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Research Article

ANALYSIS OF THE EFFECT OF NON-UNIFORM LOAD ANCHOR SUBSIDENCE THE COOLING TOWERS OF STEEL

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ABSTRACT
Anchor non-uniform subsidence of structures is special and important issue because this kind of subsidence may create additional troops to structures and thus building should be able to endure such forces. In huge building such as cooling towers, non-uniform subsidence is more important matter, because the large dimensions of the foundation increases the possibility of changing in soil type and causes non-uniform subsidence at cooling tower. According to super elevation of structures, wind power is an important loading factor which causes different troops at columns and the result is non-uniform subsidence. At first, a steel cooling towers in previous studies was modeled with finite element method and anchor non-uniform subsidence was applied to tower through mathematical model with the other loadings. Then the tower behavior were analyzed under loading in nonlinear static load cases. The results showed the steel cooling tower had elastic behavior against the wind but components of lower levels of tower had plastic behavior and eventually will lead to the destruction of the tower.

Keywords: *Cooling Tower Steel, Non-uniform Support Subsidence, Wind Load, Software Abaqus*

INTRODUCTION
In the design of power plants, usually due to a simpler technology than metal-concrete cooling towers, concrete option is selected, but in areas where earthquake risk is high or low in the wake of the cooling tower is the soil resistance, the use of lighter materials, such as materials The metal is considered. It is much lighter than concrete structures and for use in areas with high risk of earthquakes seems appropriate, therefore, the main advantage of steel over concrete towers, weight loss and subsequent reduction of the earthquake forces and stresses exerted on the soil bed (Kollar 1985).Cooling towers are one of the great human inventions and due to the specific issues in the analyzing and designing are interesting for researchers and engineers. In thermal power plants, power generation and petrochemical, machines heat should be transferred to the external environment to prevent increasing the temperature in different parts of the plant. When the soil loading soil deformation takes place, or in other words the subsidence. Soil session consists of two parts. The first part of the overall grain volume change (change of soil due to factors such as density and compression) and the second part of your reshape grains (shrinkage soil structure). Using formulas in soil mechanics, soil subsidence under the influence of forces can be calculated in different locations (Khojasteh, 1990). Low subsidence in soil under the foundation of a structure or rotating foundation and structures (like a rigid material) won't create new tensions in the structure. But non-uniform subsidence of foundation can create considerable tension in structures and foundation. As a result, non-uniform subsidence is considered as a structural loading. So in different regulations of structures designing, there are coefficients for considering corresponding troops with non-uniform subsidence of structures and its combining with other loading factors. The difference of subsidence in the sandy soil is approximately equal to the maximum subsidence but in clay soil the difference of subsidence is lower than maximum subsidence (Tsytovich, 1976). The results show that stress changes to a depth of 10 to 20 percent penetration of the tower height, which caused large cracks in the concrete towers on the skin and cause damage to the tower. In 1972, the first subsidence of the non-uniform cooling towers research was conducted by Gould (Gould, 1972). He was a hyperbolic cooling tower generally use the model. In 1986 Lu Gould model to study the uneven settlement payments (Lu *et al.*, 1986). One of empirical research in the field of heterogeneous subsidence was conducted by

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Ciesielski (Ciesielski *et al.*, 1977). Another research conducted by Rao in 1994 was uneven in terms of subsidence (Rao and Rao, 1994). In 2001 Kabirbaik a concrete tower with dimensions of the model (Kabirbaik, 2001). Akhtari studied non-uniform subsidence through provided formula by kaloza and matza on mathematical model $\omega = \Delta U \cos(n\theta)$ in arak cooling tower (Akhtari, 2002). This study was aimed to evaluate the effect of non-uniform subsidence on behave of steel cooling towers under wind load.

MATERIALS AND METHODS

This research was done through Kato model and tower behave was studied after applying different loads. The geometry of tower is as follows:

The tower height is 170 meters above the ground. The maximum radius was 60 meters at the bottom and the minimum radius was 36.5 in the upper part. Tower had hyperbolic shape to height of 122 meters and it had cylinder shape to height of 170 meters after the balance. Equation of each balance radius of the tower is as follows:

$$r = \begin{cases} 36.5\sqrt{1 + (\frac{z-122}{c})^2} x < 0 \\ 36.5 \; x \geq 0 \end{cases} \tag{1}$$

Z: tower balance of the ground, C: radius of curvature of the hyperbolic tower =93.51. Tower geometry is shown in Figure 1 (Kato *et al.*, 2004).

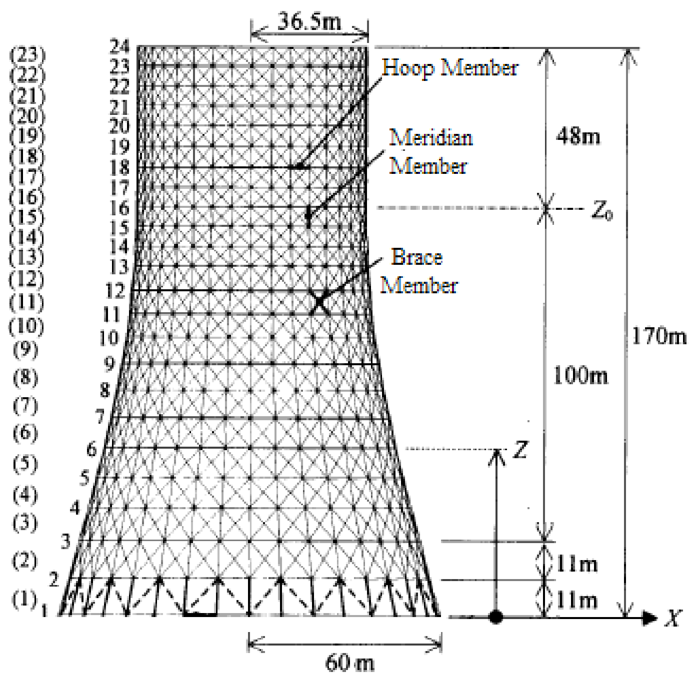

Figure 1: Geometry of cooling tower (Kato *et al.*, 2004)

Due to the length of used parts in steel cooling towers, the members should possess high zirasion radius to keep emaciation in limit. Truss compound tools were used to achieve this purpose, but these tools were inchmeal replaced by. The weights of used steel were decreased due to using of tubular sections in cooling tower. All of segment are tubular sections in *Kato* model. Profiles of used sections are mentioned in Table 1 (Kato *et al.*, 2004). Beams and columns are rigidly connected to each other in *Kato* model. The connecting of bracing members is in articulation type and the members are connected in the middle part so that buckling length is reduced by half. Columns and braces are connected to each other in articulation type in first row and the members also act axially.

Table 1: Specification of cooling towers sections (Kato *et al.*, 2004)

Member	Balance	Cross section (Cm^2)	Moment of inertia (Cm^4)
	H24-24	96.3	59000
	H16-23	74.4	23100
(Hoop Members)	H06-15	40.2	8050
	H04-05	80.4	16100
	H02-03	364	256850
	M17-23	33.7	4100
	M11-16	109	40600
(Meridiomal Member)	M08-10	149.2	66000
	M02-07	200.2	159000
	M01	280	336500
	B20-23	33.7	4100
	B16-19	50	6070
(Brace Member)	B03-15	80.4	16100
	B02	88.6	21900
	B01	87.5	26900

Type of used steel in the profiles of the cooling tower is "steel ST-37" with yield stress 2,400 kN/cm^2 and modulus of elasticity is 2,000,000 kgN/cm^2.

Buckling of Compression Members

One of the most important issues in structures is buckling in the pressure member. Euler equation was used for controling of buckling of cooling tower members so this equation is presented as maximum thrust force of pressure (Pcr) for each member.

$$p_{cr} = \frac{\pi^2 EI}{L_e^2} \tag{2}$$

Assuming a uniform axial stress in each member:

$$\sigma_{cr} = \frac{\pi^2 EI}{AL_e^2} \tag{3}$$

L_e is the effective length depending on the support conditions. Support and values of effective length for different support conditions is presented (Popov, 1990).

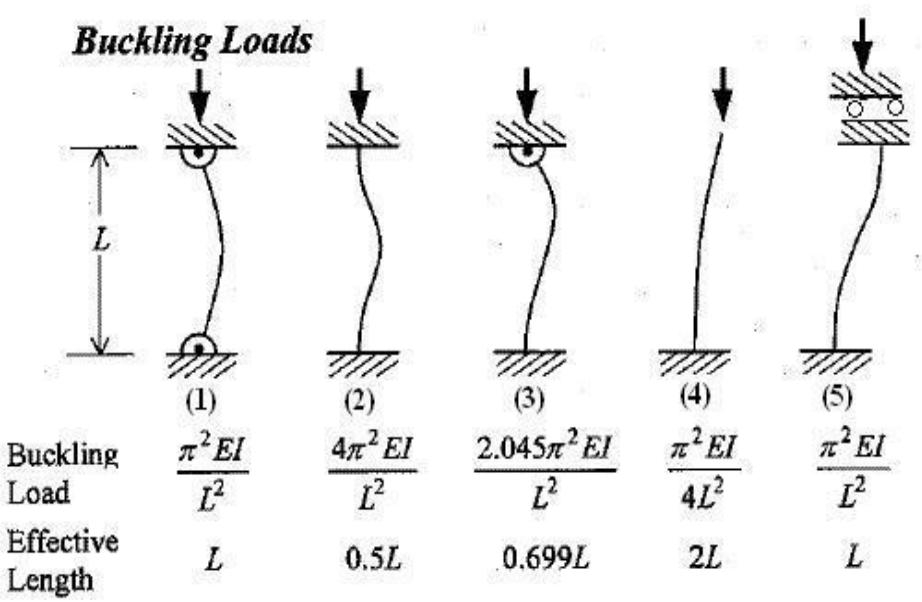

Figure 2: Figure of buckling load and the effective length for different support types (Popov, 1990)

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According to Figure 2, L_e is effective length for bracing members in fact the support conditions of beams and columns were between (1) and (2) status, also due to this issue, effective length for each member is 0.075 L. According to equation (3) and Table 1, calculated values of σ_{cr} for all members is provided in Tables 2 to 4.
According to obtained values of σ_{cr} compressive stress didn't reach to step buckling before submission in all members (2400 $\frac{kgf}{cm^2}$ = $_{yield}\sigma > _{critical}\sigma$).

Table 2: Buckling stress values in beams of cooling tower

Balance	Columns			
	Length (m)	**Cross section (Cm²)**	**Moment of inertia (Cm⁴)**	**Buckling stress (KNcm⁻²)**
1	11.12	363	256850	20012
2	10.49	363	256850	22490
3	9.95	80.4	16100	7102
4	9.48	80.4	16100	7816
5	9.05	40.2	8050	8589
6	8.68	40.2	8050	9317
7	8.35	40.2	8050	10070
8	8.06	40.2	8050	10828
9	7.79	40.2	8050	11565
10	7.57	40.2	8050	12247
11	7.42	40.2	8050	12769
12	7.30	40.2	8050	13193
13	7.23	40.2	8050	13460
14	7.18	40.2	8050	13625
15	7.17	74.4	23100	21213
16	7.17	74.4	23100	21213
17	7.17	74.4	23100	21213
18	7.17	74.4	23100	21213
19	7.17	74.4	23100	21213
20	7.17	74.4	23100	21213
21	7.17	74.4	23100	21213
22	7.17	74.4	23100	21213
23	7.17	96.3	59000	41859

Table 3: Buckling stress values in columns of cooling tower

Balance	**Columns**			
	Length (m)	**Cross section (Cm^2)**	**Moment of inertia (Cm^4)**	**Buckling stress ($KNcm^{-2}$)**
1	11.50	280	336500	31899
2	11.46	200.2	159000	21224
3	10.38	200.2	159000	25870
4	9.31	200.2	159000	32177
5	9.27	200.2	159000	32428
6	8.21	200.2	159000	41369
7	8.18	200.2	159000	41696
8	8.14	149.2	66000	23413
9	8.11	149.2	66000	23604
10	8.08	149.2	66000	23788
11	7.05	109	40600	26335
12	7.03	109	40600	26473
13	6.01	109	40600	36170
14	6.00	109	40600	36258
15	6.00	109	40600	36302
16	6.00	109	40600	36308
17	6.00	33.7	4100	11859
18	6.00	33.7	4100	11859
19	6.00	33.7	4100	11859
20	6.00	33.7	4100	11859
21	6.00	33.7	4100	11859
22	6.00	33.7	4100	11859
23	6.00	33.7	4100	11859

Table 4: Buckling stress values in braces of cooling tower

Balance	**Braces**			
	Length (m)	**Cross section (Cm^2)**	**Moment of inertia (Cm^4)**	**Buckling stress ($KNcm^{-2}$)**
1	8.11	87.5	26900	9226
2	8.00	88.6	21900	7625
3	7.77	80.4	16100	6549
4	7.19	80.4	16100	7650
5	6.64	80.4	16100	8957
6	6.48	80.4	16100	9425
7	5.97	80.4	16100	11073
8	5.84	80.4	16100	11573
9	5.73	80.4	16100	12051
10	5.62	80.4	16100	12496
11	5.54	80.4	16100	12893
12	5.12	80.4	16100	15106
13	5.07	80.4	16100	15404
14	4.70	80.4	16100	17897
15	4.68	80.4	16100	18044
16	4.67	50	6070	10971
17	4.67	50	6070	10972
18	4.67	50	6070	10972
19	4.67	50	6070	10972
20	4.67	33.7	4100	10996
21	4.67	33.7	4100	10996
22	4.67	33.7	4100	10996
23	4.67	33.7	4100	10996

Modeling in Abaqus Software

Abaqus software was used for modeling the steel cooling tower between *CSI*, *Abaqus*, and *Open SEES* (Soroshnia, 2013). In this research, steel was defined by using "*steel101*"recipes. The stress-strain diagram of steel is presented in Figure 3.

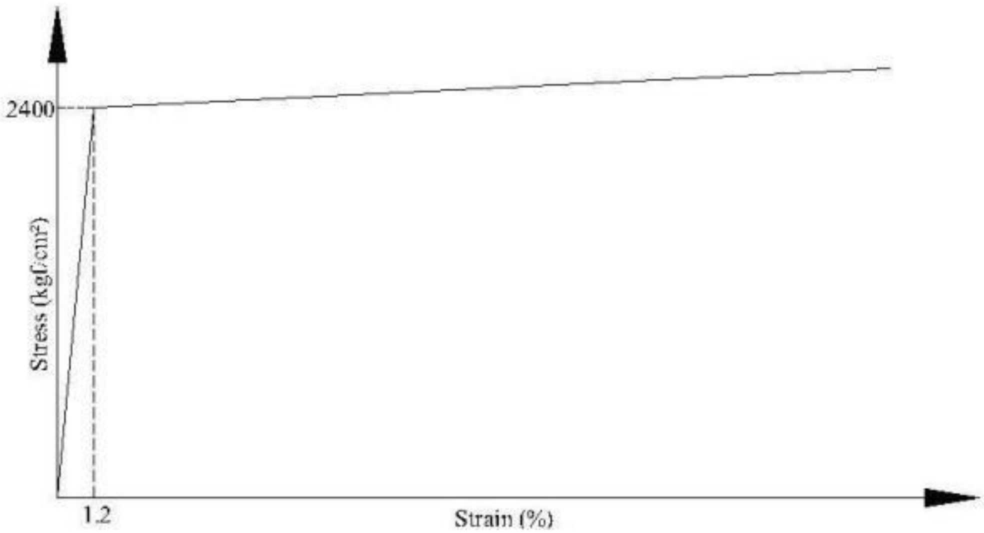

Figure 3: Diagram stress-strain of used steel in cooling tower

All of defined sections are fiber section type in model. Modeled sections by Fiber are the most complete sections which determine properties of finite element sections by using the fibers well. Figure 4 indicated a sample of fiber element sections which defined in tower (Gould 1972).Existence changing location of different member is reason of one factor of non-linear behave structures which caused extra forces P-Δ force in member. Another factor of the behave is changing location of nodes compared to the initial status. Usually the software considers the effects of changing the location as stiffness matrix addition the main stiffness matrix which called the geometric stiffness matrix. Option P-Δ should be selected in Abaqus software to consider the effects of P-Δ in section of definition the geometric stiffness matrix. Option *corotational* should be selected for considering the simultaneous effects P-Δ and shift nodes. *Corotational* geometric stiffness matrix was used in studied model.

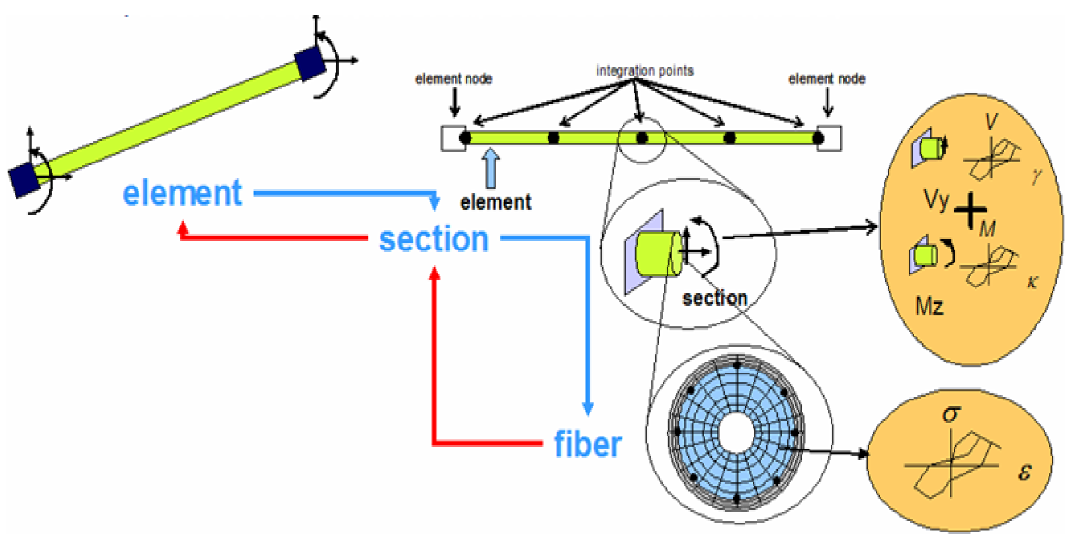

Figure 4: Model fiber section in cooling tower (Gould, 1972)

Nonlinear beam column was used for defining the elements of cooling tower. This element is one of the most complete non-linear elements in *Abaqus* software. It determined the plastic hinge along the length of member by defining a series of plastic joint.

RESULTS AND DISCUSSION

According to research conducted at the World Summit on the size and shape actions to support the cooling tower, one of the last formulas applied to the backrest subsidence cooling tower is a formula provided by the patient in 2000 (Gould, 1972). The formula is as follows:

$$\omega = \frac{k}{2-k} U_0 \cos(n\theta) \qquad (4)$$

Where ω of subsidence each column and θ is the central angle of each column. U0 even after the session under the weight of the cooling tower. n Number session from 2 to half the number of columns tower mode can be changed. The cooling tower is 32, so the number of columns n varies from 2 to 16. k in the soil under the foundation to be used for a fixed amount determined according to soil type. If the value k equals 0.3, and if the clay is sand of this amount would be equal to 0.66.

We know the hardness of the soil depends on soil engineering characteristics and also the shape and dimensions of the foundation. Following the study, a circular cooling tower is the thickness of 1.2 m and a width of 3.8 meters is considered the foundation. In this study, calculations for both clay and sandy soil was carried out. In order to calculate the value of Pi uniform sat under the weight of the cooling tower, the soil under the foundation was modeled by springs with certain difficulties. For sandy soil, the following is considered:

$$E = 80\ \mathrm{MPa}, \mu = 0.3 \rightarrow G = \frac{E}{2(1+\mu)} = 32\ \mathrm{MPa}$$

In order to calculate the spring stiffness of the soil under the foundation tape following expression has been suggested [14].

$$\frac{K}{2L} = \frac{0.8G}{1-\mu} = 34\mathrm{MPa}$$

In this regard, L half-length basis. The relationship between the soil under the foundation in order to calculate the total hardness is used. Determination of soil under each column instead of 2L, the length between the two columns are replaced, so we have

$$2L = R\theta = 60 * 11.25° * \frac{\pi}{180} = 11.775m \qquad (5)$$

$$\rightarrow K = 400 * 10^6 \frac{\mathrm{N}}{\mathrm{m}}$$

If all the above calculations for the clay with the assumption E = 30 MPa and μ = 0.2 do we get the spring stiffness of the soil under the foundation tape

$$K = 150 * 10^6 \frac{\mathrm{N}}{\mathrm{m}} \qquad (6)$$

Given the above information, the two towers under its own weight and with two different soil samples were analyzed. As a result of these subsidence, the uniformity of the following values were obtained:

For Sandy soils: $U_0 = 12.7$ mm

For clay soils: $U_0 = 33.9$ mm

Dispute settlement amount is calculated for each soil sample taken place:

For Sandy soils:

$$\Delta U = \frac{2*0.66}{2-0.66} * 12.7 = 12.5\ mm$$

For clay soils

$$\Delta U = \frac{2*0.3}{2-0.3} * 33.9 = 12.0\ mm$$

By comparing the difference value and sandy clay soil subsidence is observed even though the modulus of elasticity of the soil is sandy clay 2.5 times the amount of clay and sand dispute settlement because of differences in coefficient k is obtained almost identical.

According to the above calculations, the following simplified relationship for the subsidence to support the cooling tower, we assume.

$U = 6\cos(n\theta)\ mm$ (7)

In order to better compare the behavior of members of different models, the results of axial stress in tower height for each member is presented in Figures 5 to 13.

The following forms apply to the subsidence, all members of tension in various models in the range of elastic tensions remain. In all modes, there generally stresses the pillars in the most critical level of about 60 percent σy to about 25 percent σy and in braces and beams σy is less than 10%.As the charts show, regardless of the mode numbers summit subsidence in the bar as well as gravity load, main load-bearing columns and braces by almost 25 percent of the load-bearing columns involved.

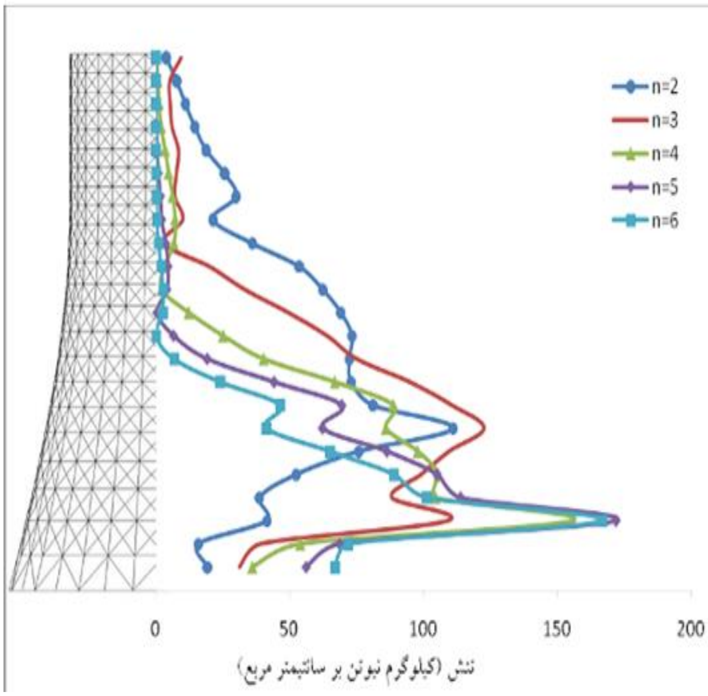

Figure 5: Axialstress under load beam anchor subsidence in the second to sixth modes

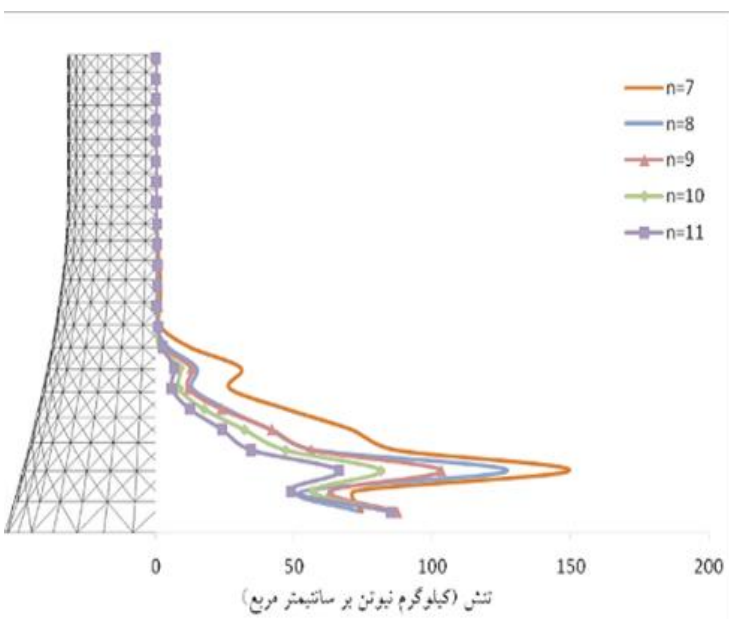

Figure 6: Axialstress under load beam anchor subsidence in the seventh to eleventh modes

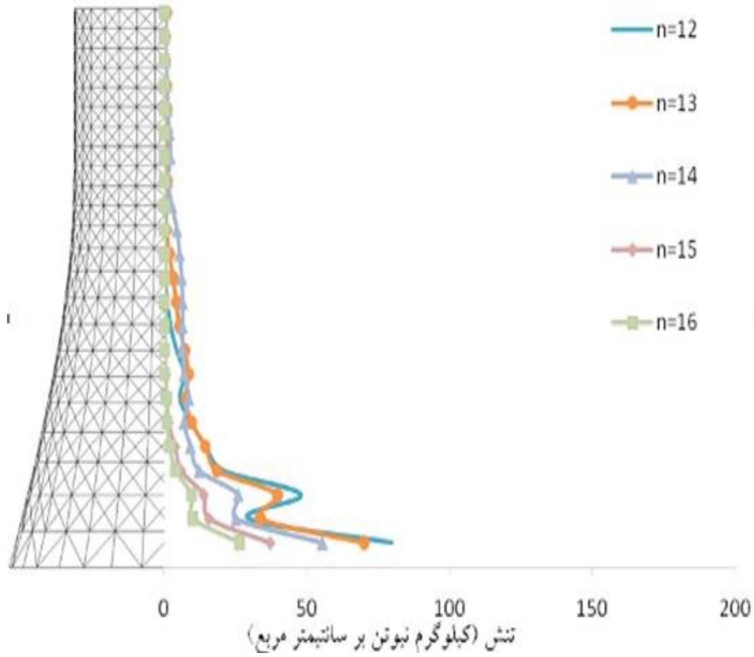

Figure 7: Axialstress under load beam anchor subsidence the twelfth to the sixteenth mode

As is known, with an increase in stress mode beam subsidence at different levels decrease, but due to low levels of stress beam more detailed examination of the tension between the values of the members of the different modes is not important. Also check the tension beams in the tower height to indicate if the subsidence takes place in the second mode affects all structural beams and tension in the entire height of the tower is completed, If the subsidence takes place in the third mode beam tension tower height expands to about 60% and less than 40% in the rest of the modes affect the height of the tower. Structural bracing behavior in different models, subsidence times of Figures 8 to 10 are provided.

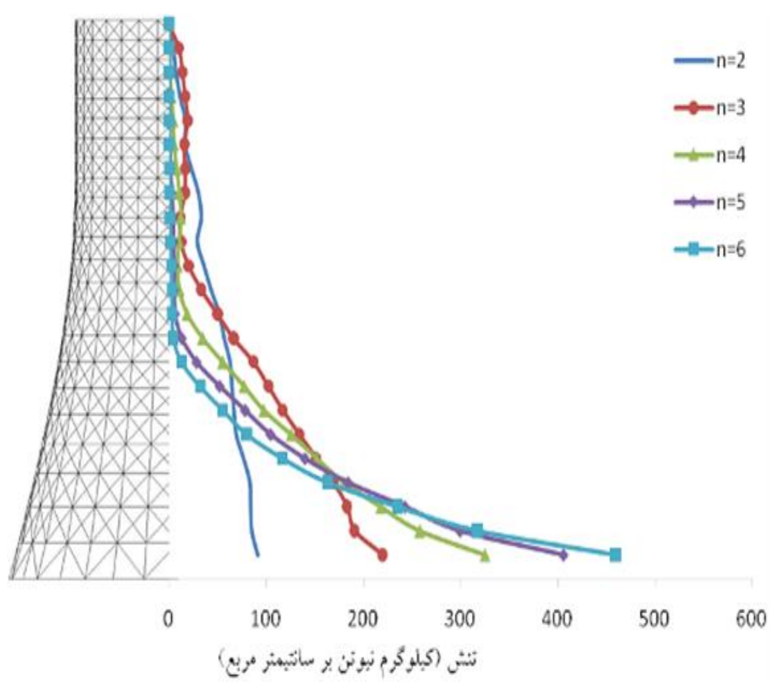

Figure 8: Axial stress under load bracing anchor subsidence in the second to sixth modes

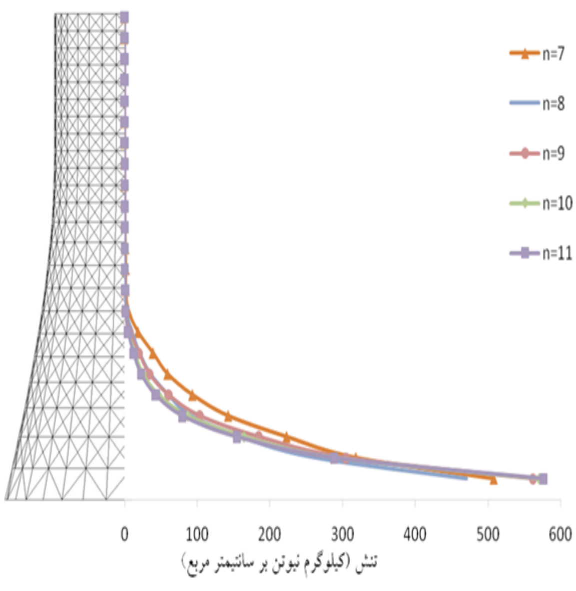

Figure 9: Axialstress braces under load bracing anchor subsidence in the seventh to eleventh modes

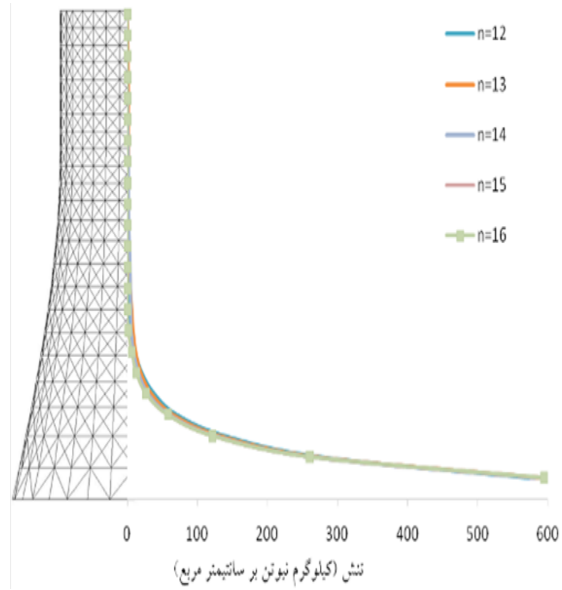

Figure 10: Axial stress under load bracing anchor subsidence in the twelfth to sixteenth modes

Looking at the chart above, unlike bracing beams at various levels increased with increasing tension in the subsidence mode. Check tension at the height of the tower braces indicate if the subsidence happens in a second mode at different levels of altitude affects all members of the diameter and tension in the entire height of the tower is completed, if the subsidence takes place in the third to sixth modes the stress members of the tower height of about 50 percent faster and 20 percent in the rest of the tower height affects mode.

Structural columns in different modes of fruition is provided in Figures 11 to 13.

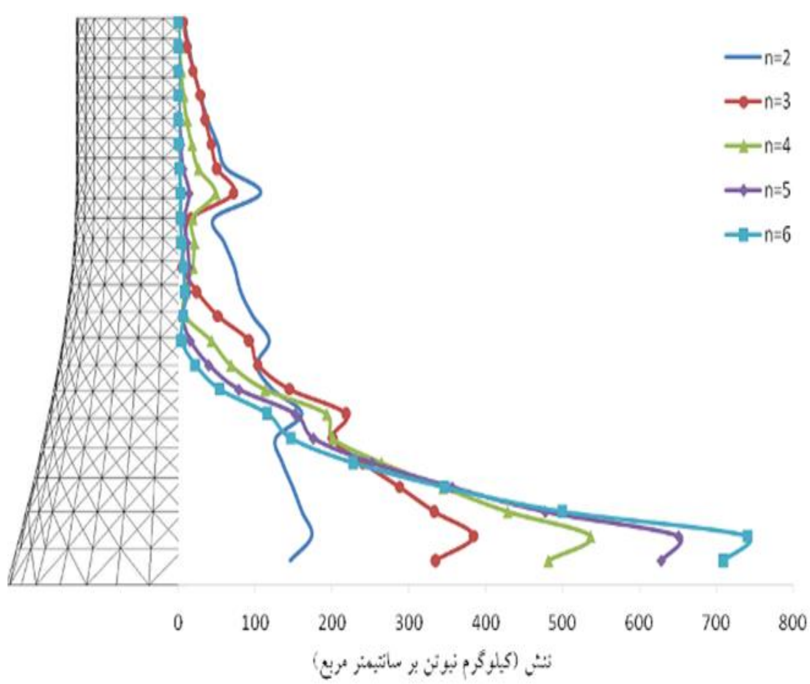

Figure 11: Axial stress under load columns anchor subsidence in the second to sixth modes

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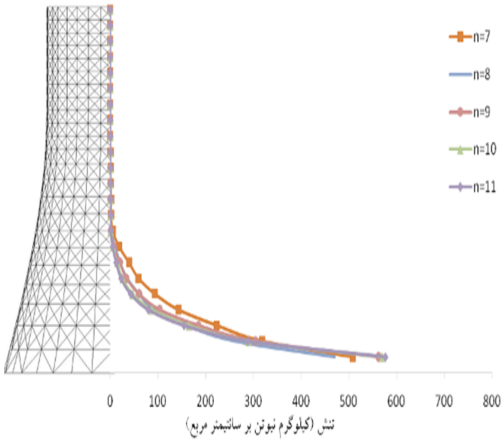

Figure 12: Axial stress braces under load columns anchor subsidence in the seventh to eleventh modes

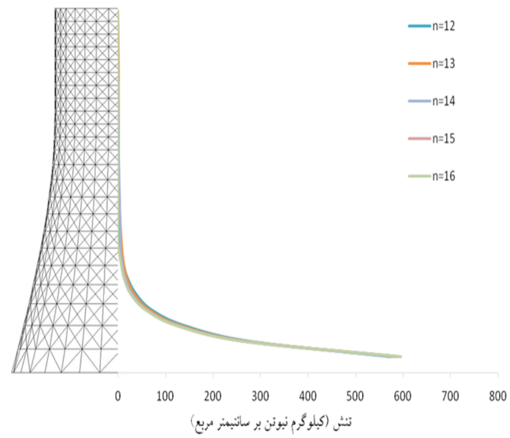

Figure 13: Axial stress under load columns anchor subsidence in the twelfth to sixteenth modes

Looking at the chart above beams and braces against the increase or decrease tension by increasing our mood. Columns with increased tension initially increase and then decrease the subsidence mode and critical mode will be subsidence for the sixth column mode. Review progress in the field of tension tower height indicates the second mode if the subsidence occurs, all affected columns at different elevation levels and tension in the entire height of the tower is completed, if the subsidence happens in third to sixth modes of stress by approximately 40% of the members of the extended height of the tower and the rest of the modes affected about 20% of tower height. As it was, the general subsidence of stresses caused by the load in the columns is greater than the braces and beams. Subsidence the critical load mode is also sixth in column mode, so the work and apply the combination over time subsidence in this mode will apply to structures.

Conclusion

1. One of the main challenges of space structures buckling problem is structural members. As was observed in this study is obese cooling tower members and compressive stress does not buckle None of the members before submission to the stage.
2. Stress distributing subsidence initially increases and then decreases with increasing mode and critical mode will be the sixth subsidence of the braces and beams to columns mode with increasing mode session, different levels of stress increased and the last mode is the most tensions with there.
3. Members tension tower height to show progress in the second mode if the subsidence occurs, all affected columns at different elevation levels and stress will influence the entire height of the tower, if the subsidence takes place in the third to sixth modes, stressed the members to about 40% of the height of the tower and the rest of the modes affected about 20% of the tower's height.
4. In general, the tension columns of braces and beams more. Elevation can be seen in the distribution of stress fractures due to sudden changes in cross-section of the alignment to another level. Such changes, however, may be analytical calculations, responsive to the load on the structure, but in the implementation of Union members, additional stresses arise that can destroy the connection.

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