EXPERIMENTAL DESIGN DEFLECTION DISTANCES OF LONGITUDINAL BARRIERS IN KOREA

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ABSTRACT

Longitudinal barriers are fairly common safety features that are installed within the median and at the outside of the shoulder along with the traveled way. They are installed to prevent an errant vehicle from entering a median or a roadside area that would be more severe than impacting the longitudinal barrier. Actually there are three sorts of barriers such as roadside barriers, median barriers, and bridge railings. Although more focus has recently been given to the end-treatments of the barriers and to the new designs for transition sections between two barriers which have different stiffness in strength, it is still important to develop the barriers that have proper heights, proper strengths, and that utilize cost-effective materials without trading off any amount of safety that is expected of them. To evaluate the crashworthiness of the longitudinal barriers, full-scale vehicle crash tests are requisite in general. With the tests, we can check the structural adequacy, the occupant risk and the post-impact vehicle trajectory of the barriers.
In Korea, emphases are still laid on the necessity for the construction of new highways to cope with the overcrowded traffic in urban areas. However, we cannot afford to secure the adequate space to be designated as a clear zone that is necessary for a longitudinal barrier because of the limited space in the area. This limitation in Korea makes it important to know the design deflection distances (DDD) of the respective safety barriers. However, ignorance and lack of understanding of the DDD in Korea makes longitudinal features that are adjacent to the fixed objects such as lightings and utility poles easy to find. This may happen just because there is no reference on the DDD which a road designer can refer to in Korea.
Therefore, this paper aims at the summary of the DDD of all longitudinal barriers that had been evaluated on the performances at the proving ground in Expressway & Transportation Research Institute (ExTRI) of Korea Expressway Corporation (KEC). Specifically, it was the full-scale vehicle crash test result that was analyzed and summarized for 5 years (2004~2008) on the DDD of the total number of 77 longitudinal barriers.

The summary is intended to be utilized not only by highway engineers when they consider proper type of longitudinal barrier in their design process but also by the officials who are responsible for the construction and maintenance of highways in Korea.

Keywords: Traffic Safety, Longitudinal Barrier, Design Deflection Distance, Vehicle Crash Test

DESIGN DEFLECTION DISTANCES

Longitudinal barriers are fairly common safety features that are installed within the median and at the outside of the shoulder along with the traveled way. They are installed to prevent an errant vehicle from entering a median or a roadside area that would cause a more severe impact than impacting the longitudinal barrier itself.

Actually there are three sorts of barriers such as roadside barriers, median barriers, and bridge railings. Although more focus has recently been given to the end-treatments of the barriers and to the new designs for transition sections between two barriers which have different stiffness in strength, it is still important to develop the barriers that have proper heights, proper strengths, and that utilize cost-effective materials without trading off any amount of safety that is expected of them. To evaluate the crashworthiness of the longitudinal barriers, full-scale vehicle crash tests are requisite in general. With the tests, we can check the structural adequacy, the occupant risk and the post-impact vehicle trajectory of the barriers.

In Korea, emphases are still laid on the necessity for the construction of new highways to cope with the overcrowded traffic in urban area. However, with the limitation of space in the highways, we cannot afford to secure the enough space to be designated as a clear zone that is necessary for a longitudinal barrier. This spatial limitation in Korea makes it important to know the design deflection distances (DDD) of the respective safety barriers. However, ignorance and lack of understanding of the DDD make it easy for us to frequently find longitudinal features that are adjacent to fixed objects such as lightings and utility poles. Although a clear zone for a specific barrier type is considered in spite of the spatial limitation, it is often difficult to find proper lateral offset for it. This may happen just because there is no reference on the DDD which a road designer can refer to in Korea.

Therefore, this paper aims at the summary of the DDD of all longitudinal barriers that had been evaluated on the performances at the proving ground in Expressway & Transportation Research Institute (ExTRI) of Korea Expressway Corporation (KEC). Specifically, a total of 77 vehicle crash tests on the longitudinal barriers, which had been done for 5 years (2004~2008), were analyzed and summarized to find out the DDD of them.

This summary is expected to be utilized not only by highway engineers when they consider the proper type of longitudinal barrier in their design process but also by the officials who are responsible for the construction and maintenance of highways in Korea.

This paper is composed of four sections. Following the introductory section, Section two describes methods of analysis in detail. In it, a full-scaled vehicle crash test is introduced with brief explanations on the procedure for a test and the criteria for evaluation on the test results.

For the analysis of DDD of longitudinal barriers, all crash tests which had been carried out from 2004 to 2008 are considered. The test results on the DDD can be intuitively understood, since they are displayed as graphs. The significance of this paper on the new DDD criteria of longitudinal barriers in Korea is given in the end. A brief conclusion is given in section three with further research, which is necessary for completing the subject discussed in this paper.

CRASH TESTS FOR NEW CRITERIA

Full Scale Vehicle Crash Test

In developing any roadside safety feature, a full scale vehicle crash test is done at the last stage to verify the performance that feature. For the evaluation of the performance of any safety feature, the researcher may consider a static or dynamic loading, a computer simulation using various kind of commercial software, or a full scale vehicle crash test. However, the full scale vehicle crash test is regarded as the final step for the performance verification throughout the world, since it is similar to real world conditions with least number of constraints.

It is sure that almost all developers utilize the computer aided simulation and static/dynamic loadings in designing a specific roadside safety barrier because the full scale vehicle crash test is very expensive. However, it is a general rule for a specific roadside barrier that is to be applied on a real highway to go through the full-scale vehicle crash test not only in America, Europe and Japan but also in Korea.

Figure 1 - A vehicle crash test on a roadside barrier

ExTRI also understood the importance of the full scale vehicle crash test and opened a new proving ground in 2003. At the same time, ExTRI was granted government approval as an official certification institute for the performance of roadside safety features and carries on more than 60 crash tests annually.

Figure 2 - A full-scale vehicle crash test site in ExTRI

Limited by the power of the pulling motor, the highest test level that can be performed at the site is the condition when a test vehicle of 25,000 kg does impact to a test article at the speed of 80km/h.

Test Conditions and Performance Evaluation Criteria

To carry on the full scale vehicle crash test explained the above, test conditions need to be set in advance. Therefore, both test conditions and performance evaluation criteria in Korea will be briefly explained here.

Test conditions

With the full scale vehicle crash test, three aspects of performance of a safety barrier are considered. For the structural adequacy, a test using a heavy vehicle is considered. And for the occupant risk, a passenger car is used as a test vehicle. It is common to check the stability of trajectory of the test vehicle before and after the impact on the test article. This will show the possible impact of an errant vehicle on the adjacent traffic when accident happens. Table 1 below shows the test conditions for the evaluation of the structural adequacy of safety barriers.

Table 1 - Test condition for the structural adequacy in Korea

<table>
<tr><th>Test level</th><th>Impact speed (km/hr)</th><th>Total mass of test vehicle (kg)</th><th>Impact angle (◦)</th><th>Impact Severity (kJ)</th></tr>
<tr><td>SB1</td><td>55</td><td rowspan="3">8,000</td><td rowspan="7">15</td><td>60</td></tr>
<tr><td>SB2</td><td>65</td><td>90</td></tr>
<tr><td>SB3</td><td>80</td><td>130</td></tr>
<tr><td>SB4</td><td>65</td><td rowspan="2">14,000</td><td>160</td></tr>
<tr><td>SB5</td><td rowspan="3">80</td><td>230</td></tr>
<tr><td>SB6</td><td>25,000</td><td>420</td></tr>
<tr><td>SB7</td><td>36,000</td><td>600</td></tr>
</table>

In America, 8 and 36 ton vehicles are used for the heavy vehicle test. An impact speed of 80 km/h is commonly used with 15 degrees of impact angle to establish basic structural adequacy of the barrier. In Europe, a number of combinations of test conditions exist with a test vehicle from 10 to 38 tons, a test speed from 65 to 80 km/h, and an impact angle from 8 to 20 degrees, to verify that an attainment of a particular safety barrier is satisfactory. Table 2 shows the test conditions for the evaluation of the occupant risk of safety barriers in Korea.

Table 2 - Test condition for the occupant risk in Korea

<table>
<tr><th>Test level</th><th>Impact speed (km/hr)</th><th>Total mass of test vehicle (kg)</th><th>Impact angle (◦)</th></tr>
<tr><td>SB1</td><td>60</td><td rowspan="4">1,300</td><td rowspan="4">20</td></tr>
<tr><td>SB2, SB4</td><td>80</td></tr>
<tr><td>SB3</td><td rowspan="2">100</td></tr>
<tr><td>SB5, SB6, SB7</td></tr>
</table>

The basic condition for the occupancy risk check up in America is composed of a vehicle which has a total mass of 820 kg with an impact angle of 20 degrees at a test speed of 50, 70, or 100 km/h. However, a combination of test conditions which is selected among test vehicles which have a total mass of 900, 1300, or 1500 kg at a test speed of 80, 100, or 110 km/h with an impact angle of 8, 15, or 20 degrees will check that the satisfactory result of the truck test can guarantee the safety for occupants in Europe.

Performance evaluation criteria

After the crash test, evaluation of the result of it is necessary. For evaluating structural adequacy, DDD is working as a critical criterion. Two values such as THIV (Theoretical Head Impact Velocity) and PHD (Post-impact Head Deceleration) work as critical criteria for the occupant risk. They are obtained from the calculation of velocity and acceleration data, which are collected from sensors attached to the test vehicle. To evaluate the potential impact on adjacent traffic, the angle of reflection and the post-impact speed need to be measured and compared to the impact angle and the test speed separately.
According to the embedment type of post, two critical DDDs are set as thresholds for checking structural adequacy of longitudinal barriers in Korea. If posts are embedded in general soil, the critical DDD is set as 1.1m. However, if posts are embedded in concrete, then the critical value decreases to 0.3m.

Table 3 - Performance evaluation criteria for the structural adequacy

Criterion	Threshold value (m)
Post embedded in soil	1.1
Post embedded in concrete basement	0.3

For the evaluation of crashworthiness in heavy vehicle test in America, they use qualitative criteria as follows:

1. Test article should contain and redirect the vehicle.

2. The test article should readily activate in a predictable manner by breaking away, fracturing, or yielding.

3. Acceptable test article performance may be by redirection, controlled penetration, or controlled stopping of the vehicle

On the contrary, they use both a dynamic deflection and a working width as evaluation criteria in Europe (CEN, 1995). The researcher must compare the deformation with the available space or distance behind the barrier to calculate the working width, which varies from 0.6 m to 3.5 m according to the classes of the test article.
In the passenger car test to evaluate the occupant risk, two important numbers are introduced as shown in table 4. They can be calculated using electric signals which come from sensors attached around the center of gravity (C.O.G.) within a compartment.

Table 4 - Performance evaluation criteria for the occupant risk

Criterion	Unit	Threshold value
Theoretical Head Impact Velocity (THIV)	km/hr	33
Post-impact Head Deceleration (PHD)	g	20

In America, the damage and occupant risk are evaluated in the passenger car crash test. To quantify the damage and occupant risk, the researcher measures the Occupant Impact Velocity (OVI) and the Occupant Ridedown Acceleration Limits (ORAL). The maximum allowable value for the OVI is 5 m/s in the lateral direction and 12 m/s for the composition of longitudinal and lateral directions. In the case of ORAL, the threshold is 20 G's in the summation of longitudinal and lateral directions.

THIV and PHD are also used in Europe to evaluate the occupant risk. Another measure, which is called the Acceleration Severity Index (ASI), is utilized in addition. Both THIV and PHD have the same thresholds as those in Korea. However, the ASI has maximum allowable values like 1.0 or 1.4, according to the level of the test article.

Lastly, the post-impact vehicle trajectory must be satisfactory too. The test vehicle should remain upright during and after collision. Exit speed should be greater than or equal to 60% of the impact speed. In addition, exit angle must be smaller than or equal to 60% of the impact angle. This criterion is also considered in America and Europe. In summary, the point is that the test vehicle's trajectory should be stable enough not to intrude into adjacent traffic lanes.

Data Collection of the Crash Tests

For the DDD analysis, 77 crash test data, which had been achieved for 5 years (2004~2008) in ExTRI, were collected and summarized. The test results were summarized according to the type of longitudinal barriers and the test conditions. Table 5 shows the summarized crash tests.

Table 5 - The number of tests carried on the three types of longitudinal barriers

Test level	Roadside barrier	Median barrier	Bridge railings
total	32	15	30
SB1	1	-	-
SB2	16	-	-
SB3	10	-	-
SB4	4	12	14
SB5	1	3	16
SB6	-	-	-
SB7	-	-	-

Considering the conditions in proving ground, test levels 6 and 7 are difficult to perform often. Therefore, various levels of test had been done for the roadside barriers, but only limited levels of test had been done for the median barriers and bridge railings. Median barriers and bridge railings which pass test level 4 can be installed at basic sections in national highways. Similarly, median barriers and bridge railings which pass test level 5 can be installed at basic sections in expressways. This is the reason why the above table has values only for the test levels 4 and 5 with the median barriers and bridge railings.

Analysis of the Crash Tests

The 32 tests on the roadside barriers are considered first, as shown in figure 3. The results show a range from 0.00 m to 1.90 m of deflection distances. Only one test was reported with regard to the test level 1 (SB 1), and only a small number of tests have been done for the test levels 4 and 5 (SB 4 and 5). Therefore, no meaningful number can be drawn from those levels of crash test on the roadside barriers. On the contrary, 16 and 10 records were reported with regard to test levels 2 and 3 (SB 2 and 3). The results are involved in determining new thresholds for the deflection distance of roadside barriers. The test numbers for both of the test levels are outstanding, since SB 2 is for the basic roadside barriers on national highways and SB 3 is for the basic roadside barriers on national expressways.
The average deflection distance of the 32 test is 0.72 m. Except for one test result, all other numbers are below 1.1 m. Therefore, the threshold of 1.1 m can be regarded as a reasonable upper limit for roadside barriers.

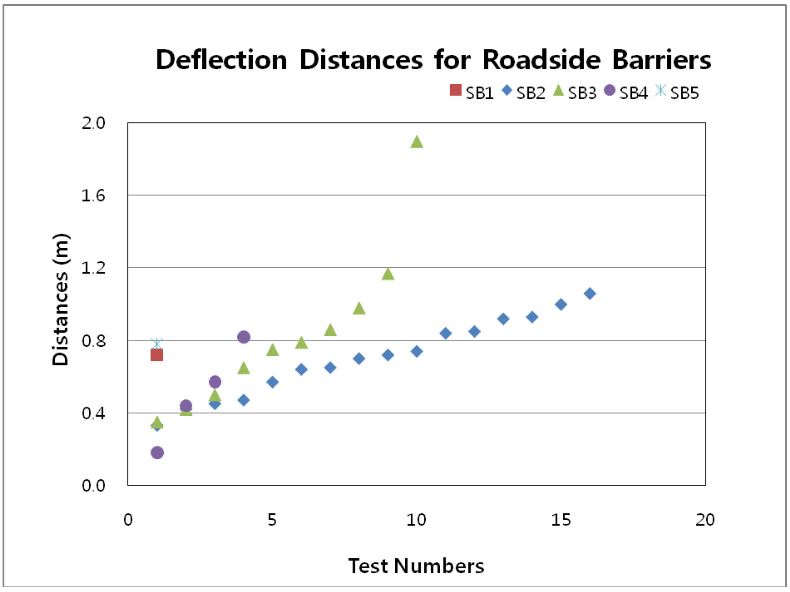

Figure 3 - The deflection distances from the 48 tests on the roadside barriers

In general, greater deflection distances are expected with a higher test level, since greater impact energy is transferred to the test article as test level goes up. However, this is not always true because the design of the test article for the higher test level is usually stiffer than that of the lower test level.
Secondly, 15 tests on the median barriers reported the deflection distances from 0.00 m to 0.99 m, as shown in figure 4. Test level 4 is used for the basic median barriers on national highways and test level 5 is used for the basic median barriers on national expressways. In this paper, 12 and 3 records of test level 4 and 5 (SB 4 and 5) are considered in setting thresholds of deflection distance of median barriers.

The average deflection distance of the 15 tests is 0.43 m. The average deflection distance of test level 4 is 0.52 m and that of test level 5 is 0.09 m. Since 3.0 m width of median for national expressways and 1.0~1.5 m for national highways are general, 1.1 m of maximum allowable deflection distance is only good for the test level 5, and 0.3~0.5 m of maximum allowable deflection distance should be chosen for the test level 4, considering the widths of median and median barrier itself.

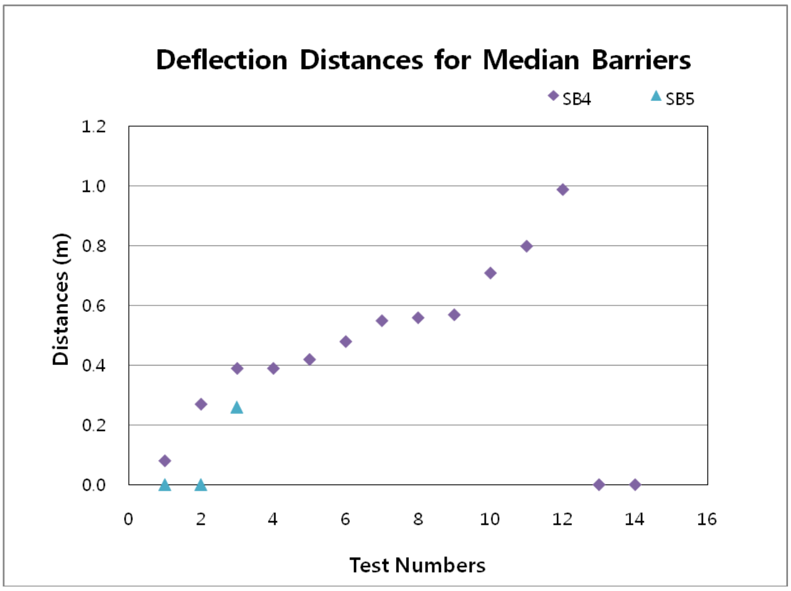

Figure 4 - The deflection distances from the 21 tests on the median barriers

With regard to the bridge railings, 30 tests reported the deflection distances from 0.00 m to 0.44 m, as shown in figure 5. Similar to the median barriers, test level 4 (SB 4) is used for the basic designs of bridge railings on national highways and test level 5 (SB 5) for those on national expressways. The average deflection distance of the 30 tests is 0.12 m. The average deflection distance of test level 4 is 0.12 m and that of test level 5 is 0.13 m. Among the 30 tests, all results do not exceed the deflection distance of 0.25 m, except for one test result (0.44 m). Since virtually no deflection to the bridge railings is expected, 0.25 m of deflection is a good threshold. However, considering our limited test numbers, 0.3 m of limit is suggested for the design deflection distance of the bridge railings.

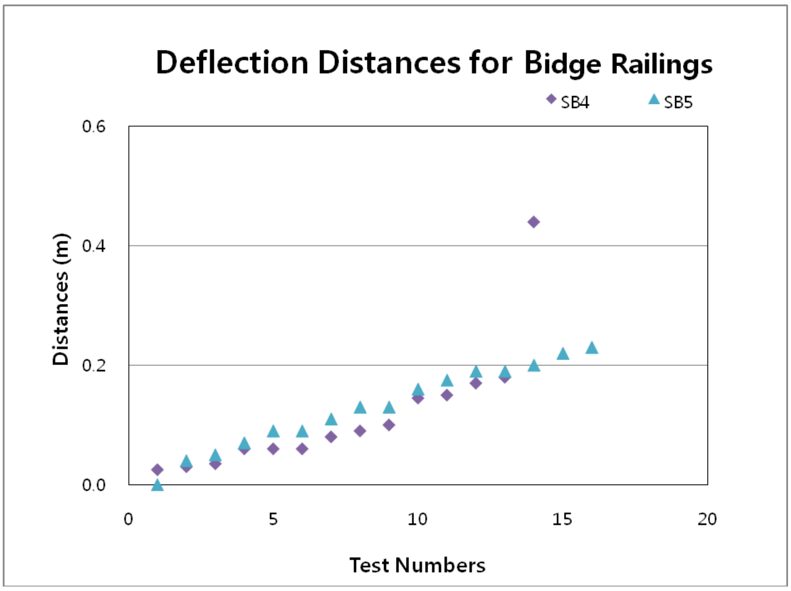

Figure 5 - The deflection distances from the 34 tests on the bridge railings

CONCLUSIONS

77 crash tests, which had been carried on for 5 years (2004~2008), have been summarized and analyzed in the above. Specifically, test results have been considered according to three types of longitudinal safety barriers from the viewpoint of lateral deflection distance in this paper.

With regard to the roadside barriers, it is practical to set a new threshold of 1.1 m for test levels 2 and 3, which are basic levels for national highways and expressways, and 0.3 m of maximum allowable deflection distance for upper levels, rather than current values of both 0.3 m (post embedded in concrete) and 1.1 m (post embedded in soil).

For median barriers, the maximum allowable deflection distance of test level 4 on national highways is suggested to be 0.5 m. Also, 0.3 m of DDD may be set for the median barriers under the test level (SB 4). For higher levels of median barriers, 1.1 m of DDD is suggested. In deciding maximum allowable deflection distances for those levels, the limitations of current median widths are considered.

A great value of deflection distance in bridge railings means the falling down of an errant vehicle to outside the bridge. Therefore, 0.3 m of maximum deflection distance is suggested for bridge railings. It is sure that no deflection distance is ideal for bridge railings, but this is impractical except for concrete bridge railings. Moreover, the whole impact energy may be transferred to the structure of the bridge in that case.

Table 6 - Maximum allowable design deflection distances (unit: m)

Test level	Roadside barriers	Median barriers	Bridge railings
SB1	1.1	0.3	0.3
SB2	**1.1**	0.3	0.3
SB3	**1.1**	0.3	0.3
SB4	0.3	**0.5**	**0.3**
SB5	0.3	**1.1**	**0.3**

SB6	0.3	1.1	0.3
SB7	0.3	1.1	0.3

A number of reasonable deflection distances have been recommended here according to the type of longitudinal barrier, and a number of full scale vehicle crash tests have been summarized. It is sure that more crash tests on various test levels should be performed and evaluated to complete the above table. However, this study is a very new approach in Korea to find the reasonable design deflection distances for different types of longitudinal barriers. The summary of crash tests will be continued, to confirm the numbers which are speculated in the above table.

Crash tests on the various test levels of each type of longitudinal barriers are necessary to exchange the numbers which are not supported by crash test in the above table for tested numbers.

In particular, higher levels of tests should be done for the roadside barriers to develop design deflection distances for roadside barriers that can be installed in more vulnerable locations. For median barriers, there may not be possibilities to set much different thresholds for each test level. This is because the width of median is determined at the early stage of the highway design. Therefore, once the width of median is determined, then the maximum allowable deflection distance may be automatically set. Variety in the width of median according to the class of roads is not that high in Korea because of the limitation of space.

However, design deflection distances for test level 1 to test level 3 need to be researched for implementation to the passenger car only highways. And the same is true of the bridge railings.

REFERENCES

European Committee for Standardization (1995), “Road restraint systems – Part 2: Safety barriers –Performance classes, impact test acceptance criteria and test methods,” CEN/TC226N187E, Central Secretariat, Brussels

Ministry of Land, Transport and Maritime affairs (2008), “Handbook of Road Safety Facilities Installation and Maintenance,” Korea

Ross, H. E., D. L. Sicking, and R. A. Zimmer (1993), “Recommended procedures for the safety performance evaluation of highway features,” NCHRP Report 350, Transportation Research Board, Washington, D.C.