ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)

https://doi.org/10.17559/TV-20230412000527
Original scientific paper

Standardizing Self-Certification for Small Scale Production Roadsters: A Space Frame Crash Analysis Approach

Sungyong HA

Abstract: With the gradual expansion of the market for small-scale, multi-variety, small-volume production electric vehicles, the need arises to develop appropriate crash stability evaluation standards and techniques. This study focuses on utilizing a space frame suitable for small-volume production vehicles for design and manufacturing purposes. The research involves measuring acceleration values and comparing them between computer simulation crash analysis and crash tests conducted on an actual fixed wall frontal crash scenario. The collision analysis and test were performed with a collision speed of 50 km/h, and the measured acceleration values were compared with those obtained from finite element analysis. The results of the crash analysis and crash test indicate that in both cases, the main frame experienced breakage, with the analysis results aligning closely with the actual test outcomes. Although some performance conditions led to differences in acceleration values, overall, the trends exhibited similarities between the crash analysis and crash test. Based on these findings, computer simulation can be employed as a substitute for the crash analysis vehicle certification method when modifying the certification method for low-scale production vehicles. This research contributes to developing crash stability evaluation standards and techniques for small-scale production of electric vehicles. The study demonstrates the feasibility of utilizing computer simulation as an effective tool for crash analysis vehicle certification, providing valuable insights for future certification methods and improving the efficiency of small-volume production vehicle evaluation.

Keywords: crash analysis; crash test; small-scale production vehicle; space frame structure; vehicle body frame; vehicle design

1 INTRODUCTION

Occupant safety is one of the most critical factors in manufacturing automobiles. Therefore, to protect them, safety devices that can protect occupants are used in automobiles and considered when designing automobiles [1, 2].The industry continues to study crash safety, leading manufacturers in producing high-safety vehicles by developing standards for each country, evaluating, certifying and disclosing scores to consumers [3-5]. This is done according to relevant Korean laws and regulations, and vehicle manufactures are also evaluated and certified by adhering to automobile management regulations [6, 7]. However, it is expensive for small-scale production companies to get certified as per automobile management norms. Small-scale production cars are defined as cars with less than 100 units, but many vehicles must be used for crash tests to obtain certification. In addition, there is no clear basis for whether the result value of the computer simulation crash analysis is the same as the actual crash in the current certification.

The space frame is characterized by being more rigid and lighter than other frames. Moreover, it can be made in a production facility at a low cost [8]. However, it is not easy to apply to mass-produced vehicles where manufacturers must weld directly. Small-scale producers choose the low-cost space frame method because there is a limit to their production facilities. The crash test is dynamically conducted with the amount of change in acceleration with time. Vehicles judged to have good safety in this evaluation have a wide range of acceleration over time after a collision, but the increase in acceleration is low. One of the essential conditions to consider when designing a car is to absorb collision energy with a bumper and a crash box to avoid injuring passengers. Kang [9] conducted crash analysis and structural analysis on the vehicle structure based on the structural safety and lightness of the vehicle using steel as the material of the space frame to determine the maximum stress acting on all sides of the frame and calculated for computer simulation of the frame. Kim [10] made a three-dimensional space frame as a commercial vehicle that used aluminium for a light body and expressed it in terms of acceleration, velocity, and displacement through computer simulation and actual crash tests. Lee [11] conducted a head-on crash test at about 50 km/h, referring to European legislation ECE R.12, and derived acceleration, kinetic energy, and internal energy by attaching an acceleration sensor to the lower B-pillar. However, the above studies analysed the vehicle model applied to mass production, and studies on electric vehicles applied to small-scale production were not conducted.

In order to produce and sell small-volume vehicles, the vehicle must be certified and evaluated. For small and medium-sized enterprises that produce small-scale vehicles, obtaining certification according to the nationally recognized procedures costs a considerable amount of money. Therefore, by revising the Automobile Management Regulations in 2017, in the case of small-scale production vehicles of less than 100 units, the crash test was replaced by computer simulation analysis and self-test results [12]. Therefore, in Korea, the standards of related laws could be more transparent and more straightforward for manufacturers. In addition, the standards of self-test-related laws could be more precise and confusing for manufacturers. Accordingly, for manufacturers to quickly determine whether or not a small-scale production vehicle is targeted, a performance test agent from an automobile specialized agency was ordered to replace the small-scale production vehicle object inspection.

This paper used a computer simulation crash analysis applicable to the reorganized small-volume production vehicle certification and evaluation regulations and the corresponding actual crash test conducted, and the results validated through comparison. It intends to reduce the cost of evaluation and certification for the safety evaluation of small-scale, multi-variety, small-volume production electric vehicles.

2 LITERATURE REVIEW

Each year, automakers come out with new cars. To sell a new car, a car crash test to evaluate whether it can protect the safety of passengers. Vehicle crash tests are primarily divided into frontal, side, and offset crash tests. In order to conduct a vehicle crash test, an actual vehicle must be provided for each test, which consumes a lot of time, resources, and cost. Hence, studying a method of making a car crash with computer software is still used. The virtual test uses the FE model for the crash. The advantage of the virtual crash test is that once the FE model is modelled for the vehicle, it can be used again rather than newly created, and it is possible.

Williams et al. [13] conducted a similar study and conducted material tests to create an FE model to predict the crash behavior of a small sports car with a space frame structure using Caterham 7. They made an FE model for the frame and BIW, etc. The Frontal impact analysis is performed to predict vehicle body deformation.

Ambati et al. analyzed frontal crashes using the Chevrolet C1500 FE model. In the case of [14], the data of NCAC (National et al. Center) compared with the author's two models [14]. In the case of the first model, the same material as NCAC was compared to a model with reduced parts, and in the case of the second model, the materials of some parts were changed, and the data were compared.

Consumers are paying more attention to safety as traffic accidents that increase every year cause damage to human life and property. As a result, the New Car Assessment Program (NCAP), which provides information about vehicle safety to consumers and induces manufacturers to produce safer vehicles, is called the New Car Assessment Program (NCAP), and many countries use it to certify, and Korea also introduced KNCAP. The safety level is measured for frontal and side crashes of vehicles, partial frontal collisions, and vehicle aggression toward pedestrians. In a vehicle crash, the head of the occupant is one of the places where injuries should be reduced. The time to calculate the Head Injury Criterion (HIC) is essential to determine the possibility of skull or brain damage in the event of a collision. The higher this reference value, the higher the fracture or brain damage probability. When the value is 1000~1500, skull fracture occurs nine times out of 15 experiments, and brain damage occurs ten times out of 17. It was found to be high, and it was suggested to set the HIC result to 15 ms or less [15].

US-NCAP calculates the value of the devised Head Injury Risk Curve (HIRC) in the fixed wall frontal crash test (Offset Crash) using HIC15, and Euro-NCAP and KNCAP use HIC36 to derive the value. In the case of the driver's seat, a 50-tile Hybrid III male dummy was placed in the fixed wall frontal crash test to derive a head injury standard value through HIC36, and a 5% tile Hybrid III female dummy was seated in the front passenger seat, followed by US-NCAP and HIC15 with HIC15. The head injury standard value is derived and evaluated, and the equation is expressed as Eq. (1) [16].

$$HIC = \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t) \mathrm{d}t \right]^{2.5} (t_2 - t_1) \le 1000 \tag{1}$$

where $a(t)$ is the resultant linear acceleration (g) measured and $(t_2 - t_1)$is time duration (ms).

Abbreviated Injury Scale (AIS) is used as standard. Also the HIC value is used to determine the standard value of the injury risk curve (HIRC) [16]. Using AIS4 as the standard, the injury risk curve of HIC36 can be created, and Eq. (2) that can create the possibility of head injury (P_{head}) [17] can be obtained using HIRC for the probability of causing damage.

$$P_{\text{head}} = \left[1 + \exp\left(5.02 - 0.00351 \times HIC \right) \right]^{-1} \tag{2}$$

Also, according to each country's NCAP, vehicle crash tests must be conducted with multiple vehicles. This creates constraints such as investing a large amount of money only for the test and the time it takes for the car dealer to take test. In order to address this limitation, the collision analysis of computerized simulation running the computer simulation studies and the cost of the test could be compromised. Research into data reliability has been ongoing for a long time, and in particular, research into the comparability of data from two trials has continued [18, 19].

When a vehicle crashes, the physical part is calculated as kinetic energy (*KE*), and the two tests are compared based on acceleration and velocity values. The formula for converting kinetic energy into acceleration is as Eq. (3).

$$a_v = \frac{1}{9.8} \sqrt{\frac{2KE}{m}} \tag{3}$$

where a_v is the acceleration value of a crashing vehicle and m is the mass of the vehicle.

Existing studies typically examine vehicles and conclude the data. Unlike previous studies, this study produced a small-scale production vehicle design, a pre-crash test was conducted, and similar trend analysis results were compared. Most vehicle crashes and computer simulations compare monocoque frames. In this paper on computer simulation crash analysis, we investigated whether comparing actual space frame crash tests and computer simulation test data is possible.

3 RESEARCH METHODOLOGY

3.1 Experimental Vehicle Benchmarking

Small cars are mainly designed and manufactured as a space frame. This is because the space frame can lower equipment investment costs. Before proceeding with computer simulation crash analysis and crash testing, the vehicle designs and manufactures benchmarks to quantify information such as vehicle specifications. The vehicle benchmarked the frame shape of the racing vehicle Radical SR1. Also, due to the nature of the roadster, it is mainly produced for a two-seater, and it was designed and manufactured by referring to the 2016 Hyundai Ioniq specifications in consideration of the purchase and production of a ready-made product. Tab. 1 is the specification of Hyundai Motor Company Ioniq.

Table 1 2016 Hyundai Ioniq electric specification

2016 Ioniq Overall Dimension		
Size		G.V.W
L 4,470 × W 1,820 × H 1,450 (3248 × 1820 × 1200)		1,445 kg
Wheel base	Front Track	Rear Track
2,700 mm	1,555 mm	1,564 mm

3.2 Design and Manufacture of Small-Volume Vehicles

Before testing, the Radical SR1 was specified for the shape of the vehicle skeleton required for the experiment, and it was designed to 2016 Hyundai Ioniq Electric so that the vehicle parts used globally would be used. When designing, material selection is inexpensive and easy to purchase from small-scale companies, and material selection for small-scale production companies is not expensive and not readily available for design, and materials considered to have sufficient strength are selected. A crash test vehicle was prepared based on this.

The finite element method analysed the computer simulation, which includes a frame using shell elements, a solid elements bumper, and a bumper connector. In order to proceed with the above process, a vehicle was modelled in CATIA, and a crash analysis study was conducted using ABAQUS 2020. A crash test was conducted with a fixed wall frontal crash test, and a driver's seat and a male dummy were seated on the left side. The experiment was carried out under the given conditions [20].

In order to design a small-volume production vehicle, the model to benchmarks determining the shape in advance and investigating the specifications. In order to model the vehicle to use for computer simulation crash analysis, the benchmarked vehicle was directly airlifted as a sample and drafted in Fig. 1 which shows the frame shape of the sample.

Figure 1 Radical SR1 frame

According to the initial setting specifications, the arm and bracket positions are determined using the drafted frame dimensions and modelling performance by 3D CAD software. Tab. 2 and Fig. 2 show the modelling specifications and shape of the model of the 3D CAD software used for modelling CATIA respectively.

Table 2 Roadster specification

Overall Dimension		
Size		G.V.W
L 3,860 × W 1,820 × H 1,200 (3248 × 1820 × 1200)		350 kg
Wheel base	Front Track	Rear Track
2,700 mm	1,555 mm	1,564 mm

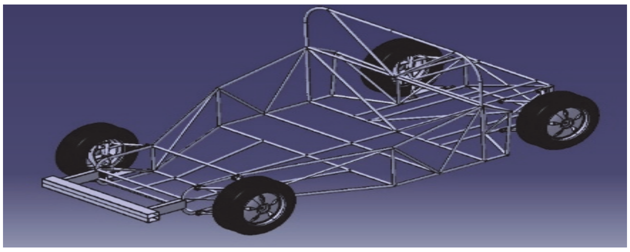

Figure 2 Designed small manufacture roadster

In order to manufacture the modelled vehicle and perform computer simulation crash analysis, it is necessary to determine the material of the main frame. The material for the main frame should be inexpensive and readily available from automakers in small quantities. Therefore, KS D 3576 was used for a pipe of piping (SPP). Fig. 3 shows the selected materials and modelling of a two-seater roadster for the crash test manufacturers and the manufactured roadster.

Figure 3 Roadster for frontal crash test

3.3 Modelling for Frontal Crash Analysis

The crash analysis of the space frame type was performed in Fig. 4 by finite element modelling using commercial CAE software ABAQUS 2020. The crash analysis conditions indicated that the space frame vehicle collided with a wall strong enough not to deform at a speed of 50 km/h.

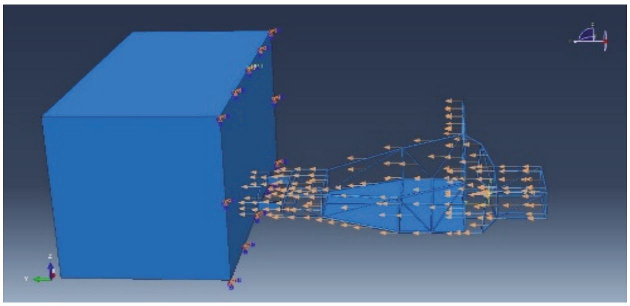

Figure 4 Computational frontal crash analysis of roadster

The vehicle's properties are needed to calculate the stresses and strains of the collision in a CAE. When designing a space frame-type vehicle, the material of the main frame is carbon steel for piping (SPP) and refers to physical properties of SPP [21]. Bumper installation and material is AL6082, a floor plate is included to lift the vehicle seat and dummy, and S355J2 is used for additional analysis and comparison. Its physical properties are the same as in Tab. 3.

Table 3 Roadster material property

Materials Properties	SPP	AL6082	S355J2	Mild Steel
Density / g/cm^3	7.84	2.53	7.874	7.84
Yield Strength / MPa	363.6	277	355	235
Young's Modulus / GPa	179.4	71.1	210	211
Poisson's Ratio	0.29	0.29	0.3	0.29

In finite element modelling, the main frame is modelled as a shell element and other parts, such as bumpers, are modelled as solid elements. The number of each node and element is obtained in Tab. 4, and the criterion for distributing nodes and elements is the criterion for mass scaling in collision analysis.

Table 4 Quantity of roadster modelling elements and nodes

Classify	Non-Mass Scaling (Mild Steel)	Non-Mass Scaling (S355J2)	Mass Scaling (S355J2)
Element	26,464	32,504	30,504
Node	29,690	28,700	28,700

3.4 Setting for a Frontal Crash Test

Based on the vehicle data designed in the space frame format, an experimental car was created. Automotive crash tests are generally conducted with commercial vehicles, and most tests are conducted using monocoque and ladder frame-type vehicles used in SUVs. However, there are not many crash test cases for space-frame sports cars, and it is difficult for small automakers to find crash test data for space-frame vehicles. The fixed wall frontal impact test was conducted at 50 km/h using the designed vehicle [16, 17], and an acceleration sensor was installed in the B-pillar lower frame part shown in Fig. 5 to proceed with the measurement. An additional accelerometer was installed on the side of the seat near the B-pillar to prevent errors.

Figure 5 Equipment location of roadster acceleration sensor r

According to the Small Production Vehicle Certification Regulations, small production vehicles must be demonstrated to be safe. However, if the crash analysis of the dummy is based on the crash analysis of a vehicle for a small-volume automobile, the calculation and simulation cost increase, and the modelling and analysis of the dummy become more difficult. Therefore, a method was chosen to convert the dummy's data by seating the dummy in a designed and manufactured roadster.

4 RESULTS AND DISCUSSION

Fig. 6, Fig. 7, and Fig. 8 show the results of the crash analysis. Fig. 6 is the result of analysis using mild steel as the base material for the analysis and mild steel without mass scaling as the base material, and the calculated maximum acceleration was 23.76 g. Due to the characteristics of mild steel, it cannot withstand the force of impact after impact and collapses. Fig. 7 shows the analysis result when the base material of the bottom plate is used as S355J2. As a result, the main frame collapsed and stopped at the bottom plate. Compared with the mild steel in Fig. 6, the bumper part absorbs some impact energy, but when it collides with the main frame of the SPP part, it lowers. Due to the acceleration value, the impact energy was not absorbed and decreased as it is, and the maximum acceleration was derived as 19.3 g.

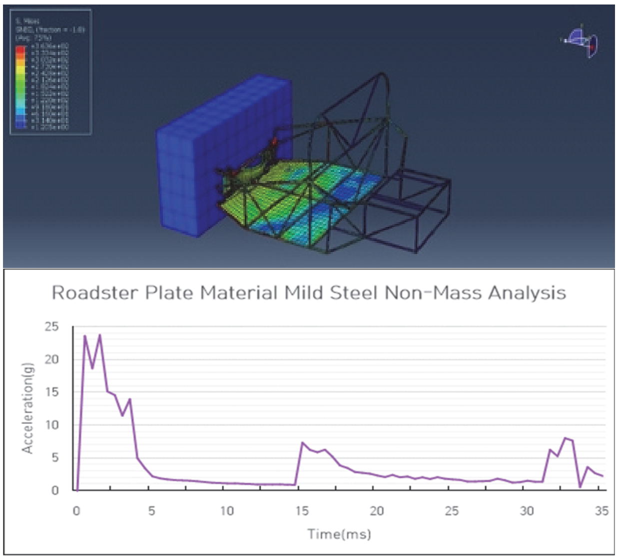

Figure 6 Roadster plate material mild steel non-mass scaling frontal crash analysis results (upper: FEA result, lower: acceleration variation over time)

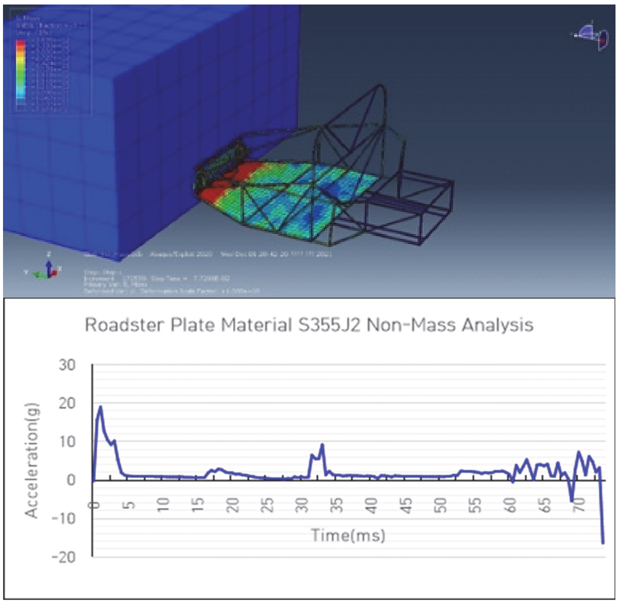

Figure 7 Roadster plate material S355J2 non-mass scaling frontal crash analysis results (upper: FEA result, lower: acceleration variation over time)

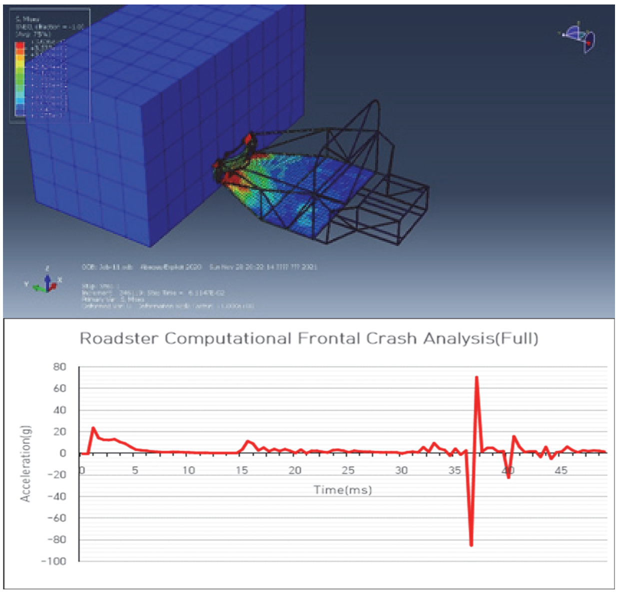

Figure 8 Roadster plate material S355J2 mass scaling frontal crash analysis results (upper: FEA result, lower: acceleration variation over time)

Fig. 8 shows the analysis results by applying the physical properties of S355J2 and adjusting the empty weight to 350 kg using mass scaling. The maximum acceleration value is 23.92 g, and the difference in mass is higher than in Fig. 7, but the pattern shows similar results.

Figs. 9 and 10 show the results of the crash test of the space frame vehicle and the acceleration of the vehicle body, respectively. The graph divides into left and right pairs in the B-pillar lower frame. It shows the acceleration values of the B-pillar's left and right acceleration sensors and the redundant acceleration sensors. A graph shows a similar trend in each pair of graphs. However, compared to the blue graph line (LH side sill accelerometer) and the yellow graph line (RH side sill accelerometer), the reason why the yellow graph line is higher is because the weight of the sheet and the dummy part (left) increases. The acceleration value is higher due to the increased force applied.

Figure 9 Roadster frontal crash test

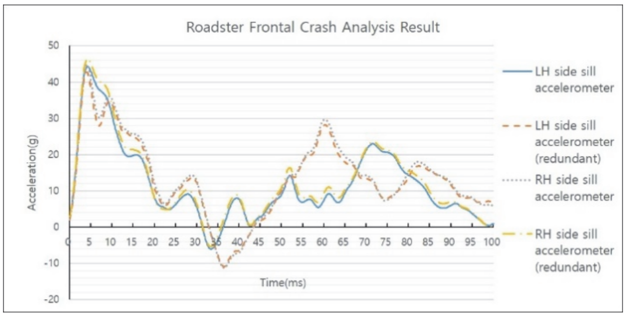

Figure 10 Acceleration result of roadster frontal crash test

Fig. 9 shows that the main frame of the space frame vehicle buckles and collapses before the front bumper and the crash box in the collision. This is because the rigidity of the main frame is weak compared to the bumper, so the impact energy directly affects the frame. Fig. 10 shows that the bumper and crash box do not absorb much impact energy at 44.27 g when the maximum acceleration is 4.3 ms. The crash will eventually end after it has collided with the underside of the vehicle.

When comparing the scene of the actual crash test and the analysis scene, it confirms that the part in charge of the body suspension alone extensively destroys. It confirmed that the size of the material used to manufacture the vehicle does not withstand the impact force and rapid destruction. In addition, comparing Figs. 6, 7, 8 and Fig. 10 the upward trend of the graph comes out in a similar form. The result in the graph shows that the main frame supporting the bumper is weak and cannot absorb the impact. The main frame destroys as it is, resulting in the maximum acceleration at the beginning of the collision.

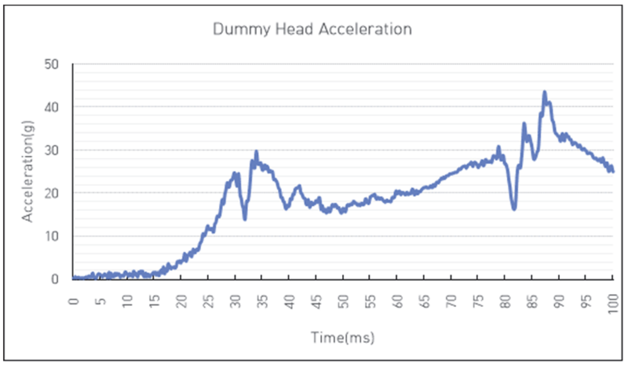

Figure 11 Dummy head acceleration result of roadster frontal crash test

About the safety of the occupant, the most important data in the dummy head injury criterion value (HIC, Head Injury Criterion) in a collision. HIC36 measured the standard value for a head injury, and the maximum value was set to 1000 or less to derive a head injury probability of 20% or less. Fig. 11 and Tab. 5 show the head acceleration values of the dummy.

Table 5 Measured head injury criterion (HIC36) of roadster frontal crash test dummy

Head Injury Measurements	Driver (50th%)		
	Threshold Value	Measured Value	% of Threshold
Head Injury Criterion - 36 ms Interval (HIC-36)	1000	155	16%
Head Resultant - 3 ms Clip	80	34	43%

When comparing the values in Tab. 5 with the Head Injury Risk Curve (HIRC), the probability of head injury was within 10%, injury risk: when the probability was calculated using Eq. (2), it showed that the probability of head injury was 7.59%.

The HIC value of the dummy in the actual crash test is coming out low. Followingly, Fig.11 shows this, and unlike the vehicle's acceleration, it confirms that the maximum acceleration comes out at the end of the collision. This is the part where the reaction force is the largest, and the head acceleration of the dummy is the highest in this part. Acceleration also appears to be low.

5 CONCLUSION

In this study, a space frame, which is judged suitable for small-volume production vehicles, was used for design and manufacture, and a computer-simulated crash analysis and an actual fixed wall frontal collision test were used to measure and derive the acceleration values between the computer simulation crash analysis and the crash test was performed. The crash analysis and the actual crash test set the collision speed to 50 km/h, and the acceleration values were measured and compared with the finite element analysis. The results are summarized as follows.

1) Comparing the crash analysis and the crash test, the main frame breaks in both cases and the analysis results showed similar results.

2) Due to analysis and crash testing, there should be guidelines recommending that the mainframe uses a more rigid material than the crash box currently used commercially.

3) Looking at the graphs of the computer simulation crash analysis and crash test results, we can see that there are errors due to differences in some performance levels in the case of acceleration values, but similar trends are shown in the graphs.

4) In the crash test, when the HIC value is less than 1000, and the probability of injury is low, the head injury protection area of a small space frame product car is judged to be satisfactory.

5) Comparing the results of the computer simulation crash analysis with the actual crash test results, it was confirmed that a graph with a similar trend was generated. Therefore computer simulation can replace the crash analysis vehicle authentication method when modifying the low-volume production vehicle certification method.

6) Based on the above judgment, it is possible to sufficiently prove the computer simulation crash analysis authentication method for small-volume production vehicles. However, additional research is needed to analyse and present clear values for the physical properties of small-volume automobile manufacturers to facilitate computer simulation crash analysis. Manuscript to anyone other than the corresponding author, reviewers, potential reviewers, other editorial advisers, and the publisher, as appropriate.

Acknowledgements

This study was carried out with the support of the KOREA Ministry of Land, National Transport Science and Technology Agency Promotion (RS-2023-00253588).

6 REFERENCES

[1] Krzysztof, W., Arkadiusz T., Stanisław B., & Wojciech W. (2019). On estimation of occupant safety in vehicular crashes into roadside obstacles using nonlinear dynamic analysis. *MATEC Web of Conferences*, *285*(22), 1-8. https://doi. org/10.1051/matecconf/201928500022

[2] Belingardi, G., Beyene, A. T., Koricho, E. G., & Martorana, B. (2015). Alternative lightweight materials and component manufacturing technologies for vehicle frontal bumper beam. *Composite Structures*, *120*, 483-495. https://doi. org/10.1016/j.compstruct.2014.10.007

[3] Maria, S. G., Francisco, J. L. V., & Richard, F. (2010). Real-world performance of vehicle crash test: the case of EuroNCAP. *Injury Prevention*, *16*, 101-106. https://doi. org/10.1136/ip.2009.023812

[4] Hobbs, C. A. & McDonough, P. J. (1998). *Development of the european new car assessment program (EURO NCAP), Transport Research Laboratory*, 98-S11-O-06, 2439-2453. https://www-nrd.nhtsa.dot.gov/pdf/esv/esv16/98s11o06.pdf

[5] Youn, Y., Han, W. H., Kim, G. H., Kim, H. J., & Park, J. K. (2011). Assessment of 12 Years KNCAP Performances and Plan for Elderly Occupant Protections. *Proceedings of the 22nd International Technical Conference on Enhanced Safety of Vehicles*, 1-8.

[6] Youn, Y., Lee, J., Kang, B., Kim, G., & Kwon, H. (2017). The Proposed New KNCAP Frontal Crash Test Based on the In-Depth Accident Data. *ESV Conference*.

[7] Lee, D. J., Choi, Y. T., Lee, K. W., & Lim, J. M. (2011). A consideration on the results of side impact and pole side impact tests in 2011 KNCAP. *Journal of Automobile Safety Society*, *3*(2), 22-27.

[8] Bulgu, C. J. (2019). Design a Space Frame Chassis for Light Weight Automobiles for Improved Safety and Reliability. *Mechanical Engineering Research*, *9*(2), 36-50. https://doi. org/10.5539/mer.v9n2p36

[9] Kang, S. S. & Cho, S. G. (2010). Structural Design and Analysis for the Reinforced Frame of Vehicle. *Journal of the Korean Society of Manufacturing Technology Engineers*, *19*(4), 504-510.

[10] Kim, B. J., Kim, J. H., Kim, B. G., Heo, S. J., Kang, H., & Kim, J. M. (2002). Design and Analysis Considering Collision Safety of Vehicles with Aluminum Space Frame. *Symposium of Automobile Engineers Korea*, 629-634.

[11] Kim, H. K. & Kang, S. J. (2004). Analysis of Load Intrusion Collision of Multi-Purpose Vehicle Seat. *Proceedings of the Korean Society of Automotive Engineers Conference*, 7-13.

[12] National Law Information Center (2017). Republic of Korea, Automobile Management Regulations.

[13] Williams, T. D., de Pennington, A., & Barton, D. C. (2000). The frontal impact response of a spaceframe chassis sportscar. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, *214*(8), 865-873.

[14] Ambati, T., Srikanth, K. V. N. S., & Veeraraju, P. (2012). Simulation of vehicular frontal crash-test. *International Journal of Applied Research in Mechanical Engineering (IJARME)*, *2*(1), 37-42.

[15] Prasad, P. & Mertz, H. J. (1985) The Position of the United States Delegation to the ISO Working Group 6 on the Use of HIC in the Automotive Environment. *SAE Technical Paper Series*, *94*, 106-116. https://doi.org/ 10.4271/851246

[16] Versace, J. (1971). A review of the severity index. *Proceedings of the 15th Stapp Car Crash Conference, Coronado*. https://doi.org/10.4271/710881

[17] Lim, J. H., Park, I. S. & Huh, S. J. (2005). A Study on the Characteristics of Human Injury through Car-Bogie Collision Test Considering Collision Safety. *Proceedings of the Korean Society of Automotive Engineers' Spring and Fall Conference*, 1160-1164.

[18] Greene, J. E. (1977). Computer Simulation of Car-To-Car Collisions. *SAE Technical Paper 770015, SAE International*, 38-48. https://doi.org/10.4271/770015

[19] Lee, H. W. & Shin, H. W. (1996) A Study on the Characteristics of Frontal Collision of a Vehicle with Frame. *Proceedings of the 1996 Spring Conference of the Korean Society of Automotive Engineers*, 173-178.

[20] Ministry of Land, Transport and Maritime Affairs Ordinance No. 234, Article 102 Paragraph 1.

[21] Nam, J. S., Sakong S. H., Baek C. S., Lim K. G., Jeong, J. H., & Min K. T. (2007). A Study on the Strength Analyses of T-Branch Pipes. *Journal of Korean Institute of Fire Science and Engineering*, *21*(2), 36-41.

Contact information:

Sungyong HA
Joongbu University,
(10279) 305, Dongheon-ro, Deogyang-gu, Goyang-si, Gyeonggi-do,
Republic of Korea
E-mail: hsy1396@joongbu.ac.kr