International Journal of Advanced Smart Convergence Vol.8 No.4 161-168 (2019)
http://dx.doi.org/10.7236/IJASC.2019.8.4.161

IJASC 19-4-20

A Study on the Installation of a Barrier to Prevent Large-Scale Traffic Accidents in Tunnel

Se-Ryong Baek[1], Jun-Kyu Yoon[2], Jong-Han Lim[2*]

[1]*Senior Researcher, Gachon-Samsong Automotive Research Center, Gachon University, Korea*
[2]*Professor, Deptment of Mechanical Engineering, Gachon University, Korea*
baek-seryong@samsong.co.kr, kkjong@gachon.ac.kr, *kkjong@gachon.ac.kr

Abstract

Traffic accidents in tunnel can lead to large traffic accidents due to narrow and dark road characteristics. Therefore, special care of the driver is required when is driving in a tunnel. However, accidents can happen at any time. In the event of an accident, a narrow road structure may lead to a second accident. Therefore, all facilities installed inside the tunnel should be allowed to minimize damage in the event of an accident. We confirmed the safety of the collision target through the action of the sedan, Sport Utility Vehicle (SUV) and truck when the vehicle crashed into a stairway installed on the tunnel emergency escape route, and when a concrete barrier or guard rail was installed in front of the stairway. The behavior of the vehicle has resulted in a total of three results: rollover or rollover, change of speed and angle of the vehicle after collision. The sedan and SUV were the most secure when colliding with the guardrail, but considering the truck as a whole, concrete barriers were judged to be the most suitable for minimizing damage from the first accident and reducing the risk of the second accident.

Keywords: *Traffic Accidents, PC-Crash Tunnel, Barrier, Collision Speed, Collision Angle*

1. Introduction

There have been 6,913 casualties and 130 deaths from tunnel accidents over the past five years [1]. The overall traffic accident rate in Korea is decreasing, while the number of tunnel traffic accidents is increasing, and the number of injured and killed is also increasing. The tunnel's structure is equipped with pedestrian paths and evacuation facilities for evacuation by persons inside the tunnel in the event of a fire or collapse. The pedestrian walkway is installed at a height of about 1m to protect from the collision of vehicles and is equipped with a staircase to access the pedestrian path. If a vehicle hits a stairway for access to a pedestrian due to an accident during driving, the front part of the vehicle coming into contact with the stairway is heard. If the vehicle speed is high, the vehicle may overturn or tip over. Even if the vehicle is not rolled over or overturned, if the angle of departure after a collision is high, the angle of departure should be minimized.

Manuscript Received: November. 11, 2019 / Revised: November. 19, 2019 / Accepted: November. 24, 2019
Corresponding Author: kkjong@gachon.ac.kr
Tel: +82-10-5351-1551
Professor, Dept. of Mechanical Engineering, Gachon University, Korea

because there is a risk of a second accident with the vehicle. Unlike general roads, tunnels are not brightly lit and spaces are narrower, so they are more affected by air resistance than ordinary roads. In addition, black ice may occur on roads in tunnels with low temperatures, and black ice may be invisible when driving, and the vehicle may slip easily. A previous study involving tunnel traffic accidents found the installation of safety robots to prevent secondary accidents in tunnels [2], development of vehicle fire simulation combustion systems for reproducing fire accidents in tunnels and underground spaces [3], study on increase rate of accidents caused by weather conditions such as snow, rain and dark roads [4], to identify potential risks when considering the road traffic environment at points of frequent accidents [5]. In addition, the reliability of crash analysis using PC-Crash program was studied, and about 1.2 to 3.1% errors were generated in the reconstruction of the collision using PC-Crash. The results show that you are confidence to reconstruct. [6].

The purpose of this study is to examine the behavior of a vehicle when it collides with a staircase installed in an evacuation facility and to examine the effect of improving the behavior of a vehicle after a collision when a fence is installed. In addition, by examining the presence and departure angle of the vehicle before and after the collision, we want to find the optimal driving conditions to minimize the injuries of the occupants and reduce the collision damage caused by the subsequent vehicles.

2. Theory

2.1 Collision mechanics of the vehicle

Traffic accidents can be divided into collisions in one-dimensional form, such as collision accidents, and accidents occurring in two-dimensional planes, such as side collisions [7]. Figure 1 shows a rectangular collision in a two-dimensional plane. Vehicles traveling in a straight line show a one-dimensional motion, but when it hits the side, the momentum is decomposed into right angles and two-dimensional motion is performed. Each component can be represented by Formula (1) and (2).

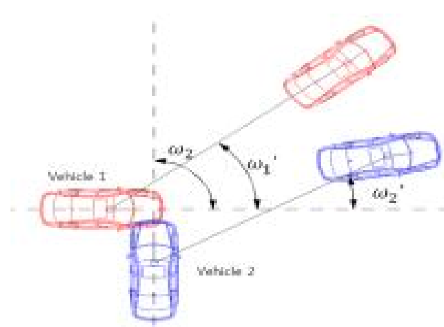

Figure 1. Diagram of two-dimensional collision

$$m_1 v_1 cos\omega_1 + m_2 v_2 cos\omega_2 = m_1 v_1' cos\omega_1' + m_2 v_2' cos\omega_2' \quad (1)$$

$$m_1 v_1 sin\omega_1 + m_2 v_2 sin\omega_2 = m_1 v_1' sin\omega_1' + m_2 v_2' sin\omega_2' \quad (2)$$

2.2 Collision mechanics of the vehicle

PC-Crash can analyze vehicle collisions using collision calculation and FBI model using the law of conservation of momentum [8]. In this study, vehicle collision analysis was performed using FBI model. The

FBI model is an ellipsoid-based impact analysis model that is calculated based on the contact force between two bodies or between the body and the ground. This model can be used for vehicle-vehicle contact or vehicle-road contact, such as rollover or contact between the vehicle and the ground. The ellipsoid model also uses the same impact model as the pedestrian multi-body system to calculate contact force and position. A linear stiffness model with restoring force is used and sliding impact is calculated according to the specified contact friction. Friction always acts in the opposite direction of the relative velocity at the contact. Figure 2 shows an ellipsoidal model of a vehicle used in PC-Crash.

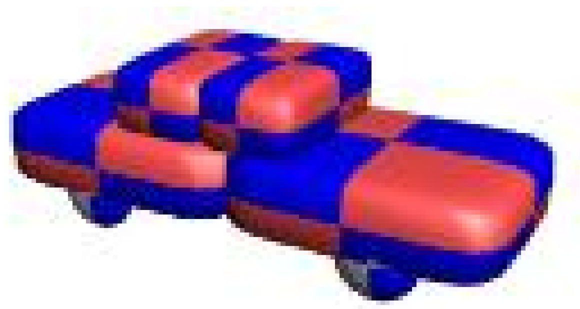

Figure 2. The ellipsoid model of the PC-Crash

PC-Crash users can input Friction, Restitution, and Static deformation, and the input value is applied to Equation (3) to determine the stiffness of the body [8].

$$S = \frac{m \cdot g}{s_{Def}} \tag{3}$$

PC-Crash's multi-body vehicle model consists of two bodies, two roofs and four wheels, and the calculated values apply to the body, typically 90% for wheels and 25% for roofs. Calculate

2.3 Vehicle crash barrier

In this study, concrete barriers and guard rails were installed to reduce the injuries of the occupants and prevent secondary collisions. Concrete barriers are generally concrete barriers installed in the center to separate up and down lanes on highways, and guard rails are structures consisting of struts and rails and are usually installed at the edges of roads. Figure 3 shows the concrete barriers installed in the stairway of the tunnel.

Figure 3. Concrete barrier installed at the stairway of the tunnel escape route

3. Analysis range

3.1 Specification of the test vehicle

In this study, the vehicle was selected and analyzed as a truck that can cause great damage in case of traffic accident in sedan, Sport Utility Vehicle (SUV) and tunnel which are the user's favorite in Korea.

Table 1. Specification of the vehicle

Unit ; mm, kg

Model	Length	Width	Height	Track axle	Wheel base	Weight
Sedan	4855	1865	1475	1590	2795	1550
SUV	4440	1855	1635	1614	2640	1305
Truck	7150	2500	2345	1880	3600	9999

Table 1 shows the specifications of the vehicle. The specifications of the vehicle were used as the basic specifications provided by the manufacturer, and the center of gravity of the vehicle, which has a major influence on the overturning and falling, was applied by citing the research results of the Korea Institute of Transportation Safety.

3.2 Simulation condition

The simulation set the condition that the driving vehicle collided toward the tunnel's evacuation p ath and collided with the stairs going up the evacuation path. To evaluate the occupant protection p erformance, the collision speed is set to 60 to 120km/h according to the grade of the vehicle protec tive fence. A vehicle weighing 1,300kg hits the barrier at a 20∘ angle and is measured by evaluati ng the speed of departure and the angle of departure.

Table 2 shows the vehicle type, the collision target and the speed condition of the vehicle. The coll ision vehicle was set with three models of sedan, SUV and truck, and the three collision targets we re stairs, concrete barriers and guard rails. The collision speed was increased from 30km/h by 10km /h to 120km/h and a total of 90 analyzes were performed.

Table 2. Conditions of vehicle velocity according to impact position

Vehicle	Collision object	Collision speed [km/h]
Sedan	Stairs	30
		40
		50
SUV	Concrete Protective wall	60
		70
		80
Truck	Guard-rail	90
		100
		110
		120

4. Results and Discussion

4.1 Simulation condition

Table 3 shows the vehicle's speed and whether the vehicle rolled over according to the collision target.

Table 3. Vehicle rollover status according to vehicle type and collision barrier

Impact velocity [km/h]	Sedan			SUV			Truck		
	A	B	C	A	B	C	A	B	C
30	X	X	X	O	X	X	X	X	X
40	X	X	X	O	X	X	X	X	X
50	X	X	X	O	X	X	X	X	O
60	X	X	X	O	X	X	O	X	O
70	O	X	X	O	O	X	O	X	O
80	O	X	X	O	O	O	O	X	O
90	O	O	X	O	O	O	O	O	O
100	O	O	O	O	O	O	O	O	O
110	O	O	O	O	O	O	O	O	O
120	O	O	O	O	O	O	O	O	O

A: Stairs, B: Concrete protective wall, C: Guard-rail

As a result, if the car crashed into the stairs, fall or rollover occurred at very low speeds, such as sedan 70 km/h, SUV 30km/h, and truck 50km/h. Sedan 90km/h, SUV 70km/h and truck 90km/h resulted in felling or rollover at normal road speeds. Particularly, in the case of the concrete firew all, the side parts are inclined so that the wheels of the vehicle can be lifted, so that the front and rear wheels of the crashed side of the vehicle are floating, unlike the stairs that float only in front of the vehicle. The result was that the other lanes could be blocked more in the fall or overturn s ituation. Lastly, when the vehicle collides with the guard rail, the props are deformed in the sedan and SUV, and the energy is absorbed, leaving the rails on the rails without floating. However, in t he case of trucks, the guard-rails were overly deformed to collide with the staircase and conducted at a relatively low speed of 50km/h.

4.2 Speed change according to collision target and speed

The magnitude of the speed change due to the collision of the vehicle is proportional to the def ormation of the vehicle body or the impact the passenger receives. In evaluating the strength perfor mance of vehicle fences, the after-collision velocity should satisfy at least 60% of the collision velo city. If the drop-off speed falls below 60%, the impact on the vehicle and the occupant is large. Ta ble 4 shows the speed change rate of the vehicle after the collision according to the vehicle collisio n target.

Table 4. Vehicle speed changes after collision with vehicle type and collision target

Impact velocity [km/h]	Sedan			SUV			Truck		
	A (%)	B (%)	C (%)	A (%)	B (%)	C (%)	A (%)	B (%)	C (%)
30	0	8	73	-	13	60	0	50	30
40	0	72	65	-	75	57	0	72	30
50	0	74	64	-	78	52	0	78	-
60	0	75	58	-	75	33	-	78	-
70	-	67	55	-	-	0	-	77	-
80	-	63	38	-	-	-	-	72	-
90	-	-	0	-	-	-	-	-	-
100	-	-	-	-	-	-	-	-	-

A: Stairs, B: Concrete protective wall, C: Guard-rail

As a result, the sedan crashed down the stairs at 30～60km/h and finally stopped. Over 70km/h, th e sedan fell over or overturned. Overturned or inverted above 40km/h In addition, the truck climbed the stairs below 40km/h and finally stopped as the vehicle was inclined, and over 50km/h fell or r olled over. In the case of the stairs, the departure speed was more than 60% under all conditions r egardless of the vehicle type and speed, and it was confirmed that the passenger and the vehicle ha d a great impact.

In the case of concrete barriers, sedans and trucks collided with stairways due to overturning or o verturning at speeds of over 80 km/h and SUV over 70km/h. In terms of break-off speed after colli sion, all of them were measured at 60% or more except for 30km/h speed conditions. The speed ch ange after the collision was found to be somewhat large at the 30km/h condition, but since the abs olute speed is not high, the impact on the occupant or the vehicle is not expected to be large.

Finally, for guardrails, sedans and SUV showed similar or better results than concrete barriers, but trucks did the opposite. In the case of trucks, due to the weight of the large body, the guardrail was pushed up to the stairs, stepping over the guardrail and finally stopping at40km/h, which is lo wer than the impact of the stairs.

4.3 Deviation angle according to collision target and speed

The angle of departure of the vehicle after a collision has a great effect on the secondary collisi on. The vehicle moves along the wall after the collision and the speed is slowed down by friction. If the barrier does not absorb enough energy, the vehicle will bounce in the opposite direction and cause a second collision with the vehicle. Tunnels are generally composed of two to three lanes, s o a large departure angle of the vehicle after a collision can lead to a large accident. Figure 4 sho ws the standard of marking the departure angle of the vehicle after the collision. The blue vehicle i s marked with (+) as the behavior that is rotated in the opposite direction after the collision. The re d vehicle takes the front part after the collision and rotates in the collision angle direction. It is rep resented by (-) as the behavior. Table 5 was prepared according to this notation.

In evaluating the strength performance of a vehicle fence, the angle of departure after collision should be less than 60%. If the vehicle's departure angle exceeds 60% of the collision angle, the ve hicle can travel to another lane and cause a second accident. In the stairway collision conducted in this study, all vehicles exceed 60% or the wheels are caught on the stairs and rotated in the revers e direction. In the case of concrete barriers, the sedan and SUV met the conditions of less than 6 0% at speeds of 50km/h and trucks at 60km/h.

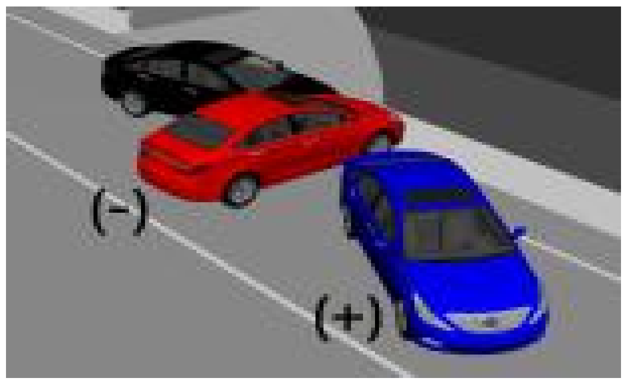

Figure 4. Reference is made to the degree of departure of the vehicle after the collision

The guard-rails met less than 60% post-collision angles at speeds below sedan 80km/h and SUV 60km/h, but trucks were only satisfied at speeds below 40km/h. In the case of trucks, the concrete barrier collision conditions showed better results than the SUV, like sedans, but in the case of gua rd-rails, the guard-rails are pushed in at 50km/h and the fall occurs on stairs, indicating that the saf ety is much lower than that of sedans and SUV.

Table 5. Vehicle departure angle after collision with vehicle type and collision target

Impact velocity [km/h]	Sedan			SUV			Truck		
	A (◦)	B (◦)	C (◦)	A (◦)	B (◦)	C (◦)	A (◦)	B (◦)	C (◦)
30	**100**	0	0	-	0	0	**-85**	0	0
40	**210**	0	0	-	0	0	**-50**	0	0
50	**450**	45	10	-	40	0	**-165**	15	-
60	**500**	**85**	15	-	**105**	0	-	50	-
70	-	**250**	15	-	-	**-185**	-	**90**	-
80	-	-	20	-	-	-	-	**155**	-
90	-	-	**-135**	-	-	-	-	-	-
100	-	-	-	-	-	-	-	-	-

A: Stairs, B: Concrete protective wall, C: Guard-rail

4. Conclusion

In this study, we looked at post-crash behavior when the vehicle crashed into a stairway installed on the tunnel emergency escape route, and when concrete barriers or guard-rails were installed in f ront of the stairway, we identified safety resulting from collision targets through the behavior of sed an, SUV and truck.

(1) The vehicle felling and overturning after the collision was the highest when the sedan and SUV hit the guard rail, and the truck showed the highest safety in the concrete barrier.

(2) The speed change of the vehicle after the collision was confirmed to be the highest when a ll the vehicles collided with the concrete barrier.

(3) The change in the angle of the vehicle after the collision was the highest when the sedan a nd SUV hit the guard rail, and the truck hit the concrete barrier.

This study assumes that vehicles and structures are rigid bodies, and shows the results of simul ation analysis by applying rigidity.

It can be used as a reference for judging whether or not the vehicle is overrun or felling due to a crash and reducing collision damage. In the future, if the FE analysis that can accurately apply t he characteristics of the actual vehicle and the structure is performed, the damage of the traffic acci dent in the tunnel can be reduced.

References

[1] National Police Agency, "TAAS system of National Police Agency", 2019.

[2] W. A. Kim, W. K. Lee, and D. J. Seo, "A Study on the Tunnel Safety Robot to Prevent Car Accidents in a Tunnel", Proceeding of KIIT Conference, pp. 444-445, 2018.

[3] S. Y. Yang, H. J. Kim, and M. H. Moon, "Performance Evaluation of Vehicle Fire Simulator for Reconstruction of Fire Disaster in Tunnel and Underground Space II", Korean Institute of Fire Science & Engineering, pp. 275-276, 2018.

[4] Y. J. Kim, S. K. Choi, H. W. Kim, J. K. Sim and B. C. Choi "An Analysis of the Traffic Volume and Traffic Accident Rate on National Roads and Freeways according to the Weather Conditions" , Proceedings of the Autumn Meeting of KMS, pp. 374-375, 2017.

[5] J. H. Kim, S. B. Lee and B. J. Park "Enhancement of Identification of Potentially Hazardous Highway Segments" , Korean Society of Civil Engineers, Vol. 3, No. 3, pp. 291-297, 2003.

[6] J. D. Kim, and J. K. Yoon "Reliable Study on the Collision Analysis of Traffic Accidents Using PC-Crash Program" , Journal of the Institute of Webcasting, Internet and Telecommunication, Vol. 12, No. 5, pp. 115-122, 2012.
http://dx.doi.org/10.7236/JIWIT.2012.12.5.115

[7] "Traffic Accident Analysis Manual", Korea Road Traffic Authority, 2011.

[8] "PC-Crash Technical Manual", Dr. Steffan Datentechnik, 2017.