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Dynamic Analysis and Improvement of Crashworthiness Characteristics of Trainsets of Iran Railway

M.A. Rezvani[1], M.Afkar[2], A. Afkar[3]
[1]*School of Railway Engineering, Iran University of Science and Technology, Narmak, Tehran, Iran*
[2]*MATSA Co., Technology Incubator, Narmak, Tehran, Iran*
[3]*Faculty of Electrical, Mechanical and Construction Engineering, Department of Automotive Engineering, Standard Research Institute (SRI), Karaj P. O. Box 31745-139, Iran*

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[*]Corresponding Author. E-mail: afkar@iust.ac.ir

Abstract
In this paper, an investigation has been carried out to improve crashworthiness parameters of a passenger train using the dynamical simulation tool LS-DYNA. Tampons of a sample passenger train (Iran DH4-1 PARADISE) in Iran railway are modeled and the crashworthiness characteristic of it is improved by using the crashworthy element behind the set and also varying its shell material type. Among most important collision scenarios mentioned in crashworthiness standards, the collision with heavy road vehicle at an intersection is considered. The simulation results obtained are validated by energy ratio and Hourglass energy parameters.

Keywords: *crashworthiness, rail, tampon, energy absorption, LS-DYNA*

Introduction
Nowadays due to the development of the railway network in Iran and tendency of the Iranian railway industry to achieve higher transportation speeds as well as enhancing the quality of services to the international standards levels, considering safety parameters seems indispensable. One of the most important parameters which should be considered for this purpose is crashworthiness. Crashworthiness is the ability of a structure to protect its occupants during an impact. Depending on the nature of the impact and the vehicle involved, different criteria are used to determine the crashworthiness of the structure. Crashworthiness may be assessed either prospectively, using computer models (e.g., LS-DYNA, MSC-Dytran, MADYMO) or experiments, or retrospectively by analysing crash outcomes. Several criteria are used to assess crashworthiness prospectively, including the deformation patterns of the vehicle structure, the acceleration experienced by the vehicle during an impact, and the probability of injury predicted by human body models.
In the modern design of trains, the vehicle structure is deformed in a controlled way and the impact energy is exited from the safe area of the passengers [1]. In order to study the crashworthiness in the railway vehicles, four scenarios are taken into account which two of them are associated with collision of rail equipment with each other and the other two are related to the collision of train to road vehicles [2].
Among the accidents occurred between 1999 to 2007 years in railway network, 65% was the railway accidents share and 35% was non-railway accidents [3]. The railway accidents include train out-of-line, collision of train-to-train, train or wagon ran, fire in rail equipment, flooded line, landslide on the line, etc. and the non-railway accidents include collision of the rail vehicles with passengers, road vehicles and livestock and other accidents such as stone throwing leading to passenger injury, passenger fall from train, etc.

Among the above-mentioned scenarios, 16% are related to rail accidents and 33% are related to non-railway accidents, respectively [3]. Therefore, it can be seen that these two form 10.4% and 11.55% of the total rail accidents in Iran between 1999 to 2007 years which is a considerable amount. Thus, investigating how to prevent from occurrence of these accidents and reduction of their damages is a crucial issue. Also, these statistics clarify the necessity of studying crashworthiness in railway vehicles.

Although the first paper related to the collision of trains was published in 1960s, the first real investigations on crashworthiness of railway vehicles were conducted in 1980s [4]. Between 1995 to present, due to the massive improvements in computer simulation tools, numerous research works in the field of crashworthiness of railway vehicles have been conducted. Hosseini-Tehrani et al. [5-6] investigated the application of topology, size and shape optimization for the design of an efficient crashworthy wagon's frame in terms of energy absorption and passenger safety. They also studied different aspects of frontal and side impacts in designing of a crashworthy high-speed train nose. They conducted a systematic study to examine possible strategies in order to design crashworthy external and internal structures for a high-speed train nose.

In this study, the crashworthiness parameter of an Iranian railway passenger train is dynamically investigated using LS-DYNA 3D. The simulations are performed under the collision of the train set with heavy road vehicle at an intersection and the results of simulation are validated by two well-known EN 15227:2008+A1 and ECE R 66 standards.

2. Modeling

For modeling, the trainset of the Raja passenger trains (Iran DH4-1 PARADISE) having higher speed compared to other trains is selected. The crashworthiness improvement of this passenger train is studied using the EN 15227:2008+A1 standard under the two scenarios: frontal impact and impact with heavy road vehicle at an intersection [2]. It may be believed that the impact of train with road vehicles does not cause severe damages for the passengers. Of course this is somewhat true that the damages caused by this scenario is lower than the ones occurred by collision of two trains, but according to the statistical studies in Japan in 2003, the aforementioned scenario may cause considerable injuries for the train passengers as tabulated in Table 1.

Table 1. Injuries and deaths statistics in Japanese railway between 1991 and 2001[7]

	Fatalities	Injured	Total casualties
Head-on collisions	43	854	897
Level crossing collisions	1	586	587
Collision to natural obstacles	0	54	54
Side-on collisions	5	141	146
Buffer stop collisions	1	467	468
Over turnings	0	54	54
Derailments	0	16	16
Total	60	2172	2232

Due to the lower intensity of the impact at intersections compared to collision of two trains and the point that the first part involved in impact process in tampon which is an energy absorbent mechanism, the tampon of the mentioned passenger train is modeled [8-9]. It is obvious that by ameliorating the crashworthiness of this part against impact at intersection, the crashworthiness of the train against collision by other train is also improved. The selected train and its tampon are shown in Fig. 1.

Fig. 1. The passenger train Trainset Iran DH4-1 PARADISE and its tampon

The mentioned tampon is composed of three main parts: shields, housing and spring. The shields and housing are modelled in SolidWorks and the meshes are produced using Abaqus/CAE. Then by using FEMAP the meshes are transformed to LS-DYNA3D (Fig. 2).Considering the European standard EN 15227:2008+A1 to investigate the crashworthiness at an intersection, a full train is collided by a deformable lorry. The mass of this lorry is 15000 kg and the impact velocity is 110 km/h [2]. Due to the complexity of model solution by deformable lorry, a rigid wall is used for the modeling. Moreover, to simplify the model, constrained are applied on the rear of tampon.

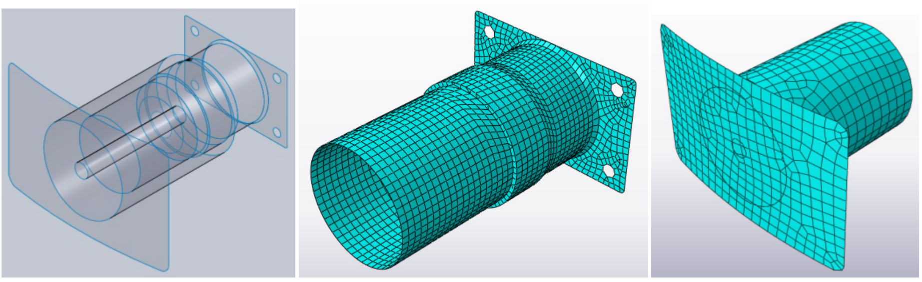

Figure 2. The model and produced meshes for housing and shield

3. Simulation validation

Fig. 3 shows the total displacement of the model, housing, shield and spring displacement respectively. The red, green, dark blue and light blue curves (A, B, C, D) depict the total tampon, tampon shield, tampon housing and tampon spring displacements, respectively. The overall displacement is about 28 centimeters which most of it is because of shield displacement. According to the UIC-528 standard, 11 centimeters is ordinary stroke of the tampon, hence the overall created deformation is 17 centimeters and based on the standard the model is correct. Furthermore, according to the ECE R 66 standard, the simulation is validate when the energy ratio parameter and Hourglass energy complies with this standard and their value should be in the range of 1 ∓ 0.05 and lower than 5% of total energy [10-11].

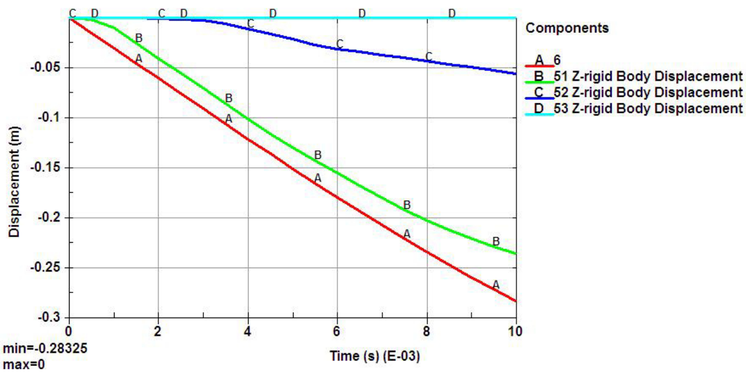

Figure 3. Displacement versus time in total tampon model and its components

Fig. 4 shows the energy ratio during the modeling. As can be seen, the energy ratio is within the considered range and ECE R 66 standard conditions are met. Fig. 5 illustrates the total energy, kinetic energy, total energy absorption of the model and Hourglass energy. It can be seen that the amount of Hourglass energy is trivial and the model complies with the ECE R 66 standard conditions.

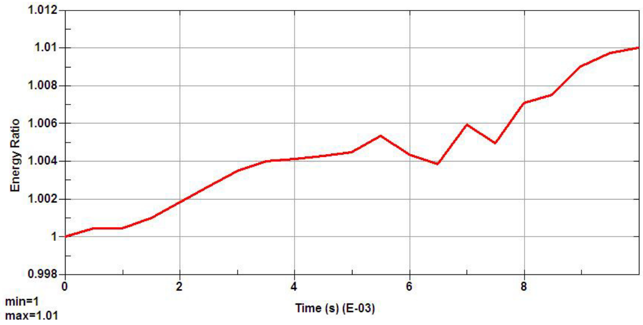

Figure 4. Diagram of energy ratio versus time

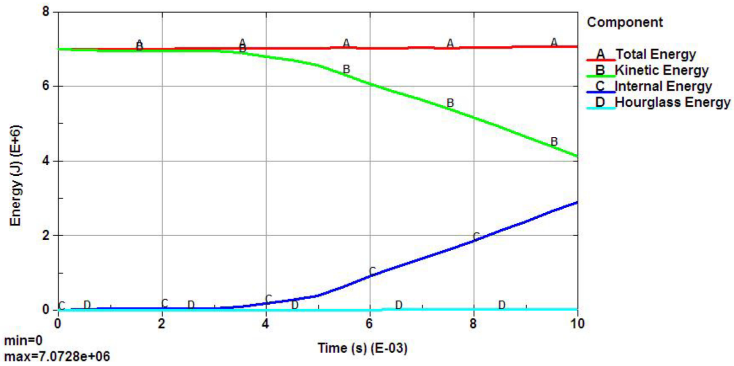

Figure 5. Diagram of energy versus time for different energies

4. Results and discussion

The energy absorption status by the model and its components is depicted in Fig. 6.The red, green, dark blue and light blue curves (A, B, C, D) show the shield, housing, spring and total energy absorption by the model, respectively. The shield and housing deformations are shown in Fig. 7.

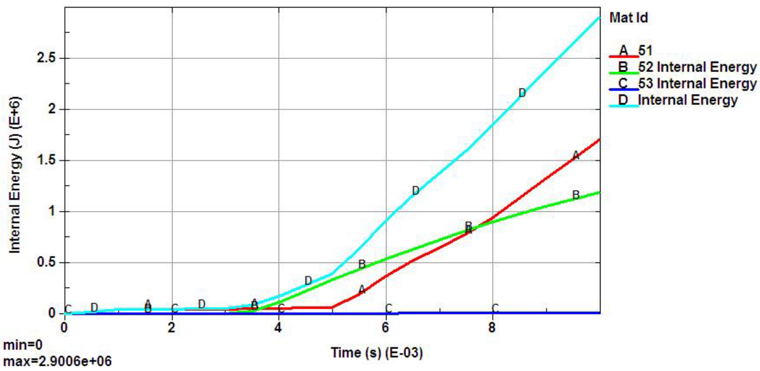

Figure 6. Energy absorption versus time in total tampon model and its components

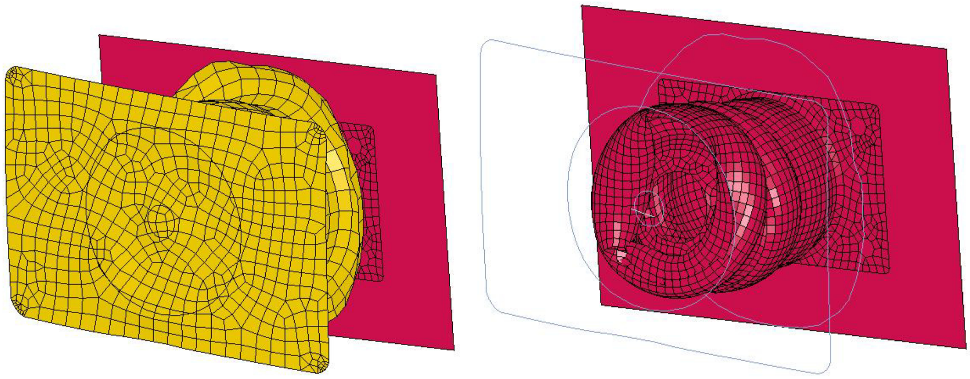

Figure 7. Tampon's shield and housing deformations

It should be mentioned that the cast steel GS 52 N is used in Iran for manufacturing of tampon shell. In this paper, the GS 70 N and GS CrNiMo 6 V are chosen for housing material in order to improve energy absorption parameter and crashworthiness of the tampon as shown in Fig. 8.

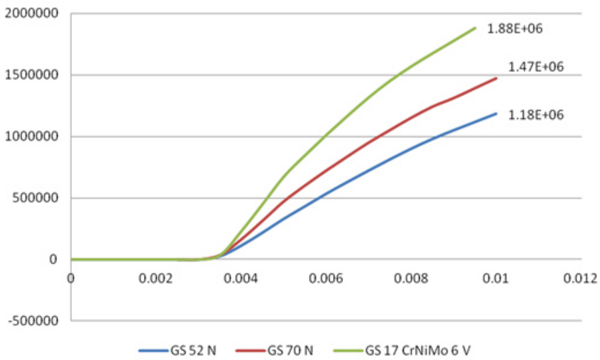

Figure 8. The improvement in energy absorption of housing through material change

Furthermore, according to the EN 15227:2008+A1 standard which allow the rear of tampons to be designed crashworthy, a thin-walled crashworthy element with rectangular cross section can be embedded behind them in order to increase energy absorption significantly (Fig. 9).

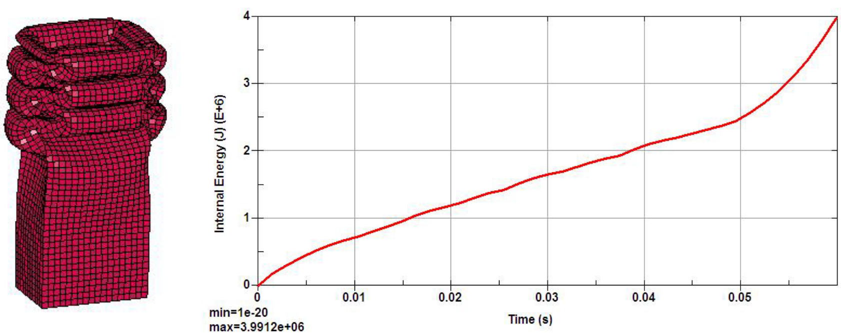

Figure 9. The embedded crashworthy element in tampon rear and energy absorption improvement by it

Conclusions

In this paper, the tampon of a passenger train (Trainset Iran DH4-1 PARADISE) was modeled using LS-DYNA 3D finite element package and was analyzed under the collision of it with heavy road vehicles at an intersection and the results of simulation were verified by two well-known EN 15227:2008+A1 and ECE R 66 standards. According to the results obtained, the amount of energy absorption in tampon spring was lower compared to other components. Moreover, the energy absorption was initially higher in housing and after the collision of shield with the main structure of the train; its energy was higher than housing's. Regarding this issue that no special force was applied to the housing, the energy absorption and crashworthiness characteristics of the tampon was ameliorated by varying the housing material. It is also found that by adding a crashworthy element in the tampon rear, energy absorption was considerably increased. It can be concluded that by varying housing material and adding crashworthy element, the tampon's crashworthiness characteristics was successfully improved in the both cases of impact at an intersection and impact of transporter equipment.

References

1. Xue, X., Schimd, F. Crashworthiness of conventionally designed railway coaching stock and structural modifications for enhanced performance.Proceedings of the 5th European LS-DYNA Users Conference, Birmangham, UK, (2005).
2. Standard EN 15227:2008+A1, Railway Applications – Crashworthiness Requirements for Railway Vehicle Bodies, English Version, European Committee for Standardization, (2010).
3. Accidents statistical bulletin, office of protection and safety of transportation, accident analysis group, (2008).
4. Nankali, A., Hosseini-Tehrani, P. An investigation on using foam in high speed trains nose, Proceedings of the 2nd International Conference on Recent Advances in Railway Engineering, Tehran, I. R. Iran, 27-28 (2009).
5. Hosseini-Tehrani, P., Nankali, A. Study on characteristics of a crashworthy high-speed train nose, *International Journal of Crashworthiness* 15 (2010) 161–173.
6. Hosseini-Tehrani, P., Bayat, V. Study on crashworthiness of wagon's frame under frontal impact, *International Journal of Crashworthiness* 16 (2011) 25–39.
7. Ujita Y., Funatsu, K., Suxuki, Y. Crashworthiness investigation of railway carriages, *QR of RTRI* 44 (2003) 28-33.
8. Zobory I., Reimerdes, H.G., Bekefi, E.,Marsolek, J., Nemeth, I. Longitudinal dynamic of train collisions – crash analysis, Proceedings of the 7th Mini Conf. on Vehicle System Dynamics, Identification and Anomalies, Budapest, Hungary, 6-8 (2000).
9. Nemeth, I., Kovacs, K., Reimerdes, H.G., Zobory, I. Crashworthiness study of railway vehicles – developing of crash elements, Proceedings of the 8th Mini Conf. on Vehicle System Dynamics, Identification and Anomalies, Budapest, Hungary, 11-13 (2002).
10. Schon, M., Schober, M. EUCAB Mock-Up-The industrial design process to develop tangible hardware. Proceedings of MODOLINK Conference, (2006).
11. Addendum 65: Regulation No. 66, Uniform Technical Prescriptions Concerning the Approval of Large Passenger Vehicles with regard to the Strength of their Superstructure, (2006).

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