FE MODEL OF A MISSING BOLTED JOINTS INFLUENCE ON A GUARDRAIL RESTRAIN SYSTEM DURING IMPACT

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UDC:62.78;608.4

1. INTRODUCTION

The most common road vehicles restrain systems that are used on the roads are W-beam, bridge parapets, concrete barriers, etc. and they differ by their ability to retain different types of vehicle out runs. Single sided W-beam guardrail segments with metal posts compressed in the ground is the most frequent type of guardrail found on the highways. The existing European normative EN1317:1998 is the framework for the guardrail design. Trough different parameters thresholds among which the most important are ASI (acceleration severity index) and PHD (post impact head deceleration) the vehicle impact severity level is approached [1][2]. The regulative is determining for example both the maximum deceleration in the passenger compartment considering the vehicle and the maximum guardrail deflection for specific type of impact, given in the test matrix. If all of the parameters are within the prescribed range and if other obligations are fulfilled like the vehicle motion after the impact should be in the specified exit box boundaries, nothing is allowed to penetrate in the passenger compartment and no part of the guardrail system should be separated from it becoming danger for the other road users. Or the guardrails are designed to absorb the energy coming from the vehicle motion safely lowering the velocity through desired vehicle path.

The road restrain systems installation on different highway sections depends on the vehicle frequency, most common types of vehicles driving on that road, maximum permitted velocity, coming turns etc. The highway inspection authorities considering these facts will decide about the minimum containment level that the restrain system has to fulfill. According to the regulations the guardrail should comply with the criteria for the defined containment level. In reality the impact parameters can vary significantly but proper standard implementation means maximum safety for all crash scenarios.

The importance of the guardrail protection comes from the fact that in most of the countries the restrain systems normative is accepted as regulation. The stated is confirmed with the following extracts of different EU-countries regulations.

- Finland (Finnish Transport Agency) - „Barriers bearing the CE mark and complying with standard SFS-EN 1317-5 are used on roads if they satisfy the requirements set out in this guide. “
- Germany (Forschungsgesellschaft für Straßen- und Verkehrswesen) - „Vehicle restraint systems must meet the requirements of DIN EN 1317 - Restraint systems on roads. The compliance with the requirements must be verified by presenting the relevant test reports.“

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- Norway (The Directorate of Public Roads) - „…it has been harmonized with the common European guidelines for testing and approval of vehicle restraint systems - NS EN 1317, which was prepared under the auspices of CEN and set by Norwegian Standard.“
- United Kingdom (The Highways Agency) - „This Standard describes the procedures to be followed by the various parties involved in the design and provision of various types of Road Restraint Systems.“

2. FE MODELS

2.1. Vehicle model

For FEM vehicle model the Ford Taurus (model year 2001) is chosen because its closeness to the European mid-sized vehicle fleet [3]. The model was developed for general purposes so it needed some modifications to address certain deficiencies in the vehicle to barrier simulations. The model had to undergo some modifications for lowering the simulation time and bringing the response closer to the realistic.

- removing parts of less importance for the vehicle behavior.
- adding element mass adequate to the removed parts mass. The element mass was added at the B-pillars because of the position of the centre of gravity at the mid plane between the B-pillars trough the vehicle width.
- fixing the free turning of the wheel with the first contact to the guardrail and consequently the change of the load path. During the research phase it was seen from the crash test videos that the wheel experience slight inclination after the engagement during the oblique collision.
- mass was added to the accelerometers to damp the oscillation amplitude of high frequency noise and getting more stable results.

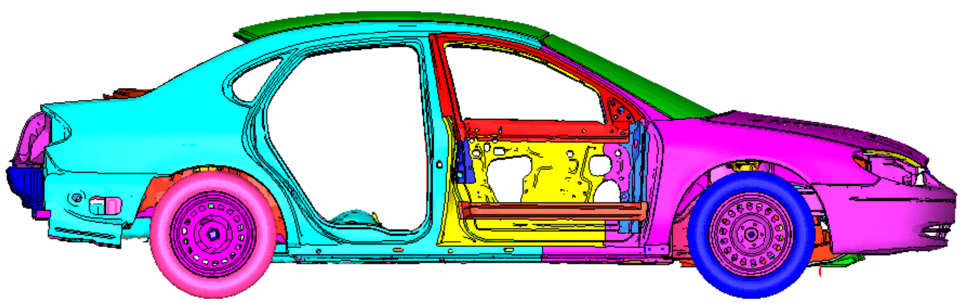

Figure 1. Simplified vehicle geometry model

2.2. Guardrail model

The guardrail consists of twelve segments or rails and thirteen support posts compressed in the ground. For the rails connection eight pairs of fastener sets are used, and for the rail to post connection one pair of fastener is used. For a more accurate representation the guardrail model had to undertake some adjustments like:

- the bolt to nut connection is modeled by using beam connection, specifying the beam stiffness, cross-section area and the mass density. This type of connection gives us the possibility of defining the pre-load force as initial force acting in the beam direction joining the segments together and is used as more direct approach instead of already known methods of temperature difference or initial strain method. The joining components, bolt and nut are modeled with their standard dimensions except modeling the threads which was found in the literature as non-essential factor affecting the results [4]. They are tied together with linear beam between connecting nodes, first as the centre node of spider rigid body elements around the circumference at the end of the bolt head and the second one as the centre node of spider rigid body elements around the hole at the beginning of the nut (Fig.2).
- the soil is modeled as a solid cylinder meshed with hexagonal elements, with a centre hole trimmed with the projection nodes of the post.
- the contact on separate segments is defined trough the static and dynamic coefficient of friction, one between the guardrails segments, other between the post and the ground and the last between the vehicle and the guardrail elements.
- guardrail end elements are connected by dampers to rigid constrains. Dampers are used because they have the possibility to absorb energy, corresponding to the deformation of the adjacent rails. For adequate representation the “length of need” according to NCHRP 350 as a general rule should not be less than 30m for a flexible barrier, and in this case is 48,3m [5].
- local weakening around the fastener holes. From the crash analysis was concluded that the bolt head is pulled out of the guardrail segment. These local deformations are reached in the model by defining lower Young’s elastic modulus for the elements around the holes that will enable the fastener unbuckle (Fig.2).

3. MODEL VERIFICATION

One of the possible arrangements of improper guardrail installation is shown on Fig.3. The numerical FE model verification will be done trough comparison by visual inspection of the guardrail elements involved in a real crash accident with the appropriate virtual model.

Real crash tests only are used as verification tools accompanied by measurements and videos for the specific case. The scene investigation provided information about the deformation modes of the guardrail components and some relevant measurements for the verification are the holes openings, segments final displacement and magnitude of the posts bending.

The initial impact parameters were gathered from the police reports. The vehicle closing speed was 141 km/h, angle of impact 8 degrees and vehicle weight including the driver was approximately 1710kg.

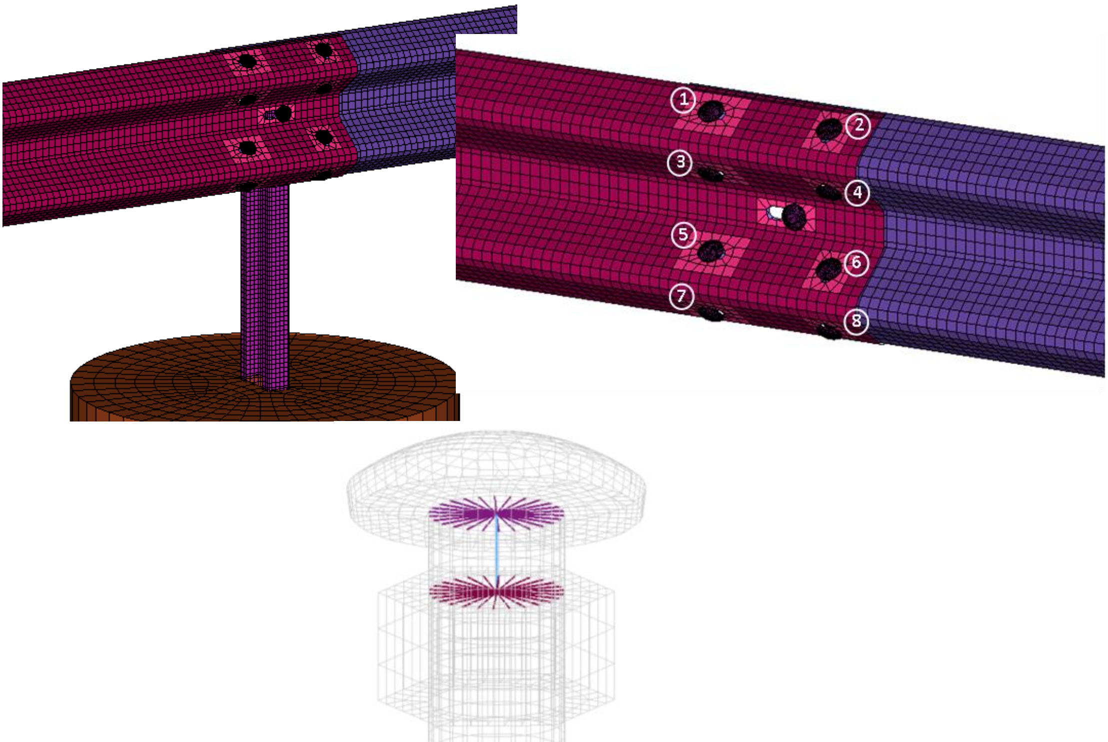

Figure 2. Fastener sets connecting elements and weakened areas

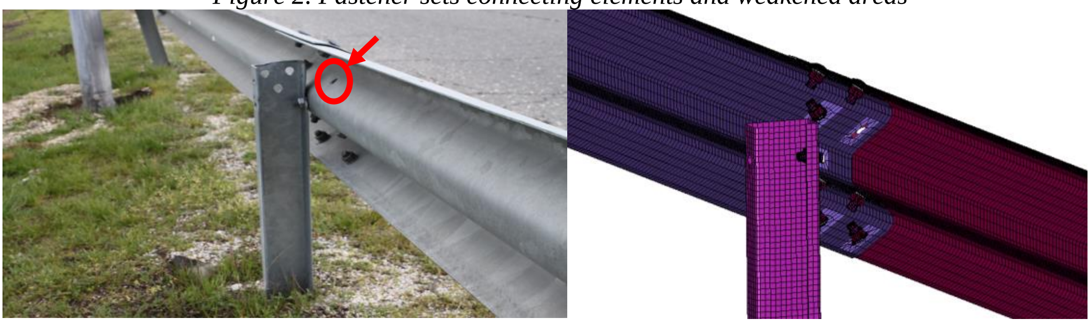

Figure 3. Real and FE missing fastener set model

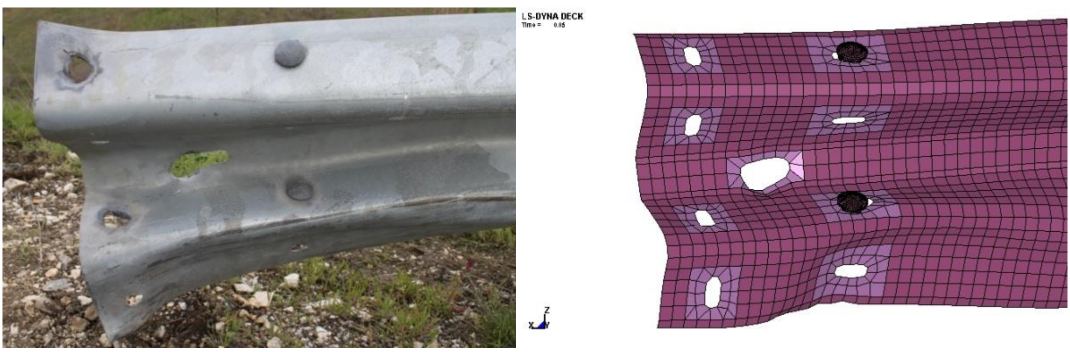

Figure 4. Real and FE segment deformation mode

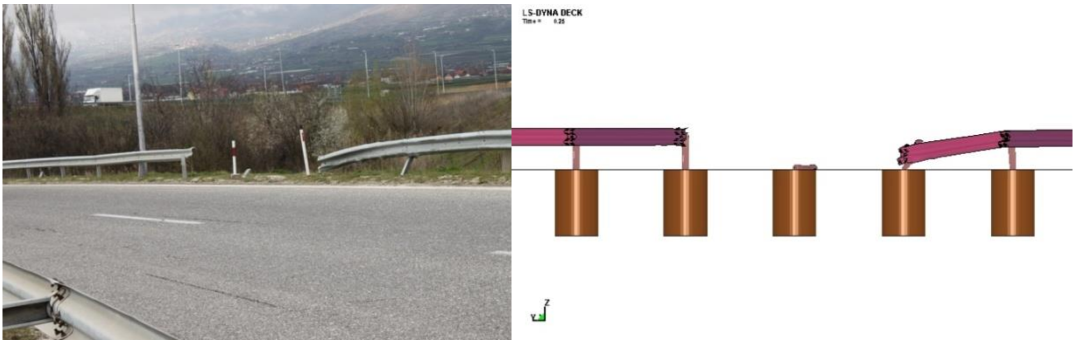

Figure 5. Real and FE accident severity

From visual observation, part of it presented on the pictures above (Fig.4 and Fig.5), can be seen the close behavior of the guardrail FE model and the scenes from the real-life accident. The first picture shows the fastener hole widening as a result of local deformations, clearly seen on the photograph taken at the place of the accident. As the impact progresses the segments are being subjected to complex deformation modes, both bending and shear, causing bolted joints pulling through the deformed holes [6]. On the second picture the segment separation on the place of the vehicle run off can be seen. Two of the segments have been carried away by the vehicle and were found several meters away from the place of impact.

As noted before some of the segments were connected with less than the needed eight fastener sets. At the point of impact the segments were connected with seven or fasteners number 1,2,3,5,6,7 and 8 as marked on Fig.2 and the adjacent segments were connected with only four fasteners 1,2,5 and 6, which can be seen by the hole imprints on Fig.4. The result and the consequences of this badly installed guardrail are enormous and can be noted as a fact that there was nearly no absorption of the guardrail segments or the vehicle just passed through and ran off the road.

4. RESULTS AND DISCUSSION

For analyzing the missing bolted joints influence on a guardrail segment separation, fasteners for segment to segment connection have been removed. At first the outer (ones farther away from the post connection, bolts number 1,2,7 and 8) and afterwards the inner (ones closer to the post, bolts number 3,4,5 and 6). Both are compared with the real accident outcome.

For grading guardrails performance parameters from European normative [1,2] are used.

- Acceleration severity index (ASI)

This parameter measures the severity of the vehicle motion over a person seated in the proximity of a chosen point during an impact.

$$ASI(t) = \sqrt{\left[\left(\frac{\overline{ax}}{\hat{ax}}\right)^2 + \left(\frac{\overline{ay}}{\hat{ay}}\right)^2 + \left(\frac{\overline{az}}{\hat{az}}\right)^2\right]}, \qquad (1)$$

where $\hat{ax}$, $\hat{ay}$, $\hat{az}$ are the threshold values of a human body accelerations (for passengers using safety belts ax = 12g, ay = 9g, az = 10g) and $\overline{ax}$, $\overline{ay}$, $\overline{az}$ are the accelerations of a driver seating point, averaged over a time interval of 50ms.

Table 1. Acceleration severity index

	accident	with outer	with inner
ASI [/]	1.4052	1.5498	1.3711

- Post Impact Head Deceleration (PHD)

This is the maximum value of an averaged longitudinal and transversal component accelerations of a vehicle centre of gravity computed over 10ms. It is assumed that the head remains in contact with the vehicle after the impact for the rest of the time period.

$$PHD = \max \sqrt{\left(\ddot{x}_C\right)^2 + \left(\ddot{y}_C\right)^2}$$

Table 2. Post impact head deceleration

	accident	with outer	with inner
PHD [g]	16.8285	18.5612	16.4201

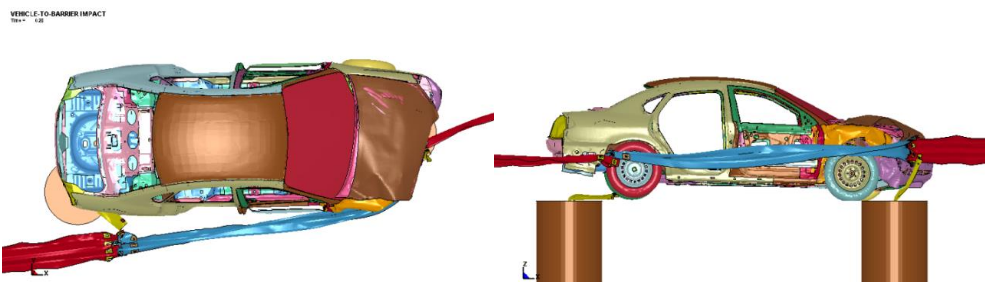

Figure 6. Vehicle and guardrail deformation modes at time 0.28 [s]

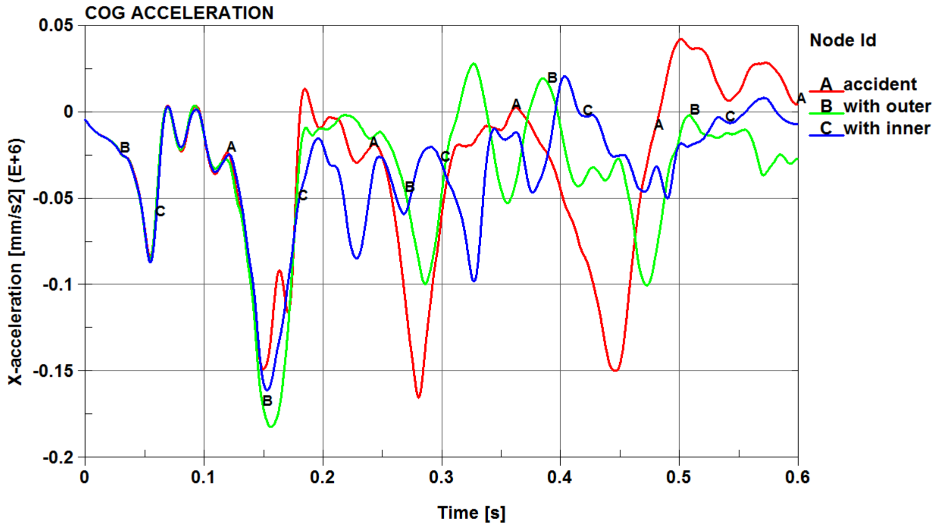

Figure 7. Centre of gravity acceleration

The diagram on Fig.7 presented above shows the vehicle centre of gravity acceleration curve. Some of the impact characteristic tracing points are described. At the beginning of the crash the acceleration impulse follows same trend which is expected till more of the structures interact. The first contact of the vehicle to guardrail starts at 0.01s. At 0.05s the vehicle wheel comes into contact with the guardrail post but no wheel snagging occurs because the wheel slides outside the post. The second vehicle to post interaction occurs at 0.15s when the direct impact separates the post from the guardrail. At the time of 0.28s the guardrail deforms so that it gets the vehicle front shape and together with the coming post holds back the vehicle (Fig.6). The last acceleration peak happens at 0.45s and this is the time when the third post directly subjected to the impact breaks the connection with the rails. For the rest of the time duration the guardrail segments separate and the accelerations are getting lower.

From the presented tables of ASI and PHD the highest values are for the case of segments connected with only outer fasteners, following the one for the real accident and the last is with only inner fastener case. This corresponds to the acceleration peaks occurring at the same order as stated but for different time moment.

5. CONCLUSION

Properly modeled and verified model can be adequate replacement of the actual crash tests. The models have to address certain modifications for bringing the response closer for the corresponding test. The state of the art achievements in this paper are in the direction of general improvements of the FEM models in the virtual impact testing and the influence of the missing fastener in the guardrail installation during impact.

The vehicle to guardrail model used can be appropriate representative considering the above stated modifications. Some of the adjustments made are: parts of less importance of the model can be removed with no influence to the response and replaced with element mass, like the back parts of the vehicle in the front impact tests, and being aware of not re-positioning the vehicle centre of gravity; there is no driver's response to the steering wheel and the vehicle front wheels are turning freely resulting in changing the driving path, the adjustments are in fixing the turning of the wheel; damping the oscillations by adding mass to the accelerometers that are modeled as a solid rigid cubes with its edges defining local coordinate system and measuring the origin acceleration.

The advantages of virtual testing methods are used for finding the influence of the missing guardrail bolted joints stimulated from real crash accident. The conclusions regarding the fasteners are the following. Missing inner bolted joints is much severe than missing the outer ones. The difference in acceleration severity index between both is about 11.5%. For impacts in guardrail restrains with only outer fastener sets between the rails, from the post impact head deceleration can be assumed that the human head is for almost 2g's higher deceleration subjected to.

6. REFERENCES

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