

# Računalniško podprto konstruiranje cestne varnostne ograje

## Computer-Aided Design of a Road Restraint Barrier

Matej Vesenjak - Zoran Ren

Cestne varnostne ograje na javnih cestah so namenjene za preprečitev zleta vozila s cestišča ali preboja na nasprotni vozni pas. Evropski standard SIST EN 1317 podaja merila, ki jih mora ograja izpolnjevati pod testno obremenitvijo.

Dosedanja praktična opažanja kažejo, da je sedanji distančnik cestne varnostne ograje, ki se uporablja v Republiki Sloveniji, pretog. To ima za posledico prevelike pojemke pri naletu osebnega vozila. Zato je določitev primerne oblike distančnika izrednega pomena za povečanje varnosti udeležencev v prometu.

Namen raziskave je oblikovanje novega distančnika, ki se bo nadzorovano deformiral in bo zmožen povečati akumulacijo deformacijske energije pri naletu vozil. V ta namen so z uporabo metode končnih elementov analizirane različne oblike distančnikov. V začetni fazi razvoja je analizirana togost različnih oblik distančnikov z navidezstatično elasto-plastično analizo trirazsežnega modela odseka varnostne ograje. Ugotovljeno je, da ima sedanji distančnik zelo veliko togost in da so distančniki novih oblik zmožni večje, nadzorovane elasto-plastične deformacije pri naletu vozil.

© 2003 Strojniški vestnik. Vse pravice pridržane.

**(Ključne besede: varnost na cestah, ograje varnostne, konstruiranje, simuliranje numerično, simuliranje nelinearno)**

Road restraint barriers on public roads are used to prevent a vehicle from veering off the road or breaking through on to the opposite carriageway. The European standard SIST EN 1317 specifies the criteria that the road restraint barrier has to meet during testing.

Practical observations have shown that the distance spacer currently used in the road restraint barriers in Slovenia is too stiff. This results in too rapid decelerations during vehicle impact. Designing an improved distance spacer is therefore extremely important for increasing the safety of vehicle occupants.

The purpose of this research was to design a new distance spacer that deforms in a controllable manner and has an increased capacity for strain-energy absorption during vehicle impact. The new designs were analyzed with the finite-element method. In the initial phase of the research, the stiffness of various designs of distance spacer was analyzed using quasi-static elastic-plastic analyses of a three-dimensional road-restraint-barrier model. It was found that the currently used distance spacer is indeed much too stiff and that new distance-spacer designs are capable of larger, controllable elastic-plastic deformation during vehicle impact.

© 2003 Journal of Mechanical Engineering. All rights reserved.

**(Keywords: roadside safety, road restraint barriers, computer aided design, numerical simulations, nonlinear simulations)**

### 0 UVOD

Pri vedno strožjih varnostnih zahtevah in skrbi za prometno varnost so pri načrtovanju varnejših javnih cest nujno potrebne cestne varnostne ograje. Uporaba teh konstrukcij preprečuje vozilom in pešcem vstop v nevarna območja. Zaradi tega je ustrezna konstrukcija izrednega pomena.

V pripravi je slovenski pravilnik o varnostnih ograjah, ki predpisuje pogoje in načine njihove postavitve na javnih cestah. Pravilnik predpisuje,

### 0 INTRODUCTION

Because of increasing safety demands and concerns about road safety, road restraint barriers are of crucial importance for the planning of safer public roads. The use of these barriers prevents vehicles and pedestrians from entering into dangerous zones. Their design is therefore extremely important.

A new Slovenian technical guide for road restraint barriers is in preparation. This regulation prescribes the conditions and the methods of barrier place-

da morajo ograje ustrezati Evropskemu standardu SIST EN 1317 glede obnašanja ograje pod testno obremenitvijo [2].

Zaradi dosedanjih praktičnih ugotovitev, da ima sedanja konstrukcija cestne varnostne ograje preveliko togost, je potrebno poiskati ustrezno rešitev, ki bo zmanjšala togost ograje in s tem pojemke pri naletu vozila ob ograjo ter tako povečala varnost potnikov v vozilu. Namen raziskave je oblikovanje novega distančnika, ki bo zmožen nadzorovane deformacije in akumulirati več deformacijske energije pri naletu vozil. Obravnavane so štiri različne oblike distančnikov.

Togost različnih oblik distančnikov je bila analizirana z navidezstatično elasto-plastično analizo trirazsežnega modela dela varnostne ograje po metodi končnih elementov.

## 1 OSNOVNE KONSTRUKCIJSKE ZAHTEVE VARNOSTNE OGRAJE

Namen varnostnih ograj je preprečiti zlet vozila s ceste ali preboj vozila na nasprotni vozni pas in s tem preprečiti oziroma zmanjšati poškodbe potnikov v vozilu, oseb in objektov ob vozišču, oziroma zadržati vozila, ki nenadzorovano spreminjajo smer vožnje, in jih ohraniti na ustreznem voznem pasu. Pri tem mora biti ograja zmožna akumulirati čimveč deformacijske energije, pri čemer se ne sme pretrgati.

Varnostno ograjo postavljamo na mestih, kjer je nevarnost poškodb zaradi udarca vozil v varnostno ograjo manjša od nevarnosti prehoda vozil v nevarno območje, ki je ločeno z varnostno ograjo. Na javnih cestah v Republiki Sloveniji se v skladu s sprejemom evropske zakonodaje lahko postavljajo le varnostne ograje, ki so atestirane po SIST EN 1317.

Na cestah se praviloma uporablja jeklena varnostna ograja (sl. 1), v posameznih primerih pa je potrebno ali dovoljeno uporabiti tudi betonsko

ment on public roads. The regulation prescribes that the road restraint barrier's behaviour under a testing load must fulfil the European standard SIST EN 1317 [2].

Practical observations of the barriers that are currently in use indicate that the design is too stiff. Therefore, a solution has to be found that will decrease the stiffness of the road restraint barrier and thus the decelerations during vehicle impact and consequently improve the safety of vehicle occupants. The purpose of this research was to design a new distance spacer that will deform in a controlled manner and will absorb more strain energy during the vehicle impact. Four different distance-spacer designs were evaluated.

The stiffness of the various distance-spacer designs was analyzed with quasi-static elastic-plastic finite-element analyses of a three-dimensional model of a road restraint barrier.

## 2 BASIC DESIGN REQUIREMENTS OF THE ROAD RESTRAINT BARRIER

The purpose of a road restraint barrier is to prevent a vehicle from veering off the road or breaking through to the opposite side of the road, and so to prevent or reduce the injuries of road users and the damage caused to certain objects. The barrier also needs to be able to restrain vehicles that are changing their driving direction in an uncontrollable way and keep them on the proper side of the road. During vehicle impact the barrier has to absorb as much strain energy as possible and must not rupture.

Road restraint barriers are used in places where the danger of injuries caused by a vehicle hitting the road restraint barrier is lower than that of a vehicle veering off into a dangerous zone that is protected by a road restraint barrier. In compliance with European legislation, only road restraint barriers that fulfil the SIST EN 1317 regulation can be used on Slovenian public roads.

The restraint barriers are usually made of steel (Fig. 1), although higher containment levels can sometimes be achieved by using concrete

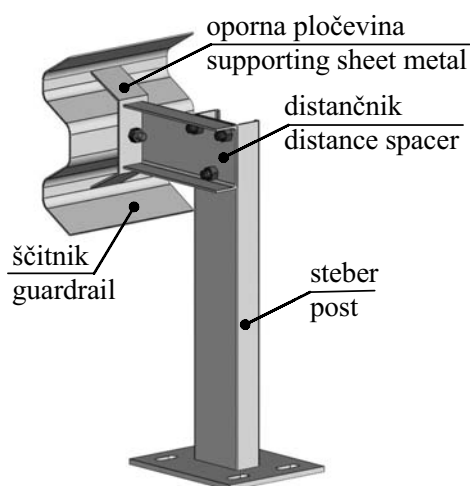


Sl. 1. Jeklena cestna varnostna ograja  
Fig. 1. Steel road restraint barrier

(kadar želimo zagotoviti največjo stopnjo zadrževanja vozil) in leseno varnostno ograjo (na malo prometnih cestah iz naravovarstvenih in estetskih razlogov).

Konstruktivski elementi jeklene cestne varnostne ograje so (sl. 2):

- ščitnik: v primeru udarca vozila s svojo deformljivo konstrukcijo zmanjša posledice udarca, pri čemer se ne sme pretrgati;
- oporna pločevina: povezuje ščitnik in distančnik, ščitniku pa daje še dodatno oporo;
- distančnik: ublaži učinek udarca vozila ob ograjo in je namenjen za povezavo med ščitnikom in stebrom ali drugo oporo;
- steber: je nosilec distančnika in/ali ščitnika, ki zagotavlja lego ščitnika na določeni oddaljenosti od vozišča oziroma nad njim (sl. 3).



Sl. 2. Sestavni elementi cestne varnostne ograje  
Fig. 2. Parts of the road restraint barrier

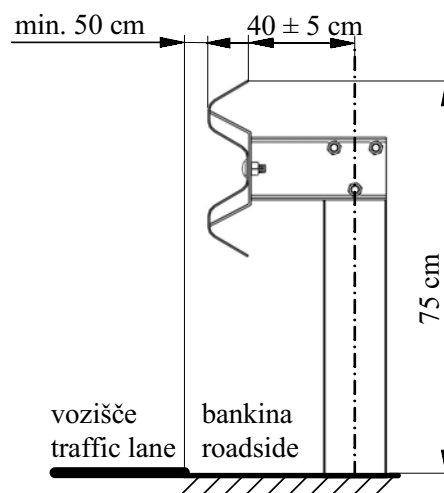
Cestne varnostne ograje so lahko eno- ali dvostranske, z distančnikom ali brez njega. Enostranska jeklena varnostna ograja je predvidena za zadrževanje vozil z ene strani (ob robovih cest), medtem ko je dvostranska ograja predvidena za zadrževanje vozil z obeh strani (ločuje levi in desni pas na vozišču). Ograje z distančnikom se prvenstveno uporabljajo predvsem na avtocestah in drugih hitrih cestah, ograje brez distančnikov pa na ožjih cestah, kjer zaradi ozkih bankin ni mogoče uporabljati distančnikov.

Zgornji rob jeklene varnostne ograje mora biti postavljen 75 cm nad robom vozišča. Oddaljenost ščitnika varnostne ograje mora biti najmanj 50 cm od roba vozišča. Razdalja med ščitnikom in sredino stebra mora biti  $40 \pm 5$  cm (sl. 3).

blocks. Wooden restraint barriers are used when a lower containment level is needed or because of nature conservation or for esthetic reasons.

Steel road restraint barriers comprise the following elements (Fig. 2):

- the guardrail: in the event of an impact the guardrail reduces the consequences with its deformable construction, although it has to be strong enough not to rupture;
- the supporting sheet metal: connects the guardrail with the distance spacer and gives the former some additional support;
- the distance spacer: decreases the severity of the impact and connects the guardrail with the post;
- the post: carries the distance spacer and/or the guardrail and ensures positioning of the guardrail at a certain distance from and above the road (Fig. 3).



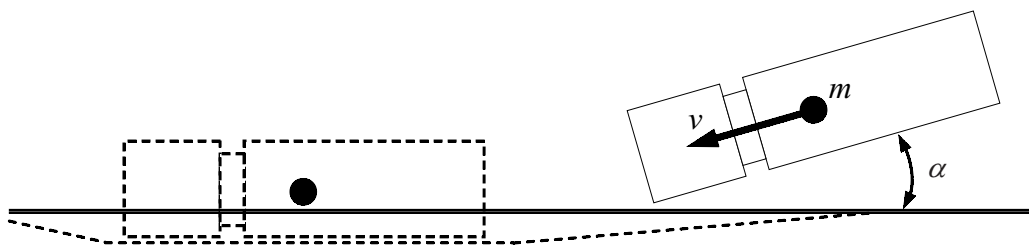
Sl. 3. Mere postavitve cestne varnostne ograje  
Fig. 3. Dimensions for positioning of the road restraint barrier

A road restraint barrier can be one or two-sided, with a distance spacer or without it. A one-sided road restraint barrier is used to restrain a vehicle from one side (on roadsides), whereas a two-sided road restraint barrier is supposed to restrain vehicles from both sides (it separates the left-hand and the right-hand sides of the road). Distance spacers are normally used on highways and other roads with high-speed traffic, whereas guardrails without distance spacers are used in places where the space for their installation is limited.

The upper edge of the guardrail must be 75 cm above the road surface. The distance between the guardrail and the roadside must be at least 50 cm and the distance between the guardrail and the middle of the post is required to be  $40 \pm 5$  cm (Fig. 3).

## 2 RAZVRSTITEV VARNOSTNIH OGRAJ PO SIST EN 1317

Naleti vozil na cestno varnostno ograjo se razlikujejo glede na maso ( $m$ ), hitrost ( $v$ ), kot približevanja ( $\alpha$ ), tip in obnašanje vozila ter razmere na cesti (sl. 4).



Sl. 4. Parametri teoretičnega naleta vozila  
Fig. 4. Parameters of a theoretical vehicle impact

Glede na standard SIST EN 1317 so varnostne ograje razvrščene v več razredov zadrževanja vozil, pri čemer standard predpisuje kriterije, ki jih mora cestna varnostna ograja izpolniti pri določenih testnih pogojih naleta vozil.

Pri tem je treba upoštevati, da mora ograja zadržati trke različnih tipov vozil, od osebnih avtomobilov do tovornjakov. Pri naletu vozil z manjšo maso (manjšo kinetično energijo), mora biti ograja nadzorovano deformabilna (mehka), da so pojemki vozila pri trku čim manjši. Pri naletu vozila z večjo maso (večjo kinetično energijo) pa mora imeti ograja dovolj veliko nosilnost, da vozilo zadrži na cestišču. Tako je pri konstruiranju cestne varnostne ograje ves čas treba iskati kompromis med togostjo (deformabilnostjo) in nosilnostjo ograje.

Cestne varnostne ograje morajo po SIST EN 1317-2 izpolnjevati naslednje kriterije:

- Stopnja zadrževanja vozil: stopnja zadrževanja različnih vrst vozil, ki je za posamezno javno cesto odvisna od njene kategorije, povprečnega letnega dnevnega prometa (PLDP), specifičnega obcestnega prostora ali nevarnega odseka ceste. Standard določa štiri stopnje zadrževanja vozil: majhno stopnjo zadrževanja (T1, T2 in T3), normalno stopnjo zadrževanja (N1 in N2), veliko stopnjo zadrževanja (H1, H2 in H3) in zelo veliko stopnjo zadrževanja (H4a in H4b). Standard predpisuje za vsako posamezno stopnjo pogoje testnega naleta vozila (masa, hitrost in kot naleta), ki jih mora cestna varnostna ograja pri trku vzdržati.
- Jakost udarca: jakost udarca vozila ob cestno varnostno ograjo v smislu ugotavljanja posledic za potnike v vozilu merimo z vrednotenjem indeksa velikosti pospeškov (IVP - ASI), z določanjem teoretične hitrosti glave pri udarcu (THGU - THIV) in z merjenjem pojemka glave

## 2 PERFORMANCE CLASSES OF ROAD RESTRAINT BARRIERS ACCORDING TO SIST EN 1317

Vehicle impacts on a the road restraint barrier differ in terms of the vehicle mass ( $m$ ), the vehicle velocity ( $v$ ), the impact angle ( $\alpha$ ), the type and behaviour of the vehicle and the road conditions (Fig. 4).

According to SIST EN 1317, road restraint barriers are divided into several performance classes of vehicle containment. The standard prescribes criteria that the road restraint barrier has to fulfil under certain test-vehicle impact conditions.

The road restraint barriers have to sustain impacts of different vehicle types (from passenger cars to trucks). In the case of a low-weight vehicle impact, the restraint barrier should deform controllably to reduce the vehicle decelerations as much as possible. However, in the case of a high-weight vehicle (higher kinetic energy) impact, the barrier must be strong enough to restrain the vehicle on the road. Thus, the design of the road restraint barrier is a compromise between its stiffness (deformability) and its strength.

Road restraint barriers have to satisfy the following criteria according to SIST EN 1317-2:

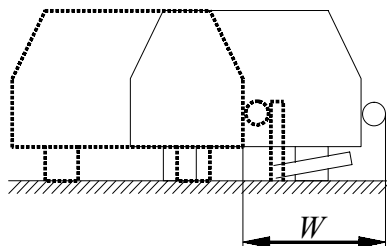
- Containment level: This represents the level of containment for different types of vehicles. The levels depend on the type of road, the average daily traffic over a year, the roadside space and dangerous road zones. The standard defines four levels of containment: the low containment level (T1, T2 and T3), the normal containment level (N1 and N2), the high containment level (H1, H2 and H3) and the very high containment level (H4a and H4b). The standard prescribes exact testing impact conditions (weight, velocity and impact angle of a vehicle) for each containment level that the road restraint barrier has to sustain in the event of an impact.
- Impact severity: The consequences of an impact for the occupants of the impacting vehicle are evaluated with the acceleration severity index (ASI), the theoretical head impact velocity (THIV) and the post-impact head deceleration (PHD). According to the standard, the limit val-

po udarcu (PGU - PHD). Glede na standard so mejne vrednosti teh parametrov naslednje: IVP  $\leq 1,0$  (1,4), THGU  $\leq 33$  km/h in PGU  $\leq 20$  g.

- Deformacija cestne varnostne ograje: pomik (delovna širina) ograje ( $W$ ) pomeni razdaljo med licem ščitnika varnostne ograje v prvotni legi pred naletom vozila in skrajno, od vozišča odmaknjeno točko na ograji po naletu vozila na ograjo (sl. 5). Standard navaja 8 deformacijskih razredov varnostne ograje (W1 do W8).

ues of these parameters are: ASI  $\leq 1.0$  (1,4), THIV  $\leq 33$  km/h and PHD  $\leq 20$  g.

- Deformation of the restraint barrier: The working width of the restraint barrier ( $W$ ) is the distance between the road-face of the W-beam before the impact of a vehicle and the maximum lateral position of any major part of the barrier after the impact (Fig. 5). The standard distinguishes between eight classes of deformation of the restraint barrier (W1 to W8).



Sl. 5. Delovna širina ( $W$ ) cestne varnostne ograje  
Fig. 5. Working width ( $W$ ) of the road restraint barrier

### 3 IZBIRA PRIMERNE OBLIKE DISTANČNIKA

Obravnavana konstrukcija cestne varnostne ograje (sl. 6a) je izdelana iz konstrukcijskega jekla S 235 (St 37-2 po DIN). Ščitnik je izdelan iz 3 mm debele pločevine in preoblikovan v obliko črke W, ki trdnostne lastnosti še povečuje. Dolžina odbojnika je običajno 4200 mm, pri čemer je dolžina spoja (prekritja) 200 mm. Oporna pločevina je izdelana iz 6 mm debele pločevine in je privarjena na distančnik. Sedanji distančnik je iz profila U, dimenzij 120 x 50 in dolžino 260 mm. Razdalja med oporno pločevino in stebrom znaša 140 mm. Stebri so izdelani iz profila C, izmere 55 x 120 x 4 mm. Praviloma so dolžine 1,9 m. Postavljeni so na medsebojni oddaljenosti 1,33 m, 2 m in 4 m, kar je odvisno od potrebne stopnje zadrževanja vozil. V primeru večje stopnje zadrževanja so razdalje med stebri manjše. V nasprotnem primeru, kadar zadošča manjša stopnja zadrževanja, so lahko razdalje med stebri večje. Steber je postavljen tako, da je zaprti profil obrnjen proti smeri vožnje. Če stebra ni mogoče zabiti v zemlino, ga je potrebno s podložno ploščo pritrditi na sidrno ploščo. Odbojniki, stebri in distančniki so spojeni s pocinkanimi vijaki M16 x 35 mm trdnostnega razreda 5.8.

Pri konstruiranju nove oblike distančnika je bilo treba upoštevati različne zahteve. Distančnik mora biti oblikovan tako, da ograja geometrijsko ustreza državnemu pravilniku o postavitvi cestnih varnostnih ograj. Nadalje mora s svojo obliko čim bolj ublažiti nalet vozila prek akumulacije čim večje količine kinetične energije vozila s svojo nadzorovano elasto-plastično deformacijo.

### 3 SELECTION OF A SUITABLE DISTANCE- SPACER DESIGN

The evaluated road restraint barrier (Fig. 6a) is made of S 235 construction steel (St 37-2 according to DIN). The guardrail is made of 3-mm-thick metal sheet, which is W-shaped to improve its strength characteristics. The usual length of a guardrail segment is 4200 mm; where the splice length is equal to 200 mm. The supporting sheet metal is 6-mm thick and is welded to the distance spacer. The currently used distance spacer is U-shaped with dimensions of 120 mm x 50 mm and 260 mm. The distance between the guardrail and the post is 140 mm. The post is C-shaped with dimensions of 55 mm x 120 mm x 4 mm and it is usually 1900-mm long. The distance between the posts depends on the required containment level and can be 1.33 m, 2 m or 4 m. For higher containment levels the distance between the posts is shorter. In the opposite case, when a lower containment level is required, the distance must be longer. Posts are always oriented with the closed profile towards the direction of traffic flow. If a post cannot be rammed into the soil, it has to be fixed with an anchor-plate. W-beams, posts and distance spacers are joined with standard bolt connections M16 x 35 mm of strength class 5.8.

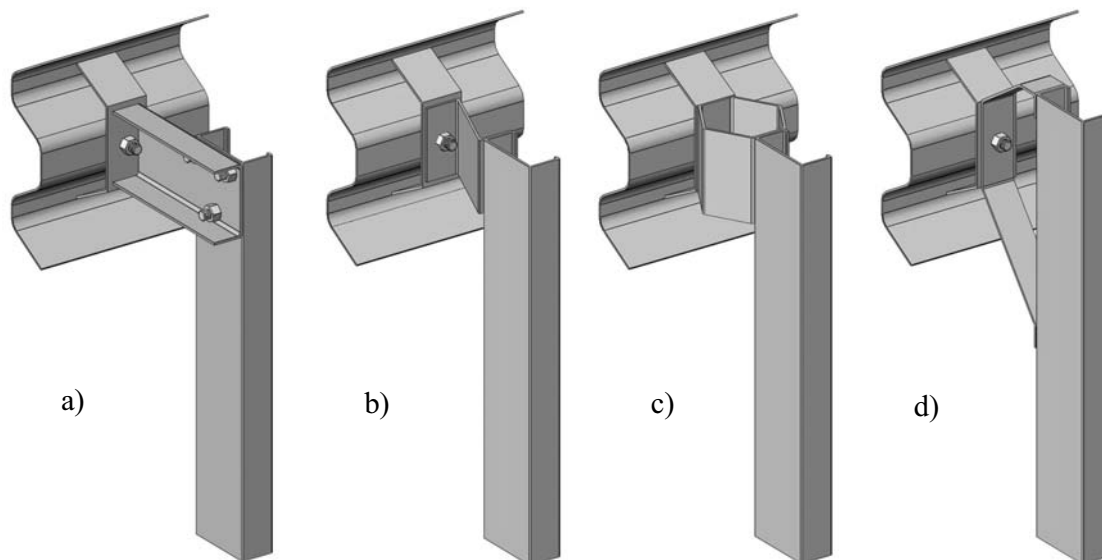
When designing a new shape of distance spacer, various requirements have to be taken into consideration. The distance spacer has to be designed in such a way that the road restraint barrier geometrically suits the basic regulations. Furthermore, in the event of an impact, it should deform in a controlled manner, thus absorbing as much kinetic energy as possible through elasto-plastic deformation. The dis-

Distančnik mora zagotavljati zadosten odpor silam, ki delujejo nanj, vendar ne sme biti pretog. Pri trku in po njem mora ostati distančnik ves čas povezan s ščitnikom ali stebrom. Distančnik mora biti preprost za izdelavo in montažo in omogočati mora stalno in preprosto vzdrževanje.

Obravnavane so bile štiri različne oblike distančnikov, ki so prikazane na sliki 6.

tance spacer must provide enough resistance to the impacting forces but should not be too stiff. It has to stay connected to the guardrail or the post during and after an impact. It also has to be easy and cheap to produce, simple enough to assemble and it should allow permanent and simple maintenance.

Four different distance spacer designs were investigated (Fig. 6).



Sl. 6. Različne oblike distančnikov:

a – profil U (prvotni distančnik); b – profil Z; c – šestkotni profil; d – profil D

Fig. 6. Different distance spacer designs:

a – U profile (current distance spacer); b – Z profile; c – hexagonal profile; d – D profile

#### 4 PRIMERJALNA ANALIZA DISTANČNIKOV PO METODI KONČNIH ELEMENTOV

#### 4 COMPARATIVE ANALYSES WITH THE FINITE-ELEMENT METHOD

Vsi sestavni deli varnostne ograje so izdelani iz konstrukcijskega jekla S 235. Z namenom, da bi ugotovili materialne lastnosti pločevin različnih debelin, so bili izvedeni natezni preizkusi preskušancev iz jeklene pločevine v skladu s standardom DIN 50115. Iz eksperimentalno dobljenih rezultatov so bile določene elasto-plastične lastnosti materiala (modul elastičnosti, meja plastičnosti in modul plastičnosti), ki so bile uporabljene v bilinearnem elasto-plastičnem modelu materiala pri računalniških simulacijah. Izmerjene materialne lastnosti so podane v preglednici 1.

Računalniški model cestne varnostne naprave je sestavljen iz naslednjih elementov:

- ščitnika: modeliran z linearnimi lupinskimi štirikotnimi elementi, debeline 3 mm;
- oporne pločevine: modelirana z linearnimi lupinskimi štirikotnimi elementi, debeline 6 mm;
- distančnika: modeliran z linearnimi lupinskimi štirikotnimi elementi, debeline 4 mm (razen profil D = 5 mm);
- stebra: modeliran z linearnimi lupinskimi štirikotnimi elementi, debeline 4 mm;

All the parts of the road restraint barrier are made of S 235 construction steel. To acquire the appropriate material properties for sheet metal with different thicknesses, standard tension tests were carried out on specimens according to DIN 50115. The required material properties (Young's modulus, yield stress and plasticity modulus) were determined from analyses of the obtained experimental data and were used in the isotropic bilinear elasto-plastic material model in the computational analyses. The measured material properties are listed in Table 1.

The computational model of the road restraint barrier was composed of the following components:

- the guardrail: discretised with linear rectangular shell elements of 3-mm thickness;
- the supporting sheet metal: discretised with linear rectangular shell elements of 6-mm thickness;
- the distance spacer: discretised with linear rectangular shell elements of 4-mm thickness (only the D profile is made of 5-mm-thick sheet metal);
- the post: discretised with linear rectangular shell

Preglednica 1. Materialne lastnosti jeklenih pločevin iz jekla S 235

Table 1. Material properties of sheet metals made of S 235 steel

Debelina pločevine Sheet metal thickness	Modul elastičnosti Young's modulus	Poissonovo število Poisson's ratio	Meja plastičnosti Yield stress	Modul plastičnosti Plasticity modulus	Natezna trdnost Tensile strength
mm	MPa	/	MPa	MPa	MPa
3	190000	0,29	285	696	400
4	200000	0,29	330	969	450
6	210000	0,29	380	1200	480

- vijčnih spojev: v začetni fazi raziskav so vijaki modelirani s togimi končnimi elementi, ki pomenijo vijčne zveze;
- zvarnih spojev: modelirani s togimi elementi.

Povprečna velikost štirikotnih lupinskih elementov je 10 mm. Celoten model je sestavljen iz približno 3200 končnih elementov.

Pri določanju robnih pogojev smo si pomagali s standardom SIST EN 1317, kjer smo za obremenitev v začetni fazi raziskave določili silo trka  $F = 30$  kN. Ta konzervativna sila je bila enakomerno porazdeljena na dotikalno površino ščitnika v dolžini 300 mm (sl. 7). Celotno konstrukcijo smo toga vpeli na spodnjem delu stebra po robu 3 (sl. 7). Ščitniku smo po robu 1 in 2 predpisali periodične simetrične robne pogoje (sl. 7).

Za izdelavo mreže končnih elementov in nelinearne analize je bil uporabljen programski paket MSC.visualNastran za Windowse. Konvergenca rešitve je bila zagotovljena pri 10 do

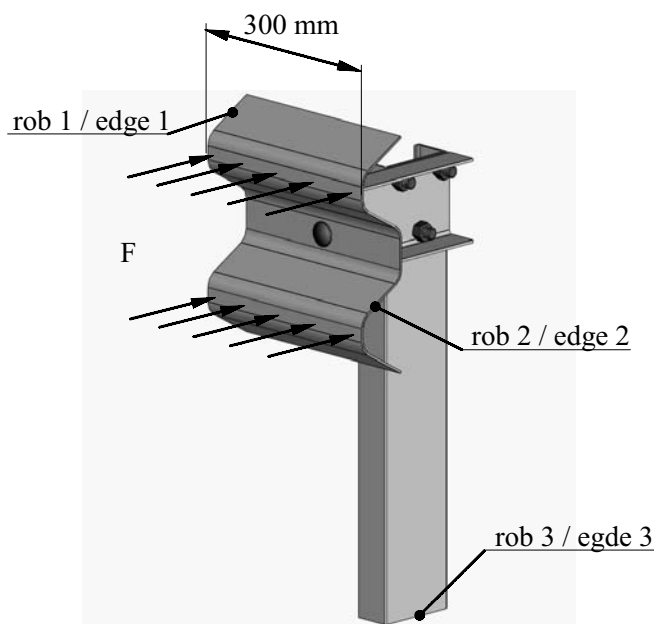
elements of 4-mm thickness;

- bolts: the bolt connections were modelled with rigid finite elements;
- welds: the weld connections were modelled with rigid finite elements.

The average size of the rectangular shell elements is 10 mm. The whole model consists of approximately 3200 finite elements.

The loading was defined according to the standard SIST EN 1317, where a constant impact force of 30 kN was evenly distributed along the guardrail contact surface (Fig. 7), 300 mm in length. The post was fixed at the lower part on the edge 3 (Fig. 7) and periodic symmetry boundary conditions were defined at both ends of the guardrail – edges 1 and 2 (Fig. 7).

The MSC.visualNastran for Windows FE system was used for pre-processing, nonlinear analyses and post-processing of the computational results. To obtain a convergent solution it was necessary to



Sl. 7. Robni pogoji

Fig. 7. Boundary conditions

50 obremenitvenih korakovih, s 25 iteracijami znotraj koraka ob toleranci obremenitve in dela, ki je znašala  $10^{-5}$ . Uporabljena je bila metoda posodobitve togostne matrike po prvi iteraciji v posameznem koraku obremenitve.

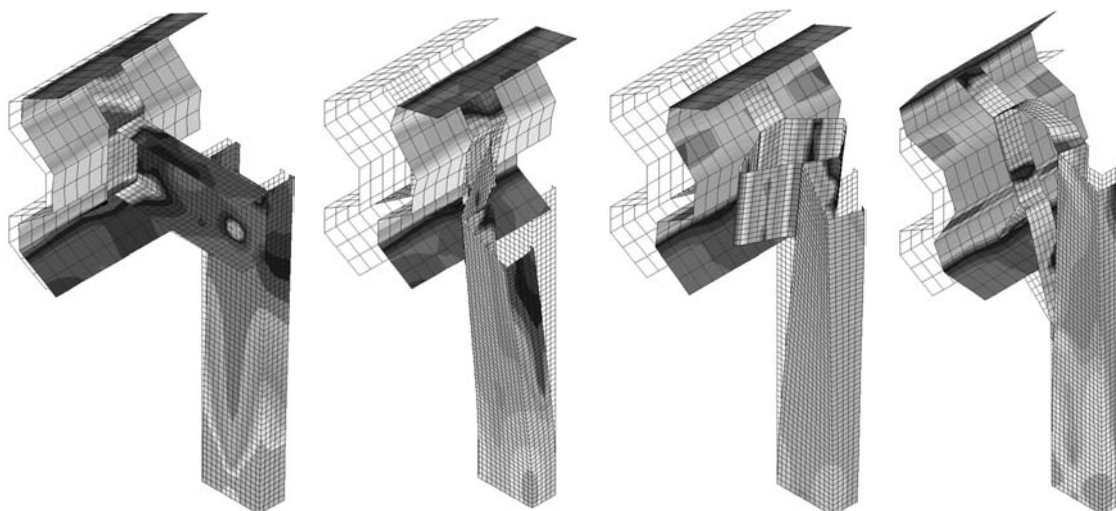
define 10–50 load increments and a maximum of 25 iterations inside one load increment. The work and load convergence tolerances were set to a value of  $10^{-5}$ . The stiffness matrix was updated after the first iteration in each load increment.

5 PRIMERJAVA REZULTATOV

5 COMPARISON OF THE RESULTS

Rezultati računalniških analiz v obliki pomikov ograje so prikazani na sliki 8.

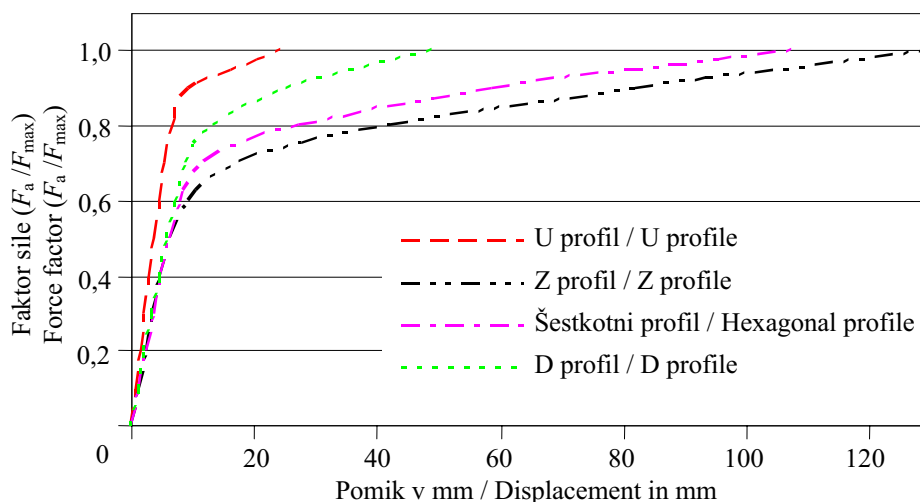
The results of the computational analyses in the form of barrier displacements are shown in Fig. 8.



Sl. 8. Pomik cestne varnostne ograje pod obremenitvijo  
 Fig. 8. The displacement of the road restraint barrier under an applied load

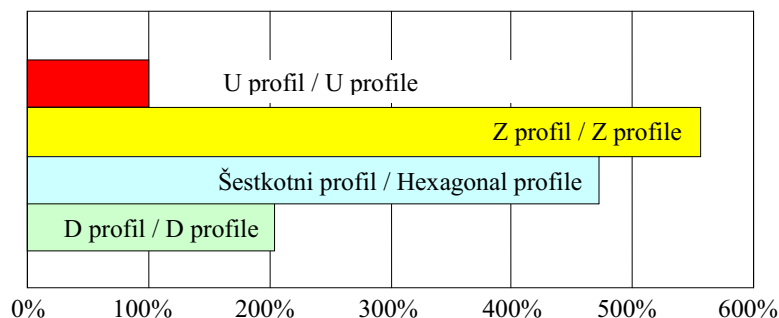
Pri vrednotenju rezultatov so bili najpomembnejši pomiki v smeri delovanja sil, ki ponazarjajo deformacijo ograje pri naletu vozila. Za vrednotenje jakosti udarca je pomembna tudi deformacijska energija, ki jo sprejme konstrukcija varnostne ograje (sl. 9).

The most important data in the process of evaluating the results were the displacements in the direction of the acting forces, which illustrate the deformation of the road restraint barrier in the event of a vehicle impact. When evaluating the impact severity, it is important to consider the strain energy that is absorbed by the safety barrier (Fig. 9).



Sl. 9. Diagram sila – pomik  
 Fig. 9. Force – displacement diagram





Sl. 10. Primerjava akumulirane deformacijske energije  
Fig. 10. Comparison of the strain-energy absorption

Diagram na sliki 10 prikazuje normirane vrednosti akumulirane deformacijske energije, pri čemer znaša izhodiščna vrednost sedanjega distančnika 100%.

Razvidno je, da se trenutni distančnik najmanj deformira, kar ima za posledico zelo velike pojemke pri naletu vozila v ograjo. Tudi zmožnost akumuliranja deformacijske energije kaže na zelo togo konstrukcijo, ki ne more zagotavljati najboljše varnosti na cestišču. Največji pomik in največjo zmožnost akumuliranja deformacijske energije dosežemo z distančnikom profila Z, vendar je ta deformacija precej nestabilna zaradi nesimetrične oblike distančnika. Najbolj nadzorovano se deformira distančnik v obliki šestkotnika. Njegova zmožnost akumuliranja deformacijske energije je 4,8-krat večja od akumulirane deformacijske energije sedanjega distančnika. Distančnik v obliki črke D je dosegel najslabše rezultate. Dobra lastnost tega distančnika je v tem, da potisne ščitnik navzgor in s tem prepreči, da bi ga vozilo prevozilo. Primerjava rezultatov računalniških simulacij je podana v preglednici 2.

Primerjava rezultatov dokazuje, da sedanji distančnik ne zadovoljuje vseh pogojev uporabe. Ugotovljeno je bilo, da lahko z drugačnimi oblikami distančnikov povečamo zmožnost akumuliranja deformacijske energije in tako posledično

The diagram in Figure 10 shows normalized values of the absorbed strain energy. The value of the currently used distance spacer is 100%.

It is obvious that the currently used distance spacer has the smallest deformation and consequently causes the highest decelerations during vehicle impact. The amount of strain-energy absorption indicates that this design is very stiff and cannot assure proper highway safety. The Z-shaped distance spacer experiences large deformations and higher strain-energy absorption. However, its deformation is very unpredictable due to its non-symmetrical shape. The deformation of the hexagonal-shaped distance spacer proved to be the most controllable. Its energy absorption is 4.8 times higher than the strain-energy absorption of the currently used distance spacer. The D-shaped distance spacer has the worst overall performance. However, its major advantage is that it pushes the guardrail up during impact, which prevents the vehicle from overrunning the guardrail. A comparison of the computational analyses results is shown in Table 2.

A comparison of the computational results shows that the currently used distance spacer does not fulfil all the conditions. We found that the use of different distance-spacer designs could increase the strain-energy absorption and consequently decrease the

Preglednica 2. Primerjava rezultatov simulacij  
Table 2. Comparison of the computational results

Distančnik Distance spacer	Pomik v prečni smeri Lateral displacement	Največja primerjalna napetost Maximum equivalent stress
	mm	MPa
profil U / U profile	24,1	402
profil Z / Z profile	129,9	480
šestkotni profil / hexagonal profile	108,1	510
profil D / D profile	48,6	480

zmanjšamo pojemke, ki jih pri trku utrpijo potniki v vozilu.

## 6 SKLEP

Za vrednotenje različnih oblik distančnikov so bile izvedene nelinearne navidezstatične analize odseka cestne varnostne ograje ob upoštevanju naleta osebnega vozila.

Iz rezultatov računalniških simulacij je razvidno, da lahko z drugačnimi oblikami distančnikov zmanjšamo togost varnostne ograje, omogočimo večjo zmožnost deformiranja in tako posredno zmanjšamo pojemke pri naletu vozila ter povečamo varnost potnikov v vozilu.

Rezultati računalniških simulacij dokazujejo, da je dosedanji distančnik pretog in je očitno konstruiran zgolj po geometrijskih pravilih, ne glede na funkcionalnost. Najboljše rezultate dosegata distančnika oblike Z in šestkotnega profila. Čeprav ima distančnik iz profila Z manjšo togost in večjo zmožnost akumuliranja deformacijske energije, se distančnik iz šestkotnega profila deformira bolj predvidljivo in zaradi svoje simetričnosti ni občutljiv na kot naleta vozila na ograjo.

V nadaljnjih raziskavah bo simuliran dinamični nalet realnega vozila na varnostno ograjo (sl. 11), pri čemer bo upoštevana tudi deformacija podlage, v katero so nameščeni stebri.

decelerations experienced by the vehicle occupants during an impact.

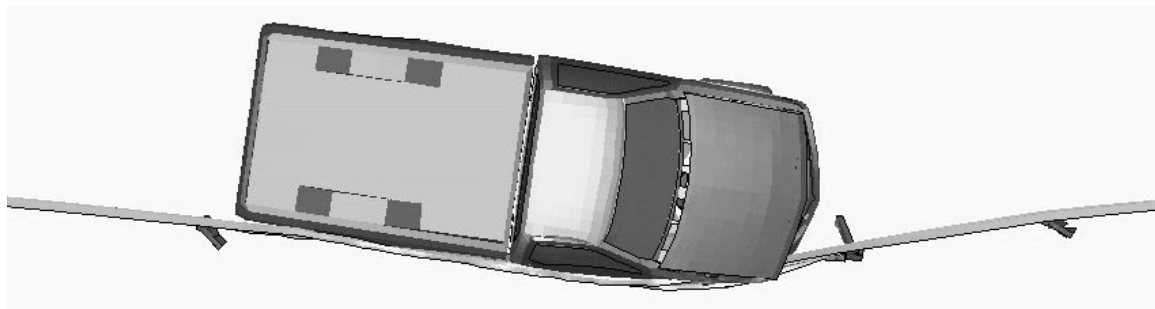
## 6 CONCLUSION

The nonlinear quasi-static analyses of a segment of road restraint barrier under vehicle-impact conditions were carried out to evaluate a variety of distance-spacer designs.

The results of the computational analyses show that it is possible to reduce the stiffness of the road restraint barrier and increase its ability to absorb energy by using a range of distance-spacer designs, thus reducing the deceleration of an impacting vehicle and consequently increasing the safety of the vehicle occupants.

The computational simulations showed that the current distance spacer is far too stiff and was obviously designed only according to geometrical rules, and not according to its functionality. Better results can be achieved by using a Z-shaped or hexagon-shaped distance spacer. Although the Z profile has a lower stiffness and a higher strain-energy absorption capability, the hexagonal profile deforms in a more predictable way and is not sensitive to the vehicle impacting angle, due to its symmetry.

It is intended to continue this research with fully transient dynamic analyses of the road restraint barrier under real vehicle-impact conditions (Fig. 11). The soil deformation will also be taken into consideration during subsequent computational simulations of the road restraint barrier.



Sl. 11. Dinamična simulacija cestne varnostne ograje  
Fig. 11. Dynamic simulation of the road restraint barrier

## 7 LITERATURA

## 7 REFERENCES

- [1] Engstrand, K. E. (2000) Improvements to the weak - post w - beam guardrail. *Worcester: Worcester Polytechnic Institute.*
- [2] *European Committee for Standardization.* (1998) European Standard EN 1317-1, EN 1317-2, Road Restraint Systems.
- [3] Nafems (1992) Nafems - introduction to nonlinear finite element analysis, *Nafems Birniehill, Glasgow.*
- [4] Ministrstvo za promet (2001) Tehnična specifikacija za javne ceste. Urad za standardizacijo in meroslovje. Direkcija republike Slovenije za ceste. TSC 02.xxx, Varnostne ograje, pogoji in načini postavitve.
- [5] Vesenjak, M., Z. Ren (2002) Konstruiranje distančnika cestne varnostne ograje. Kuhljevi dnevi '02, Ribno pri Bledu, 26.-27. september 2002. *Zbornik del. Ljubljana: Slovensko društvo za mehaniko.*
- [6] Železarna Jesenice (1974) Cestna varnostna ograja, Kranj.

Naslov avtorjev: Matej Vesenjak  
prof.dr. Zoran Ren  
Univerza v Mariboru  
Fakulteta za strojništvo  
Smetanova 17  
2000 Maribor  
m.vesenj@uni-mb.si  
ren@uni-mb.si

Author's Address: Matej Vesenjak  
Prof.Dr. Zoran Ren  
University of Maribor  
Faculty of Mechanical Eng.  
Smetanova 17  
2000 Maribor, Slovenia  
m.vesenj@uni-mb.si  
ren@uni-mb.si

Prejeto: 20.8.2003  
Received:

Sprejeto: 18.12.2003  
Accepted:

Odprto za diskusijo: 1 leto  
Open for discussion: 1 year