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Ronald L. Woolley, Alan F. Asay and Dagmar Buzeman Jewkes
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ABSTRACT

Damage analysis methods in accident reconstruction use an estimate of vehicle stiffness together with measured crush to calculate crush energy, closing speed, and vehicle delta-V. Stiffness is generally derived from barrier crash test data. The accident being reconstructed often involves one or more conditions for which vehicle stiffness is not well defined by existing crash tests.

Massive moving barrier (MMB) testing is introduced as a tool to obtain additional and accident specific stiffness coefficients applicable for reconstruction. The MMB impacts a stationary vehicle of similar structure as the accident vehicle under accident-specific conditions like impact location, angle, over-ride / under-ride, offset and damage energy. A rigid or deformable structure is mounted to the front of the MMB, representative of the impacting structure in the accident.

Four illustrative tests are presented. A 1984 Honda Civic frontal impact (2x), a 1988 Dodge Caravan rear impact and a 1992 Isuzu Rodeo frontal offset / over-ride impact were conducted using the MMB. The tests demonstrated that the MMB testing method is an efficient means to attain stiffness, crush energy and acceleration data for specific accident conditions.

INTRODUCTION

Massive Moving Barrier (MMB) tests are intended to complement existing data bases. Since the late 1970's, tests have been conducted in accordance with Federal Motor Vehicle Safety Standards (FMVSS) 208, 214, and 301 for front, side and rear crash performance, respectively. Additionally, New Car Assessment Program (NCAP) tests have been performed, of which some are conducted against a load cell barrier consisting of 36 cells [NHTSA, 1999]. The crash database provides 30 and 35 mph frontal barrier data, side impacts at 33.5 mph by a 3000 pound moving deformable barrier at a 27 degree crab angle, and rear impacts at 30 and 35 mph by a 4000 pound rigid moving barrier. (3000 lb = 13345 N, 4000 lb = 17793 N, 30 mph = 48.3 kph, 33.5 mph = 53.9 kph, 35 mph = 56.3 kph)

In accident reconstruction, the vehicle damage may have occurred under one or more conditions for which the vehicle stiffness is not well defined by the existing crash test data. Such situations occur when crush is a result of over- or under-ride, when the direction of force differs markedly from above-mentioned test-conditions (oblique impact), when the involved structure is not represented in the database (side impact into axles) or in offset and narrow impacts (poles). A versatile test method is needed, which allows variation of impact conditions like amount of overlap, impact orientation and location, as well as impact speed.

OBJECTIVE

The objective of this paper was to introduce a new and versatile test method with a Massive Moving Barrier, as an effective tool for accident reconstruction purposes. Four tests are presented to illustrate the MMB test method and show that it provides a valid tool for estimation of vehicle stiffness data, nonlinear force-deflection characteristics, acceleration pulses, vehicle BEV's, and vehicle crush energy.

METHOD

GENERAL – Massive Moving Barrier tests involve driving a large, specially reinforced vehicle into a stationary target test vehicle. The structures of both vehicles experience the same force at each instant in accordance with Newton's 3rd Law. Typically the MMB is about 10 times heavier than the test car. Since crash delta-V is proportional to the closing speed and the ratio of opposite vehicle mass to total mass, a delta-V on the test car of 9/10th of the impact speed is achieved while the MMB experiences a speed change of only about 1/10th the impact speed. The low delta-V allows the MMB to be driven into the pre-positioned test vehicle at various impact angles and/or locations. Repeated hits into the same structure can be performed easily. MMB testing simplifies utilization of previously wrecked cars for test vehicles since they remain stationary until impact.

MMB testing is dynamically the opposite of fixed barrier testing in that a stationary test vehicle is accelerated through a change in velocity and then slides to rest over some distance whereas in fixed barrier testing the car is decelerated to a stop from an initial impact speed.

TEST PROCEDURE – One of the more obvious differences between MMB testing and the more conventional test track method is the absence of a test track. Instead, a paved road is required of sufficient length and width to accelerate the MMB up to impact speed and to accommodate post-impact run-out of both the test vehicle and MMB. Since both vehicles are moving post-impact at a speed of roughly 9/10th of the impact speed, this becomes an essential safety consideration. The four tests presented in this paper were run on low traffic roads, closed briefly during testing.

INSTRUMENTATION – Instrumentation consisted of two tri-axial piezo-resistive accelerometers (range = 200 g's, accuracy = 2%) mounted to the body structure at the base of the "B" pillars on the test vehicles. Two capacitive type accelerometers (range = 10 g's, 2% accuracy) were mounted on the MMB frames behind the cab for the Honda and Caravan tests. All accelerometers were connected to "Data Brick" acquisition systems provided by GMH Engineering. The data was acquired in accordance with the SAE J211/1 MAR95 Recommended Practice. All channels were sampled at 12.8 kHz with anti-aliasing filters of the channel frequency class (CFC) 1000. Right and left acceleration pulses were averaged and filtered with a SAE CFC 60 filter when used for comparisons of acceleration or MMB force data, and with a SAE CFC 180 filter before integration to velocity and displacement time-histories. The speed of the MMB just prior to impact was measured with two laser speed traps (accuracy of 0.5%) provided by GMH.

DOCUMENTATION – Honda and Caravan tests were video taped from various angles. All tests were photographed with 35 mm print film to document damage and test conditions.

CRUSH PROFILES – Residual or post-impact crush profiles were obtained by measuring a set of pre-defined points on the vehicle both before and after testing, using a total-station surveying instrument. The two 3-dimensional data sets were then aligned by matching three widely spaced points on the least damaged part of the tested car with corresponding points on the undamaged car. Displacement of corresponding points in the damaged zone provides both 2D and 3D residual crush profiles and displacement vectors.

ANALYSIS

NOTATION – In the equations which follow, subscripts "a" and "b" represent accident vehicles, subscript "c" represents the test car which corresponds to vehicle "a" in the accident and subscript "MMB" represents the massive moving barrier. V_{MMB} is the average speed of the MMB as measured by the speed trap.

TEST DELTA-V – Test vehicle delta-V is given by the equation of conservation of momentum with zero restitution.

$$Delta - V_c = \frac{M_{MMB}}{M_{MMB} + M_c} V_{MMB} \qquad (1)$$

VEHICLE DYNAMICS – The impact force time-history on the test vehicle was calculated as the average MMB longitudinal acceleration pulse, multiplied by the mass of the MMB. It is possible to use the acceleration of the MMB for this calculation, since the conservation of its mass is guaranteed by its rigid structure. The acceleration of the test car cannot be used for this purpose, since the vehicle mass to be decelerated decreases with car deformation. An overestimate of the barrier-force would be attained from initial-mass times test-car acceleration [Fossat,1994]. Collision or MMB force was adjusted by a small offset to attain a zero force at time zero.

$$F(t) = M_{MMB} * a(t)_{MMB} \qquad (2)$$

Velocity – time graphs were obtained by integration of the average vehicle acceleration trace. The MMB result was matched with the pre-impact speed as measured by the speed trap.

$$V(t)_{MMB} = V(0)_{MMB} - \int a(t)_{MMB}\, dt \qquad (3)$$

$$V(t)_c = \int a(t)_c\, dt \qquad (4)$$

Longitudinal displacements in these tests were approximated by double integration of the average longitudinal acceleration pulse of both vehicles. The difference between the MMB and test-car displacements was then taken as an approximation of dynamic crush, $X(t)_d$. The result's offset was set to zero. Accelerometer calibration errors and vibration errors were then minimized by scaling the entire dynamic crush trace to match the calculated residual crush, $X_{c,r}$, to the measured crush, $X_{m,r}$.

$$X(t)_c = \int \left(\int a(t)_c \, dt + 0 \right) dt \qquad (5)$$

$$X(t)_{MMB} = \int \left(\int a(t)_{MMB} \, dt + V_o \right) dt - X_o \qquad (6)$$

$$X(t)_d = [X(t)_c - X(t)_{MMB}] * \frac{X_{m,r}}{X_{c,r}} \qquad (7)$$

DAMAGE ANALYSIS – Massive Moving Barrier testing is conducted to determine missing or inadequately defined crash stiffness data. Test conditions are selected with the objective of approximating either damage energy or vehicle delta-V by using rough estimates of stiffness coefficients in a damage analysis model. Or, given an estimate of the ratio of stiffness of the collision partners, an estimate of the damage energy for one car may be obtained through Newton's 3rd law, a crush model, and an estimate of the damage energy for the other car. The vehicle stiffness and subsequent test conditions (if needed) are then refined by the new MMB test data.

Damage analysis, as used in accident reconstruction, is generally based upon a force deflection model such as the linear spring model of CRASH3 [Campbell, 1974; NHTSA, 1981]. Extensions to the basic model have been made for non-linear effects such as force saturation [Strother, 1986; Strother, 1990; Fonda, 1990; Woolley, 1991; Varat, 1994; Wood, 1997]. The basic linear spring model is written as an integral over the crush profile with stiffness coefficients: A, B, G [Campbell, 1974]. However, this is a quadratic, two parameter model with $G=A^2/2B$.

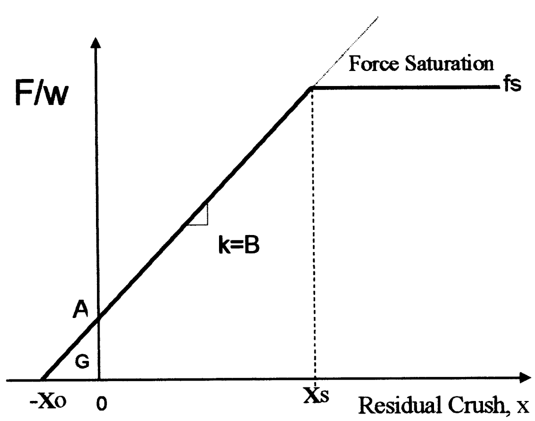


Figure 0. FForce Saturation Model Notation.

To emphasize the linear spring basis of the model and for analytical convenience, this integral may be written in factored form using linear spring notation where k is the spring stiffness per unit width, *w*, and x_o is the structural recovery distance between dynamic and residual crush. The first term of Equation (8) represents the basic Campbell model and the second term provides the force saturation extension in which f_s represents the force saturation level and x_s is the corresponding crush value at saturation [Woolley, 1991].

$$E = \int_0^{w_c} \frac{1}{2} k (x + x_o)^2 dw - n \int_0^{w_c} \frac{1}{2} k (x - x_s)^2 dw \qquad (8)$$

$$Where \quad n = 0 \quad for \;\; x <= x_s$$

$$n = 1 \quad for \;\; x > x_s \qquad f_s = k(x_s + x_o)$$

$$k = B \qquad x_o = A/B \qquad G = 1/2 \, k x_o^2 = A^2/2B$$

When the crush profile is essentially uniform, as in barrier crush, then the integral may be represented by an average crush integrated over a characteristic width, w_c. For the constant stiffness model (only the first term of Equation 8), the square root of the equation provides a linear result, with slope, $\sqrt{k}$, and intercept value, x_o [Woolley, 1983].

TEST / ACCIDENT ENERGY AND DELTA-V – In the accident reconstruction, the crush energy for both collision partners must be added to obtain the total crush energy in the accident (E_a+E_b). This total damage energy equals the difference in the kinetic energy before and after the impact, neglecting tire forces. By combining the principles of conservation of energy and conservation of momentum the damage energy can be related to the closing velocity (Equation 9a). The vector difference of the delta-V's of the two collision partners is equal to the vector difference between closing and separation speed.

$$(E_a + E_b) = \frac{1}{2} \frac{M_a M_b}{M_a + M_b} (V_{cl}^2 - V_{sep}^2) \qquad (9a)$$

The same method is used to calculate the MMB impact velocity necessary to match the damage of the test car, "c", and accident car, "a" (Equation 9b):

$$E_{a\,Acc} \approx E_{c\,Test} = \frac{1}{2} \frac{M_c M_{MMB}}{M_c + M_{MMB}} V_{MMB}^2 \qquad (9b)$$

Usually, the mass of the test car, M_c, is selected to closely match the mass of the accident car, M_a. However, it should be noted that the delta-V experienced by the test car generally will not match that of the accident car when matching the damage energy. The delta-V match is related to the total crush energy and mass ratio of the two accident vehicles (car a and car b), as well as the mass of the MMB. The damage energy in the accident and test can be rewritten in terms of the delta-V:

$$(E_a + E_b)_{Acc} = \frac{1}{2}\frac{M_a}{M_b}(M_a + M_b)\ \Delta V^2_{a\,Acc} \quad (10)$$

$$E_{c\,Test} = \frac{1}{2}\frac{M_c}{M_{MMB}}(M_c + M_{MMB})\ \Delta V^2_{cTest} \quad (11)$$

The test delta-V thus relates to the accident delta-V by:

$$\frac{\Delta V_{a\,Acc}}{\Delta V_{cTest}} = \sqrt{\frac{E_{a\,Acc}}{E_{cTest}}\left(1+{}^{E_b}\!/_{E_a}\right)_{Acc}\frac{1+{}^{m_c}\!/_{m_{MMB}}}{1+{}^{m_a}\!/_{m_b}}} \quad (12)$$

When the damage energy is matched, the test delta-V approximates the accident vehicle's when the crush energy ratio of the two accident vehicles is inversely proportional to their mass ratio, and the MMB mass is many times larger than that of the accident car. In the special case comparing an MMB test with a rigid fixed barrier test, $m_b=\infty$ and $E_b=0$. Then the delta-V's would match if damage energy in the MMB test were larger than in the fixed barrier by the mass ratio of test car to MMB ($E_{cTest}/E_{aAcc} = 1+m_c/m_{MMB}$).

Equations 9 – 12 apply to a collinear collision. For oblique collision MMB testing in which rotational terms are significant, use of a 2D collision model computer program will provide more accurate delta-V and damage energy computations.

It is not essential to match either the damage energy or delta-V given the objective of vehicle stiffness determination via MMB testing for an unusual crash configuration. The task is simpler and fewer test runs are needed if the goal is to exceed the accident damage in the test in order to provide interpolation rather than extrapolation stiffness data. Considering the potential delta-V mismatch, the added complication of additional instrumentation to provide occupant injury data during MMB testing may not be worthwhile.

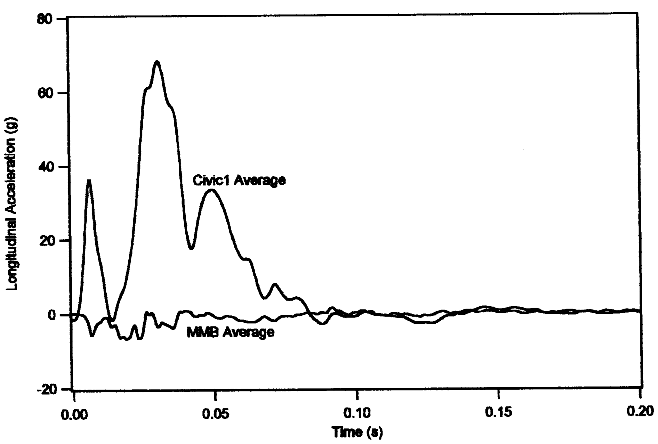
MMB VALIDATION TEST – 1984 HONDA CIVIC FRONTAL IMPACT

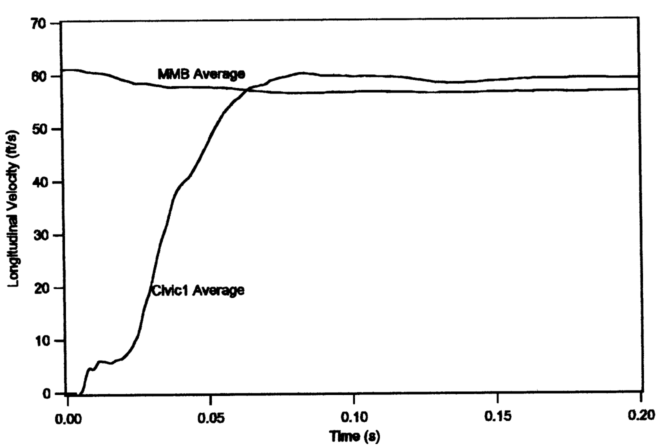
The Massive Moving Barrier was driven into the front of a stationary 1984 Honda Civic at a speed of 41.4 mph (66.6 kph) (Table 1). The front face of the MMB consisted of a flat, rigid barrier similar to the fixed barrier face in FMVSS 208 and NCAP tests. The Honda Civic was positioned such that the impact was head-on with full engagement of the front structures (Figure 1). The impact speed was selected such that the delta-V in the test exceeded the delta-V of the NCAP test.

Figure 1. Frontal Crash Test of the MMB with a 1984 Honda Civic.

Table 1. Frontal Crash Test; 1984 Honda Civic with MMB

	1984-Honda Civic 4dr		MMB	
	US units	SI	US Units	SI
Mass	1960 lb	889 kg	26,760 lb	12138 kg
Speed	0 mph	0 km/h	41.4 mph	66.6 km/h
Delta-V	38.6 mph	62.1 km/h	-2.8 mph	-4.5 km/h
Ave. Crush	26.6 inch	67.6 cm	0 inch	0 cm
Max. Crush	27.2 inch	69.1 cm	0 inch	0 cm
PDOF	0 degree		0 degree	
Crush Energy	104,637 ft-lbf	141,869 Nm	0 ft-lbf	0 Nm
$\sqrt{2E}/w_c$	201.3 $\sqrt{lbf}$	424.6 $\sqrt{N}$	0 $\sqrt{lbf}$	0 $\sqrt{N}$
Max. Force	170,744 lbf	759,640 N	170,744 lbf	759,640 N
Peak Acceleration	64.8 g		6.7 g	
BEV	40.0 mph	64.4 km/h	0 mph	0 km/h





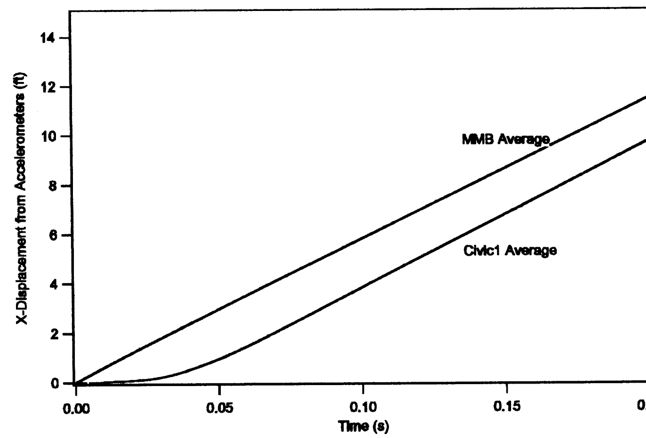


Figure 2. Acceleration, Velocity, and Displacement Data for the Civic / MMB Test. (3 data traces).

Figure 2 presents the longitudinal acceleration, velocity and displacement of the MMB and the test-car as measured and calculated in accordance with equations 3-6. NHTSA conducted a load cell barrier test on a 1984 Honda Civic as part of the NCAP test program (NCAP-694). In this test the Honda was towed into a fixed barrier which was fitted with 36 load cells (4 rows of 9 cells each). The output from each cell was added, and the total force of all 36 cells was given for the test. The force-deflection curve of the MMB to Civic test was validated against that measured in NCAP-694 test. The dynamic deformation of the Civic was obtained using equation (7) and is compared to that found through double integration of the acceleration in the NCAP test (Figure 3). The crush in the MMB test increased more quickly, as expected from the higher closing speed (41.4 mph (66.6 km/h) vs 35 mph (56.0 km/h) in the NCAP).

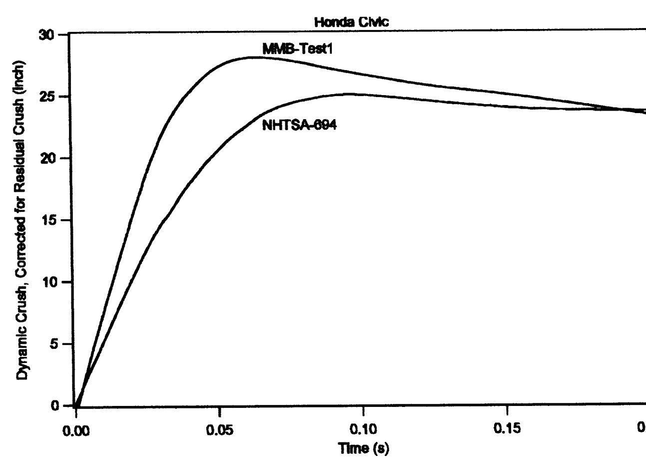


Figure 3. Dynamic Crush of the Honda Civic.

Figure 4 gives the force - time history for the NCAP test 694 and for the MMB test as calculated from the mass times acceleration of the MMB. Both methods show similar force peaks and rise times.

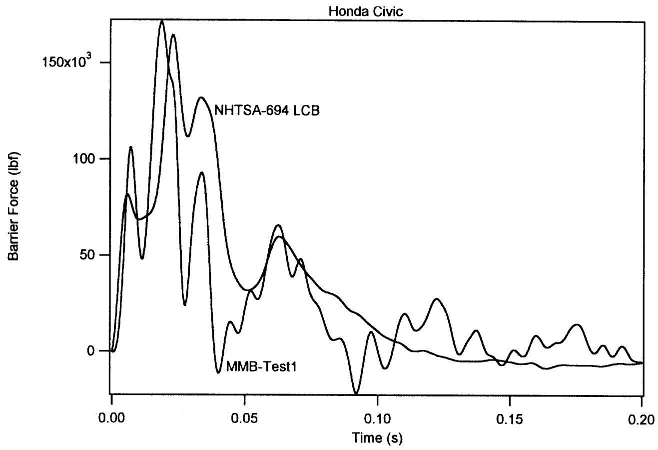


Figure 4. Comparison of NCAP-694 Load Cell Barrier Force time-history with MMB Force on the Honda Civic.

Force-deflection curves as measured by the NHTSA load cell barrier and MMB agree well. Both show local force peaks at similar deflections of approximately 6 inches (15 cm), 14 inches (36 cm) and 23 inches (58 cm) (Figure 5). Differences in the two curves reflect vibrations of the MMB frame to which the accelerometers were mounted, and differences between otherwise identical car-models. The maximum dynamic crush and the crush energy were higher in the MMB test, due to the greater delta-V in the MMB test than in the NCAP.

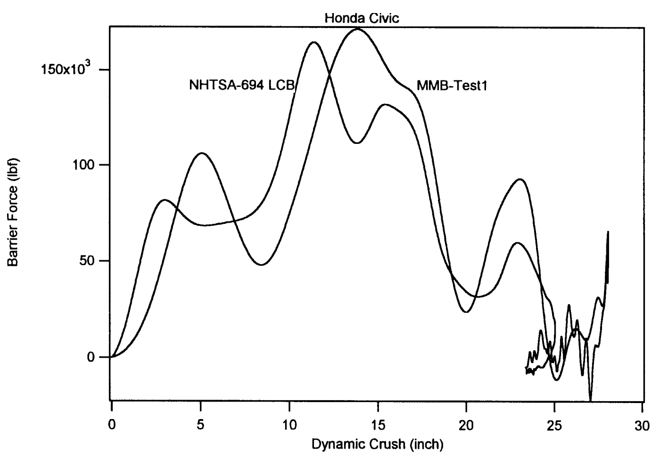


Figure 5. Comparison of Force-Deflection Curves for NCAP-694 Load Cell Barrier Test and MMB Test on the Honda Civic.

Several FMVSS-208 and NCAP tests have been conducted on 1984 and 1983 Honda Civics. These are NHTSA tests 694 and 705 for the 1984 model Civic and NHTSA tests 1892, 2066, 2000, 1801, and 1725 for the 1983 model year Civic. The crush energy parameter, √(2E/w), and average residual crush were calculated for these tests and compared to those of the MMB test (Figure 6).

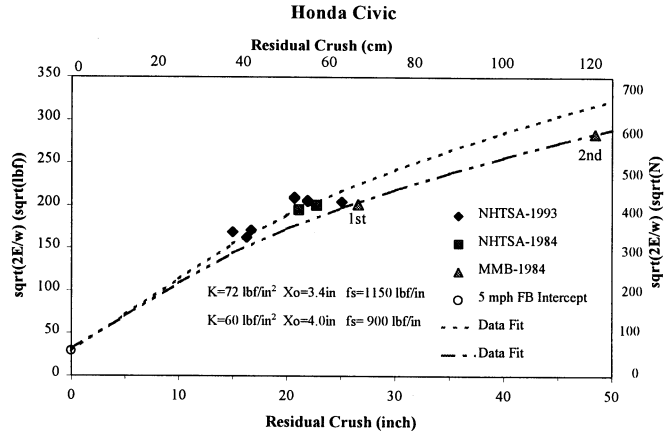


Figure 6. Crash Plot ($\sqrt{2E/w_c}$ vs Residual Crush) of Honda Civic Frontal Test Data.

A straight line through the data is indicative of a constant stiffness over the range of the data. A curve with decreasing slope with greater crush is indicative of decreasing stiffness coefficient or force saturation. The 1984 Civic data and the MMB test data point reflect a force saturation trend in Figure 6. The MMB test data point at high residual crush is the result of a repeated crash by the MMB into the Civic (see below). Damage to the Civic in the 1st test was documented as described previously, and the resulting damage profile is shown in Figure 7.

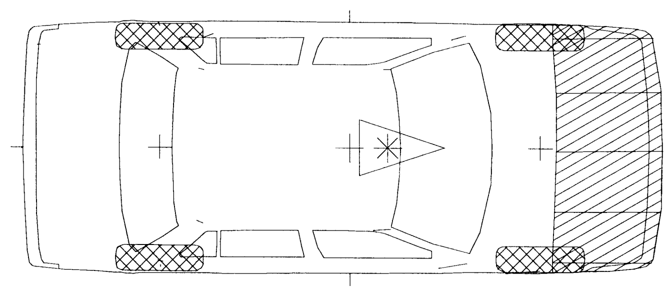


Figure 7. Honda Civic Damage Profile after 1st Impact

MMB TEST 2: SECOND REPETITION – 1984 HONDA CIVIC FRONTAL IMPACT

The Honda Civic from test 1 was again positioned on the roadway with equal orientation as the first test, and the post-crash vehicle attitude was not adjusted. A second full frontal impact test was conducted at an MMB speed of 41.4 mph (66.6 kph), Figure 8. Table 2 gives the conditions for this repeated test. In this test, the high crash severity caused the cables to be cut on the Civic by deformation of the compartment, and the accelerometers mounted on the MMB to exceed the range. Hence, the force-deflection plot for this crash was invalid. MMB accelerometer extremes at these high force levels appear to be a combination of excessive vibration of the MMB frame to which the accelerometers were mounted and the relative motion of various MMB masses such as engine, bed, rear axle, etc. The acceleration trace from the surviving instrument on the Civic is shown in Figure 9, with a peak acceleration of 88 g.

Figure 8. Repeated Frontal Crash Test of the MMB with a 1984 Honda Civic.

Table 2. Repeated Frontal Crash Test; 1984 Honda Civic with MMB

	1984 Honda Civic 4dr		MMB	
	US Unit	SI	US Unit	SI
Mass	1960 lb	889 kg	26,760 lb	12,138 kg
Speed	0 mph	0 km/h	41.4 mph	66.6 km/h
Delta-V	38.6 mph	62.1 km/h	-2.8 mph	-4.5 km/h
Equivalent Delta-V	54.6 mph	87.9 km/h	*	*
Ave. Crush,	48.5 inch	123.2 cm	0 inch	0 cm
Max. Crush	49.0 inch	124.5 cm	0 inch	0 cm
PDOF	0 degree		0 degree	
Crush Energy	208,228 ft-lbf	282,319 Nm	0 ft-lbf	0 Nm
$\sqrt{2E/w_c}$	283.9 √lbf	598.8 √N	0 √lbf	0 √N
Max. Force	*	*	*	*
Peak Acceleration	88.6 g		*	*
BEV	56.4 mph	90.8 km/h	0 mph	0 km/h

(Note: * MMB accelerometers exceeded range.)

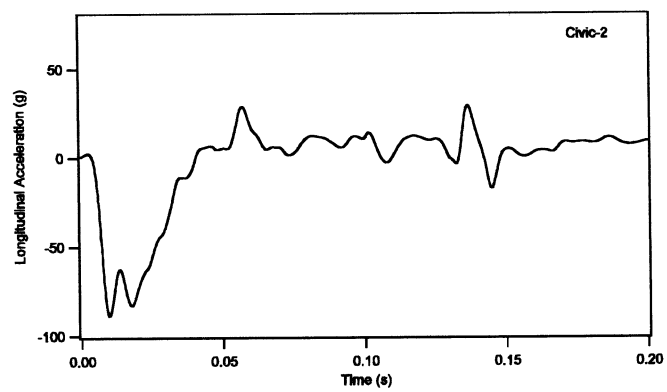


Figure 9. Acceleration of the Honda Civic During the Repeated Impact.

It was learned that this 15 year old car had previously been repaired in the rear half of the car. This repair, plus the excessive crash of 56 mph BEV (90 kph) caused the unlocked doors to open during the repeated crash, which reduced the vehicle stiffness. Hence, the crush vectors shown graphically in Figure 10 exceed those which would have resulted without door openings. The reduced stiffness effect is reflected in Figure 6, where the MMB crush data follows the force saturation trend as previously described, although the crush required slightly lower deformation energy relative to the other data points.

The validity of the force / deflection curve for the 2nd Civic test is questionable for the reasons stated above. The force-deflection curve is not presented in this paper.

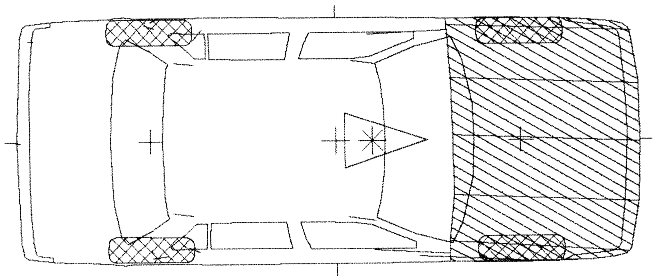


Figure 10. Honda Civic Damage Profile after 2nd Impact.

MMB TEST3: REAR IMPACT OF 1988 DODGE GRAND CARAVAN

In the third example test, a 1988 Dodge Grand Caravan was rear-impacted by the MMB at a speed of 41.4 mph (66.6 kph) (same speed as for the Civic tests because the MMB engine is governed). The result was a 36.75 mph delta-V. This test is vastly more severe than the FMVSS-301 or NCAP rear impact tests because of the large weight of the MMB and the higher impact speed (Table 3). In the NHTSA tests, the delta-V is roughly half the test closing speed depending upon test vehicle weight, which for this test car would result in 16.2 mph delta-V in the FMVSS-301 and 18.9 mph delta-V in the NCAP (26.0 or 30.4 kph).

The focus of this test was examination of the post-impact dynamics of the Caravan with respect to a stationary car located 10 feet ahead, which was simulated by foam core side panels (Figure 11). In the accident under reconstruction, the Caravan was struck by a semi tractor-trailer and pushed into the rear of the next car. This produced an unusual and unexplained rear crush dynamic on that car.

Table 3. Rear Impact Test; 1988 Dodge Grand Caravan with MMB

	1988 Dodge Grand Caravan		MMB	
	US Unit	SI	US Unit	SI
Mass	3420 lb	1551 kg	26,968 lbf	12,232 kg
Speed	0 mph	0 km/h	41.4 mph	66.6 km/h
Delta-V	36.75 mph	59.1 km/h	-4.66 mph	-7.5 km/h
Ave.Crush	31.7 inch	80.5 cm	0 inch	0 cm
Max. Crush	32.3 inch	82.0 cm	0 inch	0 cm
PDOF	180 degree		0 degree	
Crush Energy	173,900 ft-lbf	235,777 Nm	0 ft-lbf	0 Nm
√2E/Wc	244.6 √lbf	515.9 √N	0 √lbf	0 √N
Max. Force (*)	215,633 lbf	959,183 N	215,633 lbf	959,183 N
Peak Acceleration	47.1 g		7.9 g	
FB BEV	39.0 mph	62.8 km/h	0 mph	0 km/h
Equivalent-BEV (4000 lbf MB)	53.1 mph	85.5 km/h	0 mph	0 km/h

(*) Observed force extremes are uncertain.

Figure 11. Rear Impact of a 1988 Dodge Grand Caravan by the MMB.

Instrumentation in and data-reduction processing of the Caravan test was identical to that of the Civic tests. The force-deflection data was again obtained from equations (2) and (7) and is shown in Figure 12. The observed result is a rapid rise to a peak force followed by plastic yielding of the rear structures at low force followed by a rise to an approximately constant force of around 100,000 pounds. MMB frame vibration and relative motion of various MMB masses amplified extremes in the force measurement at these high loads in the current MMB structure. Hence, peak and minimum force values are uncertain. Additional testing to evaluate the size of the error is warranted.

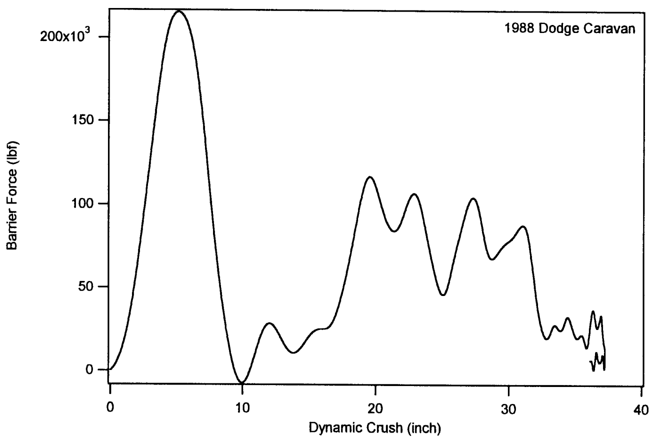


Figure 12. Observed Force-Deflection for Rear Impact of a 1988 Dodge Grand Caravan (Extreme values exaggerated by MMB accelerometer motion).

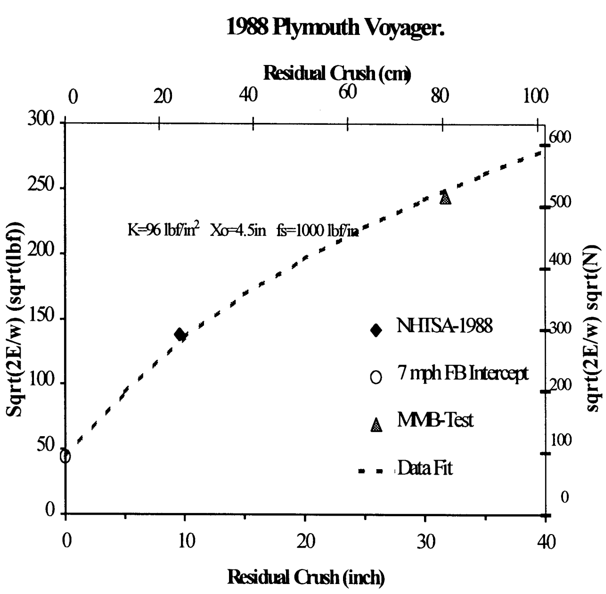


Figure 13. Crash Plot for Rear Impact Tests of 1988 Plymouth Grand Voyager and Dodge Grand Caravan.

The rear axle was pushed downward as it was driven forward, causing the rear of the van to lift upward. Rear average crush was measured post-impact at 32 inches (81 cm), more than 3 times the 9.6 inches of crush (24 cm) in the 30 mph FMVSS-301 NHTSA-1262 test. The required impact speed would have been 53.1 mph (85.5 kph) to produce the same damage to the Caravan, were the MMB replaced by a 4,000 pound barrier.

The crash plot for the 1988 Caravan consists of three data points, NHTSA test 1262 on a 1988 Plymouth Voyager (same structure as Dodge Caravan), the MMB test run at 41.4 mph (66.6 kph) and a 7 mph (11.3 kph) fixed barrier assumed intercept value [Woolley 1991]. These three data points indicate that the rear structure could be modeled by a constant stiffness and force saturation model (Figure 13). Figure 14 shows the extent of the residual damage to the Caravan in this crash.

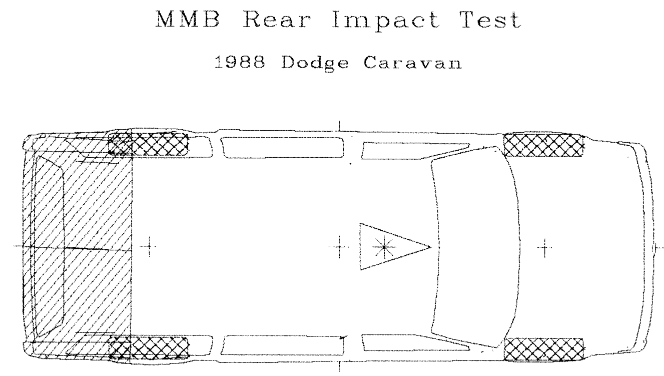


Figure 14. Damage Profile at the Rear of a 1988 Dodge Grand Caravan.

MMB TEST 4: OFFSET /OVERRIDE FRONTAL IMPACT OF A 1992 ISUZU RODEO

In test example 4, the front face of the MMB was mounted to accommodate an offset – override crash into the front driver’s side of a 1992 Isuzu Rodeo. The amount of the overlap (20 %) and the override (24.5 inches (62 cm) ground to MMB lower edge) was set to model a specific accident being reconstructed. The Rodeo was set at an angle of 4 degrees to the path of the oncoming MMB. With this alignment the corner of the MMB directly contacted the top of the left front tire as it passed through the fender but missed the engine entirely.

Figure 15 shows the pre-test setup and post-test vehicles at rest. No video was taken of this test. The purpose of the test was to obtain the acceleration of the Rodeo under these accident conditions for studies of restraint system performance via sled testing. Therefore the Rodeo was instrumented with triaxial accelerometers mounted to the base of the “B” pillars. Following the MMB test, the Rodeo compartment was converted into a sled buck.

Test results are given in Table 4. The longitudinal acceleration in this test is shown in Figure 16. Three peaks are observed. These are believed to correspond to the MMB interaction with the top of the bumper of the Rodeo, with the tire, and with the “A” pillar, respectively. The tire impact gave rise to the largest acceleration without deflating the tire. Because of the offset, the Rodeo rotated and therefore produced different left / right accelerations.

Figure 15. 1992 Isuzu Rodeo Test Setup and Post-Test Rest Positions.

Table 4. Frontal Offset Override Impact Test; 1992 Isuzu Rodeo with MMB

	1992 Isuzu Rodeo		MMB	
	US unit	SI	US unit	SI
Mass	3720 lb	1687 kg	25,240 lb	11,449 kg
Speed	0 mph	0 km/h	22.9 mph	36.9 km/h
Overlap	~ 20%		*	
Top of Bumper	28.5 inch	72.4 cm	*	*
Override Height	24.5 inch	62.2 cm	*	*
Bottom of frame	16 inch	40.6 cm	*	*
Crush Width	12.6 inch	32 cm	*	*
Delta-V	20.0 mph	32.2 km/h	-2.94 mph	-4.7 km/h
Ave. Crush, rms	33.1 inch	84 cm	0 inch	0 inch
Max. Crush	34.2 inch	86.9 cm	0 inch	0 cm
PDOF	-10 degree		0 degree	
Crush Energy	56,837 ft-lbf	77,061 Nm	0 ft-lbf	0 Nm
√2E/Wc	329.2 √lbf	694.3 √N	0 √lbf	0 √N
Peak Acceleration	8.9 g		*	
BEV	21.4 mph	34.4 km/h	0 mph	0 km/h

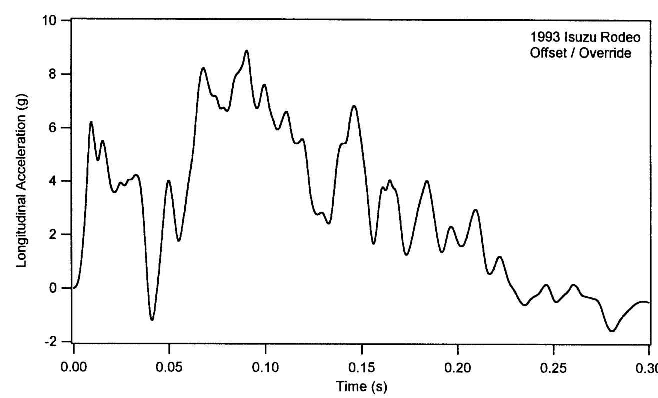


Figure 16. Isuzu Rodeo Average Longitudinal Acceleration.

The crush energy parameter, √(2E/w), v. residual crush is presented in Figure 17 for NHTSA frontal impact tests 1586, 1891, 2313 and 2406 on 1991 – 1996 Isuzu Rodeos. The assumed intercept of 5 mph (8 kph) is also shown [Strother 1990]. These data imply a straight line, or constant stiffness for the frontal tests. The graph includes the result of the offset / override crash. The average residual crush in this test required lower damage energy per unit width than the NHTSA tests. This is caused by a relatively low local stiffness per width unit of the structure impacted in this specific accident compared to the average full frontal stiffness. Buzeman-Jewkes et al. (1999) has previously indicated the importance of local stiffness data for accident reconstruction applications.

Residual damage to the Rodeo front is shown in the photographs (Figure 15) and depicted as displacement vectors in Figure 18. It is noted that displacement of the right side of the hood is the result of induced damage.

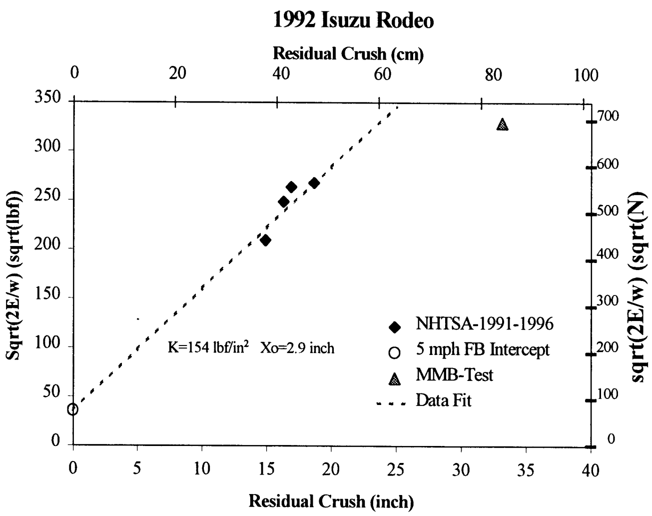


Figure 17. Crash Plot for Isuzu Rodeo Offset Override Impact.

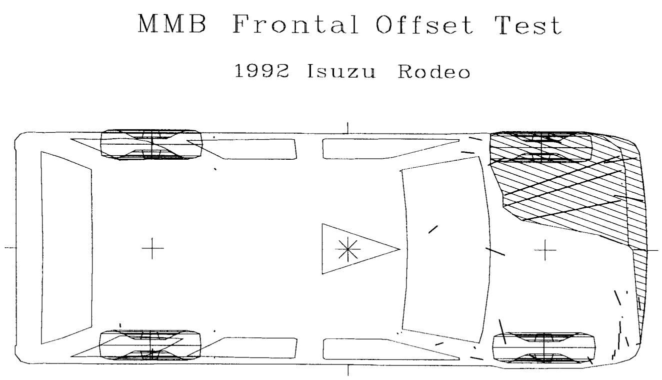


Figure 18. Damage Profile at the Left Front of a 1992 Isuzu Rodeo

CONCLUSIONS

Massive moving barrier (MMB) crash testing for accident reconstruction purposes provides an efficient means for generating stiffness and crush energy data under unique conditions. This data supplements existing crash test data of the NHTSA database and other sources. In principle, a wide variety of test conditions can be obtained by modification of the impacting front face attached to the MMB. The stationary test car can be set at the appropriate angle to attain the desired principal direction of force and strike the appropriate vehicle structure.

The great mass of the MMB minimizes its delta-V and rotation during impact while causing great speed changes in the test-car. The tests showed that vehicle delta-V in excess of NCAP tests can be successfully performed either directly or by applying the repeated crash-test method. Repeated tests are straightforward in their setup, and can provide energy vs. crush data at damage levels well in excess of FMVSS test damage.

MMB testing is dynamically the opposite of fixed barrier testing in that a stationary test vehicle is accelerated through a change in velocity and then slides to rest over some distance whereas in fixed barrier testing the car is decelerated to a stop from an initial impact speed.

A central advantage of the MMB test method is the absence of a permanent testing facility, while providing the versatility of contact area, impact location and orientation, colliding structures and impact speed. Low velocity change of the MMB allows the MMB to be driven into contact with the test vehicle and braked to a stop after impact. The central disadvantage is location of a suitable test roadway with sufficient width to safely accommodate the post-impact run-out of both test vehicle and MMB. Simulations of the proposed test should be performed beforehand to evaluate the potential for unanticipated events.

MMB tests generally can not match both accident damage energy and delta-V in the same test. Therefore, instrumentation for occupant injury measures is discretionary, subject to evaluation for each test condition and objective.

It is not essential to match either the damage energy or delta-V given the objective of vehicle stiffness determination via MMB testing for an unusual crash configuration. The task is simpler and fewer test runs are needed if the goal is to exceed the accident damage in the test in order to provide interpolation rather than extrapolation stiffness data.

Crush energy and frontal crush in the MMB-Civic tests were compared to corresponding NHTSA test data as validation of MMB testing. The force-deflection characteristic obtained from accelerometers on the MMB and Civic in test 1 was compared to corresponding NCAP load cell barrier data. The results indicated that force-deflection and nonlinear vehicle stiffness observations can be obtained through MMB testing for accident reconstruction purposes. A test-vehicle delta-V can be obtained comparable to NCAP frontal barrier tests, and an even higher delta-V can be achieved by a repeated impact.

The second crash repetition on the Civic produced excessive vibration of the MMB accelerometers, indicating that the accuracy of peak force measurement is diminished at MMB acceleration levels exceeding approximately 0.7 g's with current MMB structure and instrumentation. Improvement requires more rigid accelerometer mounts on the MMB to reduce vibration, and the addition of other accelerometers on major masses of the MMB that are capable of elastic relative motion at high impact loads.

The four tests illustrate that MMB testing allows variation of contact area, impact location, overlap and orientation, shape of colliding structures and impact speed. As such, the method can be adjusted to accident specific conditions to obtain accident reconstruction crash test data on each collision partner, one vehicle at a time.

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CONTACT

Ronald L. Woolley, P.E., Ph.D.
Woolley Engineering Research Corp.
5314 North 250 West, Provo, Utah, 84604
801-431-0220
woolley@wer.com