr,op}$ is the minimum amplifier for the in plane design loads to reach the elastic critical resistance of the structural component with regards to lateral or lateral torsional buckling without accounting for the in plane flexural buckling.

2. Researching model of roof's structure. Determination of efforts in the elements and reserve of bearing capacity.

Using software SAP 2000 v.14.2 [2] a lot of spatial models of sphere shaped domes were created. Their structure is built by radial girders and circular elements. They are modelled as frame elements, with their real geometrical characteristics and material. For more reliable results roof sheets are not included in the research models, because they are not joined to supporting structure.

In the middle of the dome is formed central ring who joints all radial girders. They are rigid connected to the central ring. In joint roof - shell is formed upper supporting ring. The radial girders have hinge joints to the upper ring.

Transfer of the loads from the cover plates to supporting structure is simulated through using of loading areas. All loads are equally distributed on the whole surface of domes. Unequal distribution of snow on the roofs is not considered.

To consider horizontal displacement of supports of roof structure, in the 3D - model are further included upper stiffening ring (top angle) and part of last shell course, with their real dimensions, see Fig. 1.

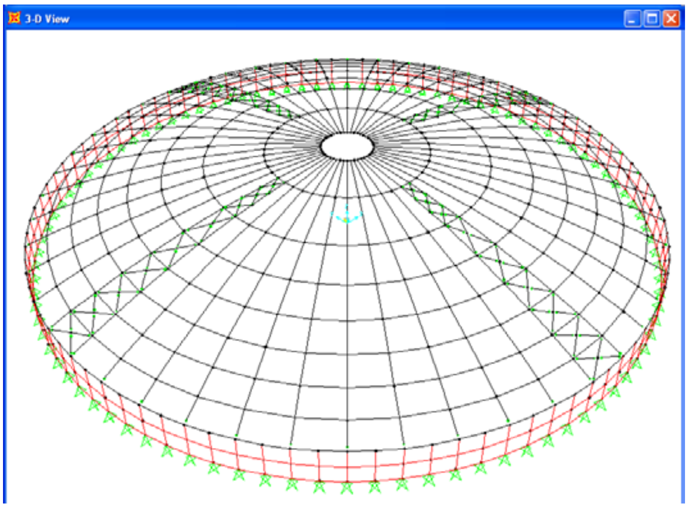


Fig. 1. Spatial researching model of the roof.

Buckling Analysis option in software SAP 2000 is used to perform this analysis. It is possible to observe the reserve of resistance, before one particular element or the whole structure losses stability. The solution is linear, but taking into account the deformations in the roof's structure.

3. Research

Several self-supporting tank's roofs are analysed in current research. They are really designed and are in exploitation now. Table 1 shows their main geometrical dimensions, number of radial and circular elements, and loads on them

Table 1. The researched spatial domes, tank roofs.

Dome	T-105	Litv.	T-253	Treb.	T-113	Merc.	T-111	T-5
Volume V, m^3	5 000	7 000	10 000	15 000	25 000	32 000	40 000	62 000
Diameter D, m	22,8	23,8	28,5	33	41,5	40,37	52,5	60
radial. girders, pcs.	32	32	36	44	52	56	72	84
ring, бр.	5	5	5	6	8	7	8	5
snow S, kPa	1,5	2,0	1,2	1	1,2	1,2	1,2	1
вакуум p_v, kPa	0,5	0	0,5	0,5	0,5	0,5	0,5	0,25
cover plates, kPa	0,392	0,392	0,392	0,392	0,392	0,471	0,392	0,392

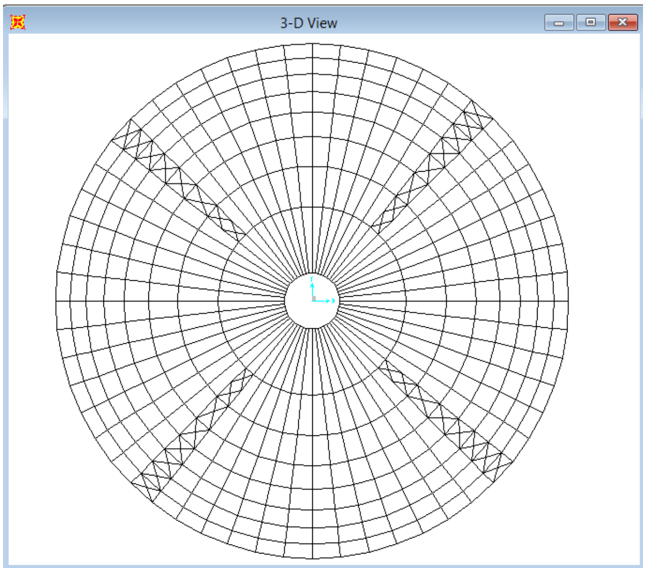
Spherical domes are examined for the following constructive solutions:

Solution №1
a) joints between radial girders and circular elements are rigid;
b) stabilizing braces are not put between elements of the roof structure.

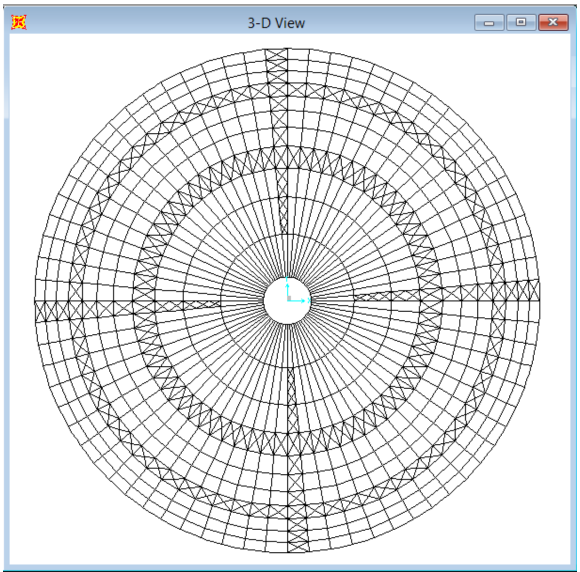
Solution №2
a) joints between radial girders and circular elements are rigid;
b) four stabilizing braces are put between elements of the roof structure. They are developed in radial direction at every 90 ^{0} in plan, see Fig. 2. - a).

Solution №3
a) joints between radial girders and circular elements are hinge;
b) four stabilizing braces are put between elements of the roof structure. They are developed in radial direction at every 90 ^{0} in plan, see Fig. 2. - a).

Solution №4
a) joints between radial girders and circular elements are hinge;
b) stabilizing braces are put between elements of the roof structure. They are developed in the radial and circular direction, see Fig. 2. - b).



a) in radial direction



b) in radial and circular direction

Fig. 2. Position of stabilizing braces

4. Results from the research

4.1. Tank roof T-105, V = 5 000 m^3, *D* = 22 800 mm

Radial girders have section IPE 160, S235. They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2.

Constructive solution	$\alpha_{ult,k}$	K	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	Stability
Solution №1	1,84	1,1294	0,86	1,463	0,356	35,86	NO
Solution №2	1,949	2,339	1,781	1,046	0,633	19,04	YES
Solution №3	2,055	0,3347	0,255	2,84	0,1151	99,41	NO
Solution №4	2,099	0,9459	0,72	1,671	0,309	37,87	NO

4.2. Tank roof Litv., V = 7 000 m^3 , *D* = 23 800 mm

Radial girders have section IPE 180, S235. They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2.

Constructive solution	$\alpha_{ult,k}$	K	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	Stability
Solution №1	1,339	2,8091	1,904	0,839	0,773	22,71	NO
Solution №2	1,308	4,6802	3,172	0,642	0,873	20,57	YES
Solution №3	1,326	0,4266	0,289	2,141	0,1853	95,64	NO
Solution №4	1,308	1,6248	1,101	1,09	0,6031	29,8	NO

4.3. Tank roof T-253, V = 10 000 m^3 , *D* = 28 500 mm

Radial girders have the section IPE 220, S235. They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2.

Constructive solution	$\alpha_{ult,k}$	K	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	stability
Solution №1	3,16	3,6161	2,462	1,132	0,516	14,42	YES
Solution №2	3,152	5,9764	4,069	0,88	0,674	11,06	YES
Solution №3	3,164	4,058	2,763	1,07	0,616	12,05	YES
Solution №4	SAP 2000 does not found form for loss of stability						

4.4. Tank roof Treb., V = 15 000 m^3 , *D* = 33 000 mm

Radial girders have the section IPE 220, S235 They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2.

Constructive solution	$\alpha_{ult,k}$	K	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	Stability
Solution №1	3,743	3,401	2,321	1,27	0,488	12,88	YES
Solution №2	3,742	5,5436	3,783	0,995	0,669	9,38	YES
Solution №3	3,762	1,7859	1,219	1,757	0,263	23,77	NO
Solution №4	3,716	2,705	1,846	1,419	0,409	15,47	YES

4.5. Tank roof T-113, V = 25 000 m^3 , *D* = 41 500 mm

Radial girders have the section IPE 240, S235. They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2, but if there is a temporary intermediate supporting.

Constructive solution	$\alpha_{ult,k}$	K	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	Stability
Solution №1	2,234	1,7909	1,219	1,354	0,441	23,84	No
Solution №2	2,225	2,3126	1,574	1,189	0,537	19,66	YES
Solution №3	2,224	1,1074	0,754	1,718	0,273	38,67	NO
Solution №4	2,221	1,2179	0,829	1,637	0,32	33,04	NO

4.6. Tank roof Merc., V = 32 000 m^3 , *D* = 40 370 mm

Radial girders have the section IPE 240, S235. They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2, but if there is a temporary intermediate supporting.

Constructive solution	$\alpha_{ult,k}$	*K*	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	Stability
Solution №1	2,378	1,7909	1,222	1,395	0,4203	23,51	NO
Solution №2	2,381	2,7218	1,857	1,132	0,574	17,19	YES
Solution №3	2,384	0,7894	0,539	2,104	0,1913	51,53	NO
Solution №4	2,366	1,305	0,89	1,63	0,298	33,28	NO

4.7. Tank roof Merc T-111, V = 40 000 m^3 , *D* = 52 500 mm

Radial girders have the section IPE 300, S235. They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2, but if there is a temporary intermediate supporting.

Constructive solution	$\alpha_{ult,k}$	*K*	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	Stability
Solution №1	3,568	1,819	1,238	1,719	0,294	21,88	YES
Solution №2	3,657	2,6404	1,798	1,426	0,405	15,86	YES
Solution №3	3,666	0,4396	0,299	3,5	0,0743	86,29	NO
Solution №4	3,65	0,5469	0,372	3,131	0,0917	70,19	NO

4.8. Tank roof T-5, V = 62 000 m^3 , *D* = 60 000 mm

Radial girders have the section IPE 330, S275. They satisfy verification for mounting condition at static scheme simply supported girder and load Q_m = 0,3 kN/m^2.

Constructive solution	$\alpha_{ult,k}$	*K*	$\alpha_{cr,op}$	λ_{op}	χ_{op}	σ_{pr} kN/cm^2	Stability
Solution №1	2,424	1,4387	1,002	1,555	0,323	35,16	NO
Solution №2	2,415	2,057	1,433	1,298	0,471	24,16	YES
Solution №3	2,444	0,4239	0,295	2,877	0,1076	104,62	NO
Solution №4	2,436	0,6482	0,452	2,323	0,1599	70,61	NO

5. Research on the domes for seismic impact

In addition to the above done research of the domes for general loss of stability, it was analysed also their behaviour during earthquake. The conditions are:

a) coefficient of the horizontal seismic acceleration a_g = 0,23;

b) soil - category „C" ;

c) coefficient of behaviour - *q* = 1,5;

d) horizontal and vertical components of seismic influence are taken an account;

e) during earthquake the snow on the roof has 30% of its nominal value;

f) the tanks are empty, in other words there is no hydrodynamic effects of formed by waves in the liquid;

g) the roof's structure is corresponding to the shown in the **Solution №2,** in other words the joints are rigid and radial braces are used .

As a result of this research it can concluded that seismic impact is not disruptive load for self - supporting spherical roof when the tank is empty.

Conclusions

From the research of the spatial models of domes with radial and circular elements may be made the following conclusions:

a) the rigid joints between radial girders and circular elements are much better constructive solution than hinge joint and stabilizing braces between elements;

b) in some cases rigid joints between elements of roof structure can entirely eliminate the need of additional stabilizing braces;

в) satisfaction of verification of radial girders for mounting condition considerably increase the possibility of spherical dome not to loses overall stability during the exploitation.

LITERATURE

[1] EN 1993-1-1:2005, Design of steel structures - Part 1-1: General rules and rules for buildings.
[2] SAP 2000 v.14.2. Structural analysis program. Computers and Structures, Inc.