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Fracture and Damage to the Material accounting for Transportation Crash and Accident

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Abstract

In this paper, reviews of several fractures and damage to materials in their use are presented. As happened in the coal train axle and the gas pipelines are corrosion and can cause fracture and damage. Prevention and lessons that can be drawn from several events are positive things to avoid similar incidents in the future. Damage to the material also can occur one of them due to the influence of nature like floods and earthquakes. This paper also reviews crashes in transportation, one of which is due to a lack of attention among motor vehicle drivers who contribute to almost one in three fatal traffic accidents between 2011 and 2015 in Norway. Hence, the finite element method done to estimate the event of a crash between transportation to improve passenger safety as consideration is the location of the center of gravity of the vehicle and the safety of the passenger compartment.

Keywords: Fracture; damage; crash

1. Introduction

Material such as steel become part of daily needs like in the train axle, rail, gas pipes, and also transportation infrastructure. A combination of conditions that occur over a long period, e.g., consisting of corrosion, can cause

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fracture and damage to the material. Further, material damage also can occur due to natural influences such as floods, storms, and earthquakes that remain particularly vulnerable. Understanding fracture and damage to the material are essential to improve the quality of the material and also to prevent the damage.

According to World Health Organization (WHO) statistics, every year around the world approximately 1.24 million people die in traffic accidents where frontal, side and rear-ends contribute around half of all types, while this regulates as high as two-thirds in some countries or regions (Yuan et al., 2020). Numerical methods such as the finite element method in transportation accidents can also be used to estimate the events during crashes between transports, one of which is to improve passenger safety. Understanding the improvement in intrusion on the passenger increase in accidents for vehicle users is also vital to enhance and improve safety. In this paper, several causes of fracture and damage to the material are presented, such as the train axle, gas pipeline, and transportation infrastructure. This paper also includes several crashes and also crashes in transportation using the finite element method to estimate the event of a crash between transportations to improve passenger safety.

2. Fracture in material

The mechanical properties at head and foot regions of high strength rail steel, CZECH TZ IH caused by the effect of temperature have been investigated by Yu et al. (2015). The results showed an apparent influence of temperature on the fracture toughness in terms of K_{Ic} values, with the decrease of temperature from 23°C to -40°C, an approximate 20% reduction of K_{Ic} for rail head, web, and foot. The damaged railway used by coal transport and the railway wheel and axle with the fractured surface is shown in Fig. 1a and 1b, respectively.

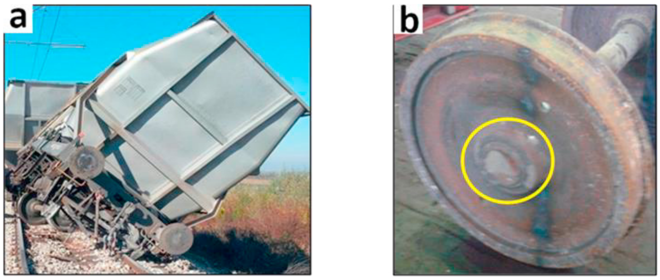


Fig. 1. (a) Damaged railway used by coal transport, and (b) the railway wheel and axle with the fractured surface (Odanovic, 2017).

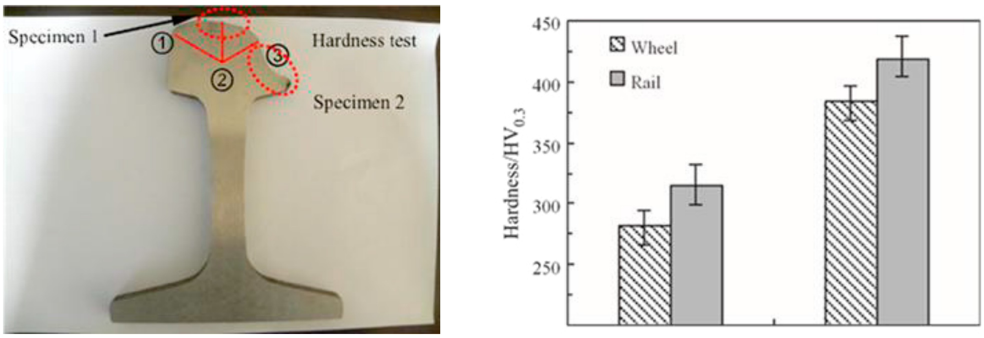
An investigation by Odanovic (2017) showed that the initial crack at the surface of the critical radius of the rail transport axle was caused by corrosion that results from damage to the axle coat. This corrosion occurs from underneath the coat and spreads to the entire surface of the shaft. It is thereby creating conditions for the formation of the pit. Fracture in railway freight cars can also occur due to the selection of the mechanical properties, e.g., yield stress and tensile strength of the material under the recommendation (Odanovic 2015). In addition, to prevent related failures in the future, the paper investigated by Odanovic (2017) suggested the need to improve corrosion protection control and axle inspection from the initial crack aspect during routine maintenance.

In work by Jun et al. (2016) investigated that fracture and fatigue crack growth on a weld-repaired railway rail due to the direction of cracks was perpendicular to the course of the applied force. When a train set passes over the crack, tensile residual stress opens the crack and accelerates the crack growth. In contrast, it closes the crack and decelerates the crack growth by compressive residual stress. Hence in the paper by Jun et al. (2016), to reduce the unanticipated initiation and propagation of the crack, it was essential to change the tensile stress to compressive stress at the railhead. To prevent the crack from growing, especially on the rail surface, the transition from tensile to compressive stress was beneficial due to contact stress. Some fractures that occurred on the eastbound Norfolk Southern railroad tracks in the city of Columbus, Ohio, on July 11, 2012, are shown in Fig. 2. Further, to identify and remove internal defects before reaching critical size, inspection, and maintenance programs based on damage-tolerance programs must be developed (Zakar and Mueller, 2016).

Fig. 2. Fracture on eastbound Norfolk Southern railroad tracks on July 11, 2012 (Zakar and Mueller 2016).

3. Damage to material

One of the investigations that have been carried out on material damage is carried out by Wang et al. (2013) on the Datong-Qinhuangdao heavy-haul rail show in Fig. 3a. Damage types for the Datong-Qinhuangdao heavy-haul rail were dominated by severe rail side wear and surface spalling. Railside wear has become a determining part of the replacement of heavy-haul curved rails caused by the increase of axle load and the annual transportation volume. According to Wang et al. (2013), surface hardness and wear resistance of wheel/rail materials can be increased by laser quenching. The hardness of the surface of the wheel/rail specimens was shown in Fig. 3b. In the case of the increase ratio in the surface hardness of the wheel and rail specimens by laser quenching was 35.7%, 33.5%, respectively. Laser quenching can also be used to treat rail sides and wheel flange to extend the wear life of heavy-haul wheel/rail in the field. An investigation by Ding et al. (2015) showed that the damaged surface of the train wheels due to the effect of rotating speed was dominated by fatigue cracks and adhesive wear, while the surface of the rail presents peeling and spalling damage.



(a) (b)

Fig. 3. (a) the analysis schematic diagram of damage rail, and (b) the surface hardness of wheel/rail specimens (Wang et al. 2013).

An investigation by Syromyatnikova et al. (2019) on the gas pipeline in the Republic of Sakha (Yakutia) showed that destruction could occur due to conditions that were difficult to detect the current state like the presence of corrosion catalysts over a long period. Earthquakes can also cause damage such as a bridge in Tawarayama, Kumamoto, Japan in 2016, as shown in Fig. 4c. An investigation by Aye et al. (2018) conducted that this damage was caused by a massive ground motion that led to the movement of the entire bridge. Further, material damage also can occur due to natural influences, such as floods and storms. The transportation infrastructure remains vulnerable and can be damaged by floods, such as broken road fences and traffic signs (Diakakis et al. 2020). Damaged road fences and road signs were shown in Figs. 4a and 4b, respectively.

Fig. 4. Damage on infrastructure due to floods and earthquakes, including (a) damaged road fences, (b) broken road signs (Diakakis et al. 2020), and (c) damage to the Tawarayama bridge (Aye et al. 2018).

4. Crash investigation in transportations

An investigation by Sundfør et al. (2019) in the traffic accident in Norway between 2011 and 2015 showed that the lack of attention among motor vehicle drivers contributed to almost one in three fatal traffic accidents in Norway. Further, about one-third of accidents related to lack of awareness involves pedestrians hit by motorized vehicles, usually because the driver was late in detecting pedestrians. The category of lack of attention in descending order based on the frequency and whether it might/undoubtedly or might have contributed to the crash, according to the paper by Sundfør et al. (2019) were shown in Fig. 5a. Lack of attention (no clear evidence of the type of lack of awareness, but it was clear that it was involved) was the common frequent category. The driver failed to look or scan for potentially safety-critical information was the most frequent specific category related to lack of attention. Insufficient attention efforts or low concentration on traffic, including cognitive distractions were the second most frequent category related to lack of attention. These types of lack of attention mainly concern the mechanism of proactive attention, namely the extent to which the driver was actively seeking information. In addition, failing to check data in blind spots or behind other visual obstructions was a form of lack of attention.

The car-to-cyclist crash has also been investigated by Ito et al. (2018) in great detail. Fig. 5b showed the percentage of crashes and near-crashes based on the type of visual obstacles on the road. In the classification by Ito et al. (2018), "Fixed objects" included fixed structures such as houses, telegraph poles, and trees. However, if there were no obstacles when the cyclist appeared, the data was classified as "none". In the case of both crashes and near-crashes, nearly 80% of obstacles along the road that obstruct the driver's view were fixed objects, e.g., buildings and vehicles, as shown in Fig. 5b.

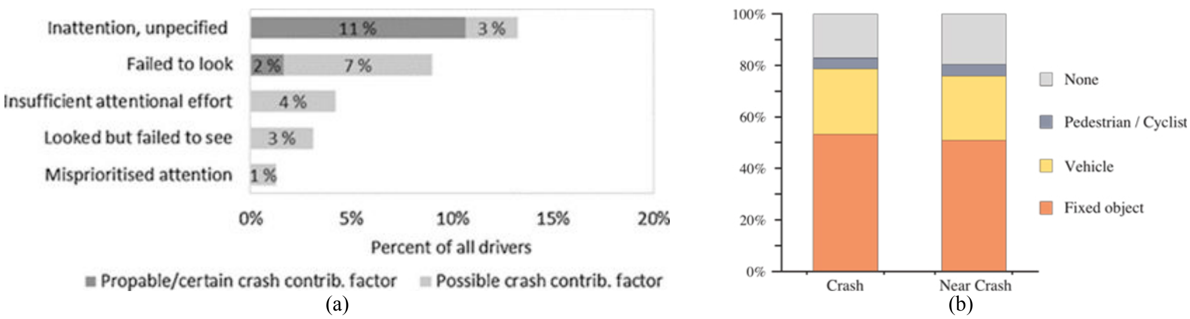


Fig. 5. (a) Prevalence of various types of inattention among at-fault drivers in fatal crashes in the year 2011-2015 with the cases N = 544 (Sundfør et al. 2019), and (b) obstacles along the road that obstruct the view of the driver in car-to-cyclist crashes and almost crashes (Ito et al. 2018).

Yuan et al. (2020) have investigated by employing accident data from130 side crashes between vehicles at an intersection in the Beijing period 2009-2012. However, the fatal case was sharply reduced when the traffic lights were working correctly. Further, small vehicles significantly increase severe injuries. NHTSA (National Highway Traffic Safety Administration) has identified changes in vehicle structure to reduce intrusions in the occupant compartment from NHTSA's oblique offset frontal crash condition (Singh et al. 2018). There has been a review of test results and literature that showed for the four-passenger, sub-compact, compact, mid-size, and large car segments, the structural performance of sub-compacts has a higher structural intrusion as shown in Fig. 6a. Further, the vehicles studied were Mid-Size sedan structure - 2014 Honda Accord. The work needed to reduce interferences in the passenger compartment by adding a mass of 4.3 kg to the 2014 Accord. In addition, LS-DYNA finite element software has also been performed in the study. The general material properties of steel and aluminum used in the LS-DYNA model were listed in Tables 1 and 2, respectively.

Table 1. Common engineering properties of steels used in CAE models (Singh et al. 2018).

Steel grade	Density (kg/m^3)	Poisson's ratio	Modulus of elasticity (MPa)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Failure elongation (%)
Mild 140/270	7,850	0.3	21.0×10^4	140	270	No Failure
BH 210/340	7,850	0.3	21.0×10^4	210	340	No Failure
BH 260/370	7,850	0.3	21.0×10^4	260	370	No Failure
BH 280/400	7,850	0.3	21.0×10^4	280	400	No Failure
HSLA 350/450	7,850	0.3	21.0×10^4	350	450	No Failure
HSLA 420/500	7,850	0.3	21.0×10^4	420	500	No Failure
HSLA 550/650	7,850	0.3	21.0×10^4	550	675	No Failure
DP 700/1000	7,850	0.3	21.0×10^4	700	1000	29
HF 1050/1500	7,850	0.3	21.0×10^4	1050	1600	18
DP 1150/1270	7,850	0.3	21.0×10^4	1150	1270	24
MS 1250/1500	7,850	0.3	21.0×10^4	1250	1500	13.5

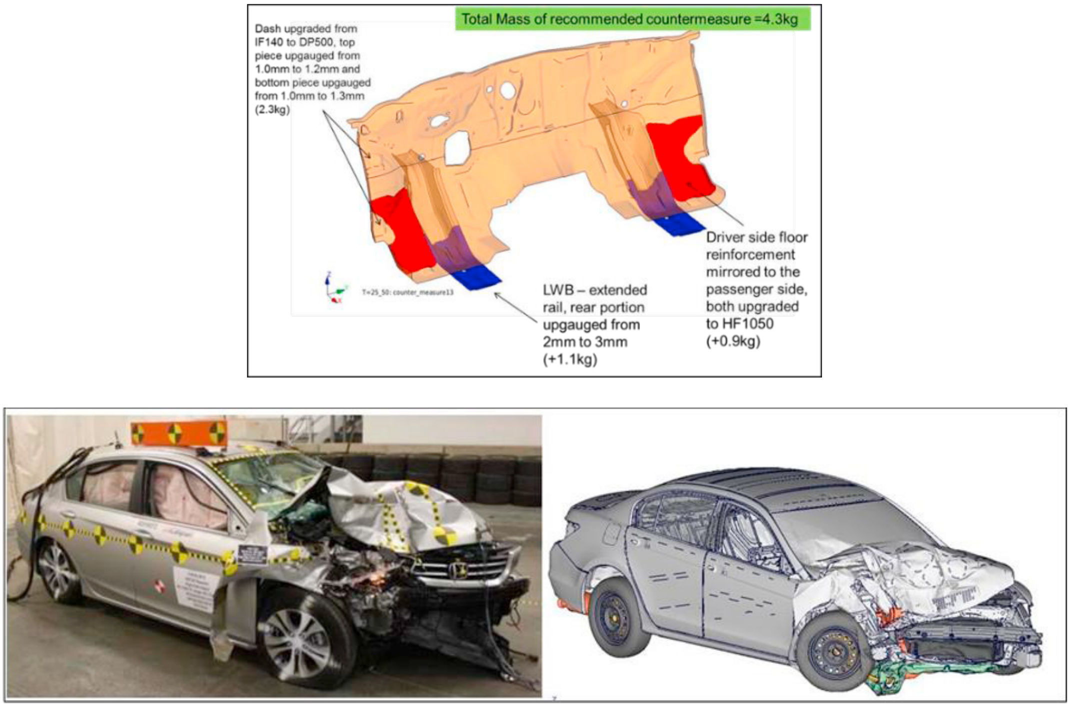


Fig. 6. (a) Countermeasures to reduce occupant compartment intrusions, and (b) Post-crash comparison in test versus CAE (Singh et al. 2018).

The post-crash test and CAE of the NHTSA oblique test passenger side are shown in Fig. 6b. The work also found that the simulation structure correlated well with the testing in the overall kinematics, deformation shapes, and material failures, particularly in sub-frameworks. The improvement in intrusion on the passenger floor pan after the design (countermeasure) is applied shown in Fig. 7 and also, approximately 50 percent of interventions are reduced. Further, the finite element model was also used to carry out simulations to improve passenger safety, including vehicle interiors and a passenger bag (airbag) system for drivers and front-seat passengers developed by Singh et al. (2018).

Table 2. Common engineering properties of aluminum used in CAE models (Singh et al. 2018).

Aluminum alloy grade	Density (kg/m3)	Poisson's ratio	Modulus of elasticity (MPa)	Yield strength (MPa)	Ultimate tensile strength (MPa)	Failure elongation (%)
AL 5754	2,700	0.33	7.1×10^4	120	250	16
AA 6014-T7	2,700	0.33	7.1×10^4	200	270	17
AA 6014-T6	2,700	0.33	7.1×10^4	225	294	18
AA 356-T6 CAST	2,700	0.33	7.1×10^4	232	302	10
AA 6111-T6	2,700	0.33	7.1×10^4	270	355	16

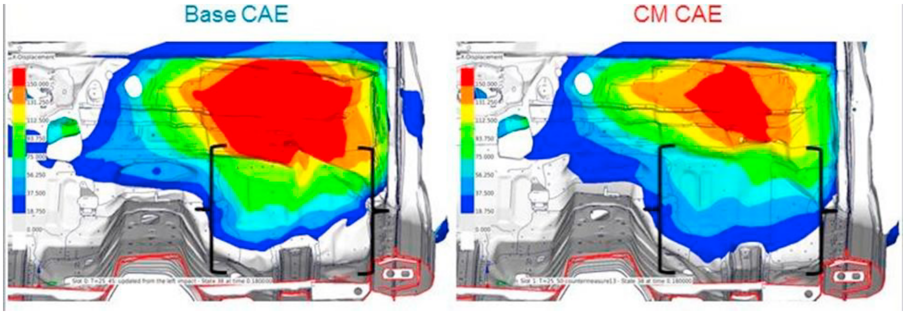
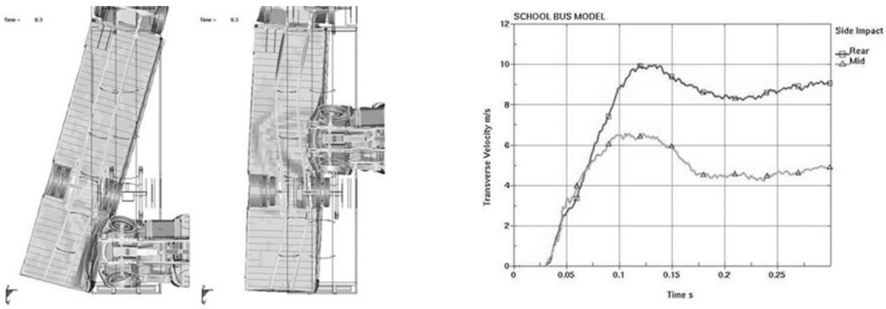


Fig. 7. Dash intrusion view base CAE (before adding the weight) versus CM CAE (after adding the weight) (Singh et al. 2018).

5. Crash analysis of transportation using the finite element method

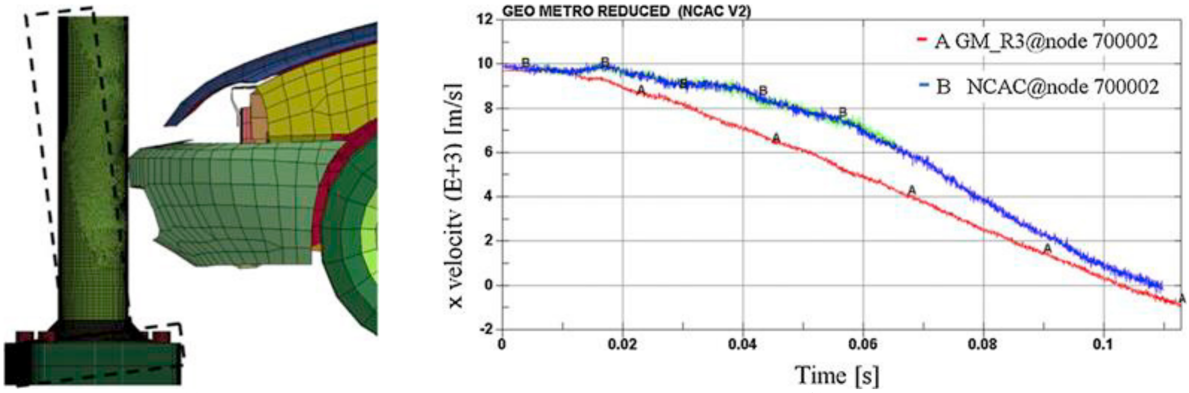
According to Evtiukov et al. (2018), the finite element method for reconstructing road traffic crashes was accurate and efficient and can be used to restore road traffic accident mechanisms. Tanov et al. (2003) investigated using finite element modeling and analysis of crash school buses in the United States. This study aimed at obtaining the results of the dynamic response of school buses in various crash scenarios such as rear and side crash. Further, the response results obtained can be utilized efficiently for the development of passenger safety. An illustration of the crash event is shown in Fig. 8a, where the starting position was also outlined. The velocity curve of the school bus floor center in the impact area for both side impacts is shown in Fig. 8b. The two vehicles were still moving when both crashes occurred with considerable transverse velocity.



(a) (b)

Fig. 8. (a) Comparison of bus motion for back and center side impact with initial position seen outlined, and (b) comparison floor transverse velocity for back and center side-impact (Tanov et al. 2003).

The work carried out by Moradi et al. (2013) using finite element analysis has found that intrusion in the passenger compartment based on IIHS guidelines, and deceleration experienced by the occupants were identified as the main factors causing fatal injuries. Studies performed by Mariusz (2016), which has been examined using the finite element model showed that the location of the vehicle's center of gravity had influenced the behavior of the impact, in this study was the impact on the column that is shown in Fig. 9a. The work performed by the Suzuki Geo Metro model with a modified suspension system and a higher center of gravity on the z-axis (Ver. GM_R3), and Suzuki Geo Metro were a lower center of gravity on the z-axis (Ver. NCAC). Further investigation of Ver. GM R30 showed that the energy absorbed by the column was higher, and the velocity decreased more smoothly and regularly from the beginning to the end of the impact. However, in the Ver. NCAC, the energy absorbed by the column was lower, and the velocity decreased more abruptly compared to the previous condition, as shown in Fig. 9b. In the Ver. NCAC, the kinetic energy turned into internal energy more slowly. The simulation results using the finite element method can be used to evaluate the overall behavior of vehicle structures (Berzi et al. 2018). Extended investigations to maritime-based transportation are an interesting subject, which a series of work by (Prabowo et al. 2019; Prabowo et al. 2018; Prabowo et al. 2017), Muttaqie et al. (2019) and Bae et al. (2016) may be considered as references.



(a) (b)

Fig. 9. (a) Movements of the column in the soil during impact, (b) X velocity curves for two Suzuki Geo Metro models (Mariusz 2016).

6. Conclusions

Several reviews have been done on the fractured material on transportation, such as the train axle and railway. One of these broken materials is caused by corrosion that results from damage to the axle coat. It also can occur due to the selection of the mechanical properties, e.g., yield stress and tensile strength of the material under the recommendation, respectively. Further, to prevent this phenomenon in the future, improving corrosion protection control, inspection, and maintenance programs must be developed. Case of the damage to the material may occur during daily use, consisting of violations and influence of nature, e.g., floods and earthquakes. Besides, damage types for the Datong-Qinhuangdao heavy-haul rail were dominated by severe rail side wear and surface spalling. Nevertheless, surface hardness and wear resistance of wheel or rail materials can be increased by laser quenching. Case of the violation, e.g., challenging to detect by diagnosing the current state due to the presence of a corrosion catalyst, can destroy like in the gas pipeline of the Republic of Sakha. However, transportation infrastructure remains particularly vulnerable to floods and earthquakes. On the other hand, the most common frequent category crashes among motor vehicle drivers occur because of the lack of attention that contributes to almost one in three fatal traffic accidents in Norway. Improving passenger safety, including changes in vehicle structure to reduce intrusions in the occupant compartment, vehicle interiors, and a passenger bag (airbag) system for drivers and front-seat passengers could reduce fatal injury to the occupant. A numerical approach, like the finite element method, can be done to estimate the event of a crash between transportation to improve passenger safety. However, deceleration experienced by the occupants were identified as the main factors causing fatal injuries. Hence, the location of the center of gravity of the vehicle could absorb higher energy, and the velocity decreases more smoothly and regularly from the beginning to the end of the impact when hitting the column.

References

Aye, M.N., Kasai, A., Shigeishi, M., 2018. An Investigation of Damage Mechanism Induced by Earthquake in a Plate Girder Bridge Based on Seismic Response Analysis: Case Study of Tawarayama Bridge under the 2016 Kumamoto Earthquake. Advances in Civil Engineering, 2018.

Bae, D.M., Prabowo, A.R., Cao, B., Sohn, J.M., Zakki, A.F., Wang, Q., 2016. Numerical simulation for the collision between side structure and level ice in event of side impact scenario. Latin American Journal of Solids and Structures, 13(16), 2991–3004.

Berzi, L., Baldanzini, N., Barbani, D., Delogu, M., Sala, R., Pierini, M., 2018. Simulation of crash events for an electric four wheel vehicle. Procedia Structural Integrity 12, 249–264.

Diakakis, M., Boufidis, N., Salanova Grau, J.M., Andreadakis, E., Stamos, I., 2020. A systematic assessment of the effects of extreme flash floods on transportation infrastructure and circulation: The example of the 2017 Mandra flood. International Journal of Disaster Risk Reduction, 47, 101542.

Ding, H.H., Fu, Z.K., Wang, W.J., Guo, J., Liu, Q.Y., Zhu, M.H., 2015. Investigation on the effect of rotational speed on rolling wear and damage behaviors of wheel/rail materials. Wear, 330–331, 563–570.

Evtiukov, S., Golov, E., Ginzburg, G., 2018. Finite element method for reconstruction of road traffic accidents. Transportation Research Procedia 36, 157–165.

Ito, D., Hayakawa, K., Kondo, Y., Mizuno, K., Thomson, R., Piccinini, G.B., Hosokawa, N., 2018. Difference between car-to-cyclist crash and near crash in a perpendicular crash configuration based on driving recorder analysis. Accident Analysis and Prevention 117, 1–9.

Jun, H.K., Seo, J.W., Jeon, I.S., Lee, S.H., Chang, Y.S., 2016. Fracture and fatigue crack growth analyses on a weld-repaired railway rail. Engineering Failure Analysis 59, 478–492.

Mariusz, P., 2016. The Acceleration Severity Index in the impact of a vehicle against permanent road equipment support structures. Mechanics Research Communications 77, 21–28.

Moradi, R., Setpally, R., Lankarani, H.M., 2013. Use of Finite Element Analysis for the Prediction of Driver Fatality Ratio Based on Vehicle Intrusion Ratio in Head-On Collisions. Applied Mathematics 04(05), 56–63.

Muttaqie, T., Thang, D.Q., Prabowo, A.R., Cho, S.R., Sohn, J.M., 2019. Numerical studies of the failure modes of ring-stiffened cylinders under hydrostatic pressure. Structural Engineering and Mechanics 70(4), 431–443.

Odanovic, Z., 2017. Analysis of the railway freight car axle fracture. Procedia Structural Integrity 4, 56–63.

Odanovic, Z., Ristivojevic, M., Milosevic-Mitic, V., 2015. Investigation into the causes of fracture in railway freight car axle. Engineering Failure Analysis 55, 169–181.

Prabowo, A.R., Nubli, H., Sohn, J.M., 2019. On the Structural Behaviour to Penetration of Striking Bow under Collision Incidents between Two Ships. International Journal of Automotive and Mechanical Engineering 16, 7480–7497.

Prabowo, A.R., Sohn, J.M., Bae, D.M., Zakki, A.F., Harsritanto, B.I., 2018. Investigating crashworthy single and double skin structures against accidental ship-to-ship interaction. Curved and Layered Structures 5(1), 180–189.

Prabowo, A.R., Bae, D.M., Sohn, J.M., Zakki, A.F., Cao, B., Cho, J.H., 2017. Effects of the rebounding of a striking ship on structural crashworthiness during ship-ship collision. Thin-Walled Structures 115, 225–239.

Singh, H., Ganesan, V., Davies, J., Paramasuwom, M., Gradischnig, L., 2018. Vehicle Interior and Restraints Modeling Development of Full Vehicle Finite Element Model Including Vehicle Interior and Occupant Restraints Systems for Occupant Safety Analysis Using THOR Dummies. Washington, DC.

Singh, H., Ganesan, V., Davies, J., Paramasuwom, M., Gradischnig, L., Wood, P., Mogal, V., 2018. Structural Countermeasure/Research Program Mass and Cost Increase Due to Oblique Offset Moving Deformable Barrier Impact Test. Washington, DC.

Sundfør, H.B., Sagberg, F., Høye, A., 2019. Inattention and distraction in fatal road crashes – Results from in-depth crash investigations in Norway. Accident Analysis and Prevention 125, 152–157.

Syromyatnikova, A., Bolshakov, A., Ivanov, A., Alexeev, A., Bolshev, K., Andreev, Y., 2019. The corrosion damage mechanisms of the gas pipelines in the Republic of Sakha (Yakutia). Procedia Structural Integrity 20, 259–264.

Tanov, R., Brueggert, M., Yang, S., 2003. Finite Element Modeling and Crash Analysis of a School Bus.

Wang, W.J., Guo, H.M., Du, X., Guo, J., Liu, Q.Y., Zhu, M.H., 2013. Investigation on the damage mechanism and prevention of heavy-haul railway rail. Engineering Failure Analysis 35, 206–218.

Yu, F., Jar, P.Y.B., Hendry, M., 2015. Effect of temperature on deformation and fracture behaviour of high strength rail steel. Engineering Fracture Mechanics 146, 41–55.

Yuan, Q., Xu, X., Xu, M., Zhao, J., Li, Y., 2020. The role of striking and struck vehicles in side crashes between vehicles: Bayesian bivariate probit analysis in China. Accident Analysis and Prevention 134, 105324.

Zakar, F., Mueller, E., 2016. Investigation of a Columbus, Ohio train derailment caused by fractured rail. Case Studies in Engineering Failure Analysis 7, 41–49.