REPRODUCIBILITY OF *AHOF400* AND *KW400*

Guy Nusholtz
Lan Xu
Edith Lugo Velez
Tim Hsu
Sadegh Babaii Kochekseraii
Chrysler LLC.
USA
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ABSTRACT

AHOF400 estimates the average height, from the ground, of the interacting force between a vehicle and the barrier in a rigid barrier crash test. Similarly, *KW400* estimates the "stiffness" derived from the force-crush relationship corresponding to a vehicle crashing into a ridge barrier. Both metrics are calculated during the first 400 mm of crush. Although, the formulas for calculating both *AHOF400 and KW400* appear simple, the reproducibility for these two measures has not been determined. One area of concern is variations in numerical methodology, signal processing algorithms and/or labs can lead to different results: numerical issues such as, determining time zero of a signal may increase lab to lab variability. In addition, AHOF400 and KW400 may not be the invariants of the system: they may be velocity dependent.

INTRODUCTION

As a part of NHTSA's compatibility program [1-4], there was an attempt to measure the Average Height Of Force, AHOF. The height of force was defined as [5-6]

$$HOF(t) = \frac{\sum_{i=1}^{i=n} Fi(t) * Hi}{\sum_{i=1}^{i=n} Fi(t)} \qquad (1).$$

Where, $Fi(t)$ was the *i*-th load cell force and Hi was the height of the corresponding load cell. *AHOF(t)* was obtained by averaging the *HOF(t)* from the weighting function of total force *F(t)*,

$$AHOF(t) = \frac{\sum_{0}^{t} HOF(t) * F(t)}{\sum_{0}^{t} F(t)} \qquad (2).$$

The summation of *HOF* to produce *AHOF* was initiated when the total force exceeded 50kN (Eq2). An alternative of *AHOF* was introduced in [7]. Instead of using *F(t)* in Eq1 and Eq2, *F(d)* was used to obtain the height of force and averaged height of force, where *d* was the displacement of a vehicle (vehicle crush). The average height of force delivered by a vehicle in the first 400 mm of crush, *AHOF400* was formulated as:

$$HOF(d) = \frac{\sum_{i=1}^{i=n} Fi(d) * Hi}{\sum_{i=1}^{i=n} Fi(d)} \qquad (3).$$

$$AHOF400 = \frac{\sum_{d=25mm}^{d=400mm} HOF(d) * F(d)}{\sum_{d=25mm}^{d=400mm} F(d)} \qquad (4).$$

In addition to the AHOF400, the "stiffness" metric KW400 was used in the analysis in [7]. *KW400*, defined in [8], was

$$KW400 = \frac{2\int_{25mm}^{400mm} F(d)\mathbf{d}d}{(400^2 - 25^2)} \qquad (5).$$

In the analysis presented below, Eq4 and Eq5 were used to calculate *AHOF400* and *KW400* for the16 tests presented in the paper by Patel et. al.[7], as well as other NHTSA's NCAP and FMVSS208 tests[9]. The objective of this study is to understand and investigate the reproducibility of *AHOF400* and *KW400* and to determine in a qualitative way how these two metrics vary as a function of signal processing and computation methods, usage of different software, and other relevant variables.

METHOD

HOF(d), *AHOF400* and *KW400* defined in Eq3 to Eq5 and in [7] were used in this study. The calculation of *AHOF400* and *KW400* involves obtaining forces and crush (displacements of the un-deformed part of the vehicle during impact) from a full frontal rigid barrier impact. Crush time history data used in this study were obtained from the accelerometers on the left and right rear sills or rear seat brackets. Displacement (d) was obtained by double integrating the acceleration data starting from the initiation of impact (time zero). Total impact force was the sum of all individual load cell data obtained from the rigid barrier. The force was filtered according to SAEJ211. In some cases, in the NHTSA database, the force, the acceleration or both are not aligned with the recorded time zero and either or both may have to be shifted (time-shifted) to bring them into alignment. The Software Matlab® (product of The MathWorks Company) was used for most of the calculations.

RESULTS

In this section, the treatment of the available data and calculation of *AHOF400* and *KW400* using the methodology described above will be presented and discussed.

Reproducibility of *AHOF400* and *KW400*

A comparison of the calculated *AHOF400* and *KW400* between the present study and Ref [7] for 16 reported NCAP (New Car Assessment Program) tests from NHTSA's crash test data base is presented in Figures 1 and 2, and in Table 1 below.

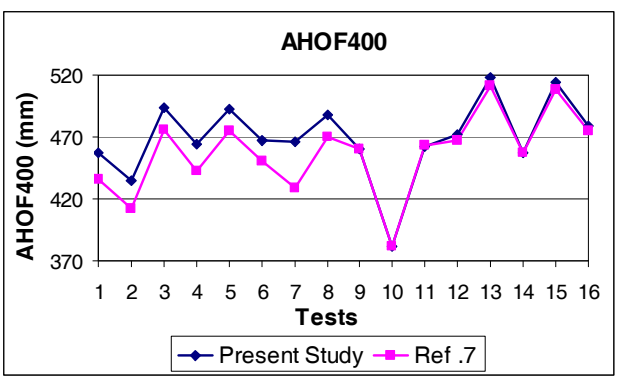

Figure 1. Comparison of *AHOF400*

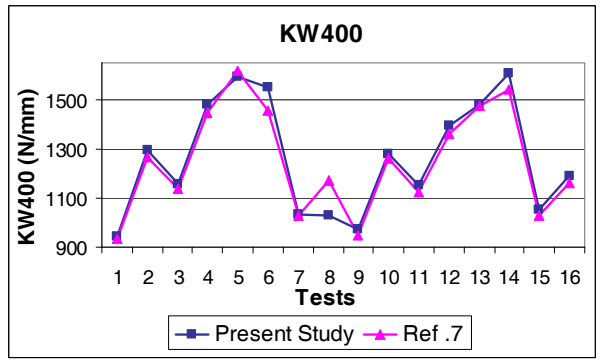

Figure 2. Comparison of *KW400*

These 16 tests can be divided into two sets of 8 tests. The two sets are identical in the aspect that they consist of vehicles of the same make and model. The set of the first 8 tests consists of full frontal barrier impacts using either a 30 or a 36 load cell flat wall. The last 8 tests utilized the same make and model vehicles in impact tests using either a 132 or a 134, or a 128 load cell flat wall [6]. The same time-shifting presented in [7] was applied. The data were processed and the results were obtained by using routines developed in MATLAB®.

A total of four types of load cell walls were used in the 16 tests. The configuration of those different types of walls is shown in Appendix A. In the first set of 8 tests, 1 through 8 in Table 1, there were two different types of load cell walls, as shown in Figures A1 and A2 (Appendix A). The second set, 9 through 16 in Table 1, used two types of load cell walls. One was a nine row barrier, with two different ground heights (from the ground to the bottom of the first row of load cells) and slightly different top row configuration , as shown in Figures A3 and A4 (Appendix A). The other was an eight row barrier, as shown in Figure A5 (Appendix). It should be noted that: the ground height and the size of the load cells and the heights to the top of the load cell wall for the four types of load cell walls are different. The total heights covered by the two rows, four rows, two of the nine rows walls, and the eight rows are 1378mm, 1050mm, 1205, 1255mm, and 1130mm, respectively. These differences result in significant differences to the heights of the center of individual load cells.

The numbers (x-axis, 1-16) in Figures 1 and 2 are the corresponding numbers in Table 1. The percentage difference *p* between two numbers, *a* and *b*, in the Table 1 was calculated using the equation,

$$p = \frac{a-b}{(\frac{a+b}{2})} \text{x}100 \qquad (6).$$

The following were observed from those results:

- *AHOF400* results of the first 8 tests differ from the corresponding results published in [7], with the range of difference from 4% to 8%.
- *AHOF400* results from the last 8 tests differ from the published results [7], with the difference no larger than 1.4%.
- *KW400* values differ from the published values [7], with the range of difference from 1% to 13%.

Table 1 –Differences of *AHOF400* and *KW400*

Number	Test No	AHOF400 (Ref. 7) (mm)	AHOF400 (Present Study) (mm)	AHOF400 difference	KW400 (Ref. 7) (N/mm)	KW400 (Present Study) (N/mm)	KW 400 difference
1	4216	436	457	5%	934	942	1%
2	3456	412	435	5%	1265	1296	2%
3	4936	476	494	4%	1137	1156	2%
4	4463	443	464	5%	1448	1477	2%
5	4472	475	493	4%	1619	1593	2%
6	5273	450	467	4%	1456	1548	6%
7	4485	429	466	**8%**	1027	1031	0%
8	2997	470	488	4%	1172	1029	**13%**
9	5712	460	460	0%	947	970	2%
10	5710	382	382	0%	1261	1279	1%
11	5713	463	462	0%	1124	1151	2%
12	5144	467	472	1%	1360	1396	3%
13	5711	511	518	1%	1472	1478	0%
14	5714	457	457	0%	1542	1607	4%
15	5062	508	514	1%	1027	1051	2%
16	4990	475	479	1%	1163	1190	2%

Analysis of Numerical Variation

Some factors that could affect the *AHOF400* and *KW400* results are: filtering, resultant total barrier force calculation, integration of the acceleration data, the software used, time shifted, zeroing, and the load cell height information used.

Filtering

The effects of different SAE filters have been investigated in this study using Hypergraph® (a product from Altair Engineering Inc.). Two Hypergraph® built-in filters, SAE60 and SAE (J211) ISO6487 Padding CFC60 were evaluated. Figure 3 shows that different peak values were observed even when the "same" SAE class 60 were used. The difference is about 2%.

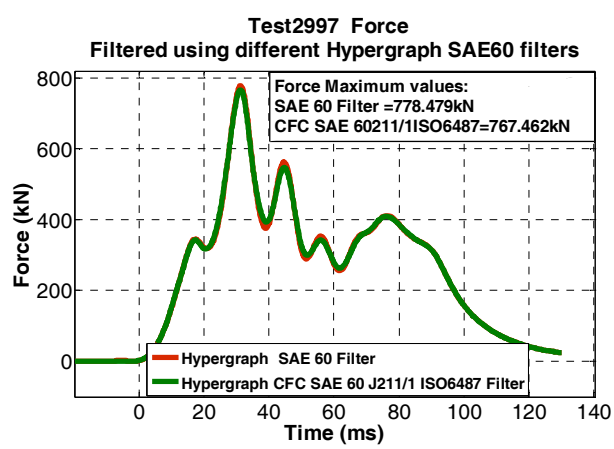

Figure 3. Comparison of Filtering

In general, filtering is shown to have minimal impact due to the fact that only the force signal for the

AHOF400 and *KW400* is affected by filtering and that the force is not directly used in the calculations. *AHOF400* is the result of a force summation process, effectively integration, and *KW400* is obtained from integration of the force and acceleration. Hence unfiltered and filtered signals have for all practical purposes the same integral values.

Software

It was observed that NHTSA has multiple data formats in the database that can be downloaded for use with different software. Two formats/softwares were used to calculate *AHOF400* and *KW400*. The two softwares were Hypergraph® and Matlab®. The results of *AHOF400* and *KW400* from these two softwares are presented in Table 2. Comparison of those two sets of results indicated that there was no significant difference from using the two softwares. The maximum difference for *AHOF400* is about 2mm, which is about 0.4%. The maximum difference for *KW400* is 5N/mm, which is about 0.5%.

Table 2 – Comparison of Result from Matlab and Hypergraph

	AHOF400 (mm)		KW400 (N/mm)	
Test No.	Matlab	Hypergraph	Matlab	Hypergraph
4216	457	457	942	941
3456	435	434	1296	1297
4936	494	494	1156	1153
4463	464	464	1477	1477
4472	493	493	1593	1592
5273	467	468	1548	1548
4485	466	466	1031	1028
2997	488	488	1029	1025
5712	460	460	970	970
5710	382	380	1279	1283
5713	462	463	1151	1150
5144	472	472	1396	1394
5711	518	518	1478	1473
5714	457	458	1607	1606
5062	514	514	1051	1046
4990	479	478	1190	1185

Influence of Signal "Zero"

The influence of aligning the beginning of the signals, time-zero, is investigated in what follows. It is possible that not all of the conventions used for the time-shifting in Ref. [7] are consistent with what was used in their calculations. It was noted that if the sign of the shifted time is reversed for the test No. 8, v2997, the difference of *KW400* between the two calculations will be as low as 0.3%, instead of 13% as listed in the Table 1.

Figure 4 illustrates that slight alternatives in the FD curve as a consequence of time-shifted change the integration results and the corresponding *KW400* values. The differences in the *KW400* could be as much as 13% between shifted force time-history by 2ms and un-shifted force time-history (orange and blue curves in the Figure 3).

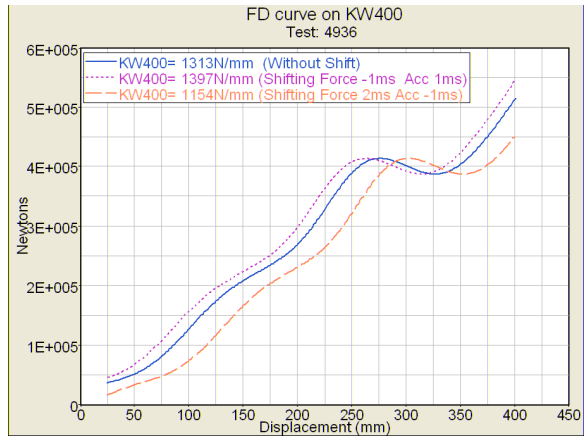

Figure 4. *KW400* Sensitive to the Signal Shift

In what follows, *KW400* and *AHOF400* values are calculated using various time-shifts of the force and acceleration time-histories at given intervals prior to the construction of the FD curves. Figures 5 to 8 and Tables 3 to 4 present the influence of the time shift to the *KW400 and AHOF400*. Applied time-shifts to acceleration and force data were from -2ms to 2 ms, where positive shift represents the movement of the signal from left to right and *vice versa*. Figures 5 and 6 represent the change of *KW400* and *AHOF400* versus time-shifts in force time-histories with zero acceleration time-shift. For other non-zero acceleration times-shifted, the same trends were observed. Figures 7 and 8 represent general trends for

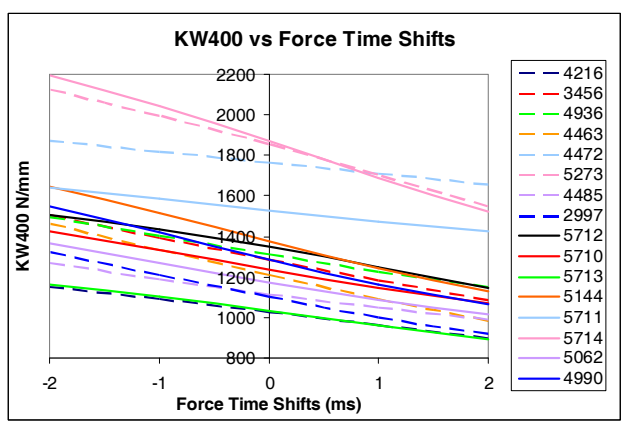

Figure 5. The Influence of Force Signal Shift to *KW400*

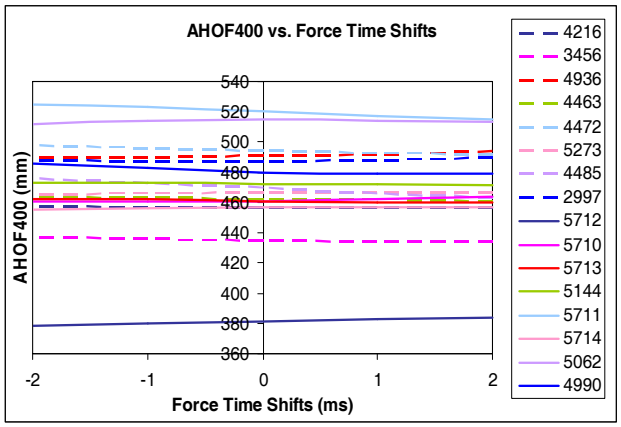

Figure 6. The Influence of Force Signal Shift to *AHOF400*

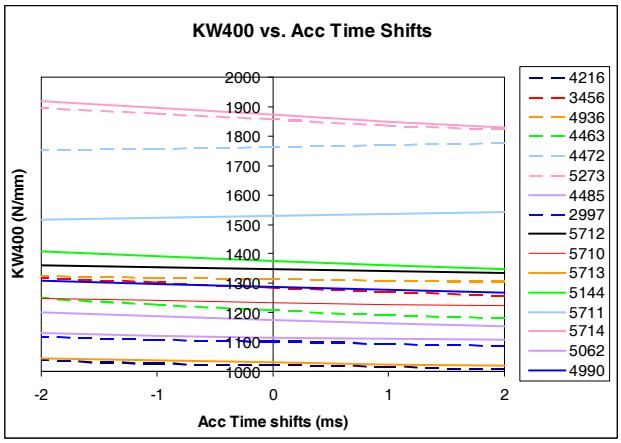

Figure 7. The Influence of Acceleration Signal Shift to *KW400*

the change of *KW400* and *AHOF400* versus the time-shifts in acceleration time-histories while the force time-shift was set to zero.

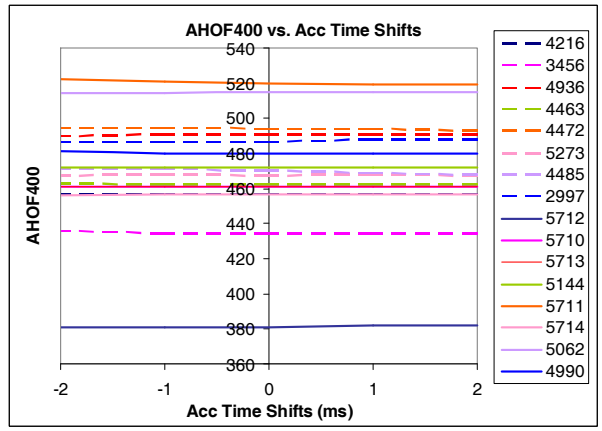

Figure 8. The Influence of Acceleration Signal Shift to *AHOF400*

For all the 16 tests investigated, it is observed that:

- Shifting force signals to the left in time (negative shifts) results in increased *KW400* values. A shift to the right results in a reduction of *KW400*. The change could be as much as 10% as shown in Figure 13, test v5714, with 1 ms force signal shift.
- Acceleration time-shifting does not influence *KW400* as much as that from force shifts. The changes range from 0.6% to 2% for each 1 ms acceleration signal shift.
- *AHOF400* does not show any significant change with time-shifting in either force signal or acceleration signal.

As an example, the *KW400* and *AHOF400* values from test v5711 are presented in Tables 3 and 4. Using the same equation (Eq1) as used in Table 1, the percentage differences in the table were calculated with a zero shift as the baseline. *AHOF400* is found to be less sensitive to the time-shifting than *KW400*. The maximum change in *AHOF400* is about 1.2%, vs. about 8.3% in *KW400* for the shift range from -2ms to 2ms.

Table 3 – *KW400* Versus Force and Acceleration Signal Shift

VC5711		Acc Shift				
	KW 400	2 ms	1 ms	0 ms	-1 ms	-2 ms
Force Shift	2 ms	-6.14%	-6.63%	-7.12%	-7.68%	-8.25%
	1 ms	-2.52%	-3.06%	-3.60%	-4.14%	-4.76%
	0 ms	0.91%	0.46%	0.00% (1528N/mm)	-0.46%	-0.92%
	-1 ms	4.35%	4.04%	3.66%	3.35%	3.09%
	-2 ms	7.56%	7.37%	7.19%	7.01%	6.89%

Table 4 – *AHOF400* Versus Force and Acceleration Signal Shift

VC5711	AHOF 400	Acc Shift 2 ms	1 ms	0 ms	-1 ms	-2 ms
Force Shift	**2 ms**	-1.16%	-1.16%	-0.97%	-0.77%	-0.58%
	1 ms	-0.77%	-0.58%	-0.58%	-0.39%	-0.19%
	0 ms	-0.19%	-0.19%	0.00% (520mm)	0.19%	0.38%
	-1 ms	0.19%	0.38%	0.58%	0.58%	0.77%
	-2 ms	0.77%	0.77%	0.96%	1.15%	1.15%

A manual method similar to what was used in Ref. [7] was utilized to find "zero" in this study. This was done without checking the values in Ref [7] first to avoid bias. Table 5 shows the time-shifts comparison of this study and Ref. [7]. The difference ranges from 0 to 1.7ms, with the RMS (Root Mean Square) about 0.8 ms.

Table 5 – Time-Shifts (ms) Comparison

Test No.	This Study	Ref. [7]
4216	1.5	1.3
3456	-0.9	-0.1
4936	1.5	1.9
4463	-3.1	-2.1
4472	2.7	3.1
5273	1	2
4485	0.2	1.3
2997	0	0.75
5712	0.5	0.9
5710	0	0.7
5713	1	1
5144	0	-0.15
5711	0.3	1
5714	0.5	1.5
5062	-0.2	1.5
4990	0.1	0.8

Effects of Load Cell Height on *AHOF400*

An almost constant difference of the *AHOF400* between this study and Ref. [7] was observed for the first 8 tests. If the *AHOF400* values from this study are reduced by 18mm for the first 8 tests, the differences between the two calculations will be in the range of 0% to 4%, instead of 4% to 8% reported in Table 1. The 18mm was determined by minimizing the difference, in a least square sense, of the two calculations. One possibility is that the load cell height from the test report is different from what was used in [7]. If this is correct, then the 18mm difference could be explained. Otherwise, it is unclear what has caused the differences.

An estimation of errors in *AHOF400* induced possibly by inaccurate height information was performed. For a *m*-rowed load cell with the height of each load cell row *Hc* and the ground height of the load cell wall *Hg*, *HOF* from Eq3 can also be expressed in the following form,

$$HOF = Hg + \frac{Hc}{F}\sum_{1}^{m} Fi*(i-\frac{1}{2}) \qquad (7).$$

Where *F* is the total barrier force and *Fi* is the force in the *i-th* row.

Based on Eq7, any error in the ground height, *Hg*, will be added onto the *HOF*, and then *AHOF400* directly. The effect of the error in a load cell height *Hc* is roughly estimated in the following example. Figure 9 shows the load cell force from a four row

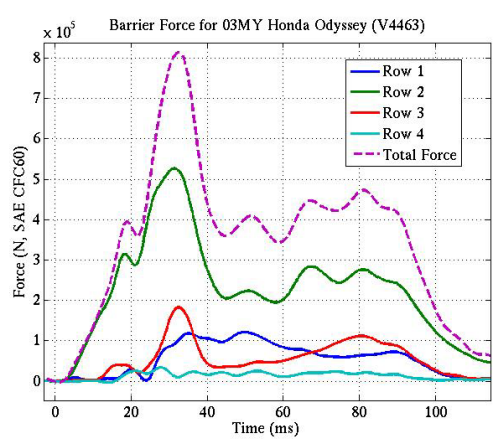

Figure 9. – Barrie Force from Each Load Cell Row in Test v4463

load cell wall test. If the forces distributed among the four load cell rows are approximately 10%, 60%, 25%, and 5% of the total barrier force *F* before 30ms, which is typically when 400mm displacement occurred, respectively, then approximately, $\Delta HOF = 1.8\Delta Hc$.

To get an estimate, it is further assumed that ΔHc is 10% of load cell height, i.e., approximately 10% of 250mm (which is typical for the barrier in many of the current test labs). Then the estimated error migrated from *HOF* to *AHOF400* could be as high as 46mm, which is about 10%.

Analysis of Experimental Variation

In this section, the effects from two variables on the *AHOF400* were examined. One variable is the vehicle impact speed, and the other is the test to test variation from a pair of repeat tests.

Influence of Impact Speed to *AHOF400*

AHOF400 is a measure of the "Average height of force" of a vehicle. The characteristic of this metric is anticipated to be mainly dependent on the characteristics of the vehicle. A preliminary investigation on the influence of impact speeds to *AHOF400* is also included in this study. *AHOF400s* for three different vehicles, at two different impact speeds (30 and 35 mph), were calculated and shown in Figure 10. The percentage differences from those results are 8%, 3% and less than 1% respectively, with the *AHOF400* from 35 mph impact always equal to or greater then those from the 30 mph impact. In addition, one other speed comparison (25, 30 mph) is also presented with the difference being -6%. The 25 to 30mph relationship is opposite to that of the 35mph to 30 mph in that the *AHOF400* is higher for the lower speed.

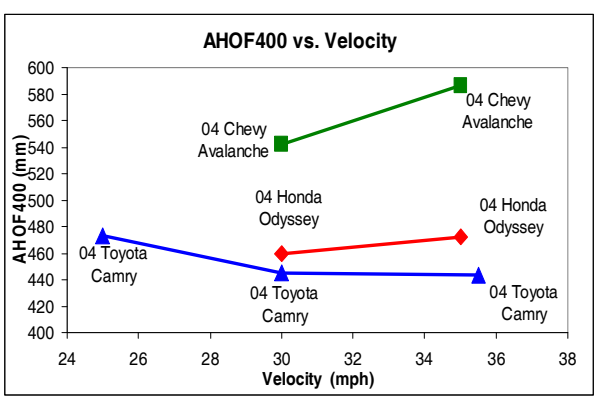

Figure 10. The Influence of Impact Speed to *AHOF400*

The FD curves from those tests are presented in Figure 11. In most of the comparison of the same vehicle at different impact speeds, the total forces in the range of 0 to 400mm are significantly different, which suggests that the barrier forces are dependent on the impact speed. The energy absorbed in the first 400 mm of displacement is presented in Table 6. In general, the higher the speed the greater the energy absorbed in the first 400 mm. The data is not entirely consistent with this relationship. In one test set, test 5216 at 30 mph and test 5071 at 25 mph, the energy absorbed in the first 400 mm is almost the same. In another test set, test 5144 at 35 mph and test 5212 at 30 mph, the energy absorbed in the first 400 mm is higher, about 4%, for the lower speed.

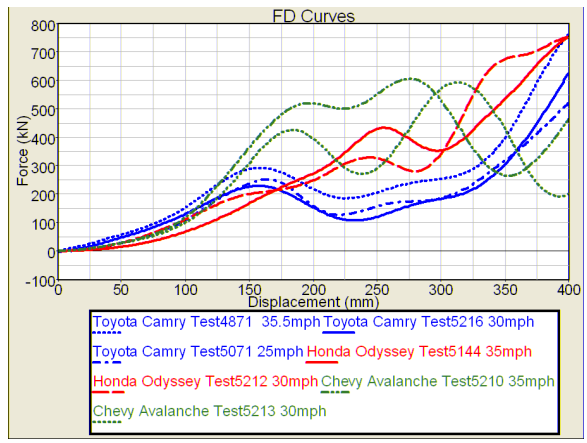

Figure 11. Force-Displacement Curves

Table 6 – Integral from FD Curve in Figure 11

Vehicle	Test No	Velocity (mph)	Integral kN*mm
Toyota Camry	4871	35.5	96891.587
Toyota Camry	5216	30	72348.884
Toyota Camry	5071	25	71919.591
Honda Odyssey	5144	35	110088.569
Honda Odyssey	5212	30	114893.049
Chevy Avalanche	5210	35	128944.091
Chevy Avalanche	5213	30	110257.985

On the other hand, the difference in the height of the individual load cells, the barrier used for the 25mph test (test 5071) in Figure 10 was a two row load cell wall, while for the 30 mph test (test 5216) was a four row load cell wall, could cause significant errors in *AHOF400,* as analyzed in the previous section. Due to the limited availability of load cell data additional analysis was not possible; therefore, from these results it is unclear if there is a trend or not. If in fact the 25 mph impact has a "true' *AHOF400* value higher than that from the 30 mph impact then this

indicates that *AHOF400* might be influenced by the impact speed but in a complicated way.

None the less it is also possible that because of the small sample size this could be the effect of test variability and not the effect of impact speed.

Effects of the Experimental Variation on *AHOF400*

The effect of the test variation in barrier force measurement was examined qualitatively in the following: The force in the *k-th* row is assumed to have an increased ΔF in one of the two repeat tests. Using the same notation from above section, and Eq7, the difference in *HOF* between those two repeats will be

$$\Delta HOF = \frac{Hc\Delta F}{(F+\Delta F)F}\sum_{1}^{m} Fi*(k-i) \quad (9).$$

It is observed from Eq9 that, typically, if *k* is above the middle of the load cell wall, the *HOF* will increase or decrease with the increase or decrease of ΔF correspondingly, and *vice versa*.

A random distribution of *Fi* and *k* were used to estimate the change of *HOF* for a four row load cell wall. It was found the change of ΔHOF /*HOF*, on average, is 0.3* ΔF /*F,* but in some cases, it could be as much as 1.1* ΔF /*F* assuming that the forces in both the top and the bottom rows are no larger than 10% of the total force *F*.

To qualitatively illustrate the effect of test variation on AHOF400, an example of two 30mph repeat tests was used. The barrier force distribution from those two tests, V4646 and V4714, with the *AHOF400* values 503mm and 522mm (about 4% difference) respectively are presented in Figure 12. The solid lines in the figure represent the load cell forces at each row, A, B, C, and D (which is corresponding to 1,2,3, and 4 in the notation above) for test V4646, and the dashed lines are for test V4717. While the forces in the third and the fourth rows are similar for the two tests, the forces in first and second rows from test V4646 are greater than those from test V4714.

The difference in row 2 (row B) is about 12% of total force, and 5% in row 1 (row A), on an average sense as shown in Figure 13. A difference in *HOF* and possible *AHOF400* between those two repeat tests is estimated to be around 5% by assuming ΔHOF /*HOF* is abut 0.3* ΔF /*F* for this case.

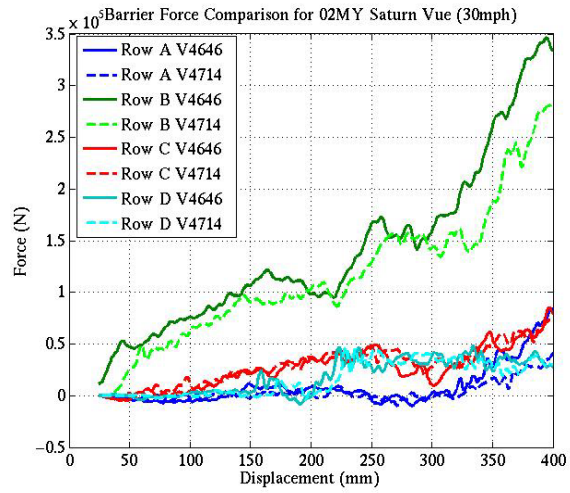

Figure 12. Overlay of Barrie Force from Each Load Cell Row

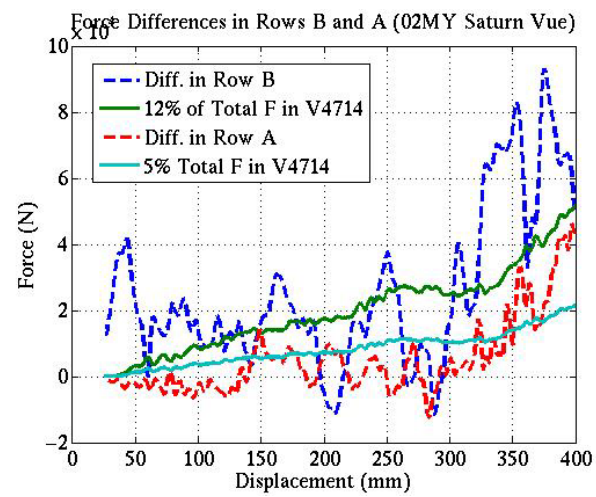

Figure 13. Differences in Barrie Force

DISCUSSION

In many of the tests in the NHTSA database the defined time zero does not coincide with the force and/or acceleration time zero, rather, they can be different by as much as 4ms. Therefore, for both force and acceleration signals, a "true" time zero is needed that can be used in the calculations. This is important because *KW400* is found to vary significantly with the determination of time zero (time-shift), which is consistent with [7].

In both this study and in [7] time-zero was obtained subjectively. Comparisons of this study and [7] indicate that KW400 could differ by as much as 20% because of subjective determination of time-zero. For the purposes of reproducibility, it will be desirable to obtain the "true" signal zero by an objective method.

Typically, in a given signal, there is a certain level of noise before time-zero of the transducer time history. This may limit the ability to determine the "true" time-zero. Consequently, improvements in signal to noise ratio of the force time histories of the barrier load cells may be needed before accurate *KW400* estimation can be made. On the other hand, the "noise" in the test signals may be due to the disturbance of the impact that produces a signal that may not lend itself to objective determination.

It is unclear why there is a need for the perceived re-determining time-zero. One possible reason for re-definition of zeros could be that the contact switch did not work correctly. However, at the initiation of impact, the force and deflection may not start at the same time: re-determining time-zero should not be done. Neither of these can be easily justified.

Another observation from this preliminary study is that *AHOF400* may vary with impact speeds for some vehicles. The hypothesis is that the body materials may be rate sensitive or the number of structural components engaged during the impact varies as the crash progresses and interact differently. Therefore, the "damping" characteristic of the vehicle structure is different which will result in a different load distribution pattern. Detailed analysis on how vehicle structure changes at different impact speed is beyond this study. If *AHOF400* changes with impact speeds, it would be interesting to know whether this has any real world significance.

CONCLUSIONS

This is a limited study on the analysis of possible sources to impediments of reproducibility of *AHOF400* and *KW400*. The results indicate that the determination of the starting time of the signals (time zero) for the different transducers could affect *KW400* values significantly. For some vehicles, it seems that *AHOF400* is dependent on impact speed. In addition, some differences observed in *AHOF400*s could be attributed to inconsistent reporting of barrier information, or experimental variations.

In this study no effort has been made to determine the utility of *AHOF400* and *KW400*, they may only be a scientific curiosity. None the less, regardless of their utility more research would be needed if it becomes necessary to understand the reproducibility of *AHOF400* and *KW400*.

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APPENDIX A

Load Cell Wall Configurations

This Appendix details the configurations of load cells on the rigid wall barriers which were used for the vehicle impact tests. The calculation of the *AHOF400* in this study was based on the heights shown in the Figures below.

1. **Two Row Load Cell Wall.**

The configuration of a rigid barrier containing two rows of load cell is shown in Figure A1. There are 2*3 (total of 6) channels of data available in the database for the tests conducted with this type of load cell configuration. The heights measured from the ground for the center of the load cells are 365.5mm for the lower row and 969mm for the upper row, which were used in this calculation for tests 3456 and 4485.

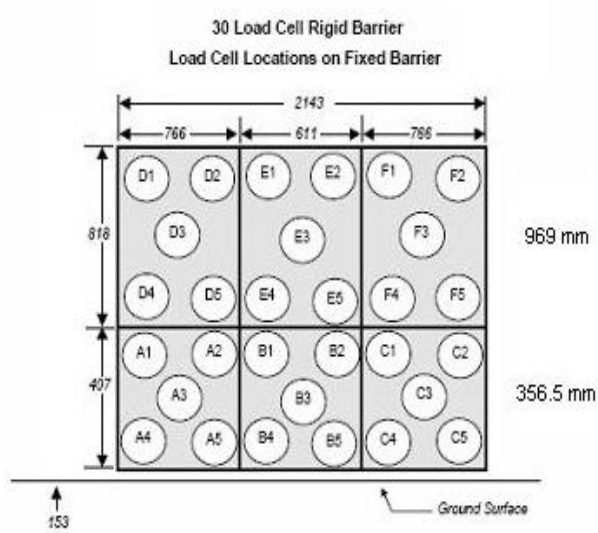

Figure A1. Configuration of the Two Row Load Cell Wall (From the Report for test 4485 [9]).

2. **Four Row Load Cell Wall**

The configuration of a rigid barrier containing four rows of load cell is shown in Figure A2.

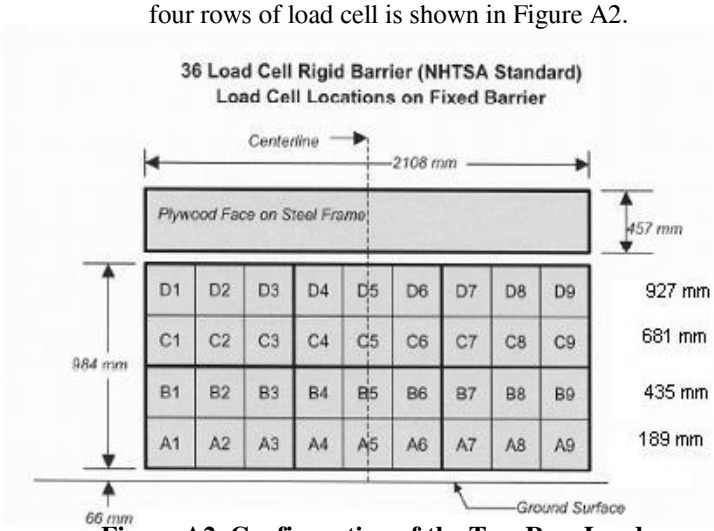

Figure A2. Configuration of the Two Row Load Cell Wall(From the Report for test 4216 [9]).

There are 4*9 (total of 36) channels of data available for the tests conducted with this type of load cell configuration. The heights for the center of the load cells used in this calculation are 189, 435, 681, and 927mm for the rows 1 through 4 (lowest to the highest) respectively. These heights were used for tests 4216, 4936, 4463, 4472, 5273, and 2997.

3. **Nine Row Load Cell Wall - 1**

The configuration of a rigid barrier containing nine rows of load cells is shown in Figure A3. There are 8*16+4 (total of 132) channels of data available for the tests conducted with this type of load cell configuration. The heights for the center of the load cells used in this calculation are shown on the right side of the Figure A3. These heights were used for tests 5712, 5710, 5713, 5711, and 5714.

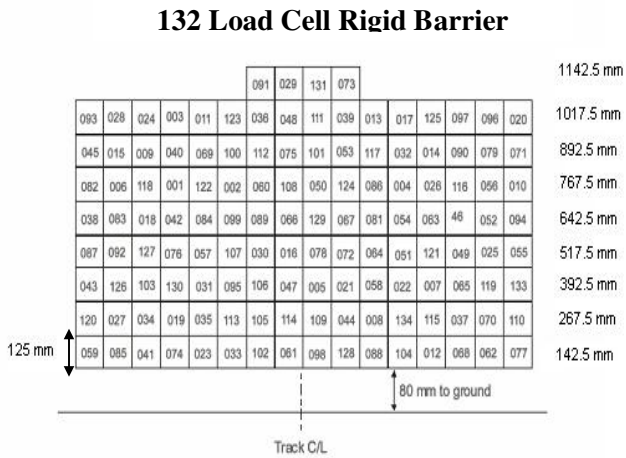

Figure A3. Configuration of the Nine Row Load Cell Wall - 1(From the Report for test 5710 [9]).

4. **Nine Row Load Cell Wall - 2**

The configuration of the other rigid barrier containing nine rows of load cells is shown in Figure A4. There are 8*16+6 (total of 134) channels of data available for the tests conducted with this type of load cell configuration. The heights for the center of the load cells used in this calculation are shown on the right side of the Figure A4. These heights were used for tests 5144, and 5062.

134 Load Cell Rigid Barrier

					109	044	134	115	110	064						1192.5 mm
133	039	085	059	116	013	119	107	095	103	129	058	126	108	025	070	1067.5mm
027	111	072	106	056	114	068	157	049	131	018	084	062	078	127	021	942.5 mm
036	052	010	034	026	022	030	016	035	092	043	076	001	087	096	015	817.5 mm
090	065	079	055	031	054	050	089	130	082	083	123	032	121	009	037	692.5 mm
040	007	071	094	067	086	118	101	073	047	099	080	097	048	061	005	567.5 mm
125	004	051	042	011	117	066	045	077	029	100	102	091	012	017	081	442.5 mm
120	063	124	093	046	122	002	060	105	020	069	041	112	074	128	075	317.5 mm
053	008	028	038	003	014	024	006	132	023	033	019	113	098	104	088	192.5 mm

125 mm

LOAD CELL SERIAL NUMBERS

130 mm

Track C/L

Figure A4. Configuration of the Nine Row Load Cell Wall - 2(From the Report for test 5144 [9]).

5. Eight Row Load Cell Wall

The configuration of the other rigid barrier containing eight rows of load cells is shown in Figure A5. There are 8*16(total of 128) channels of data available for the tests conducted with this type of load cell configuration. The heights for the center of the load cells used in this calculation are shown on the right side of the Figure A5. These heights were used for test 4990.

128 Load Cell Rigid

133	039	085	059	116	013	119	107	095	103	129	058	126	108	025	070	1067.5mm
027	111	072	106	056	114	068	157	049	131	018	084	062	078	127	021	942.5 mm
036	052	010	034	026	022	030	016	035	092	043	076	001	087	096	015	817.5 mm
090	065	079	055	031	054	050	089	130	082	083	123	032	121	009	037	692.5 mm
040	007	071	094	067	086	118	101	073	047	099	080	097	048	061	005	567.5 mm
125	004	051	042	011	117	066	045	077	029	100	102	091	012	017	081	442.5 mm
120	063	124	093	046	122	002	060	105	020	069	041	112	074	128	075	317.5 mm
053	008	028	038	003	014	024	006	132	023	033	019	113	098	104	088	192.5 mm

125 mm

LOAD CELL SERIAL NUMBERS

130 mm

Figure A5. Configuration of the Eight Row Load Cell Wall(From the Report for test 4990 [9]).