■ 論 文 ■

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Impact Conditions of Performance Evaluation, and Development of High-Performance Roadside Barrier for Longitudinal Barriers in Smart Highway

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Key Words : Impact Condition, Longitudinal Barrier, Safety Performance Evaluation, Computer Simulation, Crash Test
충돌조건, 종방향 베리어, 안전성능 평가, 컴퓨터 시뮬레이션, 충돌시험

요 약

To minimize the degree of damage in the SMART highway's punctuality and safety occurred from the car-barrier collisions, the impact conditions for longitudinal barriers in SMART highway was determined to be significantly larger than the existing maximum impact conditions. Results from computer simulation runs show that the existing domestic highest-performance roadside barrier did not satisfy the suggested impact conditions. The newly developed N-class barrier designed with computer simulation model and verified by full-scale crash tests has satisfied the SMART highway impact conditions in terms of occupant safety indexes and structural adequacy.

본 연구에서는 충돌사고시 스마트하이웨이의 정시성과 안전성의 손상정도를 최소화 하도록 스마트하이웨이의 종방향 베리어 충돌조건으로 기존의 충돌조건보다 상당히 상향된 충돌조건이 제시된다. 스마트하이웨이 충돌조건을 적용하여 기존 국내 최고 성능등급 베리어에 대한 컴퓨터 시뮬레이션 결과 탑승자 안전도를 만족하지 못하였다. 스마트하이웨이 충돌조건에 만족하는 베리어 개발을 위해서 컴퓨터 시뮬레이션에 의한 설계를 수행하고 실물차량 충돌시험을 통한 성능 검토결과 개발된 N등급 베리어가 탑승자 안전지수와 구조적 적절성을 만족하였다.

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Ⅰ. Introduction

SMART highway, advancing the development of road construction technology according to the required changes for the future is the general research and development business for the road construction technology enhancing safety, mobility and convenience. For successful construction of SMART highway, the core technology related to roads infrastructure facilities in various fields must be supported. Since the expected road design speed of SMART Highway is 140km/h, to minimize the degree of damage for the SMART highway's punctuality and safety after car-barrier collisions, the high effective and technical roadside safety facility must be developed by considering a special feature of SMART highway. In order to achieve it, a standard of the roadside safety facility test for SMART highway must be established.

The installation of roadside safety facilities in Korea are allowed for only facilities tested through full-scale crash test according to a guide of the "Installation and Management Guide for Roadside Safety Facility" (MCT, 2001) enacted in 2001. The guide for Korea allows the impact speed for securing occupants same as the road design speed, and the maximum impact speed is 100km/h.

In America that introduced the concept of "Forgiving Road" in 1950s and continues to study road safety facilities, "NCHRP Report 350" (Ross et al., 1993). which is a performance evaluation guide for road safety facilities presents the impact speed of 100km/h for the maximum road design speed of 110km/h.

In Europe, each country has developed and installed their own installation standards and evaluation, and after foundation of European Economic Community (EEC), European Committee for Normalization (CEN) conducted standardization of roadside safety facilities since 1990, and enacted "EN-1317" (CEN, 1998). The maximum road design speed in Europe is 140km/h, specifically in Germany and Italy, and the maximum impact speed is 100km/h according to EN-1317. For the design speed of 140 km/h, applying the impact speed of 100 km/h does not mean a facility passing the performance evaluation of impact speed 100 km/h is considered safe enough but worst conditions are applied for performance evaluation of impact standards in the range technically allowed without damaging economical efficiency, and considering the concept of "state-of-the-possible", considering the situation in that time to reflect the limit in economical efficiency, technologies, etc., in enacting standard.

Improvement in the level of vehicle performance and the design speed of a road leads to general high speed in driving vehicles, road users are highly interested in road safety and overall technologies for road safety facilities have been improved. This study presents SMART highway impact conditions which are extended from existing concept of "state-of-the-possible" to develop higher performance barriers. The researchers intend to develop new roadside barriers of high performance which meets the presented SMART highway impact conditions.

Ⅱ. Impact Conditions of the Domestic and International Roadside Safety Facilities

The roadside safety facility must satisfy safety for small car passengers and structural adequacy for heavy trucks simultaneously. Test results of the vehicle must coincide with the performance standard after the impact. The guide for domestic and international roadside safety facility performance evaluation is divided into the impact conditions and performance evaluation standard for the result analysis of the impact test. The impact conditions are divided into the safety evaluation for small car passengers and structural adequacy evaluation for heavy trucks.

1. Installation and Management Guide for Roadside Safety Facilities

The domestic roadside safety facility performance evaluation standard is prescribed in "Installation and Management Guide for Roadside Safety Facility" (MCT, 2009). The domestic standard classifies the barriers in seven performance levels, and provides the impact conditions according to the level. Among the seven levels, the impact conditions for normal, higher and very high levels are shown in 〈Table 1〉. The maximum impact test conditions for the occupant safety is the impact vehicle of 1,300kg, with speed of 100km/h and angle equal to 20°. The maximum impact conditions for the structural adequacy evaluation is the impact vehicle of 36,000kg, with a speed of 80km/h and angle equivalent to 15°.

〈Table 1〉 Impact Conditions of Domestic Roadside Safety Facility

Performance Level		Impact Conditions		
		Impact Vehicle (kg)	Impact Speed (km/h)	Impact Angle (deg.)
Normal	SB3	1300	100	20
		8000	80	15
Higher	SB5	1300	100	20
		14000	80	15
Very High	SB6	900	100	20
		25000	80	15
	SB7	900	100	20
		36000	80	15

2. Nchrp Report 350

The U.S. roadside safety facility standard is prescribed in "NCHRP Report 350, Recommended Procedures for the Safety Performance Evaluations of Highway Features" (Ross et al., 1993). NCHRP Report 350 classifies the performance level of the roadside safety facility into six levels, and suggests the impact conditions of each level. In 〈Table 2〉, the impact conditions among the six levels according to normal, higher and very high levels are shown. In NCHRP Report 350, the maximum impact test conditions for the occupant safety is the impact vehicle of 820kg, with a speed of 100km/h and angle of 15°, while the maximum impact conditions for the structural adequacy evaluation is the impact vehicle of 36,000kg, speed of 80km/h and angle equal to 15°

〈Table 2〉 Impact Conditions of U.S. Roadside Safety Facility

Performance Level		Impact Conditions			Remarks
		Impact Vehicle (kg)	Impact Speed (km/h)	Impact Angle (deg.)	
Normal	TL3	820	100	20	
		2000	100	25	
Higher	TL4	820	100	20	
		2000	100	25	optional
		8000	80	15	
Very High	TL5,6	820	100	20	
		2000	100	25	optional
		36000	80	15	

3. Nchrp Project 22-14

"NCHRP Project 22-14" (NCHRP, 2006) is the draft report for update of NCHRP Report 350. The important changes are ① increase of pickup truck weight from 2000kg to 2270kg, standard vehicle for evaluation of the structural adequacy of the safety facility, ② increase of the impact vehicle from 820kg to 1100kg and angle from 20° to 25° as the impact conditions of small car for occupant safety evaluation. In 〈Table 3〉, among the six performance levels of NCHRP Project 22-14, its impact conditions for normal, higher and very high levels are shown.

〈Table 3〉 Impact Condition of updated U.S. Roadside Safety Facility

Performance Level		Impact Condition			Remarks
		Impact Vehicle (kg)	Impact Speed (km/h)	Impact Angle (deg.)	
Normal	TL3	1100	100	25	
		2270	100	25	
Higher	TL4	1100	100	25	
		2270	100	25	optional
		8000	80	15	
Very High	TL5,6	1100	100	25	
		2270	100	25	optional
		36000	80	15	

4. En-1317

Since 1990 in Europe, standardization of the roadside safety facility has been conducted, and "EN-1317" (CEN, 1998) has been used as the common standard. In EN-1317, the performance level of the facility is divided into four levels. In 〈Table 4〉, its impact conditions for normal, higher and very high levels are shown. In EN-1317, the maximum impact test conditions for the occupant safety is the impact vehicle of 900kg, speed of 100km/h and angle equal to 20° and the maximum impact conditions for the structural adequacy evaluation is the impact vehicle of 38,000kg, speed of 65km/h and angle of 20°.

Ⅲ. Impact Conditions of Smart Highway Road Safety Facilities

The impact conditions for the full-scale crash test consist of impact vehicles, impact speed, and impact angles. The conditions should be determined reflecting the worst condition according to the road's features. In this research, in order to minimize the degree of damage for SMART highway's punctuality and safety after car-barrier collisions, the impact

〈Table 4〉 Impact Conditions of Europe Roadside Safety Facility

Performance Level			Impact Conditions		
			Impact Vehicle (kg)	Impact Speed (km/h)	Impact Angle (deg.)
Normal	N1	TB31	1,500	80	20
	N2	TB11	900	100	20
		TB32	1,500	110	20
Higher	H1	TB11	900	100	20
		TB42	10,000	70	15
	H2	TB11	900	100	20
		TB51	13,000	70	20
	H3	TB11	900	100	20
		TB61	16,000	80	20
Very High	H4a	TB11	900	100	20
		TB71	30,000	65	20
	H4b	TB11	900	100	20
		TB81	38,000	65	20

conditions consider a high-speed environment.

〈Table 5〉 shows impact conditions for evaluating performance of road safety facilities in SMART highways. The impact conditions are classified into Low, Normal, and High levels depending on the level of danger of a road. The normal level is for general sections of driving speed of 120km/, the Low level is for low speed sections, e.g., roads connected with national highways, expressways or tollgates, and the High level is for sections with highly dangerous road sides or with lots of heavy vehicle traffic. By classifying the amount of sold vehicles for 4 years in Korea, the weight of colliding vehicles for small passenger vehicles for the normal level was determined to be 900kg which occupies 7.5% of the accumulated sales amount in the order of weight. The maximum impact speed for the U.S. roadside safety facility performance evaluation was concluded as 100km/h to include 60% of the accumulated accident impact speed, and its speed is 90% of the designed road speed(Ross et al., 1993). The impact speed for small passenger vehicles for the normal level was determined 120km/h including the impact speed of predicted accumulated accidents of

60%, by means of the accumulated impact speed distribution for predicted accident for the design speed of a road of 140km/h. The impact angle for small passenger vehicles for the normal level was determined to be 20°, by analyzing and applying the Point Mass Model and RSAP Model (NCHRP, 2003) for calculating theoretical impact angles, assuming a vehicle concerned to be a mass unit, the result of research, European accident cases of RISER Project (European Community R&TD, 2005), and through verification by means of various simulations and full-scale crash test. See the related paper (Kim et al., 2009) for more details about methods of determining and reviewing the impact conditions of road safety facilities in SMART highway.

Maximum impact test condition for the occupant safety evaluation is 900kg for the impact vehicle, impact speed as 120km/h and impact angle as 20°. Maximum impact test condition for the structural adequacy is 36,000kg for the impact vehicle, impact speed as 85km/h and impact angle as 15°.

The domestic maximum impact test conditions for the occupant safety are 1,300kg-100km/h for the impact vehicle weight and impact speed. In U.S., they are 820kg-100km/h, while in Europe the impact test conditions are 900kg-100km/h. For the SMART Highway, 900kg for the impact vehicle weight and an impact speed of 120km/h. Therefore if developed roadside barrier satisfies impact conditions of SMART Highway then the safety of the SMART Highway will be improved

Ⅳ. Developing Smart Highway Roadside Barrier

A simulation applying various impact conditions was conducted to evaluate occupant safety and structural adequacy for the impact conditions of the suggested SMART highway longitudinal barriers. For the analysis, the best

〈Table 5〉 Impact Conditions Of Smart Highway Roadside Safety Facility

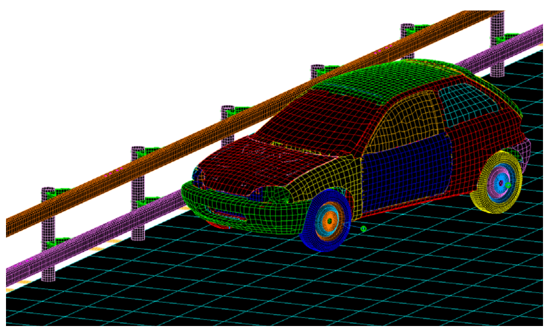
Performance Level		Vehicle	Speed (㎞/H)	Angle (Deg)
Low Level	L1 (Sb1)	1,300 (Passenger Vehicle)	60	20
		8,000 (Single Unit)	55	15
	L2 (Sb4)	1,300 (Passenger Vehicle)	80	20
		14,000 (Single Unit)	65	15
	L3 (Sb5)	1,300 (Passenger Vehicle)	100	20
		14,000 (Single Unit)	80	15
Normal Level	N	900 (Passenger Vehicle)A 1,300 (Passenger Vehicle)	120 120	20 20
		8,000 (Single Unit)	85	15
High Level	H1	900 (Passenger Vehicle)A 1,300 (Passenger Vehicle)	120 120	20 20
		14,000 (Single Unit)	85	15
	H2A	900 (Passenger Vehicle)A 1,300 (Passenger Vehicle)	120 120	20 20
		25,000 (Single Unit)	85	15
	H2B	900 (Passenger Vehicle)A 1,300 (Passenger Vehicle)	120 120	20 20
		36,000 (Trailer)	85	15

A) Optional :
Testing 900Kg Passenger Vehicles Is Recommended, But Testing 1300Kg Vehicles Is Allowed Until It Is Fully Studied Because There Is Little Possibility That Existing Facilities Meet The Performance Standard And There Are Not Various New Facilities Developed. The Facilities Passing The 900Kg Vehicle Test Do Not Need To Undergo The 1300Kg Vehicle Test.

Note 1) The Facilities Which Have Passed The High Level Test Can Be Applied To The Normal And Low Levels (However, The N Level Cannot Include L2 And L3 Levels).

Note 2) If A Competent Authority Requests Testing The N And H Levels, 2000Kg (Suv) Vehicles Can Be Added To The Passenger Vehicle Test (120Km/H, 20°).

Note 3) When Using The Normal Level For The Passenger Vehicle Only Section, The 2000Kg (Suv) Passenger Vehicle Test (120Km/H, 20°) Can Be Carried Out Instead Of The 8000Kg Vehicle Test.



〈Figure 1〉 Open Type Roadside Barrier Simulation Model

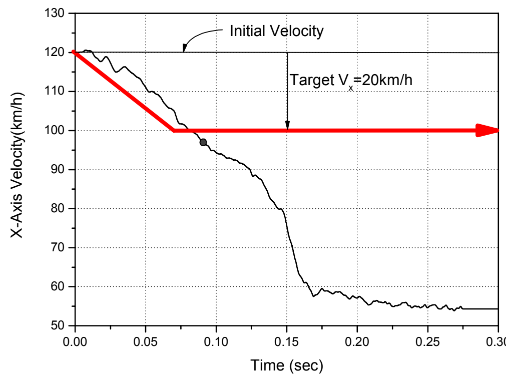
〈Table 6〉 Result of simulation of the existing open type roadside barrier

Impact conditions			THIV (km/h)	PHD (g)
Vehicle (kg)	Speed (km/h)	Angle(°)		
900	120	20	34.3	13.8

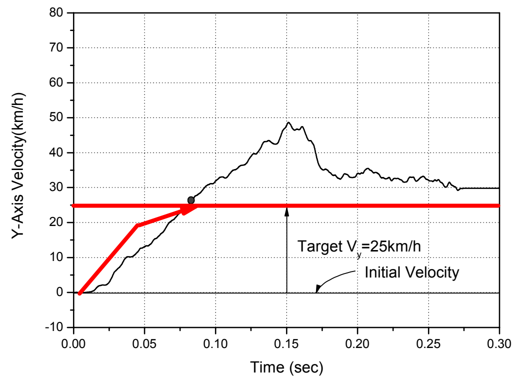
performance facility was selected among roadside barriers in the existing domestic highest performance level(SB 5). 〈Figure 1〉 shows the selected roadside barrier simulation model. The roadside barrier shown in 〈Figure 1〉 consists of struts at 2m intervals and supported with steel pipes and 2-step C steel cross beams and is a model relatively open as compared to the existing roadside barriers in which W and Thrie beams are used.

The computer simulation used was LS-DYNA (Hallquist J. O., 1998) which is a 3D non-linear dynamic analysis program widely used for analyzing road safety facilities. 〈Table 6〉 shows the result of analysis by the simulation. The analysis result was 34.3km/h for THIV(Theoretical Head Impact Velocity) which is above the reference of 33.0km/h. THIV is calculated as the sum of deceleration in the direction of vehicle traveling(V_x) and deceleration in the direction orthogonal to the direction of vehicle traveling(V_y). 〈Figures 2〉 and 〈Figures 3〉 show V_x and V_y. It is essential that V_x is at most 20km/h at the point of THIV initiation and V_y is at most 25km/h in order to meet the THIV reference of 33.0km/h. However, the analysis result was 22.8km/h for V_x, which is 14% above the targe tvalue and 29.0km/h for V_y which is 16% above the target value.

In order to develop a high performance barrier meeting the SMART highway impact conditions, the deceleration in the direction of vehicle traveling(V_x) should show the behavior that further deceleration is not shown after initial deceleration as the arrow indicates in 〈Figure 2〉 in order to meet the target value.



〈Figure 2〉 Open Type Roadside Barrier V_x

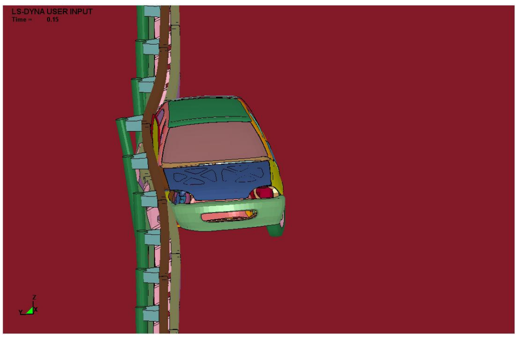


〈Figure 3〉 Open Type Roadside Barrier V_y

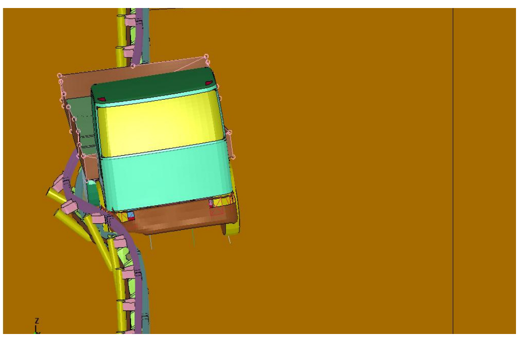
〈Figure 4〉 Proposed N level roadside barrier

Another requirement is that the deceleration in the direction orthogonal to the direction of vehicle traveling(V_y) should exhibit the type of a great initial gradient and declining gradient before THIV occurrence as the arrow indicates in 〈Figure 3〉 in order to satisfy the target value. A method of obtaining the target shape of V_x is to apply a double beam, and a method of

〈Figure 5〉 Proposed H1 level roadside barrier



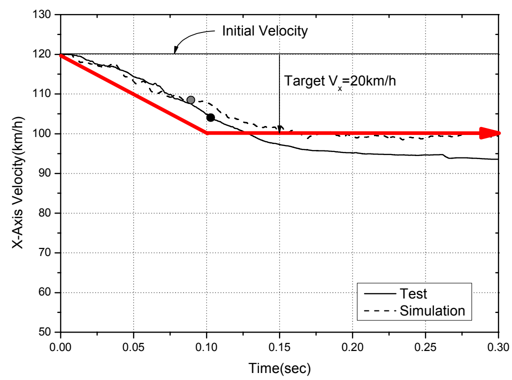
〈Figure 6〉 Simulation of N level roadside barrier



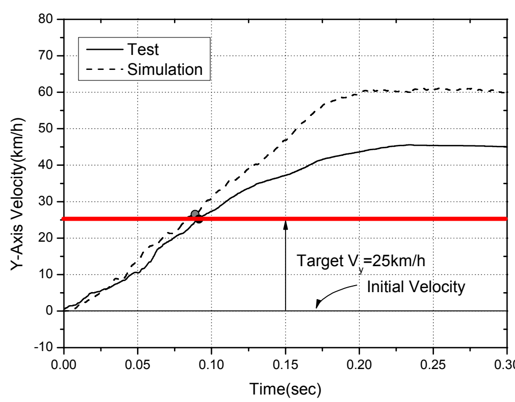
〈Figure 7〉 Simulation of N level roadside barrier

obtaining the target shape of V_y is to further strengthen front beams or to apply parallel arrangement. 〈Figures 4〉 and 〈Figures 5〉 show examples of high performance roadside barrier at N and H1 levels. The N-level roadside barrier example is made by connecting closed section beams of high rigidity in parallel and then arranging C beams at the rear of the closed section beams. The H1-level roadside barrier is made by applying modified Thrie beams stronger than typical Thrie beams and then arranging C beams at the back thereof.

For the proposed N and H1-level roadside barriers, the researchers set preliminary design models through examining roughly structural adequacy to which the Olson model and the failure mechanism were applied. For the preliminary design model, the researchers carried out computer simulation for various design variables, e.g., struts, beams, blockout, etc., to decide section details of the configuration member in order to meet the level of occupant safety. 〈Figures 6〉 and 〈Figures 7〉 show simulations for impact conditions of N-level barriers for small and large vehicles respectively. 〈Figures 8〉 and 〈Figures 9〉 show Vx and Vy by means of computer simulation for small passenger vehicle impact conditions. The behavior of Vx

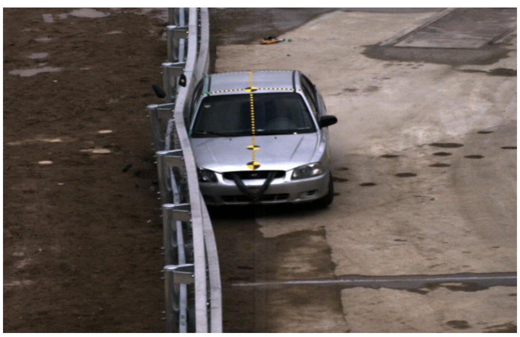


〈Figure 8〉 N-level Roadside Barrier V_x



〈Figure 9〉 N-level Roadside Barrier V_y

exhibited similar to the arrow in the simulation result for small vehicle impact conditions, and it was 17.5km/h at the point of THIV occurrence, which is 12.5% below the target value of 20km/h. For Vy, the initial gradient in the simulation result is shown greater than that of the existing barrier and Vy declined before THIV occurrence, but was 25.0km/h at the point of THIV occurrence to be the same as the target value. With respect to the key results derived from the simulation shown in 〈Table 7〉, figures of THIV and PHD for N-level and H1-level small passenger vehicle impact conditions were at most 33.0km/h and 20g, respectively, which meet the level of occupant safety. The researchers examined details of structural adequacy to which large vehicle impact conditions were applied for the model meeting the level of occupant safety. It was seen that speed deviation and angle deviation in the simulation were at least 60% of the impact speed and at most 60% of the impact angle, respectively, which satisfy structural adequacy. The researchers carried out full-scale crash test for the N-level final models examined through simulation. 〈Figures 10〉 and 〈Figures 11〉 show photo graphs of full-scale crash tests for a small vehicle and a large vehicle respectively. In the full-scale crash test result for the small vehicle impact conditions, the behavior of V_x and Vy was similar to that of simulation as shown in 〈Figures 8〉 and 〈Figures 9〉. Referring to the full-scale crash test result shown in 〈Table 7〉, it is seen that the final model meets both of the level of occupant safety and structural adequacy. Performance of H1-level vehicles will be verified through full-scale crash test.



〈Figure 10〉 Crash test of N level roadside barrier

〈Figure 11〉 Crash test of N level roadside barrier

〈Table 7〉 Analysis and test result

Impact conditions			Simulation	test
Small vehicle	N level	THIV(㎞/h)	28.7	30.8
		PHD (g)	13.5	11.2
	H1 level	THIV(㎞/h)	30.1	-
		PHD (g)	15.4	-
Large vehicle	N level	Speed deviation(㎞/h)	78.4	74.2
		Angle deviation (°)	8.7	7.2
	H1 level	Speed deviation(㎞/h)	70.0	-
		Angle deviation (°)	7.1	-

Ⅴ. Conclusion

To minimize the degree of damage for the SMART highway's punctuality and safety after car-barrier collisions, impact conditions of related domestic and international standards were examined, and the number of domestically sold passenger vehicles for each weight group, the speed in collision accidents for road design speed of 120km/h, the angle of accumulated collision accident, etc. were investigated, to present impact conditions for evaluating performance of road safety facilities in SMART highway.

Computer simulation for existing barriers at the best performance level in Korea was carried out by applying the presented SMART highway impact conditions, and it was seen that they did not exhibit the desired level of occupant safety. The researchers carried out detailed design by means of computer simulation in order to develop barriers which meet the SMART highway impact conditions, and examined performance through full-scale crash test. It was shown that the N-level barrier met the desired level of occupant safety and structural adequacy.

Roadside barriers and median barriers at various levels have been studied in order to minimize the degree of damage for the SMART highway's punctuality and safety

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