GA-4/GA-9 Honeycomb Impact Limiter Tests*

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INTRODUCTION

General Atomics (GA) is under contract to the U.S. Department of Energy, Field Office, Idaho, to develop two legal weight truck casks for transportation of spent nuclear fuel. This development project supports the Office of Civilian Radioactive Waste Management mission goal to develop a safe and efficient transportation system. The GA-4 and GA-9 Casks transport four pressurized-water-reactor (PWR) and nine boiling-water-reactor (BWR) spent fuel assemblies, respectively.

The GA-4 and GA-9 Casks have similar designs. They both are long (the GA-9 is a little longer) and have square cross-sections with rounded corners. At each end is an aluminum honeycomb impact limiter to absorb energy and limit forces during impact. To evaluate the effectiveness of the impact limiters, GA performed a test program to obtain data on the behavior of the impact limiters over the range of impact angles.

The test program was divided into three phases. Phase 1 provided the basis for understanding the behavior of honeycomb and the effects of structural backing, operating temperature and impact velocities on the honeycomb crush strength. Phase 2 provided data on the behavior of the complete impact limiter at different angles. Based on the results of Phase 1 and Phase 2 tests, the impact limiter design was optimized prior to commencing Phase 3. Phase 3 tested the final impact limiter design over a range of angles, providing a complete characterization of the impact limiter behavior. This paper discusses the test program, the test results, and how these helped optimize the impact limiter design. It emphasizes the results obtained during Phase 3 of the test program. The results obtained during Phases 1 and 2 were reported previously (Koploy, 1991). This paper also includes a discussion on how the test results compare with analytical predictions.

Summary of Phase 1 and Phase 2 Test Results

During Phase 1 of the testing program, GA tested small samples and a complete 1/4-scale impact limiter to obtain basic information on honeycomb impact limiter behavior.

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The 30-ft drop dynamic test results show that the crush strength of the tested honeycomb increases a maximum 10 percent above the static test when crushed at 1.34 m/s (44 ft/sec). Temperature tests show that the crush strength of aluminum honeycomb varies less than 6 percent from nominal when tested over the temperature range of -29° to 93°C (-20° to 200°F). The tests show that the behavior of the honeycomb can be scaled as long as adhesive failure and splitting of the honeycomb is avoided. The complete impact limiter test shows that a honeycomb impact limiter designed with three parts: center, corner and side; will behave as a unit to distribute and react to the loads of honeycomb crushing even if the honeycomb is not directly backed by the cask. These tests also show that the impact limiter attachment bolts must be designed to react to the moments produced by the unbacked honeycomb crush loads.

GA used data developed during the Phase 1 to optimize the impact limiter design. During Phase 2, GA tested two impact limiters. Each impact limiter was crushed at two angles and the load-versus-deflection curves for different crush angles measured.

Impact Limiter Design Optimized Prior to Phase 3

Based on the results of Phase 2, GA optimized the impact limiter design to minimize weight and loads to the cask during the hypothetical accident 9-m (30-ft) drop. As shown in Fig. 1, the impact limiter is made out of three sections. A center region over the end of the cask, a corner region, and a side region around the sides of the cask. The design of the impact limiters is similar to the design tested during Phase 2.

Some of the honeycomb crush strengths were reduced and the dimensions slightly adjusted, based on the results of the previous tests, in order to optimize the impact limiter weight and its response to developed g-levels. For long casks like the GA-4 and GA-9, the critical drop orientation is the side drop. In this orientation, the GA-4/GA-9 honeycomb impact limiters develop a maximum cask g-level less than 47 g. This is lower than other types of impact limiters for legal-weight-truck casks which produce g-levels closer to 60 g or higher. The total weight of the impact limiters is less than 2,000 lb each.

Phase 3 Testing

During Phase 3, four 1/4-scale impact limiters were crushed at different directions ranging from end crush to side crush. As shown in Table 1, three impact limiters were tested twice, on opposite sides. The fourth impact limiter was tested only once. The tests were performed on a compression testing machine. The impact limiters were directly backed by a solid aluminum test fixture, simulating the cask. The test setup (Fig. 2) was instrumented during the entire event to provide a complete record of the load applied to the specimen as a function of deflection. Graphs of the load-versus-deflection data were produced (Figs. 3 through 6).

Results

All tests show an even crush, and no splits or tears developed on the impact limiter face sheets. Table 1 shows the energy dissipated by the impact limiters during the tests before the impact limiter bottomed out. The same table shows the amount of energy required to be absorbed by the GA-4 /GA-9 Cask impact limiters during the different hypothetical accident 30-ft drops. All results shown are 1/4-scale data. The results show that the impact limiters can absorb at least 60 percent more energy than needed before bottoming out.

In all tests, the load-versus-deflection curves show an increase in the crushing force that indicates bottoming out of the honeycomb at depths more than 74 percent of the total thickness. For example, for the 0° test, the 1/4-scale impact limiter was initially 6.25 in. thick and bottomed out at a thickness of 1.25 in. The impact limiter is designed such that the area that bottoms out is greatest at 90° (end of cask). At other angles, the area of bottoming out is initially small and increases gradually allowing longer travel and providing a greater design margin. Table 2 shows the deflection and the percentage of the initial honeycomb thickness at which the test impact limiters bottomed out.

TABLE 1
SEVEN 1/4-SCALE TESTS SHOW IMPACT LIMITER BEHAVIOR

Impact Limiter Number	Test on Impact Limiter	Test Crush Orientation (Degrees)	E_{test} Energy Dissipated during Tests (in.-lb x 10^3)	E_{need} Energy Absorption Needed during 30-ft Drop (in.-lb x 10^3)	E_{test} / E_{need}
1	1	60	626	229	2.74
	2	15	481	92	5.21
2	1	0 (side)	324	203	1.60
	2	45	465	159	2.92
3	1	75	698	293	2.39
	2	30	218	115	1.90
4	1	90 (end)	717	293	2.45

The results of the second test on each of the impact limiters are used only to get an idea of the effectiveness of the impact limiter and the general shape of the curve, since it is hard to determine the extent, if any, of the internal damage on the honeycomb after the first test. For example, after the 75° test, the outer diameter of the impact limiter had grown from 22.48 in. to 23.06 in. This suggests that the impact limiter had suffered some damage during the test, even in areas where there was no crushing. As shown later, the results of the 30° test (the second test after the 75° test) are lower than expected. Therefore, it is safe to assume that the lower performance of the impact limiter is due to the damage due to the first test. It is harder to determine if the second load-versus-deflection curve for the other impact limiters tested is suspect, since the damage on the side opposite the initial test was not so obvious as after the 75° test. A comparison of test results with the expected analytical predictions shows good agreement on the second test curves, indicating that the damage due to the initial test did not affect the performance of the impact limiter during the second test.

TABLE 2
1/4-SCALE IMPACT LIMITERS BOTTOMED OUT AFTER CRUSHING MORE THAN 74% OF INITIAL THICKNESS

Test Angle (Degrees)	Displacement (Inches)	% of Initial Honeycomb Thickness
0	5.00	80
15	5.25	76
30	5.5	78
45	5.75	80
60	5.75	80
75	5.25	78
90	4.25	74

Comparison of Results to Analysis

The test results show good correlation with analytical predictions. Figures 3 through 6 show the impact limiter test results and how the they compare with analytical predictions obtained using the computer code ILMOD. ILMOD was developed by GA to predict honeycomb impact limiter test results. The figures show the minimum and maximum analytical load that covers the variation due to manufacturing tolerances and temperature effects on the honeycomb crush strength. All results shown are 1/4-scale data.

The largest differences between the test results and analytical predictions occur during the end crush. The test shows a higher initial crush load, dropping to the analytical value later in the crush. The higher load is attributable to the buckling of the tubes on the center top part of the impact limiter. This load is not included in the calculations. The tubes allow the impact limiter bolts to be put in place. There are also discrepancies between analytical predictions and the test results at low displacements. This is due to the resistance of the face sheet which has to buckle as the impact limiter crushes, this load is ignored in the calculations. As the honeycomb crush load increases, the load needed to buckle the face sheets gets smaller in proportion to the crush strength, and therefore, it is not as noticeable at the end of the stroke. The initial discrepancies in the load-versus-deflection curves do not affect the analysis of the cask since the critical loads occur towards the end of the crush and not at the beginning.

Conclusions

The engineering tests performed on honeycomb impact limiters show that honeycomb can effectively be used to create a lightweight impact limiter that will limit impact loads to relatively low levels. The GA-4/GA-9 impact limiters can absorb at least 60 percent more energy than needed before bottoming out. Bottoming out of the honeycomb occurred at depths more than 74 percent of the total thickness. The behavior of the impact limiter can be predicted using the computer code ILMOD.

REFERENCE

Koploy, M. A., *GA-4/GA-9 Honeycomb Impact Limiter Tests and Analytical Model*, Proceedings of the International High Level Radioactive Waste Management Conference, Las Vegas, NV (1991).

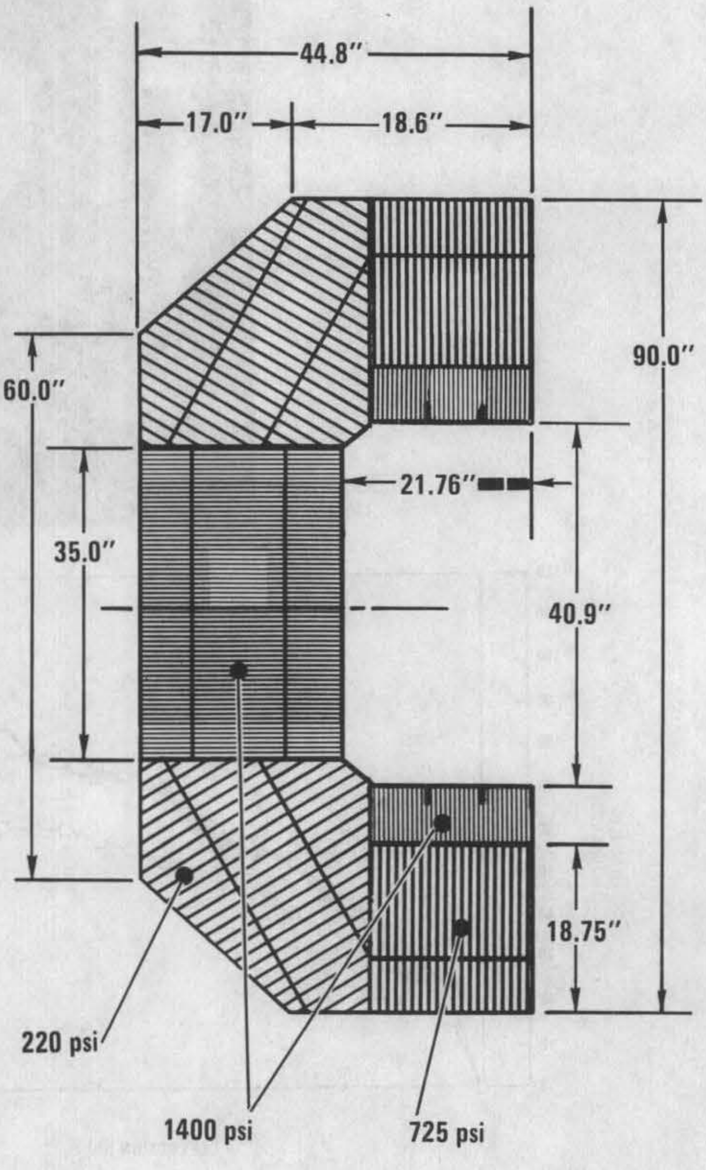

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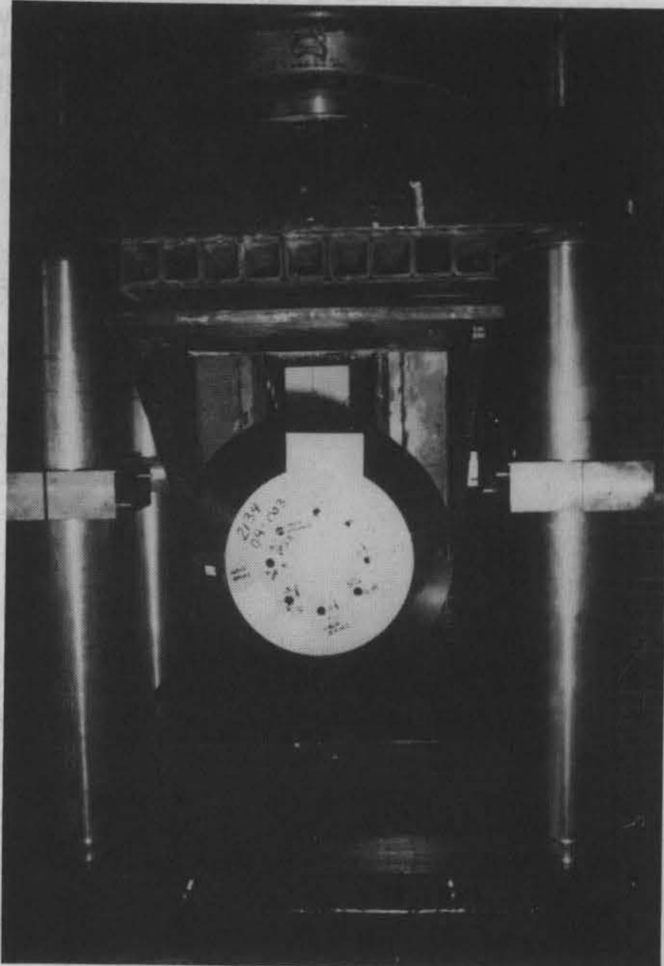
Fig. 1 **GA-4 impact limiter design has several honeycomb parts**

Fig. 2 1/4-scale impact limiter models were tested on a compression machine



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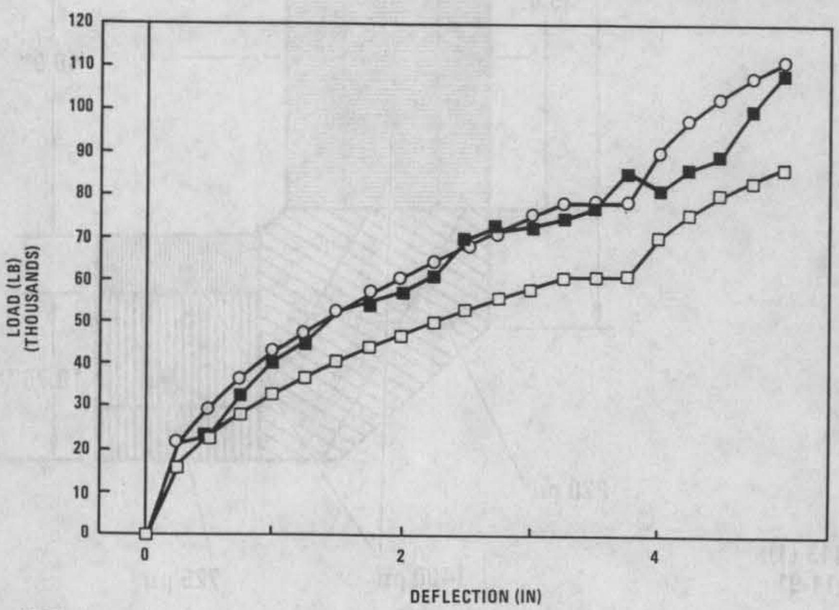

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Fig. 3 Critical side crush (0°) test and analysis results compare well

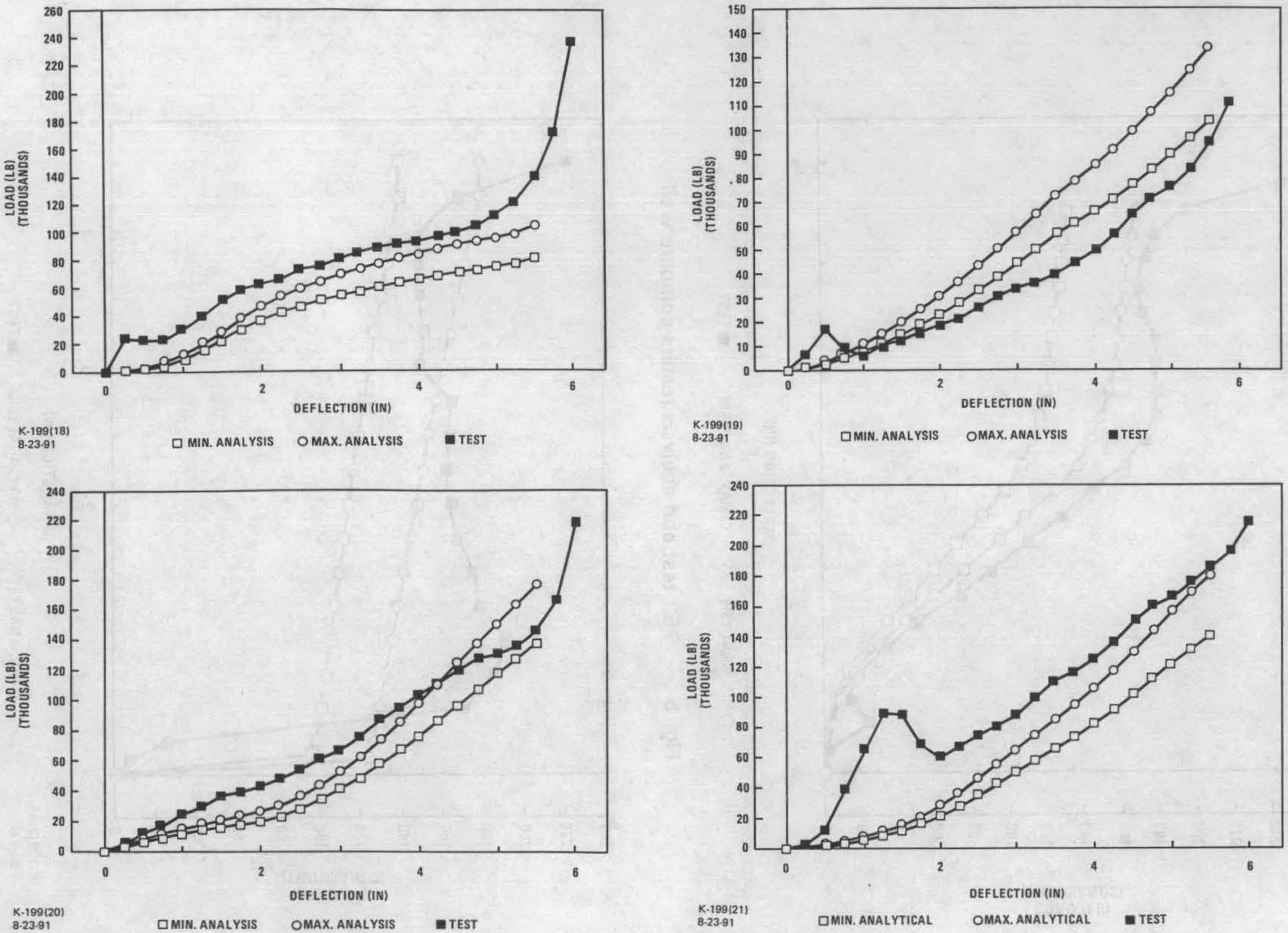

Fig. 4 Test and analysis results compare well

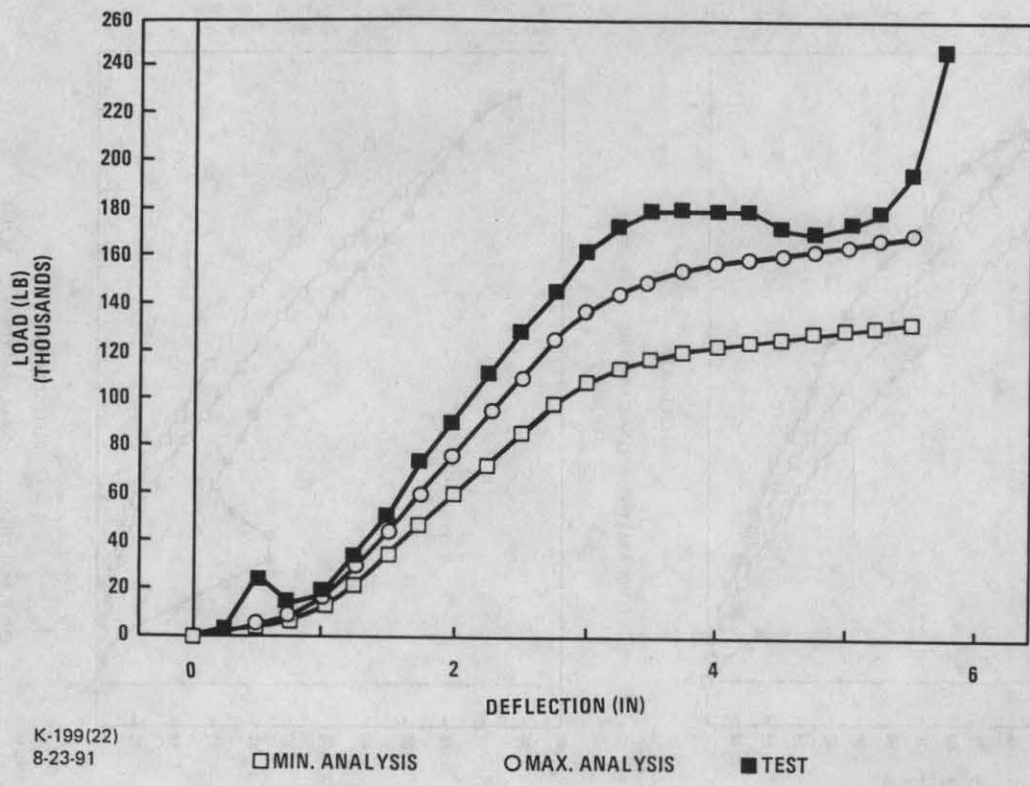

Fig. 5 75° test and analysis results compare well

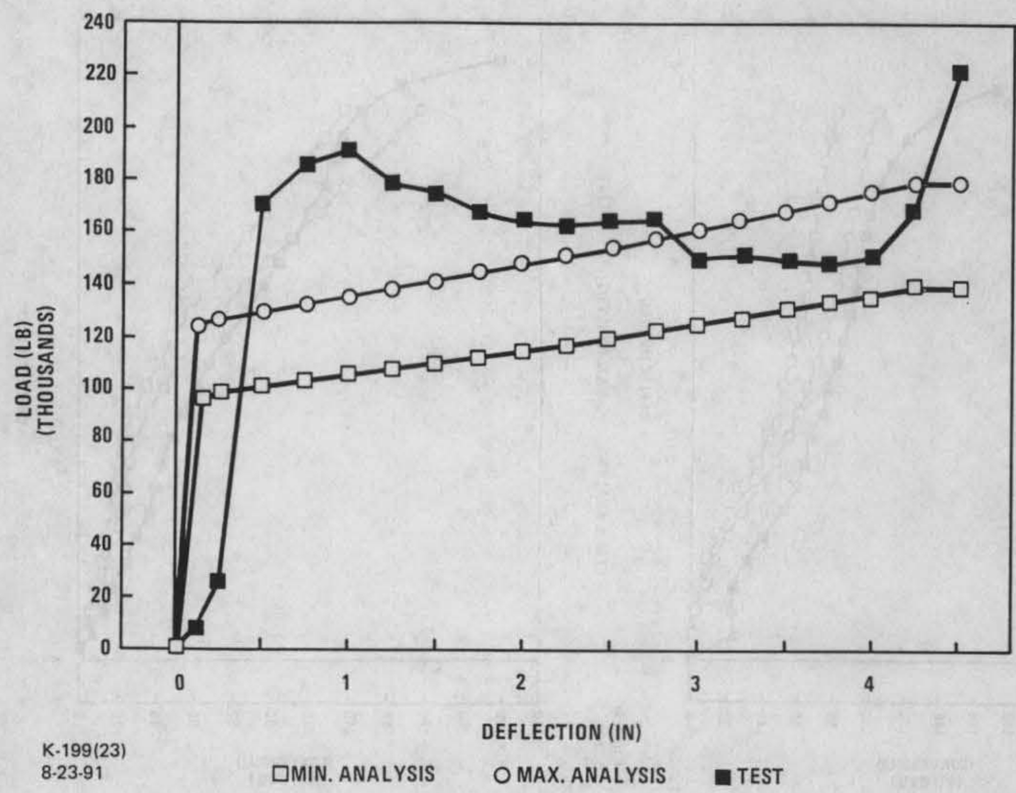

Fig. 6 Test results show higher initial crush load during end crush than analytical results

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