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Finite Element Analysis of a Cement Silo in Bar City of Montenegro

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Abstract

The aim of this study is to propose a roof design for cement silos, which is one of the commonly constructed building types. The project discussed within the scope of the study was implemented in the port in Bar, Montenegro. Within the scope of the study, the roof loaded with wind, snow and earthquake has been analyzed considering local regulations. Earthquake effects on the roof were taken into account with spectrum analysis. Radial ribbed steel roof system was preferred in the design of the cement silo. Design and analysis were done with TESLA Structures and CSI SAP2000 programs. For Montenegro, the values in the Eurocode 8 regulation were used. In the results of working; The data obtained from the analyzes were interpreted.

Karadağ'ın Bar Şehrinde Bir Çimento Silosunun Sonlu Elemanlar Analizi

Anahtar Kelimeler;
Çelik çatı
Rüzgar yükü
Doğrusal olmayan analiz

Özet

Bu çalışmanın amacı yaygın olarak inşa edilen yapı türlerinden biri olan çimento siloları için bir çatı tasarımı önermektir. Çalışma kapsamında ele alınan proje Karadağ'ın Bar şehrindeki limanda uygulanmıştır. Çalışma kapsamında yerel yönetmelikler göz önüne alınarak rüzgar, kar ve deprem yüklemesi yapılan çatı analiz edilmiştir. Çatıdaki deprem etkileri spektrum analizi ile dikkate alınmıştır. Çimento silosunun tasarımında radyal nervürlü çelik çatı sistemi tercih edilmiştir. Tasarım ve analizler TESLA Structures ve CSI SAP2000 programlarıyla yapılmıştır. Karadağ için Eurocode 8 yönetmeliğindeki değerler kullanıldı. Çalışma sonucunda; analizlerden elde edilen veriler yorumlanmıştır.

1 INTRODUCTION

Steel construction is generally used as a carrier system in sports facilities, factory buildings, steel industrial structures, silos, aircraft hangars, workshops, hangars and warehouses (Terzi et al., 2015). Steel construction structures have superior mechanical properties, ease of application and static capabilities compared to other carrier systems. In addition to being safe and economical, steel construction structures also provide great convenience in terms of quick installation and removal and transportation. At the same time, using steel structure systems on roofs allows to pass large openings and obtain transparent spaces (Ustabas et al., 2018). It is preferred in terms of ease of change and renewal situations, being a recyclable material, light but ductile building design, shorter construction time compared to conventional methods and indirect cost economy.
Roof element; consists of carrier elements such as roof cover, purlin, truss (Ozturk, 2009). The loads acting on the system from above are transferred first to the roof cover, from there to purlins and truss, then to the columns and from there to the ground. Horizontal forces are transferred to the ground by the columns by means of crosses and belts (Sahin, 2013). Structural analysis is performed according to the prescribed loading combinations in order to determine the required strengths of the components (column, beam, cross, bolt, welding, etc.) in the dimensioning of steel structures.
The entrance of steel to the dome construction coincides with the years of l8ll. After the first years of using cast iron or coarse iron elements, we see that in the 19th century, when there were rapid developments in steel production technology, many different types of steel dome systems were used to cover large openings. Steel domes are often named after the designers. Föble, Zimmerman, Fuller, Mohr Domes can be given as examples (Ay and Durmus, 2002).
The steel dome assembled in our project is a radial ribbed dome type. Radial ribs are formed by connecting to the tensile ring at the base and to the pressure ring or to each other at the top. The systems look like a spider web when viewed from the plan. There is a pressure ring in the middle and a tensile ring at the bottom to ensure the stability of the system. All ribs are supported on this pressure ring. While ribs can be made with a single profile in small openings, curvilinear plane truss systems are used as the span gets larger (Mohammed, 2015).
In this study, the assembled silo roof was modeled in the SAP2000 program. Necessary loads were made according to the Eurocode regulation and spectrum analysis was applied. For this purpose, firstly, the dimensions, sections, material properties of the static project were transferred to the program and the values obtained as a result of the load calculations were activated on the profiles. Then, spectrum analysis was performed and the results were evaluated.

2 METHOD

2.1 Structural Information

The diameter of the radial ribbed steel dome of the cement silo whose implementation project has been completed in Montenegro is 28.5 m. The photos of the steel elements on the roof is as in figure 1

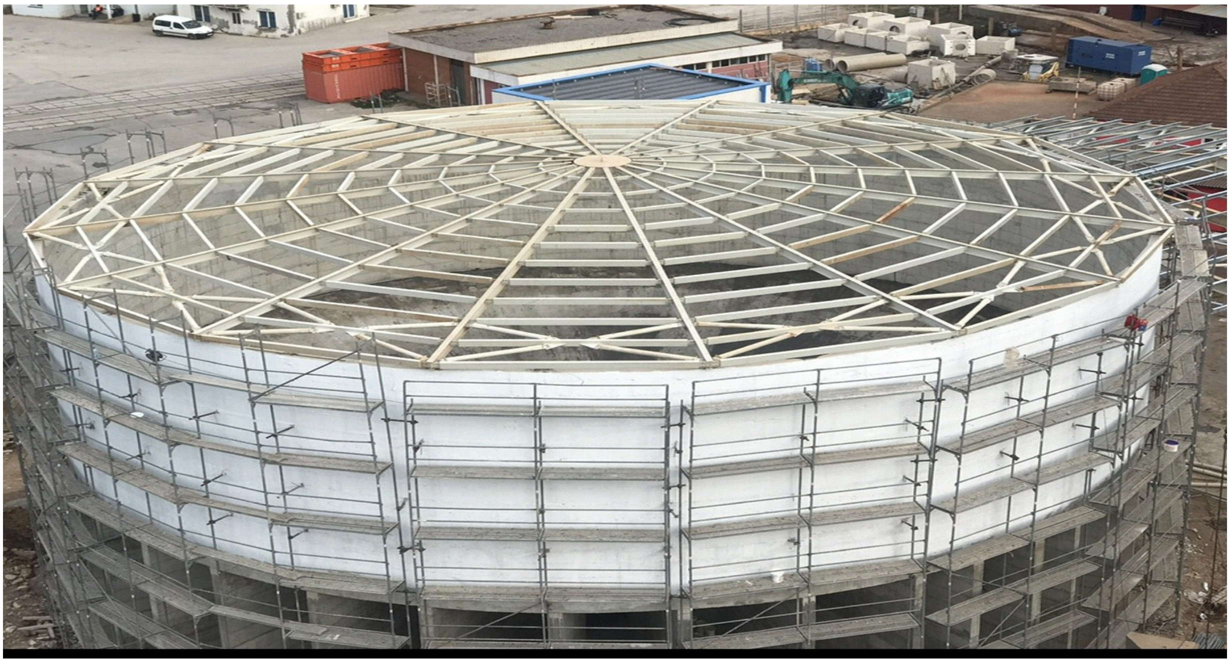

Figure 1. General view of the structure

The dome build from IPE270 Profiles, 120x60x60 box profiles, 200x100x4 wind connections and pipe profiles. The circle with a diameter of 135 cm where the beams meet consists of CHS1250 * 10. Each of the IPE270 beams of the dome is supported by 20mm anchors to the reinforced concrete curtain. The elevation difference between the highest and lowest grades of the dome is 2m.

The steel design of the project was made with the TEKLA Structures program (Trimble, 2021). During the design, attention was paid to the definition of joints as points and frame elements as frames. Then the drawing was transferred to the CSI Sap2000-Version 2020 structural analysis program (CSI SAP2000, 2020).

3 NUMERICAL EXAMPLE

The material sections and type of steel elements are defined in CSI Sap2000 (CSI, 2020). Since the box profiles are not required to take moment where they are supported to the beams, freedom was given to those points. Since no rotation or translation movement is required where the beams are supported on the reinforced concrete curtain, a built-in support was defined in the program.

3.1. Snow Load

Article 2136 of Snow Load Part No 213 in Temporary Technical Code for Building Loads used for load calculations in the country (Jugoslovenski, 1988). According to the Technical Code, a minimum load value of 0.35 kN/m2 should be used in snowy areas. Since the roof slope is 7o <20o, this value is used exactly without any reduction due to the roof slope.

While calculating the snow load to be impacted on the roof elements, first the load falling on the area between 2 consecutive box profiles was calculated. Then, it was applied as a distributed load to the beams to which it was supported. 3D view of the steel roof is shown in figure 2.

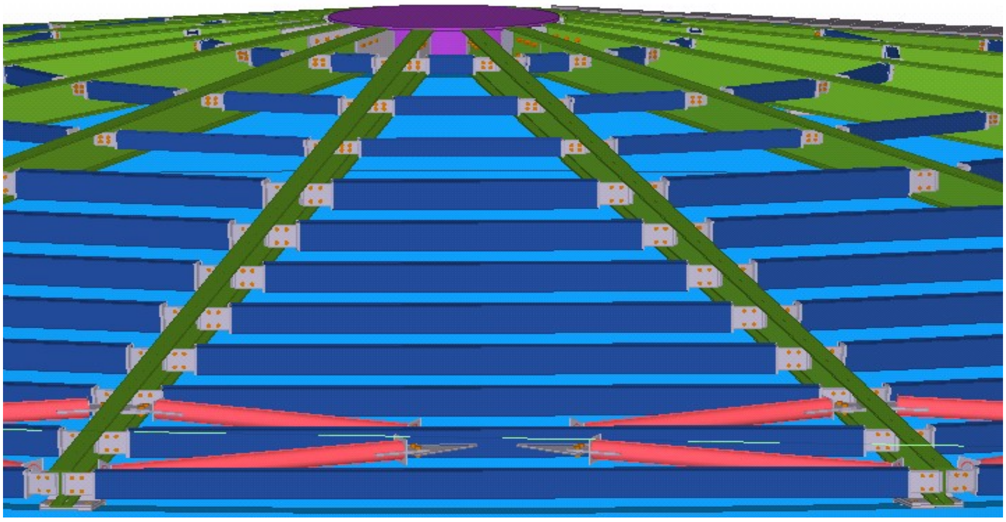

Figure 2. 3D view of the steel roof (TEKLA 2017).

3.2. Wind Load

In the load calculation, the wind should be calculated and activated well. Low-rise and roofed structural systems can be exposed to severe damages by wind effects as in industrial buildings (Huang et al., 2016). In order to prevent this, the effect of wind should be understood very well. Although wind is a load affecting the structure, this load can be impacted as an equivalent static load or as a variable load defined in the time history. However, the random behavior of the wind should not be forgotten during this process. In addition, researches conducted in recent years have shown that positioning the buildings perpendicular to the wind direction and torsional oscillation are as important as being in the same direction with the wind (Kurc et al., 2012) The wind load to be exposed to the roof was calculated according to Eurocode 1: Standard for Actions on Structures (EN 1991) (Handa, 2006). First, the baseline wind speed baseline value (vb,0) 8m/s in the city of Bar was determined (Figure 3). The values of and may differ according to regions, but usually both values can be taken as 1

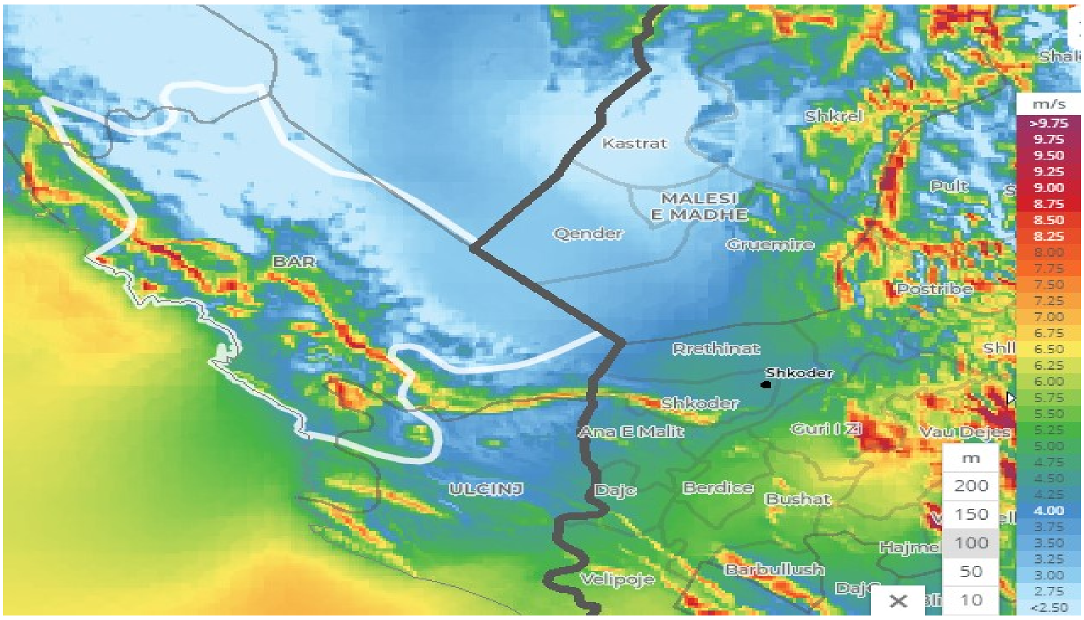

Figure 3. European Wind Map for Basic Wind Speed (WEB-1)

$$\nu_b = c_{dir} \times c_{season} \times \nu_{b,0} \quad (1)$$

ν_b : Basic wind speed $\quad$ c_{dir} : Direction coefficent

c_{season} : Seasonal coefficent $\quad$ $\nu_{b,0}$: Basic value of basic wind speed

$\nu_b = 8$ m/s

There is a correlation between the fundamental wind speed and the fundamental wind pressure..

$$q_b = \frac{\rho}{2} \times \nu_b^2 \quad (2)$$

ρ : Air specific gravity (1.25 kg/m^3)

qb : Basic wind pressure = 40

Since the value at the reference height of the structure is accepted as the basic value of the velocity pressure, it must be changed. The abrupt changes in isometric velocity and wind velocity depend on the roughness of the terrain. The roughness coefficient must be calculated to obtain the main wind velocity at isometric height.

$vm(z)=cr(z)\times co(z)\times vb$ (3)

$vm(z)$: Main wind speed $\quad$ $cr(z)$: Roughness coefficient

$co(z)$: Orography coefficient (Can be taken as 1)

The roughness coefficient depends on the minimum height value.

$cr\ (z) = kr \times \ln(z/zo)\ ,\ z \geq zmin\ = 2.70$ (4)

$kr = 0.19 \times (z/zo,II)\ 0.07$ (5)

kr: Land coefficient $\quad$ zo: Roughness length $\quad$ $zmin$: Minimum height

Land groups required for calculations are as in table 1.

Table 1. Land groups

Land Group	Land characteristic	z_0 (m)	z_{min} (m)
0	Sea or coastal area	0.003	1.0
I	Lakes; unobstructed	0.010	1.0
II	Poor vegetation; Isolated obstacle less than 20 times the height of the obstacle	0.050	20
III	Regular vegetation; Forests, slums, villages	0.300	5.0
IV	Buildings with an average height of at least 15 m and areas covered at least 15%	1.000	10.0

Depending on the group of the land, we can calculate the storm speed from the formula below.

$$\nu_p(z) = \nu_m(z) \times G \quad (6)$$

$$G = \sqrt{Ce(z)} = \sqrt{1 + 7x\frac{\sigma v(z)}{vm(z)}} \text{ ve } z \geq z_{min} \quad (7)$$

G: Storm coefficient kI: Turbulence coefficient (usually 1 is taken.)

$vp\ (z)$: Storm Speed

G = 1.34.

qp (z): Storm pressure $q_p(z) = q_b(z) \times [c_r(z)]^2 \times [c_o(z)]^2 \times [1 + \frac{7 \times kl}{Co(z) x \ln(\frac{z}{zo})}] = 531.2.$ (8)

$c_o(z) = k_I$ = can be taken as 1.0.

Calculation of wind load:

$$F_W = c_S \times c_d \times c_f \times q_p(ze) \times A_{ref} \quad (9)$$

F_W : Wind load

cs: Size coefficient (1.0 can be taken.) = 1.0

cd: Dynamic coefficient (1.0 can be taken.) = 1.0

cf: Force coefficient = 0.618

$Aref$: Reference area = 30 m2

$q_p(z)$ = 531.2

It was calculated as Fw = 9.848 kN and added to the finite element model.

3.3. Panel + Trapezoidal Load

The weight of the trapezoidal sheet (0.058 kN / m2) + insulation (0.031 kN / m2) + vapor barrier (0.018 kN / m2) + seam (0.043 kN / m2) materials on the roof is calculated as 0.15 kN / m2 and the roof is applied as a constant load. activated.

3.4. Eartquake Load

Spectrum Analysis was used for Earthquake load. There are two different spectrum curves in the Eurocode 8, (2004). One of these curves is valid if the magnitude of the Type 1 earthquake surface wave (Ms> 5.5) is greater than 5.5. If (Ms> 5.5) is less than 5.5, Type 2 is valid. Since the earthquake surface waves in the city of Bar are larger than 5.5, Type 1 was selected in spectrum analysis. The equations for the spectrum to be used during design are given below. Spectrum curve for Type 1 and Type 2 is given in Figure 4.

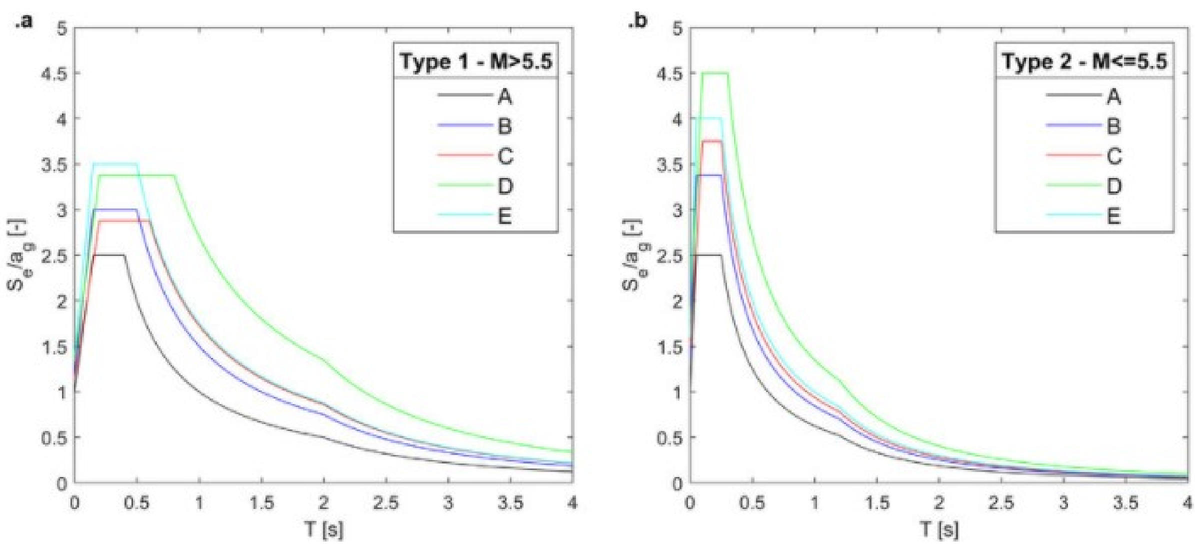

Figure 4. Spectrum Curve Limit Values for Type 1 and Type 2 (Eurocode 8)

5 different soil types are defined in the earthquake code. In addition, two different soil types have been specifically defined. Certain criteria for these floors are given in Table 3. In the city of Bar, the floor type on which the silo will be built was chosen as D as the soil type.

The values used in the drawing of the acceleration-period graph were calculated as in table 2.

Table 2. Spectrum parameteres

Horizontal Ground Acceleration	**0,3**	**Spectrum Period (Tb)**	0,2
Floor Type	D	Spectrum Period (Tc)	0,8
Ground Factor (S)	1,35	Spectrum Period (Td)	2
Behavior Coefficient	2	Spectrum Type	Tip 1

3.5 Load Combinations

The applied load combinations in accordance with Eurocode 3, (2005) are given in table 3.

Table 3. Load Combinations

G+Q+EX+0.3EY	0.9G+0.3EX+EY	1.35G+1.35Q-1.35WY
1.35G+1.5Q	0.9G+0.3EX-EY	1.35G+1.5WX
G+Q+0.3EX+EY	1.35G+1.35Q+1.35WX	1.35G-1.5WX
G+Q-EY+0.3EX	1.35G+1.35Q-1.35WX	1.35G+1.5WY
0.9G+EX+0.3EY	1.35G+1.35Q+1.35WY	1.35G-1.5WY

4. ANALYSIS RESULTS

As a result of the analysis, the displacement of the radial ribbed dome was calculated as 0.106 mm in the combination of 1.35g + 1.35q-1.35wx at joint 120. Table 4 shows the top 5 highest joints.

Table 4. Joint displacements

Combination	Joint	U3 (m)
1,35G+1,35Q-1,35WX	120	-0.000106
1,35G+1,35Q-1,35WX	105	-0.000105
1,35G+1,35Q-1,35WX	121	-0.000105
1,35G+1,35Q-1,35WX	90	-0.000104
1,35G+1,35Q-1,35WX	116	-0.000104

The normal force value has been determined as -135.87 KN at a load combination of 1.35g + 1.35q + 1.35wx at the 1.05m position of the maximum 518 rod element. Table 5 shows the maximum first 5 normal forces.

Table 5. Maximum first 5 normal forces

Combination	Frame Text	Station (m)	P KN	V2 KN	V3 KN
1,35G+1,35Q+1,35WX	518	1,05	-135,87	11,24	-1,677
1,35G+1,35Q+1,35WX	518	0,525	-134,74	10,29	-2,075
1,35G+1,35Q+1,35WX	516	1,27	-133,89	3,91	-2,182
1,35G+1,35Q+1,35WX	517	1,25	-133,75	7,03	5,99
1,35G+1,35Q+1,35WX	518	0	-133,61	9,24	-2,47

The maximum tensile was determined as 93.846.14 KN at the 1.27 m position of the rod element 469 at 1.35g-1.5wx load combination. Figure 5 shows tensile graphs on SAP2000 model of steel roof. Also table 6 shows the maximum first 5 tensile values.

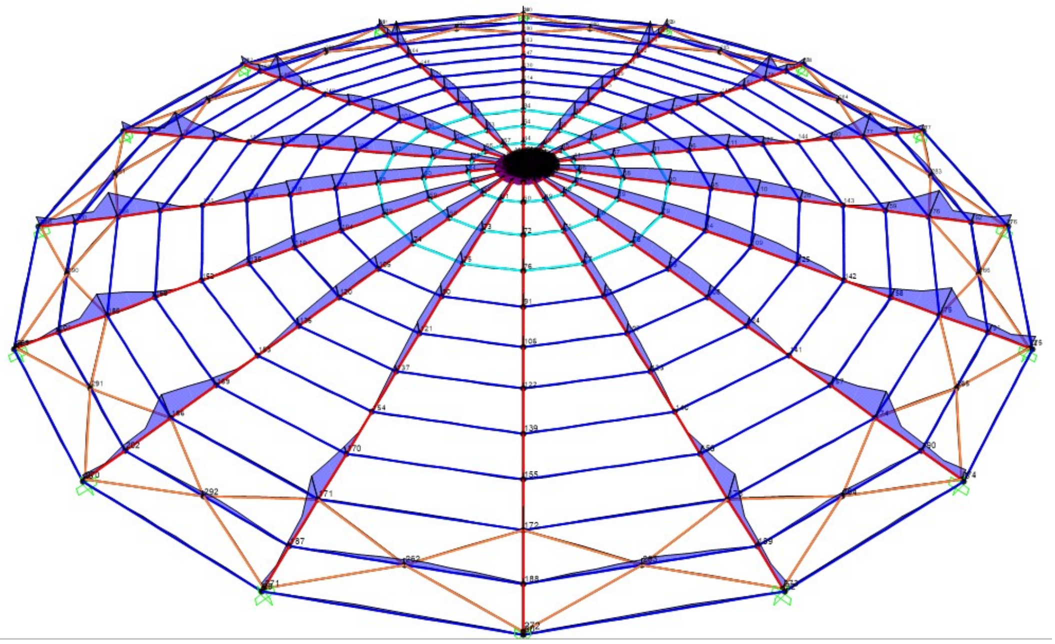

Figure 5. Tensile values on SAP2000 Model

Table 6. Maximum first 5 tensile values

Combination	Frame Text	Station (m)	Smax KN / m^2
1,35G-1,5WX	469	1,27	93846,14
1,35G-1,5WX	481	1,27	93825,02
1,35G-1,5WX	470	0	93433,35
1,35G-1,5WX	482	0	93241,39
1,35G-1,5WX	444	1,27	92473,86

4. CONCLUSION AND SUGGESTIONS

In this study, a cement silo with a diameter of 28.5 meters is considered. It shows that radial ribbed roof systems are a good solution for large span and circular structures such as cement silo under earthquake, snow and wind loads. According to the results obtained from the analysis, the following points can be pointed out.

Smax appeared at the wind junctions of the radial ribbed dome. In the load combinations prepared according to the Eurocode regulation, the maximum tensile value of 93.846,14 kN was determined in the combination of 1.35g-1.5wx.

S_{min} appeared at the wind junctions of the radial ribbed dome. In load combinations, the minimum stress value of -129.087.85 kN was determined in the combination of 1.35g-1.5wx. It can be said that the most critical load in system loading is 1.35g-1.5wx.

Normal force value has been determined as -135.87 KN at maximum 1.35g + 1.35q + 1.35wx load combination. Normal strength values increase on the IPE270 beam from the center of the dome to the outside. As can be understood in the system loading, the loadings have increased as the area from the center to the outside increases.

As a result of the analysis of the dome, the maximum displacement value was measured as 0.106 mm in the combination of 1.35g + 1.35q-1.35wx.

Generally, radial ribbed dome displacements were observed to be at acceptable levels. It has been understood that the tensile and pressure values reflect the properties of the radial ribbed dome and that the type and dimensions of the material used in the assembly can be molded on the safe side with the necessary loads and analysis.

REFERENCES

Autodesk (2019). AutoCAD v19, Commercial Computer-Aided Design and Drafting Software

Ay Z. , Durmuş G. , (2002), " TMH – Türkiye Mühendislik Haberleri " Sayı 418

CSI, SAP2000, (2020) Integrated Finite Elements Analysis and Design of Structures, Computers and Structures, Inc, Berkeley, CA.

Eurocode 3, (2005) Design Of Steel Structures, European Committee For Standartization, Brussels.

Eurocode 8, (2004) "Design of Structures for Earthquake , Doc. CEN/TC250/SC8/N388B. Comité Européen de Normalisation, Bruxelles

Handa, K. (2006). European Standard For Wınd Loads Notes (Eurocode EN 1991-1-4 Wind Actions), 10 p.

Huang, G. , Luo, Y., (2016) Gurley, K. R. ve Ding, J., 2016, Revisting Moment-Based Characterization for Wind Pressures, Journal of Wind Engineering and Industrial Aerodynamics, 151 , 158-168

Jugoslovenski Standard (1988). Riyremeni Tehnijki Propisi Za Opterecenja Zgrada

Kurç, Ö. , Kayışoğlu, B., Shojaee, S. M. N. ve Uzol, O., (2012), Yüksek Binalarda Rüzgar Etkilerinin Rüzgar Tüneli Deneyleriyle Tespiti, İMO Teknik Dergi, 389, 6163-6186.

Mohammed A. , (2015) , " Çelik Kubbe Sistemler " Yüksek Lisans Tezi , Süleyman Demirel Üniversitesi , Isparta

Öztürk, A. Z. , (2009) , " Çelik Yapılar Kısa Bilgi ve Çözülmüş Problemler ", 5. Baskı, Birsen Yayınevi, İstanbul, 232-266.

Terzi, C., Gürbüz, A., Süme, V., & Ustabaş, İ., (2015). Kar Yükünün Tetiklemesi Sonucu Çöken Örnek Bir Çelik Çatının İncelenmesi . 6. Çelik Yapılar Sempozyumu (pp.363-372). Eskişehir, Turkey

Trimble Co (2021). Tekla Structures 2017 Program. www.tekla.com

Ustabas, İ.; Sume, V.; Baki, V. A.; Gurbuz, A., (2018). Evaluation of a Steel Roof of a Football Field That Collapsed due to a Heavy Snowfall . 13th International Congress on Advances in Civil Engineering (pp.1-8). İzmir, Turkey

Web-1, (2021) https://globalwindatlas.info/area/Montenegro/Bar