C31 Threshold Energy for Vehicle Damage in Rear Impact Collisions

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After attending this presentation, attendees will have a greater understanding of the relationship between speed, energy, and damage in collisions.

This presentation will impact the forensic science community by enabling attendees to more accurately reconstruct and analyze low-speed no-damage collisions.

Over the last two decades, more than a thousand full scale vehicle-to-vehicle collision tests have been performed by a variety of investigators and organizations. In addition, an even greater number of full scale vehicle-to-barrier crash tests have been performed. These tests have provided substantial amounts of data regarding damage and energy absorption in bumper-to-bumper impacts. The data has revealed that vehicles absorb significant amounts of energy before the onset of visible damage.

For the purposes of this paper, cosmetic damage is defined as scuffing or scraping and can be considered to be similar to minor parking lot contact damage. Bumper damage is defined as damage to the bumper plates, brackets, or assemblies, including bending or misalignment provided it is limited to the bumper assembly. Structural damage is defined as damage to the sheet metal or frame of the vehicle outside the bumper assembly area.

The theoretical background for the investigation is based on the principles of conservation of momentum, conservation of energy, and restitution. The relevant energy into a rear impact is the kinetic energy possessed by the vehicles. Based on conservation of energy, the energy into the collision must be accounted for in the energy transferred to the struck vehicle in the form of increased velocity, the energy dissipated in the components of the vehicles and the kinetic energy retained in the striking vehicle. Additional energy is dissipated in the form of noise and heat but these have not been shown to be significant in terms of reconstructing the impact.

Mathematically, the principle can be represented by:

$$KE\,(V1)_{\text{pre-impact}} + KE\,(V2)_{\text{pre-impact}} = KE\,(V1)_{\text{post-impact}} + KE\,(V2)_{\text{post-impact}} + C_{\text{rush}}\,E_{\text{nergy}}\,(V1) + C_{\text{rush}}\,E_{\text{nergy}}\,(V2)$$

In addition to the conservation of energy, momentum must also be conserved. The relationship of the final distribution of the momentum between the vehicles is a function of the restitution in the collision. In order to determine the total energy absorbed by the vehicles, the equations for conservation of momentum and kinetic energy were solved simultaneously using the appropriate restitution values.

In the course of the research,[1-15] 15 SAE technical papers, IIHS test data, other fully documented unpublished test results and NHTSA research dealing with full scale bumper impacts were reviewed. Of these, 10 papers were considered to possess sufficient data to perform an analysis of the energy absorption in vehicle-to-vehicle collisions. These papers covered 163 vehicle-to-vehicle, front-to-rear collisions. IIHS and NHTSA crash test data were considered in order to compare vehicle-to-vehicle collisions with vehicle-to-barrier collisions.

Due to test constraints, many of the published tests found used the same vehicles repeatedly. Often the tests were performed with human biomechanical considerations and did not continue until vehicle damage occurred. Additionally, many of the vehicles experienced both front and rear impacts. For the purpose of determining energy absorption, frontal and rear impacts on the same vehicle were considered as separate events although total energy absorption values from all impacts for each vehicle were considered. Table 1 provides a summary of the test data reviewed and the results of each set of collisions.

One concern with the data was the over representation of 1980s and 1990s vehicles. To evaluate the effect of using older vehicles, IIHS barrier impacts were researched.[16-20] Comparing older vehicles with newer models revealed that, in general, the cost of repair in the IIHS crash test has been decreasing since 1995, the earliest year reported. Nineteen vehicles were reported for which direct comparisons of crash test damage between a new model and an older model existed. Six examples were found where repair cost increased for the newer model. Only two of these increases were significant; comparisons between the 1997 and 1999 Mazda Protégé and the 1999 and 2004 Nissan Quest. Both increases correlated with significant model changes. If the vehicles suffered similar damage there would be an escalation expected for inflation. The decrease in repair costs can be attributed to improved vehicle body and bumper structure resulting in greater resistance to damage.

A comparison to barrier impacts revealed that damage to vehicles increased significantly when striking an immovable barrier. Table 2 provides a comparison using NHTSA crash tests for 1982 and 1984 Honda Accords.[21] In this case, a vehicle-to-vehicle collision at 60.1mph. resulted in only 90% of the crush seen in a vehicle-to-barrier collision at 34.8 mph., despite the vehicle-to-vehicle collision having 298% of the kinetic energy of the vehicle-to-barrier collision. The data show that damage to vehicles is much greater when colliding with a barrier rather than another vehicle, even at lower speeds.

Analysis of the data revealed that the onset of damage to the bumper systems beyond minor cosmetic damage typically did not occur until over 10,000 foot pounds of energy had been absorbed. Damage beyond the bumper system typically did not appear until energy values approaching 15,000 foot pounds were dissipated. The highest single impact with no damage dissipated 7,642 foot pounds of energy. These values cannot be considered the upper limit since some vehicles had cumulative energy absorption in excess of 30,000 foot pounds with no damage.

The data revealed that from a reconstruction standpoint, significant amounts of energy are absorbed in vehicle-to-vehicle, bumper-to-bumper collisions before the onset of damage to the vehicles. By using the energy threshold values determined in this paper, it should be possible to determine minimum impact speeds by combining momentum, energy and restitution (MER). MER analysis has been described in the past by some authors,[22-24] but has always been limited by the lack of data regarding the initial threshold energy values.

Bullet Vehicle	Target Vehicle	Total Energy Absorbed (ft-lbs)	Bumper Damage Onset (ft-lbs)	Structural Damage Onset (ft-lbs)
1984 Ford Mustang	1982 Toyota Celica	6,967	No Damage	No Damage
1986 Honda Accord	1988 Mazda 929	15,602	10,340[1]	15,601[2]
1988 Mazda 929	1986 Honda Accord	2,021	No Damage	No Damage
1988 Mazda 929	1989 Chevrolet Cavalier	10,646[3]	No Damage	No Damage
1989 Chevrolet Cavalier	1985 Chevrolet Celebrity	15,352	5,184[4]	8,651[5]
1982 Ford Escort	1981 Ford Escort	1,863	No Damage	No Damage
1983 Ford Escort	1981 Ford Escort	28,304	18,569[6]	No Damage
1997 Volvo 244	1976 Volvo 242	32,002	No Damage	No Damage
1984 GMC C-1500	1986 Dodge 300	7,060	No Damage	No Damage
1984 GMC C-1500	1984 Buick Regal	28,136[7]	No Damage	No Damage
1988 Ford Festiva	1988 Ford Festiva	535	No Damage	No Damage
1993 Ford Festiva	1988 Ford Festiva	3,449	No Damage	No Damage
1988 Ford Festiva	1993 Ford Festiva	2,058[8]	No Damage	No Damage
1988 Ford Festiva	1988 Ford Festiva	1,273	No Damage	No Damage
1986 Dodge 600	1984 Ford Wagon	2,951	No Damage	No Damage
1984 GMC 1500	1984 Ford Wagon	12,947	No Damage	No Damage
1984 Ford Wagon	1984 GMC 1500	4,243	No Damage	No Damage
1984 Buick Regal	1986 Dodge 600	4,337[9]	No Damage	No Damage
1986 Dodge 600	1984 Buick Regal	7,355[10]	No Damage	No Damage
1984 GMC 1500	1984 Buick Regal	1,127[11]	No Damage	No Damage
1984 Ford Wagon	1984 GMC 1500	4,998[12,13]	No Damage	No Damage
1981 Volvo 240DL	1990 Honda Accord	68,023	No Damage	No Damage
1981 Ford Escort	1982 Ford Escort	29,935	No Damage	No Damage

Table 1: Onset of bumper and structural damage for reported collisions

1. Damage was to both vehicles
2. Damage was to Accord. Total absorbed energy for collisions with the 929 was 17,623 with only damage to bumper assembly.
3. Total absorbed energy for collisions with the Mazda 929 was 28,269 ft-lbs with no reported damage.
4. Damage was to the Celebrity. Total absorbed energy for collisions with the Cavalier was 10,053 ft-lbs with no reported damage.
5. Damage was to the Cavalier. Total absorbed energy for collisions with the Cavalier was 14,520 ft-lbs with small buckle to fender.
6. Total absorbed energy for collisions with the 1981 Escort was 20,432 ft-lbs.
7. Total absorbed energy for collisions with the GMC C 1500 was 35,916 ft-lbs with no reported damage.
8. Each of the four vehicles in this series was involved in two collisions. Total absorbed energy for collisions with the 1993 Festiva was 5,508 ft-lbs with no reported damage.
9. Total absorbed energy for collisions with the Dodge was 14,643 ft- lbs with no reported damage and one test omitted.
10. Combining both tests results in 11,692 ft-lbs with no reported damage.
11. Total absorbed energy for collisions with the Buick Regal was 12,819 ft-lbs with no reported damage and one test omitted.
12. Total absorbed energy for collisions with the Ford was 26,027 ft-lbs with no reported damage.
13. Total absorbed energy for collisions with the GMC was 24,203 ft -lbs with no reported damage.

Test Type	Closing Speed in m.p.h.	Average Crush in mm	% Average Crush	% Kinetic Energy
VTB	34.8	637	100	100
VTV	60.1	571	90	298
VTV	55.6	567	89	255
VTV	54.9	570	89	249

Table 2: Damage comparison between vehicle-to-barrier (VTB) and vehicle-to-vehicle (VTV) collisions for 1982 and 1984 Honda Accords

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Collision, Low Speed, No Damage