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COMPARATIVE TESTING OF ANTHROPOMORPHIC DUMMY AND A STANDARDIZED IMPACTOR FOR GLAZING MATERIAL

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1. INTRODUCTION

This report describes a test program conducted at the Highway Safety Research Institute of the University of Michigan using filled leather punching bag and anthropomorphic dummy test subjects as impactors on panels of various glazing materials. The objective was comparison of the results using the two types of impactors.

For the punching bag impactor, instrumentation consisted of an accelerometer attached to its surface. High speed motion pictures were taken to record the impact in two orthogonal directions. Force vs. penetration curves were derived from these data allowing a rough calculation of impact energy. Six impacts were conducted at the 400 ft. lb. energy level using annealed glass, tempered glass, and acrylic sheets.

Four tests were conducted using an anthropomorphic test device. It was positioned to represent a person running (2 tests), erect posture and side impact. Instrumentation consisted of triaxial accelerometer packs in the head, thorax, and pelvis region supplemented by femur axial load cells. Orthogonal high speed motion pictures were taken.

Part 2 of the report describes the test program. Parts 3 and 4 present results and list conclusions and a recommendation.

2. TEST PROGRAM

2.1 Selection of Drop Test

The Proposed Safety Standard utilizes a pendulum activated by gravity impacting an upright panel in which glazing material is mounted. This procedure was modified for this project to a configuration involving a horizontally mounted glazed panel onto which the impactor was dropped.

There were three reasons for this. The first, and most important reason was the difficulty of accurate positioning of the dummy prior to the test in order that the desired impact scenario could develop. By suspending the dummy over the panel and then dropping it, a specified relative position could be maintained between the dummy and the glazing material. The height of the drop then controlled the overall energy delivered to the panel. Using this technique it was relatively easy to control the part of the dummy (knee, hand, head, side) making the initial contact with the glazed panel. Equally satisfactory and reproducible results were also possible using the filled leather punching bag. The second reason was prior experience with dummy drop tests. A previous project at HSRI involved human injury in free falls. Dummies were dropped from various heights and in various postures onto hard surfaces during that work successfully demonstrating the experimental procedure. The third reason was material containment. By dropping the impactor toward a horizontal panel, the resulting broken fragments naturally tended to be propelled downward into a large box.

2.2 Fixture for Holding Panels of Glazing Materials

The fixture for holding the panels was a horizontal realization of the frame specified in the Proposed Safety Standard. The panel was located in a rigid framework approximately 3 ft. above the floor of the laboratory. Plywood sides were mounted to the framework to form a box into which fragments of glazing materials could drop. This allowed minimum turn-around time between tests.

A shim, 3/16 inch thick, was used to provide the required compression in the neoprene strips. It was found by direct measurement that compression of the neoprene was the required amount at the bolts, but was minimal between them. This slight bowing of the test frame between bolt holes was measured by determining the distance from the test frame to the surface of the glass using a depth gauge. The fact that the bowing was in the frame was qualitatively established by laying a straight edge on the four members of the frame. The significance of this observation on test results using the standardized frame should be established.

2.3 Impactor Positioning

Both the anthropomorphic dummy and the filled leather punching bag were suspended over the panel of glazing material using ropes. Vertical position is adjustable within 1/4 inch by means of a hydraulic lift. Horizontal positioning is accomplished by moving the lift to the desired point after vertical positioning is completed. For all ten tests the impactor was centered over the panel of glazing material. Release was automatically initiated by using an electrically-triggered rope-cutting device. Figure 1 is a photograph of the apparatus just prior to a test.

2.4 Instrumentation

Instrumentation for the punching bag drop tests consisted of an accelerometer (Endevco 2264) taped firmly to the top surface opposite the point of impact. This was supplemented by high speed motion pictures at the rate of approximately 1000 frames per second. The cameras were located directly to the side of and above the impact event.

For the anthropomorphic dummy tests, a standard instrumentation package used in automotive testing was used. This consisted of triaxial accelerometer units in the head, thorax, and pelvis. In each unit the accelerometers were directed toward the front of the body (P-A or posterior-anterior), to the side (L-R or left-right), and from head to toe (S-I or superior-inferior). Setra capacitive accelerometers were used. Additional data was obtained from strain-gauge load cells mounted axially in the femur structure of the legs.

All data was recorded, unfiltered, on a Honeywell 7600 Series tape recorder. A time channel was also recorded giving 1 millisecond intervals. This signal was also superimposed on the high speed movies allowing an accurate determination of the frame rate of the camera.

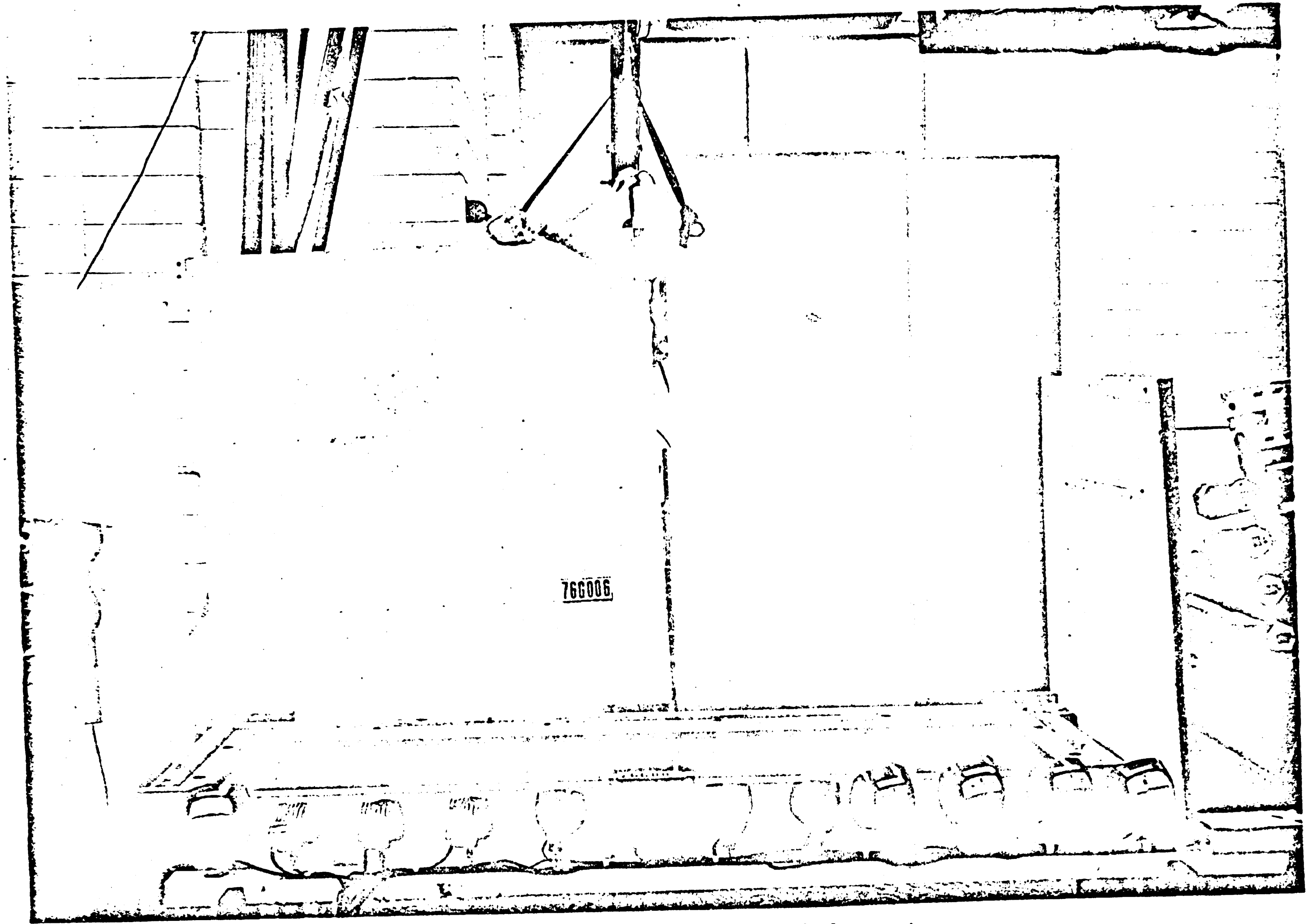

Figure 1. Drop Test Experimental Apparatus

3. TEST RESULTS

The accelerometer and motion picture data from the six drop tests using the filled leather punching bag were combined to produce force-penetration curves for the impacts. The accelerometer data were played out from the tape recorder onto a Brush recorder and are shown in Figure 2. The initial large pulse represents the contact between the bag and the panel. Any additional pulses represent the bag hitting the floor of the laboratory. The force of impact was computed by multiplying the weight of the bag (100 lbs) by the G-level. Penetration of the bag into the panel of glazing material was determined by film analysis of the movie during impact. Movement of the bag was manually measured directly from individual frames of the movie using a Vanguard Film Analyzer. Because timing markers were on the movies, it was possible to construct a displacement-time curve.

Figures 3-8 show the reduced data from the first six tests. Each figure shows the force vs. time and deflection vs. time curves determined directly from the test data. These are supplemented by the force vs. deflection curves. It was possible to compute the area under the force deflection curves in order to make a very rough estimate of the energy transmitted from the impactor to the panel of glazing material during impact.

An overall summary of the numerical results are given in Table 1. Failure modes are shown in Figures 13-15. The punching bags were essentially restrained by the acrylic panels although they did partially pop from the frame. The annealed glass panels both shattered into the usual sharp pieces. The energy absorbed in the two tests was markedly different. Many more small glass fragments were found after Test No. 2 than after Test No. 5 reflecting the increased energy transmission before failure. The tempered glass panel showed breakage in the first test (No. 3). However, energy absorption was almost complete. The impactor bounced during the first contact in Test No. 6. This is reflected in the deflection-time curve given in Figure 8. However, the bag turned over and, as it came down again, broke the panel during a contact with the padded accelerometer

TABLE 1

SUMMARY OF TEST DATA

Test No.	Material	Peak G	Pulse Duration (ms)	Peak Force (lb)	Panel Deflection (in)	Energy Absorbed (ft lb)	Failure Mode
1	Acrylic	15	65	1500	7.9	367	Panel popped from frame
2	Annealed	33	10	3350	2.7	381	Broken
3	Tempered	31	19	3100	2.7	394	Broken
4	Acrylic	16	66	1600	6.0	392	Panel popped from frame
5	Annealed	20	9	2400	1.6	149	Broken
6	Tempered	52	42	5200	2.9	381	Impactor bounced

mount. It is unknown whether the breakage was caused by the second off-center hit, the smaller radius contact, or some reinforcement of stress waves not yet damped out from the first higher energy impact.

The character of the materials resulted in different test results for the three materials. The best "cushion" was offered by the acrylic. Laceration potential was also minimal. Tempered glass yielded higher forces spread out over a significant period of time (20-40 milliseconds). The possibility for superficial laceration was present. Annealed glass behavior was typified by development of a very high force in a very short period before failure (< 10 milliseconds) and the presence of very dangerous spikes of glass.

Transducer data from the four anthropometric dummy drop tests are given in Figures 9-12. In all cases, 3/16 inch annealed glass sheets were used. The four impact scenarios were:

Test No. 7. Prone Dummy

Test No. 8. Side-Facing Dummy

Test No. 9. "Jogging" Dummy

Test No. 10. Dummy with Arm and Knee Extended.

Figures 16 and17 are photographs of the dummies after two of the tests. In all cases, the dummy was dropped from approximately 29.1 in. yielding a total kinetic energy of 400 ft. lb. if the thorax were the first part of the body to contact the panel.

The prone dummy was positioned facing and parallel to the panel. Initial contacts were with the head and the toe. Both rebounded and the following thorax-abdomen contact shattered the glass. Figure 9 shows high head and thoracic G-levels in the P-A direction as expected. The larger G-levels in the pelvic and thoracic regions occur later in time than the head loadings indicating the two-step scenario of the impact delivery.

The side-facing dummy appeared to contact the glass simultaneously from shoulder to foot and maintained this posture throughout the initiation of failure. G-levels recorded in the dummy (See Figure 10) are generally quite low.

The "jogging" dummy was positioned with the right leg extended about 30° and the left elbow similarly positioned to the front. The arm and knee were the first body parts to contact the glass. The right knee fractured the glass without affecting dummy position significantly during the event. G-levels were again quite low during the event. The blow which fractured the glass was reflected as a 160 lb. load along the axis of the right femur.

In the final test, the dummy was positioned to "straight-arm" the glass panel with his left arm. The right leg was also positioned with the femur normal to the panel. The contact scenario was much more complex. The left hand contacted first followed shortly by the right toe then knee. The hand transmitted a load through the arm to the shoulder structure causing the dummy to rotate with his head aimed toward the glass. During this time the right knee was sliding to the side and the leg was straightening out. At about the same time, the head, left knee, and right shoulder contacted the glass. It is not clear from the movies which of these impacts caused the failure which followed. A substantial early femur load was recorded which did not cause the failure. G-loadings were generally higher in this test than the previous ones.

4. CONCLUSIONS AND RECOMMENDATIONS

Several conclusions have been reached based on the results of this work. These are:

1. The drop test and instrumentation adopted for this program offer a means for comparative testing of panels of glazing materials using different impactors.

2. Annealed glass, tempered glass, and acrylic show markedly different behavior when tested under similar conditions of impact.

3. The impact scenarios are markedly different for punching bag and dummy impacts.

4. Dummy impact scenarios depend strongly on body posture and body region of initial impact.

5. Dummy G-levels measured during the drop tests are well within standard tolerance values used in automotive safety studies and compare in magnitude with values measured on the punching bag.

6. Current generation anthropomorphic test dummies cannot be used to predict laceration injuries but may be useful in establishing impact scenarios qualitatively.

Two recommendations are also submitted. These are:

1. The significance of the observation of apparent non-uniform clamping of the panels of glazing materials should be established.

2. Human body impact energy depends on the effective mass of the body part and its velocity at the time of impact. The scenario of the impact depends on the human energy delivered, the geometric configuration of the subject with respect to the product using glazing materials, and the strength of the product. To determine the validity of the test procedures used in the current project, it is recommended that correlation with the real world of impacts which break glass be established beyond a reasonable doubt.

76G001 -- ACRYLIC PLASTIC

76G002 -- ANNEALED GLASS

76G003 -- TEMPERED GLASS

76G004 -- ACRYLIC PLASTIC

76G005 -- ANNEALED GLASS

76G006 -- TEMPERED GLASS

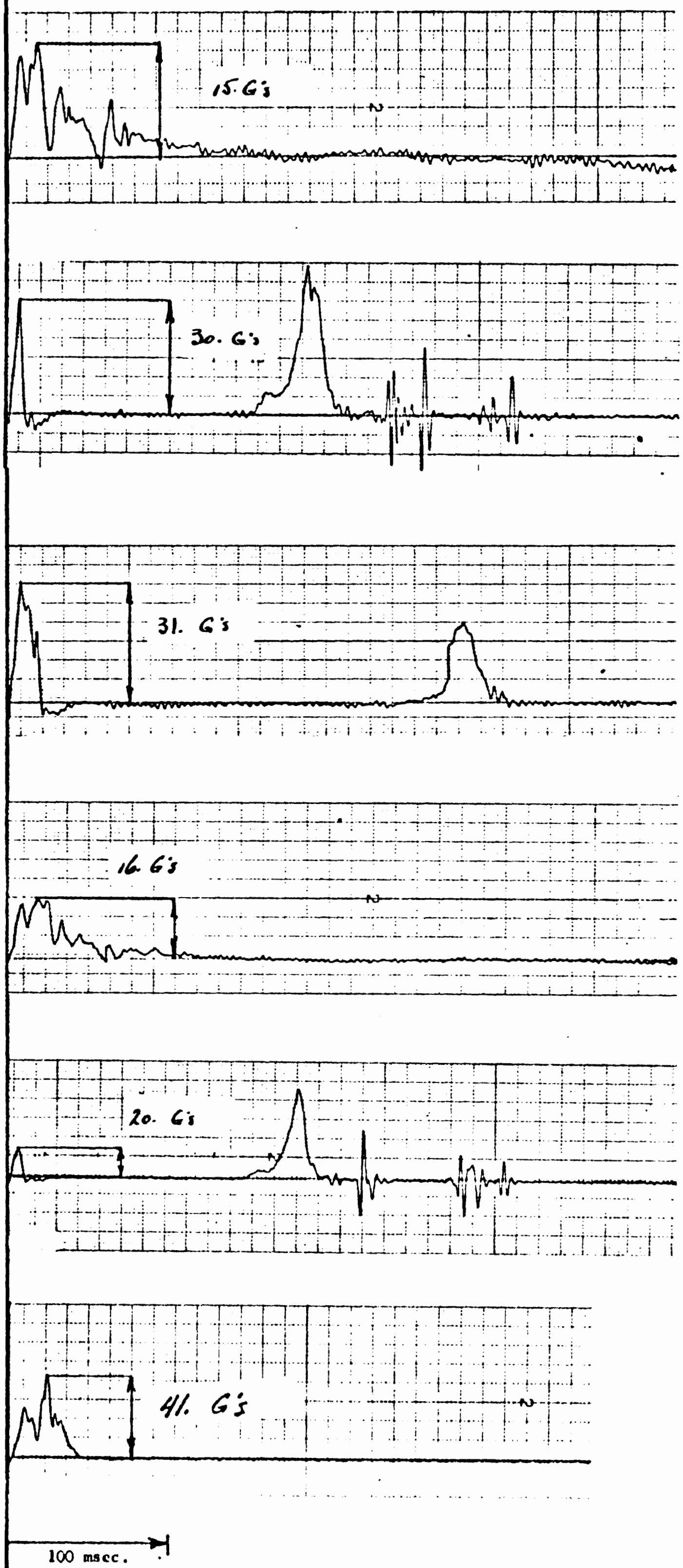

Figure 2. Accelerometer Data from Punching Bag Drop Tests

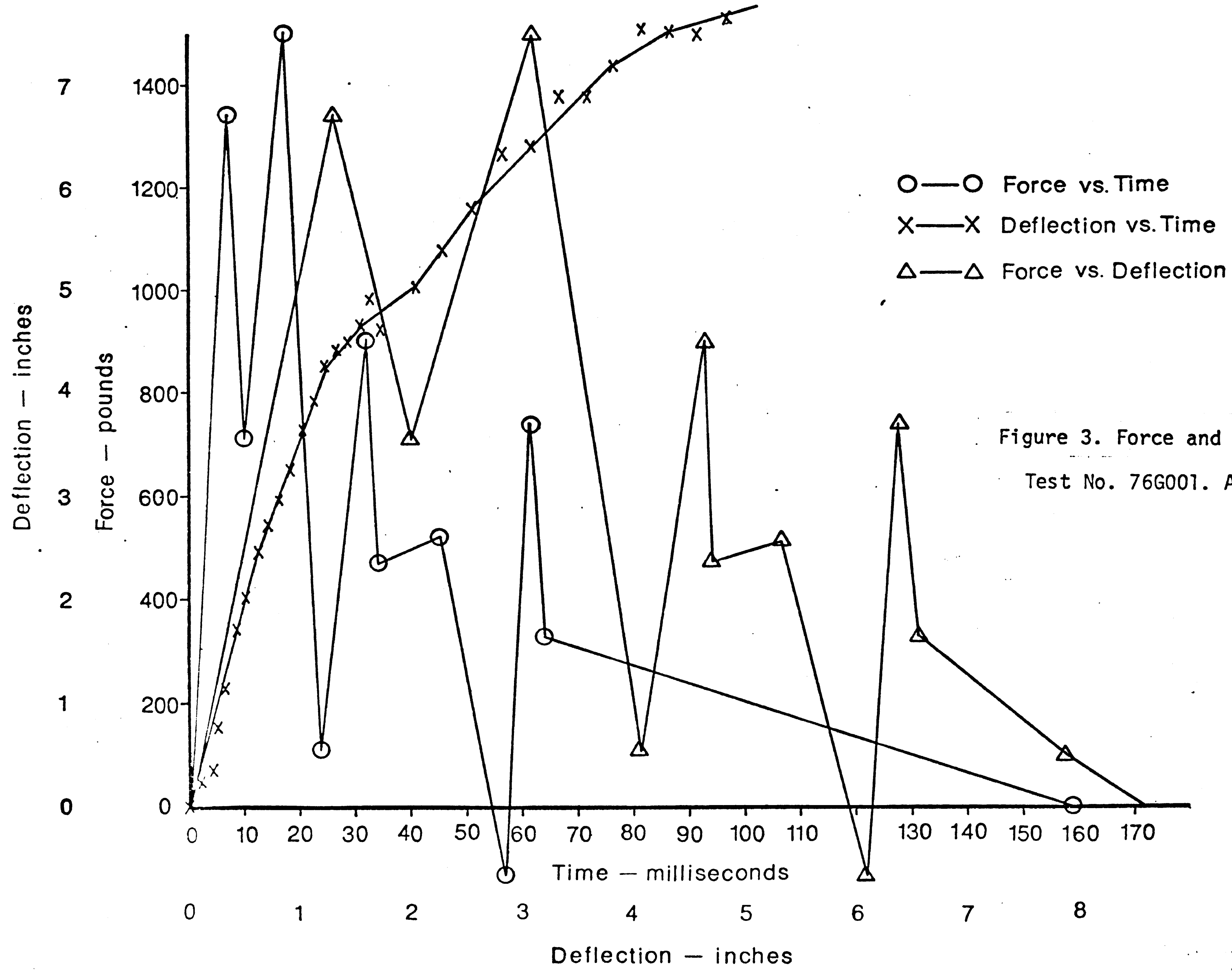

Figure 3. Force and Deflection Data.

Test No. 76G001. Acrylic Plastic

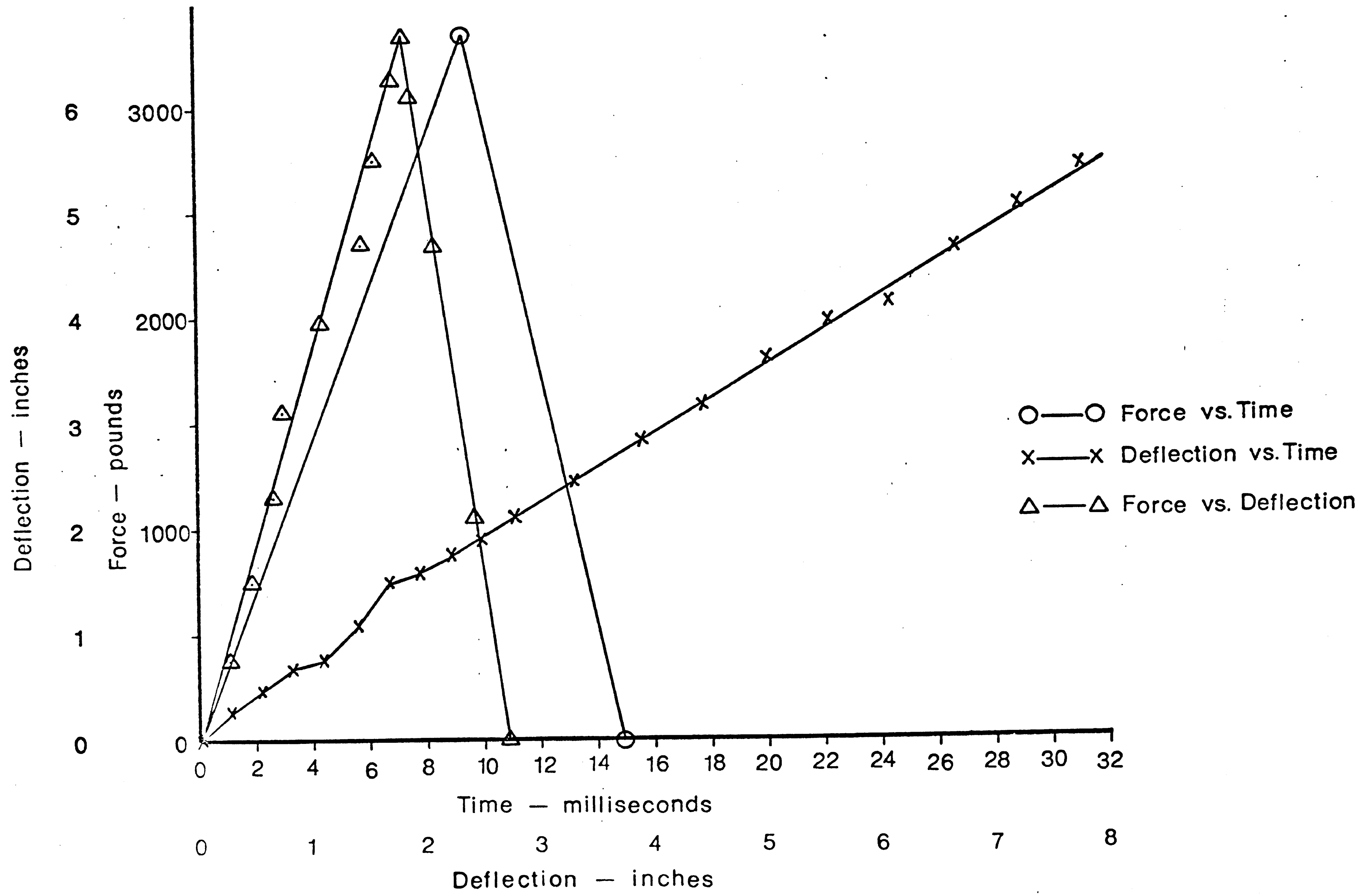

Figure 4. Force and Deflection Data. Test No. 76G002. Annealed Glass

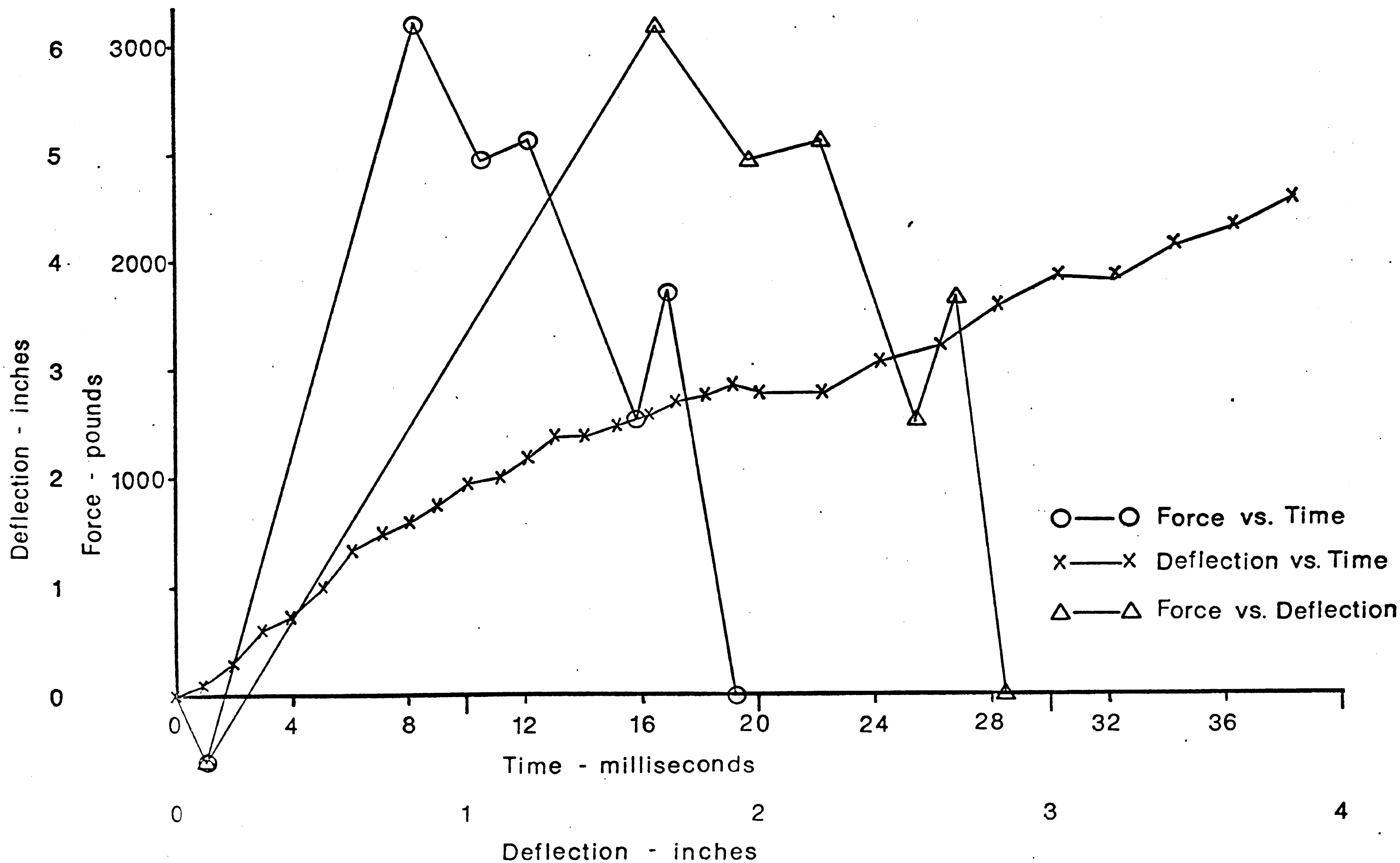

Figure 5. Force and Deflection Data. Test No. 76G003. Tempered Glass

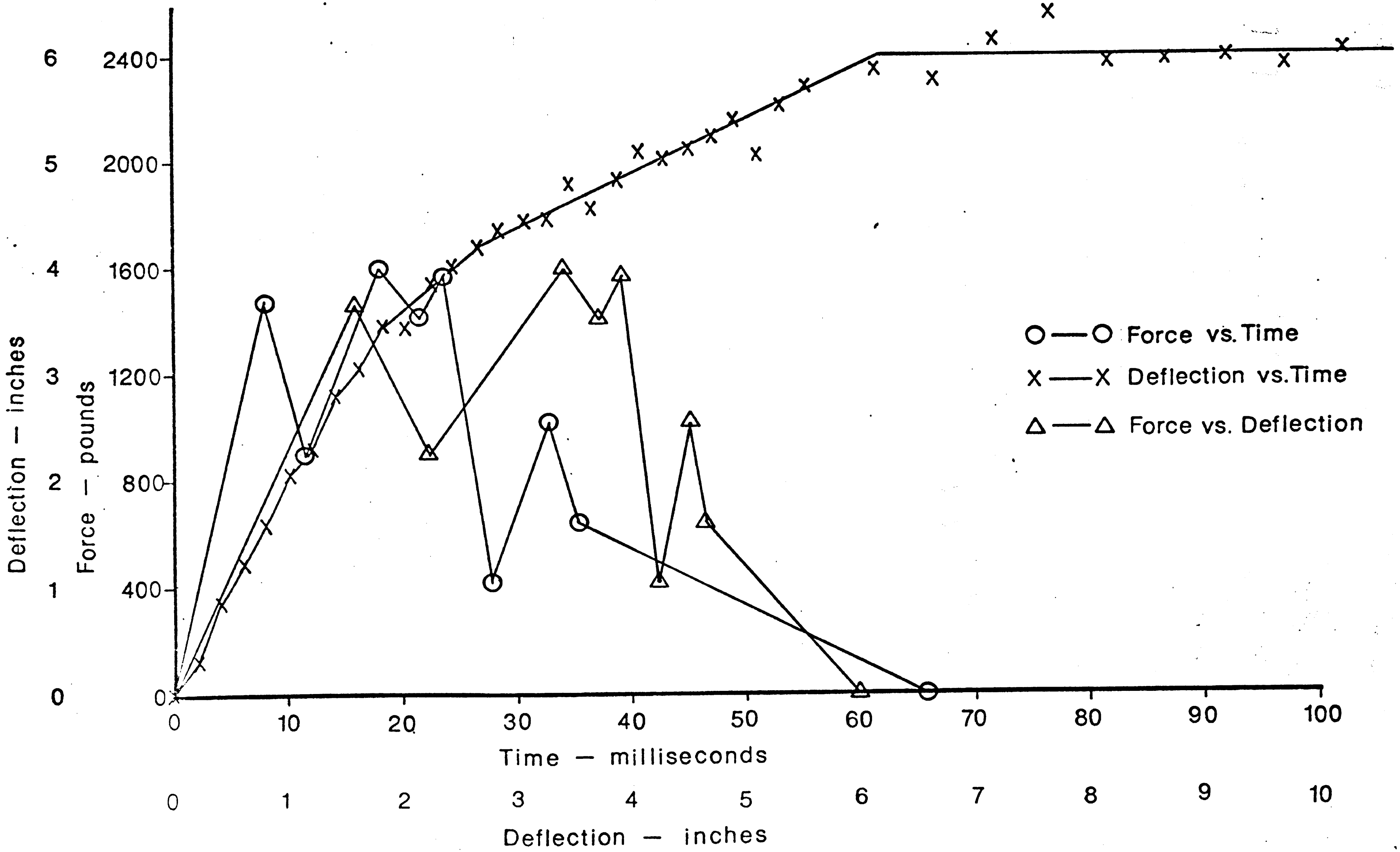

Figure 6. Force and Deflection Data. Test No. 76G004. Acrylic Plastic

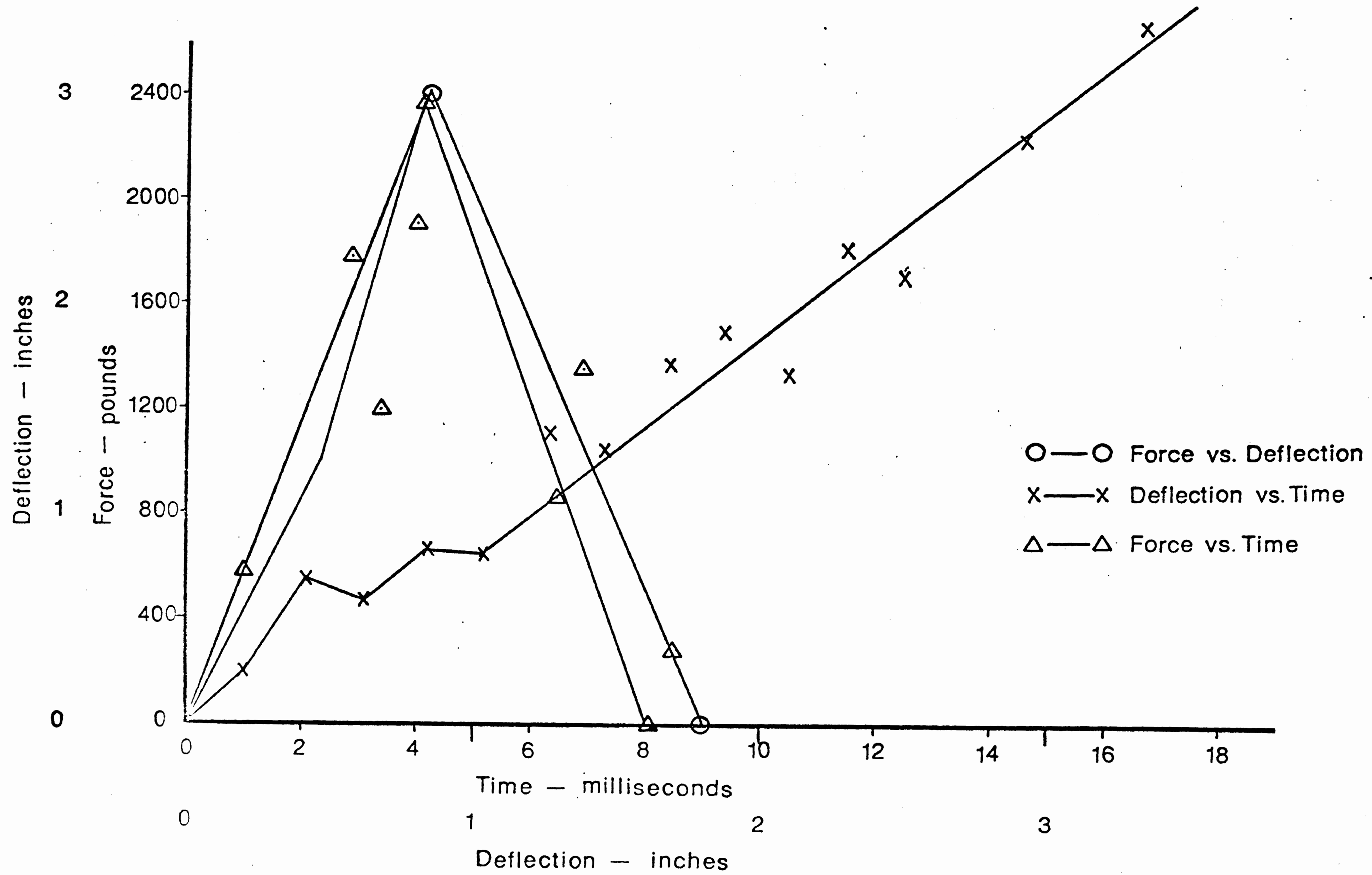

Figure 7. Force and Deflection Data. Test No. 76G005. Annealed Glass

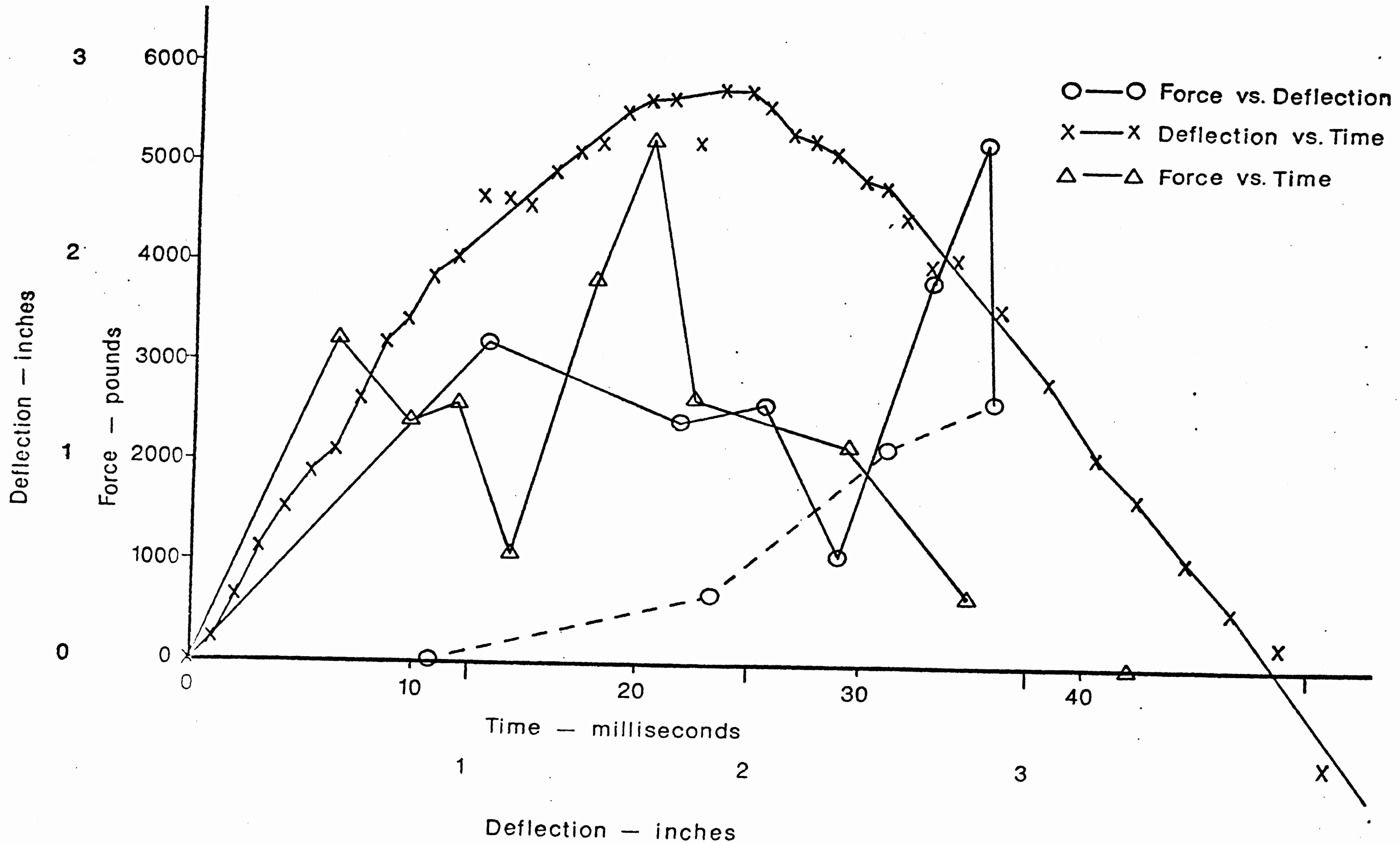

Figure 8. Force and Deflection Data. Test No. 76G006. Tempered Glass

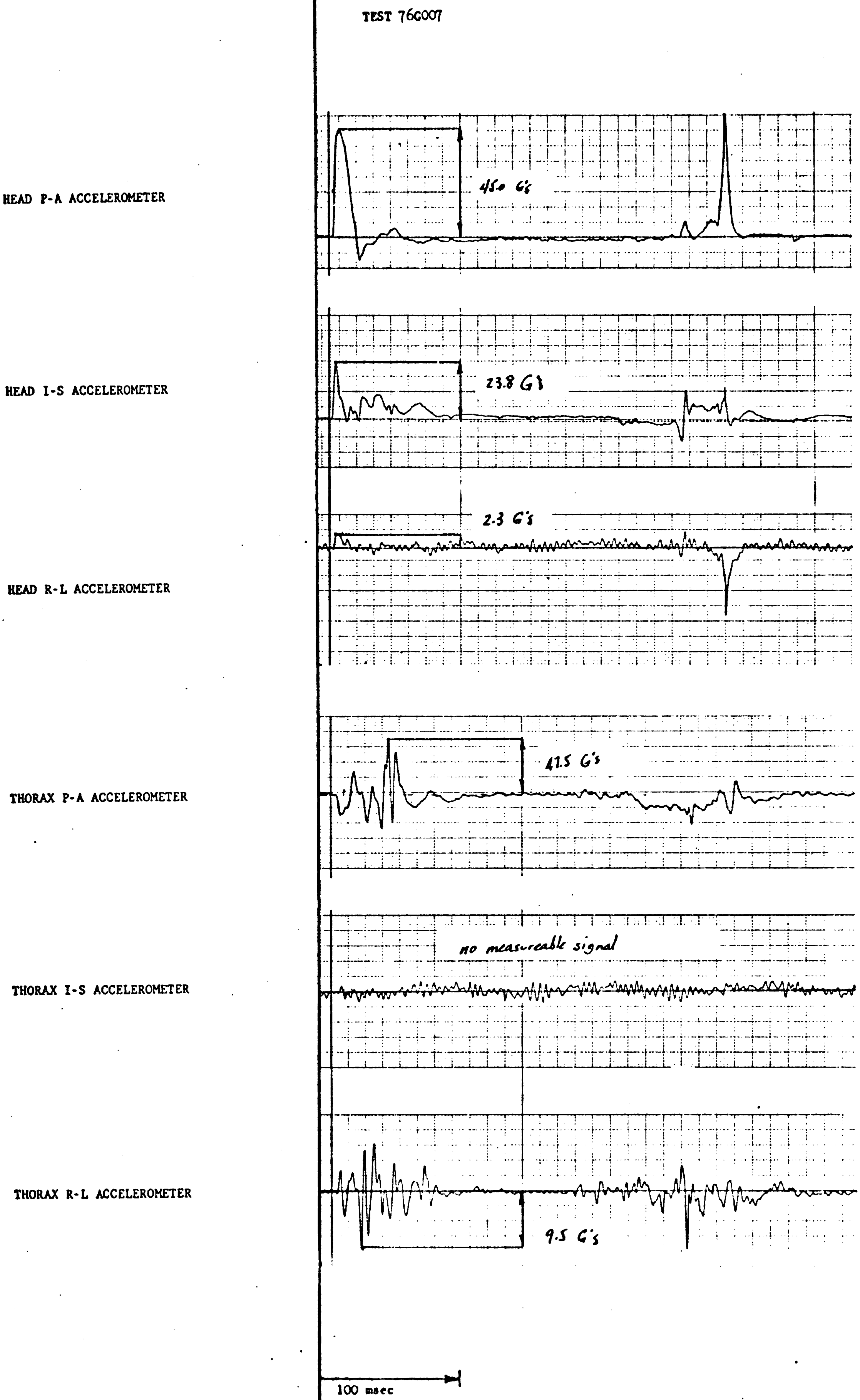

Figure 9a. Accelerometer Data. Test No. 76G007. Prone Test Dummy

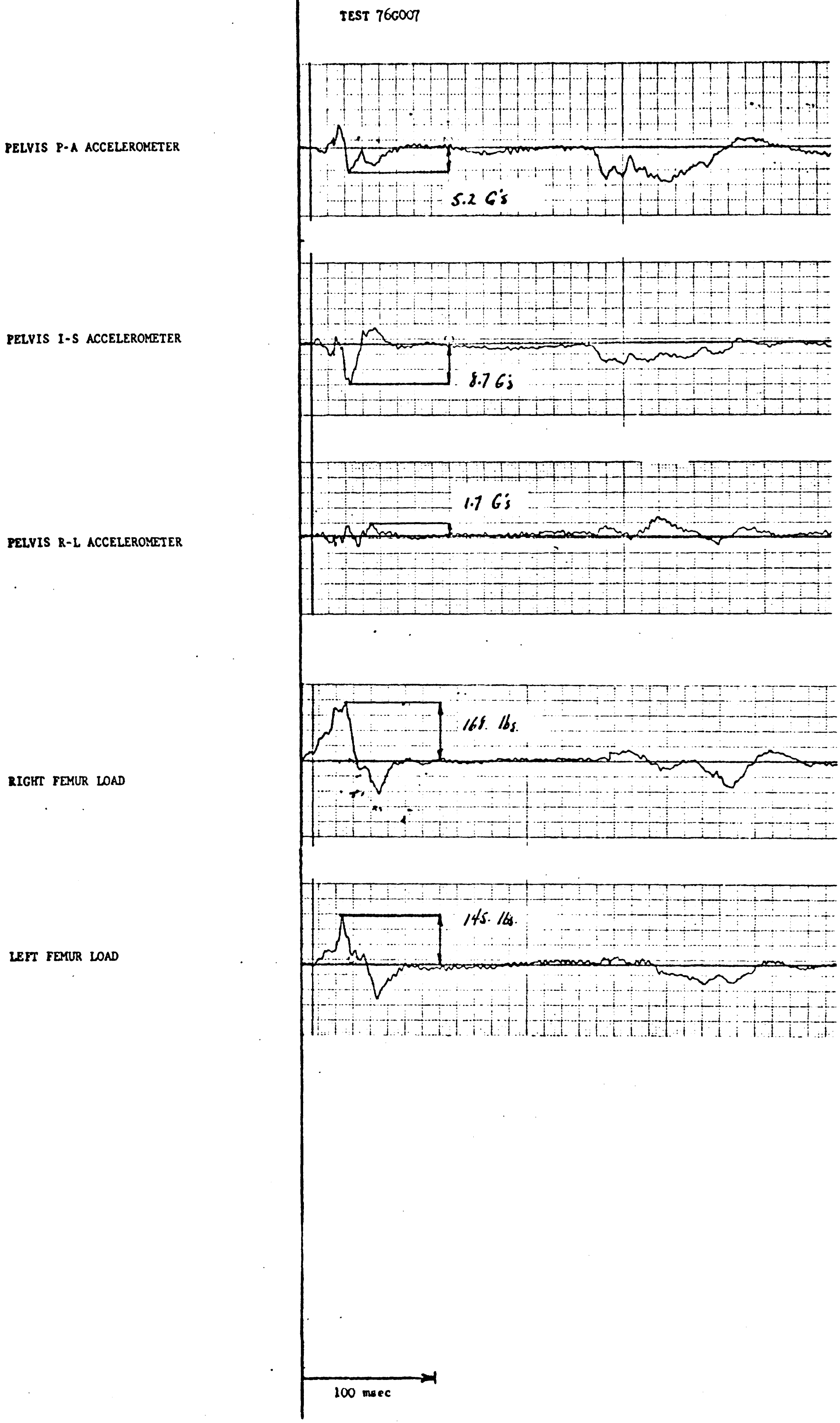

Figure 9b. Accelerometer Data. Test No. 76G007. Prone Test Dummy

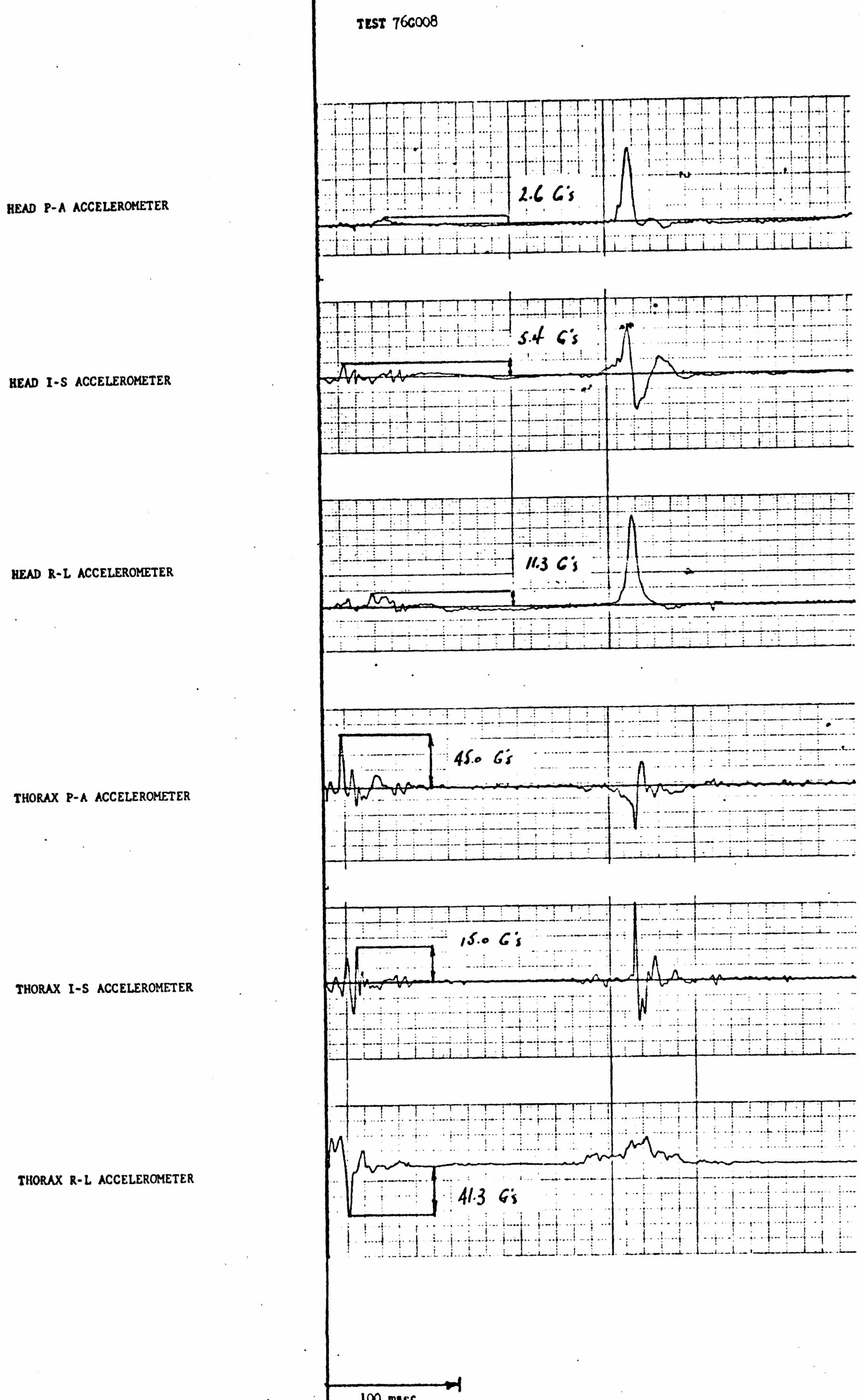

Figure 10a. Accelerometer Data. Test No. 76G008. Side-facing Test Dummy

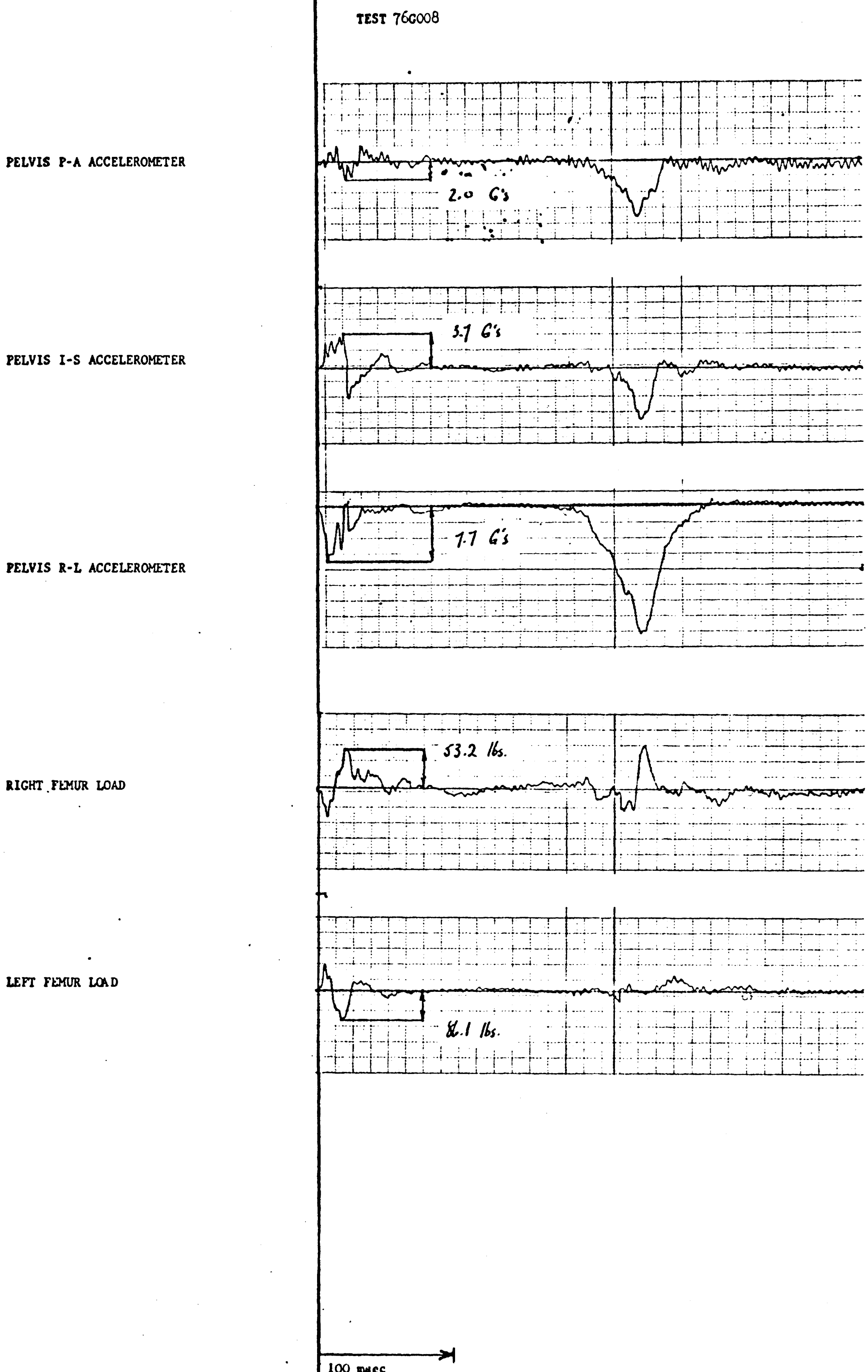

Figure 10b. Accelerometer Data. Test No. 76G008. Side-facing Dummy

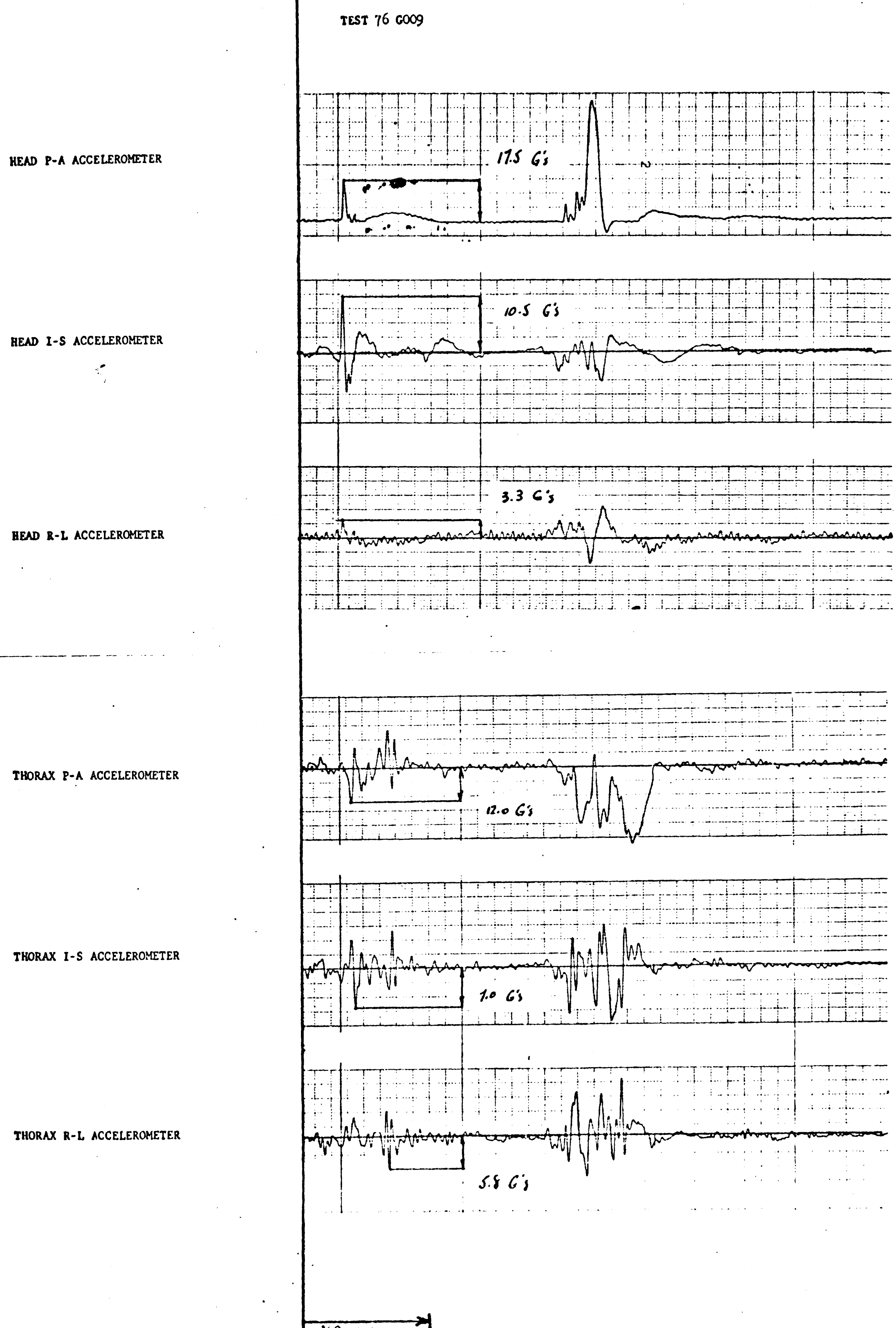

Figure 11a. Accelerometer Data. Test No. 76G009. "Jogging" Test Dummy

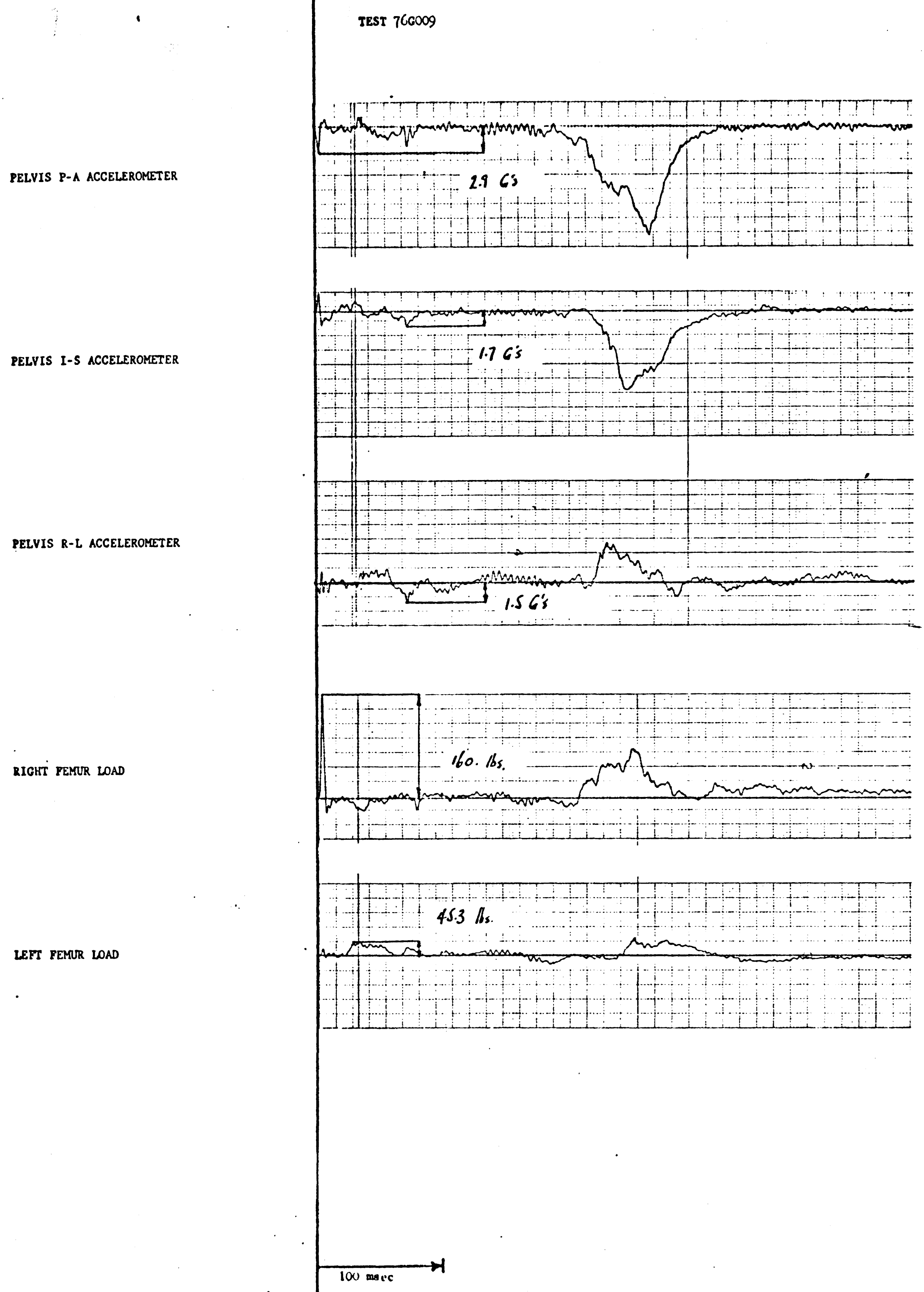

Figure 11b. Accelerometer Data. Test No. 76G009. "Jogging" Test Dummy

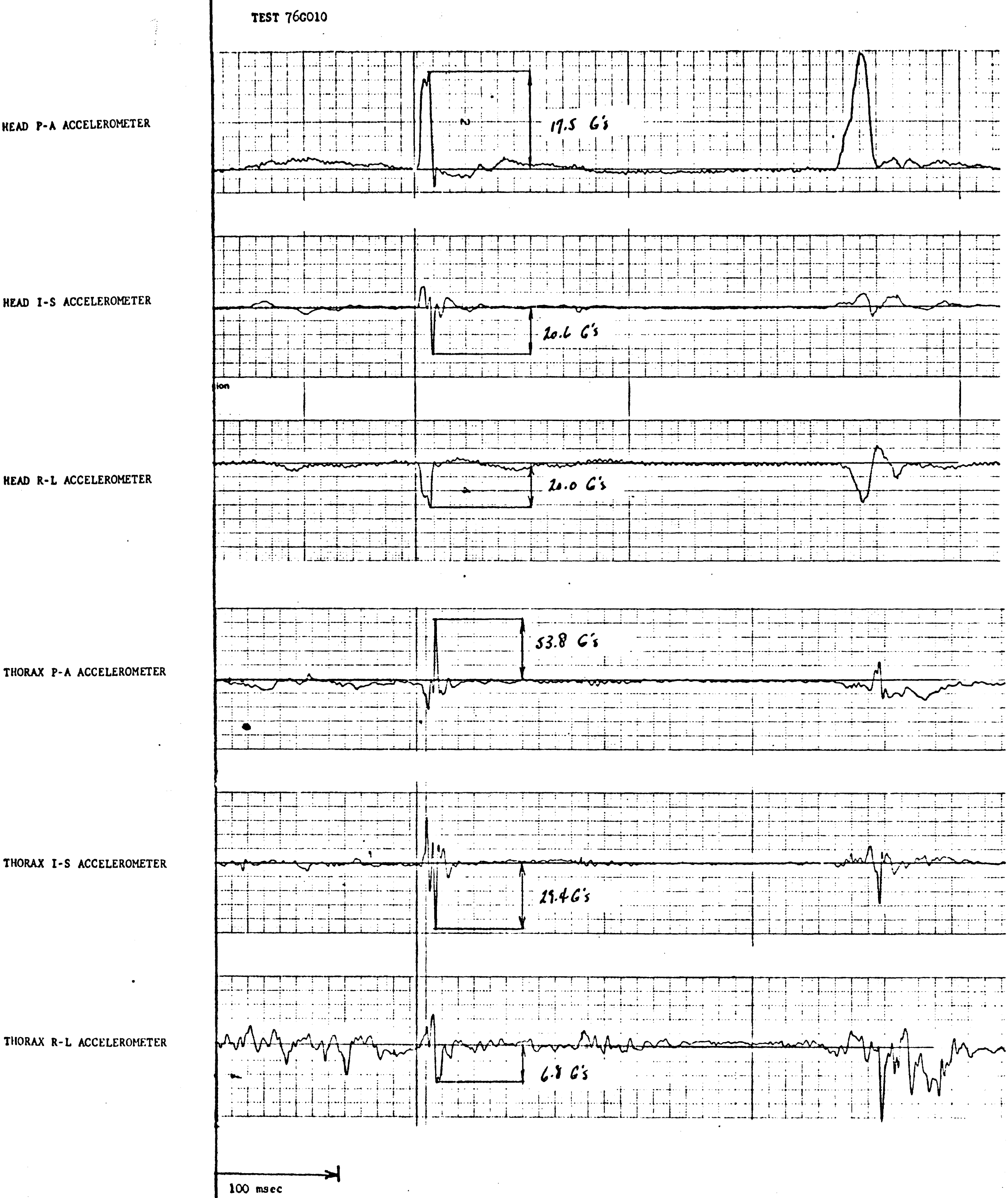

Figure 12a. Accelerometer Data. Test No. 76G010. Test Dummy with Arm and Knee Extended

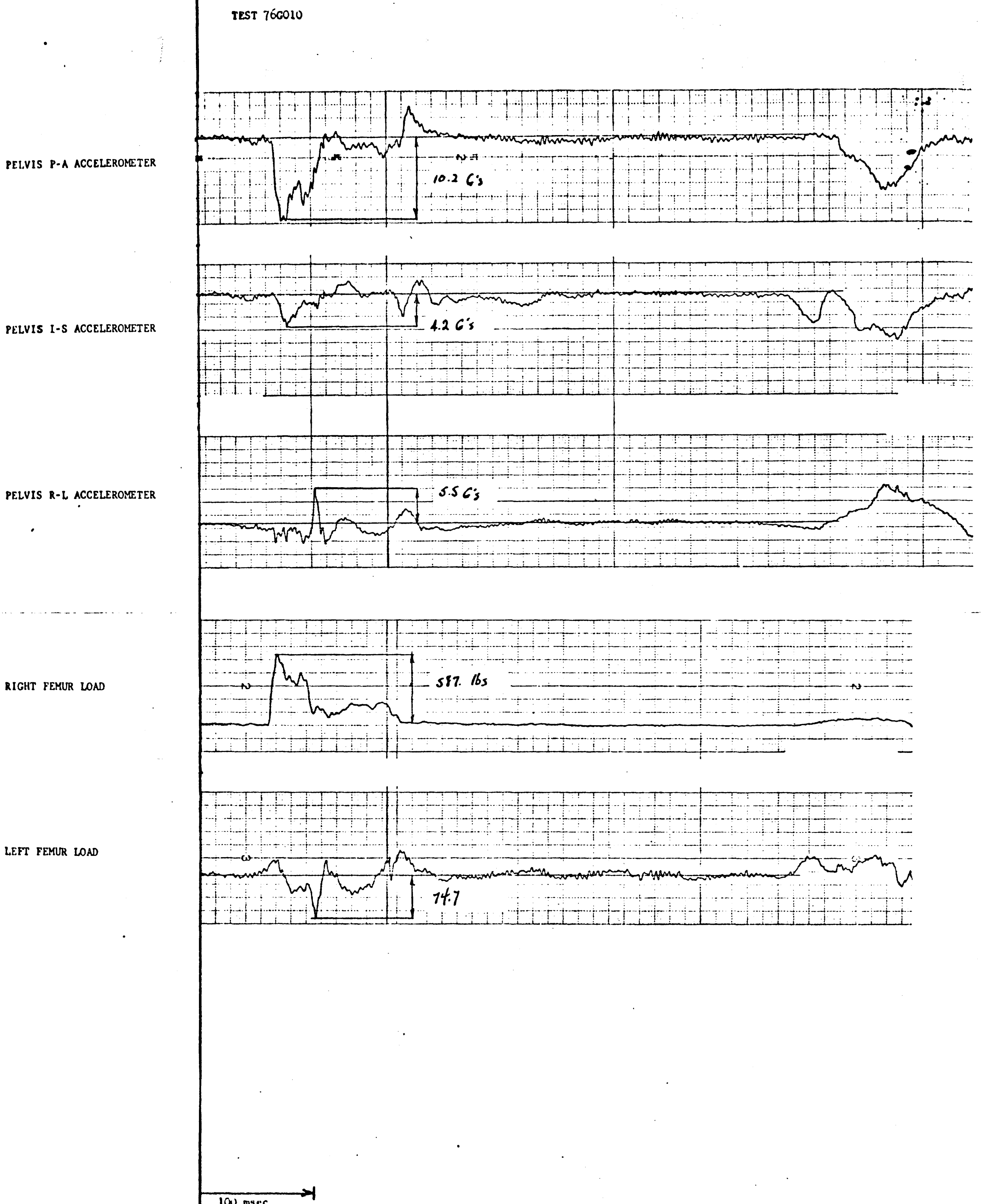

Figure 12b. Accelerometer Data. Test No. 76G010. Test Dummy with Arm and Knee Extended

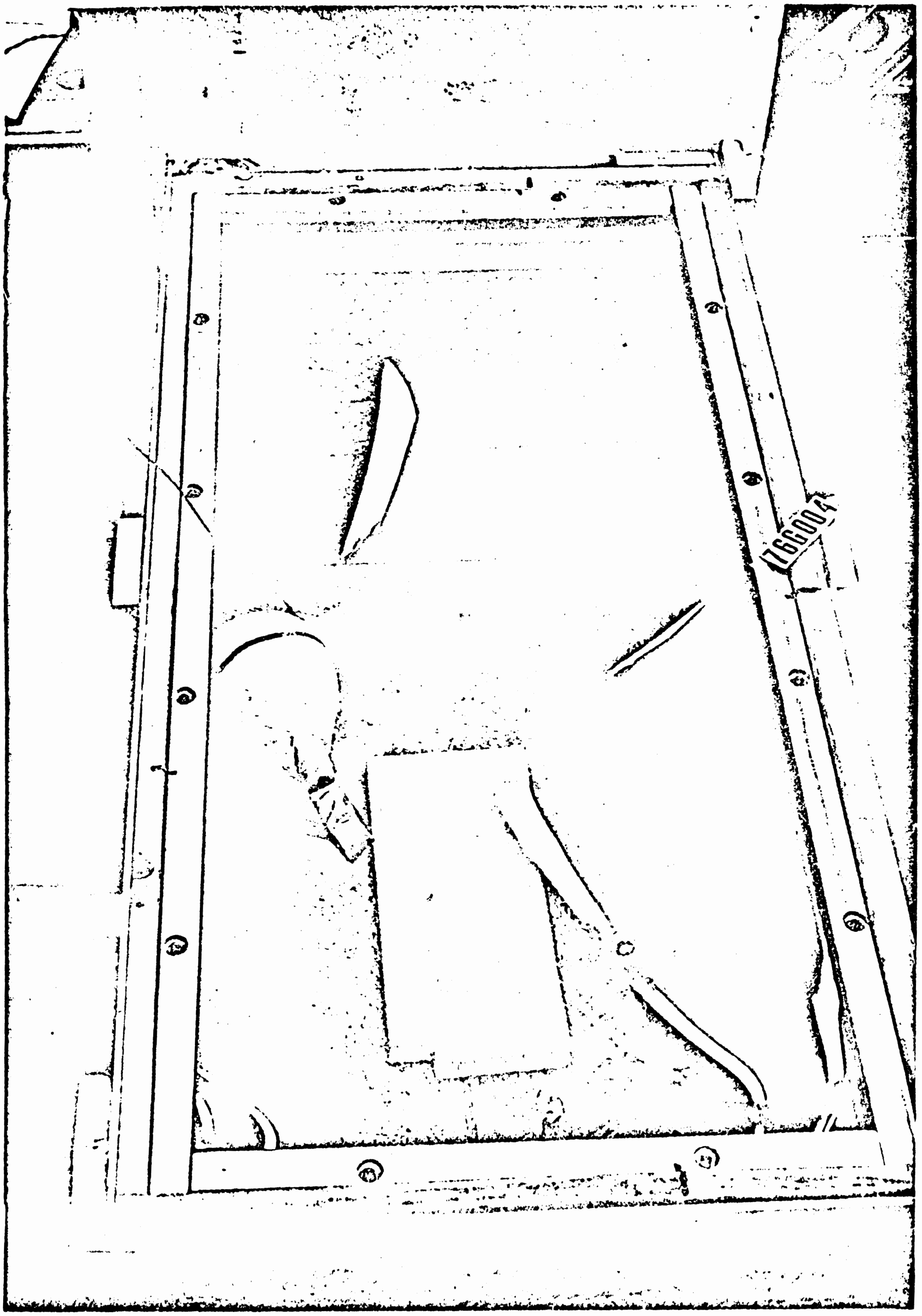

Figure 13. Acrylic Plastic Panel after Punching Bag Drop Test

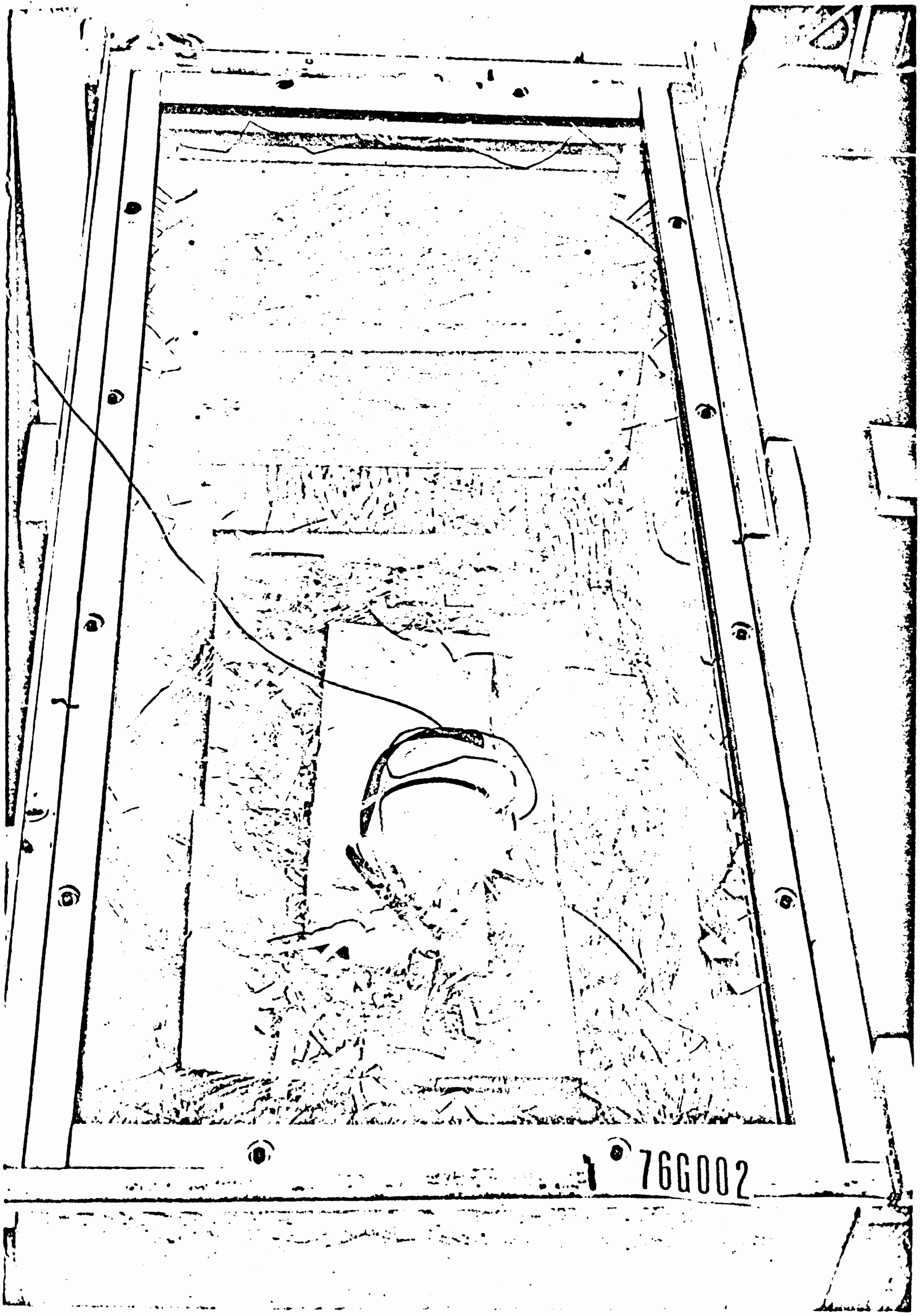

Figure 14. Annealed Glass Panel after Punching Bag Drop Test

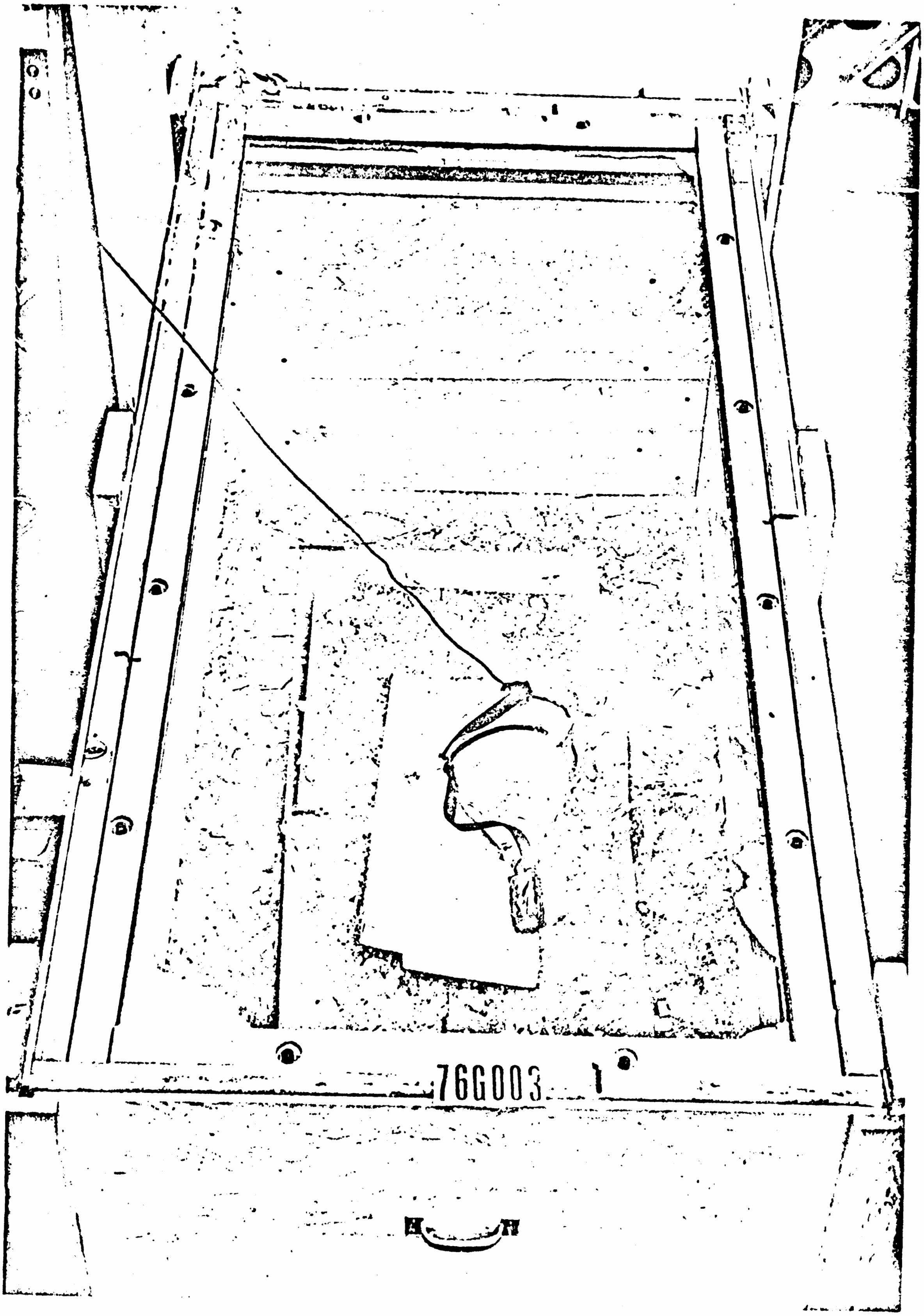

Figure 15. Tempered Glass Panel After Punching Bag Drop Test

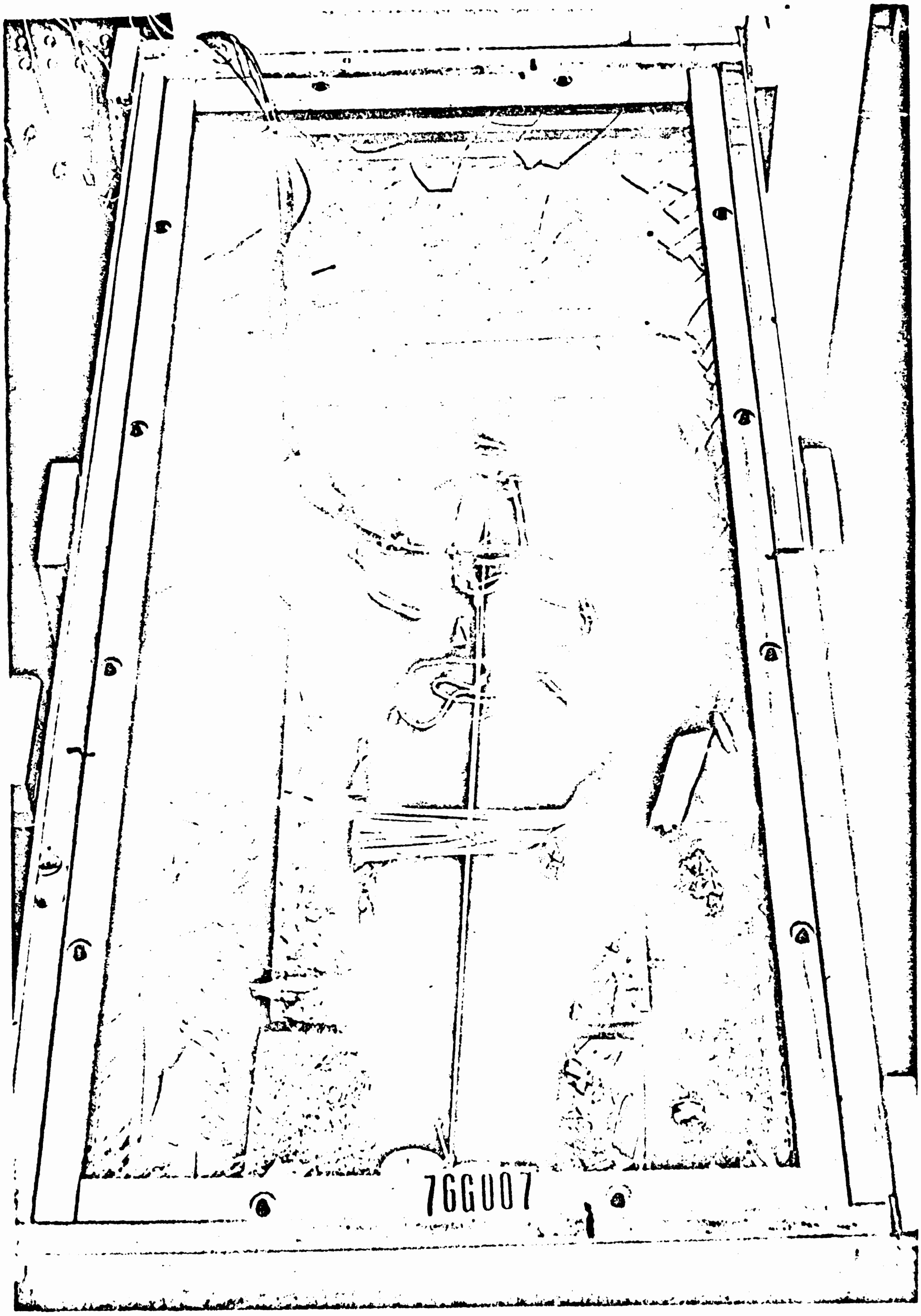

Figure 16. Dummy Position After Test No. 76G007

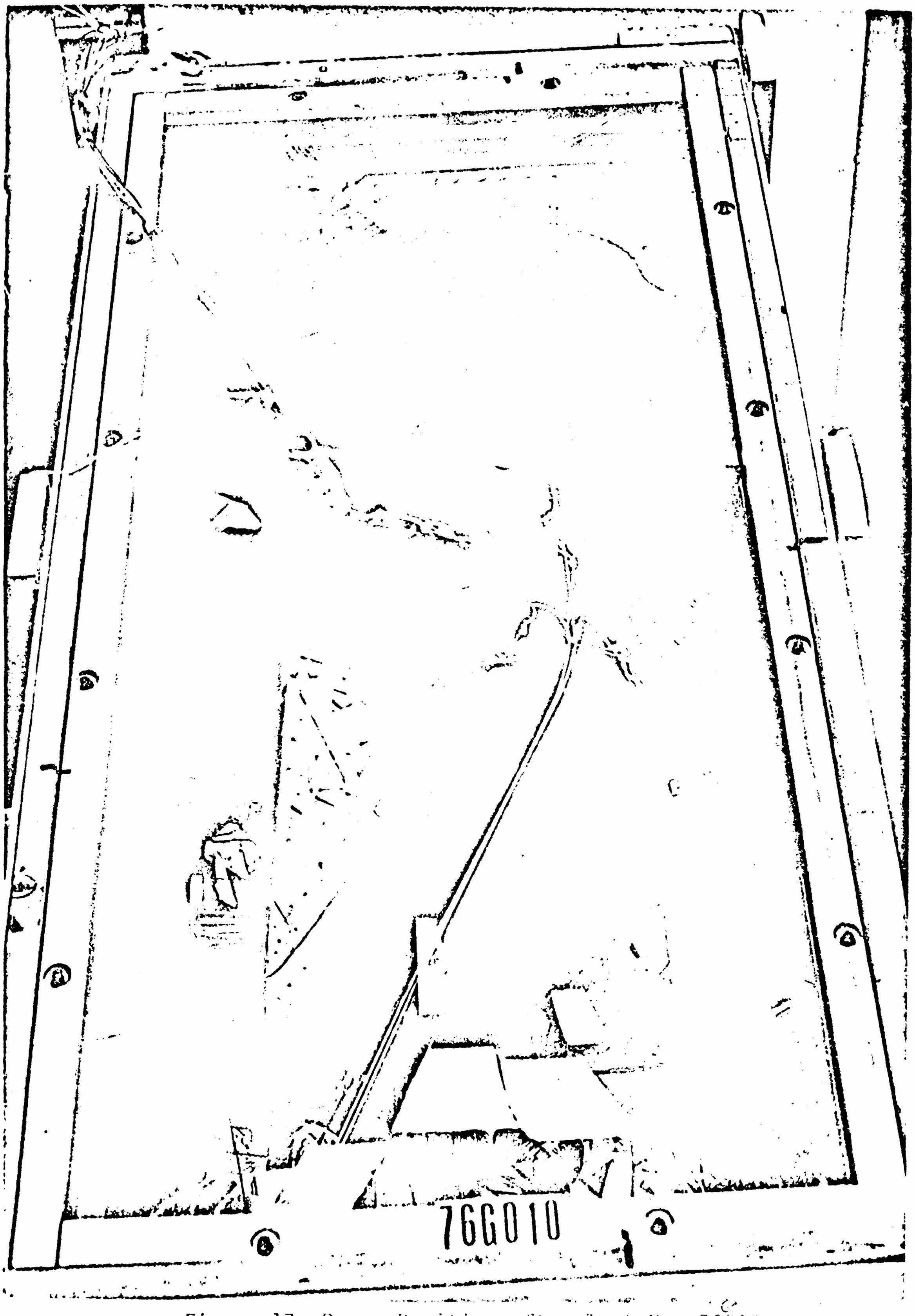

Figure 17. Dummy Position after Test No. 76010