



THE ANALYSIS OF FRICTIONLESS CONTACT EFFECTS IN WIRE ROPE STRAND USING THE FINITE ELEMENT METHOD

ANALIZA UTICAJA KONTAKATA BEZ TRENJA U PLETEMU UŽADIMA POMOĆU METODE KONAČNIH ELEMENATA

Gordana KASTRATOVIĆ, Nenad VIDANOVIĆ

University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia

Abstract: This paper discusses the problem of frictionless contact effects in wire rope strand subjected to axial loading. The analysis was carried out by finite element method based computer program. The software used allowed two types of linear contacts, and both of them were applied in this analysis. The comparison of the obtained results was carried out on the parametric 3D model of 6x7 IWRC.

Key words: wire rope, strand, contact, finite element method.

Apstrakt: U ovom radu se analizira problem uticaja kontakata bez trenja u pletenim užadima, koje je podvrgnuto aksijalnom opterećenju. Analiza je sprovedena primenom kompjuterskog programa koji je baziran na metodi konačnih elemenata. Korišćeni program dopušta dva tipa linearnih kontakata i oba su primenjena u ovoj analizi. Rezultati su dobijeni i njihovo poređenje je izvedeno za parametrijski 3D model 6x7 pletenog užeta sa nezavsnim žičanim jezgrom IWRC.

Ključne reči: uže, žica, struk, kontakt, metoda konačnih elemenata.

1 INTRODUCTION

High strength wire ropes are very important tensile structural members. Due to their flexibility and high strength, ropes are in widespread use throughout the mechanical, electrical, mining and naval engineer industries. Applications include lifts, suspension bridges, electrical power transmission, aircraft arresting cables, and mining equipment. It is well known that a major advantage of such elements is their capacity to support large axial load.

In order to predict the wire rope behavior, several theoretical models and analytical studies have been presented in the literature, [1, 2]. Most of them neglect frictional and contact effects, but there are some, that takes those effects into consideration.

1 UVOD

Pletena užad velike nosivosti su veoma važni strukturni elementi koji su opterećeni na zatezanje. Zbog svoje fleksibilnosti i visoke čvrstoće, ona su u širokoj upotrebi u mašinskoj i elektro industriji, brodarstvu, ruderstvu itd. Koriste se kod liftova, visećih mostova, kablova za prenos električne energije i rudarske opreme. Opšte je poznato da je glavna prednost ovih elemenata njihova sposobnost da prenose velika aksijalna opterećenja.

U literaturi je predstavljeno niz teorijskih i analitičkih modela [1, 2], u cilju što boljeg razumevanja, predviđanja i analize ponašanja užadi. Neka od ovih istraživanja zanemaruju efekte trenja i kontakta uopšte, a neka od njih ih manje ili više uzimaju u obzir.

As technology and computer sciences were developing and became more available, numerical analyses started to be frequently used in predicting the wire rope behavior.

One of the first finite element analysis of simple straight strand has been presented by Jiang and al in [3].

Elati et.al [4] developed a new model for simulating the mechanical response of an IWRC.

Elasto-plastic contact problem of laying wire rope using finite element analysis has been presented in [5].

A simple straight strand based on Cartesian isoparametric formulation was presented through finite element method in [6].

A realistic 3D structural model and finite element analysis of a simple wire strand has been briefly explained in [7], by Imrak and Erdonmez. The same authors presented 3D solid model and wire-by-wire analysis of IWCR in [8].

However, it is still very difficult to model and analyze wire ropes using numerical methods, such as finite element method, because of its complex geometry and frictional and contact effects. Also, this kind of analysis requires substantial computer resources. On the other hand, both, analytical studies and numerical analyses show that friction has no effect for certain amount of loading.

The aim of this paper is to explore this aspect of wire rope behavior and to analyze of frictionless contact effects in the independent wire rope core (IWRC), - using the finite element method computer program, in order to minimize the extensive hardware requirements and computational time.

2 FINITE ELEMENT MODEL AND ANALYSIS

A 3D finite element model of ICWR was created by using both CATIA and Ansys12 Workbench. First, the parametric geometrical model was created in Generative Shape Design mode of Catia. The obtained geometrical model was then imported as IGES format to Ansys

Sa druge strane, kako su se tehnologija i računarske tehnike razvijale i postajale dostupne, numeričke analize i metode su počele sve češće da se koriste u predviđanju ponašanja pletenih užadi.

Jednu od prvih analiza metodom konačnih elemenata su predstavili Jiang i grupa autora u [3].

Elati i ostali [4] razvili su novi model simulacije mehaničkog odziva pletenog užeta sa nezavisnim žičanim jezgrom (IWRC)

Elastično-plastični problem kontakata između žica u pletenom užetu pomoću metode konačnih elemenata je analiziran u [5].

Model jednostavnog pravog struka zasnovan na metodi konačnih elemenata je opisan u radu [6].

Realni 3D strukturni model, kao i analiza metoda konačnih elemenata osnovnog struka su ukrašeni objašnjeni u radu Imraka i Erdonmeza [7]. Isti autori su u radu [8] predstavili 3D solid model i analizu wire-by-wire užeta sa nezavisnim žičanim jezgrom.

Međutim, bez obzira na postojeća istraživanja, uvek je veoma teško modelovati i analizirati wire rope užet pomoću numeričkih metoda, kao što je na primjer metoda konačnih elemenata. Razlog tome je izuzetno komplikovana geometrija, kao i uticaj kontakata i trenja između žica u pletenim užadima. Isto tako, ova vrsta analize zahteva znatne kompjuterske resurse. Sa druge strane, i analitičke numeričke analize pokazuju da se uticaj trenja može zanemariti za određene veličine opterećenja.

Cilj ovog rada jeste istraživanje ovog aspekta ponašanja pletenih užadi, kada se trenje može zanemariti, a analiza kontakata sprovodi se metodom konačnih elemenata, što bi sumarizovalo duge i zahtevne kompjuterske prorade, tj. simulacije.

2 ANALIZA I MODELOVANJE METODOM KONAČNIH ELEMENATA

3D model konačnih elemenata pletenog užeta sa nezavisnim žičanim jezgrom kreiran je pomoću dva softvera, CATIA and Ansys12 Workbench. Prvo je ostvareno parametarski geometrijski model u CATIA-u, odgovarajućeg moda u Catia. Dobijeni geometrijski model je, zatim, importovan kao IGES format u Ansys12 Workbench.

12 Workbench. This program allowed specification of material properties, application of loads, generation of finite element mesh, and contact definition as well as solving and obtaining necessary output data.

As mentioned earlier, a number of analytical and numerical studies show that for certain amount of axial loading, friction, has no effect. But regardless of friction, the contacts between wires exist and must be taken into consideration. They determine how the wires can move relative to one another, and the distribution of loading between them as well.

The software used in this study allows two types of linear contacts, and both of them were applied in this analysis. Bonded contact is the default configuration of contact and applies to all contact regions (surfaces, solids, lines, faces, edges). If contact regions are bonded, then no sliding or separation between faces or edges is allowed, as if the bodies were *glued*. No Separation contact setting is similar to the bonded case. It only applies to regions of faces (for 3-D solids) or edges (for 2-D plates). Separation of faces in contact is not allowed, but small amounts of frictionless sliding can occur along contact faces.

2.1 Numerical Example and Analysis of Results

The elastic behavior of IWRC subjected to axial loading exists until the value of the applied axial strain reaches 0.008 (Figure 1), and that is the domain of the investigated behavior.

12 Workbench. Ovaj softver omogućava, zadavanje odgovarajućih karakteristika materijala, opterećenja, vrši se kreiranje mreže konačnih elemenata, definisanje odgovarajućih tipova kontakata, kao i reševanje i dobijanje odgovarajućih izlaznih veličina.

Kao što je već rečeno, više analitičkih i numeričkih analiza pokazuju da se uticaj trenja može zanemariti za određene veličine opterećenja. Međutim, bez obzira na trenje, kontakti između žica pletenih užadi moraju biti uzeti u obzir. Oni određuju relativno pomeranje između žica, kao i međusobnu raspodelu opterećenja.

Korišćeni softver dopušta dva tipa linearnih kontakata i oba su primenjena u ovoj analizi. "Vezani" (bonded) kontakt je "default" konfiguracija kontakata koja se može primeniti na sve kontaktne regije (površine, solide, linije, stranice, ivice). Ako su kontaktne regije vezane, nije dozvoljeno proklizavanje ili odvajanje stranica ili ivica, drugim rečima, vezana tela se ponašaju kao da su slepljena. Konfiguracija kontakata "bez odvajanja" (no separation) je slična prethodnoj. Može se primeniti samo na regije stranica (kod 3D solida) ili ivica (kod 2D ploča). U ovom slučaju, kao što i sam naziv kaže, odvajanje stranica u kontaktu nije dozvoljeno, ali malo proklizavanje bez trenja se može javiti duž stranica u kontaktu.

2.1 Numerički primer i analiza rezultata

Elastično ponašanje pletene žice podvrgnute aksijalnom opterećenju je prisutno sve dok aksijalna elongacija ne dostigne vrednost 0.008 (slika 1), a to je upravo područje u kome se ova analiza i sprovodi.

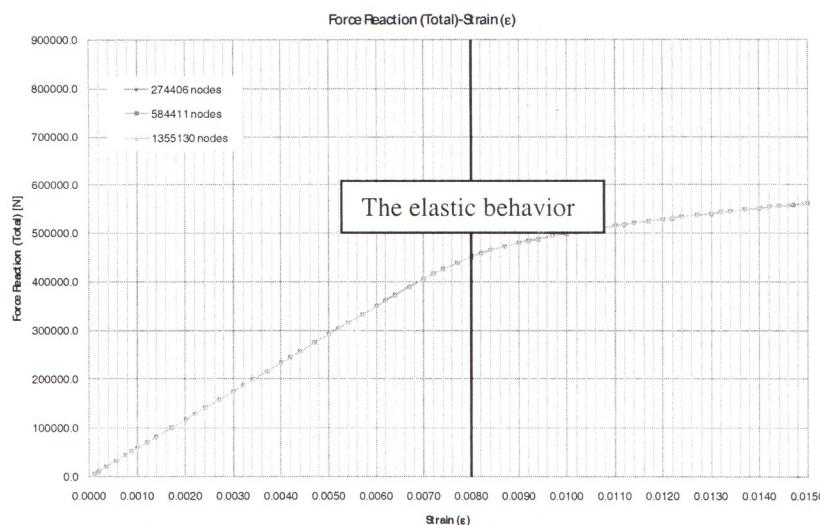


Figure 1 Diagram of resulting axial force for IWRC 6x7 wire rope
slika 1 Dijagram rezultujuće aksijalne sile za IWRC 6x7

As it can be observed, friction has no effect on resulting axial force in investigated domain, which is indicated in [7].

The IWRC 6x7 wire rope has been taken as an example. The core strand the radius of center wire is $r_1=1.97$ mm, and outer wire $r_2=1.865$ mm, and pitch length 70 mm; the outer strand center wire radius is $r_3=1.6$ mm, and outer wire radius $r_4=1.5$ mm and pitch length 193 mm. The overall length of the wire rope model is 18 mm (Figure 2).

Kao što se može uočiti, trenje nema uticaja na rezultujuću aksijalnu silu u analiziranom području, kako je i naglašeno u [7].

Kao primer je analizirano pleteno uže sa nezavsnim žičanim jezgrom IWRC 6x7. Poluprečnik centralne žice jezgra je $r_1=1.97$ mm, a spoljašnje $r_2=1.865$ mm, sa dužinom koraka od 70 mm, dok je poluprečnik centralne žice struka $r_3=1.6$ mm, a spoljašnje žice struka $r_4=1.5$ mm, sa dužinom koraka od 193 mm. Ukupna analizirana dužina pletenog užeta je 18 mm (slika 2).

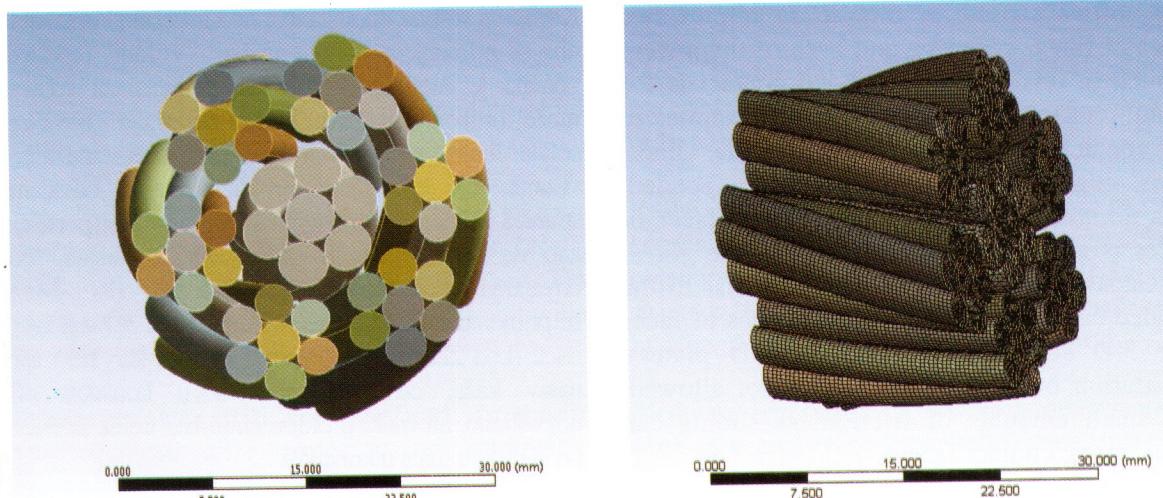


Figure 2 3D Finite element model
slika 2 3D model konačnih elemenata

The model was meshed, and the prescribed boundary conditions were used for solving. On one end of the model the degree of freedom in all three directions were constrained, and on the other end the displacement in x and y directions were restrained to zero. As mentioned, the axial loading behavior was analyzed. An axial strain in increments of 0.001 was applied, the modulus of elasticity was $E=1.88e11$ Pa, and Poisson's ratio $\nu=0.3$.

Izršeno je generisanje mreže konačnih elemenata na prethodno kreiranom geometrijskom modelu, unešeni su prethodno definisani granični uslovi neophodni za sprovođenje simulacije. Jedan kraji modela je fiksiran, dok su na drugom kraju pomeranja u x i y pravcu svedena na nulu. Kao što je već rečeno, analizirano je ponašanje užeta pod aksijalnom opterećenju, pri čemu je zadavana podužna elongacija u z pravcu sa inkrementom od 0.001, pri čemu je modul elastičnosti $E=1.88e10$ Pa, a Poasonov koeficijent $\nu=0.3$.

3 COMPARISON OF THE RESULTS

The described numerical model is solved, and results are presented in the following diagrams. To be more specific, the solutions were obtained for three different meshed models, i.e., for 274406, 584411 and 1355130 number of nodes.

3 POREĐENJE REZULTATA

Ovako definisan numerički model je analiziran, rezultati su predstavljeni na sledećim dijagramima. Zapravo, rešenja su dobijena za tri različita modela konačnih elemenata, tj. za modele 274406, 584411 i 1355130 čvorova.

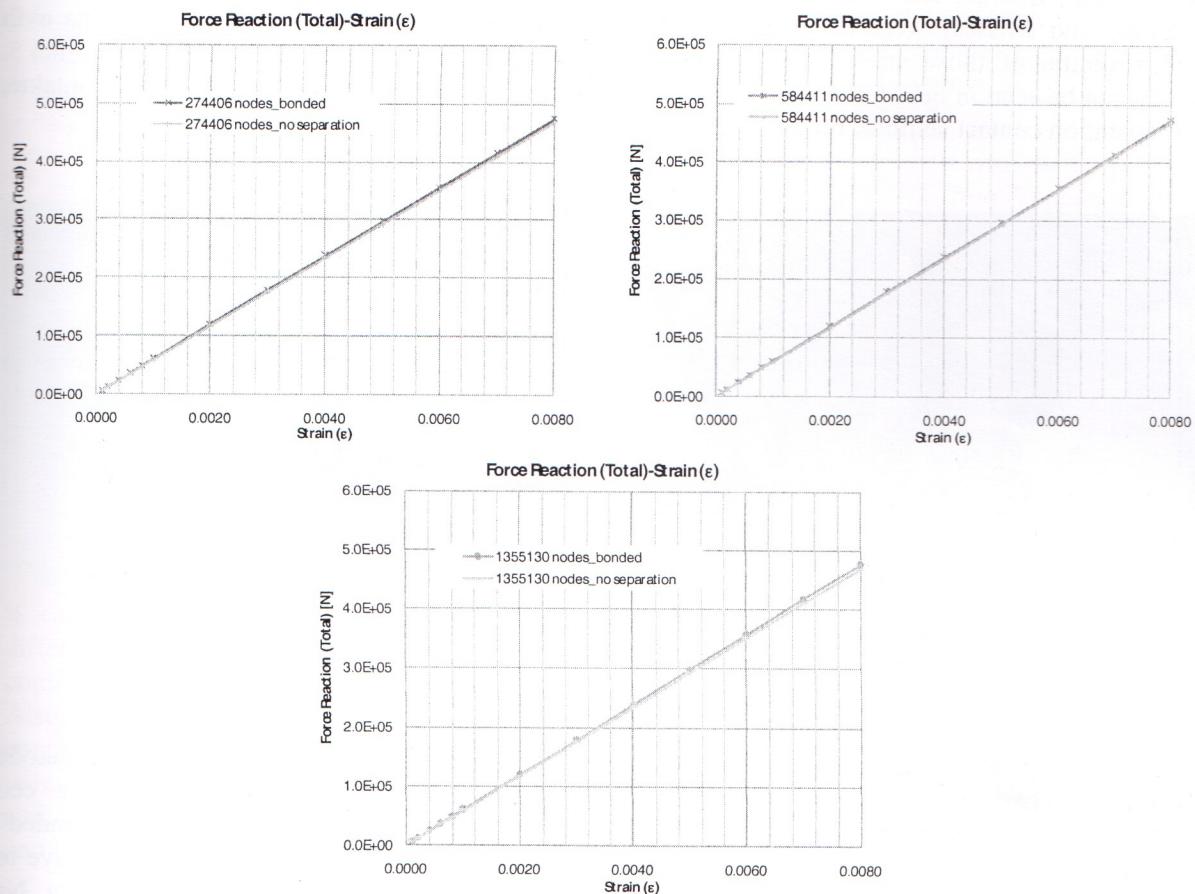


Figure 3 Diagram of resulting axial force for two different types of contact
 slika 3 Dijagram rezultujuće aksijalne sile za dva različita tipa kontakta

The diagrams (Figure 3) show axial force for two different types of contact and three different meshed models. They also show excellent agreements between obtained results and with the results from [7]. That comparison is presented in following diagram (Figure 4).

Na ovim dijagramima (slika 3) je prikazana rezultujuća aksijalna sila za dva različita tipa kontakta i tri različita modela konačnih elemenata. Na njima se može uočiti odlično međusobno poklapanje dobijenih rezultata i rezultata iz [7], koje je dato na narednom dijagamu (slika 4).

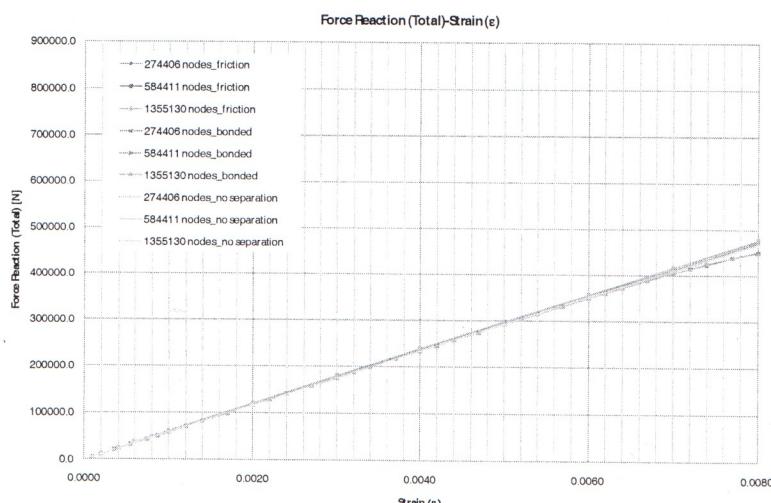


Figure 4 Comparison of the resulting axial force
 slika 4 Poređenje rezultujuće aksijalne sile

Besides the resulting axial force, the equivalent stresses (von Misses) were calculated as well. The variation of those stresses throughout the model can be seen in next figure, for bonded and no separation contact settings, respectively.

Pored rezultujuće aksijalne sile analizirani su i ekvivalentni (von Misses) naponi. Promena ovih naponova kroz ceo model može se videti na Slici 5. i to za "bonded" i "no separation" kontakte, respektivno.

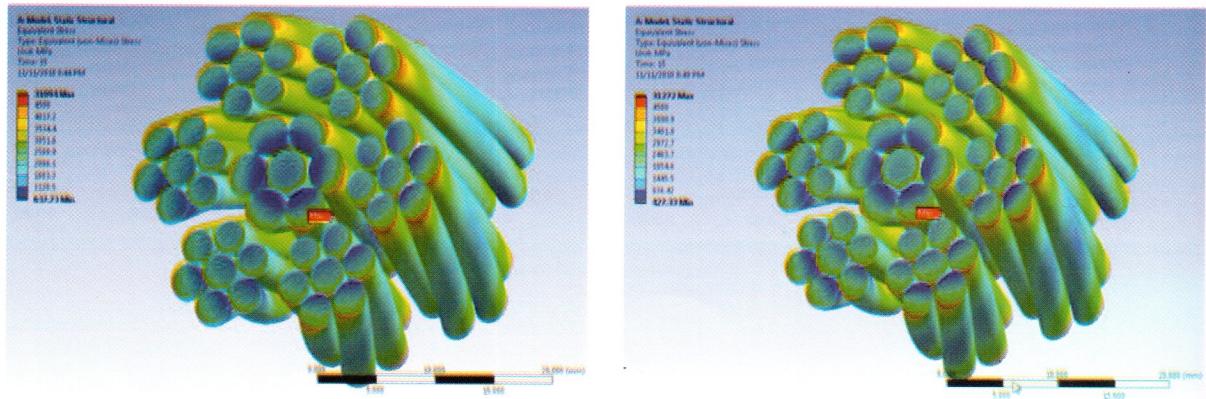


Figure 5 Von Misses stresses for two different types of contact
slika 5 Von Misses naponi za dva različita tipa kontakta

Pressures between individual wires were calculated, also. The variation of pressures throughout the model can be seen in Figure 6. for bonded and no separation contact settings, respectively, for model with maximum number of nodes. The figure shows that the position of maximum pressure is in the middle of contact line between outer core wires and core center wire.

Pritisici između pojedinačnih žica su takođe analizirani. Promena ovih pritisaka kroz ceo model može se videti na Slici 6. i to za "bonded" i "no separation" kontakte, respektivno, a sve to za modele sa maksimalnim brojem čvorova. Na slici se može uočiti da je u oba slučaja mesto maksimalnog pritiska na sredini linije dodira između žica u jezgru.

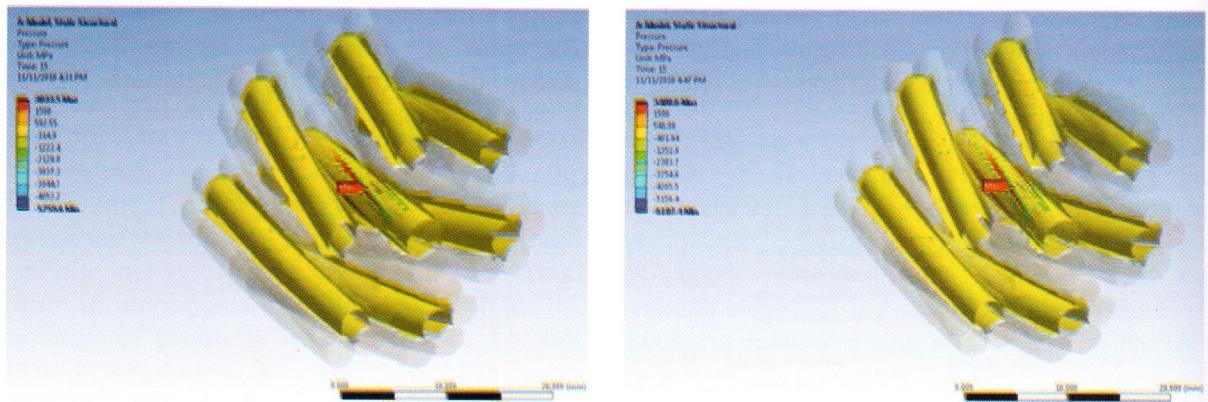


Figure 6 Pressure for two different types of contact
slika 6 Pritisici za dva različita tipa kontakta

Those pressures, their minimum and maximum values are shown on diagrams in Figure 7. On diagrams are shown pressures for all three meshed models.

Minimalne i maksimalne vrednosti ovih pritisaka su prikazane na dijagramima na Slici 7. Na njima je predstavljena promena pritisaka za sva tri različita modela konačnih elemenata.

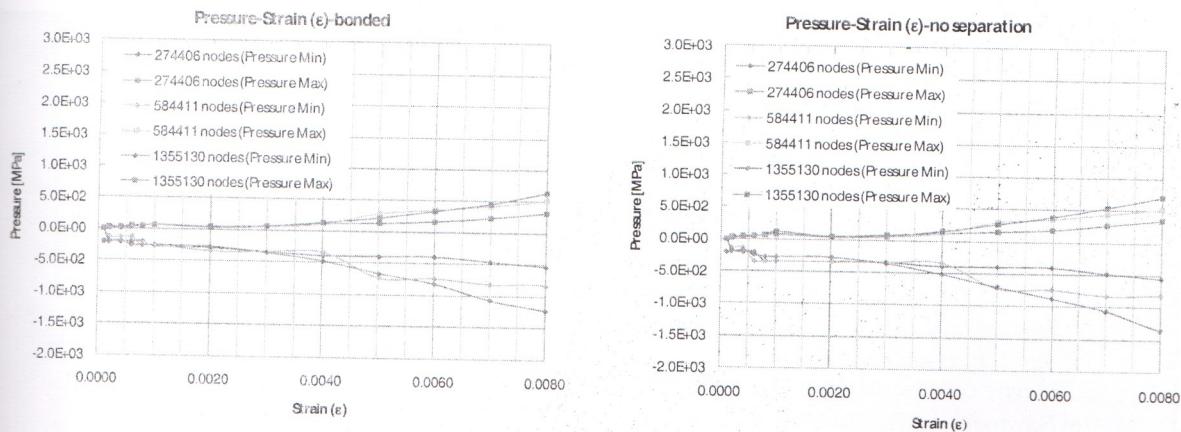


Figure 7 Diagrams of pressures for two different types of contact
slika 7 Dijagrami pritiska za dva različita tipa kontakta

It can be seen that there are no significant difference in these values for two analyzed contact settings, for all three meshed models. Also, based on those pressures, it can be concluded that the contact between the outer core wires and center wire core, along with all other contacts play a key role in predicting behavior and load distribution of wire rope.

4 CONCLUSION

Using commercial software, which is currently widely available, the analysis of frictionless contact effects in wire rope strand using the finite element method was carried out. The wire rope was subjected to axial loading. Because, it is still very difficult to model and analyze wire ropes using numerical methods, due to its complex geometry and frictional and contact effects, this analysis took into consideration only the elastic behavior domain, where frictional effects could have been neglected. The two different types of linear contacts between wires were applied. The obtained results showed excellent agreements with the results from the literature that was available. The results also emphasize the significance of the nature of the contact between wires in IWRC, once more. At the end it can be concluded that this kind of analysis can be more than useful in cases when the strain of wire ropes does not exceed 0.008.

Može se uočiti da ne postoje bitne razlike između vrednosti pritisaka za dva različita tipa analiziranih kontakta, za sva tri različita modela konačnih elemenata. Isto tako, na osnovu ovih pritisaka se može zaključiti da kontakti između žica u jezgru, imaju glavnu ulogu u predviđanju ponašanja i prenošenju opterećenja između žica pletenog užeta.

4 ZAKLJUČAK

U ovom radu je, uz pomoć komercijalnog softvera baziranom na metodi konačnih elemenata, koji je bio dostupan, analiziran problem uticaja kontakata bez trenja u pletenim užadima, koja su podvrgнутa aksijalnom opterećenju. U okviru ove analize razmatrano je samo ponašanje užeta unutar elastične oblasti, jer je još uvek veoma teško modelovati i analizirati užad pomoću numeričkih metoda, zbog izuzetno komplikovane geometrije, kao i uticaja kontakta i trenja između žica u pletenim užadima. To je omogućilo zanemarivanje uticaja trenja. Razmatrana su dva različita tipa kontakata. Dobijeni rezultati su pokazali odlično slaganja sa rezultatima koji postoje u dostupnoj literaturi. Dobijeni rezultati takođe još jednom ističu značaj prirode kontakata između žica u pletenim užadima. Na kraju se može zaključiti da ovakva vrsta analize može biti korisna u svim onim slučajevima aksijalnog opterećenja užeta u kojima elongacija ne prelazi vrednost od 0.008.

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