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Study of Shock Attenuation for Impacted Safety Barriers

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Abstract

Romania is increasing and modernizing its highway network to manage the new transportation system as a result of the development of its economy. It is consequently important that the roads system should be efficiently responsible to the standard traffic requirements. Every safety barrier producer must have an investigation report, known as crash-test. Protective guardrails have as most important aim the redirection of the vehicles on the roadway, ensuring directing pedestrians and other road users. Safety barriers are situated on hazardous road sections in terms of traffic security, to keep vehicles on roadway. Crash-tests are quite expensive and given that they have need of specialized services and qualified personnel, the result is that important decisions are quite often based on the results of a few full-scale impact tests. At present, worldwide, protective guard rails are manufactured in different geometric configurations, depending on different fixing modes in soil, in order to enlarge impact strength capacity for different types of collisions. In this paper, the authors propose and analyze the impact behavior of two new safety guardrail systems in order to raise the impact energy absorption. The tests were performed using as impact or a 1500 kg Chevrolet C1500 pick-up truck from the NCAC models library.

Keywords: attenuator; guardrail; crash-test; collision; impact; safety; strength capacity

1. Introduction

Protective guardrails, known as safety barriers represent a system designed to keep vehicles from (in most cases unintentionally) straying into dangerous or off-limits areas and to redirect them on the main roadway. The National Crash Analysis Center (NCAC) [1] has made great strides in determining the safest guardrail post for highway use.

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The NCAC developed computerized crash simulation finite element (FE) models that were used in combination with traditional crash testing to determine the optimal post for highway use.

These tests helped determine the optimal choice of posts, steel quality, and post gaps for optimal guardrail performance. Many transportation agencies are installing guardrail in an effort to reduce the number of fatalities and serious injuries that result from run-off-road crashes. W-beam guardrail (flexible-post and stiff-post) has been used for decades since it is an effective guardrail system that can be used in a variety of roadside situations. Since crash tests are relatively expensive and due to the fact they require specialized services and qualified personnel, the result is that important decisions are quite often based on the results of a few full-scale impact tests. Several highly effective roadside safety hardware systems have been created using this process, but difficult issues remain.

In the present paper, the authors propose and analyse the impact behaviour of two new safety guardrail configurations in order to increase the impact energy absorption. Knowing the impact energy is not sufficient to predict the effect of collision. The answer depends also on the collided structure geometry, its material and the impact or velocity. The impact velocity can be low (< 70 km/h), medium (from 70 km/h up to 100 km/h) or high (>100 km/h). Mass impact or material and shape also play an important role in assessing the impact of the request. The next level of impact velocity is achieved when the dynamic model is required to predict the response of the structure.

2. Results and discussions

Studies were performed with LS-DYNA [7] software processing of the ANSYS program. In a first phase a deformable guardrail was tested; this barrier is met on most of the roads and highways, especially on hazardous routes. An image of such a guardrail system is depicted in Fig. 1.

a b

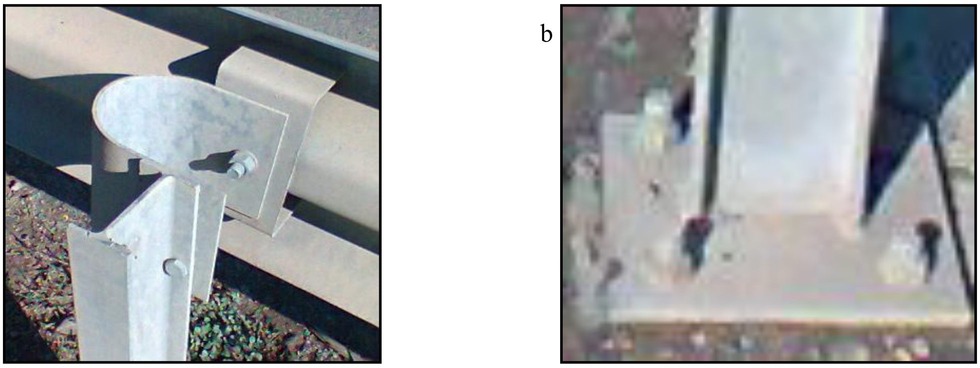

Fig. 1. (a) actual safety guardrail; (b) fixing system of the guardrail.

Recently, in parallel with the continuous development of digital computing systems have emerged and developed specialized software created to simulate and to analyze the impact behavior of structures. These numerical codes are used by all vehicle manufacturers in the world to simulate the collision tests or other types of passive safety predictions. Results from these types of simulations have been fully and unanimously accepted as a result of the continuous improvement of their software. The study of a body motion during the collision represents a major difficulty related to the very short time in which it occurs.

Structural modeling of impact actions is one of the most complex and difficult tasks for the structures analyst, involving dynamic modeling action, properties of materials, possible interaction vehicle - guardrail, sensitivity influence at high speed deformation of materials. The objective of this study was to analyze through a finite element model viable for W-beam standard guardrail system in order to investigate the effects of design variations on the performance of safety railing systems. The study involved three steps. A first one was to create a detailed finite element model of the guardrail, including its details – W beams, connections, posts, fixing bolts and ground fixing system. The second step was to obtain a numerical model of a valid vehicle, correlated to a real one. With this validated model, in a third step, the effects of design variations of W beam guardrail have been analyzed. The LS-DYNA [7] code uses an explicit Lagrangian numerical method for solving 3D problems, dynamic, nonlinear, with large displacements.

2.1. Modeling of guardrail components

According to roadside bulletin published in 2005, the proposed system for analysis is defined as one of the most effective and efficient support systems mounted on retaining walls in terms of energy absorption produced at the collision between the vehicle and the guardrail. This system is composed of a 2.5 mm thick W beam sheet, mounted on steel posts and provided with spacers (U20 profile and shock absorbers) in order to reduce the possibility of post vehicle hanging at the moment of collision.

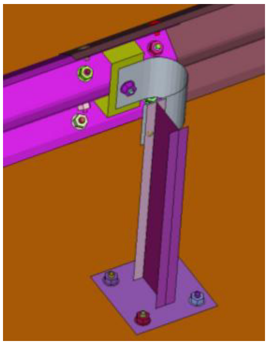

Fig. 2. Model of the guardrail components [6].

The finite element model developed for this simulation includes detailed representations of all components in order to be as precise as the real model. The explicit geometry of all components has been incorporated into the model [6], as one can see in Fig. 2. Metal components such as posts and W beams are modeled through nonlinear plastic materials. Simulations with this type of material were used extensively by the National Institute Analysis CRASH CENTER USA, the modeling results being fully validated. Material behavior is isotropic, elastic-plastic with deformation rate effects. Even if the improvement of parameters of steel products for the automotive industry is still one of the most important factors, which influence effectiveness of manufacturing [9], the chosen material isin conformity with the EN 10025-2: 2005 Standard, the analyzed guardrail is made of S235JR steel, with a stress-strain curve, presented in Fig. 3.

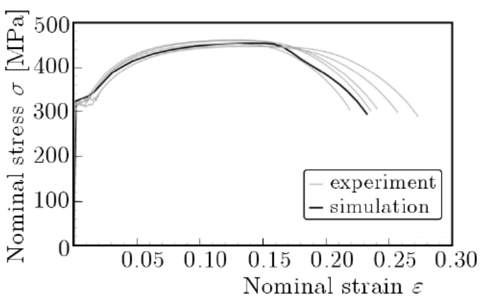

Fig. 3. Stress-strain curve for S235JR steel [1].

As one can see in Table 1 and Fig. 4, according to Roadside Bulletin published in 2005, the supporting INP 120 posts profile has the following features:

Table 1. Features of INP120 post profile.

Profile	Size						Mass	Transverse section
	h [mm]	b [mm]	g [mm]	t [mm]	r [mm]	r_1 [mm]	M [kg/m]	A [cm^2]
120	120	58	5.1	7.7	5.1	3.1	11.2	14.2

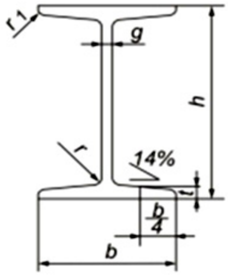

Fig. 4. INP 120 profile.

The actual safety guardrail system is depicted in Fig. 5.

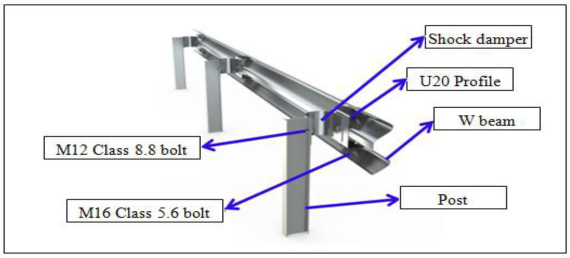

Fig. 5. Actual safety guardrail system.

The wall retaining system (Fig. 6) is made of reinforced concrete OB 37 Ø 25 equipped at the ends with metric thread M22. The ultimate stress of the material is R_m = 360 MPa. All posts, shock dampers and all W beams were modeled using quadrilateral shell elements.

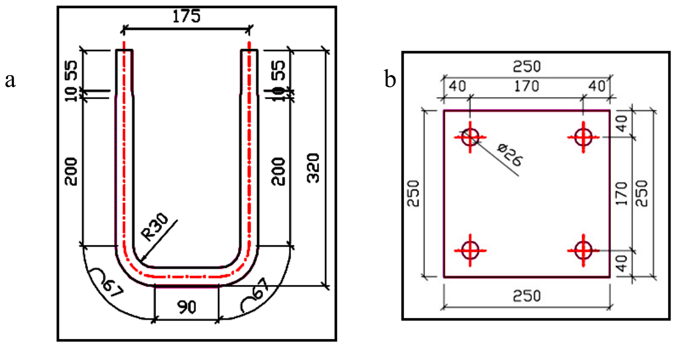

Fig. 6. (a) wall fixing system; (b) post basis [2].

For bolts and nuts modeling an elastic material with very high modulus was used in order to become stiffer. This assumption was adopted in order to define for these screws SPOTWELD constraints that usually could not be attributed for rigid materials [4]. It is necessary to define these types of constraints in order to simulate mechanical screw-nut assembly and to define the axial and shear force when the bolt fails. The properties of these constraints are determined by the material properties and cross-sectional area of the screw. This method has successfully been used in previous studies conducted by FAMU-FSU College of Engineering Computer Impact Simulation Laboratory and has been proven to be very accurate and effective. To have a legitimate numerical model, the used car (impactor) had to be validated. To create such a model is very expensive and lengthy. Consequently, the authors used an n already validated vehicle, with the agreement of the Texas Transportation Institute.

2.2. Simulation crash analysis

2.2.1. Simulation of a common safety guardrail, used in the present on roadways

For the analysis of this type of guardrail the following parameters have been taken into account:

- impact angle: 20°;
- impact velocity: 110 km/h;
- vehicle mass: 1500 kg;

In order to check if the guardrail retains the vehicle on the roadway after collision, the authors analyzed two crash scenarios, depicted in Fig. 7 and Fig. 8:

a) when the car collide the safety barrier at a far distance between the posts;
b) when the car collide the safety barrier in the vicinity of a post.

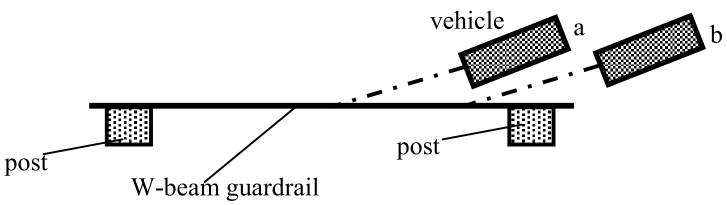

Fig. 7. Crash scenario.

a

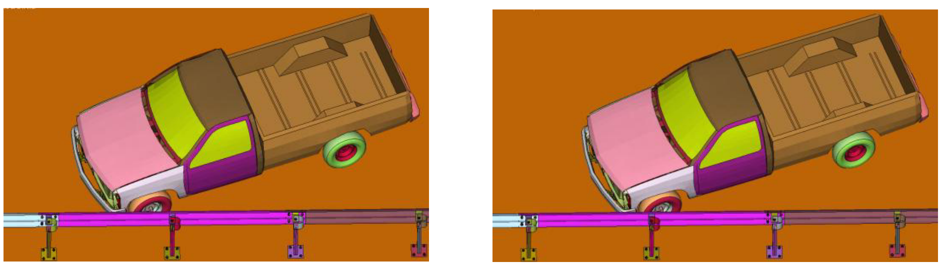

Fig. 8. (a) first scenario; (b) second scenario.

As one can see in Fig 9, the authors performed [7] comparative studies on the two crash scenarios and some remarks on the different behaviors at the moment of collision.

In scenario a) the vehicle remains on the roadway, while in scenario b) the vehicle override the safety barrier. The difference between the two cases is given by the way on how the wheel hits the post:

- in case a) the wheel has no a direct contact with the first post and slides along the guardrail, damaging the next others, remaining on the roadway;
- in case b) the wheel has a direct contact with the first post, and due to the dampers, the wheel has a tendency to override the guardrail, the car continuing to penetrate the barrier.

a

Fig. 9. (a) first scenario; (b) second scenario [7].

In Fig. 10 are represented the variation in time [8] of the contact force magnitude for the two scenarios.

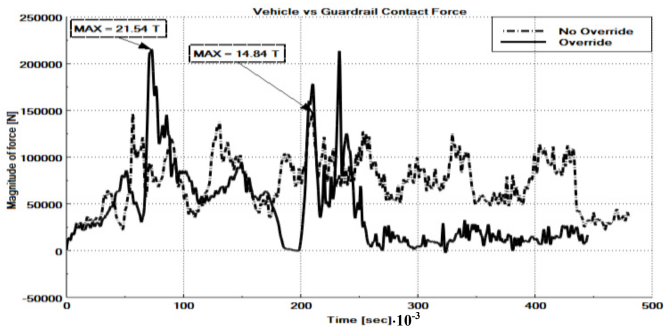

Fig. 10. Time dependence of the contact force [8].

As one can see, with dashedline is represented the force dependence for the a) scenario, when the car collide the safety barrier at a far distance between the posts, whereas the continuous line depicts the force variation for the b) scenario. As a first conclusion, it could be observed that this type of guardrail do not represent - for speeds exceeding 100 km/h and mass over 1000 kg – an effective protective system which should safely retain the vehicle on the roadway.

2.2.2. Simulation of a safety guardrail, equipped with rubber dampers

For this simulation, the authors used in the modeling two different UNP shaped posts:

- a UNP10 profile with an approximately same mass as the INP12 post, corresponding to a 11,2 kg/m;
- a UNP28 profile with an approximately same flexural modulus as the INP12 post (W = 54,7 cm^3).

The first case was efficient only from the point of view of material consumption, being totally inefficient from the point of view of strength capacity (with occurred stresses six times higher than the existing post). The second case, is more convenient from the strength capacity point of view, but totally inefficient in terms of material consumption (over 3.5 times heavier than the existing post).

The vehicle behavior at 400 milliseconds after the impact is depicted in Fig. 11.

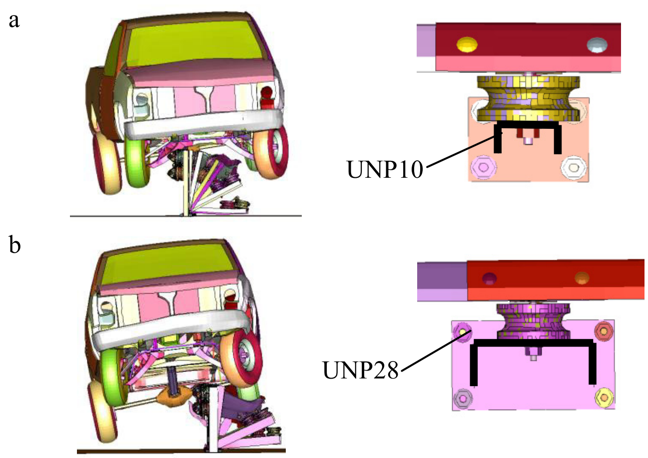

Fig. 11. (a) Vehicle behavior after impact for UNP10 posts; (b) UNP28 shaped posts.

In conclusion, as one can see, in both cases the vehicle overrides the safety guardrail. In these conditions none of the two barriers have been considered efficient from the safety point of view.

2.2.3. Simulation of a safety guardrail equipped with rubber dampers and lamellar shock absorbers

According to the studies realized on safety guardrails, achieved by National Crash Analysis Center (NCAC) at The George Washington University's Virginia Campus U.S.A., it has been shown that, in order to prevent the vehicle to catch on the posts, a certain distance between the W beam and the poles should be assured.

For this reason, the authors suggested a supplementary lamellar shock absorber fixed on the rubber dampers, as one can see in Fig. 12.

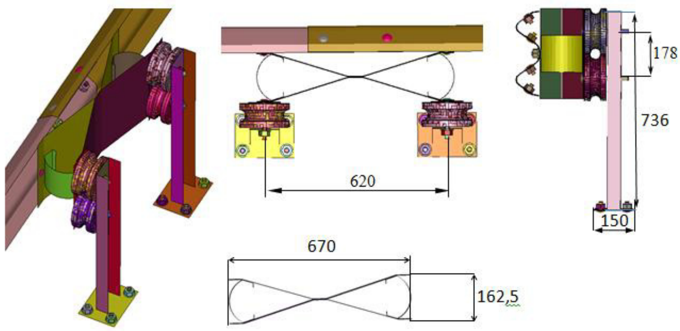

Fig. 12. New proposal for the safety guardrail.

For this simulation, instead of post INP12 profiles, the authors opted for UNP14 profiles, the fixing system remaining the same as in the initial case. At first appearance, since the UNP14 is heavier than INP12 profile (16 kg/m versus 11,2 kg/m) and its flexural modulus lower than the first case (14,8 cm^3 versus 34,2 cm^3), one might ask why we have chosen this second variant instead of the first one.

Our interest was to increase the safety of the collided vehicle. Fig. 14 depicts the vehicle behavior at 400 milliseconds after the collision. In case a), with a small U shaped bended sheet (Fig. 13), the vehicle catch on the posts and remains stuck, while in case b) the vehicle is off the ground, with an elevation of about 40 cm from the ground, being redirected on the roadway.

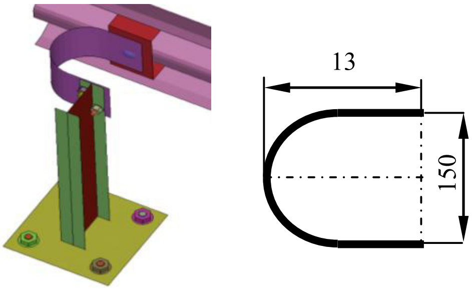

Fig. 13. Actual shock absorber

a b

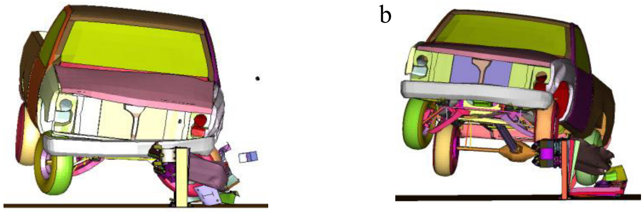

Fig. 14. (a) Actual U shaped guardrail; (b) Proposed absorber.

In Fig. 15 is represented [8] the absorbed energy of the damper elements – the U shaped (variant a) and the lamellar + rubber damper (variant b). For theactual guardrail, with U shaped dampingelements, the deformationsare very large,the impactenergydevelopedduring the collision beingtaken upalmost entirelyby thefixingguardrailand fixing posts. For the second variant – guardrail equipped only with rubber dampers – this case presents also high deformations, proving that the damping rubber rolls take only a smaller amount of impact energy compared to the previous case. In addition, the absorbed energy is higher in the third case, due to the great deformation of the lamellar damping elements, which take a great part of theenergydevelopedduring the collision.

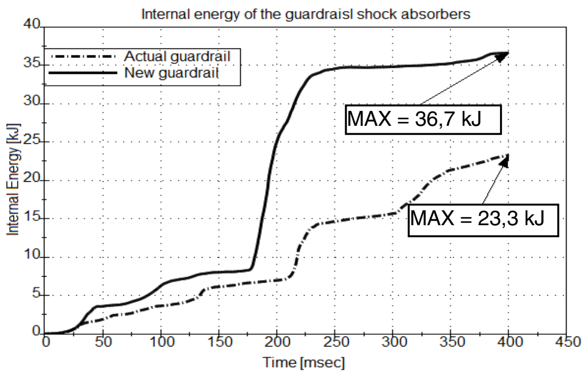

Fig. 15. Absorbed energy of the damper elements for the actual and new proposed solution.

In Fig. 16 are plotted [8] the force magnitudes during the contact between the vehicle and the guardrail, for the two discussed variants. Even that the contact force is lower in the second case (guardrail equipped with lamellar elements), in an interval of 50 ms, between 175 and 225 ms, the force magnitude has a maximum of 212500 [N] corresponding to the moment when the wheel collides the post, actually why the vehicle is off the ground for about 40 cm.

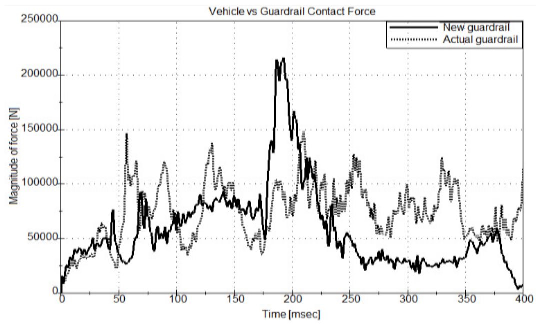

Fig. 16. Force magnitudes in time during the contact guardrail-vehicle.

In Fig. 17 is plotted [8] the velocity of the vehicle center of gravity (COG). As it could be seen, at 400 milliseconds after the impact, in the first variant (actual guardrail) the vehicle has the tendency to stop, due to the guardrail stuck, whereas in the second case (with lamellar and rubber dampers), after the collision, the vehicle is redirected on the road with a velocity of 19,56 m/s (70,4 km/h).

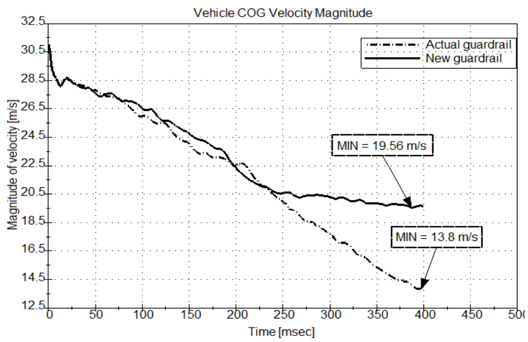

Fig. 17. Velocity of the vehicle COG.

According to NBN EN 1317-2 Standard for performance classes, impact test acceptance criteria, approved by most European member countries [3], one of the test parameters to be taken into account in case of crash tests is the retaining level. Since the authors considered the analysis to be performed on usual vehicles, with a mass not exceeding 1500 kg., in this study the impact angle has been considered 20°, corresponding to a N2 retaining level, with an impact velocity of 110 km/h. A parameter to be taken into account in a crash analysis is the yaw displacement-rotational angle. A yaw rotation is a movement around the yaw axis(Fig. 18) of a vehicle that changes the direction the vehicle is facing, to the left or right of its direction of motion. The yaw axis is defined to be perpendicularto the vehicle, with its origin at the center of gravity and directed towards the bottom of the car.

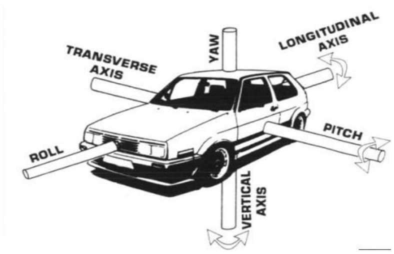

Fig. 18. Yaw motion in a vehicle.

In Fig. 19 is plotted [8] the time dependence of the yaw rotation angle for the existing guardrail system and the new proposed solution.

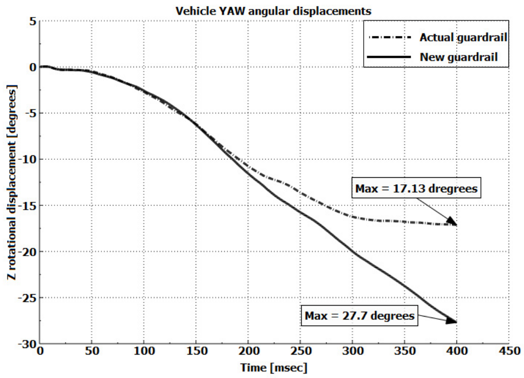

Fig. 19. Time dependence of the yaw rotational angle.

In order to redirect the vehicle on the roadway, the yaw angle should be greater than 20°. As one can see, for the existing guardrail mounted on national roads, this angle being lower than 20° (17.13°), in this case the car is stuck in the barrier, while in the second case (the proposed solution), the yaw angle being higher than 20°, there is a tendency for the vehicle to be redirected on the roadway.

3. Conclusion

Our proposed solution for the crash attenuator reduces the damage to structures, vehicles, and motorists resulting from a motor vehicle collision. From the above, it follows that he lamellar and rubber roller elements should be a better solution for the absorption of energy developed during the collision. In this case, the elastic lamellar system could be substituted by a simplest deformable damper, which could take at least the same amount of energy. In addition, this system should be designed as an enclosed complex attenuator hat would fit at the interface between guard rail and fixing post. Even that the lamellar and rubber damping elements system is mounted on a U profile with a lower flexural modulus, the structural integrity of the guardrail is affected only, the vehicle being safely redirected on the roadway. The new proposed solution is very appropriate one, due to the vehicle yaw displacement-rotational angle, avoiding large deformations of the vehicle structure and simultaneously a good redirection on the roadway. In future, new experimental tests will be performed in order to check the availability of the proposed solution.

Acknowledgements

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