

Midwest Guardrail System (MGS) W-Beam to Thrie-Beam Transition

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ABSTRACT

For longitudinal barriers, it is common practice to use standard W-beam guardrail along the required highway segments and to use a stiffened Thrie-beam guardrail in a transition region near the end of a bridge. As a result of the differences in rail geometries, a W-beam to Thrie-beam transition element is typically used to connect and provide continuity between the two rail sections. However, the W-beam to Thrie-beam transition element has not been evaluated according to current impact safety standards. Therefore, an approach guardrail transition system, including a W-beam to Thrie-beam transition element, was constructed and crash tested. The transition system was attached to Missouri's Thrie-beam and channel-bridge railing system.

INTRODUCTION

Throughout the United States, State Highway Departments commonly use standard strong-post, W-beam guardrail systems to prevent errant vehicles from leaving the roadway and encountering roadside hazards. One of the most common applications of this barrier is to shield traffic from the ends of bridge rails and their associated drop offs. Although the strong-post W-beam guardrails are generally considered to be “semi-rigid,” these barriers are much more flexible than most bridge railings. In order to eliminate the potential for vehicle pocketing or wheel snag at the point of attachment to a rigid bridge rail end, an approach guardrail transition region is added between the W-beam guardrail and the bridge rail to provide a more gradual change in lateral barrier stiffness.

This change in lateral barrier stiffness is normally accomplished by some combination of reduced post spacing, nesting of the guardrail, placing additional stiffening rails in the region, and incorporating a curb under the barrier. Many of these approach guardrail transition systems have incorporated Thrie-beam guardrail elements to help meet the increased stiffness requirements. In this situation, a W-beam to Thrie-beam transition element is utilized near the beginning of the transition system to account for the differences in rail geometries and provide structural continuity between the two barrier systems.

Although the field experience of the W-beam to Thrie-beam section has generally been believed to be acceptable, previous crash testing efforts with passenger-size and small car sedans have been met with mixed results (1, 2). While several crash tests on the W-beam to Thrie-beam section resulted in acceptable performance, other tests have resulted in severe wheel snagging and even vehicle rollover. Furthermore, all prior crash tests of these systems were conducted under NCHRP Report 230, *Recommended Procedures for the Safety Performance Evaluation of Highway*

Appurtenances (3) and did not evaluate the transition element's performance with light truck vehicles. As a result, questions remained as to the performance of the W-beam to Thrie-beam transition element, including whether the element could prevent vehicle underride by mini-size vehicles and prevent pocketing or rollover during light truck impacts. Therefore, the Midwest States Pooled Fund Program funded a study to examine the safety performance of the W-beam to Thrie-beam transition element under the current guidelines set forth in National Cooperative Highway Research Program (NCHRP) Report No. 350, *Recommended Procedures for the Safety Performance Evaluation of Highway Features* (4).

RESEARCH OBJECTIVE

The objective of the research project was to investigate the safety performance of the W-beam to Thrie-beam transition element used in conjunction with an approach guardrail transition. It is important to note that the performance of the transition element is somewhat dependent upon the stiffness of the transition system. Therefore, it is generally accepted that a stiffer transition element will increase the risk of pocketing, wheel snag, and vehicle underride. Accordingly, it was determined to examine the performance of the W-beam to Thrie-beam transition element when attached to a very stiff transition system, specifically the system utilized by the Missouri Department of Transportation (2).

RESEARCH APPROACH

W-beam to Thrie-beam transition elements are utilized by most state departments of transportation across the nation. In recognition the wide application of this guardrail element, it was decided that full-scale crash testing would be warranted even if computer modeling indicated that the existing design would be likely to fail the testing. Tests 3-20 and 3-21 from NCHRP Report 350 were therefore conducted on the W-beam to Thrie-beam transition element. After Test 3-21 failed on

the original design, a simulation study was undertaken to redesign the approach guardrail transition to improve the system's performance.

TRANSITION SYSTEM

As shown in FIGURE 1, the standard Missouri DOT transition system incorporates a 5715-mm (18-ft 9-in.) section of nested 12-gauge Thrie-beam mounted on W152x22.3 (W6x15) steel posts. The W-beam to Thrie-beam transition element is attached directly to the nested Thrie-beam section and is supported by standard W152x13.4 (W6x9) steel guardrail posts. A standard, metric-height, strong steel post guardrail was attached to the upstream end of the transition element. The direct attachment of the transition element to a nested section of Thrie-beam rail mounted on heavy steel posts makes this transition one of the more critical designs where the W to Thrie transition is utilized.

Preliminary Testing

Tests 3-20 and 3-21 were conducted on the approach guardrail transition system shown in FIGURE 1. Critical impact points for both tests were selected using BARRIER VII (5) analysis. The impact point for Test 3-20, an 820C vehicle impacting at 100 km/h (62.1 mph) and 20 degrees, was selected to maximize the risk of the front of the vehicle to wedge under the transition element. This behavior is believed to be most likely when the lateral deflection at the mid-point of the W-beam to Thrie-beam element is maximized. For this test, the selected impact point was 1219 mm (48 in.) upstream of the beginning of the transition element. During the test, the vehicle's front tire became wedged under the guardrail and snagged on the blockouts at the mid-span and the downstream end of the transition element. The wheel snag caused the tire to blowout, and severely damaged the vehicle's suspension. However, the snagging was not so severe that the occupant risk values were adversely affected, and the test vehicle was successfully contained and redirected. Hence, Test 3-20

was deemed a success.

The impact point for Test 3-21 was selected to maximize the potential for wheel snagging on the steel post on the downstream end of the W-beam to Thrie-beam transition element. The target impact location was 2235 mm (88 in.) upstream of the beginning of the transition element or 4140 mm (163 in.) upstream of the post supporting the downstream end of the component. During this test, labeled MWT-2, the 2000P test vehicle struck the W-beam guardrail just downstream from the target impact location at a speed of 98.3 km/h (61.1 mph) and an angle of 25.3 degrees. Upon impact, the guardrail upstream of the transition element began to deform laterally and the test vehicle slowly began to redirect. As the vehicle progressed into the barrier, a pocket began to develop at the downstream end of the transition element where it was connected to the nested Thrie-beam rail. As the test vehicle approached the nested Thrie-beam rails, a sharp kink developed at the end of the transition element and eventually ruptured at this point. When the front of the test vehicle contacted the end of the largely undeformed nested Thrie-beam elements, it was forced up into the air and rolled over on the traffic side of the barrier.

As shown in FIGURE 2, this test failed due the abrupt stiffness change between the approach guardrail and the stiff transition system. Hence, it was determined that the W-beam to Thrie-beam transition element performed acceptably and that the approach to the transition element should be stiffened to eliminate the severe pocketing that was observed.

CRITICAL TRANSITION ANGLE

As a vehicle approaches the stiffened, semi-rigid approach guardrail transition region from the relatively flexible guardrail region, there is a potential for pocketing of the vehicle. Pocketing occurs when the lateral deflection of the transition region is much less than the abutting guardrail region, creating a sharp bend in the guardrail system before the transition region. This sharp bend

produces a high longitudinal force on the vehicle that can create excessive deceleration, or in the case of MWT-2, can force the vehicle to override the pocket and rollover.

Although BARRIER VII can predict the creation of a sharp bend in a guardrail system that could lead to pocketing, there are no objective criteria with which to measure the risk of serious consequences associated with pocketing. After reviewing crash tests of many guardrail systems, it was theorized that at a critical pocketing angle, θ_p , could be defined such that at angles smaller than θ_p , the bend in the guardrail would not cause serious pocketing. However, at angles more severe than θ_p , where the difference between the guardrail and transition regions was more abrupt, the vehicle would not be able to escape from the pocket and undesirable vehicle response can be expected. The critical pocketing angle is defined as the angle between the guardrail region, just in front of the impacting vehicle and the downstream section of rail. Note that this definition of θ_p is only applicable where there is a sharp bend in the guardrail and the pocketing angle is essentially a measure of the magnitude of that angle. It should also be noted that the depth of the pocket may also have a significant impact on the performance of a guardrail system. However, for the purposes of using BARRIER VII to design a guardrail stiffness transition, the authors have assumed that the depth of the pocket will always be sufficient to create a problem, provided the critical pocketing angle is reached. The critical pocketing angle is shown in FIGURE 5.

Many guardrail and approach guardrail transition tests involving 2000P vehicles were carefully reviewed in order to identify the critical pocketing angle. Based upon this analysis, the critical pocketing angle was estimated to be approximately 23 degrees. Every test that exhibited a pocketing angle of 23 degrees or less resulted in a successful redirection of the 2000P vehicle, whereas most tests with pocketing angles greater than 23 degrees exhibited significant pocketing and corresponding adverse vehicle behavior. For example, the pocketing angle from test MWT-2 was

estimated to be 45 degrees; as a result of pocketing, the rail ruptured and the test vehicle rolled over during that test.

In order to determine the critical transition angle, computer simulations were conducted using BARRIER VII (5). BARRIER VII was first calibrated against Test MWT-2 to assure that it could accurately predict pocketing in advance of the guardrail transition section. The program was then used to analyze stiffening of the guardrail upstream of the W-beam to Thrie beam transition element to reduce the pocketing angle below the critical value of 23 degrees.

In order to reduce the predicted pocketing angle to 23 degrees or less, it was necessary to alter the stiffness differential between the transition and guardrail sections. This was achieved by changing the post sizes and depths, both by weakening the transition region and strengthening the guardrail region, as indicated in TABLE 1.

As a result of the increased stiffness, the significant pocketing observed in Test MWT-2 was not present in Test MWT-3. However, the increased system stiffness caused the vehicle to begin to roll over the top of the guardrail, as shown in FIGURE 3. This was the result of a combination of the effects of the relatively high center of gravity of the 2000P vehicle combined with the relatively low height of 706 mm (27.75 in.) for standard guardrail.

MIDWEST GUARDRAIL SYSTEM

The rapid vehicle roll velocity induced during the early stages of Test MWT-3 highlights a fundamental problem associated with standard metric height guardrail. This barrier is very near its performance limit when installed at its design height and any further stiffening of the guardrail is likely to cause light trucks to rollover (6). Further, guardrail deflections observed during Test MWT-3 were very similar to that predicted by the BARRIER VII analysis used in the design process. It was therefore concluded that the guardrail stiffening designed to prevent vehicle pocketing had

achieved its purpose and that the vehicle instability observed in Test MWT-3 could not be effectively resolved without raising the height of the W-beam guardrail.

The Midwest Guardrail System (MGS) (7, 8, 9) was recently developed and utilizes a 787 mm (31 in.) mounting height, 305 mm (12 in.) blockouts, and mid-span splices, all of which improve the barrier's capacity to contain and redirect light truck vehicles without inducing rollover. The MGS guardrail has demonstrated greatly improved performance with light truck impacts as well as a greater capacity to tolerate stiffening and other design variations without inducing rollover. For example, the MGS has been successfully tested with 1/4-post spacing, installed behind a 152 mm (6 in.) barrier curb such that each post is embedded an additional 152 mm (6 in.), and installed at a 5:1 flare rate. In view of the improved performance of the MGS guardrail, it was decided to utilize this barrier on the approach to the transition system. BARRIER VII analysis was then repeated with the conversion to the MGS guardrail. Even though the degree of pocketing was predicted to be increased slightly with the higher guardrail height and the associated reduction in post embedment, the simulation indicated that the same post configuration utilized for Test MWT-3 would provide acceptable performance with the MGS guardrail.

Unfortunately, converting to the MGS guardrail was not as simple as replacing the upstream barrier, as the height of the top of the MGS is approximately the same as the top of the Thrie-beam transition system. Hence, the standard symmetrical W-beam to Thrie-beam transition element could not be utilized to attach the two barrier systems. Instead, an asymmetrical transition element had to be utilized that would extend the bottom of the W-beam downward to meet the bottom of the Thrie-beam element. Unfortunately, the only asymmetrical W-beam to Thrie-beam transition element available was a segment fabricated by cutting a triangular piece from the bottom of a standard 12-gauge Thrie-beam rail. A 10-gauge flat plate was then welded along a portion of the cut region to

reduce the risk of the exposed edge slicing through the sheet metal on an impacting vehicle, as shown in FIGURE 4. Although this element clearly included some undesirable stress concentrations and utilized a light-gauge rail element compared to the 10-gauge symmetrical W-beam to Thrie-beam transition element, it was the only readily available alternative and therefore it was selected for use in the next test, MWT-4.

TEST MWT-4

During this test, a 2018 kg, (4450 lb) 3/4-ton pickup struck the barrier at a speed of 98.1 km/h (61.0 mph) and an angle of 25.3 degrees. Upon impact, the test vehicle began to be redirected in a very stable manner with no significant roll velocity. As the truck progressed into the guardrail, vehicle redirection continued until the front bumper contacted the point of the flat plate extension on the bottom of the transition element. The start of the weldment proved to be a stress concentrator that produced a tear in the W to Thrie transition piece. The tear quickly propagated through the entire segment and ruptured the rail system. Thereafter, all redirection stopped and the test vehicle moved forward into the end of the stiff transition section where it was brought to an abrupt stop. Although the performance of the guardrail system initially looked promising and the rapid roll velocity associated with Test MWT-3 was eliminated, the premature failure of the available transition piece caused this test not to be successful.

Test MWT-4 indicated that the basic transition system design would be capable of meeting NCHRP Report 350 testing, but that the fabricated asymmetrical W-beam to Thrie-beam transition element that was available at the time was unacceptable. The research team then undertook an effort to develop a more acceptable W-beam to Thrie-beam transition element. The new design incorporated the same basic philosophy utilized in the symmetrical transition piece, i.e. gradually introduce a new peak between the two existing peaks in a W-beam. The new component was to be

manufactured from 10-gauge plate conforming to AASTHO M-180 material specifications. FIGURE 6 shows the final design of the new MGS Asymmetrical Transition Element.

Three guardrail component producers were then contacted in an attempt to produce prototypes of the new transition element: GSI Highway Products, Inc., Mid-Park, Inc., and IMH Products, Inc. GSI and Mid-Park collaborated to produce a welded part while IMH attempted to produce a component by creating a complicated bending operation to produce the component from a single flat plate. After obtaining both sets of components, the welded part was found to have fewer stress concentrations and was selected for use in the full-scale crash test program.

Following a review of test MWT-4, the pocketing observed in the guardrail system prior to the rupture was deemed significant and warranted further analysis. BARRIER VII analysis was then conducted on the MGS guardrail with an asymmetrical W-beam to thrie beam transition element. In order to reduce the predicted pocketing angle, it was necessary to alter the stiffness between the transition and guardrail sections. This was achieved by changing the post sizes and depths in order to strengthen the transition and guardrail sections.

TEST MWT-5

Test MWT-5 was conducted on the same system as in Test MWT-4 with the exception that the post size and embedment depth for post nos. 9 through 15 was increased and the prototype asymmetrical W-beam to thrie beam transition element was incorporated in place of the available component. For this installation, post nos. 9 through 15 were 2,286-mm (7.5-ft) long, galvanized ASTM A36 steel W152x17.9 (W6x12) sections with embedment depths of 1,473 mm (58 in.). During this test a 2010 kg (4431 lb), 3/4-ton pickup struck the guardrail system at a speed of 99.0 km/h (61.5 mph) and an angle of 24.9 degrees. Upon impact, the vehicle began to redirect in a very stable manner with little or no roll angle. The guardrail began to deflect as the test vehicle

progressed into the system and the vehicle's front tire snagged on the post at the upstream end of the transition element. The tire snagging pulled the front of the test vehicle down and induced a modest pitch motion in the test vehicle. The rear of the test vehicle continued to rise slowly until the pickup reached a maximum pitch angle of approximately 12 degrees. Thereafter, the test vehicle was safely redirected away from the barrier, as shown in FIGURE 7. As has been observed in all successful MGS guardrail tests, after losing contact with the guardrail system, the test vehicle was steered back toward the barrier. The vehicle's final rest location was downstream and behind the simulated bridge railing. All occupant risk parameters were within recommended limits and this test was deemed a success.

TEST MWT-6

The impact point for Test 3-20, an 820C vehicle impacting at 100 km/h (62.1 mph) and 20 degrees, occurred between post nos. 8 and 9 or 330 mm (13 in.) upstream of the centerline of post no. 9. During this test, the transition system smoothly redirected the vehicle. Detached elements and debris from the system did not penetrate nor show potential for penetrating the occupant compartment, nor did they present any other hazard. There were no deformations of or intrusion into the occupant compartment. Furthermore, the vehicle remained upright during and after the collision and did not penetrate or rupture the guardrail. Notably, as with previous testing performed on the MGS to date, the vehicle was safely redirected along the direction of the barrier and away from opposing traffic. Finally, occupant risk indices were within the recommendations of NCHRP Report 350, making MWT-6 a successful test.

SUMMARY AND CONCLUSIONS

This study set out to examine the safety performance of the symmetrical W-beam to Thrie-beam transition element commonly used with approach guardrail transitions. Two full-scale crash

tests of this element incorporated into a relatively stiff transition system revealed that

- the symmetrical transition element performs acceptably for small car impacts and
- rapid changes in stiffness from conventional metric height guardrail to a transition system can lead to pocketing, rail rupture, and vehicle rollover during a light truck impact.

It is reasonable to conclude from these test results that some widely used Thrie-beam transition systems that incorporate a W-beam to Thrie-beam transition element attached to standard metric height guardrail may not meet NCHRP Report 350 safety performance evaluation criteria. It is therefore recommended that whenever new transition designs are developed in the future, the stiffness change at the end of the approach guardrail should be investigated as well as the stiffness change near the attachment to the rigid bridge railing.

In an attempt to produce a more gradual change in guardrail stiffness in front of the transition design, additional posts were added to the standard metric height guardrail. Full-scale crash testing showed that, although the resulting design eliminated the pocketing problem observed previously, the stiffening of the standard W-beam guardrail induced a roll velocity that ultimately lead to vehicle rollover. Based upon BARRIER VII simulation, Test MWT-3, and prior full-scale tests reported in references (1) and (10), it can be concluded that standard metric height guardrail is likely to induce rollover whenever it is stiffened in transition systems or additional posts are added to reduce deflections in front of fixed objects. It is important to verify this finding and/or identify ways to eliminate this problem if standard strong post guardrail is to continue to be stiffened in order to reduce deflections in front of fixed objects by adding extra posts.

One full-scale crash test was also conducted with an asymmetrical W-beam to Thrie-beam transition piece fabricated by cutting off the bottom corner of a 12-gauge Thrie-beam element and

welding a flat plate across the cut section. This test showed that the current design is unsafe, and should not be used on high-speed highways.

Finally, a stiffening system for the Midwest Guardrail System and a new asymmetrical W-beam to Thrie-beam transition element were developed. The stiffening system and new transition element were attached to a very stiff approach guardrail transition design and subjected to two full-scale crash tests. These tests verified that the new designs comply with the safety performance evaluation criteria contained in NCHRP Report 350. The new guardrail stiffening system and transition element is recommended for use whenever the Midwest Guardrail System must be attached to an approach guardrail transition. Because a very stiff approach guardrail transition design was used in the full-scale crash testing, the guardrail stiffening system developed herein should be applicable to most other transition designs utilizing Thrie-beam rail elements. This transition design represents the final component needed for full implementation of MGS barrier system. The full-scale crash testing reported herein and by Sicking and Faller (7, 8, 9), have demonstrated that implementation of the MGS guardrail will offer dramatic safety improvements for high speed highways by reducing rollovers for light truck impacts and reducing the incidence of secondary impacts after a car is successfully redirected by the guardrail system.

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FIGURE 7 Successful Redirection Using the MGS Asymmetrical Transition Element (MWT-5).

TABLE 1 Comparison of Post Sizes and Embedment Depths.

| Post Number | MWT-2 | MWT-3 |
|-------------|--------------------------|-------------------------|
| 1 | 350 Compliant Transition | |
| 2 | | |
| 3 | | |
| 4 | W152x22.3 by 2,135 long | W152x13.4 by 2,135 long |
| 5 | W152x22.3 by 2,135 long | W152x13.4 by 2,135 long |
| 6 | W152x13.4 by 1,980 long | W152x13.4 by 2,135 long |
| 7 | W152x13.4 by 1,980 long | W152x13.4 by 2,135 long |
| 8 | W152x13.4 by 1,980 long | W152x13.4 by 2,135 long |
| 9 | W152x13.4 by 1,830 long | W152x13.4 by 2,135 long |
| 10 | W152x13.4 by 1,830 long | W152x13.4 by 2,135 long |
| 11 | W152x13.4 by 1,830 long | |
| 12 | W152x13.4 by 1,830 long | |



FIGURE 1 Missouri W-Beam to Thrie-Beam Transition (MWT-1 through MWT-3).



FIGURE 2 Rollover Induced by Transition Element (MWT-2).



FIGURE 3 Rollover Induced by Increased Stiffness (MWT-3).



FIGURE 4 Asymmetrical Transition Element Prototype (MWT-4).

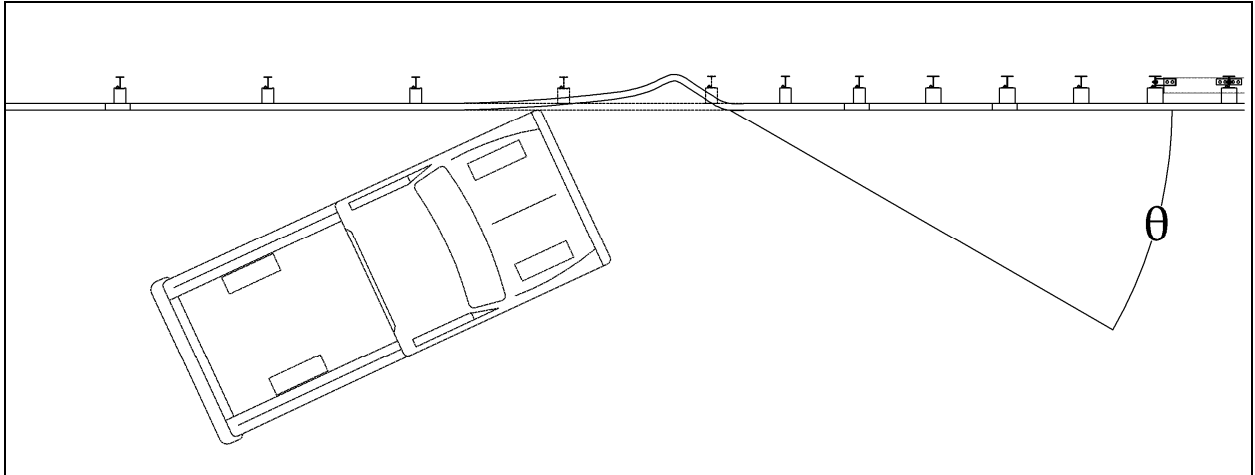


FIGURE 5 Critical Pocketing Angle.



FIGURE 6 MGS Asymmetrical W-Beam to Thrie-Beam Transition Element (MWT-5 & 6).



FIGURE 7 Successful Redirection Using the MGS Asymmetrical Transition Element (MWT-5).

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