에너지 흡수 장치를 부착한 트라이빔 가드레일 시스템의 거동

Performance of Thrie-Beam Guardrail System with Impact Attenuator

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요약 : 최근 교통상황은 교통량의 급격한 증가와 차종의 다양성에 그 특징이 있다. 우리나라에서 가장 많이 사용되고 있는 W형 보를 사용한 가드레일은 14ton-60Km/h-15° 의 충돌조건에 대하여 구조물의 강성이 충분치 못한 반면에, 보다 현실적인 충돌속도에 대하여 소형차의 탑승자 안전을 충족시키지 못하는 것으로 나타났다. 대형차에 대응하기 위하여 구조물의 강성을 증가시키는 일과 소형차에 대하여 탑승자의 안전을 도모(에너지 소산)해야하는 두 가지의 서로 상반된 목표를 달성하기 위하여, 두께 3.2mm 의 강판을 이용한 보와 고무로 만든 충격 흡수재를 이용한 트라이-빔 가드레일 시스템을 고안하여 정적 실내 실험, 컴퓨터 시뮬레이션 및 실차 충돌실험을 통하여 거동 및 성능을 조사하였다. 2%의 무게증가로 기존의 W형 보에 비하여 보의 높이가 약 100mm 증가된 트라이-빔(450 mm) 가드레일 시스템은 범퍼 높이가 다른 다양한 차종에 보다 좋은 수용능력을 보였고 강성과 충격흡수 능력 또한 W-보 가드레일 시스템에 비하여 크게 향상되었다. 그리고 실차 충돌실험을 실시한 결과 NCHRP 350의 Test 3-10 충돌시 성능 요건을 만족시켰다.

ABSTRACT : The current traffic situation in Korea can be described as rapid change in traffic volume and diversity in vehicle size from compact cars to large trucks. W-beam barrier most widely used in Korea was found not to satisfy the stiffness requirement for the Korean impact condition of 14ton-60km/h-15deg. and it was too stiff for small vehicles impacting with more realistic speed to satisfy the safety of vehicle occupants. To develop a guardrail system satisfying the two contradicting goals, a thrie-beam guardrail system, which had the beam thickness of 3.2mm and rubber cushions, was conceived. Even though the height of the thrie-beam(450mm) is increased by 100mm as compared to that of W-beam(350mm), there was only 2% increase in the weight of the thrie-beam. The new thrie-beam barrier system could contain more wide range of vehicle bumper heights, and showed better performance in the viewpoint of stiffness and energy absorbing capability than the W-beam system. The impact performance was evaluated from a crash test. The developed thrie-beam guardrail system satisfied all applicable criteria for NCHRP 350 test designation 3-10.

핵심용어 : 트라이-빔, 가드레일, 충돌실험, 충격 흡수재, 충돌조건, 충격거동
KEYWORDS : Thrie-Beam, Guardrail, Impact Test, Rubber Cushion, Impact Condition, Impact Behavior

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본 논문에 대한 토의를 2001년 2월 28일까지 학회로 보내주시면 토의 회답을 게재하겠습니다.

1. INTRODUCTION

Most of the guard rail system in Korea is W-beam barrier which was introduced into Korea without understanding of the design method and design criteria. This barrier has been applied in Korea based on the simple mechanics for the impact condition of 3.5ton (and 14ton) - 60km/h - 15deg. without numerical analyses and/or crash tests. Rapid increase of traffic volume and wide variety of vehicles required to know exactly what the capacity of current W shape guardrail system is and what should be amended. To investigate these problems, the evaluation of the existing W shaped guardrail system was made using computer simulation and static tests. New guardrail system to meet the higher standard impact condition was found to be necessary. Thrie-beam guardrail system with the optimal weight of material, in which a rubber cushion was inserted between a guardrail beam and a post to reduce the damage to the occupant of impacting vehicle, was developed and crash - tested at TTI proving ground(1). This is the results of the evaluation for the existing W shaped guardrail system, and the development and validation for thrie-beam guardrail system with rubber cushions.

Composition of traffic fleet is mainly classified as small cars and large trucks. Guardrail system designed for large trucks may be too stiff for small size cars. Guard rail system designed for small cars may be too flexible for large trucks. The height of current W-shape guardrails is too low for large trucks, and in the area where road surface terrain irregularities are significant, underriding potentials for small size cars are significant.

To resolve these problems, guardrail systems which had enough stiffness to contain large trucks and enough height to contain large size trucks and small cars, were sought for. Thrie-beam rail was a candidate for this case, but the material cost could not be increased even though the height of the beam should be increased. Bottom line was to develop a section of which the cost will not be significantly increased as compared to the currently used system. To offset the stiffness increase which may cause problems to small size vehicles, a rubber cushion, which was made of used materials, was inserted between a rail and a post.

The dimensions and section properties of the W- beam and developed thrie-beam systems are presented in Table 1 and Fig.1.

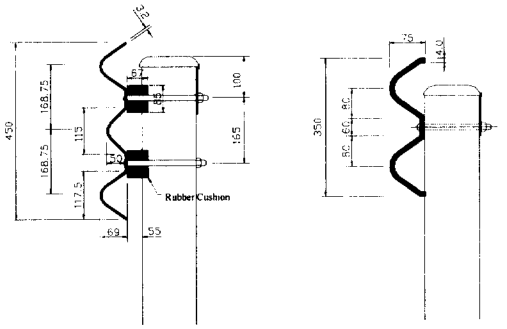
To validate the superiority of the new developed system, the evaluation is implemented as follows;

1) Energy absorbing characteristics are compared through stretch tests
2) Overall impact performance is investigated by simulation work using Barrier

Table 1 Dimensions of Beam and Post

Type	Beam				Post			Height from Ground Level to Beam C.G. (cm)	Post Space (m)
	Height (mm)	Cor. (mm)	Thk. (mm)	Area (cm)	O.D. (mm)	Thk. (mm)	Penetration (cm)		
W-Beam	350	75	4.0	18.7	139.8	4.5	165	60	4
Thrie-Beam	450	69.50	3.2	19.5	139.8	4.5	165	60	4

* Cor. = Corrugation, Thk. = Thickness, O.D. = Outer Diameter.



Thrie-Beam Sections W-Beam Sections

Fig. 1 Thrie-Beam and W-Beam Sections

VII(2), and is compared with Korea Standard(3) and NCHRP 350(4).

3) Static tests are performed to check the overall strength and stiffness of the two systems.
4) When problems are addressed during steps 2 and 3, modifications are made to the trial system

2. STRETCH TEST

Stretch tests were conducted to compare the energy absorbing capacities of the two systems. Segment of 5 cm in width for each section was cut and stretch - tested until it was reached to the original configurations i.e. straightened. W-beam was made by cold-bending a steel plate with the thickness of 4mm and the width of 455mm. Thrie- beam section was made from the plate thickness of 3.2mm and the width of 610mm. Thus, disregarding their thickness, the ratio of contraction (length after bending vs. length before bending) for the thrie- beam (0.26=(610-450)/610) was higher as compared to the contraction ratio of the conventional W-beam section (0.23=(455- 350)/455). The difference indicates that the thrie-beam section will absorb more impact energy than the W-beam section. Figure 2 shows the results of stretch tests. To investigate energy absorbing capacity, the area under the load-deformation curve is estimated. To compare the areas, two curves are superimposed and the curve for the thrie-beam section is shifted. The area under the curve for the thrie-beam section is 4425kg-cm while the area under the curve for the W-beam section was 3850kg-cm. This clarifies that the new thrie-beam section has 15% higher energy absorbing capacity as compared to the W-beam section.

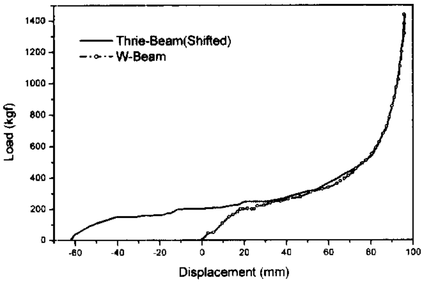


Fig. 2 Load - Displacement Curve of Stretch Test

3. SIMULATION

To look into the response of impact vehicles and the barrier systems, computer simulations were conducted using Barrier VII for the test matrix shown in Table 2. The dimensions and section properties of each system are shown in Table 1.

The simulation results with the criteria of Korea standard and NCHRP 350 are presented

Table 2 Simulation Matrix

Designation	Vehicle Weight	Velocity	Impact Angle
WSC (W-Beam , Small Car)	0.82Ton	60km/h	15°
WST (W-Beam, Small Truck)	3.5Ton	60km/h	15°
WLT (W-Beam, Large Truck)	14Ton	60km/h	15°
TSC (Thrie-Beam, Small Car)	0.82Ton	60km/h	15°
TST (Thrie-Beam, Small Truck)	3.5Ton	60km/h	15°
TLT (Thrie-Beam, Large Truck)	14Ton	60km/h	15°

Table 3 Simulation Result (60km/h and 15°)

System	50msec Acceleration (G)		Relative Impact Velocity (m/s)		Ride down Acc.(G)		Max. Deflection (cm)
	Long.*	Lat.*	Long.	Lat.	Long.	Lat.	
WSC	2.55	3.41	2.99	3.36	0.42	1.15	13.12
WST	1.00	1.67	2.33	2.45	0.32	2.04	43.7
WLT	0.34	0.83	1.50	1.57	0.16	0.87	129.3
TSC	2.45	3.41	2.94	3.59	0.37	1.10	10.95
TST	0.95	1.67	2.29	2.48	0.33	1.99	41.9
TLT	0.34	0.84	1.48	1.57	0.16	0.89	129.1
Korea Standard	-	4	-	-	-	-	110
NCHRP 350	-	-	12	12	20	20	-

* Long. = Longitudinal, Lat. = Lateral

in Table 3.

Findings from the comparisons of the results and the criteria are as follows;

1) For the small car and 3.5ton truck with the impact condition of 60km/h-15deg., both the W- and thrie-beam type guardrail systems satisfied the criteria. Maximum 50msec (millisecond) average acceleration for the small car was 2.55g and 3.41g in the longitudinal and lateral direction, which were less than the limit value of 4g. Ride down accelerations and velocities were much below the limit values of NCHRP350. Deflection was much less than the limit value of 110cm as can be seen in Table 3.
2) Since for the smaller vehicle the occupant safety was satisfied, for the 14ton truck it is not concern but the structural adequacy is important. For both the W- and thrie-beam type guardrail systems the maximum deflection was found to be 129.1 and 129.3cm which were beyond the limit value of 110cm set forth in Korea standard.

In Table 4, the simulation results for the small car (1800lb) with the impact condition of more realistic impact speed are presented. From this table, it can be seen that for the impact speed of 100km/hr, maximum 50msec average acceleration was 4.88g and 5.11g for the W-beam and the thrie-beam, which were higher than the limit value of 4g. This necessitates measures to be taken to reduce the impact force to the small cars.

Simulation results reveal that the structural stiffness of both the W-beam and thrie-eam systems needs to be increased to satisfy the deflection limit of 110cm for large trucks. At the same time, the deceleration of small car impacting with more realistic impact speed should be reduced. Current impact speed of Korea standard is 60km/hr much lower than the road design speed and actual traffic speed.

Since the simulation program has an inherent limitation, the increase of thrie-beam stiffness will be determined after static tests. To reduce the deceleration of small car impacting with higher impact speed, an energy absorbing device will be conceived.

Table 4 Simulation Result (1800lb, 15deg, 80km/h, 100km/h)

Speed (km/h)	System	50msec Acceleration (g)		Relative Impact Velocity (m/s)		Ride down Acc. (g)		Number of Failed Posts	Heading Angle	Exit Angle	Max Deflection (cm)
		Long.	Lat.	Long.	Lat.	Long.	Lat.				
80	T.B	2.76	3.90	4.13	4.41	0.61	2.87	0	4.10	6.92	21.36
	W.B	2.87	3.93	4.14	4.34	0.65	2.73	0	3.80	7.33	21.74
	T.B.R	1.66	2.61	3.50	3.65	0.76	2.57	2	-0.30	6.52	50.42
100	T.B	3.28	5.11	5.46	5.20	0.87	5.58	0	8.40	9.63	33.68
	W.B	3.17	4.88	5.60	5.16	1.21	5.36	0	8.40	10.39	34.11
	T.B.R	1.87	2.89	3.77	3.81	0.85	3.48	3	-1.40	6.16	67.44

* T.B = Thrie-Beam, W.B = W-Beam, T.B.R = Thrie-Beam With Rubber Cushion

4. ENERGY ABSORBING DEVICE

Occupant safety of a small car impacting with a realistic speed seemed to be vulnerable. To reduce the deceleration level of impacting small car, a special part to absorb the impact energy was shown to be needed.

Thus, a cylindrical type rubber cushion made of EPDM and recycled rubber, which would be placed between the beam and a post, was developed and tested for the durability and its mechanical properties. Durability was tested according to the test method designated for the rubber dock fender system in Korea standard (KSM6709-93). Various samples were made changing the composition of rubber cushion. Mechanical properties were compared before and after aging (70 ℃×96hr). Increasing the recycled rubber from 0% to 30% did not change the mechanical properties nor it caused any problems to durability. Therefore, the rubber cushion was composed of 30% recycled rubber and 70% EPDM. To assess the effect of the rubber cushion on the impacting vehicle, computer simulation was conducted modeling the rubber cushion as a serial spring connected to the lateral spring for the post. The stiffness of post was 6.7k/in and that of cushion was 2.59 k/in(linear portion of the load deflection curve).

The simulation results are shown in Table 4. The results indicate that the cushion reduces the deceleration level to below the limit value even at the impact speed of 100km/h. The rubber cushion contributes to the safety of occupants.

5. STATIC TEST

So far, the structural adequacy and occupant safety were studied using the simulation program. In this work, the difference of the impact performance between the W-beam and the thrie-beam guardrail systems was not noticeable due to the modeling limit of the Barrier VII program. To investigate the overall responses of the systems, static load tests were performed. Figures 3, 4, and 5 show the test setup.

Test specimens consisted of three spans (4m×3) and horizontal force was applied at the center of the second span. Deflection

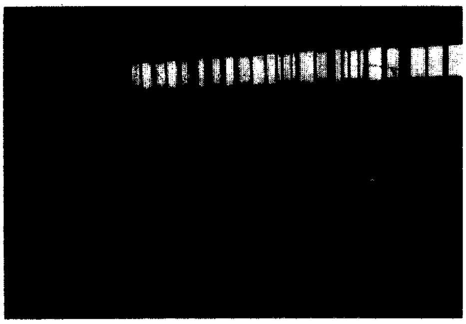


Fig. 3 Test Setups

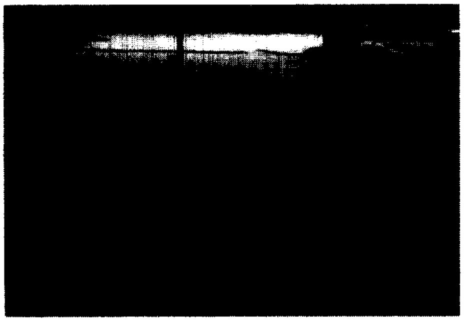


Fig. 4 Tension Load Cell

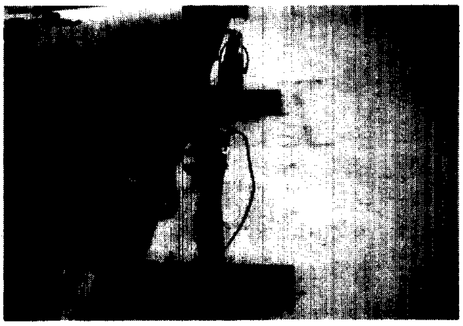


Fig. 5 Displacement Transducer

at the beam center and lateral displacement of the second post were measured using DP-2000C string transducer and LDP-25 transducer. Force was applied by a 15ton hoist crane and a TLP-10B tension load cell was used to measure it. Total 6 tests were performed and the summary of the tests is shown in Table 5.

Table 5 Static Test Result

TEST	Guardrail Type	Post Type	Stiffener to Post	Failure Load (Ton)	Deformation (cm)	Failure Mode*
TEST 1	Thrie Beam	Circular	O	12	85	A
TEST 2	W Beam	Circular	O	7.5	70	A
TEST 3	Thrie Beam	Circular	X	8.5	75	B
TEST 4	W Beam	Circular	X	4.5	60	B
TEST 5	Thrie Beam	H	O	6	87	C
TEST 6	Thrie Beam	Circular + Rubber Cushion	O	15	40	D

* A = Buckling of Post,
B = Crack at Welding,
C = Torsional Buckling of Post + Tearing of Beam Plate at Bolt Hole,
D = Separation of Beam from Post

Some of the representative test results are presented. Figures 6 and 7 show the load - deflection curve at the beam center and the load - post lateral displacement curve for Test 3 and Test 4. Figure 8 shows the lateral deflection of a post.

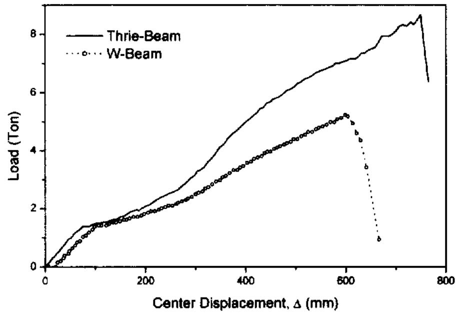


Fig. 6 Load - Deflection Relation at Beam Center for Tests 3 and 4

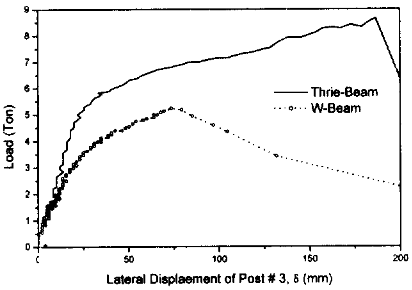


Fig. 7 Load - Post Displacement Relation for Tests 3 and 4

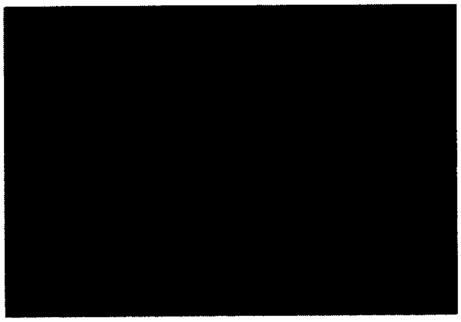


Fig. 8 Deflection of Post

From the figures, it can be seen that the system stiffness and energy absorbing capability of the thrie-beam guardrail system are superior to those of the W-beam guardrail system. The main reason for this difference is due to the difference in the number of connection bolts. The thrie-beam attached to a post by 2 bolts, transfers the force to other spans more effectively, and the connection using 2 bolts hinders the detachment of the beam from a post, which is the main cause for the system failure in the W section guardrail system. It enhances the structural integrity up to failure. And it will be more effective when posts are not evenly constructed, i.e., in such cases as the variance of penetration depth and compacting degree of embankment, and road surface irregularities.

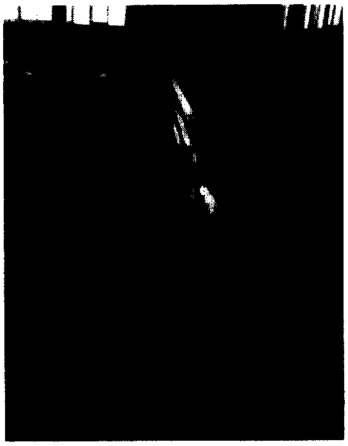


Fig. 9 Thrie-Beam Prior to Testing

Fig. 10 Thrie-Beam Deflection at End of Test

Figures 9 and 10 show the test article before and after testing. Figures 11 and 12 represent the test results of Test 1 and Test 5. Those two have the same rail section (thrie-beam) but used different post members. Test 1 used circular posts and Test 5 used H type posts. All other test conditions were the same. Looking into the figures, the system with H type posts failed at the load of 6ton and at the center deflection of 870mm. And it was more flexible as compared to the circular post case. This is mainly due to early torsional buckling of H type posts and tearing of the bolt holes in H type posts.

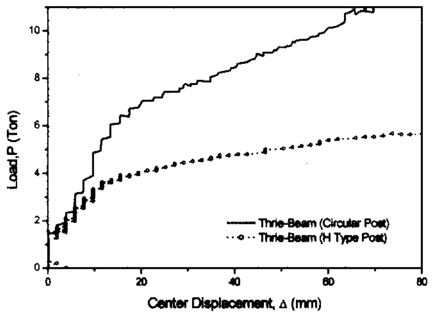


Fig. 11 Load - Post Displacement Relation for Tests 1 and 5

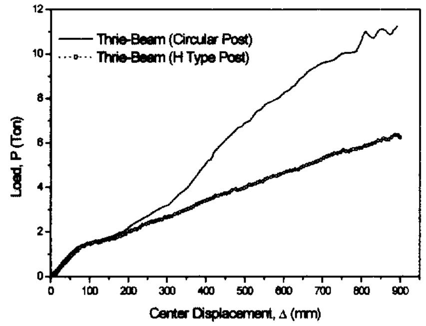


Fig. 12 Load - Deflection Relation at Beam Center for Tests 1 and 5

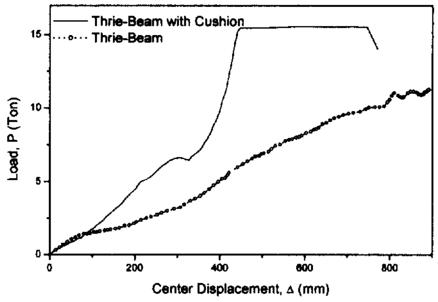


Fig. 13 Load - Deformation Relation at Beam Center for Tests 1 and 6

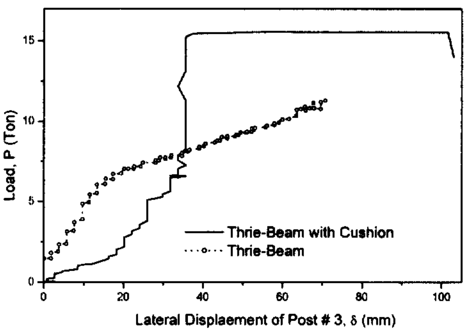


Fig. 14 Load - Post Displacement Relation for Tests 1 and 6

Figures 13 and 14 show the responses of Tests 1 and 6. Both of the two systems consist of thrie- beams and circular posts. But one has rubber cushions (Test 6) and the other (Test 1) does not. Looking into Fig. 13, for the system of Test 1 the stiffness decreases at the load of 1.5 ton due to beam yielding, and then the stiffness increases due to stiffening until the stiffness decreases at 7ton due to yielding of the post (See Fig.14). The response of Test 6 shows that the system with rubber cushions is more flexible up to 1.5ton as compared to the result of Test 1, which is attributed to the serial connection of the cushion to the post. Looking at Fig. 14, the post stiffness of Test 6 from 1.5ton to 7 ton is very similar to the corresponding stiffness of Test 1. This may be attributed to the fact that up to 1.5ton the deformation of the cushion is used up, and beyond that load level the post stiffness of Test 6 is the same as that of Test 1. From Fig. 13, it can be shown for the range from 1.5 ton to 7 ton that the stiffness of Test 6 is much higher than that of Test 1 even though the post stiffness for the two cases were almost the same. This is attributed to the bending action of the connecting bolts for the specimen of Test 6, while in the specimen of Test 1 no such bending of bolts was noticeable. Figure 13 shows that as the load increases from 7 ton to 15ton, the stiffness of Test 6 was much higher than that of Test 1. This was thought as the result of bearing effects of the beam plate near bolt holes and stiffening effects of bolts. At 15 ton a post was detached from the beam and remaining 3 posts resisted the load, and large plastic deformation without load increase was sustained until the system failed due to cracks near the tip of rib stiffener. Looking into the response of the system up to the failure, the thrie-beam guardrail system with rubber cushions showed superior energy absorbing characteristics as compared to the same system without the rubber cushions.

Conclusively, the thrie-beam system with rubber cushions showed the best performance when compared to the W-beam system and the thrie-beam system without rubber cushions. The stiffness of the thrie-beam system was significantly superior to that of the W-beam system while in computer simulations the difference between the stiffnesses of the two systems was negligible. Therefore, the thrie-beam system with rubber cushions shown in Fig. 1 is determined. as the final trial section for a crash test.

6. CRASH TEST

A single crash test was to be performed on the thrie-beam system with rubber cushions to determine whether the impact performance of the developed barrier complied with Korean standards. At that time of the crash test there were no established standards for small cars in Korea. Therefore, it was recommended that the test be conducted and evaluated in accordance with the requirements of the United States standards: National Cooperative Highway Research Program (NCHRP) Report 350.

NCHRP Report 350 test designation 3-10 involves an 820 kg passenger vehicle impacting the critical impact point of a longitudinal barrier at a nominal speed and angle of 100 km/h and 20 degrees. The vehicle chosen for this test was a 1991 Hyundai Sonata which weighed 1300 kg, and the impact angle was reduced to 15 degrees. With these exceptions, all other aspects of the testing and evaluation complied with those for NCHRP Report 350 test designation 3-10. The objective of this test was primarily to evaluate occupant risk, and the overall performance of the thrie-beam system with rubber cushions.

6.1 Test Vehecle

A 1991 Hyundai Sonata shown in Fig. 15 was used for the crash test on the thrie-beam barrier. Test inertia weight of the vehicle was 1225 kg, and its gross static weight was 1300 kg. The height from the ground level to the lower edge of the vehicle bumper was 380 mm and it was 550 mm to the upper edge of the bumper.

The vehicle was directed into the installation using the cable reverse tow and guidance system, and was released to be free-wheeling and unrestrained just prior to impact.

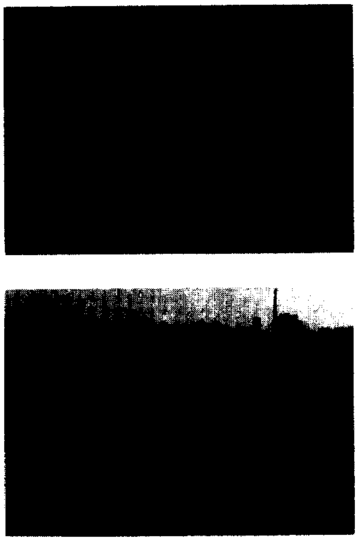
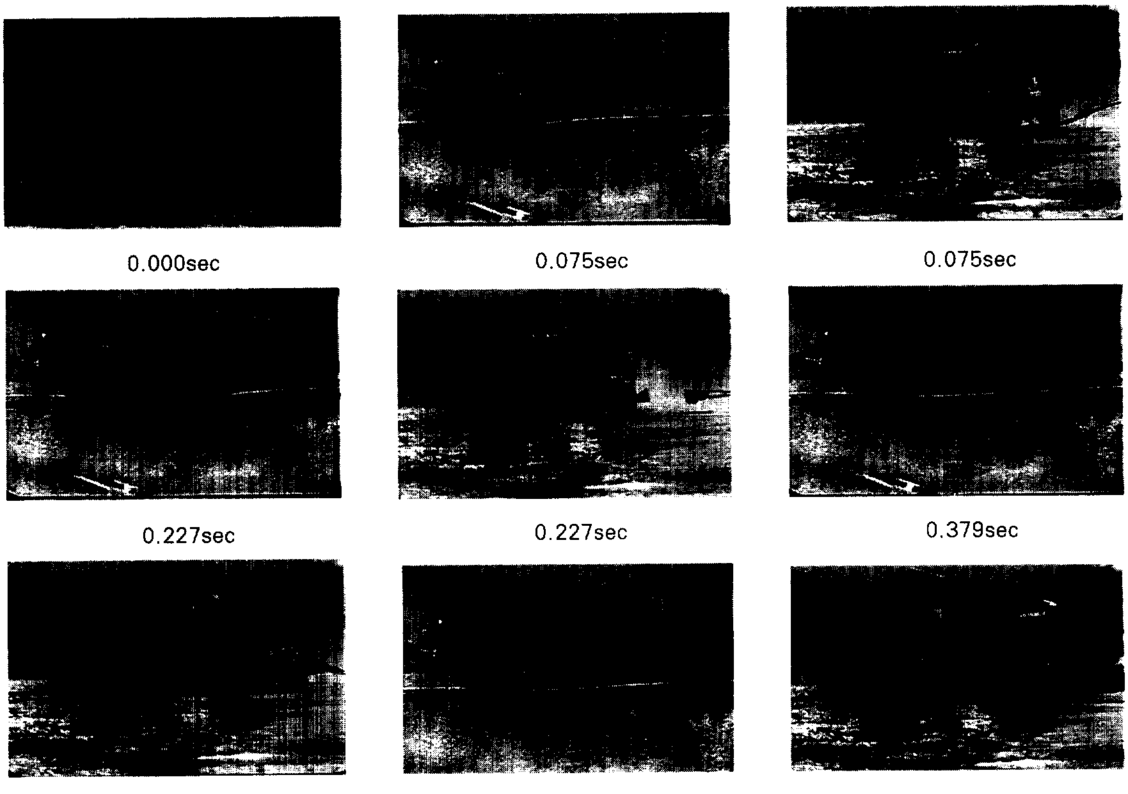


Fig. 15 Vehicle and Installation for Crash Test

6.2 Test Description

The vehicle, traveling at 100.62 km/h, impacted the thrie-beam guardrail at an impact angle of 15.04 degrees, 1990 mm down from post 4. Shortly after impact, the movement of the thrie-beam was noted, and at 0.020 sec movement was noted at post 4 and post 5. The vehicle began to redirect at 0.056 sec after impact. At 0.086 sec, the right front tire contacted post 5 and brushed the face of the post but did not snag. The rear of the vehicle contacted the thrie-beam at 0.169 sec. The vehicle became parallel with the thrie-beam at 0.206 sec, traveling at 89.32 km/h. At



0.000sec 0.075sec 0.075sec

0.227sec 0.227sec 0.379sec

0.379sec 0.539sec 0.539sec

Fig. 16 Sequential Photographs for Crash Test (overhead and frontal views)

0.443 sec the vehicle lost contact with the thrie-beam, traveling at 88.86 km/h and at an exit angle of 9.32 degrees. Brakes were applied at 2.5 sec following impact. The vehicle came to rest at 68.63 m down and 7.32 m behind the initial point of impact. Sequential photographs of the test period are shown in Fig. 16.

6.3 Damage to Test Installation

There was minor damage to the thrie-beam barrier. The vehicle was in contact with the thrie-beam over the length of 6.6 m. Maximum dynamic deflection of the thrie-beam during the test was 0.49 m and the maximum permanent deformation of the thrie-beam after the test was 0.13 m, both occurred between post 4 and 5. Post 4 was pushed back 10mm, Post 5 was pushed back 95 mm, and Post 6 was pushed back 50 mm. Posts 3 and 7 were little disturbed. There were tire marks on the face of post 5 and the tire track went over the original position of post 5.

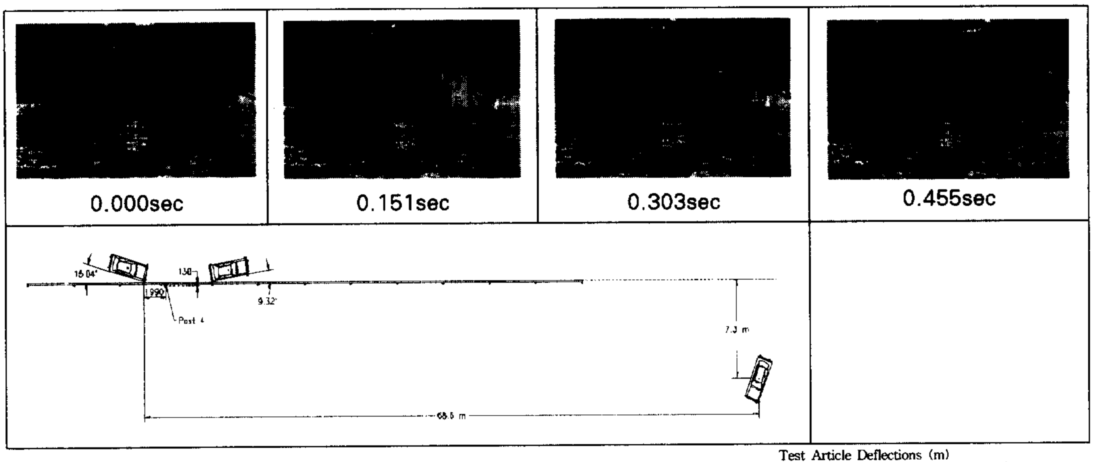
6.4 Vehicle Damage

The vehicle sustained damage to the right front strut and right front axle. The right front tire and wheel were bent, as was the right rear wheel. The right front and rear quarter panels were damaged. The bumper, hood, and right side doors were also deformed. Maximum exterior crush of the vehicle was 180 mm, measured at 550 mm above the ground. There was no deformation or intrusion into the occupant compartment.

6.5 Occupant Risk Values

Data from the accelerometer located at the vehicle center-of-gravity were digitized for evaluation of occupant risk and were computed as follows. In the longitudinal direction, the occupant impact velocity was 3.36 m/s at 0.341 sec, and the highest 0.010 sec occupant ridedown acceleration was -2.39g from 0.202 to 0.212 sec. In the lateral direction, the occupant impact velocity was 4.81 m/s at 0.162 sec and the highest 0.010 sec occupant ridedown acceleration was 7.26g from 0.202 to 0.212 sec. These data and other pertinent information from the test are summarized in Fig. 17.

The thrie-beam barrier contained and redirected the vehicle. The vehicle did not penetrate, underride, or override the installation. There was no debris to show potentials for penetrating the occupant compartment, or to present undue hazard to others in the area. There was no deformation or intrusion into the occupant compartment. The vehicle remained upright during and after the collision. Occupant risk factors were within the limits specified in NCHRP Report 350. The vehicle did not intrude into adjacent traffic lanes after exiting the rail. However, the exit angle at loss of contact with the thrie-beam was 9.3 degrees, which was 62 percent of the impact angle (impact angle was 15.04 degrees). The developed thrie-beam met all applicable criteria for NCHRP Report 350 test designation 3-10, except criterion M. The exit angle was more than 60 percent of the impact angle; however, the criterion M is preferable, not required.



General Information
Test Agency..........Texas Transportation Institute
Test No..........404261-1
Date..........08/25/97
Test Article
Type..........Guardrail
Name..........Korean Thrie beam
Installation Length (m)..........58.0
Size and/ordimension
and material of key Korean thrie beam guardrail on
elements..........round steel posts/rubber blockouts
Soil Type and Condition..........Standard soil, dry
Test Vehicle
Type..........Production
Model..........1991 Hyundai Sonata
Mass (kg) Curb..........1225
Test Inertial..........1225
Dummy.......... 75
Gross Static..........1300

Impact Conditions
Speed (km/h)..........100.5
Angle (deg)..........15.04

Exit Conditions
Speed (km/h)..........88.86
Angle (deg)..........9.32

Occupant Risk Values
Impact Velocity (m/s)
x-direction..........3.36
y-direction..........4.48
Ridedown Accelerations (g's)
x-direction..........-2.39
y-direction..........-7.26
Max. 0.050-s Average (g's)
x-direction..........-1.95
y-direction..........-5.53
z-direction.......... 1.51

Test Article Deflections (m)
Dynamic..........0.49
Permanent..........0.13

Vehicle Damage
Exterior
VDS..........01RFQ2
CDC..........01FREK1

& 01RYEW2
Maximum Exterior 180
Vehicle Crush (mm)..........
Interior RF0000000
OCDI..........

Max. Occ. Compart. 0
Deformation (mm)..........
Post-Impact Behavior
(during 1.0 s after impact)

Max. Roll Angle (deg).......... 4
Max. Pitch Angle (deg).......... -1

Max. Yaw Angle (deg)..........-26

Fig. 17 Summary of Results for Crash Test

7. CONCLUSIONS

The new thrie-beam guardrail system was developed to meet the current traffic conditions in Korea. Korea standards for roadside barriers are 14ton(and3.5ton)-60km/h-15deg for impact condition, maximum 50msec deceleration of 4g for occupant safety, and maximum deflection of 110 cm for structural adequacy. Considering the current traffic conditions in Korea, these criteria are not realistic. The characteristics of traffic situation can be described as rapid change in traffic volume and diversity in vehicle size from compact cars to large trucks. From the simulation and maintenance experiences, W-beam barrier most widely used in Korea was found not to satisfy the impact condition of 14ton-60km/h-15deg. and its structural stiffness needed to be improved. On the other hand, for small vehicles current system was too stiff for the impact condition of 1800lb-100km/h-15deg. and was required to be more flexible. To develop a guardrail system satisfying the two contradicting goals, a thrie-beam guardrail system, which had the beam thickness of 3.2mm and rubber cushions, was conceived through computer simulations and laboratory tests. In the W-beam system the thickness was 4mm. Even though the height of the thrie-beam (450mm) is increased by 100mm as compared to that of W- beam(350mm), there was only 2% increase in the weight of the thrie-beam. The new thrie-beam system could contain more wide range of vehicle bumper heights, and showed better performance in the viewpoint of stiffness and energy absorbing capability than the W-beam system. Final impact performance was evaluated from a crash test. The developed thrie-beam guardrail system satisfied all applicable criteria for NCHRP 350 test designation 3-10.

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