MASH Implementation for Guardrail

Katherine Smutzer
Standards Engineer, INDOT

Purdue Road School
March 7, 2017

Content in this presentation is for information only. Changes to INDOT design guidance and Standards for w-beam guardrail will be forthcoming.
What is MASH

- The AASHTO Manual for Assessing Safety Hardware (MASH) is the new state of the practice for the crash testing of safety hardware devices

What is MASH superseding?

- NCHRP Report 350

Why are the test standards changing?

- Increased size of current vehicle fleet
- Increased understanding of safety performance

Why is INDOT moving to MASH?

- This is a nation wide implementation. Many States have already updated their w-beam systems.
Significance of MASH

This publication marks the first time that AASHTO has officially adopted crash-testing procedures for use in assessing roadside hardware.

MASH presents uniform guidelines for crash testing permanent and temporary highway safety features and recommends evaluation criteria to assess test results.

MASH is the new state of the practice for the crash testing of safety hardware devices for use on the National Highway System (NHS).

All roadside hardware will need to be MASH test, even if it is already NCHRP 350 approved.
Changes with MASH

- The height of guardrail will increase
  - 2’-3\(\frac{3}{4}\)” to 2’-7” (often referred to as 31”)

- INDOT will adopt the non-proprietary guardrail system, Midwest Guardrail System (MGS)
  - This system has the same components, posts, w-beam, blockout, and guardrail hardware as our existing w-beam guardrail system.
  - Standard 6-ft post length
  - Rail height 2’-7” (3\(\frac{1}{4}\)” higher than 2’-3\(\frac{3}{4}\)”)
  - Mid-span splice
Changes with MASH

- MGS W-Beam System, width is the same
Changes with MASH

- MGS W-Beam System, Mid-Span Splice

  Located away from the post, there is less stress on the splice.

- The MGS w-beam guardrail system has shown to improve vehicle re-direction (Truck and Car)
Changes with MASH

- **Guardrail naming convention**
  - The current name of 2’-3³/₄” is W-Beam Guardrail.
  - The new name of 2’-7” is **MGS W-Beam Guardrail**.
  - Midwest Guardrail System

- **Block** is now **Blockout**

- **Barrier Deflection terminology convention**
  - The current terminology is Maximum Dynamic Deflection.
  - The new terminology is **Working Width**.
Changes with MASH

- **Working Width**

The distance between the traffic face of the test article (w-beam) before the impact and the maximum lateral position of any major part of the system or vehicle “during” the impact.

“during” is actually “after” in the MASH Definitions. This is causing some confusion with Permanent Deflection.
Changes with MASH

- **Working Width**

In this picture you can see that the posts are bent over and the w-beam is still containing the vehicle and the vehicle is protruding past the rail slightly.

So, the working width is measured from the initial face of w-beam to the maximum protrusion of the vehicle past the w-beam (wheel).
How does MASH affect Design?

- MGS W-Beam guardrail can still be placed adjacent a 4” vertical or sloping curb.
  - Tests have also shown that MGS w-beam guardrail may be adjacent a 6” vertical or sloping curb, however INDOT has not decided to make that the preferred practice.

- The height of guardrail will increase from 2’-3\(\frac{3}{4}\)” to 2’-7”
  - Intersection sight distance at intersections and driveways will need to be re-evaluated for the increase in guardrail height where the line of sight crosses the MGS W-Beam guardrail.
How does MASH affect Design?

- Working width is dependent on the minimum offset of 2’-0” between the back of post and the shoulder slope break.

Where the slope break offset is less than 2’-0”, the working width will need to be verified for the proposed slope break offset.

Labeled “D” in the table of the next slide.
How does MASH affect Design?

- Working Width Table

<table>
<thead>
<tr>
<th>Guardrail Type</th>
<th>Post Spacing</th>
<th>D</th>
<th>Working Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard MGS W-Beam</td>
<td>6'-3&quot;</td>
<td>2 ft</td>
<td>5.0 ft</td>
</tr>
<tr>
<td>Standard MGS W-Beam w/Omitted Post</td>
<td>6'-3&quot;</td>
<td>2 ft</td>
<td>5.0 ft</td>
</tr>
<tr>
<td>Standard MGS W-Beam</td>
<td>6'-3&quot;</td>
<td>&lt; 2 ft</td>
<td>6.5 ft</td>
</tr>
<tr>
<td>Half Post Spacing MGS W-Beam</td>
<td>3'-1 1/2&quot;</td>
<td>2 ft</td>
<td>4.5 ft</td>
</tr>
<tr>
<td>Quarter Post Spacing MGS W-Beam</td>
<td>1'-6 3/4&quot;</td>
<td>2 ft</td>
<td>4.0 ft</td>
</tr>
<tr>
<td>MGS Structure Top Mount</td>
<td>6'-3&quot;</td>
<td>1.5 ft</td>
<td>4.2 ft</td>
</tr>
</tbody>
</table>

Conservative because lesser post spacing has not been tested yet.

Distance between back post and inside face of structure headwall.
How does MASH affect Design?

- New Long-Span replaces Nested System
- Both MASH Types are greater than 100 ft
  - Type 1 system length (2 Posts Removed) = 131’-3”
  - Type 2 system length (3 Posts Removed) = 150’-0”

An MGS run of guardrail that contains a long-span must NOT be placed adjacent a vertical or sloping curb.
How does MASH affect Design?

- New Long-Span replaces Nested System
- Where the structure headwall projects > 2”
  - 8 ft from face of guardrail and inside face of headwall should be provided.
How does MASH affect Design?

- New Long-Span replaces Nested
- Where the structure headwall projects ≤ 2”
  - 2 ft from face of guardrail and inside face of headwall should be provided.
How does MASH affect Design?

- An omitted post may be used within an MGS Standard Guardrail Run.
  - There are restrictions as to where an omitted post can be placed...

An MGS run of guardrail that contains an omitted post must **NOT** be placed adjacent a vertical or sloping curb.
How does MASH affect Design?

- An omitted post: placement restrictions

MINIMUM DISTANCE BETWEEN OMITTED POSTS

- \( \geq 56' - 3'' \)
- \( \geq 43' - 9'' \) of MGS Standard Post Spacing

MINIMUM DISTANCE BETWEEN OMITTED POST AND MGS GUARDRAIL TRANSITION

- \( \geq 34' - 4\ 1/2'' \)
- \( \geq 28' - 1\ 1/2'' \) of MGS Standard Post Spacing
How does MASH affect Design?

- An omitted post: placement restrictions

MINIMUM DISTANCE BETWEEN OMITTED POST AND MGS LONG SPAN OUTER CRT POSTS

MINIMUM DISTANCE BETWEEN OMITTED POST AND FLARED MGS W-BEAM
How does MASH affect Design?

- An omitted post: placement restrictions

Minimum distance between omitted post and guardrail end treatment:

- \( \geq 12\text{'-6”} \)

Minimum distance between omitted post and MGS cable terminal anchor system:

- \( \geq 62\text{'-6”} \)
How does MASH affect Design?

- An MGS Guardrail Transition (at a bridge) will replace the current TGB, TGT, and WGB
How does MASH affect Design?

- An MGS Guardrail Transition (at a bridge)
  - Length is 40'-6 1/2” from the end of the bridge rail transition

Per testing 4” max. curb for the Guardrail Transition.

12 ft- 6 in. of tangent MGS w-beam guardrail shall be placed beyond the MGS guardrail transition limits.

12-6” Two Nested W-Beam Sections
12-6” W-Beam Section

Elevation View

MGS GUARDRAIL TRANSITION
Optional 4 in. sloping curb. See Standard Drawing
The toe of the sloping curb shall be placed flush with the backside face of the guardrail and extended the length of the transition, to post 17.

E 605-CCCG-01 and E 605-CCIN-01
How does MASH affect Design?

- An MGS Guardrail Transition with Curb: Additional placement notes

MwRSF Report No. TRP-03-291-14

1. The length of W-beam guardrail installed upstream of the nested W-beam section is recommended to be greater than or equal to the total system length of an acceptable TL-3 guardrail end terminal. Thus, the guardrail terminal’s interior end (identified by stoke length) should not intrude into the nested W-beam section of the modified MGS stiffness transition.

2. A recommended minimum barrier length of 34 ft – 4½ in. (10.5 m) is to be installed beyond the upstream end of the nested W-beam section, which includes standard MGS, a crashworthy guardrail end terminal, and an acceptable anchorage system.

3. For flared guardrail applications, a minimum length of 12.5 ft (3.8 m) is recommended between the upstream end of the nested W-beam section and the start of the flared section (i.e. bend between flare and tangent sections).
How does MASH affect Design?

- An MGS Guardrail Transition with Curb:
  Additional placement notes

  - Nested W-Beam
  - Half Post Spacing

Where another anchor system is used, other than an OS, the min. length of MGS w-beam and anchor system shall be 34’-4½”
How does MASH affect Design?

- An MGS Guardrail Transition without Curb: Additional placement notes

MwRSF Report No. TRP-03-210-10

1. A recommended minimum length of 12 ft – 6 in. (3.8 m) for standard MGS is to be installed between the upstream end of the asymmetrical W-beam to thrie beam transition section and the interior end of an acceptable TL-3 guardrail end terminal. This segment includes one half-post spacing for Design K and three half-post spacings for Design L.

2. A recommended minimum barrier length of 46 ft – 10½ in. (13.3 m) is to be installed beyond the upstream end of the asymmetrical W-beam to thrie beam transition section, which includes standard MGS, a crashworthy guardrail end terminal, and an acceptable anchorage system. This segment includes one half-post spacing for Design K and three half-post spacings for Design L.

3. For flared guardrail applications, a minimum length of 25 ft (7.6 m) is recommended between the upstream end of the asymmetrical W-beam to thrie beam transition section and the start of the flared section (i.e. bend between flare and tangent sections). This segment includes one half-post spacing for Design K and three half-post spacings for Design L.
How does MASH affect Design?

- An MGS Guardrail Transition without Curb:
  Additional placement notes

Where another anchor system is used, other than an OS, the min. length of MGS w-beam and anchor system shall be 34’-4½”
How does MASH affect Design?

- An MGS Guardrail Transition (at a bridge) uses 12” blockouts, not 8”, for now.

A 2’-0” offset needs to be maintained between the back of post and shoulder slope break.

The shoulder slope break will transition given the deeper blockouts along the Transition.
How does MASH affect Design?

- Do Not Just Take Out Posts and Rails!

This may be more of a hazard

Another solution should have been considered at this location

This utility pole is well within the Working Width of the 12 ft open span of the guardrail

Shared Use Path
How does MASH affect Design?

- **Cable Terminal Anchor System**
  - The components are the same
  - The configuration has changed to accommodate the MGS mid-span slice.

Flared End was move off the post, half a post spacing to position the mid-span splice.
How does MASH affect Design?

- Cable Terminal Anchor System
  - IDM Section 49-5.05(02) will be corrected
  - A cable terminal anchor system must always be used at the outgoing end of an MGS w-beam guardrail run that is not exposed to oncoming traffic.
  - Testing has shown that the last 31-3” will gate.
  - 31’-3” of MGS w-beam guardrail, including the cable terminal anchor system must be placed downstream of the length of need (LON)
  - 25 ft of MGS w-beam is NOT equivalent to a cable terminal anchor system.
How does MASH affect Design?

- Cable Terminal Anchor System
  - A Minimum of 31’-3” of MGS w-beam guardrail, including the cable terminal anchor system, should be placed beyond the LON.

![Diagram showing the placement of MGS w-beam guardrail and cable terminal anchor system with a 31'-3" minimum distance. The diagram also includes a point of LON, one-way traffic, and a hazard area.](diagram.png)
How does MASH affect Design?

- Minimum length of free standing MGS w-beam guardrail.
- MGS w-beam guardrail run with two OS End Treatments, two-way traffic, 112.5 ft

This length is required to absorb the compression area and to allow enough posts to develop the compression load of a car striking an OS End Treatment at the nose of the treatment.
How does MASH affect Design?

- Minimum length of free standing MGS w-beam guardrail.
  - MGS w-beam guardrail run with one OS End Treatment and one Cable Terminal Anchor System, one-way traffic, 112.5 ft
How does MASH affect Design?

- Guardrail Transition for Rail Height, MGS w-beam to w-beam (Rail height of 2’-3¾” to 2’-7”)
  - Transition Length of 37’-6”
    - Additional length is to account for the mid-span splice
- More guidance on this transition is to come.

\[ \geq 37’-6” \]
How does MASH affect Design?

- Curved End Treatments
  - Have not been MASH tested at the 2’-7” height
  - Transition the MGS w-beam Guardrail down to 2’-3¾” where a curved end treatment is needed.
  - Where there is not room, 37’-6”, to transition an MGS w-beam guardrail run prior to placing a 2’-3¾” rail height curved end treatment, that run of guardrail or quadrant of the bridge will need to be called out as w-beam guardrail at the 2’-3¾” height.

- See next slides for examples
How does MASH affect Design?

- Curved End Treatments

This entire quadrant would need to be NCHRP 350 tested, w-beam guardrail, TGB transition, and curved end treatment at 2’-3¾”.
Curved End Treatments

This entire guardrail area would need to be NCHRP 350 tested, w-beam guardrail and curved end treatments at 2’-3¾”.
How does MASH affect Design?

- Curved End Treatments

This guardrail run has enough room to transition down to the curved end treatment at 2'-3\(\frac{3}{4}\)".
How does MASH affect Design?

- **Structure Top-Mounted Post**
  - MGS w-beam guardrail does have a MASH tested structure top-mounted post.
  - There will be an INDOT Standard Drawing
  - To be used as a last resort, where an omitted post or long-span system can not be placed.
  - Min. Cover 9”
  - Max. Cover 3’-5” (anything deeper a standard 6 ft post can be place)
Coming Updates for MASH

- Future Updates
  - Updates to Section 601, through a Recurring Special Provision (RSP)
  - Updates to Standard Drawings
  - Updates to the Indiana Design Manual (IDM)
  - Updates to Pay Items, and ……
  - A Design Memo!!!! 😊
January 1, 2018

All projects let on or after January 1, 2018 will need to be submitted with MASH approved MGS w-beam guardrail. (Stage 3 Aug. 2017)

INDOT is discussing implementing MASH for only Projects on the NHS letting on or after January 1, 2018 and implementing MASH for all other projects on or after July 1, 2018. The thought is to help reduce the rush for January 2018.
Dates to Remember

- **Other dates to remember**
  - Projects let on or after July 1, 2018 will need to be submitted with MASH approved MGS w-beam end treatments. (Designer do not need to call this out differently, they will be taken care of on the list of approved materials.)
  - INDOT is currently evaluating MASH compliant end treatments
Other dates to remember

- Projects let on or after January 1, 2019 will need to be submitted with MASH approved cable barrier, cable barrier terminals, and crash cushions.
- Projects let on or after January 1, 2020 will need to be submitted with MASH approved bridge rails, bridge rail transitions, all other longitudinal barriers, all other terminals, sign supports, and all other breakaway hardware.
Dates to Remember

- Other dates to remember
  - Temporary work zone devices, including portable barriers, manufactured after December 31, 2019, must have been successfully tested to the 2016 edition of MASH. Such devices manufactured on or before this date, and successfully tested to NCHRP Report 350 or the 2009 edition of MASH, may continue to be used throughout their normal service lives.
Two Items to Remember

- Check your designs:
  - Intersection Sight Distance where the line of sight runs over MGS w-beam guardrail
  - Length of special features, Long-Span, guardrail transition, min. length of MGS w-beam guardrail, etc.
  - working width
  - shoulder slope break offset from back of guardrail post

- All w-beam guardrail will need to be updated to MGS w-beam guardrail for projects Letting on or after January 1, 2018.
QUESTION

Office of Standards and Policy

Elizabeth Phillips
ephillips@indot.in.gov

Katherine Smutzer
ksmutzer@indot.in.gov

Naveed Burki
nburki@indot.in.gov

Mark Orton
Morton@indot.in.gov

NEW!!

General Email for Design Manual Inquiries

DesignManuallnquiries@indot.in.gov
MASH Updates

- **NCHRP 350 to MASH 2016**
  - Manual for Assessing Safety Hardware (MASH) replaces NCHRP 350 as the current crash testing standard for safety hardware.
  - Since 2011, all **new** products had to be tested under MASH. Hardware accepted under NCHRP 350 can still be installed.*

- **Why did it change?**
  - Vehicles have increased in size and light truck bumper heights have risen since the NCHRP Report 350 criteria were adopted in 1993
  - Updated crash test criteria was based primarily on changes in the vehicle fleet.

* For right now
MASH Updates

* AASHTO-FHWA Implementation Agreement signed January 2016. “For contracts on the National Highway System with a letting date after the dates below, only safety hardware evaluated using the 2016 edition of MASH criteria will be allowed for new permanent installations and full replacements.”

- December 31, 2017: w-beam barriers and cast-in-place concrete barrier
- June 30, 2018: w-beam terminals
- December 31, 2018: cable barriers, cable barrier terminals, and crash cushions
- December 31, 2019: bridge rails, transitions, all other longitudinal barriers (including portable barriers installed permanently), all other terminals, sign supports, and all other breakaway hardware
- Temporary work zone devices, including portable barriers, manufactured after December 31, 2019, must have been successfully tested to MASH.
# MASH Updates

## NCHRP 350 vs. MASH: Vehicles

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>NCHRP 350</th>
<th>MASH 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small car</td>
<td>820C</td>
<td>1100C</td>
</tr>
<tr>
<td></td>
<td>Weight: 1,809 lb</td>
<td>Weight: 2,420 lb</td>
</tr>
<tr>
<td>Pickup Truck</td>
<td>2000P</td>
<td>2270P</td>
</tr>
<tr>
<td></td>
<td>Weight: 4,409 lb</td>
<td>Weight: 5,000 lb</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Min. c.g. height: 28 in.</td>
</tr>
<tr>
<td>Single Unit Truck</td>
<td>8000S</td>
<td>10000S</td>
</tr>
<tr>
<td></td>
<td>Weight: 17,636 lb</td>
<td>Weight: 22,000 lb</td>
</tr>
<tr>
<td>Tractor Trailer</td>
<td>36000V</td>
<td>36000V</td>
</tr>
<tr>
<td></td>
<td>Weight: 79,366 lb</td>
<td>Weight: 79,300 lb</td>
</tr>
</tbody>
</table>

Source: AASHTO Technical Committee on Roadside Safety
## Longitudinal Barrier Impact Conditions

<table>
<thead>
<tr>
<th>Test Level</th>
<th>Test Vehicle</th>
<th>NCHRP 350</th>
<th>MASH 2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>TL-3</td>
<td>Small Car</td>
<td>Speed: 62 mph</td>
<td>Speed: 62 mph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Angle: 20°</td>
<td>Angle: 25°</td>
</tr>
<tr>
<td>TL-3</td>
<td>Pickup</td>
<td>Speed: 62 mph</td>
<td>Speed: 62 mph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Angle: 25°</td>
<td>Angle: 25°</td>
</tr>
<tr>
<td>TL-4</td>
<td>S.U.T.</td>
<td>Speed: 50 mph</td>
<td>Speed: 56 mph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Angle: 15°</td>
<td>Angle: 15°</td>
</tr>
<tr>
<td>TL-5</td>
<td>Tractor Trailer</td>
<td>Speed: 50 mph</td>
<td>Speed: 50 mph</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Angle: 15°</td>
<td>Angle: 15°</td>
</tr>
</tbody>
</table>

Source: AASHTO Technical Committee on Roadside Safety
Table A13.2-1 Design Forces for Traffic Railing

<table>
<thead>
<tr>
<th>Design Forces and Designations</th>
<th>TL-1</th>
<th>TL-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_T$, Transverse (kips)</td>
<td>13.5</td>
<td>27.0</td>
</tr>
<tr>
<td>$F_L$, Longitudinal (kips)</td>
<td>4.5</td>
<td>9.0</td>
</tr>
<tr>
<td>$F_V$, Vertical (kips) Down</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>$L_T$ and $L_L$ (ft)</td>
<td>4.0</td>
<td>4.0</td>
</tr>
<tr>
<td>$L_V$ (ft)</td>
<td>18.0</td>
<td>18.0</td>
</tr>
<tr>
<td>$H_r$ (min) (in.)</td>
<td>18.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Minimum $H$ Height of Rail (in.)</td>
<td>27.0</td>
<td>27.0</td>
</tr>
</tbody>
</table>

NOTE: The MASH design forces shown are preliminary. Final values will be those published in future editions of the LRFD Bridge Design Specifications.

![Diagram of Metal Bridge Railing Design Forces, Vertical Location, and Horizontal Distribution Length](image-url)
INFLUENCE OF BARRIER HEIGHT ON IMPACT LOAD

Lateral force increases as barrier height increases
Vehicle contact area changes (box structure engaged)
Less vehicle roll (more mass engaged)

Comparison of contact area
36 in. Tall Barrier

Floor of the box is not engaged in the impact

Floor of the box is engaged in the impact

42 in. Tall Barrier

Source: Texas Transportation Institute
## SUMMARY OF MASH TL-4 LOADS ON RIGID BARRIERS

<table>
<thead>
<tr>
<th>Design Forces and Designations</th>
<th>Barrier Height (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>36</td>
</tr>
<tr>
<td>$F_t$ Lateral (kip)</td>
<td>67.2</td>
</tr>
<tr>
<td>$F_L$ Long. (kip)</td>
<td>21.6</td>
</tr>
<tr>
<td>$F_v$ Vertical (kip)</td>
<td>37.8</td>
</tr>
<tr>
<td>$L_t$ and $L_L$ (ft)</td>
<td>4</td>
</tr>
<tr>
<td>$H_e$ (in.)</td>
<td>25.1</td>
</tr>
</tbody>
</table>

$L_t = \text{longitudinal distribution of } F_t$

$H_e = \text{vertical resultant height of } F_t$

Source: Texas Transportation Institute
CONCLUSIONS FOR MASH TL-4 LOADS

Minimum barrier height for truck stability = 36 inches.

Magnitude and resultant height of lateral impact force ($F_t$) varies with barrier height.
  For 36-inch tall barrier: $F_t = 67.2$ kips and $H_e = 25.1$ in.
  For 42-inch tall barrier: $F_t = 79.1$ kips and $H_e = 30.2$ in.

Although $F_t$ has 24% increase for 36-inch tall MASH TL-4 barrier compared to Table A13.2-1 *Design Forces for Traffic Railings*, associated moment for deck cantilever design does not change.
  Table A13.2-1 $\Rightarrow$ 54 kips x 32 in. = 1,728 in-kips
  MASH 36-inch barrier $\Rightarrow$ 67.2 kips x 25.1 in. = 1,687 in-kips
**MASH Updates**

**How is INDOT responding the new requirements for Guardrail?**

- INDOT is moving from strong-post w-beam guardrail to the Midwest Guardrail System (MGS) in anticipation of the Dec. 2017 deadline.
  - top rail height of 31 in., 8 in. blockout, mid-span splice.
  - uses a 6-ft post with an embedment depth of 3’-4”.
    - Requires a 2-ft offset from the back of post to the slope break (hinge point)
- Remaining 600-series standard drawings will be revised, eliminated, or designated as For Maintenance Only.
- Review of policy for existing non-MASH systems on-going.
- MASH-Compliant Guardrail End Treatments are being evaluated for inclusion on the Approved Material List.
How is INDOT responding the new requirements for Bridge Railing?

- Updating the Type FC bridge railing to 39 in.
  - FT railing will remain unchanged and acceptable as TL-5
- Reviewing the Bridge Railing Test Level policy.
- Reviewing test level selection charts.
  - NCHRP 22-12(03), Bridge Railing Test Level Selection was proposed to updated for MASH
- Monitoring the progress of NCHRP 20-7 (Task 395)
  - Prioritizing bridge railing for full scale crash testing
  - Completing crash testing as funding allows.
MASH Resources

- FHWA Roadside Hardware Policy and Guidance webpage
  https://safety.fhwa.dot.gov/roadway_dept/policy_guide/road_hardware/#crashworthy

- FHWA Roadway Departure Research and Resources webpage
  https://safety.fhwa.dot.gov/roadway_dept/research/

- Midwest Roadside Safety Facility webpage
  https://mwrsf.unl.edu/mgs.php

- Roadside Safety Research Program Pooled Fund Study
  https://www.roadsidepooledfund.org/