Development and Preliminary Validation of Computational Finite Element Truck Underride Guards through Reverse Engineering

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I. INTRODUCTION

Truck underride guards were initially developed in 1953 under a standard issued by the Bureau of Motor Carriers to protect cars, trucks and other passenger vehicles in the event of a collision with the rear of a truck/trailer [1]. This standard was updated and strengthened in 1998 under the Federal Motor Vehicle Safety Standards (FMVSS) Nos. 223 and 224 to lower the guard height from 30 inches to 22 inches, to shorten the wheel setback dimension from 24 inches to 12 inches, and to introduce strength and testing standards [1]. A study conducted by the Transportation Research Institute at the University of Michigan, which analysed fatal crashes with trucks between 2008 and 2009, noted that 7,423 fatal crashes occurred, of which 55.4% involved a rear underride guard [1]. Recently, NHTSA released a new final rule upgrading safety standards for rear underride protection, making them similar to the requirements set forth by Transport Canada [2]. The goal of this study was to develop and validate finite element (FE) models of truck underride guards for future studies involving quasistatic loading and dynamic semitrailer crash tests for use in future safety studies.

II. METHODS

Three unique truck underride guards were independently purchased to use in the development and validation of the FE models (Manac 914-0901002-G, Great Dane GDP11716266, and Wabash 05006821-07). Upon receipt, the underride guards were measured to accurately obtain measurements of distances, angles and thicknesses. A CAD model of each guard was developed using SolidWorks (Dassault Systemes, Velizy-Villacoublay, France). The models were meshed in ANSA using primarily quadrilateral shell elements with a target edge length of 10 mm. A combination of top and mid-surfaces was selectively meshed and assigned appropriate element thickness projection direction (nloc) values to accurately capture geometries and thicknesses of the guards. The total element count for each truck underride guard was 15,688 (Wabash), 18,414 (Great Dane) and 21,338 (Manac), with all guards having greater than 99% quad elements.

Two ASTM E8 (sheet type; 12.5 mm) dog bones were machined from each guard and tested in uniaxial tension. The simulations of these tensile tests were conducted under identical boundary conditions and a *MAT_SIMPLIFIED_JOHNSON_COOK material model was developed through inverse FE analysis for each guard.

Simulations of the fully meshed underride guards were conducted to replicate quasistatic tests as per the previous FMVSS No. 223 standard. The prior FMVSS No. 223 states that NHTSA may test a rear-impact guard when attached to either a rigid test fixture or to a complete trailer, per manufacturer's instruction [3]. Video and Force-Displacement evidence suggests that the fixture device deflects elastically during loading. This phenomenon was captured in the model through a stiff spring element at each attachment point, allowing the guard to minimally displace translationally during the loading phase.

For brevity, this manuscript only includes the quasistatic testing conducted at the P3 impact location. FMVSS impact location P3 is located 355–635 mm from the horizontal member centreline and prescribes 125 mm of displacement to the guard with a 203 mm x 203 mm steel flat impactor. Force vs. Displacement (P3) data from the physical tests were digitised and plotted against the results of the simulations [4-6].

III. INITIAL FINDINGS

Material properties of the *MAT_SIMPLIFIED_JOHNSON_COOK material card for each truck underride guard were obtained through the results of the LS-OPT study comparing physical uniaxial tension tests with their associated computational simulations. The final set of material properties for the FE truck underride guards can be found below (Table I).

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TABLE I
MATERIAL PROPERTIES USED FOR EACH TRUCK UNDERRIDE GUARD
ALL VALUES ARE IN GPA, EXCEPT FOR "N", WHICH IS UNITLESS

Guard Type	E	A	B	N	SIGMAX/SIGSAT
Great Dane	196.84	.6177	.7432	.8963	.7565
Manac	209.91	.6007	.7271	.8944	.7402
Wabash	189.93	.6274	.7788	.8780	.7057

Validation of the FE truck underride guards was based upon matching physical data presented by tests conducted on the three physical guards. Figures 1–3 show the results of the physical tests at location P3 for each guard compared to the results of the associated simulation.

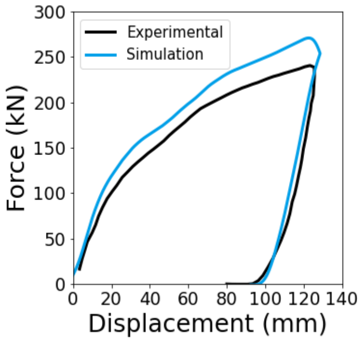

Fig. 1. Great Dane P3 Force vs. Displacement.

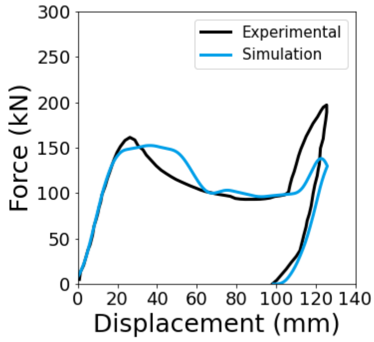

Fig. 2. Manac P3 Force vs. Displacement.

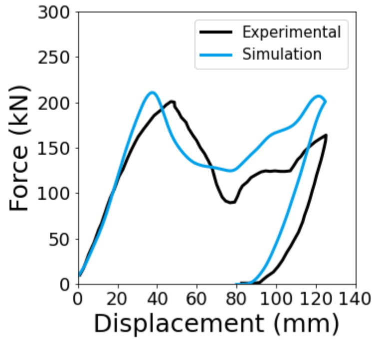

Fig. 3. Wabash P3 Force vs. Displacement.

Agreement demonstrated between simulations of the FE truck underride guards and the physical P3 tests provides confidence in proceeding with further tests using the newly developed models. The next steps are to simulate impact locations P1 and P2 from the FMVSS 223 test series. To account for variations in thicknesses of the sheet metal, the model will be further optimised to tune the response to physical tests by modifying shell thicknesses within the measured range. Additionally, the data evaluation software CORrelation and Analysis (CORA) will be used at the end of all simulations to quantify a goodness of fit and provide an objective evaluation for the obtained results [7]. Next steps in the overarching study are to modify the guards such that they minimally meet the requirements of the newly implemented final rule, while also minimising the total mass of the structure [2]. Based upon these results, modifications will be made to the bumper assembly to prevent passenger compartment intrusion (PCI) in a range of overlaps and two vehicle models. Finally, the FMVSS quasistatic load cases will be re-simulated with the modified guards. The overall goal of the full study is to further understand the link between testing standards and rear-impact guard performance in full-vehicle impacts.

IV. REFERENCES

[1] NHTSA, DOT HS 811 725, 2013.
[2] Federal Register, *87 FR 42339,* 2022
[3] Federal Register, *80 FR 78417,* 2015.
[4] NHTSA, "223-MGA-18-003", *MGA Research Corporation, Troy, MI*, 2018
[5] NHTSA, "223-MGA-18-002", *MGA Research Corporation, Troy, MI*, 2018
[6] NHTSA, "223-MGA-18-008", *MGA Research Corporation, Troy, MI*, 2018
[7] Gehre, C., *et al.*, *ESV*, 2009.