

Komparativna analiza naponskog stanja gornjih delova noseće konstrukcije portala kod portalnih dizalica

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Različita konstruktivna izvođenja portala portalnih dizalica su nametnula potrebu za razvoj i primenu različitih proračunskih metoda. Cilj je da se dođe do konstruktivnog rešenja noseće konstrukcije portala koje će zadovoljiti ekonomske i tržišne zahteve, među kojima su najvažniji cena, masa dizalice i pouzdanost u radu. U radu su prikazani rezultati proračuna portala kod portalnih dizalica sa okretnim stubom, primenom teorijskih metoda i primenom metode konačnih elemenata (MKE).

Visoka podudarnost vrednosti napona i pomeranja u preseccima elemenata gornjih delova noseće strukture portala potvrđuju opravdanost primene oba metoda, pri čemu primena MKE daje mogućnost, variranja većeg broja ulaznih parametara.

Ključne reči: naponska analiza, portal, teorijski proračun, proračun MKE

1. UVOD

Izučavanje uticaja odnosa geometrijskih veličina elemenata noseće konstrukcije portalnih dizalica na način veze sa okretnom platformom u mnogome zavisi od mogućnosti variranja većeg broja ulaznih parametara. Kako je primena teorijskih proračunskih metoda u direktnoj zavisnosti od broja ulaznih parametara, zbog nemogućnosti rešavanja matematičkih problema koji se tada javljaju, to se vrlo često analize i proračunske metode sprovode sa izvesnim stepenom redukcije tih parametara.

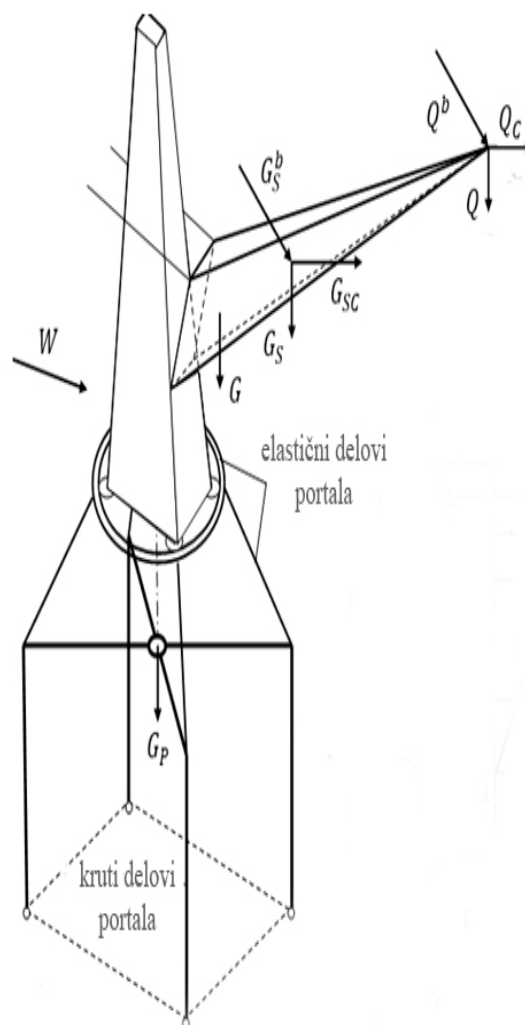
Jasno je da se pri tome umanjuje sveobuhvatnost analize, ali sve dok se nenarušava opštost razmatranog problema primena navedenog pristupa pri definisanju osnovnih zavisnosti geometrijskih karakteristika elemenata gornjih delova noseće konstrukcije portala je potpuno opravdana.

Sa definisanim odnosima geometrijskih veličina elemenata portala, moguće je njihovim variranjem definisati optimalne vrednosti. Tada, naravno, dolaze do izražaja primene računarskih softvera baziranih na različitim proračunskim metodama, od kojih značajnu ulogu ima MKE.

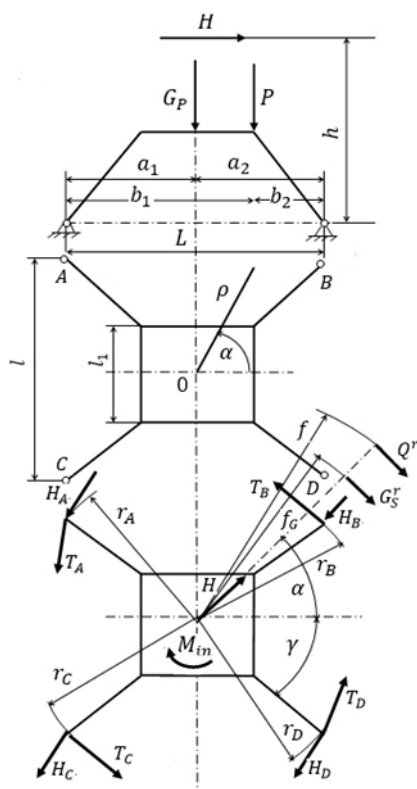
2. ŠEMA OPTEREĆENJA PORTALA

Opšti izgled jedne portalne dizalice sa okretnim stubom, kod koje je veza okretnog i neokretnog dela izvedena preko prstena, prikazana je na sl.1. Na osnovu analize izvedenih rešenja, varijantno rešenje kod koga su prsten i gornji delovi portala elastični, a donji delovi portala su kruti u podužnom i poprečnom pravcu se pokazuje kao optimalno.

Ovako definisano varijantno rešenje obezbeđuje, dobro kretanje po dizaličnim šinama, a oscilovanje gornjih delova portala sa prstenom je sa izraženim prigušenjem, čime se znatno smanjuje uticaj dinamičkih opterećenja.



Slika 1: Šema opterećanja portalne dizalice



Slika 2: Proračunske šeme portala

Na slici 1 i 2 uvedene su oznake:

G_p - težina portala

G - težina okretne platforme bez strele i tereta

G_s - težina strele

Q - vertikalna komponenta od tereta i uređaja za zahvataje tereta

W - sila vetra

G_s^b i G^b - sile inercije od ubrzanja ili usporenja strele i okretne platforme

G_s^c i Q_c - centrifugalne sile od strele i tereta

P - sile od vertikalnih opterećenja okretne platforme:

$$P = G + G_s + Q \quad (1)$$

H - horizontalna sila:

$$H = W + G_s^c + Q_c \quad (2)$$

M_{in} - moment od sila inercija:

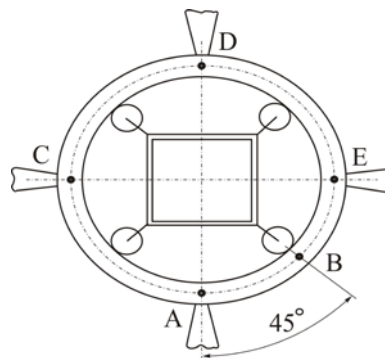
$$M_{in} = Q^b \cdot f + G_s^b \cdot f_G \quad (3)$$

3. PRORAČUN NAPONA I POMERANJA U KARAKTERISTIČNIM PRESECIMA PRSTENA

Sa definisanim opterećenjima moguće je odrediti napadna opterećenja u presecima veze gornjih delova portala sa prstenom. Pri definisanju tih opterećenja korišćeni su teorijski izrazi za proračun prstenova.

Dalje u radu su prikazane proračunske vrednosti napona za dva karakteristična preseka (Slika.3):

- presek veze prstena sa gornjim delom noge portala (tačka A)
- presek prstena koji se nalazi na sredini veza gornjih delova nogu portala sa prstenom (tačka B)



Slika 3: Karakteristični preseki za proračun prstena

Radijalne sile u osloncima su:

$$F_{rA} = F_{rD} = 41,54 \text{ kN}, \quad F_{rC} = F_{rE} = 37,30 \text{ kN} \quad (4)$$

dok sumomenti u osloncima koji deluju normalna na ravan prstena:

$$M_A = M_D = 166 \text{ kNm}, \quad M_C = M_E = 144 \text{ kNm} \quad (5)$$

Vertikalno opterećenje u osloncu stuba je $F_V = 485 \text{ kN}$.

Proračunske vrednosti napona u karakterističnim tačkama prstena A i B, za konstrukcije portala tipa "H i X" prikazane su u tabeli 1.

Tabela 1.

Presek prstena	Tip portala					
	„H” - tip			„X” - tip		
	M [kNm]	M_t [kNm]	σ_u [kN/cm ²]	M [kNm]	M_t [kNm]	σ_u [kN/cm ²]
A	60,87	83,12	5,10	124,55	144,75	6,04
B	110,82	-7,63	5,50	213,53	52,40	5,85

Takođe, korišćenjem navedene teorije o proračunima prstenova mogu se odrediti i odgovarajuća pomeranja u

navedenim tačkama prstena. Rezultati pomeranja prikazani su u tabeli 2.

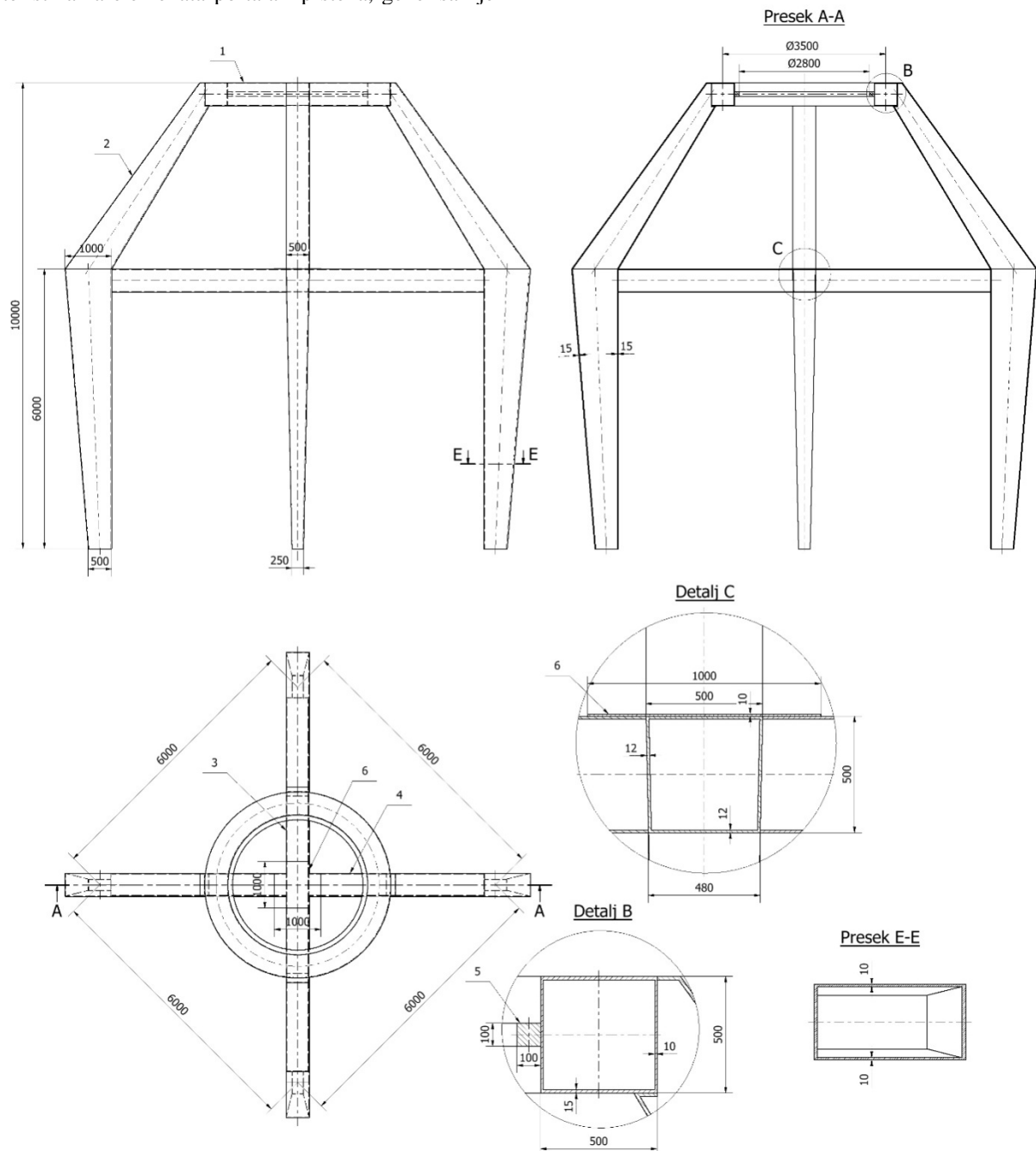
Tabela 2.

Pomeranja preseka	Tip portala			
	„H” - tip		„X” - tip	
	A	B	A	B
x [mm]	-3,67	-0,19	-3,43	-1,60
y [mm]	13,37	7,66	-7,94	9,31

trodimenzionalni zapreminski (solid) model noseće strukture portala portalne dizalice sa dimenzijama koje su prikazane na slici 4.

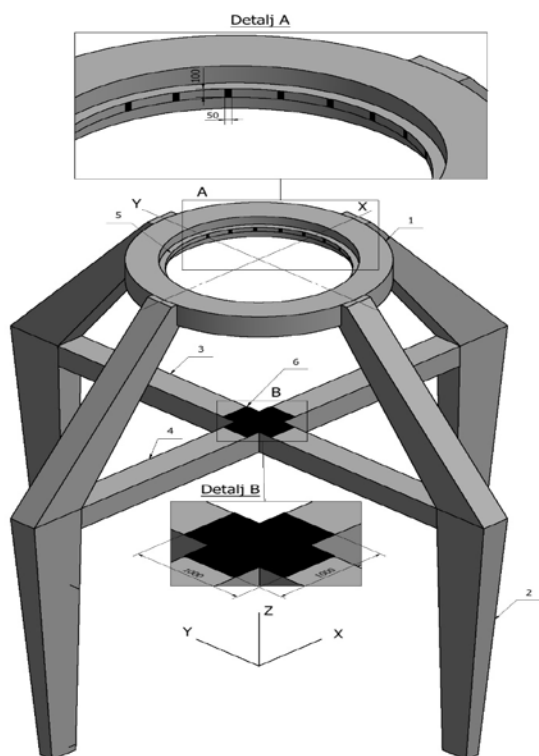
4. NAPONSKO-DEFORMACIJSKA ANALIZA PORTALA PRIMENOM MKE

Saglasno već usvojenim geometrijskim karakteristikama elemenata portala i prstena, generisan je



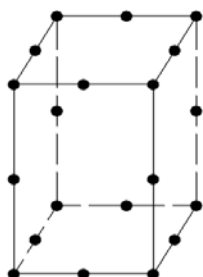
Slika 4: Geometrija i dimenzije portala

S obzirom na to da su osloni točkovi simetrično postavljeni u odnosu na vertikalnu ravan strele, potpuna slika o promeni naponsko-deformacionog stanja strukture portala, time i prstena, za pun ugao obrtanja stuba sa strelom, može se formirati na osnovu analiza za slučaj otklona 0° i 45° . Rezultantna horizontalna sila F_H , dobijena razlaganjem ukupnog momenta u vertikalnoj ravni, se tako razlaže na dve, po intenzitetu jednake, sile F_N , koje deluju na oslone točkove. Ako se usvoji korak otklona od 15° , imaćemo četiri karakteristična položaja strele 0° , 15° , 30° i 45° , što je naznačeno na slici 5.



Slika 5: Povšine za unos opterećenja strukture portala

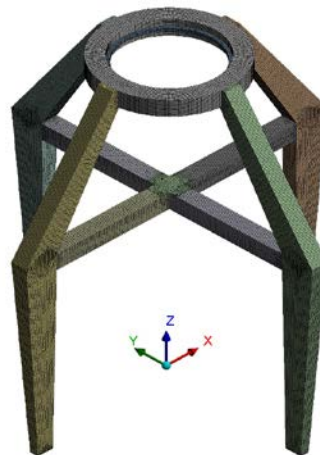
Analiza naponsko-deformacionog stanja strukture portala je sprovedena korišćenjem softverskog paketa Ansys. Trodimenzioni model strukture je diskretizovan mrežom heksagonalnih zapreminskih konačnih elemenata sa po 20 čvorova na temenima i sredinama ivica, sa maksimalnom dužinom ivice od 50 mm, slika 6.



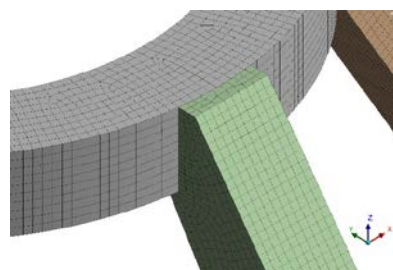
Slika 6: Heksagonalni prizmatični konačni element sa čvorovima u temenima i sredinama ivica

Ovakva podešavanja su rezultirala u finoj mreži od ukupno 119541 konačna elementa i 555880 čvorova. Cela mreža i njen detalj, koji daje uvid u odnos dimenzija

konačnih elemenata i strukturnih elemenata portala, prikazan je na slikama 7 i 8, respektivno.



Slika 7: Celokupna mreža konačnih elemenata



Slika 8: Detalj mreže konačnih elemenata

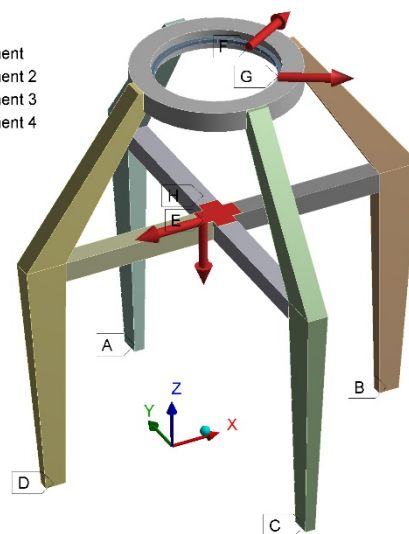
U okviru analize naponsko deformacionog stanja strukture portala, formirana su dva slučaja ispitivanja koji su određeni uglom vertikalne ravni strele i koordinatne ravni XZ globalnog koordinatnog sistema: 0° i 45° .

Sila pritiska jednog točka na kružnu šinu iznosi $F_N = 280$ kN, dok ukupna horizontalna sila koja deluje u donjem osloncu okretnog stuba iznosi $F_H = 485$ kN.

Na slikama 9 i 10 prikazani su granični uslovi za ova dva položaja strele.

E: 0
Figure

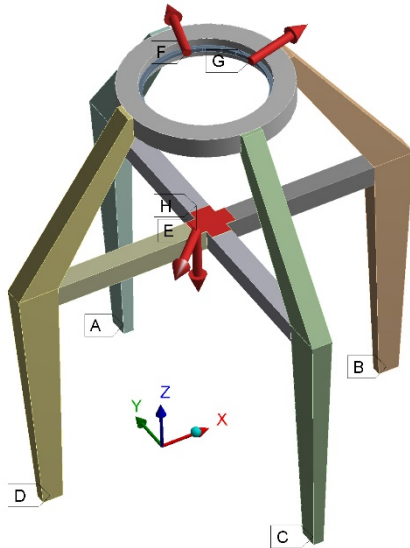
- A Remote Displacement
- B Remote Displacement 2
- C Remote Displacement 3
- D Remote Displacement 4
- E Fv: 2.e+005 N
- F L: 2.8001e+005 N
- G D: 2.8001e+005 N
- H Fh: 4.85e+005 N



Slika 9: Granični uslovi za slučaj 0°

B: 45
Figure

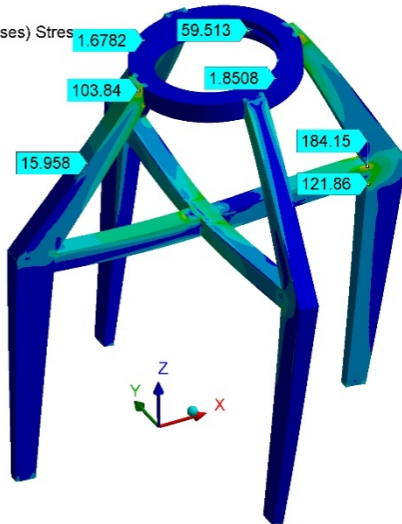
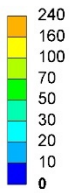
- A Remote Displacement
- B Remote Displacement 2
- C Remote Displacement 3
- D Remote Displacement 4
- E Fv: 2.e+005 N
- F L: 2.8005e+005 N
- G D: 2.8005e+005 N
- H Fh: 4.8508e+005 N



Slika 10: Granični uslovi za slučaj 45°

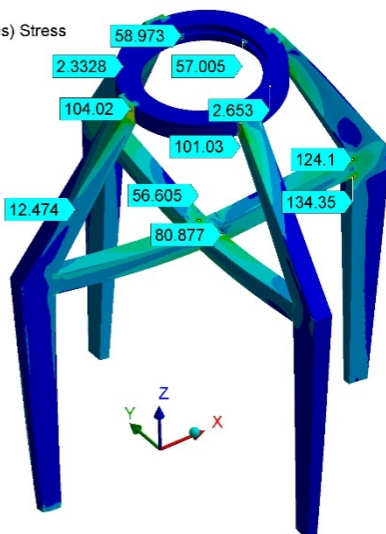
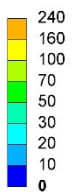
Na slikama 11 i 12 prikazani su uporedni naponi u karakterističnim tačkama za ova dva slučaja.

E: 0
Figure
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1



Slika 11: Uporedni naponi za slučaj 0°

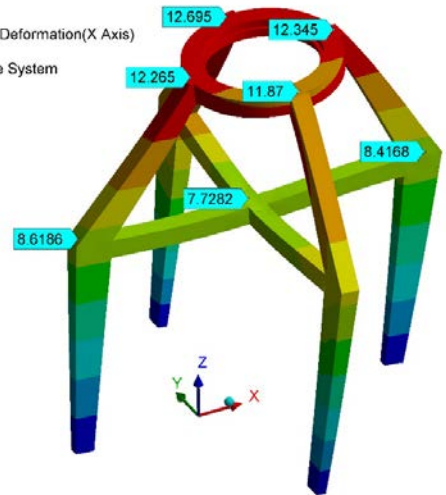
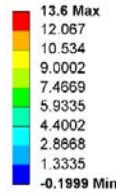
B: 45
Figure
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1



Slika 12: Uporedni naponi za slučaj 45°

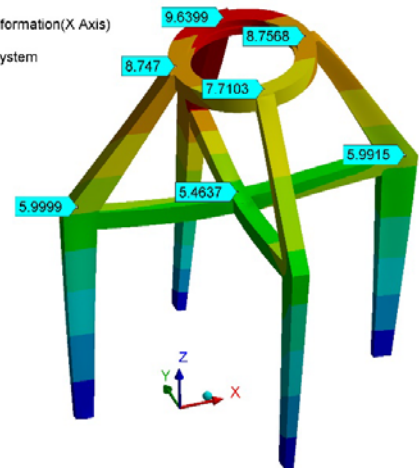
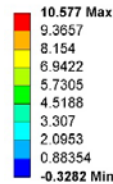
Na slikama 13 i 14 prikazana su pomeranja karakterističnih tačaka u pravcu ose X za ova dva slučaja.

E: 0
Figure
Type: Directional Deformation(X Axis)
Unit: mm
Global Coordinate System
Time: 1



Slika 13: Pomeranje po X osi za slučaj 0°

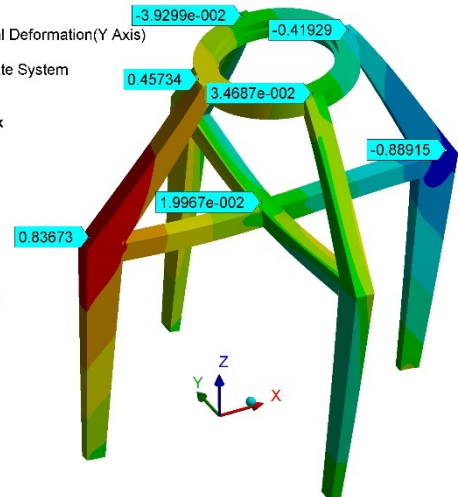
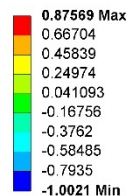
B: 45
Figure
Type: Directional Deformation(X Axis)
Unit: mm
Global Coordinate System
Time: 1



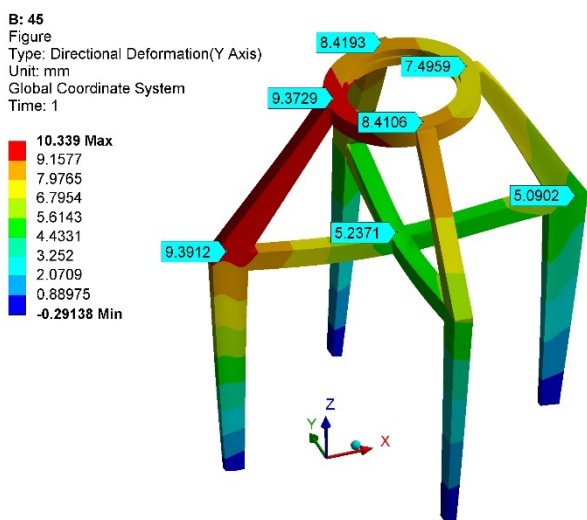
Slika 14: Pomeranje po X osi za slučaj 45°

Na slikama 15 i 16 prikazana su pomeranja karakterističnih tačaka u pravcu ose Y za ova dva slučaja.

E: 0
Figure
Type: Directional Deformation(Y Axis)
Unit: mm
Global Coordinate System
Time: 1

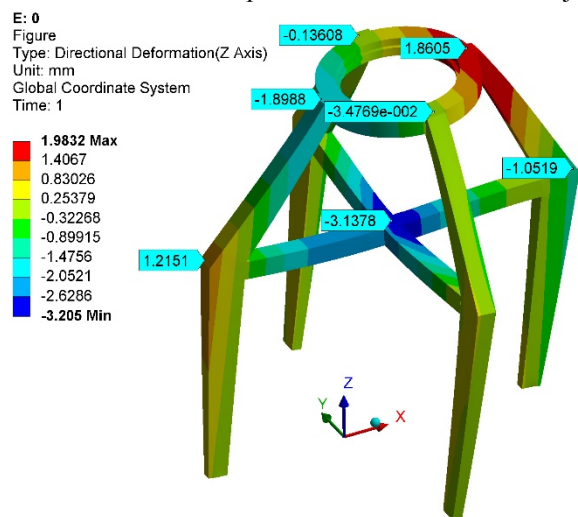


Slika 15: Pomeranje po Y osi za slučaj 0°

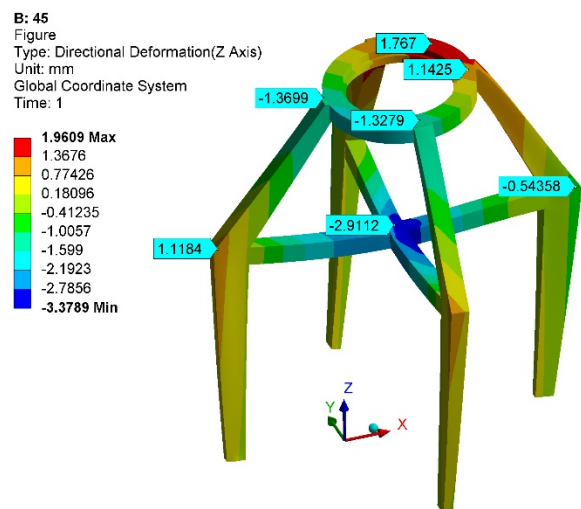


Slika 16: Pomeranje po Y osi za slučaj 45°

Na slikama 17 i 18 prikazana su pomeranja karakterističnih tačaka u pravcu ose Z za ova dva slučaja.



Slika 17: Pomeranje po Z osi za slučaj 0°



Slika 18: Pomeranje po Z osi za slučaj 45°

5. ZAKLJUČAK

Sprovedene teorijsko-numeričke metode analize naponskog i deformacijskog stanja gornjih delova noseće konstrukcije portala kod portalnih dizalica pokazuju da proračunske teorijske metode i metode primenom MKE pokazuju podudarnost rezultata koja ne izlazi iz okvira tačnosti prihvatljive za inženjersku praksu. Značaj primene teorijskih proračunskih metoda se ogleda u definisanju okvirnih vrednosti geometrijskih parametara elemenata noseće strukture portala, dok se nakon toga primenom MKE dobijaju tačniji rezultati u tako određenim okvirnim vrednostima

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Comparative Analysis of Stress in Upper Parts of Portal Framework in Portal Cranes

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Different constructions of portals in portal cranes have caused the development and application of different calculation methods. The aim is to reach the construction of portal framework which can satisfy economic and market demands: price, crane mass and reliability are the most important ones. The paper presents the calculation results of the portal with rotating column by means of theoretical method and final element method (FEM).

High compatibility between stress values and displacement values at the cross sections of upper elements of the portal structure justifies the application of both methods whereas the application of FEM provides the variation of a larger number of input parameters.

Key words: stress analysis, portal, theoretical calculation, FEM calculation

1. INTRODUCTION

Study of the influence that geometrical values of elements of portal crane framework have on the type of connection with rotating platform largely depends on the possibility to vary a larger number of input parameters. Given that application of theoretical calculation methods directly depends on the number of input parameters, analyses and calculation methods are often conducted with a certain reduction of these parameters.

It is obvious that analysis comprehensiveness becomes lower this way but as long as generality of the problem is not violated, the application of the stated method to defining basic relationships between geometrical characteristics of portal framework upper parts is entirely justified.

Once the relationships between geometrical values of portal elements are identified, it is possible to define optimal values by their variation. Then, of course, the computer software, based on different calculation methods (FEM being the most significant), is applied.

2. LAYOUT OF PORTAL LOAD

General layout of a portal crane with rotating column, whose connection between rotating and stationary parts is made by a ring, is shown in Figure 1. The analysis of existing solutions has shown that the optimal solution is the one whose ring and upper portal parts are elastic while lower portal parts are rigid at longitudinal and transverse directions.

A solution defined like this provides a good movement along crane tracks while the oscillation of upper portal parts with the ring has notable dumping, which significantly decreases the influence of dynamic loads.

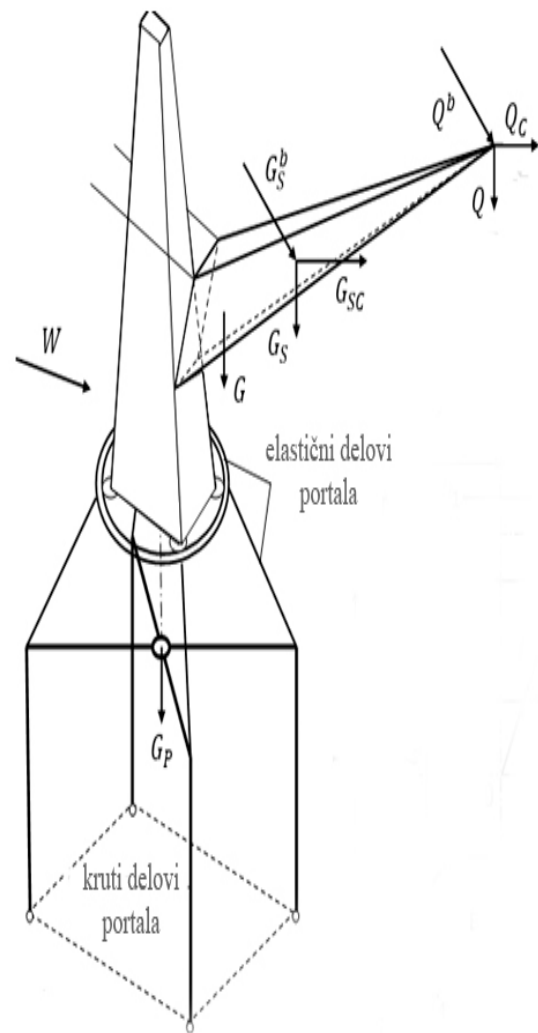


Figure 1: Layout of portal crane load

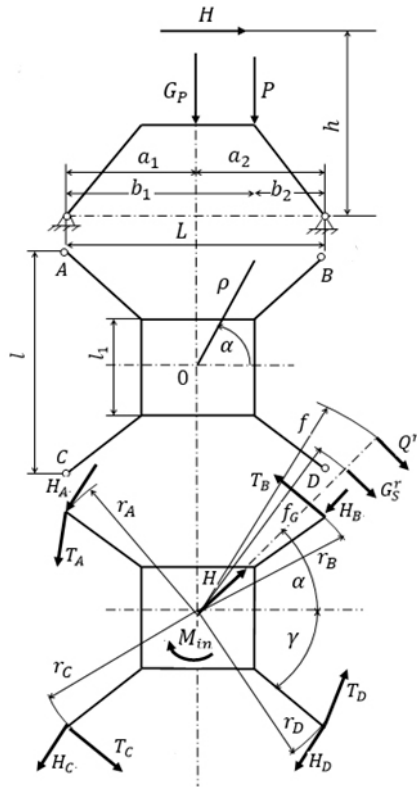


Figure 2: Calculation layout of the portal

Figures 1 and 2 contain the following symbols:

G_p - portal weight,

G - weight of rotating platform with no boom and load,

G_s - boom weight,

Q - vertical component of load and lifting equipment,

W - wind force,

G_s^b and G^b - forces of inertia caused by acceleration or slowing down of the boom and rotating platform, respectively,

G_s^c and Q_c - centrifugal forces of the boom and load, respectively,

P - forces of vertical loads of rotating platform:

$$P = G + G_s + Q \quad (1)$$

H - horizontal force:

$$H = W + G_s^c + Q_c \quad (2)$$

M_{in} - moment caused by inertia forces:

$$M_{in} = Q^b \cdot f + G_s^b \cdot f_G \quad (3)$$

3. CALCULATION OF STRESS AND DISPLACEMENT AT CHARACTERISTIC RING SECTIONS

If loads are defined it is possible to determine loads at sections of connection between upper portal parts and the ring. Theoretical expressions for ring calculation are used to define these loads.

The calculated values of stress for two characteristic sections are shown in Figure 3:

- the section between the ring and upper part of portal leg (point A)
- section between the ring being in the middle of connection between upper leg parts and the ring (point B)

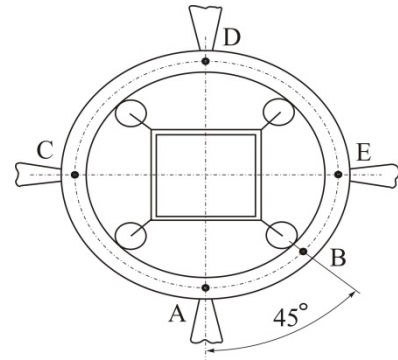


Figure 3: Characteristic sections for the ring calculation

Radial forces at supports are:

$$F_{rA} = F_{rD} = 41,54 \text{ kN}, \quad F_{rC} = F_{rE} = 37,30 \text{ kN} \quad (4)$$

while the moments at supports acting perpendicular to the ring plane are:

$$M_A = M_D = 166 \text{ kNm}, \quad M_C = M_E = 144 \text{ kNm} \quad (5)$$

Vertical load at the column support is $F_V = 485 \text{ kN}$.

Calculation values of the stress at characteristic points of the ring (points A and B), for portal types H and X, are shown in Table 1.

Table 1.

Ring section	Portal type					
	type H			type X		
	M [kNm]	M_t [kNm]	σ_u [kN/cm ²]	M [kNm]	M_t [kNm]	σ_u [kN/cm ²]
A	60,87	83,12	5,10	124,55	144,75	6,04
B	110,82	-7,63	5,50	213,53	52,40	5,85

Application of the stated theory on ring calculations can also provide identification of displacements in the

mentioned ring points. The results of displacement are shown in Table 2.

Table 2.

Section displacements	Portal type			
	type H		type X	
	A	B	A	B
x [mm]	-3,67	-0,19	-3,43	-1,60
y [mm]	13,37	7,66	-7,94	9,31

4. STRESS AND DEFORMATION ANALYSIS BY FEM

Three-dimensional solid model of portal crane framework has been generated in accordance with adopted

geometrical characteristics of portal elements and ring (portal dimensions are presented in Figure 4).

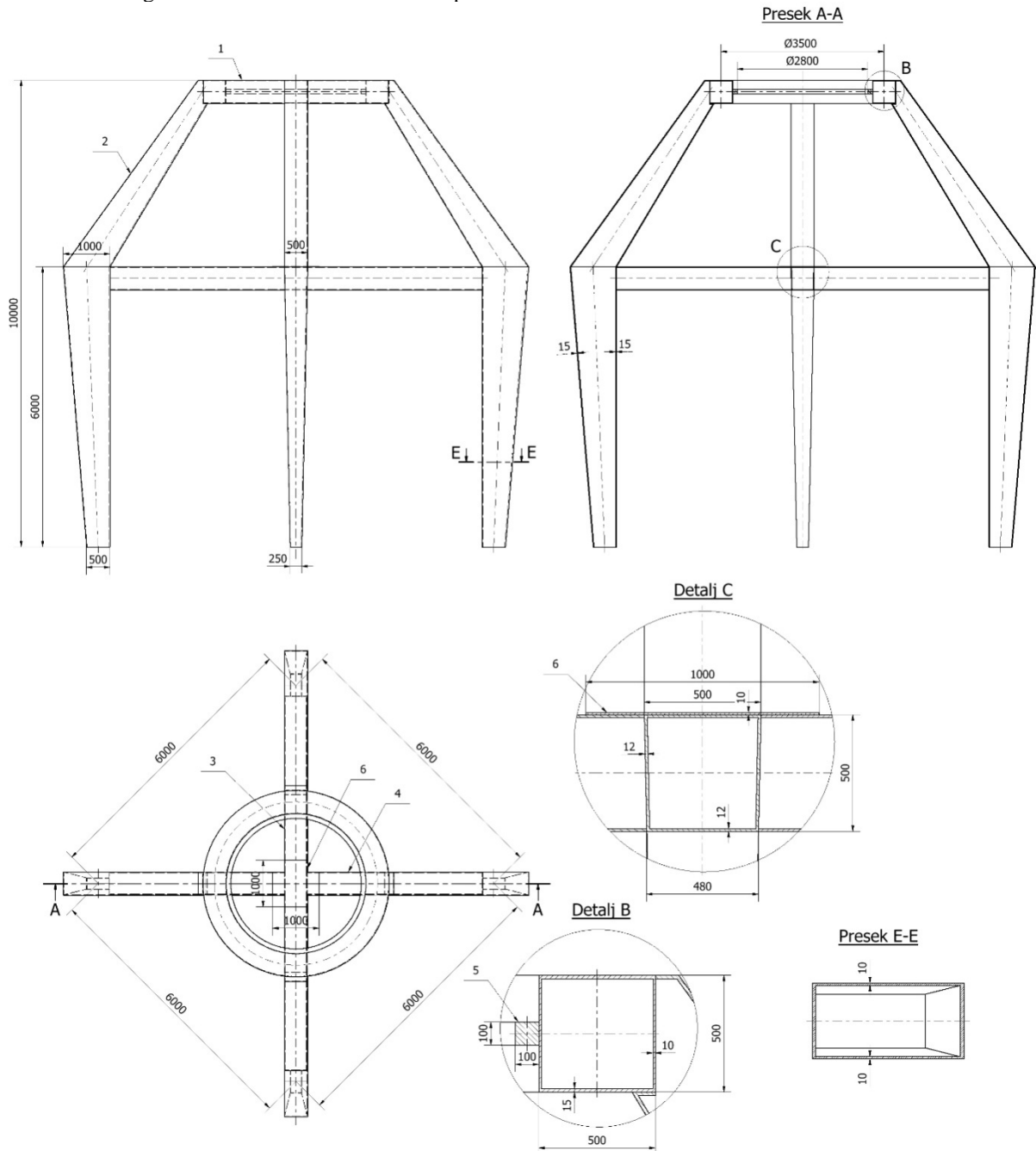


Figure 4: Geometry and dimensions of the portal

Given that supporting wheels are placed symmetrically to the vertical boom plane, the entire concept of the stress and deformation state of portal structure, and

the ring as well, for the 360° angle of rotation of column with the boom, can be formed by means of analyses of the deflection cases of 0° and 45°.

Resultant horizontal force F_H , obtained by decomposing entire moment in vertical plane, is thus decomposed into two identical forces F_N which act on the supporting wheels. If deflection pitch of 15° is adopted, there are four characteristic positions of the boom: 0° , 15° , 30° and 45° as indicated in Figure 5.

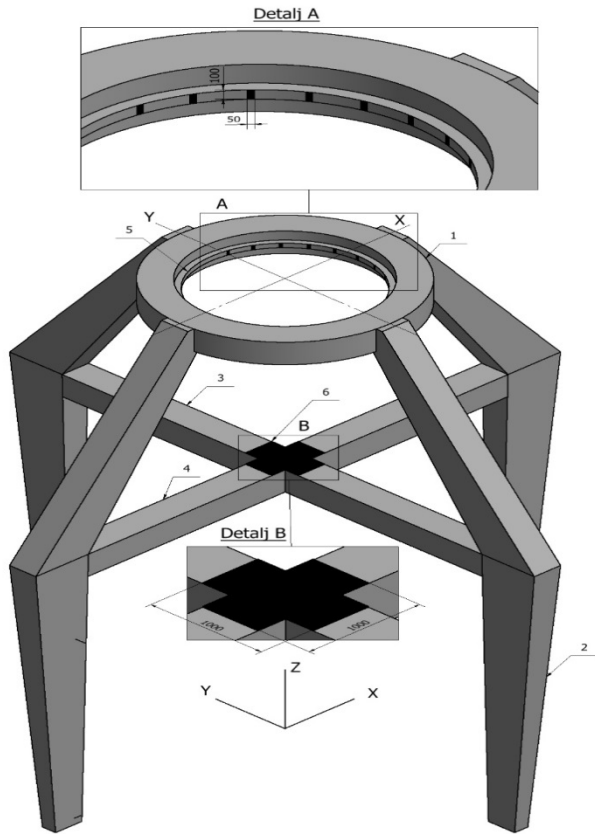


Figure 5: Surfaces for entering portal loads

Analysis of stress and deformation state of portal structure is done by software package Ansys. Three-dimensional model of the structure is discretized by the network of hexagonal volumetric final elements having 20 nodes at apexes and middle points of the edges whose maximum length is 50 mm (Figure 6).

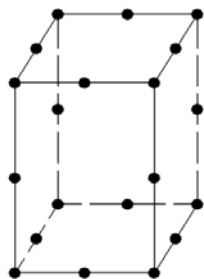


Figure 6: Hexagonal prismatic final element with nodes at apexes and middle points of the edges

These settings result in a fine network of 119,541 final elements and 555,880 nodes. The entire network and its detail which show the relationship between dimensions of final elements and structural elements of the portal are presented in Figures 7 and 8, respectively.

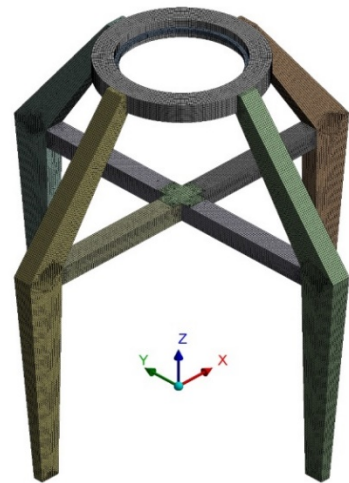


Figure 7: Entire network of final elements

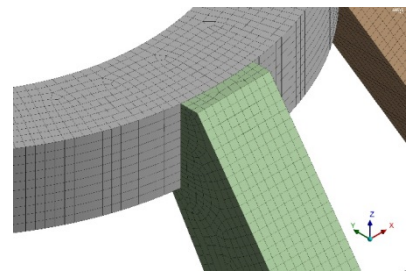


Figure 8: Detail of final elements network

Within the analysis of stress and deformation state of the portal structure, two research cases are formed. They are defined by the angle of vertical boom plane and coordinate plane of XZ global coordinate system: 0° and 45° .

The force of pressure of one wheel on the circular track is $F_N = 280$ kN, while the total horizontal force acting on lower support of rotating column is $F_H = 485$ kN.

Figures 9 and 10 show the boundary conditions for these two positions of the boom.

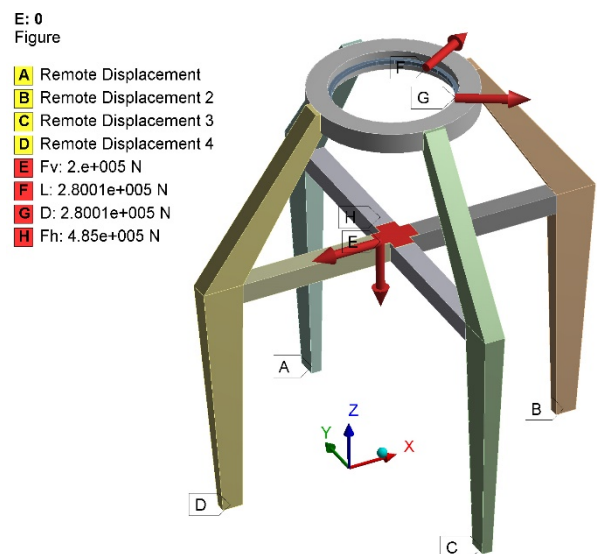


Figure 9: Boundary conditions for 0°

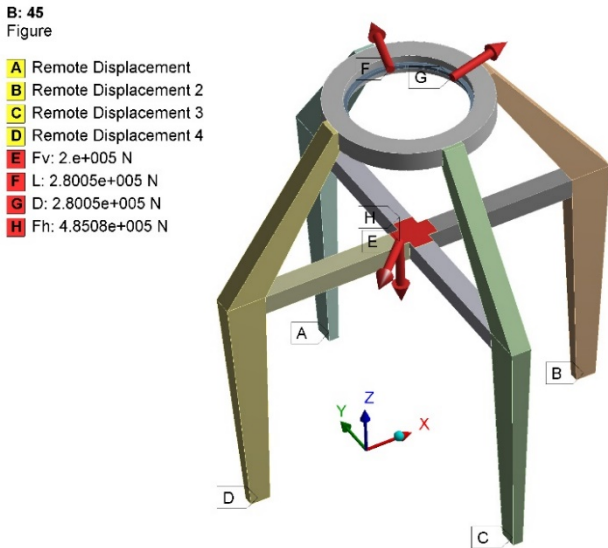


Figure 10: Boundary conditions for 45°

Figures 11 and 12 show equivalent stresses at characteristic points for these two cases.

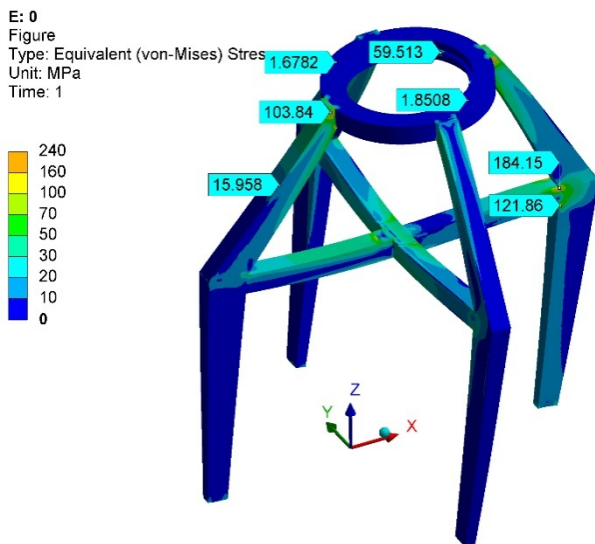


Figure 11: Equivalent stresses for 0°

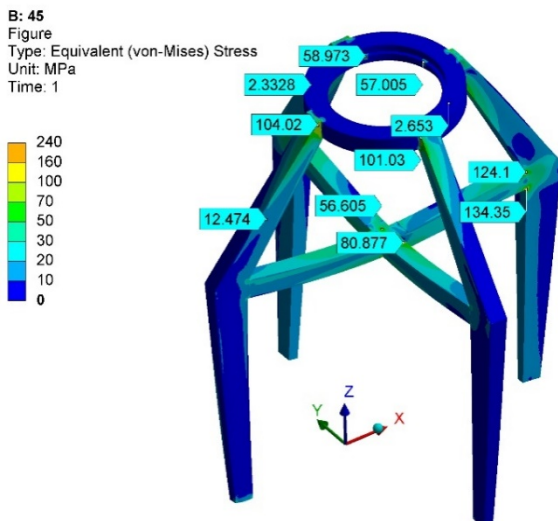


Figure 12: Equivalent stresses for 45°

Figures 13 and 14 show displacements of characteristic points in direction of X axis for these two cases.

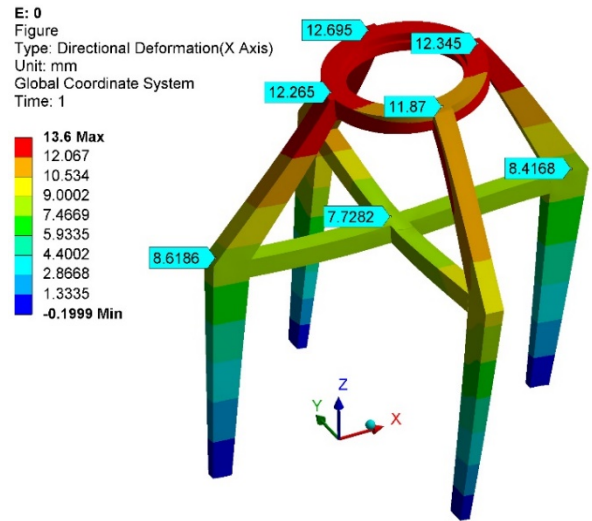


Figure 13: Displacement along X axis for 0°

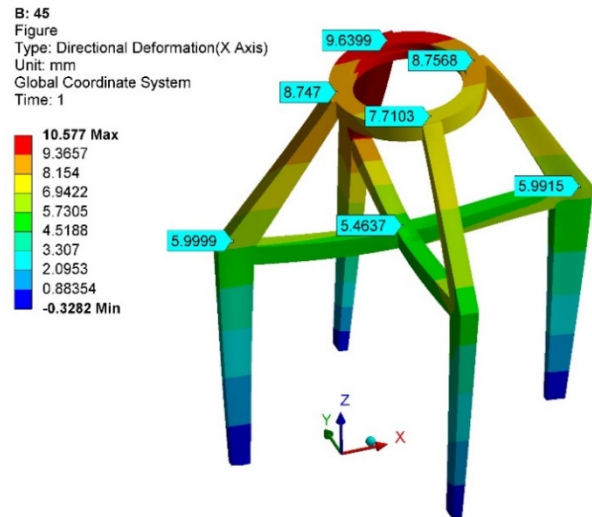


Figure 14: Displacement along X axis for 45°

Figures 15 and 16 show displacements of characteristic points in direction of Y axis for these two cases.

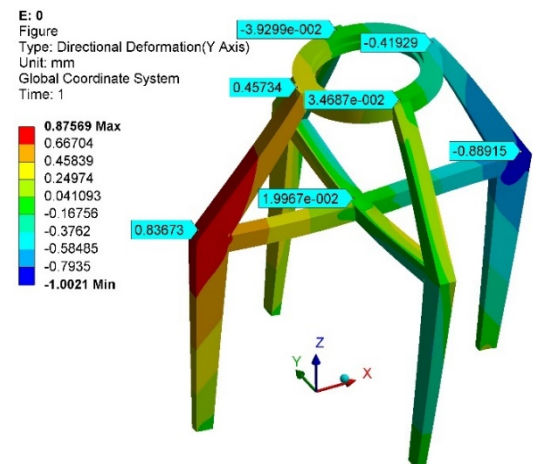


Figure 15: Displacement along Y axis for 0°

5. CONCLUSION

Theoretical and numerical methods for analyzing stress and deformation state of upper parts of portal framework of portal cranes show that theoretical calculation methods and final element method provide compatibility between results which is not beyond the range of accuracy being acceptable in engineering practice. The application of theoretical calculation methods is important in terms of defining general values of geometrical parameters of portal framework, followed by application of FEM which provides more precise results.

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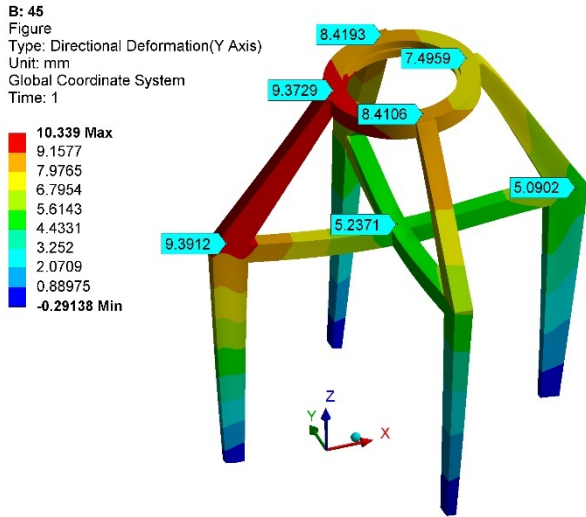


Figure 16: Displacement along Y axis for 45°

Figures 17 and 18 show displacements of characteristic points in direction of Z axis for these two cases.

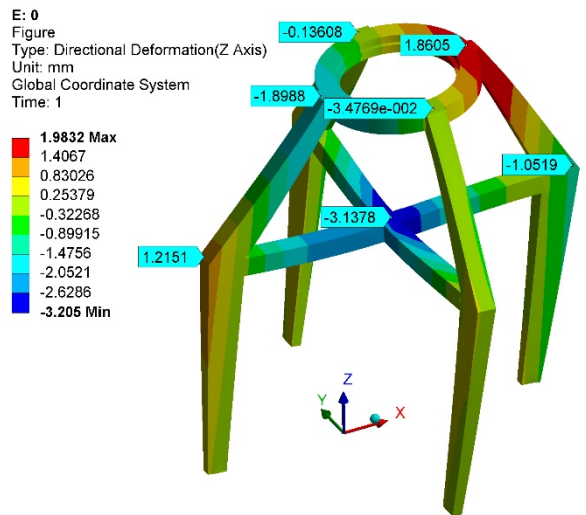


Figure 17: Displacement along Z axis for 0°

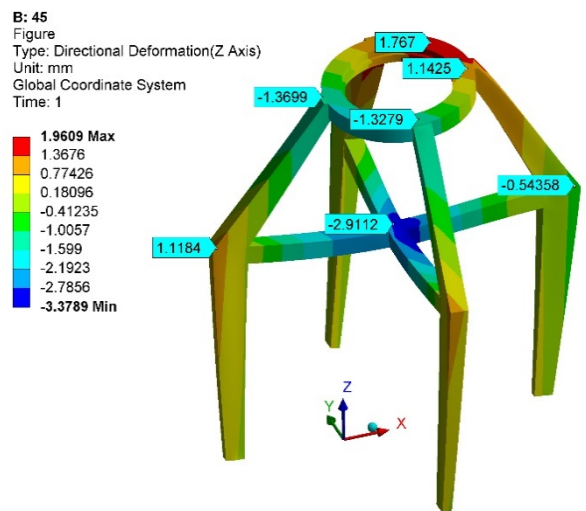


Figure 18: Displacement along Z axis for 45°