SESSION 21 - “MASH CRITERIA, CRASH TESTING, GUARDRAIL AND BRIDGE RAIL DESIGN”
Crash Testing has been used as a tool for evaluating the safety performance of roadside features for many years.
Procedures for how to perform crash tests have evolved

- Highway Research Correlation Services Circular 482 (1962)

1973: NCHRP Report 153 – 16-page document, based on technical input from 70+ individuals and agencies and a special ad-hoc panel.


1980: NCHRP Report 230 – 36-page document, brought procedures up to date with available technology and practices, updated the evaluation criteria.


2009: AASHTO Manual for Assessing Safety Hardware (MASH)
PRACTICAL WORST CASE CONDITIONS

• CRASH TESTING MUST BE PRACTICAL SO THAT ROADSIDE SAFETY FEATURES DEVELOPED ARE COST-EFFECTIVE AND PROVIDE INCREASED LEVELS OF SAFETY WITHOUT PLACING UNREALISTIC FINANCIAL BURDEN ON USER AGENCIES - FROM “MASH”
NCHRP 350
CRASH TESTING GUIDELINES

- NCHRP Report 350 created 6 Test Levels
- Levels 1-3 based on speed
  - TL1 – 50 km/h (31 mph)
  - TL2 – 70 km/h (43 mph)
  - TL3 – 100 km/h (62 mph)
- Levels 4-6 add large trucks
# MASH GENERAL TEST LEVELS

<table>
<thead>
<tr>
<th>TEST LEVEL - TL</th>
<th>TEST VEHICLE Type – (weight Lbs)</th>
<th>SPEED mph</th>
<th>ANGLE OF IMPACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PASSENGER CAR – (2,420)</td>
<td>31</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>PICKUP TRUCK – (5,000)</td>
<td>31</td>
<td>25</td>
</tr>
<tr>
<td>2</td>
<td>PASSENGER CAR – (2,420)</td>
<td>44</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>PICKUP TRUCK – (5,000)</td>
<td>44</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>PASSENGER CAR – (2,420)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>PICKUP TRUCK – (5,000)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td>4</td>
<td>PASSENGER CAR – (2,420)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>PICKUP TRUCK – (5,000)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>SINGLE UNIT TRUCK – (22,000)</td>
<td>56</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>PASSENGER CAR – (2,420)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>PICKUP TRUCK – (5,000)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>TRACTOR VAN TRAILER – (79,300)</td>
<td>50</td>
<td>15</td>
</tr>
<tr>
<td>6</td>
<td>PASSENGER CAR – (2,420)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>PICKUP TRUCK – (5,000)</td>
<td>62</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>TRACTOR TANK TRAILER – (79,300)</td>
<td>50</td>
<td>15</td>
</tr>
</tbody>
</table>
Old vs. New
NCHRP 350 VS. AASHTO MASH CHANGES

- **TEST VEHICLES UPDATED TO WHAT’S BEING PRODUCED AND SOLD TODAY**
- **IMPACT CONDITION CRITERIA UPDATE TO CORRECT NEEDED CONDITIONS.**
- **PROMOTE MORE IN-SERVICE EVALUATIONS IN THE FIELD.**
- **SMALL CAR INCREASED FROM 1,800 LBS. TO 2,420 LBS.**
- **SMALL CAR IMPACT ANGLE INCREASED FROM 20 TO 25 DEGREES**
- **PICKUP TRUCKS INCREASED FROM 4,400 LBS TO 5,000 LBS.**
- **TL-4 TRUCK INCREASED FROM 17,600 LBS. TO 22,000 LBS.**
- **TL-4 TRUCK SPEED INCREASED FROM 50 MPH TO 56 MPH**
AGENCIES ARE URGED TO ESTABLISH A PROCESS TO REPLACE EXISTING HIGHWAY SAFETY HARDWARE THAT HAS NOT BEEN SUCCESSFULLY TESTED TO NCHRP REPORT 350 OR LATER CRITERIA.

AGENCIES ARE ENCOURAGED TO UPGRADE EXISTING HIGHWAY SAFETY HARDWARE TO COMPLY WITH THE 2015 EDITION OF MASH EITHER WHEN IT BECOMES DAMAGED BEYOND REPAIR, OR WHEN AN INDIVIDUAL AGENCY’S POLICIES REQUIRE AN UPGRADE TO THE SAFETY HARDWARE.

FOR CONTRACTS ON THE NATIONAL HIGHWAY SYSTEM WITH A LETTING DATE AFTER THE DATES BELOW, ONLY SAFETY HARDWARE EVALUATED USING THE 2015 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 BARRIERS
- 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
CRASH TESTING ASSISTANCE

HIGHWAY SAFETY POOLED FUND GROUP – LA DOTD IS A MEMBER

Random video from this site

Background
Many state DOT's have sponsored research on roadside safety issues that include crash testing of features in accordance with FHWA adopted standards (NCHRP Report 350 and MASH). Many of the research and functional problems are common to more than one state and so there is efficiency and cost effectiveness in pooling resources to conduct certain crash tests.

Objective
To establish an ongoing roadside safety research program that meets the research and functional needs of participating states in a cost-effective and timely manner.

Scope
A committee of representatives from participating states formed a technical committee to identify common research needs, select projects for funding and oversee implementation of results. Specific research activities addressed within the program include the design, analysis, testing, and evaluation of crashworthy structures, and the development of...
• AASHTO ROADSIDE DESIGN GUIDE – AASHTO TCRS

• AASHTO LRFD BRIDGE DESIGN SPECIFICATIONS, BRIDGE RAILING CHAPTER 13

• LA DOTD BRIDGE DESIGN AND EVALUATION MANUAL – NEW HIGHWAY SAFETY SECTION BEING DEVELOPED

• LA DOTD BRIDGE DESIGN MANUAL, 4TH ENGLISH EDITION – ARCHIVED.

• LA DOTD STANDARD PLANS FOR GUARDRAIL

• LA DOTD SPECIAL DETAILS FOR BRIDGE RAILING

• LA DOTD EDSM’S FOR GUARDRAIL
LA DOTD “MASH” GUARDRAIL STANDARDS

- ADOPTED MGS OR MIDWEST GUARDRAIL SYSTEM – 31” HEIGHT – STANDARD PLANS BEING UPDATED

- GUARDRAIL TOLERANCES – 1” UP AND 3” DOWN - OVERLAYS

- GUARDRAIL W-BEAM SPLICES AT MID-SPAN OF POSTS

- POST LENGTHS NOT CHANGED

- CAN USE WITH 8” OR 12” BLOCKOUTS

- IMPROVED PERFORMING SYSTEM FOR “MASH” CRITERIA

- MUST DEVELOP A TRANSTION FOR THE BRIDGE RAIL CONNECTION

- CRASHWORTHY YEND TREATMENTS ARE AVAILABLE
31-in. guardrail system benefits
 Increased Safety
 Reduced high CG vehicles rollover
 Improved re-directive capacity
 Improved height tolerance
LARGE VARIETY OF BRIDGE RAIL SYSTEMS THAT EXIST – LA DOT D CURRENTLY USED A TL-4 NCHRP 350 32” F-SHAPE CONCRETE RAIL

AASHTO SUBCOMMITTEE FOR BRIDGES AND STRUCTURES (SCOBS), TECHNICAL COMMITTEE T-7, BRIDGE RAILING AND GUARDRAIL

AASHTO TECHNICAL COMMITTEE FOR ROADSIDE SAFETY (TCRS)

TEXAS A&M TRANSPORTATION INSTITUTE (TTI)

UNIVERSITY OF NEBRASKA – MIDWEST ROADSIDE SAFETY

UNIV. ALABAMA BIRMINGHAM (UAB)

NEW NCHRP RESEARCH PROJECT FOR MASH BRIDGE RAILS
## Table A13.2-1—Design Forces for Traffic Railings

<table>
<thead>
<tr>
<th>Design Forces and Designations</th>
<th>TL-1</th>
<th>TL-2</th>
<th>TL-3</th>
<th>TL-4</th>
<th>TL-5</th>
<th>TL-6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_t$ Transverse (kips)</td>
<td>13.5</td>
<td>27.0</td>
<td>54.0</td>
<td>54.0</td>
<td>124.0</td>
<td>175.0</td>
</tr>
<tr>
<td>$F_L$ Longitudinal (kips)</td>
<td>4.5</td>
<td>9.0</td>
<td>18.0</td>
<td>18.0</td>
<td>41.0</td>
<td>58.0</td>
</tr>
<tr>
<td>$F_v$ Vertical (kips) Down</td>
<td>4.5</td>
<td>4.5</td>
<td>4.5</td>
<td>18.0</td>
<td>80.0</td>
<td>80.0</td>
</tr>
<tr>
<td>$L_t$ and $L_L$ (ft)</td>
<td>4.0</td>
<td>4.0</td>
<td>4.0</td>
<td>3.5</td>
<td>8.0</td>
<td>8.0</td>
</tr>
<tr>
<td>$L_v$ (ft)</td>
<td>18.0</td>
<td>18.0</td>
<td>18.0</td>
<td>18.0</td>
<td>40.0</td>
<td>40.0</td>
</tr>
<tr>
<td>$H_v$ (min) (in.)</td>
<td>18.0</td>
<td>20.0</td>
<td>24.0</td>
<td>32.0</td>
<td>42.0</td>
<td>56.0</td>
</tr>
<tr>
<td>Minimum $H$ Height of Rail (in.)</td>
<td>27.0</td>
<td>27.0</td>
<td>27.0</td>
<td>32.0</td>
<td>42.0</td>
<td>90.0</td>
</tr>
</tbody>
</table>

Figure A13.2-1 shows the design forces from Table A13.2-1 applied to a beam and post railing. This is for illustrative purposes only. The forces and distribution lengths shown apply to any type of railing.
• Current AASHTO Test Level 4 (TL-4) impact load is 54 kips based on NCHRP Report 350. The minimum barrier height is 32 in.

• Impact Severity (IS) (i.e., lateral kinetic energy) for TL-4 impact increased 57% from 99 kip-ft in NCHRP Report 350 to 155 kip-ft in MASH.

  - NCHRP Report 350: 17,600-lb, 50 mph, 15 degrees.
  - MASH: 22,000-lb, 56 mph, 15 degrees.

• Research performed to determine minimum barrier height and design impact loads for MASH TL-4, and associated affects on cantilever design.
RECENT MASH TL-4 CRASH TESTS

<table>
<thead>
<tr>
<th>Test No. (Funding Agency)</th>
<th>Impact Conditions</th>
<th>Barrier Height (in.)</th>
<th>Barrier Type</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vehicle Weight (lb)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speed (mph)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Angle (deg.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>476460-1 (NCHRP)</td>
<td>22,090</td>
<td>32</td>
<td>N.J Safety Shape</td>
<td>Vehicle rolled over</td>
</tr>
<tr>
<td></td>
<td>57.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>420020-9B (TxDOT)</td>
<td>22,000</td>
<td>36</td>
<td>Single Slope Barrier</td>
<td>Test Pass</td>
</tr>
<tr>
<td></td>
<td>57.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16.1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

BASED ON CRASH TESTING AND FINITE ELEMENT IMPACT SIMULATIONS, A HEIGHT OF 36 IN. HAS BEEN SELECTED AS THE MINIMUM BARRIER HEIGHT REQUIRED FOR VEHICLE STABILITY FOR MASH TL-4. FUTURE BRIDGE DECK OVERLAYS MUST ALSO BE CONSIDERED.
MASH TL-4 TEST ON 32-INCH JERSEY BARRIER
1. Concrete is Class S (4000 psi) for the deck, and Class C (3600 psi) for the parapet.
2. Transverse bars in deck weld to existing rebar (not shown) protruding from runway.
3. Deck is canti-levered from runway. Moment slab is back-filled with compacted crushed limestone.
4. Transverse bars at 6" spacing in top mat, 18" at bottom.
5. Rebar lap splices are 17" for #4's and 21" for #5's.
6. This bar may be adjusted laterally +/- 3" to allow tying to stirrup.

MASH TL-4 TEST ON 36-INCH SINGLE SLOPE BARRIER
MASH TL-4 TEST ON 36-INCH SINGLE SLOPE BARRIER
Different approaches used to quantify design impact load for *MASH* TL-4 impact:

- **Analytical Approach**
  - Combination of various mathematical models (with their inherent assumptions) and data from previous full-scale crash tests.
  - Wide range of load values obtained (80 to 99 kips).

- **Finite Element Approach**
  - Detailed impact simulations into rigid vertical barrier using a *MASH* single unit truck model validated against TTI crash test 476460-1.
  - Provides information on magnitude and resultant height of lateral load.
Research under NCHRP Project 22-20(02) “Design Guidelines for TL-3 through TL-5 Roadside Barrier Systems Placed on Mechanically Stabilized Earth (MSE) Retaining Walls.”

FE analysis performed with varying heights of vertical rigid barriers
- 36”, 39”, 42” and tall rigid wall

Lateral, longitudinal and vertical forces from truck impacts obtained for MASH TL-4 impact conditions.

Longitudinal and transverse distributions of the lateral impact force studied. Corresponding resultant load height computed.
SET-UP OF THE FE ANALYSES FOR MASH TL-4 IMPACT

FE model for the 36” tall barrier. Minimum barrier height for MASH TL-4

FE model for the tall rigid wall. Captures maximum possible force for MASH TL-4
**SIMULATION RESULTS: 36” TALL BARRIER**

**MASH TL-4 Lateral Impact Force: 36” Vertical Wall**

![Graph showing lateral force over time](image-url)

- **Lateral Force, kips**
- **Time, sec**
- **Raw Data**
- **50-msec Ave.**

1. 0 to 0.1 sec
2. 0.2 to 0.3 sec

---

25
Longitudinal Impact Force on the Barrier
\[ F_L = 21.6 \text{ kips} \]

Vertical Impact Force on Top of the Barrier
\[ F_v = 37.8 \text{ kips} \]
Distribution of the Maximum Lateral Impact Force

Vertical Distribution
(Resultant height at 25.1 in.)

Longitudinal Distribution
(approx. 4 ft)
### 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>

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

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

42 in. Tall Barrier
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 TL-5

- No change in TL-5 impact conditions between NCHRP Report 350 and MASH

- MASH Test 5-12
  - 80,000 lb tractor-van trailer impacting barrier at 50 mph and 15 degrees

- TL-5 barriers successfully tested under NCHRP Report 350 will satisfy MASH requirements.
Video courtesy Texas A&M Transportation Institute
Alabama DOT
- UAB doing research on concrete barrier to determine appropriate design methodology for the loads used in Section 13, Table A13.2-1.

Manitoba TL-5 Bridge Rail
- Full-scale testing at MwRSF in fall 2015
  - 49” tall single slope barrier with 195 kip design capacity
    - Mounted on 11” deck with ¾” gap at joint
    - Impact point upstream of open joint in barrier and deck
    - Steel cover plate over 200 mm barrier joint to prevent snag & transfer shear

TxDOT TL-5 Bridge Rail
- Full-scale testing at TTI August 21, 2015
  - 42” tall open beam and post concrete barrier
    - Mounted on 8 ½” thick, empirically reinforced concrete deck cantilever
    - Impact point upstream of open joint in barrier and deck
    - Dowel bars used to transfer shear across barrier joint