WP# 2016-2

Analysis of SIMON/DYMESH Simulations for Underride Collisions

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ABSTRACT

Underride impacts present a challenge to traditional reconstruction methods, such as conservation of energy, crush analyses, and two-dimensional simulation models (e.g. EDSMAC4 and EDCRASH), where the structural components of the involved vehicles are partially contacted or not contacted and there is deformation to the cosmetic vehicle components. SIMON/DYMESH provide the combination of three-dimensional vehicle dynamics and collision algorithms within the commercially available HVE simulation package to account for the bumper mismatch in underride collisions.

Several staged vehicle-into-barriers and vehicle-into-vehicle collisions were evaluated. The post-impact damage to the underride vehicle, pre-impact travel speed, and peak accelerations from the simulations were compared with the measured values in the staged collisions. The effect of relaxation length and stiffness coefficient conversion height is presented.

INTRODUCTION

It is common practice to use the technique for calculating crush energy based on measuring the residual crush depth as developed by Campbell [1]. This methodology requires the application of stiffness coefficients derived from full-frontal rigid barrier impact tests. Many researchers have found that it is appropriate to apply the A and B stiffness coefficients calculated from full-frontal rigid barrier impact tests to collisions where there is engagement of the bumper system on the subject vehicle [2]. Collisions where the front bumper bar of the bullet vehicle underrides the target vehicle's structural components present a challenging scenario for reconstructionists to calculate the impact speed using the damage profile.

Previous studies have provided methodologies to account for the damage to the cosmetic components in underride collisions [3,4]. The methodology presented by Tumbas et al. is not presented here. Research by Croteau et al. used a heavy truck and passenger vehicle in their underride analysis and used EDSMAC4 to simulate the collisions [4]. The study found that they needed to reduce the B stiffness coefficient for the side of the vehicle to 10% of its original value to get reasonable estimates of crush. The A stiffness coefficient was not adjusted. However, the collision pulse was too long and the peak acceleration was not captured.

Full-frontal rigid barrier impact test data is readily available for a majority of the passenger vehicle types that the reconstructionists may encounter. For a full-frontal rigid barrier impact, the residual crush is related to the total kinetic energy dissipated during the impact using a constant stiffness spring. This study evaluated whether those full-frontal barrier impact stiffness coefficients required modification from their default values in an underride impact and the effectiveness of modifying those stiffness coefficient values..

Engineering Dynamics Corporation offers several collision simulation programs as part of their HVE (Human-Vehicle-Environment) software package. EDSMAC4 and SIMON/DYMESH are two of the simulation packages contained within HVE. SIMON/DYMESH is a three-dimensional vehicle collision and dynamics simulation tool compared to the two-dimensional EDSMAC4 simulation tool. The physics and engineering models are independent between the two tools. The validation papers for these simulation packages and the physics and vehicle engineering methodologies have been published and are publically available on the EDC website (http://www.edccorp.com). The details of the collision models for EDSMAC4 and SIMON/DYMESH are not discussed here. The reader is directed to [5–7] for the model information contained within SIMON/DYMESH and [8] for the collision model details for EDSMAC4.

The two-dimensional EDSMAC4 model assumes that the deformation to the vehicle occurs over the entire height. The three-dimensional model, SIMON/DYMESH, has the capability of determining which surfaces on the vehicle interact during a collision and only apply the deformation to that part of the vehicle structure. The standard two-dimensional force-per-width versus deformation relationship (Figure 1) is extended to three-dimensions in Figure 2. Conversion to the three-dimensional form is achieved by dividing A and B by the conversion height, H, of the vehicle crushed when the stiffness parameters were generated. The portion of the curve with a slope K_u is the unloading path. The default value of H is 30 inches.

This work addresses applying the three-dimensional physics models of SIMON/DYMESH for underride collisions. The procedure uses staged crash data to validate the SIMON/DYMESH model.

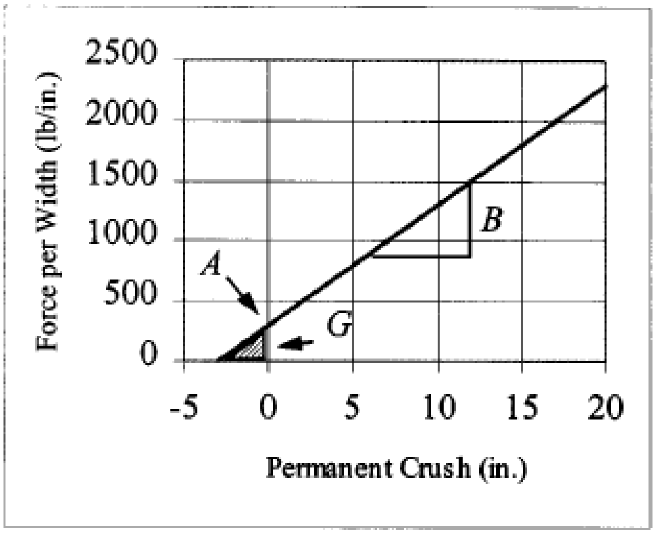

Figure 1: 2D force-per-width verses crush relationship. Image taken from: [7]

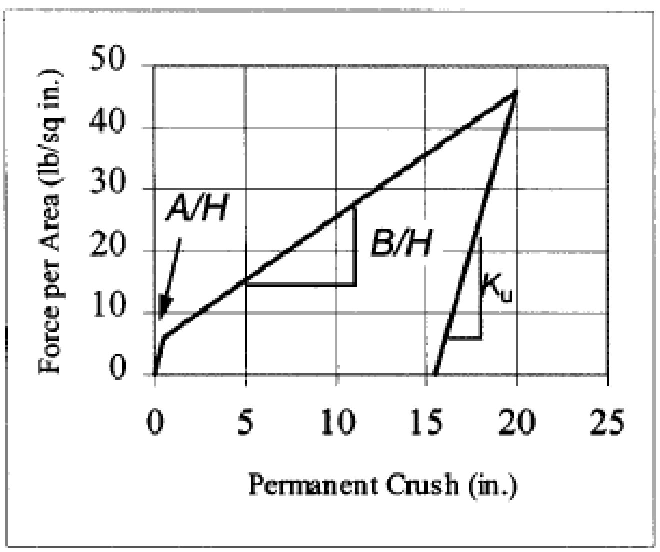

Figure 2: 3D force-per-area verses crush relationship. Image taken from: [7]

METHODOLOGY

Nine underride impact crash tests were compared to simulations at speeds ranging from 3 to 15 mph.

Goodwin et al. conducted 24 vehicle impacts into a barrier using three vehicles and a barrier [9]. The front and rear of each vehicle was impacted twice into the flat barrier and twice into the barrier after the barrier had been fitted with an attachment that produced vehicle contact above its bumper structure. The details of the testing methodology are described in the study [10]. All of the tests in the Goodwin et al. study were conducted at impact speeds less then 6 mph. The vehicles used in the testing were a 1990 Ford Escort, a 1989 Chevrolet Sprint, and a 1979 Cadillac Biarritz. A vehicle model similar to the 1979 Cadillac Biarritz was not available within the HVE vehicle library. Thus, the data from the Cadillac tests was not used in this study.

The distance from the front surface of the bumper to the sheet metal or lamp lens above the bumper was physically measured at three points along the bumper before and after each of the override tests. The vehicles were not repaired between the tests. The vehicle approach speed, impact speed and rebound speed were measured. Each vehicle was fitted with a single axis accelerometer rigidly mounted to the transmission hump just forward of the front seat to measure fore-aft acceleration.

The barrier used in the Goodwin tests was constructed of steel and was rigidly attached to anchors in the reinforced concrete floor. The steel impact face measured 1.9 meters wide by 1 meter high. The override attachment consisted of 15 cm tubes stacked to provide a “bumper” extending 30 cm from the face of the barrier. This “bumper” was 1.9 meters wide by 15 cm high and could be varied in height above the floor level. During the tests, the height was adjusted to just clear the top of the bumper cover of the vehicle being tested.

The HVE vehicle database contained a Ford Escort and Chevrolet Sprint, which were consistent with the vehicles used in the testing. The frontal stiffness coefficients for the Ford Escort were determined from an average of two NHTSA crash tests (0997 and 1323) as $A=208\ \frac{lb}{in}$ and $B=84\ \frac{lb}{in^2}$. The frontal stiffness coefficients for the Chevrolet Sprint were determined from a NHTSA crash test (1332) as $A=174\ \frac{lb}{in}$ and $B=85\ \frac{lb}{in^2}$. The vehicle dimensions and curb moments of inertia were adopted from Expert Autostats information for the Ford Escort and Chevrolet Sprint and scaled in HVE based on the test weights.

The impact barrier was created in HVE to represent the impact barrier used in the field test. The simulation barrier included two elements; a fixed barrier and an underride barrier. The fixed barrier was the SAE J850 fixed barrier included in the HVE vehicle database. The underride barrier was a modified version of the generic fixed barrier in the HVE vehicle database. The dimensions of the underride barrier matched the underride barrier dimensions documented in the Goodwin paper.

Marine et al. analyzed the results from a series of repeated-impact crash tests of a 1990 Ford Taurus sedan into a rigid, vertically offset barrier [11]. The impact speed was measured and the rebound speed was determined through integration of the longitudinal accelerometer data. The crush profile was measured after each impact.

The barrier used in the Marine tests was 92 inches wide, 60 inches tall and 12 inches deep. It was constructed on upright steel box segments that were filled with reinforced concrete and was supported by steel supports on the back side. The structure was anchored to a reinforced concrete footing. The vertically offset barrier was constructed of steel box tube sections welded to a plate that was bolted to the primary structure. The bottom of the offset barrier was positioned 20.5 inches above ground. Additionally, the offset structure was 12 inches deep.

The HVE vehicle database contained a Ford Taurus consistent with the vehicle used in the testing. The frontal stiffness coefficients for the Ford Taurus were determined from a NHTSA crash test (944) as A=287 $\frac{lb}{in}$ and B=100 $\frac{lb}{in^2}$ [12]. The vehicle dimensions and curb moments of inertia were adopted from Expert Autostats information for the Ford Taurus and scaled in HVE based on the test weights.

The impact barrier was created in HVE to represent the impact barrier used in the field test. The simulation barrier included two elements; a barrier wall and an offset barrier. The barrier wall was a modified version of the generic fixed barrier in the HVE vehicle database. The underride barrier was a modified version of the generic fixed barrier in the HVE vehicle database. The dimensions of the barrier wall and an offset barrier matched the dimensions documented in the Marine paper. Marine sequentially impacted the same vehicle into the barrier at different speeds. The equivalent barrier speed for each test was reported and that value was used as the impact speed in the Marine SIMON/DYMESH simulations. The authors are unaware of a methodology to sequentially crash the same vehicle in SIMON/DYMESH as in the testing performed by Marine.

The National Highway Traffic Safety Administration (NHTSA) conducted crash tests at various speeds using a 1990 Ford Taurus impacting a rigid underride guard [12]. In the testing, a 1990 Ford Taurus four-door sedan was subjected to repeated impacts into a fixed, rigid barrier that simulated rear underride guards found on heavy truck trailers. The underride guard was set-up such that no direct contact was made to the front bumper of the test vehicle. The vehicle dimensions and curb moments of inertia were adopted from Expert Autostats information for the Ford Taurus and scaled in HVE based on the test weights.

The impact barrier was created in HVE to represent the underride guard used in the field test. The simulation barrier included three elements; a square tube and two vertical supports. The three elements were each a modified version of the generic fixed barrier in the HVE vehicle database. The dimensions of the barrier wall and an offset barrier matched the dimensions documented in the NHTSA report.

In the vehicle editor, the stiffness coefficients derived from the NHTSA crash tests were input with the default conversion height of 30 inches. Each simulation was run at the given test speed and the default stiffness values. The peak acceleration, collision pulse, Delta-V, and maximum crush values were obtained after each simulation and compared to the test values. The conversion height and relaxation length were varied until the aforementioned variables were reasonably close to the measured values in the respective tests. Changing the conversion height linearly scales the A and B stiffness coefficients. Decreasing the conversion height increased the stiffness coefficients of the vehicles. In this work, the non-linear stiffness coefficient values C and D were left at their default values of 0 and the maximum crush and saturation crush were left at their default values of 60 inches. The relaxation length is related to the restitution of the collision [13]. The coefficient of restitution for each simulation was compared to test values, if reported.

RESULTS

The SIMON/DYMESH results that produced results closest to the test data were tabulated and are shown in Table 1. In each run, the default values underreported the peak acceleration and Delta-V. The conversion height required an adjustment in each test.

Table 1: Simulation Summary

Paper	Test	Method	Impact Speed (mph)	Conversion Height (inches)	Peak Acceleration (g's)	Collision Pulse (seconds)	Delta-V (mph)	Max Crush (inches)
Goodwin, 1999	Ford Escort	Test	2.6		1.90	0.100	3.6	1.90
	Low Speed	SIMON/DYMESH	2.6	25	1.91	0.134	3.2	3.00
	Ford Escort	Test	4.9		4.30	0.080	6.4	2.40
	High Speed	SIMON/DYMESH	4.9	15	4.22	0.108	5.8	4.30
	Chevrolet Sprint	Test	4.8		5.40	0.060	6.2	4.40
	High Speed	SIMON/DYMESH	4.8	10	5.32	0.060	5.5	3.40
Marine, 2005	Ford Taurus	Test	10.5		13.50	0.095	12.5	6.90
	1st Impact	SIMON/DYMESH	10.5	6	13.50	0.080	12.5	7.00
	Ford Taurus	Test	10.9		19.80	0.054	12.9	8.90
	2nd Impact	SIMON/DYMESH	10.9	2.75	19.90	0.055	12.7	5.20
	Ford Taurus	Test	14.4		22.38	0.065	16.3	12.50
	3rd Impact	SIMON/DYMESH	14.4	6	21.20	0.136	18.5	9.20
NHTSA, 1993	Ford Taurus	Test	10		10.90	0.125		1.50
	1st Impact	SIMON/DYMESH	10	5.5	10.41	0.15	12.6	7.30
	Ford Taurus	Test	15		16.90	0.125		8.10
	2nd Impact	SIMON/DYMESH	15	4	16.32	0.134	18.1	9.40
	Ford Taurus	Test	15		20.50	0.159		10.50
	3rd Impact	SIMON/DYMESH	15	3.5	19.99	0.159	17.5	8.80

PEAK ACCELERATION

The default conversion height underreported the peak acceleration by 2% to 58% of the measured value. The adjustment of the conversion height and relaxation length produced peak accelerations within approximately 5% in all nine of the tests. In five of the tests the SIMON/DYMESH simulations reported peak acceleration within 2% of the tests.

COLLISION PULSE

The default conversion height over-estimated the collision pulse by 47% to 537% of the measured value. The SIMON/DYMESH simulation reported longer collision pulse durations than the field measurements in five of the nine tests. Based on the optimal simulation results, the collision pulses within 0.01 seconds of the field measurements in four of the tests. SIMON/DYMESH determined the collision duration based on a force determination requirement to start and end the collision sequence.

DELTA-V

The default conversion height underestimated the Delta-V by 8% to 13% of the measured value in the Goodwin tests, and overestimated the Delta-V by 3% to 6% in the Marine tests. The underride guard tests conducted by NHTSA in 1993 did not report the Delta-V. In the remaining six tests, the adjustment of the conversion height and relaxation length produced changes in speed (Delta-V) during the collision within one mph of the reported values in five of the tests. In the sixth test, the Delta-V in the simulation was underreported by approximately 2 mph. This test was the third sequential impact on the Ford Taurus in the Marine study and also underreported the peak acceleration and over-estimated the collision pulse. As noted, SIMON/DYMESH cannot perform sequential impacts as performed in the Marine study. This could explain the difference in the aforementioned variables in the third sequential impact.

RELAXATION LENGTH

The HVE program has a default value for the relaxation length of 0.05. The relaxation length required to provide the optimum comparison between the test and simulation was between 0.04 and 0.07 in all of the tests. There was no noted trend between the relaxation length and the input variables. Fittanto found that adjustments in the relaxation length were required to adequately represent the collision pulse in the simulations [13].

MAXIMUM CRUSH

The default conversion height overestimated the maximum crush by 17% to 296% of the measured value. In the SIMON/DYMESH simulations, the crush was measured at a similar height to that reported in the tests. Based on the optimal simulation results, the maximum crush value was within two inches of the field measurements on six of the tests and within one inch on two of the tests.

CONVERSION HEIGHT

As noted, an adjustment of the conversion height from the default value of 30 inches was required. A notable relationship was found between the impact speed and conversion height. As the impact speed increased the conversion height decreased in a logarithmic regression as shown in [1]. The relationship and trend line are shown in Figure 3. The R^2 value for the regression curve was 0.85.

$$S = -10.73 \times \ln(H) + 31.572 \quad [1]$$

where:

S = Impact Speed (mph)

H = Conversion Height (inches)

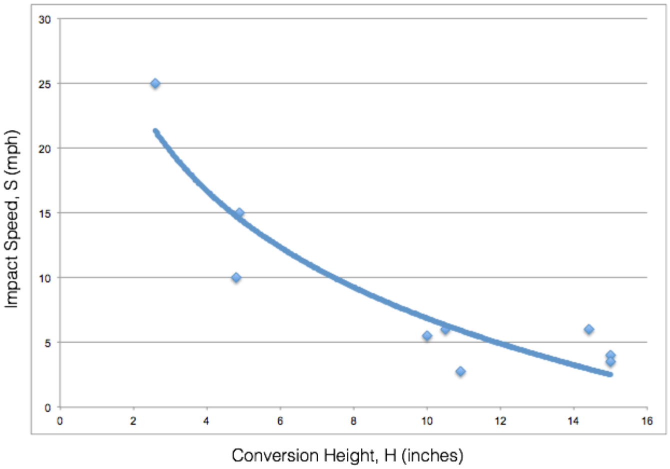

Figure 3: Relationship between Impact Speed and Conversion Height.

CONCLUSION

The simulations of the underride tests required adjustment of the conversion height to properly capture the peak acceleration, Delta-V, and collision pulse. The relaxation length sometimes required adjustment to appropriately capture the collision pulse. Based on the simulation results, SIMON/DYMESH can be used to simulate underride collisions with the appropriate modifications to the relaxation length and conversion height. The results presented in this study were based on nine tests using three vehicle models at impact speeds ranging from 2 to 15 mph. Additional analysis of impact speeds above 15 mph is recommended to ascertain the appropriate variable changes, if any, in the simulation program.

CONTACT

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