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SANACIJE I REKONSTRUKCIJE TRANSPORTERA I ODLAGAČA REPAIR AND RECONSTRUCTION OF BELT WAGONS AND STACKERS

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UVOD

Izvedene sanacije i rekonstrukcije transportera i odlagača su rezultat primene razvijene metodologije dijagnostike čvrstoće konstrukcija. Ona podrazumeva kompjuterski proračun metodom konačnih elemenata i eksperimentalna merenja. Nalaženje i rešavanje uzroka problema zahteva primenu numeričko-eksperimentalne dijagnostike čvrstoće elemenata, kompjutersko modeliranje i proračun noseće strukture konstrukcije (KOMIPS) primenom numeričke metode konačnih elemenata kroz statički, dinamički i termički proračun njenih nosećih elemenata. Eksperimentalna merenja imaju zadatak da izmere opterećenje konstrukcije u radu, ugib, pomeranja, napon i ubrzanje. To znači da ona definišu za proračun potrebno ulazno opterećenje i verifikuju rezultate proračuna. Primena navedenog proračuna omogućava minimiziranje obima merenja.

SANACIJA I REKONSTRUKCIJA OSOLONCA DONJE GRADNJE ODLAGAČA ARS1400 O&K (POVRŠINSKI KOP TAMNAVA ISTOK)

Ovaj odlagač je u eksploataciji doživeo više havarija i velika oštećenja. Poslednja havarija prikazana je na sl. 1.

Računski model konstrukcije dat je na sl. 2. Najnepovoljnije je opterećenje od 4560 kN sa težištem u tački sa radijusom od 100 cm i uglom od 60° od podužne ose.

Deformacija je prikazana je na sl. 2. Raspodela napona i energije dati su na sl. 3. Primećuje se vrlo visok nivo napona u vertikalnoj kritičnoj ploči, izraženu koncentraciju napona i dominantan smicajni napon. Izračunat kritičan Ojlerov napon smicanja ove ploče na izbočavanje iznosi 13 kN/cm² (proračunom je utvrđeno 11,5 kN/cm²).

Može se konstatovati da je navedena ploča radila u veoma nepovoljnom naponskom polju. Njeno izbočavanje i pucanje nastupilo je zbog bliskosti radnog i kritičnog napona. Ona je uzrok havarije.

Izvedena sanacija i rekonstrukcija obuhvatila je sledeće: zadržane su postojeće vertikalne ploče iste debljine, dodato je jedno vertikalno ukrucenje na polovini dužine ploče i dodate su dve vertikalne ploče debljine 2,5 cm na rastojanju 10 cm od vertikalne ploče. Nosač na drugoj strani je samo rekonstruisan.

Raspodela napona i energije data je na sl. 3.

INTRODUCTION

The repair and reconstruction of belt wagons and stackers are performed by applying a developed methodology of structural strength diagnostics. It includes procedure by computer calculation using the finite elements method and experimental tests. Finding and solving the cause of problems requires use of numerical and experimental diagnostics of element strength, computer modelling and calculation of loaded structures (KOMIPS) using numerical finite element method through static, dynamic, and thermal analysis. The purpose of experimental tests is to measure the loads in service, deflections, displacements, stresses, and acceleration. In other words, it defines necessary input for the calculation and also verifies the results. This calculation procedure minimizes the scope of experimental tests.

REPAIR AND RECONSTRUCTION OF THE SUPPORT ON THE LOWER ASSEMBLY OF THE ARS1400 O&K STACKER (OPEN-CAST MINE TAMNAVA ISTOK)

This stacker has suffered severe damages during service. The latest failure is shown in Fig. 1.

The numerical model of the structure is given in Fig. 2. The most unfavourable load value of 4560 kN is centred at a radius of 100 cm and 60° from the longitudinal axis.

The strain is shown in Fig. 2. Stress and energy distributions are given in Fig. 3. High stress level in a vertical critical plate, a high stress concentration and dominant shear stress are noticeable. The critical calculated Euler's shear stress value in this plate is 13 kN/cm² (calculations give a value of 11.5 kN/cm²).

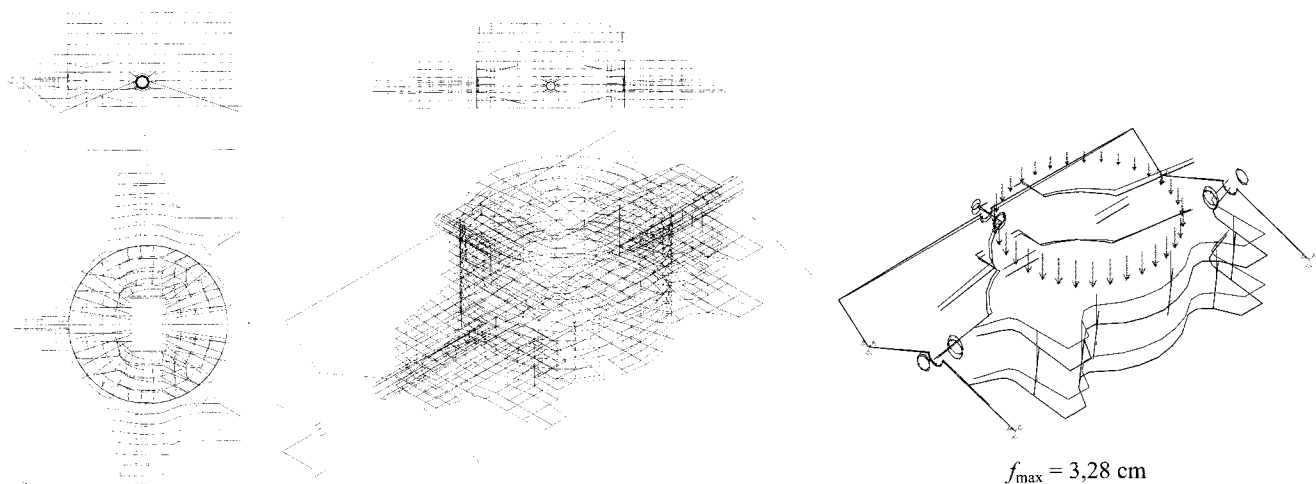
The conclusion is that the given plate has been working under very unsuitable stress field. Its buckling, followed by cracking, occurred due to close values of the working and critical stress. This is what had caused failure.

Performed repairs and reconstruction had included: two existing vertical plates of identical width had remained, a vertical stiffener was added on the half length of the plate, and two vertical plates 2.5 cm thick were added at 10 cm distance from the vertical plate. The supporting element on the other side was merely reconstructed.

Stress and energy distributions are shown in Fig. 3.



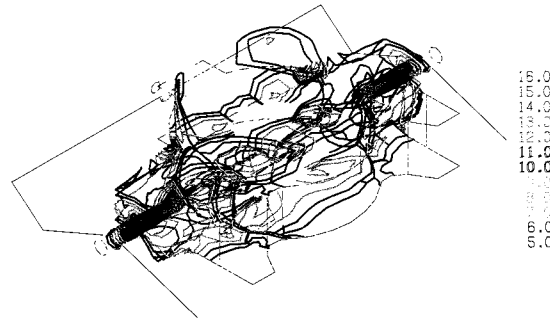
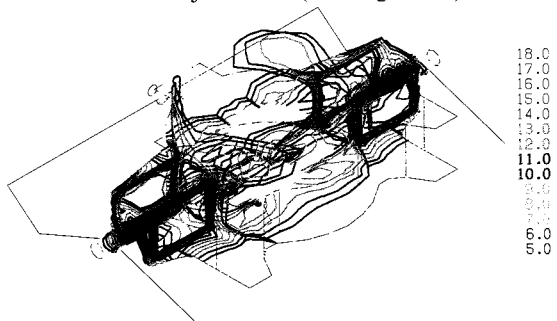
Slika 1. Havarija na odlagaču ARS1400 O&K
Figure 1. Damage on the ARS1400 O&K stacker.



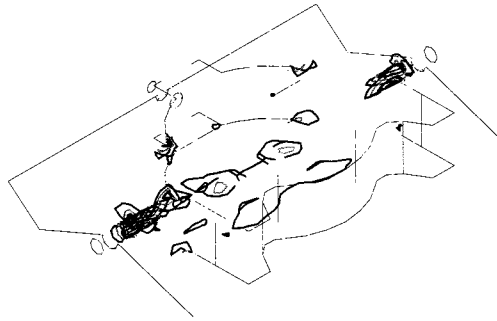
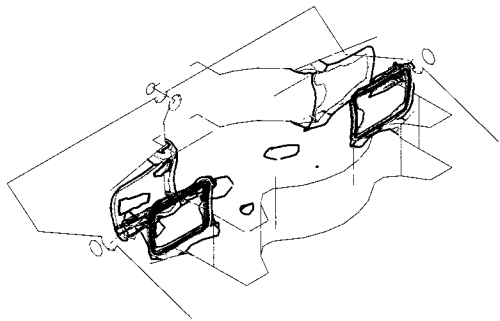
Slika 2. Računski model i deformacija
Figure 2. Numerical model and strains.

Postojeći model (Existing model)

Rekonstruisani model (Reconstructed model)

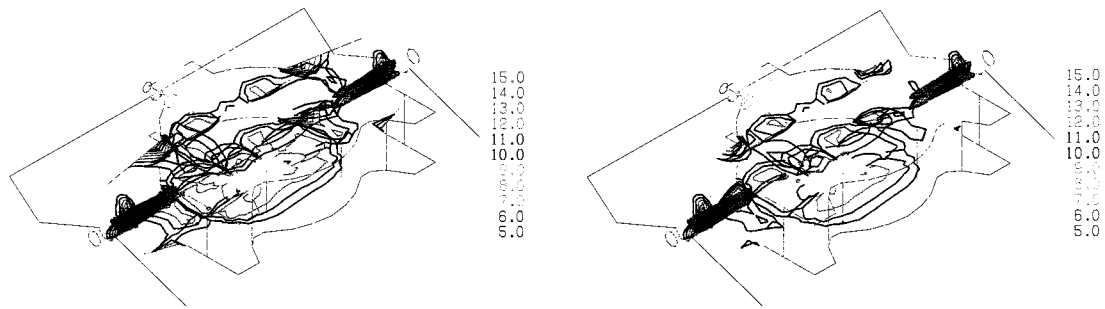


Ekvivalentni napon (Equivalent stress)

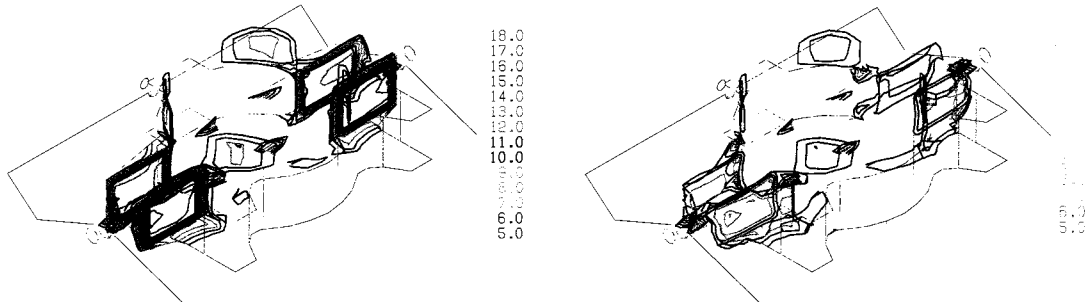


Energija deformisanja (Strain energy)

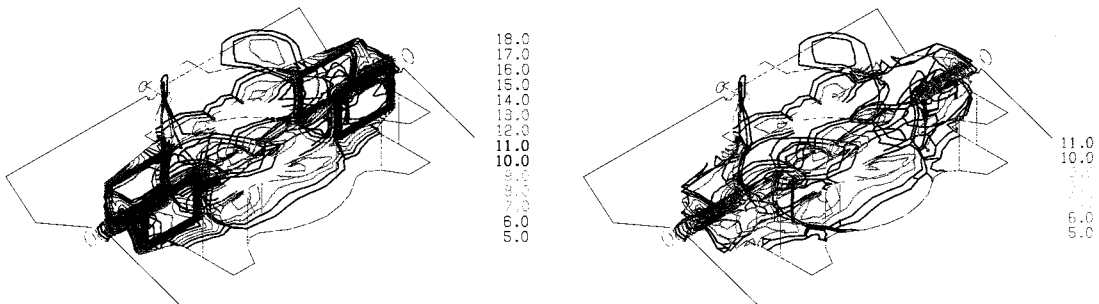
Slika 3. Raspodela napona [kN/cm²] i energije deformisanja
Figure 3. Stress [kN/cm²] and strain energy distribution.



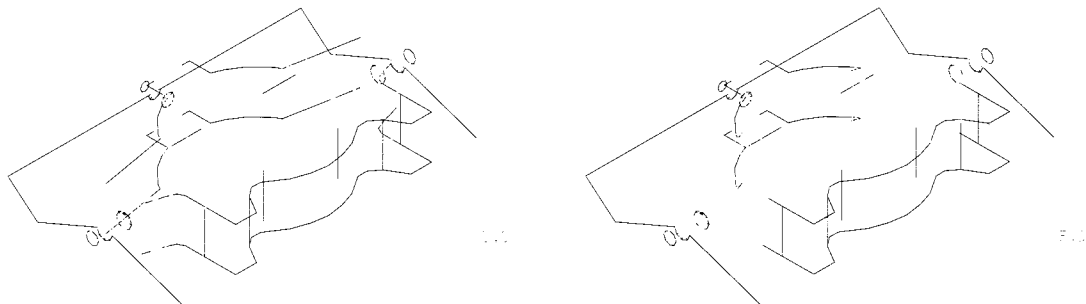
Normalni napon (kritična vertikalna ploča: postojeći 15, rekonstruisan 9)
Normal stress (critical vertical plate: existing 15, reconstructed 9)



Smicajni napon (Shear stress)



Membranski napon (Membrane stress)



Savojni napon (Bending stress)

Slika 3. Raspodela napona [kN/cm^2] i energije deformisanja [kNcm] (nastavak)
Figure 3. Stress [kN/cm^2] and strain energy [kNcm] distribution. (continued)

Posle izvedene sanacije i rekonstrukcije odlagač je uspešno nastavio sa radom.

REKONSTRUKCIJA STUBA ODLAGAČA ARS1400 O&K (POVRŠINSKI KOP TAMNAVA ISTOK)

Proračun i modeliranje stuba izvedeno je samo sa jednim stubom. Poprečno opterećenje ovde nije razmatrano. Rekonstrukcija se odnosi samo na bolje prihvatanje osnovnog opterećenja u podužnoj ravni stuba. Razmatrano je najnepovoljnije opterećenje.

After repair and reconstruction the stacker continued working successfully.

RECONSTRUCTION OF THE SUPPORT OF STACKER ARS1400 O&K (OPEN-CAST MINE TAMNAVA ISTOK)

Support calculation and modelling was performed with a single beam. Transversal loading has not been taken into account here. The only purpose of the reconstruction is to improve support behaviour in the longitudinal plane under basic loading. The worst loading case is considered.

Računski model dat je na sl. 4. Predložena rekonstrukcija je izvedena kroz produženje pojasnog lima b_2 i njegovog ojačanja a_2 (debljina oba lima je 10 mm) do vrha stuba i delimično ojačanje pojasnog lima d_1 i d_2 sa limom dimenzija $500 \times 1500 \times 20$ mm.

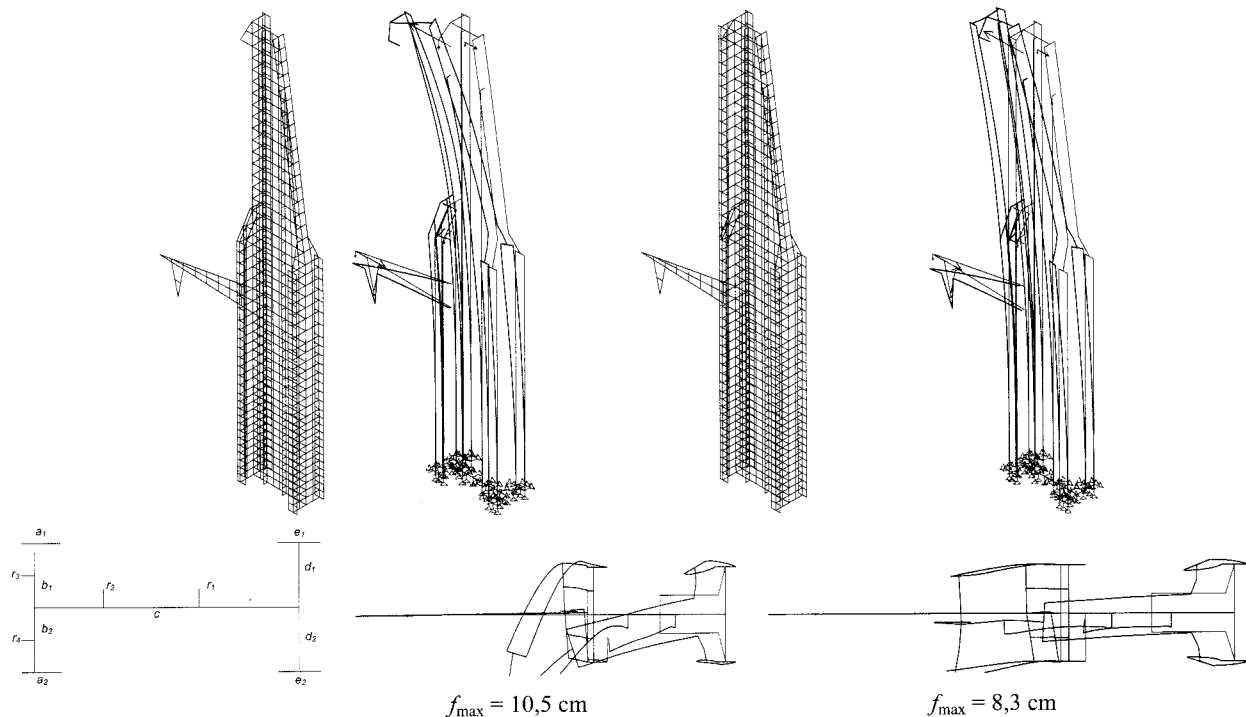
Rezultati proračuna postojeće konstrukcije i rekonstrukcije dati su paralelno na sl. 5 i u tabeli 1.

Rekonstrukcija je dovela do uklanjanja uvijanja stuba, značajnog smanjenja savijanja, smanjenja napona za 37,5% i značajnog ublaženja koncentracije napona.

The numerical model is shown in Fig. 4. The suggested reconstruction was performed by extending the plate b_2 and its reinforcement a_2 (thickness of both plates is 10 mm) up to the top of the support, and also by partial plate reinforcements d_1 and d_2 with plates $500 \times 1500 \times 20$ mm.

Numerical results of the existing structure and the reconstruction are both given in Fig. 5 and in Table 1.

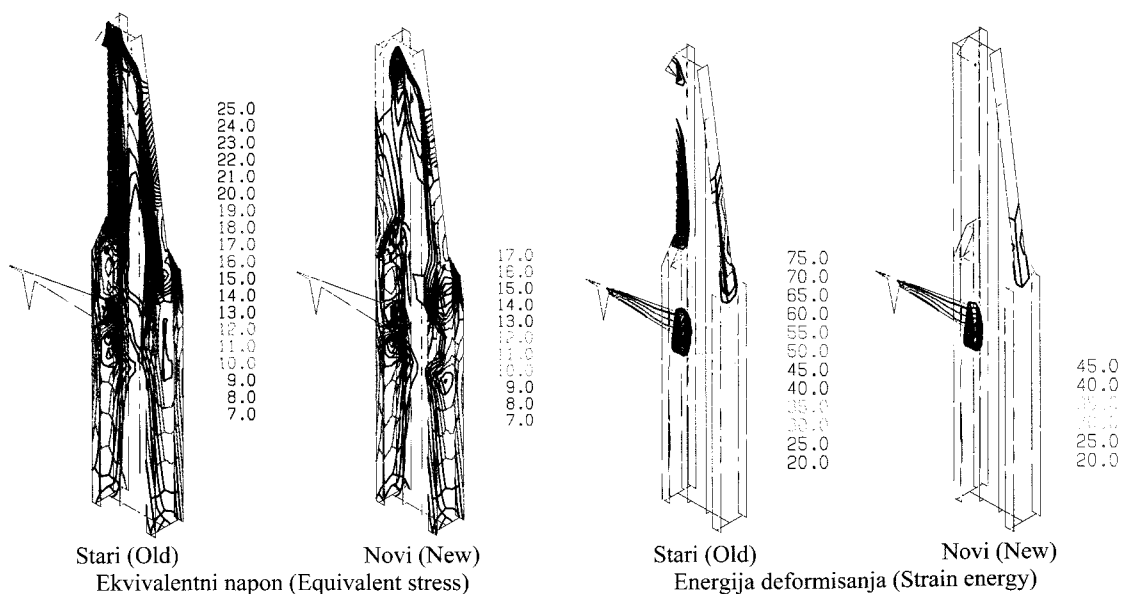
The reconstruction led to the elimination of torsion on the support, a significant reduction of bending, decrease of stress by 37.5%, and reduction in stress concentration.



Postojeći – stari model (Existing – old model) Rekonstruisani – novi model (Reconstructed – new model)

Slika 4. Računski modeli stuba odlagača (postojeći i rekonstruisani).

Figure 4. Numerical models of the stacker support (existing and reconstructed).



Slika 5. Raspodela napona $[kN/cm^2]$ i energije deformisanja $[kNcm]$.

Figure 5. Stress $[kN/cm^2]$ and strain energy $[kNcm]$ distribution.

Tabela 1. Rezultati proračuna konstrukcije (postojeće i rekonstrukcije)
Table 1. Calculation results of the structure (existing and reconstructed).

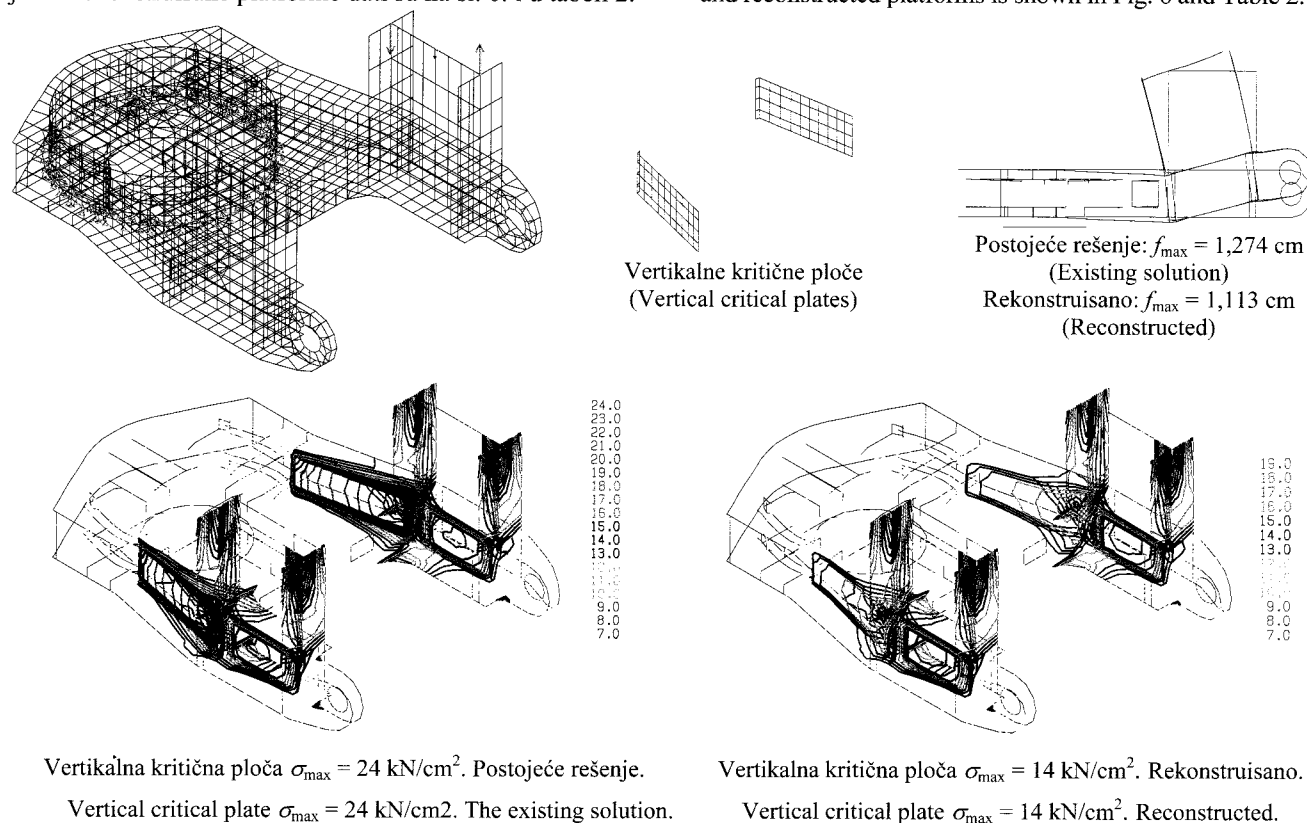
podstrukture (substructures)	mem./sav. (mem/bend.) [%]		σ/τ [%]		E_d [kNm, %]	
	Staro (Old)	Novo (New)	Staro (Old)	Novo (New)	Staro(Old)=4000	Novo(New)=3365
a	10.7/0.6	12/0.2	10.8/0.5	12/0.2	14	17
b	14.7/1.1	14.2/0.5	14.2/1.6	13.4/1.4	19.5	15.4
c	31.3/3.2	28.6/0.9	24.9/9.6	19.7/9.9	29.6	25.2
d	14.9/2.7	14.8/2.5	15.8/1.7	15.6/1.7	18	17.
e	9.8/0.4	10.2/0.4	9.7/0.7	10/0.6	10.1	11.6
r	10.2/0.4	9.4/0.1	10.1/0.4	9.3/0.2	8.9	8.8
rekonstrukcija (reconstruction)	-	5.7/0.4	-	5.5/0/6	-	4.6
Suma (Total) [%]	91.6/8.4	95/5	85.5/14.5	85.5/14.5	100	100

SANACIJA I REKONSTRUKCIJA OBRTNE PLATFORME ODLAGAČA ARS 1400 O&K

U eksploataciji odlagača ARS došlo je do vitoperenja vertikalne (kritične) ploče obrtne platforme. Računski model obrtne platforme sa delom stubova, najnepovoljnijim opterećenjem, deformacijom i sa ekvivalentni napon postojeće i rekonstruisane platforme dati su na sl. 6. i u tabeli 2.

REPAIR AND RECONSTRUCTION OF ROTATING STACKER PLATFORM ARS 1400 O&K

The vertical (critical) plate of the rotating stacker platform (ARS) experienced in-service buckling. The numerical model of the platform including few supports, in the worst case of load, strain and equivalent stress, for existing and reconstructed platforms is shown in Fig. 6 and Table 2.



Slika 6. Računski model obrtne platforme odlagača
Figure 6. Numerical model of the rotating stacker platform.

Tabela 2. Raspodela napona i energija deformacije u pločastim elementima platforme
Table 2. Distribution of stress and strain energy in the plate elements of the platform.

Raspodele (Distributions) [%]	Membr./Savij. (Membrane/Bend)	Energija deformisanja (Strain energy)
Gornja ploča (Upper plate)	18.8/5.8	15.2
Donja ploča (Lower plate)	15.8/4.3	15.0
Vertikalna kritična ploča (Vertical critical plate)	45.0/5.4	69.2 (39.7)
Orebrenja (Ribbing)	3.8/1.2	0.6
Ukupno (Total)	83.6/16.7	100

Vertikalna kritična ploča ima najveću vrednost napona, koncentraciju napona i energiju deformisanja. Ovakvo ponašanje se u celini odgovara sa ponašanjem konstrukcije u eksploataciji. Značajno smanjenje napona i eliminisanje koncentracije napona dobijeno je samo povećanjem debljine vertikalne ploče. Sem toga, malo prisustvo napona savijanja u konstrukciji ukazuje na dobro projektovanje.

SANACIJA I REVITALIZACIJA OSLONCA SAMOHODNOG TRANSPORTERA BRS/ARS O&K

Transporter je doživeo havariju u osloncu (sl. 7).

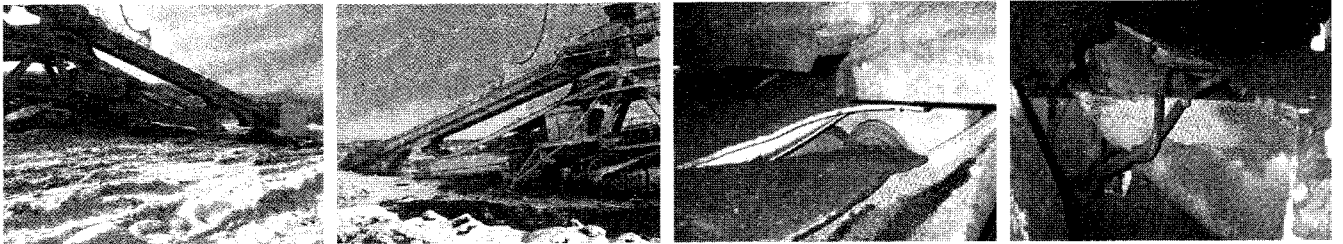
Noseća konstrukcija donje gradnje samohodnog transportera predstavlja prostornu pločastu konstrukciju (sl. 8). Modeliranje strukture mora se izvesti konačnim elementom ploče. Odgovarajuća ukrućenja pojedinih ploča mogu se modelirati grednim konačnim elementom.

The vertical critical plate has the largest stress, stress concentration, and strain energy values. The identified behaviour entirely corresponds to structural behaviour in service. Significant stress decrease and elimination of stress concentration is achieved by increasing vertical plate thickness. Apart from this, small amount of bending stress are indicates proper design.

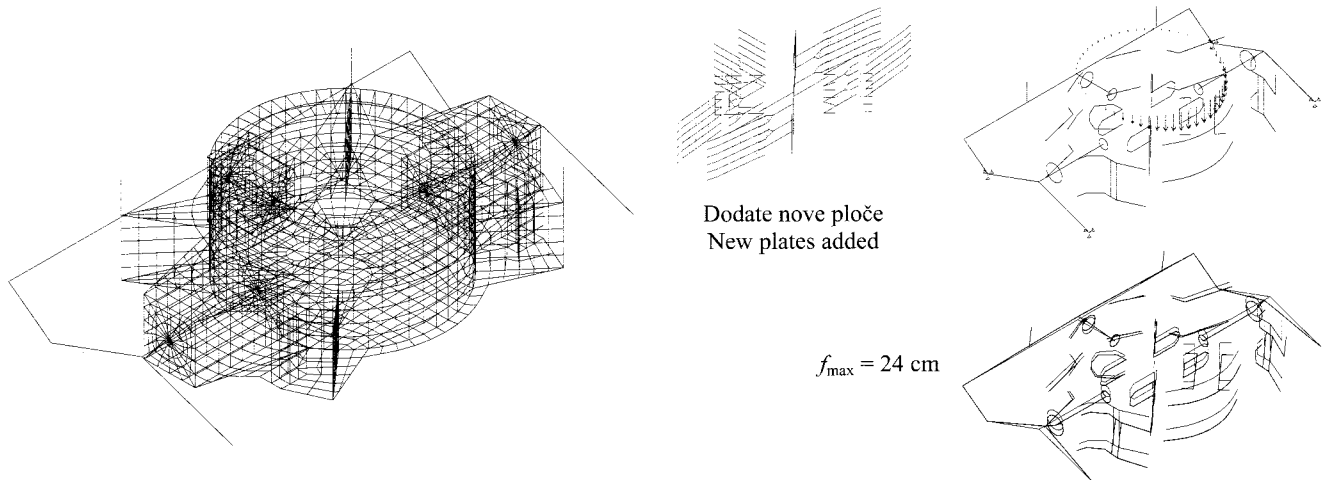
REPAIR AND REVITALIZATION OF THE SUPPORT ON BELT WAGON BRS/ARS O&K

The belt wagon on crawlers failed at its support (Fig. 7).

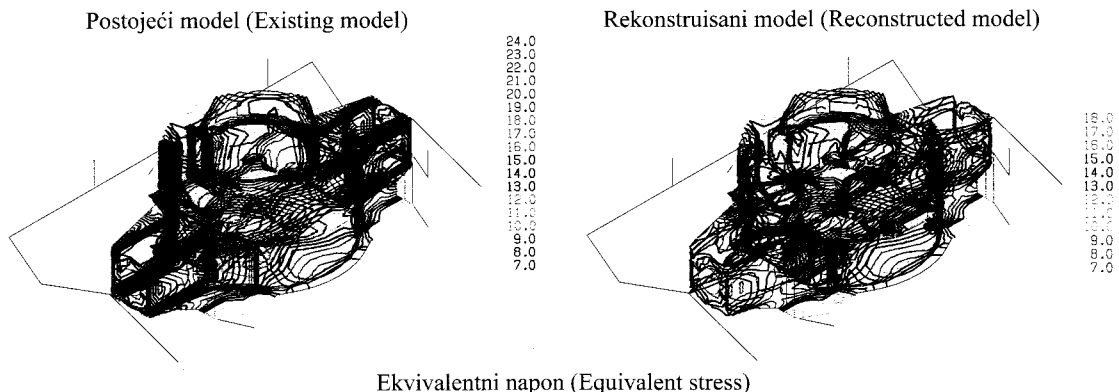
The supporting structure of the lower assembly of the belt wagon on crawlers is a 3-D plate structure (Fig. 8). Structure modelling must be performed using the finite element method for a plate. Adequate stiffeners on particular plates may be modelled by a beam finite element.



Slika 7. Havarija transportera u osloncu
Figure 7. Failure of the belt wagon at the support.

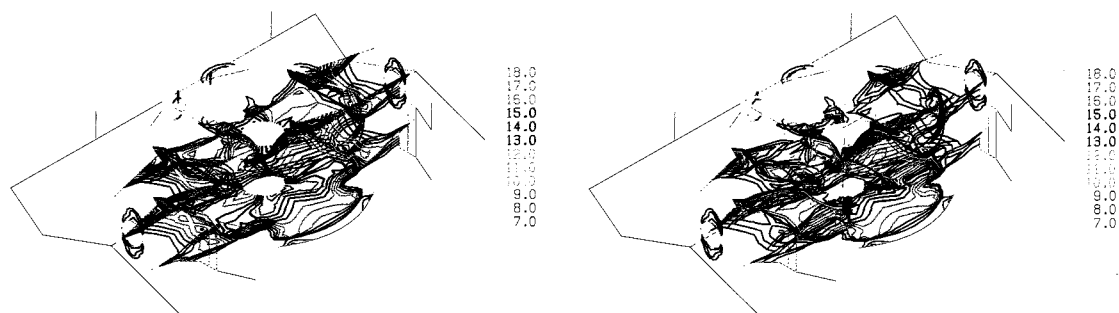


Slika 8. Model i predložena rekonstrukcija donje gradnje transportera
Figure 8. Model and proposed reconstruction of the lower belt wagon assembly.

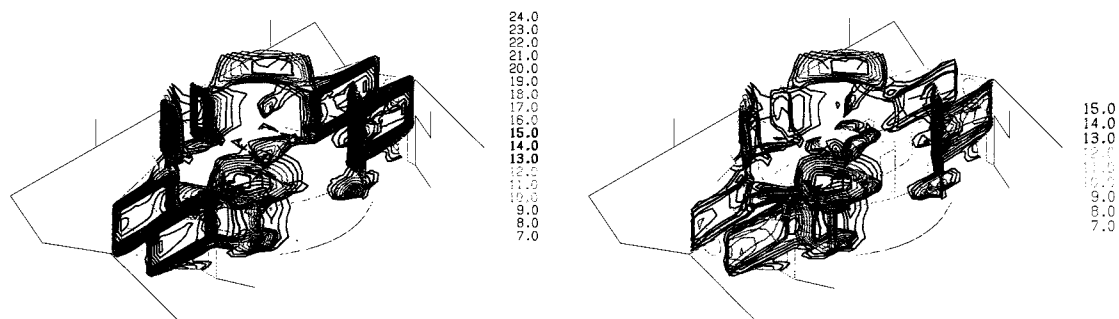


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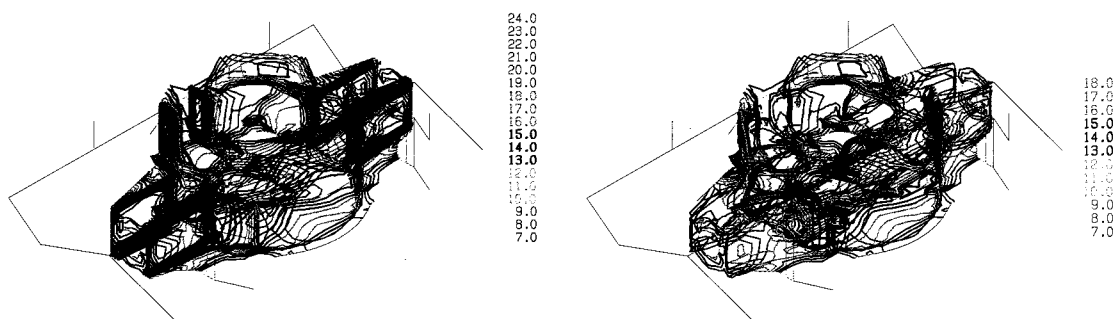
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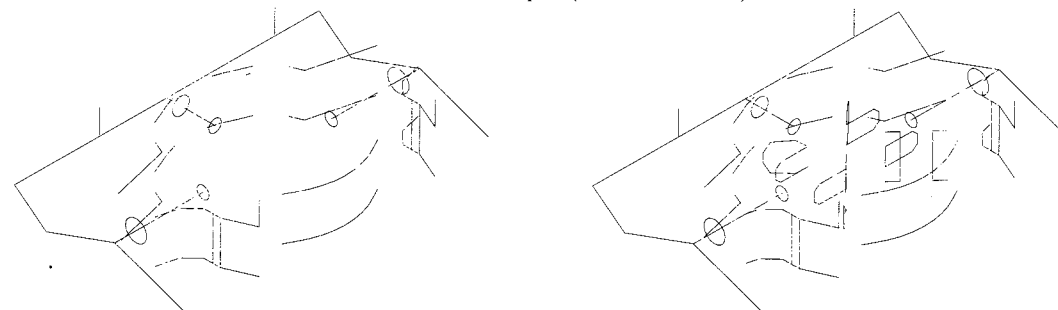
Normalni napon (Normal stress)



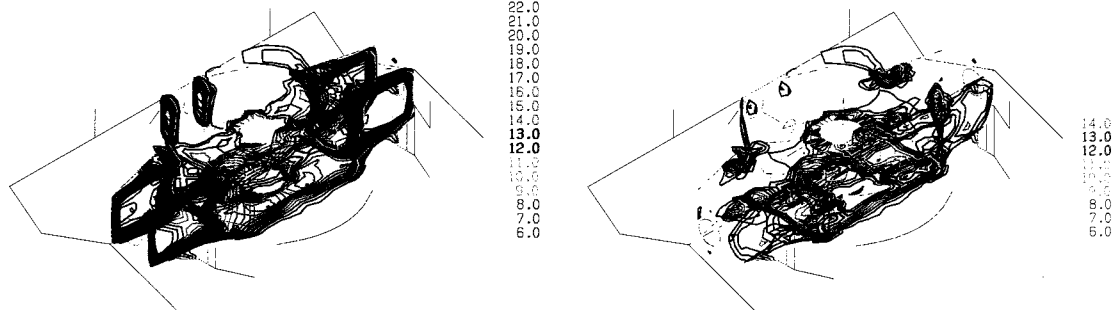
Smicajni napon (Shear stress)



Membranski napon (Membrane stress)



Savojni napon (Bending stress)



Energija deformisanja (Strain energy)

Slika 9. Raspodela napona [kN/cm²] i energija deformisanja [kNcm]
 Figure 9. Stress [kN/cm²] and strain energy [kNcm] distribution.

Na osnovu analize opterećenja, usvojene su tri kombinacije opterećenja. Sledi prikaz jedne kombinacije opterećenja čije težište opterećenja transportera pada na $R = 2$ m i na podužnoj osi donje gradnje prema dobošu elektrokabla.

Podstrukture gornje gradnje transportera su: gornja ploča transportera, srednja ploča transportera, donja ploča transportera, uzdužne i poprečne ploče između srednje i donje ploče transportera, cilindar na mestu radi-aksijalnog ležišta.

Deo gornje i donje ploče i međuploča formiraju kutijasti nosač (2 kom.) koji povezuje cilindrični deo sa voznom mehanizmom preko osovine. Ovaj nosač nazvan je kutijasti kritični nosač. Predložena rekonstrukcija donje gradnje obuhvata postavljanje ploča (sl. 8).

Rezultati proračuna i analize prikazani su na sl. 9 i u tabeli 3.

Three loading scenarios are adopted, based on loading analysis. Shown below is a combination where the centre of load on the belt wagon is at $R = 2$ m on the longitudinal axis of the lower assembly, towards the power-cable drum.

The substructures of the upper belt wagon assembly are: upper, intermediate, and lower belt wagon plates, transversal and longitudinal plates, between intermediate and lower plates, and cylinder at the radial/axial bearing.

Parts of upper and lower plates, and intermediate plates form a girder box (2 pieces), connecting cylindrical part to the mobile mechanism through the axle. This beam is called the critical box beam. The suggested reconstruction of the lower assembly includes placement of plates (Fig. 8).

Numerical results and analyses are given in Fig. 9 and in Table 3.

Tabela 3. Rezultati proračuna konstrukcije (postojeće i rekonstrukcije)
Table 3. Calculation results of the structure (existing and reconstructed).

	σ_{max} [kN/cm ²]		mem./sav.(mem./bend.) [%]		σ/τ [%]		E_d [%, kNcm]	
	Postojeće (Existing)	Rekonstr. (Reconstr.)	Postojeće (Existing)	Rekonstr. (Reconstr.)	Postojeće (Existing)	Rekonstr. (Reconstr.)	Postojeće (Existing)	Rekonstr. (Reconstr.)
horizontalne ploče (horizontal plates)	18	18	44.3/4.6	40.3/4.4	37.5/11.4	36/10.7	67.9	46.3
vertikalne ploče (vertical plates)	24	13	17/1.9	12.8/1.4	8.5/10.3	7.9/6.2	3.3	13.5
cilindar (cylinder)	18	17	10.8/1.8	10.6/1.8	6.4/6.1	6.4/5.9	13.4	14.7
ukrućenja (stiffeners)	-	-	8.1/0.7	7/10.9	8.8/0	8.6/0	10.1	11.6
oslonci (supports)	-	-	0.9/9.9	7.8/0.7	10.8/0.2	11.2/0.2	5.3	6.5
rekonstrukcija (reconstruction)	-	12	-	2.8/0.1	-	3.8/3.1	-	7.4
Suma (Total)	-	-	81.1/18.9		72/28.0	73.9/26.1	90 960	88 000

Komentar rezultata proračuna glasi: opterećenje je zahvatilo skoro celu konstrukciju donje gradnje; vrlo visok nivo napona u vertikalnim pločama prvog i drugog kutijas-tog nosača osovine za spoj sa balanserom i veoma izražena koncentracija napona; smicajni naponi su dominantni; dominantan uticaj navedenih kutijastih nosača (preuzeli su najveći deo membranskih i smicajnih napona, a spoljašnje opterećenje najviše energije je potrošilo na njihovo deformisanje), navedene ploče radile su u veoma nepovoljnom naponskom polju.

Predložena rekonstrukcija obezbeđuje drastično smanjenje napona (posebno smicajnih) i energije deformisanja.

REKONSTRUKCIJA POGONSKE STANICE JIIP POL-MAG (DRMNO KOSTOLAC)

Pogonski sistemi (reduktor, motor, noseća konstrukcija) su često imali havariju motora i noseće konstrukcije. Za vreme rada primećuju se pojačane vibracije pogonskog sistema. Iznalaženje uzroka havarija zahteva primenu numeričko-eksperimentalnog postupka. Balansiranje obrtnih masa i saosnost vratila reduktora i motora nisu rešavala uzrok problema.

Redukovani dinamički model stanice, neke glavne oscilacije i neka merenja ubrzanja dati su na sl. 10. Pobudna frekvencija motora je 16.33 Hz.

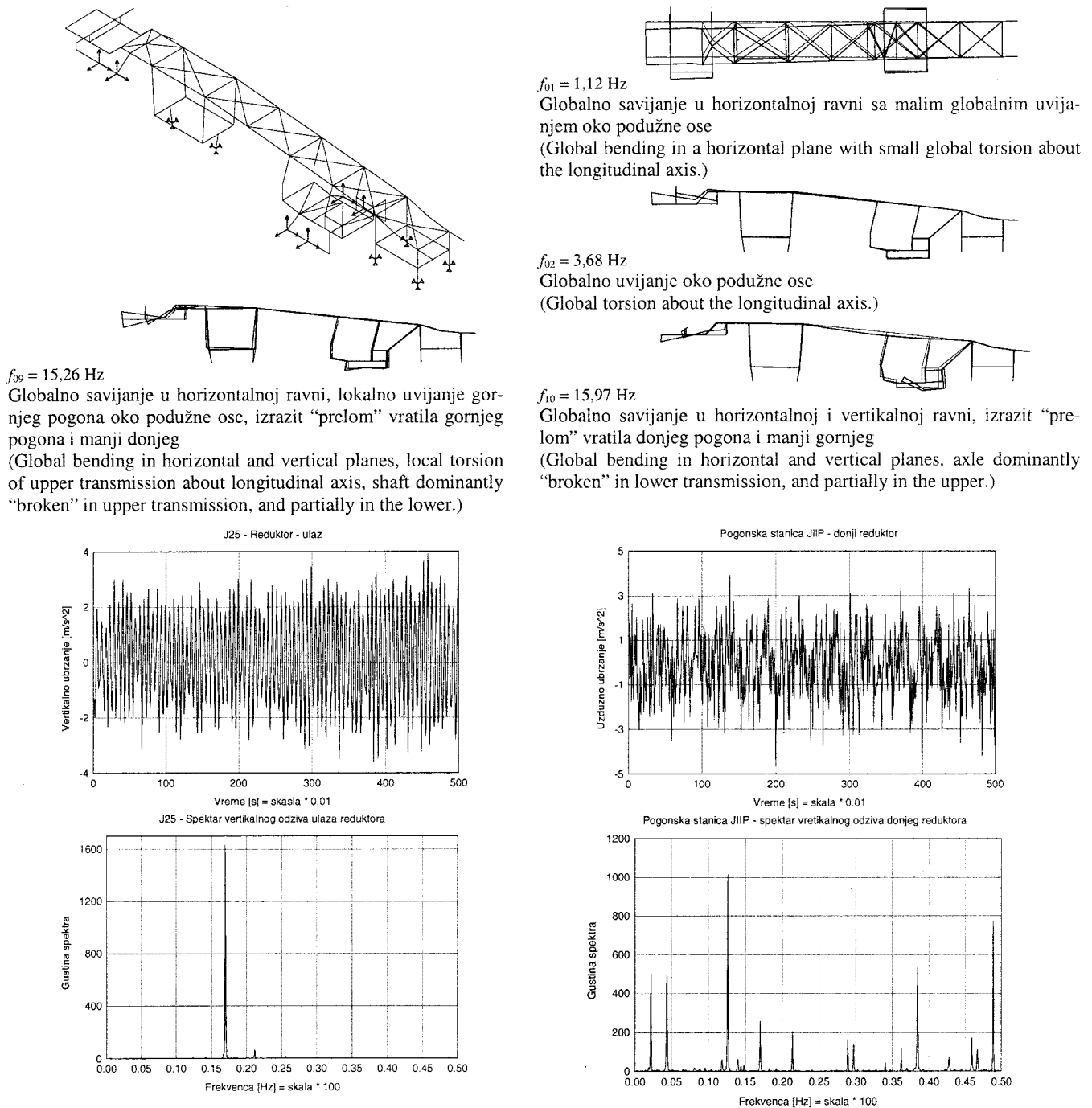
The comment on numerical results states as follows: almost the entire lower assembly is under loading influence; a very high stress level develops in vertical plates of both first and second girder box axle support beams at the connection to the balancer, with very high stress concentration; shear stresses are dominant; the mentioned girder box beams have a dominant effect (by carrying most of the membrane and shear stresses, while most of the external loads' energy is spent on beam strains); the plates were subject to a very unsuitable stress state.

The proposed reconstruction provides drastic decrease in stress (especially shear stresses) and strain energy.

RECONSTRUCTION OF THE DRIVE UNIT JIIP POL-MAG (DRMNO KOSTOLAC)

Drive unit (gear box, motor, supporting structure) have often suffered motor- and support structural failure. Increased power system vibrations occur in service. Determination of the cause of failure requires application of numerical-experimental procedures. Balance of revolving masses and axle co-axiality in the transmission and motor systems did not solve the problem.

The reduced dynamic model of the drive unit, certain major oscillations and acceleration measurements are shown in Fig. 10. The motor starting frequency is 16.33 Hz.



Slika 10. Redukovani dinamički model stanice (gore), vertikalno ubrzanje (sredina levo) i uzdužno ubrzanje (sredina desno) u vremenskom domenu i gustina spektra u frekventnom domenu (dole)

Figure 10. Reduced dynamic model of unit (top), vertical acceleration (middle left) and longitudinal acceleration (middle right) in frequency domain, and spectrum density in time domain (bottom).

Na osnovu proračuna, merenja i analize rezultata konstatujemo da je uzrok problema koji se javljaju u radu pogonske stanice njena nedovoljna prostorna krutost koja se manifestuje tako što noseća konstrukcija stanice ima sopstvene frekvence bliske pobudnim frekvencama.

Ovaj ozbiljan nedostatak konstrukcije ima globalan karakter. Njegovo potpuno eliminisanje nije tehnički opravdano zbog obimne rekonstrukcije. To znači da je potrebno lokalno ojačanje konstrukcije stanice, koje će smanjiti nepovoljan uticaj lošeg rešenja konstrukcije.

According to calculations, measurements and analysis of results, it is concluded that power station problems appearing during operation are caused by its insufficient volume stiffness, manifesting in eigen-frequencies that are close values of starting frequencies.

This serious setback in the structure is a global characteristic. Eliminating it entirely is not technically justified, since it would require large reconstruction. Therefore, it is necessary to re-enforce locally the unit structure and reduce the unwanted effect of poor structural design.

Predlog ojačanja konstrukcije dobijen je kompjuterskim proračunom na osnovu više varijanti modela.

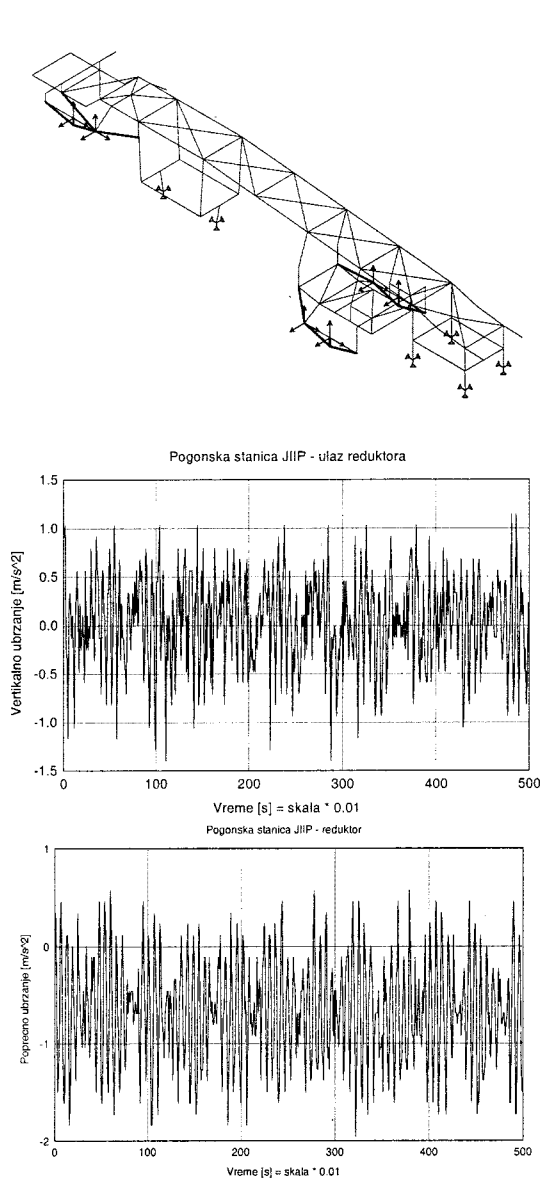
Ponovnim merenjem ubrzanja na izvedenoj ojačanoj konstrukciji stanice potvrđena je ispravnost rešenja ojačanja.

Računski model rekonstrukcije, neke glavne oscilacije i merenje ubrzanja dati su na sl. 11.

A proposed solution for reinforcement was obtained by computer calculation, based on a number of models.

Repeated acceleration measurements on the reinforced structural unit verified the correct reinforcement solution.

The numerical model of the reconstruction and some major oscillations and acceleration tests are shown in Fig. 11.



Slika 10. Računski model rekonstrukcije (gore), vertikalno ubrzanje (sredina levo) i poprečno ubrzanje (dole levo) u vremenskom domenu i gustina spektra u frekventnom domenu (desno, sredina i dole)

Figure 10. Numerical model of the reconstruction (top), vertical acceleration (middle left), and transversal acceleration (bottom left) in time domain, and spectrum density in frequency domain (right, middle and bottom).

Rezultati proračuna pokazuju samo osam (umesto 12) glavnih oblika oscilovanja ispod pobudne frekvence motora, nema više oscilacija oko pobude motora, nepovoljno dinamičko ponašanje konstrukcije stanice je značajno smanjeno. Prikaz najbitnijih merenja dat je na sl. 11.

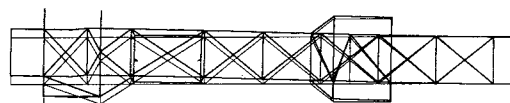
Uzrok havarija je otkriven i njegov uticaj minimiziran.

LITERATURA—REFERENCES

1. Ignjatović, D, Maneski, T. i saradnici, *Izvedeni projekti (performed projects)*

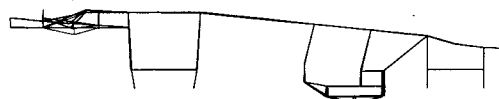
$$f_{01} = 1,54 \text{ Hz}$$

Globalno savijanje u horizontalnoj ravni sa malim globalnim uvijanjem oko podužne ose
(Global bending in a horizontal plane with small global torsion about the longitudinal axis.)



$$f_{02} = 4,26 \text{ Hz}$$

Lokalno uvijanje nosača gornjeg pogona i bočno oscilovanje donjeg
(Local torsion of upper unit support and lateral oscillation of the lower unit support.)



Calculations show only 8 (instead of 12) main oscillation forms below the motor starting frequency with no oscillations near it, and so the unfavourable dynamic behaviour of the structural unit is significantly reduced. Most important tests are shown in Fig. 11.

The cause for failure and its effects were minimized.