

Računalniško preverjanje ustreznosti zaščitne naprave pred podletom motornih tovornih vozil

Computational Safety Inspection of a Rear Underrun Protection Device for Loadcarrying Vehicles

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Prispevek podaja osnove sedanjega in možnosti novega numeričnega izračuna naprave za zaščito pred podletom od zadaj, ki pride v poštev pri homologaciji motornih tovornih vozil. Ustreznost zaščitne naprave se preverja glede na predpis ECE R 58, ki podaja natančna merila, katerim mora ustrezati konstrukcija naprave in njeno obnašanje pod obremenitvijo. Predpis dopušča možnost računskega preverjanja ustreznosti zaščitne naprave, od česar je odvisna raziskava možnosti računalniškega simuliranja obnašanja naprave pod obremenitvijo. Prispevek podaja osnovna izhodišča in postopke pravilnega računalniškega simuliranja, ki temelji na metodi končnih elementov. V tej zgodnji fazi raziskav je v računalniških simuliranjih obravnavan le primer elastičnega deformiranja analizirane zaščitne naprave, ki je tudi eksperimentalno preskušena. Dobro ujemanje numeričnih in eksperimentalnih rezultatov potrjuje primernost izbrane simulirne metode za preverjanje ustreznosti zaščitne naprave.

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(Ključne besede: naprave zaščitne, zaščita pred podletom, preskušanje, simuliranje računalniško)

This paper describes the fundamentals of the present situation and explores the possibilities of new computational safety inspection procedures for rear underrun protection devices (RUPDs), which are essential for the approval of loadcarrying vehicles. A RUPD is required to comply with the ECE R 58 regulation, which provides strict requirements in terms of device design and its behaviour under loading. The regulation allows for computational safety inspection of the protection device, which has prompted research into exploring the possibilities of computational simulation of RUPD behaviour under loading. This paper describes the conditions and procedures for proper computational simulations, which are based on the finite element method. At this early stage of the research only the elastic response of the studied RUPD is considered in the computational analyses. The studied safety device has also been experimentally tested. Reasonably good agreement of computational and experimental results leads to the conclusion that computational analysis can be used for inspection of an RUPD.

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(Keywords: protection devices, rear underrun protection, testing, computational simulation)

0 UVOD

Podlet od zadaj imenujemo nalet osebnega ali lahkega tovornega vozila pod zadnji del tovornega vozila. Naprava za zaščito pred podletom preprečuje zagozditev vozil pod tovorna vozila pri naletnih trčenjih od zadaj in s tem zagotavlja večjo varnost udeležencev v prometu. Zaradi tega je njena ustrezna konstrukcija izrednega pomena.

Odredba o homologiranju naprav za preprečevanje podleta od zadaj [1] v skladu s pravilnikom ECE R 58 predpisuje pogoje, ki jih mora naprava oziroma tovorno vozilo izpolnjevati, da lahko pridobi ustrezno homologacijo v Republiki Sloveniji. Ena izmed najpomembnejših zahtev je odpornost

0 INTRODUCTION

Rear underrun occurs when a passenger car or light vehicle crashes into a loadcarrying vehicle and is wedged under the rear part of the vehicle chassis. A rear underrun protection device (RUPD) prevents the vehicles from being wedged under the chassis during accidental crashes and significantly increases the safety of the vehicle's passengers. As a result, its appropriate design is extremely important.

The regulation of RUPD approval in Slovenia [1] is in concordance with the ECE R 58 regulation and provides the conditions, which must be fully met by the RUPD or the loadcarrying vehicle, if such a vehicle is to be registered in Slovenia. The most important condition is the RUPD's resistance

naprave na sile, ki delujejo vzporedno z vzdolžno osjo vozila. Pravilnik načrtuje tudi praktični preskus naprave na preskusnem stroju, pri čemer je naprava obremenjena z normiranimi silami na natančno predpisanih mestih. Če so izmerjene deformacije naprave v dovoljenih, predpisanih mejah, pridobi naprava za zaščito pred podletom ustrezno homologacijsko dovoljenje. Preskus naprave za zaščito pred podletom od zadaj je obvezen, kadar gre za tipsko homologacijo montirne zaščitne naprave. V primeru homologacije vgradnje tipske naprave v vozilo ali naprave, integrirane v nadgradnjo, praktičen preskus ni potreben, če se lahko računsko dokaže, da zaščita pred podletom od zadaj ustreza predpisom pravilnika ECE R 58.

Zahteve po skrajšanju in pocenitvi homologacijskega postopka ter dopuščena možnost računskega preverjanja ustreznosti naprave za zaščito pred podletom so terjale raziskavo možnosti računalniškega simuliranja obnašanja naprave pod obremenitvijo. Osnovni namen računalniškega simuliranja je izboljšanje možnosti napovedovanja deformiranja naprave pod obremenitvijo brez dragega praktičnega testiranja. Ta sestavek podaja osnovna izhodišča in postopke računalniškega simuliranja, ki temelji na metodi končnih elementov. V začetni stopnji raziskave je obravnavan preprost primer elastične deformacije zaščitne naprave, ki je sestavljena iz jeklenih zvarjenih navpičnih jeklenih profilnih nosilcev in aluminijastega prečnega nosilca.

1 OSNOVNE KONSTRUKCIJSKE ZAHTEVE ZAŠČITNE NAPRAVE

Naprava za preprečevanje podleta od zadaj mora biti nameščena čim bližje zadnjemu robu vozila. Širina naprave ne sme v nobenem primeru presežati največje širine zadnje osi vozila (merjene na skrajnih zunanjih robovih plaščev) in ne sme biti na vsaki strani za več ko 100 mm krajša (sl. 1). Če je zaščita pred podletom od zadaj integrirana v nadgradnjo vozila in ta preseže največjo širino zadnje osi, je lahko naprava širša od zadnje osi, vendar ne sme presežati širine zadnjega roba nadgradnje. Razdalja med spodnjim robom naprave za preprečevanje podleta in tlemi ne sme pri neobremenjenem vozilu biti večja od 550 mm po vsej širini. Višina profila prečnega nosilca zaščitne naprave ne sme biti manjša od 100 mm. Stranski robovi tega nosilca ne smejo biti zakrivljeni nazaj niti ne smejo imeti ostrih robov (priporočen polmer zaobljenja najmanj 2,5 mm).

Naprava za zaščito pred podletom od zadaj mora dajati zadosten odpor silam, ki delujejo vzporedno z vzdolžno osjo vozila, in mora biti v delovni legi trdno povezana z vzdolžnimi nosilci okvira vozila oziroma z njim ustreznimi deli vozila. Pri tem je osnovna konstrukcijska zahteva, da vodoravna razdalja med zadnjim delom naprave in

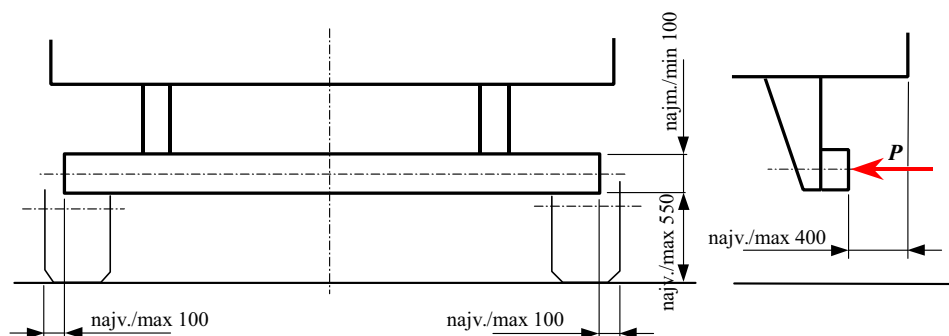
to loading forces acting along or parallel to the vehicle's longitudinal axis. The regulation also calls for practical RUPD testing on a testing machine, where the RUPD is subjected to prescribed loads at some particular loading points. If the measured deformations fall within the allowable range, the RUPD is declared to comply with the regulation. This practical testing is required for all standard mounted RUPDs. However, for standard RUPDs, which are already mounted on serial production vehicles or RUPDs which are an integral part of the vehicle chassis, the practical testing is not necessary if it can be proven with calculations that the RUPD fully complies with the ECE R 58 regulations.

The demands for shortening the approval procedure and reducing its cost, as well as the possibility of analytical or computational RUPD safety inspection, has prompted research into exploring the possibilities of computational simulation of RUPD behaviour under loading. Computational simulation allows for a better estimation of the device deformation pattern under a variety of loadings and is much cheaper than practical testing. This paper describes the conditions and procedures for proper computational simulations, which are based on the finite element method. At this early stage of the research only the elastic response of the RUPD is considered in the computational analyses. The studied RUPD comprises two welded vertical steel profile pillars and a standard deep drawn transversal aluminium profile.

1 THE BASIC DESIGN DEMANDS ON A REAR UNDERRUN PROTECTION DEVICE

The RUPD should be positioned as close as possible to the rear end of the vehicle chassis. The width of the device should not exceed the largest width of the rear vehicle axle (measured at the outer tire edges) and it should not be shorter by more than 100 mm on each side (Fig. 1). If the device is integrated into the vehicle chassis, which exceeds the largest width of the rear vehicle axle, the device can be wider than the rear axle but it should not exceed the width of the rear end of the chassis. The height of the bottom edge of the RUPD above the ground for an unladen vehicle should not exceed 550 mm along the whole width of the device. The height of the transversal profile of the device should not be less than 100 mm. The side edges of this profile should not be curved back and they should not have any sharp edges (recommended rounding radius is at least 2.5 mm).

The RUPD must offer appropriate resistance to forces that act along or parallel to the vehicle longitudinal axis and should be, in the working position, firmly connected to the longitudinal cantilevers of the vehicle chassis or corresponding parts of the vehicle. The fundamental design demand on the device is that the horizontal distance between the end of the vehicle



Sl. 1. Konstrukcija in vgradnja zaščitne naprave

Fig. 1. Design and mounting demands on the protection device

skrajnim zadnjim delom vozila tudi pri največji deformaciji zaščitne naprave pod vplivom preskusnih normiranih sil ni večja od 400 mm.

and the end of the RUPD does not exceed 400 mm, even under the largest deformation of the protection device when subjected to nominal testing forces.

2 PRAKTIČNI PRESKUS NAPRAVE PO PREDPISU ECE R 58

2 PRACTICAL DEVICE TESTING ACCORDING TO ECE R 58

Pri izvajanju praktičnega preskusa mora biti zaščita pred podletom od zadaj pritrjena na vzdolžne nosilce okvira vozila ali pa na neki drugi ustrezeni del vozila oziroma morajo pogoji vpetja naprave na preskusnem stroju ustrezati dejanskim pogojem vpetja naprave na vozilu.

During the test the RUPD should be firmly connected to the longitudinal cantilevers of the vehicle chassis or its corresponding parts, or the RUPD can be connected to the test bench in a way that most closely resembles the conditions appearing when the RUPD is mounted on a vehicle.

Predpisane preskusne sile delujejo na napravo prek obremenjevalne površine, ki je lahko visoka največ 250 mm in široka največ 200 mm, pri čemer morata biti navpična robova zaobljena s polmerom 5 ± 1 mm. Obremenjevalna površina (bat) mora biti povezana z batnico preskusnega stroja s krogelnim zgibom, ki omogoča prosto prilagajanje obremenjevalne površine deformaciji zaščitne naprave. Središče krogelnega zгиба se mora ujemanjati s središčem obremenjevalne površine.

The prescribed testing forces should be applied to the device via a loading surface not more than 250 mm in height and 200 mm wide, with a radius of curvature of 5 ± 1 mm at the vertical edges. The loading surface (piston) must be connected to the piston rod of the testing machine with a ball joint, which enables free adaptation of the loading surface to the deforming protection device. The centre of the ball joint should correspond to the centre of the loading surface.

Pravilnik ECE R 58 predpisuje tri različne primere obremenitev glede na velikost preskusne sile in točko delovanja, in sicer:

The ECE R 58 regulation prescribes the following three different load cases in terms of the testing force size and its loading position:

P_1 – vodoravna sila velikosti 25 kN ali 12,5 % mase vozila, karkoli je manjše, ki deluje zaporedoma v dveh točkah, ki sta oddaljeni 300 ± 25 mm od največje širine zadnje osi vozila proti sredini zaščitne naprave;

P_1 – a horizontal force of 25 kN or 12.5% of the force generated by the maximum mass of the vehicle, whichever is less, should be applied consecutively to two points located 300 ± 25 mm from the outer edges of the wheels on the rear axle towards the centre of the protection device;

P_2 – vodoravna sila velikosti 100 kN ali 50 % mase vozila, karkoli je manjše, ki deluje zaporedoma v dveh točkah, ki sta simetrični glede na srednjo navpično linijo naprave oziroma vozila in medsebojno oddaljeni za 700 do 1000 mm;

P_2 – a horizontal force of 100 kN or 50% of the force generated by the maximum mass of the vehicle, whichever is less, should be applied consecutively to two points situated symmetrically about the vertical centre line of the device or the vehicle at a minimum distance apart of 700 and a maximum of 1000 mm;

P_3 – vodoravna sila velikosti 25 kN ali 12,5 % mase vozila, karkoli je manjše, ki deluje na srednji navpični ravnini zaščitne naprave.

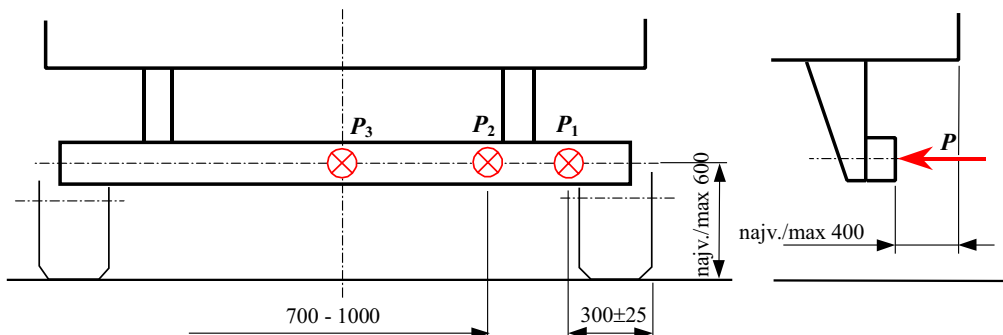
P_3 – a horizontal force of 25 kN or 12.5% of the force generated by the maximum mass of the vehicle, whichever is less, should be applied at the median vertical plane of the protection device.

Pri preskusu je treba upoštevati, da točke, v katerih delujejo preskusne sile, torej središče

When the test is carried out the height above the ground of the testing force application point, i.e.

obremenjevalne površine, ne smejo biti oddaljene od tal več ko 600 mm pri neobremenjenem vozilu (sl. 2). Preskusna sila mora počasi in zvezno naraščati do predpisane vrednosti.

the centre of the loading surface, must not exceed 600 mm when the vehicle is unladen (Fig. 2). The testing force shall be applied slowly and it should rise continuously to its nominal value.



Sl. 2. Točke delovanja preskusnih sil
Fig. 2. The points of testing force application

Šteje se, da je zaščitna naprava ustrežna, če preskus pokaže, da med preskusom z navedenimi silami in po njem vodoravna razdalja med zaščito pred podletom od zadaj in skrajnim zadnjim robom vozila ne preseže 400 mm. Meritev te razdalje je treba izvesti v točki, v kateri je bilo med preskusom prijemališče sile, torej v središču obremenjevalne površine. Pri meritvi se ne upoštevajo točke vozila, ki so več ko 3 m nad cestiščem.

The protection device can be approved, if it is proven by the test that during and after testing with the prescribed forces, the horizontal distance between the RUPD and the outmost rear end of the vehicle does not exceed 400 mm. This distance should be measured at the test force application point, i.e. at the centre of the loading surface. During the measurement all points of the vehicle being more than 3 m above the ground can be omitted.

3 RAČUNSKI POSTOPKI UGOTAVLJANJA USTREZNOSTI ZAŠČITNE NAPRAVE

V uvodu je navedeno določilo pravilnika ECE R 58, ki v primeru homologacije vozila s tipsko napravo, integrirano v nadgradnjo, ali posamezno napravo, pritrjeno na vozilo, dovoljuje simuliranje praktičnega preskusa naprave za zaščito pred podletom od zadaj z računskim preverjanjem. V tem primeru se uporabljajo običajne metode trdnostnega nadzora, ki pa v večini primerov ne dajejo zadovoljivih rezultatov, saj so v osnovi namenjene le za dvodimenzionalno elastično deformacijsko-napetostno analizo. Postopek običajnega trdnostnega nadzora daje zadovoljive rezultate le v primerih, ko je zaščitna naprava dimenzionirana tako, da se pod vplivom preskusnih sil samo elastično deformira. V večini primerov pa pride pod vplivom preskusnih sil do trajnih deformacij, za analizo katerih je treba uporabiti druge metode.

Najprimernejša metoda za numerično analizo deformacijskega stanja zaščitne naprave je postopek končnih elementov, katere osnove so za področje linearne in nelinearne (elasto-plastične in stične) analize podane v literaturi [2] in [3]. Tu je v nadaljevanju obravnavan primer nelinearne kontaktne elastične analize dejanske naprave za zaščito pred podletom od zadaj, ki je bila tudi preskušena na preskusnem stroju.

3 COMPUTATIONAL PROCEDURES FOR SAFETY INSPECTION OF THE PROTECTION DEVICE

In the introductory section it was stated that the ECE R 58 regulation allows, in the case of approval of a vehicle with on RUPD integrated into the chassis or a standard mounted RUPD, that the test procedure may be simulated by calculation. The procedures used for this purpose are mostly based on the classical solid mechanics approaches, which often cannot give satisfactory results, since they are mostly intended for two-dimensional elastic strain-stress analysis. The classical stiffness assessment gives satisfactory results, only in cases when the safety device is dimensioned such that it sustains only elastic deformation under testing forces. However, in most cases, the protection device under test is permanently deformed, analysis of which requires the use of alternative methods.

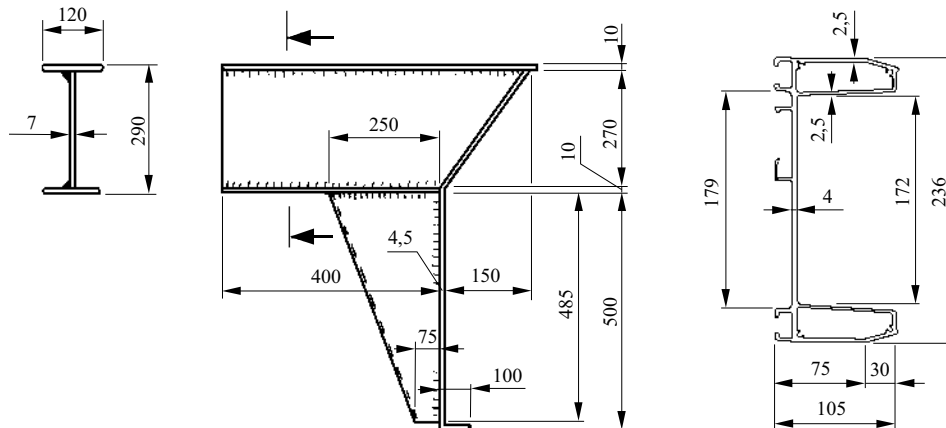
The most suitable method for computational analysis of the deformation state of the protection device is the finite element method, of which the fundamentals for linear and nonlinear (elasto-plastic and contact) analyses are given in literature [2] and [3]. In this paper we describe the case of a nonlinear contact elastic analysis of a real RUPD, which was also experimentally tested on a testing machine.

4 RAČUNSKA ANALIZA ZAŠČITNE
NAPRAVE

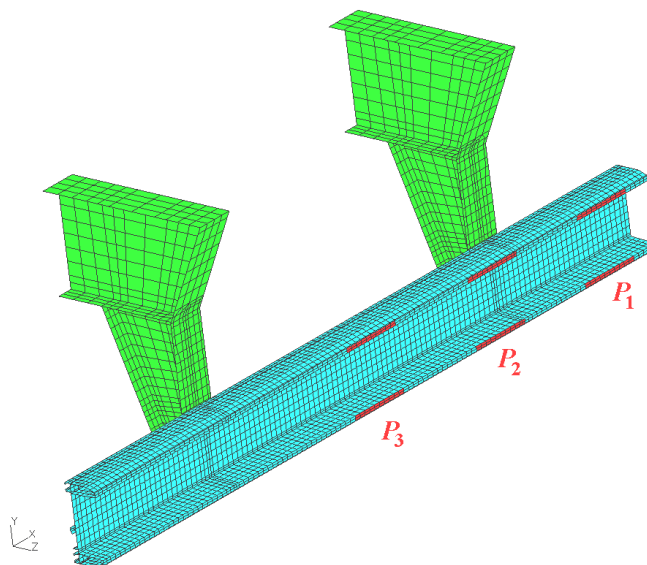
Predmet numerične analize po postopku končnih elementov je dejanska zaščitna naprava, ki sestoji iz dveh navpičnih nosilcev iz zvarjenih jeklenih profilov, katerih srednji navpični liniji sta medsebojno oddaljeni za 1180 mm, ter prečnega nosilca iz vlečenega aluminijastega profila dolžine 2365 mm. Osnovne dimenzije nosilcev so prikazane na sl. 3. Prečni nosilec je privit na navpična nosilca s štirimi vijaki M 14x30, kvalitete 10.9. Zaščitna naprava je na vozilo nameščena simetrično glede na sredino vozila, in sicer tako, da je vodoravna razdalja med zadnjim delom naprave in skrajnim zadnjim delom vozila po 150 mm, razdalja med spodnjim robom naprave in tlemi pri neobremenjenem vozilu pa je 475 mm. Največja širina vozila zadaj je enaka 2500 mm, največja masa pa 38250 kg.

4 COMPUTATIONAL ANALYSIS OF THE
PROTECTION DEVICE

The subject of the computational analysis, based on the finite element method, is the real protection device that consists of two vertical pillars made of welded steel profiles, of which the median vertical planes are 1180 mm apart, and a transversal cantilever made of a standard deep drawn aluminium profile with a width of 2365 mm. The basic dimensions of the profiles are shown in Fig. 3. The transversal profile is fastened onto vertical pillars with four screws (M 14x30) of quality 10.9. The protection device is mounted on the vehicle symmetrically in respect to the median vertical plane of the vehicle, with the horizontal distance between the rear part of the protection device and the rear end of the vehicle being equal to 150 mm, and the height of the lower edge of the device for the unladen vehicle equalling 475 mm. The maximum width of the rear end of the vehicle is 2500 mm and the maximum mass of the vehicle is 38250 kg.



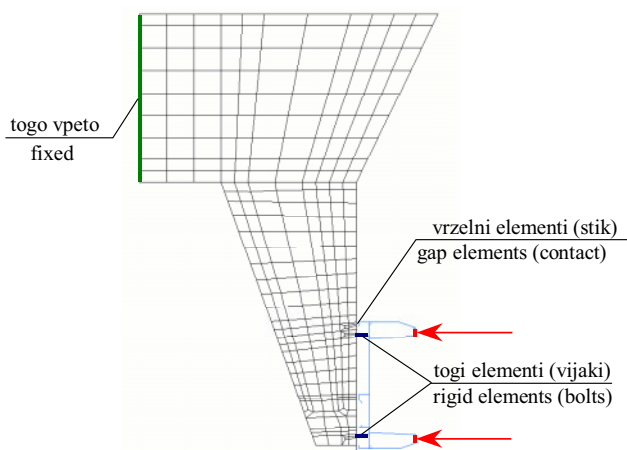
Sl. 3. Osnovne izmere navpičnih nosilcev in profila prečnega nosilca
Fig. 3. Basic dimensions of vertical pillars and transversal profile



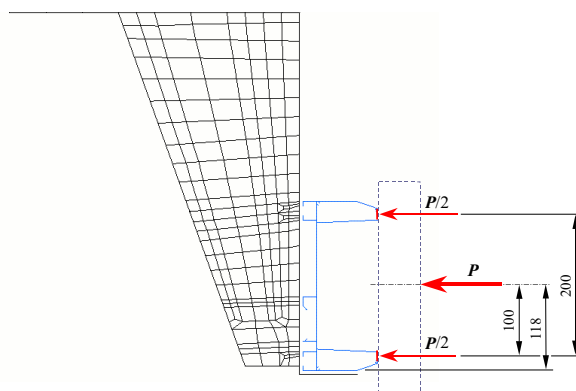
Sl. 4. Diskretiziran model zaščitne naprave
Fig. 4. Discretised model of the protection device

Navpični nosilci so izdelani iz jekla z naslednjimi podatki: modul elastičnosti $E = 206$ GPa, Poissonovo število $\nu = 0,29$, meja plastičnosti $\sigma_y \geq 260$ MPa ter porušna napetost $\sigma_M \geq 420$ MPa. Prečni nosilec je iz aluminijeve zlitine s podatki: $E = 75$ GPa, $\nu = 0,33$, $\sigma_y = 195$ MPa ter $\sigma_M = 216$ MPa.

The vertical pillars are made of steel profiles with the following data: Young's modulus $E = 206$ GPa, Poisson's ratio $\nu = 0,29$, yield stress $\sigma_y \geq 260$ MPa and ultimate stress $\sigma_M \geq 420$ MPa. The transversal profile is made of aluminium alloy with data: $E = 75$ GPa, $\nu = 0,33$, $\sigma_y = 195$ MPa and $\sigma_M = 216$ MPa.



Sl. 5. Stranski pogled zaščitne naprave in robni pogoji
Fig. 5. Side view of the protection device and boundary conditions



Sl. 6. Obremenitev zaščitne naprave
Fig. 6. The loading of the protection device

Zaščitna naprava je v celoti modelirana z 11480 tankostenimi lupinastimi linearnimi štirikotnimi končnimi elementi (sl. 4). Vijačni spoj prečnega in navpičnih nosilcev je izveden z 48 togimi končnimi elementi, ki ponazarjajo 4 vijačne spoje. Na mestih naleganja prečnega nosilca na navpične nosilce je med oba nosilca vstavljenih 384 posebnih vrzelnih elementov, ki med numeričnim reševanjem problema zagotavljajo elastični stik med nosilci (sl. 5).

Glede na osnovne podatke vozila in zaščitne naprave ter pogojev praktičnega preskusa, ki so navedeni v poglavju 2, so določene velikosti preskusnih sil P_1 , P_2 in P_3 in lega točk obremenjevanja na naletni površini prečnega nosilca:

- v vodoravni smeri:

$P_1 = 25$ kN levo ali desno v razdalji 950 mm od srednje navpične ravnine naprave,

$P_2 = 100$ kN levo ali desno v razdalji 500 mm od srednje navpične ravnine naprave,

The protection device is fully discretised with 11480 thin-shell linear four-noded finite elements (Fig. 4). The bolt connections of the transversal and vertical profiles are modelled with 48 rigid finite elements, which resemble the 4 bolt connections. At points of transversal and vertical profile contact 384 special gap elements are used, which assure elastic contact between the profiles during the computational analysis (Fig. 5).

Following on from the basic vehicle and protection device data and the requirements of practical testing, described in section 2, the size and the application points of the forces P_1 , P_2 and P_3 on the surface of the transversal profile are:

- in the horizontal direction:

$P_1 = 25$ kN left and right at a distance of 950 mm from the median vertical plane of the device,

$P_2 = 100$ kN left and right at a distance of 500 mm from the median vertical plane of the device,

$P_3 = 25$ kN na srednji navpični ravnini naprave,
- v navpični smeri:
 P_1, P_2 in P_3 : 100 mm od spodnjega roba prečnega
profila.

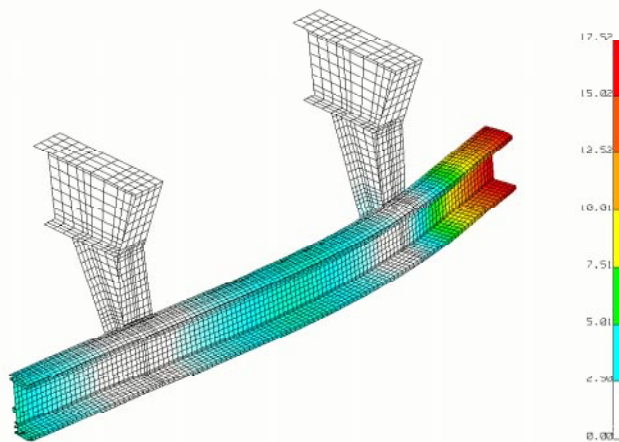
Ob upoštevanju izmer obremenjevalnega bata višine 250 mm in širine 200 mm ter lege središča obremenjevalne površine glede na prečni nosilec, so izračunane ustrezne komponente preskusne sile, ki obremenjujejo spodnjo in zgornjo naletno površino prečnega nosilca (sl. 6). Te komponente preskusne sile so predpisane kot enakomeren normalni specifični tlak na lupinaste končne elemente v območju naleganja preskusne površine na prečni nosilec (sl. 4).

Za izdelavo mreže končnih elementov in elastično analizo deformacijskega stanja zaščitne naprave je bil uporabljen inženirski programski paket I-Deas Master Series 6.0 [4]. Pri analizah je bila predpostavljena kvazi statična obremenitev. Na slikah 7, 8 in 9 so prikazane deformacije analizirane zaščitne naprave za tri zgoraj navedene obremenitvene primere. Senčeno so prikazane amplitude pomikov naprave pod obremenitvijo.

$P_3 = 25$ kN in the median vertical plane of the device,
- in the vertical direction:
 P_1, P_2 and P_3 : 100 mm from the bottom edge of the
transversal profile.

The corresponding components of the loading forces, which are applied to the lower and upper contact surfaces of the transversal profile, are calculated according to the dimensions of the loading piston of height 250 mm and width 200 mm and the position of the centre of the loading surface in relation to the transversal profile, see Fig. 6. These components are applied as a constant normal pressure on the shell finite elements in the contact area between the loading surface and the transversal profile, see Fig. 4.

The engineering computer system I-Deas Master Series 6.0 [4] has been used for mesh generation purposes and elastic analysis of the protection device deformation. Quasi-static loading was assumed in all analyses. Fig. 7, 8 and 9 show the deformations of the analysed protection device for three load cases. Shadow regions represent different amplitudes of the device displacements under loading.



Sl. 7. Pomiki zaščitne naprave pod preskusno silo P_1
Fig. 7. Displacements of the protection device under test force P_1

5 PRIMERJAVA REZULTATOV

Primerjava rezultatov praktičnega preskusa in računalniškega simuliranja je podana v preglednici 1. Kot pomik pod silo je v primeru preskusa upoštevan pomik preskusnega bata (središča obremenjevalne površine) merjen med obremenjevanjem zaščitne naprave, v primeru računalniškega simuliranja pa povprečni pomik srednje linije zgornje in spodnje naletne površine v območju obremenitve. Trajni pomik je pomik zaščitne naprave na mestu delovanja sile, ki pri praktičnem preskusu preostane po razbremenitvi.

Primerjava rezultatov kaže na dobro ujemanje simulirnih pomikov s pomiki,

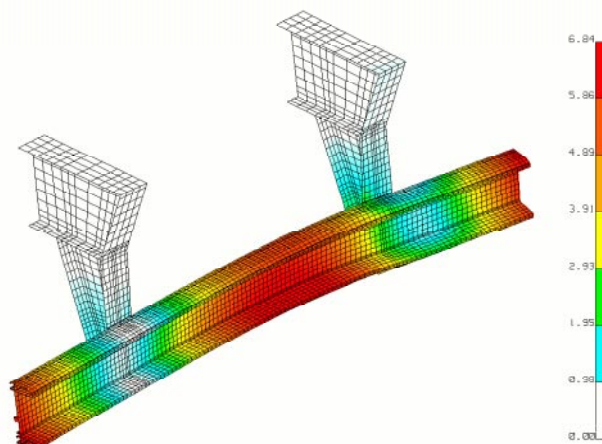
5 RESULTS COMPARISON

The comparison of the practical testing and computer simulation results is given in Table 1. In the case of the practical test the displacement under force is the displacement of the loading piston (the centre of the loading surface) measured during the force application to the protection device, while in a case of the computational simulation this is the average displacement on the median vertical line of the lower and upper contact loading surfaces. The permanent displacement is the displacement of the protection device still present at the point of force application after the unloading during the practical testing.

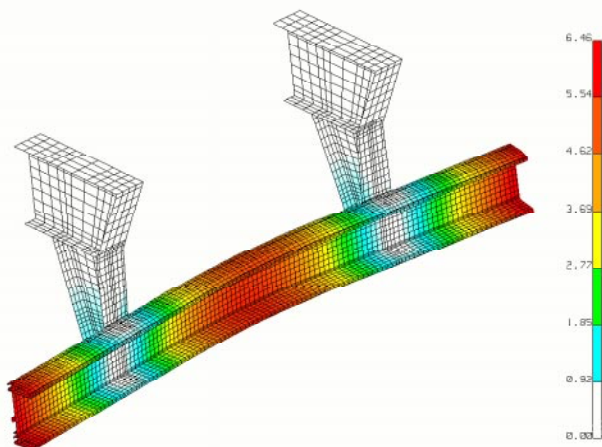
A comparison of the results indicates good agreement between the simulated displacements and the

izmerjenimi pri preskusu. Pri tem je treba pripomniti, da je pri praktičnem preskusu prišlo do trajnega deformiranja zaščitne naprave (plastična deformacija), možnost česar pa v tej začetni fazi raziskav ni bila upoštevana pri računalniških simuliranjih. Zaradi tega so simulirni pomiki precej manjši od dejanskih, saj modelirana naprava prenaša napetosti, ki so večje od meje plastičnosti materiala in je celoten odziv naprave mnogo bolj tog od dejanskega.

displacements actually measured during testing. However, it needs to be pointed out, that the protection device was permanently deformed (plastic deformation) during practical testing, the possibility of which has not been considered in the computational simulations at this early stage of the research. Due to this fact, the simulated displacements are much smaller than those observed in the practical test, since the modelled device transfers the stresses that exceed the yield stress of the material and behaves much more rigidly than the real device.



Sl. 8. Pomiki zaščitne naprave pod preskusno silo P_2
 Fig. 8. Displacements of the protection device under test force P_2



Sl. 9. Pomiki zaščitne naprave pod preskusno silo P_3
 Fig. 9. Displacements of the protection device under test force P_3

Preglednica 1. Primerjava rezultatov preskusa in računalniškega simuliranja
 Table 1. Comparison of test and computational simulation results

| Obremenitveni primer Loading case | Preskusna sila v kN Testing force in kN | Preskus Test | | Simuliranje Simulation |
|--------------------------------------|--|---|---|---|
| | | Pomik pod silo v mm Displacement under force in mm | Trajni pomik v mm Permanent displacement in mm | Pomik pod silo v mm Displacement under force in mm |
| P1 | 25 | 21 | 4 | 11,6 |
| P2 | 100 | 12,4 | 3 | 4,5 |
| P3 | 25 | 7,6 | 0,5 | 5,4 |

Preskušena naprava vsekakor zadovoljuje homologacijska pravila, saj je skupna največja vodoravna razdalja med zaščito pred podletom od zadaj in skrajnim zadnjim robom vozila $150 + 21 = 171$ mm in tako ni večja od predpisane največje razdalje 400 mm.

6 SKLEP

Začetne raziskave možnosti računalniškega simuliranja obnašanja naprave za zaščito pred podletom od zadaj pod obremenitvijo kažejo na uporabnost postopka. V nadaljevanju načrtujemo razširitev raziskave na elasto-plastične analize, ki bodo omogočale realnejše simuliranje odziva zaščitne naprave pod obremenitvami. Načrtujemo tudi analizo celotnega spektra različnih profilov nosilcev, njihovih velikosti, materialov, načinov spojev nosilcev in pritrditve naprave na karoserijo vozila.

The tested device fully meets the approval requirements, since the maximum horizontal distance between the RUPD and the rearmost point of the vehicle is equal to $150 + 21 = 171$ mm, which is well below the allowable distance of 400 mm.

6 CONCLUSION

The initial research into the possibilities of computational simulation of the RUPD's behaviour under loading indicates the feasibility of the method used. In the future, the research will be extended to include elasto-plastic analyses, which will allow for a more realistic simulation of the protection device behaviour under loading. Analyses of the complete spectre of different profiles of different sizes, materials, types of connections between profiles and different mountings on the vehicle chassis are also anticipated.

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