CALIBRATION OF IMPACT RIGS/ CRASH-WORTHINESS TESTING OF THIN SHEET METAL BOXES

Carlo Albertini
George Solomos
Kamel Labibes
European Commission, Joint Research Centre
ISIS/ Structural Mechanics Unit
ITALY
Paper Number: 98-S3-P-14

ABSTRACT

The present paper addresses the problem of harmonization of crash testing measurement techniques. It involved 14 European laboratories comprising research centres, universities, and the automotive industry, which among them included: 8 vertical drop hammers, 4 horizontal sledges, 1 gas gun, and 1 large-scale Hopkinson bar. The same type of specimens were tested by the different laboratories: extruded aluminum 6063 T7 thin-walled columns of length 400mm. Interesting conclusions were drawn on the effect of signal numerical filtering, the reproducibility of the results obtained from each laboratory, and the overall performance of the rigs at the prescribed impact velocities.

INTRODUCTION

Dynamic crush characteristics of structural components are currently assessed in impact and crashworthiness laboratories by means of horizontal sledges or vertical drop hammers. Specimens in the form of thin-walled boxes are used. The deformation of these elements can be employed as an energy absorbing mechanism in the case of car collision in order to limit the damage to the passenger compartment, and direct the folding formation and fracture along selected paths. These specimens are sandwiched between an impacting mass M_t and a heavy anvil of mass M_a. The specimen is attached to a moving mass (sledge) or to a stationary anvil (drop hammer). In either case the following relationship must hold: $M_a >> M_t >> M$, where M=mass of specimen.

The instrumentation for measuring load usually consists of load cells mounted between the anvil and the support plate or accelerometers attached to the impacting mass, together with a corresponding data acquisition system. However, measurement difficulties arise either when testing a single component or, to a larger extent, a complete structure. Separation of the true crash characteristics from the superimposed vibration of the test equipment is a notorious problem in interpreting component or full-scale automobile crash tests [1]. Thus the various laboratories resort to different filtering techniques.

The present work addresses principally this problem of harmonization of crash testing measurement techniques. It involved 14 European laboratories comprising research centres, universities, and the automotive industry, and it ran for approximately two years. It has shown that the force levels and vibration characteristics recorded on identical specimens by two different laboratories might be different even though similar equipment and similar principles were used.

The main objective of the project has been to perform a comparative study of the dynamic performance of the various types of test rigs for crashworthiness applications and to help calibrate these devices using the JRC large-scale Hopkinson bar as a reference crash test rig.

EXPERIMENTAL WORK

The results of this project were produced from two rounds of testing (corresponding to two different material batches) conducted by the participating laboratories. The crash tests were performed on triggered column specimens (Figure 1.) of extruded aluminum 6063 T7.

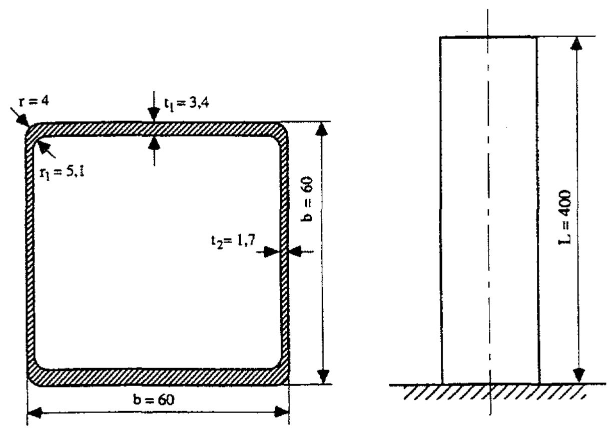

Figure 1. Crash test specimen geometry (dimensions in mm).

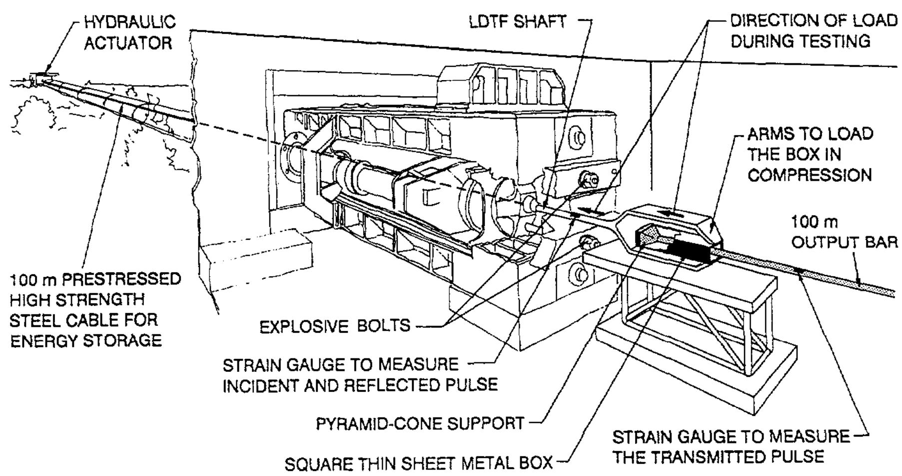

Figure 2. Layout for dynamic crash test at the LDTF.

Material Testing

The material of both batches was thoroughly characterized on small specimens, cut directly from the thin and thick sides of the above columns. Both quasi-static and high strain rate (1100/s) tensile tests were performed. Three material orientations with respect to the extrusion direction were examined: 0°, 45°, 90°.

These tests have shown some dependence of the mechanical properties on strain rate, specimen orientation and thickness in the elastic region, which, however, disappears in the plastic region. The ultimate stress at strain rate 1100/s is found to be 14% higher than its quasi-static value (low sensitivity, consistent with the literature data). The following average quasi-static values of this Al-6063-T7 have thus been derived: Young modulus E=67GPa, yield stress $\sigma_{0.2}$=104MPa, ultimate stress σ_u=166MPa, ultimate strain ε_u=0.10.

Column Crash Testing

The same type of specimens were tested by the different laboratories, which among them included: 8 vertical drop hammers, 4 horizontal sledges, 1 gas gun, and 1 large-scale Hopkinson bar. The dimensions of the thin-walled column specimens are shown in Fig.1: length 400mm, hollow square cross-section of external dimension 60mm, and thicknesses of opposite sides 1.7mm and 3.4mm, respectively.

Seven tests (designated by the letters A to G) were, on the average, performed by each participating laboratory. The agreed upon test conditions were as follows:

A, B: Impact Velocity 8.33m/s (30km/h), Impacting Mass: arbitrary;

C, D: Impact Velocity 8.33m/s (30km/h), Impacting Mass: arbitrary;

E, F: Impact Velocity 13.88m/s (50km/h), Impacting Mass: arbitrary;

G : Impact Energy 5300J, Velocity and Mass: arbitrary.

These conditions have practically been imposed by the capabilities available in the laboratories, which differed substantially. For example, it is noted that the common range of impacting mass of 7 laboratories was 500-625kg, whereas the common range of impacting velocity of 8 laboratories was 10-54km/h.

The JRC large-scale Hopkinson bar (called Large Dynamic Test Facility, LDTF) allows the testing and deforming to fracture of large size specimens of high resistance and elongation. Elastic energy is stored in its

100m cables, preloaded by hydraulic pistons. Initially this load is borne by bolts, the explosive rupture of which liberates the energy to propagate as waves to the test piece.

The incident ε_I, reflected ε_R and transmitted ε_T pulses are measured by the two strain gauge stations on the incident and transmission bar (Figure 2.). The application of the uniaxial propagation theory of elastic stress waves along bars having small transverse dimensions with respect to the wavelength of the applied stress pulse [3] allows the calculation of the required parameters. Some of the unique features of this facility include: maximum load =5MN, maximum specimen dimension =3m, maximum specimen deformation =1m, maximum cross-head velocity =40m/s, pulse duration =40ms. In terms of energy applied to the specimen, the LDTF tests can be compared with conventional tests, by equating the elastic potential energy stored in the cable to the kinetic energy of a mass *m* attached to the cable end once the bolt has been broken:

$$\tfrac{1}{2} F\, \Delta L = \tfrac{1}{2} m\, V^2 \qquad (1.)$$

where, *F*= load of pre-tensioned cable, *ΔL*= elongation of cable and *V*= speed of mass *m*.

Each laboratory furnished the non-filtered load/shortening recorded signals to the project coordinator. The inter-comparison of the results was made on the basis of the parameters described below [2].

a)First peak load. This is the maximum first load of the non-filtered load/shortening curve, denoted by P^.

b)Mean crushing load. Four definitions are applied, where permitted by the laboratory data, on the filtered load/shortening curves. The SAE CFC 180 filter is used.

Definition I:

$$Pm1 = \tfrac{1}{2} M_t\, V_o^2 \,/\, \delta_{fs} = W_i \,/\, \delta_{fs} \qquad (2.)$$

where, W_i and δ_{fs} are, respectively, the impact kinetic energy and the final shortening of the column, measured after the test.

Definition II:

$$Pm2 = \int_{x_1}^{x_1+2nH} P(\delta)\, d\delta \;\; / \; 2nH \qquad (3.)$$

where, $P(\delta)$ is the load/shortening characteristics, x_1 a suitable reference value, n an integer and H the half folding wave length. The integral limits are so chosen as to avoid the uncertainties on the measurement of the first peak load and the last part of the test, where the speed is small and the test is becoming quasi-static. The values employed in the present study are: x_1=H=31.6mm, n=1 and n=2 for lower and higher kinetic energies, respectively.

Definition III:

$$Pm3 = \int_0^{\delta_{Pm3}} P(\delta)\, d\delta \;\; / \; \delta_{Pm3} \qquad (4.)$$

This is the most frequently used method to calculate the mean crushing load; Pm3 is obtained by dividing the area of the recorded load/shortening characteristics by the shortening of the column.

Definition IV:

$$Pm(\delta) = \int_0^{\delta} P(\zeta)\, d\zeta \;\; / \; \delta \qquad (5.)$$

where, $P(\zeta)$ is the instantaneous crushing load when the instantaneous shortening is equal to ζ.

c)Loss energy coefficient. It is defined as follows:

$$le = (W_i - \int_0^{\delta_{Pm3}} P(\delta)\, d\delta \;)\; / W_i = \frac{W_i - W_d}{W_i} \qquad (6.)$$

where, W_d is the deformation energy dissipated by the column.

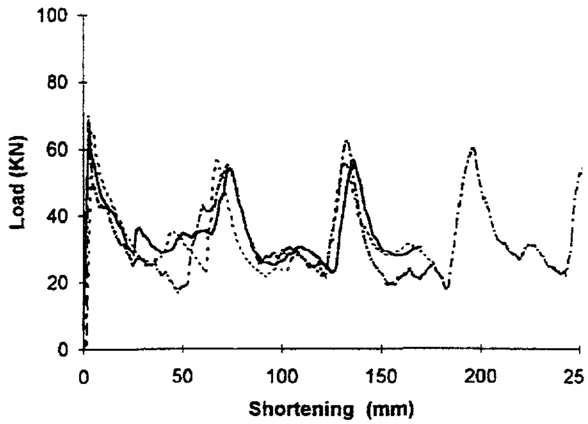

Figure 3. Non-filtered load/shortening characteristics of three static tests.

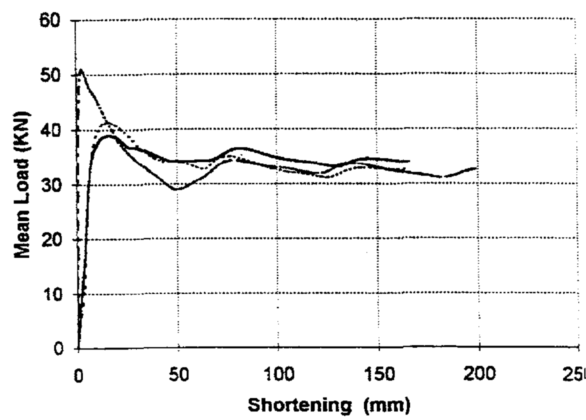

Figure 4. Non-filtered Mean-load/shortening characteristics of three static tests.

Static Crash Test Results Five triggered columns were tested under quasi-static conditions by JRC and INRETS. Satisfactory agreement of the results of the two laboratories was observed (Figures 3-4). These tests have produced an average static peak load of P^s=68.4kN, and an average crushing wave length of 2H=63.3mm. These values have been used in calibrating the dynamic tests.

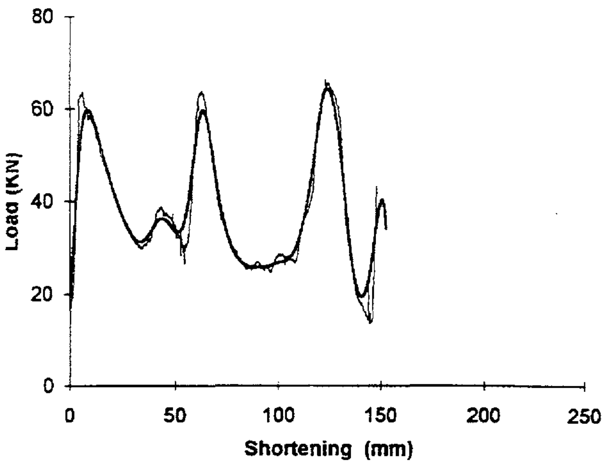

Figure 5. Load/shortening characteristics of test C from transmitted LDTF pulse (— non-filtered, — filtered).

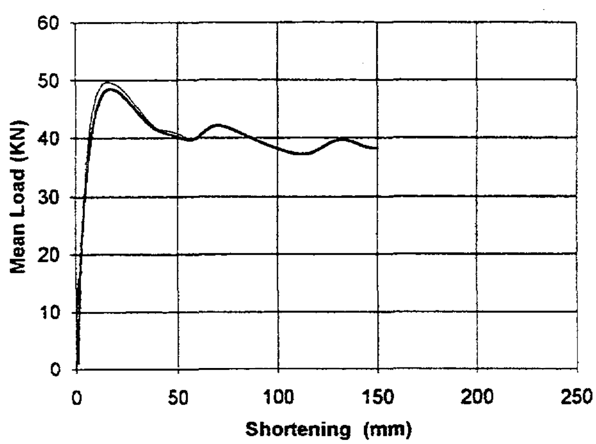

Figure 6. Mean load/shortening characteristics of LDTF test C (— non-filtered, — filtered).

Dynamic Crash Test Results The complete set of experimental results, including tables with numerical values and full load/shortening curves of all tests (A-G) for each laboratory, can be found in ref.[2].

For discussion and illustration purposes only six characteristic graphs are reported in this paper. They all refer to test conditions C-D. Figures 5-6 are plots of typical curves obtained from the LDTF tests; the absence of signal contamination is evident. Figures 7-8 are dynamic crash curves produced by a horizontal sledge apparatus, and Figures 9-10 have been produced by a vertical drop hammer device.

Clearly it would be impossible to attempt any comparisons based on non-filtered data. Thus it is recalled that the CFC 180 filter has been employed, and that all comparisons have been performed on parameters derived from filtered characteristics.

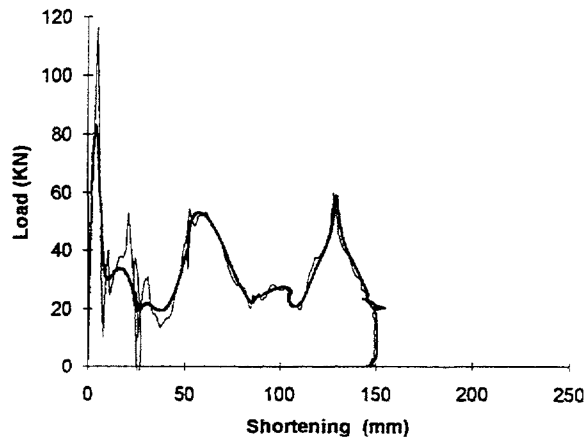

Figure 7. Load/shortening characteristics of test D from a horizontal sledge apparatus (— non-filtered, — filtered).

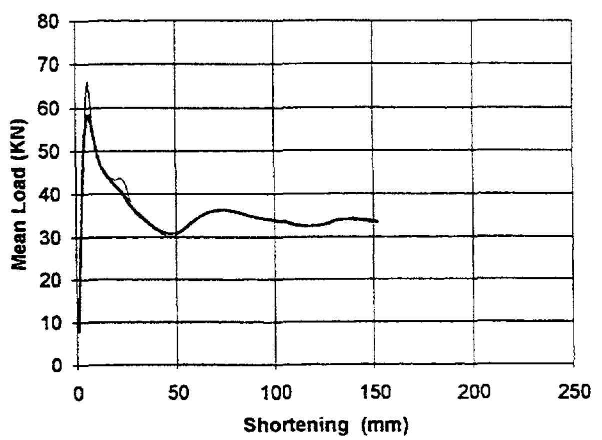

Figure 8. Mean load/shortening characteristics of test D from a horizontal sledge apparatus (— non-filtered, — filtered).

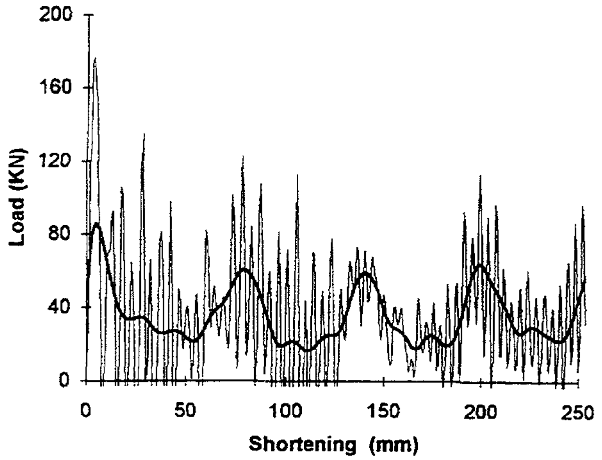

Figure 9. Load/shortening characteristics of test C from a vertical drop hammer device (— non-filtered, — filtered).

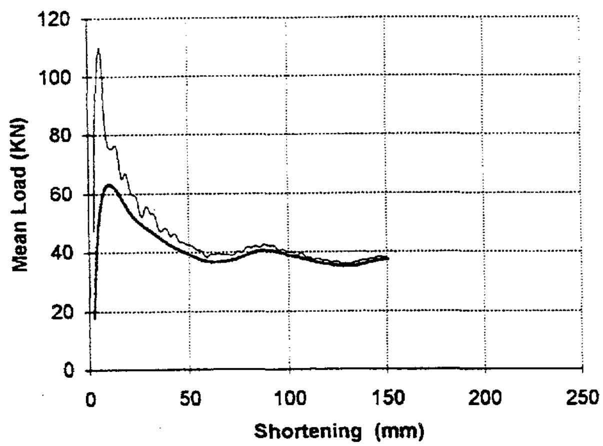

Figure 10. Mean load/shortening characteristics of test C from a vertical drop hammer device (— non-filtered, — filtered).

COMPARISON OF CRASH TEST RESULTS

Interesting observations have been made on the effects of numerical filtering, the spread of test data from the two batches, the reproducibility of the results obtained from each laboratory, and the overall performance of the rigs at the two prescribed impact velocities [2]. Some parts of them are reported below.

It has been shown that the numerical filter CFC 180 has little effect on the mean load derived from low impact speed tests. For the higher impact speeds the mean load calculated from filtered data is, in general, less than that derived from non-filtered ones. This numerical filter has, however, significant effect on the first peak obtained from horizontal sledges and vertical drop hammers, reducing its value by almost 60%.

The quantification of the spread of the experimental results has demonstrated that all laboratories are capable of performing reproducible crash tests. Only the spread of the first peak load appears to be relatively large (15%).

The two batches of aluminum present an average difference in the column crushing force by approximately 6.5%; a similar difference was also evidenced in the tensile specimen testing.

Regarding the effect of the impacting mass, it has been established that no significant differences exist between the mean forces related to the mass magnitude for the velocities around 30 km/h. This difference becomes, however, more pronounced for the tests at 50 km/h. In this case the tests performed with small masses give higher mean crushing forces, probably because of increased rebound effects.

From the comparison between dynamic conventional and LDTF tests, the high quality of the LDTF measurements has emerged and these results were adopted as reference. The degree of deviation from these values of a particular crash parameter for a given test rig may indicate a need of performing an appropriate calibration procedure. As was recognized, the fundamental advantage of this technique derives from its effective accounting of the dominant phenomenon of wave propagation and the underlying well-founded Hopkinson bar theory

CONCLUSIONS

This study of column dynamic crushing, carried out by the several laboratories with the different equipment, has produced interesting results. They concern the effect of numerical filtering, the spread of test data from the two batches, the reproducibility of the results of each laboratory, and the overall performance of the rigs at the prescribed impact conditions. Further, the efficiency and precision measurements of the LDTF (large-scale Hopkinson bar) were established and adopted as reference.

A point which is considered to require further investigation is related to the magnitude of the first peak load due to its consequences in the safety of the vehicle occupants. The crush tests of longitudinal beams should be performed with enough energy to reproduce the same strain rate in the material as in real car accidents. Attention is also drawn to the fact that materials, like carbon steel and high strength steel, often show an initial peak in their stress-strain curve at high strain rates, which can generate a significant first peak load in the load/shortening characteristics of a longitudinal beam.

ACKNOWLEDGMENTS

This benchmark exercise has been financially supported by the Human Capital and Mobility programme of the European Union, which is gratefully acknowledged. Special thanks are also due to the participants and real contributors to this work which are: Centro Ricerche FIAT (IT), INRETS (FR), BMW Technik GmbH (DE), TNO (NL), Norges Tekniske Hogskole (NO), Univ. Valanciennes (FR), VOEST-ALPINE Stahl (AT), Politecnico Milano (IT), Univ. Liverpool (UK), TÜV-Rheinland (DE), Univ.Kaiserslautern and Daimler Benz (DE), VOLVO Automotive Safety Center (SE), DRL Stuttgart (DE)

REFERENCES

1. Birch, R.S., Jones, N., Jouri, W.S., 1988, "Performance Assessment of an Impact Rig", Proceedings of the Institute of Mechanical Engineers, Vol.202, No.C4, pp.275-285.
2. Hanefi, E. H., Wierzbicki T., Albertini, C., "Calibration of impact rigs for dynamic crash testing" Report EUR 16347 EN, 1995.
3. Albertini, C., Cadoni, E., Labibes, K., "Precision measurements of vehicle crashworthiness by means of a large Hopkinson bar", Suppl. au Journal de Physique III, Colloque C3, août1997, pp.79-84.