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Evaluation of the Strength of Anchorages Needed For Attachment of Child Restraint Tether Belts

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16. Abstract

The objective of this research was to determine, in simulated 30 mph crash tests, the strength requirements of the tether belt anchor points for safe attachment of child restraint systems.

Phase I work involved the design and tensile tests of static load devices for the evaluation of the strength of the anchor points. These devices were designed for static yield strengths of 765, 1200, and 1500 pounds and were fabricated from .037 inch thick cold-rolled sheet steel. A total of eight units was made for the dynamic tests.

Phase II work consisted of dynamically testing the static load devices in sled tests employing two types of child restraints and four different weight anthropomorphic dummies. The devices were mounted between the anchor points and the connecting end of the child restraint tether belts. Load cells, mounted on the tether webbing material, monitored the strap loads.

The dynamic tests indicated that the 1200 pound load device was approximately the correct size to support all of the various weight dummies, although, in one test, it began to yield under a peak strap load of 2240 pounds.

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FOREWORD

This report presents results from a program of research to determine the strength requirements of anchorages for the attachment of child restraint tether belts in automobiles.

The reported research was performed by the Advanced Technology Center of Calspan Corporation for the National Highway Traffic Safety Administration (NHTSA) of the U. S. Department of Transportation under Contract No. DTNH22-81-P-02089. The Contract Technical Manager for this project was Mr. Vladislav G. Radovich of the NHTSA.

The opinions, findings and conclusions expressed in this publication are those of the author and not necessarily those of the National Highway Traffic Safety Administration.

This report has been reviewed and approved by:

Anthony L. Russo

Anthony L. Russo, Head
Transportation Research Department

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Appreciation is also extended to Mr. Chester J. Borkowski and his accelerator sled facility staff, which includes Messrs. Gary Gestwick and Patsy Palmeri, for their contributions in executing the dynamic performance testing phase of this program.

1.0 INTRODUCTION

The anchor point strength requirements for all occupant restraint harnesses in passenger vehicles are specified in Federal Motor Vehicle Safety Standard 210. Recently an amendment to this standard was proposed which would also specify the strength of anchorages for child restraints. The proposed specifications for the strength of anchorages for attachment of child restraint tether belts were based on test data of three-year old child dummies. Since restraints for children up to ten years old, which need tether anchorages, have also appeared on the market and restraints for even older children could be expected soon, anchor point test loads of 1,500 pounds, 1,200 pounds, and 765 pounds are being proposed by various organizations. A test load of 1,200 pounds has been proposed by the SAE and a 765 pound force is currently required by the Australian Standard. The objective of this program, therefore, was to determine in simulated 30 mph crash tests, the strength requirement of the tether belt anchor point for safe attachment of child restraint systems.

For the evaluation of the anchor point strength, three types of static load devices were designed with yielding strengths of 765 pounds, 1,200 pounds, and 1,500 pounds. These units were designed from tensile strength tests of cold-rolled steel sheets, fabricated and then dynamically tested on an accelerator sled with different child restraints and with various weight child dummies.

2.0 SUMMARY AND CONCLUSIONS

2.1 Summary

Phase I of this program involved the design of static load devices for the evaluation of the strength of anchor points for child restraint tether belts. These devices were designed for static yielding strengths of 765 pounds, 1,200 pounds and 1,500 pounds and were fabricated from thin steel sheet stock. Verification of the design yield strength of the base metal was accomplished by testing several samples of the sheet stock in a tensile test machine. A total of eight static load devices was fabricated for the dynamic tests: two-765 pound units, four-1,200 pound units, and two-1,500 pound units. A tensile test of one of the actual 1,200 pound static load devices, performed at the end of this program to verify its static yield strength, indicated a yield load between 1,100 and 1,200 pounds.

The Phase II work required the static load devices to be dynamically tested in sled runs employing two types of child restraints and four different weight anthropomorphic dummies. All sled tests were conducted at 30 mph with two child restraints tested in each run in a side-by-side configuration. Tether belt loads of each of the child restraints were measured with load cells mounted on the webbing material.

The actual anchor point loads were evaluated in these sled tests by bolting one end of the static load devices to the sled structure and attaching the other end to the tether belts of the child seats. The first two tests utilized 765 pound and 1,200 pound static load devices with 3-year-old child dummies in the first run and 6-year-old dummies in the second test. The third, fourth, and fifth runs were performed with 1,500 pound and 1,200 pound units. In these tests modified 6-year-old dummies were employed with weights of 77 pounds to simulate the approximate weight of a 10-year-old child. The final sled test used the same strength static load devices as in the previous tests, but employed two 5th percentile female dummies weighing approximately 105 pounds. These dummies simulated children in the 12 to 13 year old range.

2.2 Conclusions

(1) The 765 pound static load device did not possess sufficient tensile strength to safely anchor the 6-year-old dummy and child restraint under dynamic loading conditions. This was shown in the second sled run where the unit fractured completely.

(2) The 1,200 pound static load device contained a sufficiently high dynamic yield strength as to produce zero elongation in the last three sled tests with the heavier weight dummies. That is, this device was strong enough to support the dummies and restraints in all the 30 mph sled tests.

The 1,200 pound unit did yield, however, in the second test with the 6-year-old dummy, which experienced a maximum strap load of about 2,240 pounds (before seat failure). Based on this run and the data from the last three tests, it can be concluded that the 1,200 pound static load device contained a dynamic yield strength between 2,100 and 2,240 pounds.

(3) The 1,500 pound static load device did not yield in any of the dynamic tests. Its strength was sufficient to support all of the various weight dummies tested.

(4) These particular static load devices, that were constructed from .037 inch thick, A366 cold-rolled steel, exhibited a higher dynamic yield strength, compared to the design static levels, by a factor of roughly 2, when loaded at a rate of approximately 36,000 pounds per second. The dynamic strength of the 1,200 pound load device was sufficient to support the tested dummies. If the child restraint anchor points in actual automobiles were constructed of the same type of steel, contained a sufficient amount of material as designed into the 1,200 pound load device, and were statically tested to

1,200 pounds as specified in the proposed FMVSS No. 210, these anchors could be assumed to be strong enough to support the restraint tether belt for all children up to 12 to 13 years old.

3.0 ANCHOR POINT LOAD INDICATING DEVICES

Calspan designed and fabricated three sets of Phase I test straps to statically yield at target loads of 765, 1,200, and 1,500 pounds. A tolerance level of ±6 percent for these tensile yield loads was chosen to reflect the anticipated inconsistencies for the mechanical properties of the base metal used to fabricate the specimens. Cold-rolled low carbon steel sheet (A366) of thickness .037 ±.005 inches was used to fabricate the test samples. This low cost sheet steel is very representative of the material currently used to make rear package shelves in automobiles, which is the area where anchor points will be established.

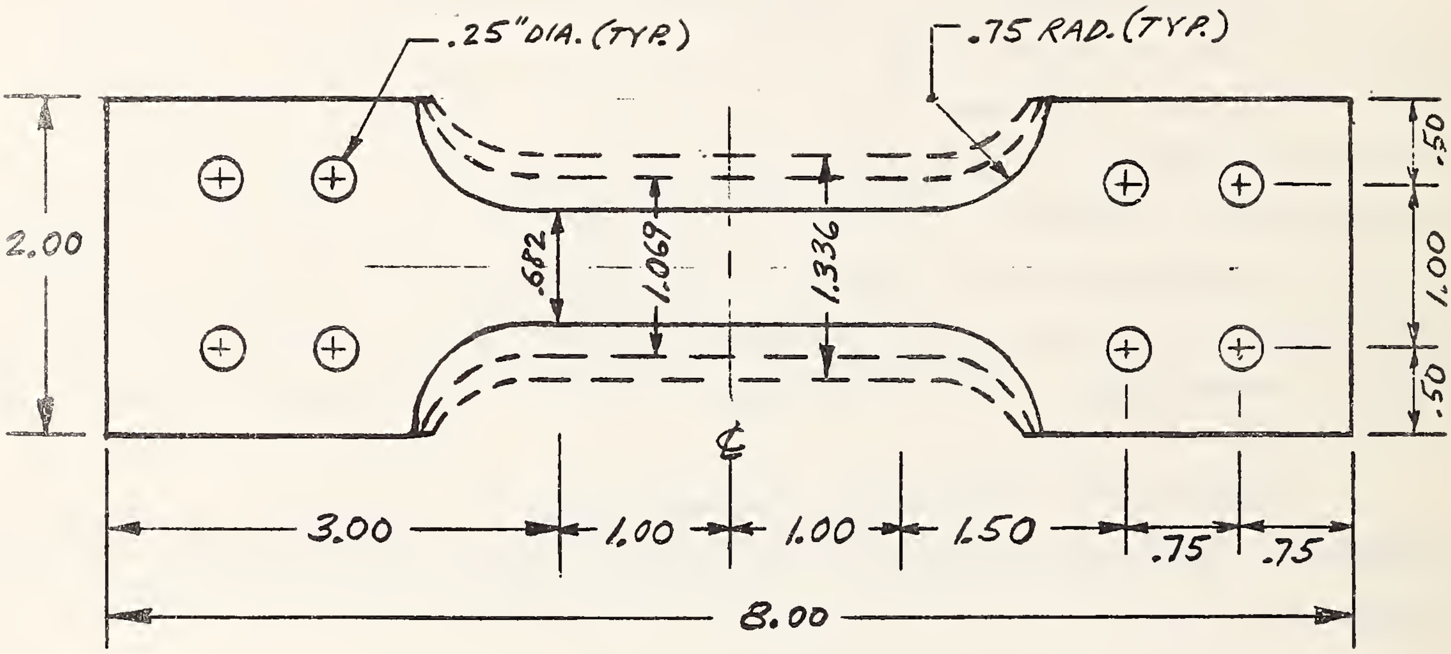
A detailed drawing of three different static load devices is provided in Figure 1. Photographs of the devices and the reinforcing end plates are included in Figure 2.

The method used to design these tensile yield devices was as follows. Five tensile specimens having a gage length of 2 inches, a width of .500 inches, and a thickness of .037 inches were fabricated as per SAE Recommended Practice J416b "Tensile Test Specimens" and tested on Calspan's Southwark-Emery Tensile Tester. A mean value of 561 pounds* was obtained for the tensile yield point for the five samples. The tensile test specimens and the static load devices for the dynamic sled tests were all fabricated from the same sheet of steel. Thus, values for the width of the test device samples were obtained by scaling the tensile specimen yield point results. Test device widths of .682, 1.069 and 1.336 inches were obtained for the 765, 1,200, and 1,500 pound load levels, respectively.

The design of the reinforcing end plates was consistent with the guidelines for connections provided in the Specifications for the Design of Cold-Formed Steel Structural Members.** Edge distance, tension stress on the net section,

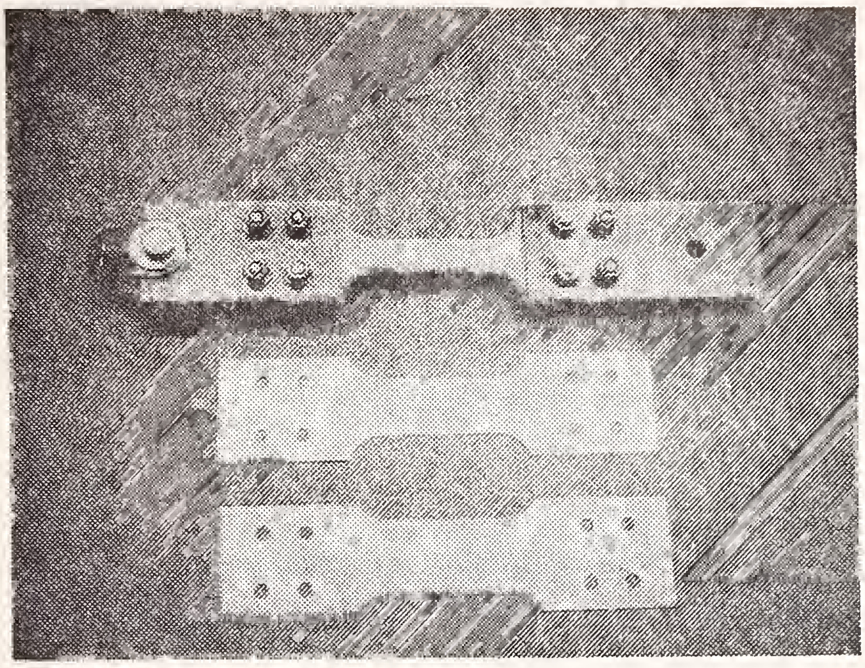
*The standard deviation was 20.7 pounds.

**Published by the American Iron and Steel Institute.



Material: A366 cold-rolled steel
Thickness: .037"

Figure 1: Dimensions of the Three Static Load Devices



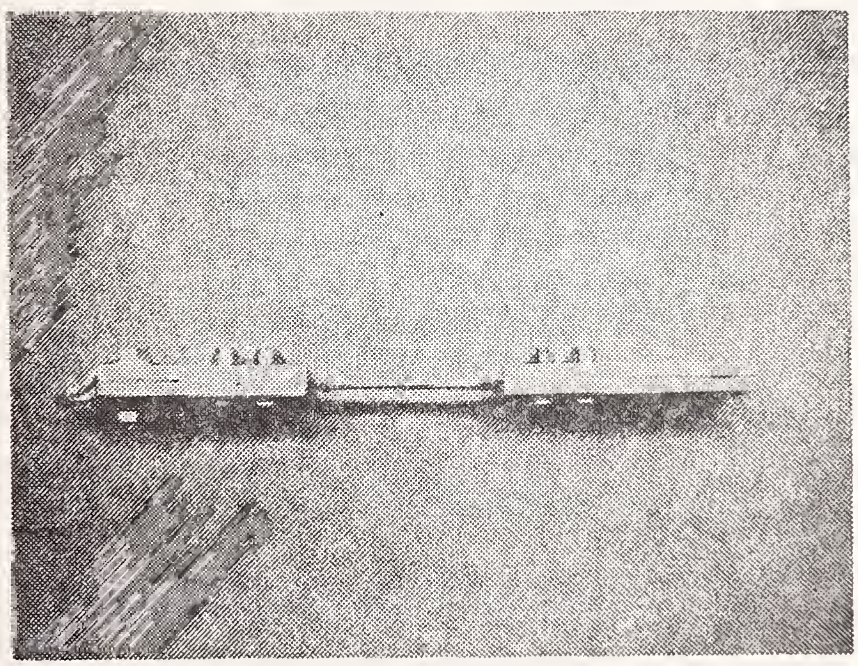


Figure 2: The Static Load Devices with End Reinforcing Plates

bearing stress, and shear stress were all taken into consideration for the bolted end connections.

A static tensile test on one of the 1,200 pound test devices was subsequently performed to validate the design methodology. The tensile test results are graphically displayed in Figure 3. As can be observed from the figure, the tensile yield point occurred between 1,100 and 1,200 pounds, which is within the design accuracy of these type of devices.

It must be noted that deformation of the static load devices would be expected if <u>static</u> loads in excess of 765, 1,200, or 1,500 pounds were applied to the respective samples. Under a dynamic loading condition the tensile yield point would be increased by an amplification factor which is material dependent. For example, minimal dynamic amplification of tensile yield as a function of strain rate has been observed for aluminum; a factor of 1.3 is typical for hot-rolled steels. For low carbon steels, such as those used in automotive rear package shelves, a factor approaching 2 may result. Thus, elongation of the test device might not be observed in the dynamic sled test even if loads approaching twice the static design level are applied.

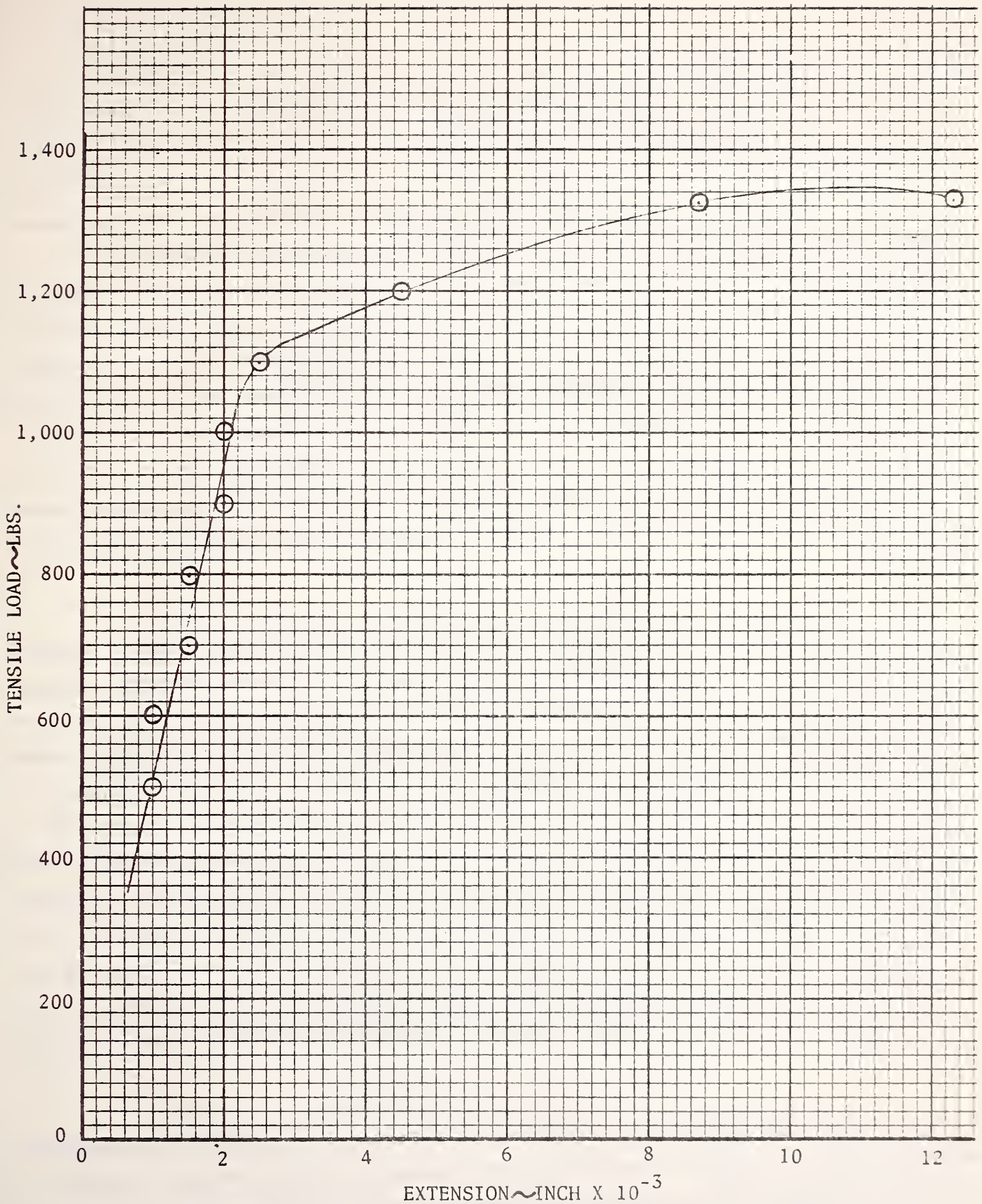


Figure 3: Tensile Test Results of a 1,200 Pound Static Load Device

4.0 SLED TESTS

4.1 Methodology

The dynamic tests of the child restraint anchor points were performed on the Calspan HYGE accelerator sled. The test procedures and acceleration environment were similar, but not identical, to those specified in the Federal Motor Vehicle Safety Standard 213 (FMVSS 213), Reference 1. For these loading tests, child restraints were used in a side-by-side configuration on the standard bench seat. Because of the length of the static load devices, the top tether anchor point locations were not exactly at the same position as those specified for use in FMVSS 213 (3.8 in. above and 1.1 in. aft of spec. point) and the acceleration versus time pulse was minutely higher (.5 g for 6 ms.) than one that would be used for an FMVSS 213 compliance test. Sled peak velocities averaged 29.5 mph for all the tests.

In order to position the various size and weight test dummies on the sled, two types of child restraints were selected, both of which contained upper tether belts for attachment to the various static load devices at the anchor points. The first child restraint was a semi-rigid plastic seat design containing a full symmetrical body harness (Century Child Love Seat). The second type of restraint used a small booster seat, held in place by a standard lap belt. The child was restrained by the lap belt and a symmetrical upper torso harness (Century Safe-T-Rider). Since the objective of these tests was to evaluate anchor point strength requirements, test dummy sizes and weights were chosen to represent various age children up to 13 years old, and these weights were sometimes over the maximum limits specified by the seat manufacturers. As a result, the performance of the seats themselves cannot be interpreted as out of compliance with FMVSS 213.

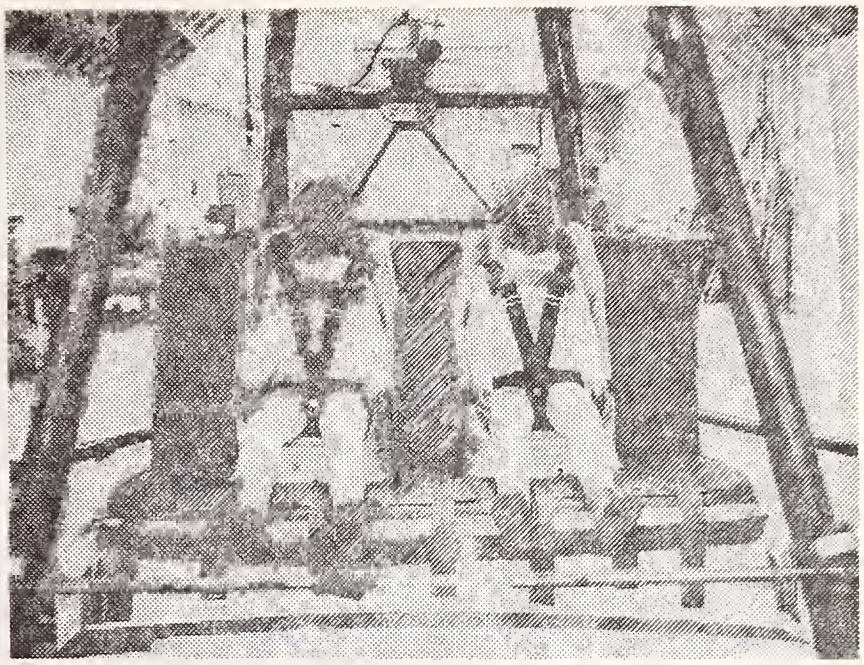
Six duplicate sled tests were performed at sled velocities of approximately 30 mph. The Calspan Square Wave No. 2 metering pin was employed in the sled accelerating system to produce the required pulse-time shape of approximately 24.5 g peak and 79.5 ms. duration.

The static load devices, attached between the anchor points and the seat tether straps were discussed in Section 3.0 of this report. The three different sizes of these devices were tested in various combinations and the resulting test data are discussed in Section 4.2.

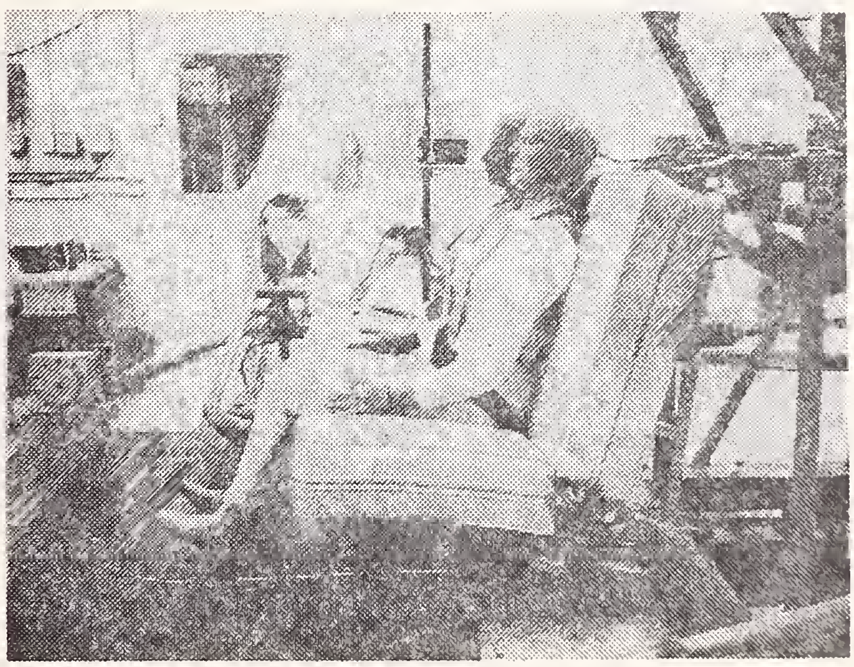
The high-speed movie coverage of the sled tests was provided by three 16 mm Stalex cameras mounted on the sled. One camera was positioned behind and above the tether anchor points so that is would view both left and right side static load devices and the tether straps. In addition, one camera was positioned on each side of the sled platform on extended camera booms to obtain side view kinematics of the dummies. These cameras were operated at framing rates of approximately 1000 frames per second. Mounted on both sides of the sled on the ground were Graph-check Sequence Polaroid cameras, which were used to provide a "quick-look" display of the dummy/seat motions.

In order to be able to apply various force levels to the static load devices, four different weight dummies were employed during the sled runs. The first set of dummies tested were three-year-old child units, type SA103C, with weights of about 33 pounds each. The next set was the 6-year old dummies, type VIP-6C, which had individual weights of 48 pounds. These dummies are shown in the upper photograph of Figure 4. The weight of the 6-year-old models was then increased by adding distributed weight along the torsos in the form of lead shot bags. The increased weight, producing a total of approximately 77 pounds, was to simulate the weight of a 10-year-old child. The largest of the dummies employed was the 5th percentile female with a total weight of 105 pounds. This dummy was used to simulate the weight of a 12 to 13 year old child. As shown in the lower picture of Figure 4, these dummies were placed directly on the bench seat and restrained by a lap belt and a symmetrical torso strap.

Instrumentation employed in the sled tests consisted of a sled accelerometer and webbing load cells (Lebow, Model 3419) mounted on each of the upper tether straps adjacent to the static load devices. Figure 5 presents two views of this anchor point set-up. The seat tether strap was attached to one end of the static load device through a reinforcing plate and a standard clip obtained with the seat. The aft end of the device also contained a reinforcement through which the main anchor bolt was secured to the sled frame structure. After each test, the static load device was removed from the sled, the end reinforcing plates were unbolted and the thin loading strap measured directly for any permanent yield or elongation. Each device contained three surface scribe-lines at its center area for measurement of metal yield.



6-YEAR-OLD CHILD DUMMIES



5TH PERCENTILE FEMALE DUMMIES

Figure 4: Dummy Test Configurations for the 6-Year-Old Child and the 5th Percentile Female

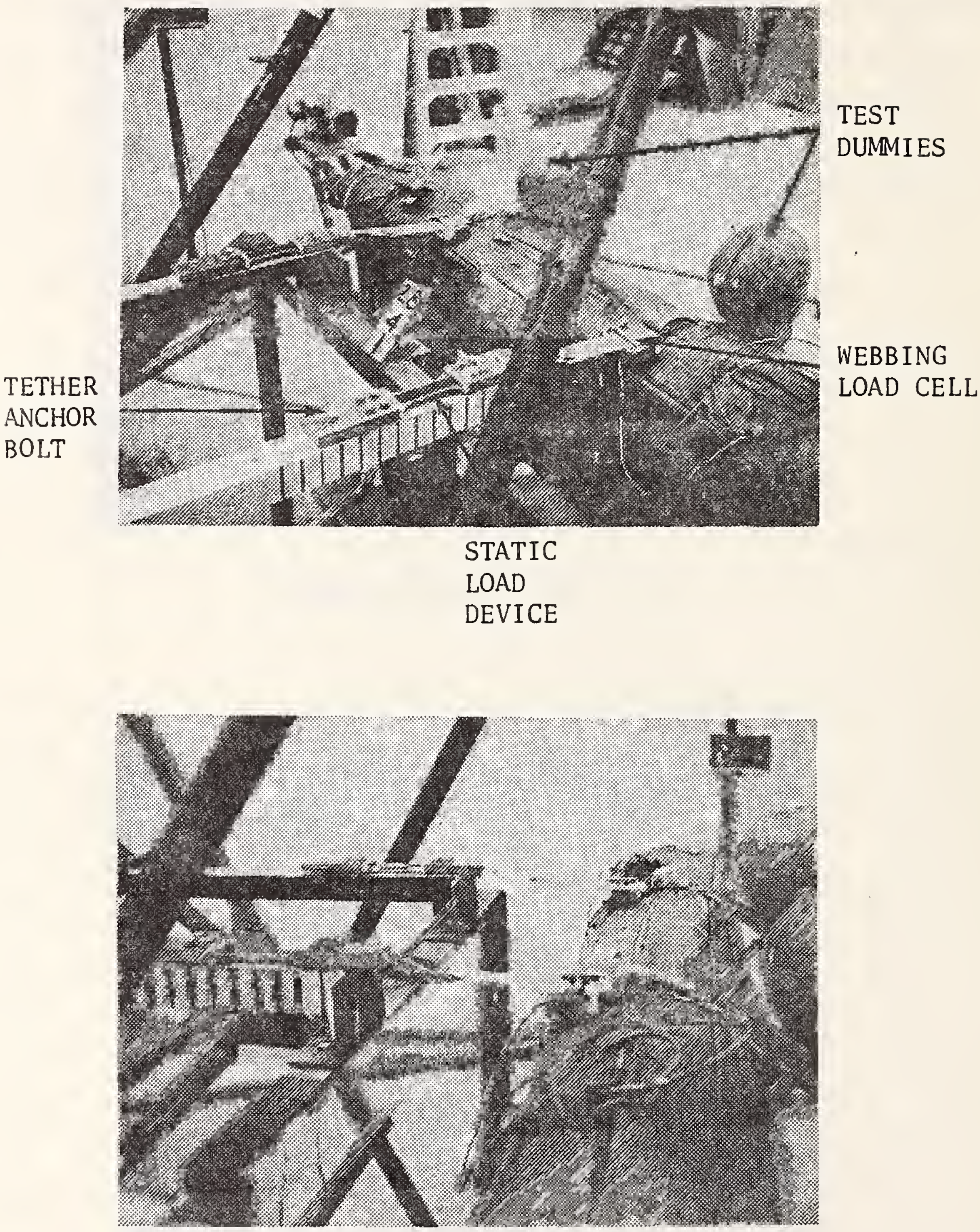


Figure 5: Sled Configuration Showing Top Tether Straps and Static Load Devices

4.2 Measured Test Data

The sled test results of the three sizes of anchor point static load devices are presented in Table 1. All measured test data were reproduced in Brush strip chart format containing time histories of sled accelerations and tether strap (anchor point) loads. The time history graphs are included in the Appendix of this report.

The first test (No. 2839) incorporated a 1,200 pound static load device on the left hand side (LHS) of the sled and a 765 pound device on the RHS. As shown in the data table, there was no measurable yield of the larger device, but the 765 pound unit indicated an elongation of approximately .065 inches. Unfortunately, the Lebow load cell malfunctioned on the RHS strap so the maximum force recorded was only 1,070 pounds. In this case, a peak load of about 2,000 pounds could be assumed to have acted at the anchor because that was the approximate level of the load on the strap of the LHS anchor.

The second test (No. 2840), which again used the 1,200 pound and 765 pound load devices but employed heavier 6-year-old dummies, resulted in the LHS strap pulling out of the child seat back. Before this seat failed, the 1,200 pound load device was subjected to approximately 2,240 pounds peak load, which yielded the strap about .033 inches. The smaller 765 pound device failed at its mid-section.

The third sled test (No. 2841), using the weighted 6-year-old dummies and 1,500 pound and 1,200 pound devices in the left and right sides, respectively, resulted in both tether strap webbing failures at the point of juncture of the single and double straps of the torso belts.

The fourth test (No. 2842) was a repeat of the previous test, but employed a three-point automobile safety belt (Type 2 belt) and new load devices. No measurable yielding of the devices was observed with 1,680 pound and 1,810 pound peak loads on the LHS and RHS units, respectively.

Table 1

SUMMARY OF SLED TEST RESULTS

Test No.	Dummy	Dummy Total Weight lbs.	Type of Restraint	Peak Tether Strap Load ~ lb. LHS of Sled	RHS of Sled	Static Load Device Elongation ~ inch 1500 lb.	1200 lb.	765 lb.	Comments
2839	3-yr. old	33	Child seat	2040	1070	--	0 (LHS)*	.065 (RHS)	Tether load cell electronic failure on RHS seat.
2840	6-yr. old	48		2240	3520	--	.033 (LHS)	Fractured (RHS)	Tether anchor bracket pulled out of LHS seat back.
2841	Modified 6-yr. old	77	Booster seat with shoulder straps	1100	1080	0 (LHS)	0 (RHS)	--	Both tether webbings broke at "Y" buckle.
2842		77	Booster seat with 3-pt. auto belt	1680	1810	0 (LHS)	0 (RHS)	--	--
2868		77	Booster seat with special Y-harness	2100	1760	0 (LHS)	0 (RHS)	--	Both torso restraints were symmetric type, fabricated from standard auto webbing material.
2869	5th% FM.	105	Special Y-harness	1960	1820	0 (LHS)	0 (RHS)	--	Restraints were same type as in previous test.

*This static load device was mounted on the left hand side of the sled.

Test No. 2868 employed the same weighted dummies as previously tested, but used shoulder restraints fabricated from automobile belt webbing. The configuration of these restraints were the same type of Y-belts as used in test No. 2841. Both static load devices exhibited zero yield under these loads. For this test and the test with the 5th percentile female dummies (No. 2869), the standard seat back rest was locked in position and not allowed to pivot forward during the sled acceleration. This was done to insure that the tether strap loads were not influenced by the seat back movement.

The final test (No. 2869) employed two 5th percentile female dummies seated directly on the bench seat. Both the 1,500 pound and 1,200 pound static load devices showed no yielding under the applied loads. The dummy kinematics in this test, however, indicated that both dummies tended to submarine under the lap belt, which may have reduced the loads on the upper tether straps to some degree.

A summary table of the eight static load devices, their test numbers, and the test results is presented in Table 2.

The type of child restraints used in the first two sled runs, in which the semi-rigid plastic seats were positioned up against the bench seat back with approximately five pounds of tension in the tether straps, could have influenced the tension load measured in these straps. The forward pivoting motion of the 72 pound seat back during sled acceleration, pressing directly on the back of the child seat, may add to the tension in the tether straps and produce higher than normal loads. In this case, the child seat cannot move forward because it is restrained by its top tether belt. However, if the tethered child seat is not present, as in the last four runs, the dummies were observed to move forward away from the seat back and not restrict its movement. Observation of this effect showed that the seat back rotation was less in the first two sled runs than in the following tests. It is not known what the force contributions were from the seat back motion, but it can be assumed that the peak tether loads in the first two runs were somewhat high.

TABLE 2

SUMMARY OF STATIC LOAD DEVICE TEST RESULTS

Static Load Device	Device No.	Test No.	Device Test Position on Sled	Test Results
765	1	2839	RHS.**	Metal yielded .065 inches
	2	2840	RHS.	Metal fractured
1200	1	2839	LHS.	No measurable yield of metal
	2	2840	LHS.	Metal yielded .033 inches
	3	2841	RHS.	No measurable yield of metal
		2868	RHS.	
		static test*	--	Metal yielded .012 inches
	4	2842	RHS.	No measurable yield of metal
		2869	RHS.	
1500	1	2841	LHS.	
		2868	LHS.	
	2	2842	LHS.	
		2869	LHS.	

*This unit was statically tested in a tensile tester at the end of the program (see Figure 3).

**RHS. - right hand side.

The purpose of the sled tests, utilizing the four different weight dummies, was to load the anchor point static load devices to various levels in dynamic tests to experimentally determine the required strength of the anchor points. The load device designed to yield at 765 pounds did yield with the force level applied from the 3-year-old child dummy. The same size device was totally ruptured in the sled run which utilized the 6-year-old child dummy. The peak forces observed in these tests were more than twice the design yield strength of this device so it can be concluded that anchor points with this static strength would not be safe with 6-year-old children and older.

The 1,200 pound static load device yielded in Test No. 2840 at a peak load of 2,240 pounds but was not elongated in any of the subsequent tests. This indicates that the dynamic yield strength of this device was probably above 2,000 pounds and was sufficiently strong to anchor the tether straps of all the dummies tested.

The 1,500 pound device was not elongated in any of the tests. The maximum peak force applied to this device was 2,100 pounds, which was obviously not within its dynamic yield range. If we assume a dynamic to static strength factor of roughly 2, based on the tests of the 1,200 pound unit, the yield strength of this 1,500 pound unit would be approximately 3,000 pounds. This level of anchor point strength would be considerably above that required by the child dummy weights and seats tested in this program.

5.0 REFERENCES

1. "Child Restraint Systems, Seat Belt Assemblies and Anchorages," National Highway Traffic Safety Administration, 49 CFR, Part 571, Docket No. 74-9, Notice 6, Federal Motor Vehicle Safety Standard No. 213, December 13, 1979.

APPENDIX

Time History Graphs of Tether Belt Loads and Sled Accelerations

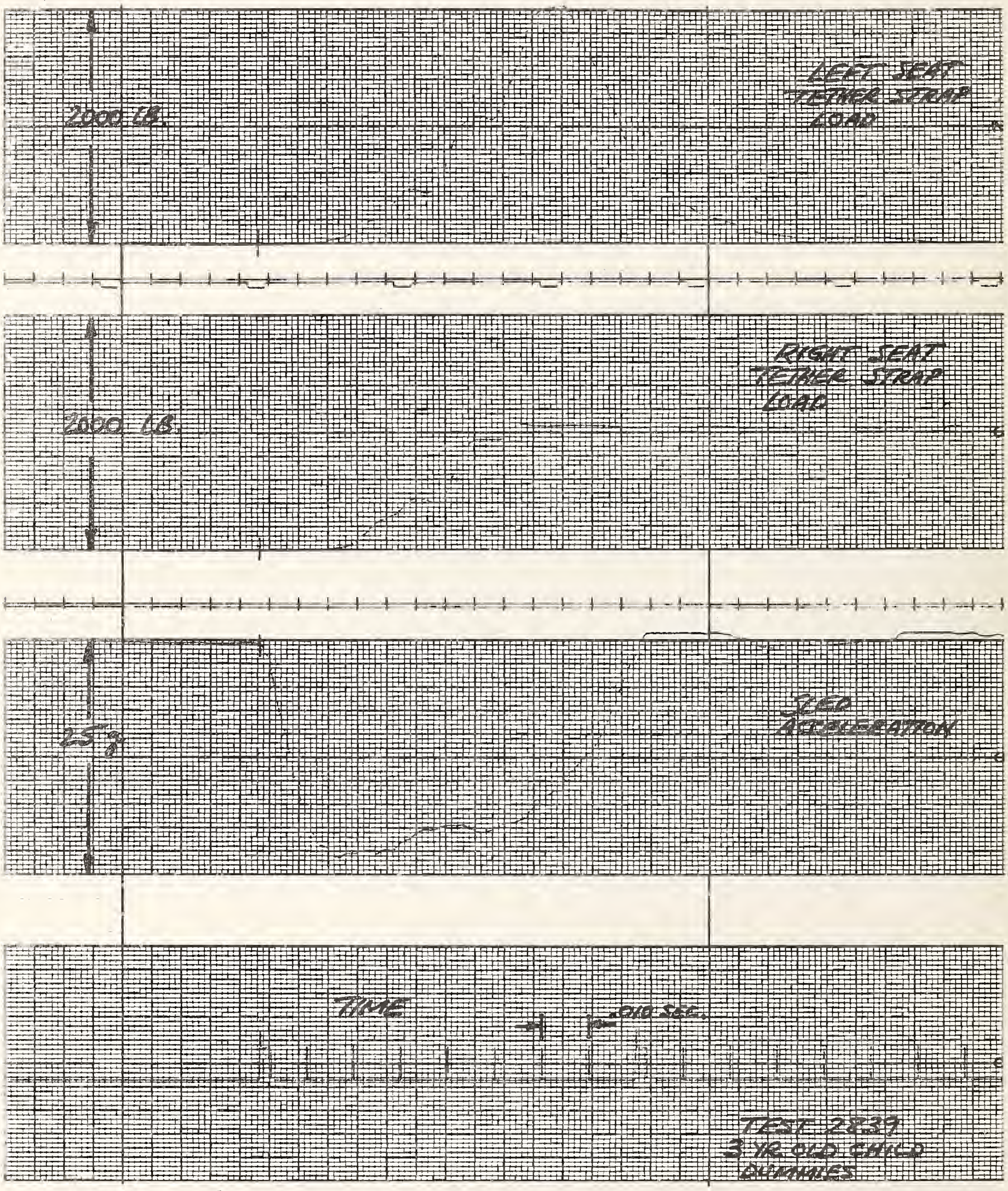


Figure A-1: Test 2839 of 3-Year-Old Child Dummies

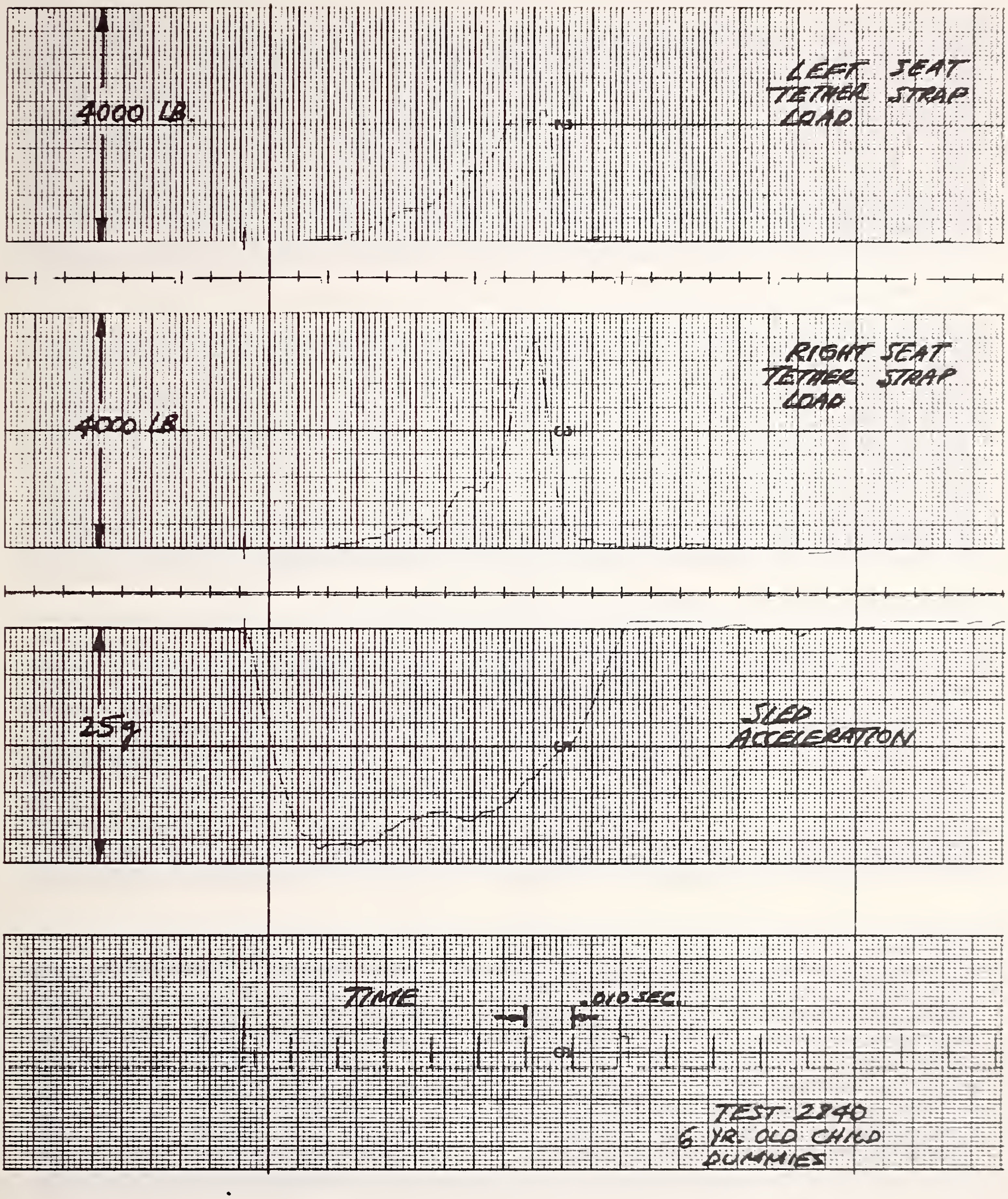


Figure A-2: Test 2840 of 6-Year-Old Child Dummies

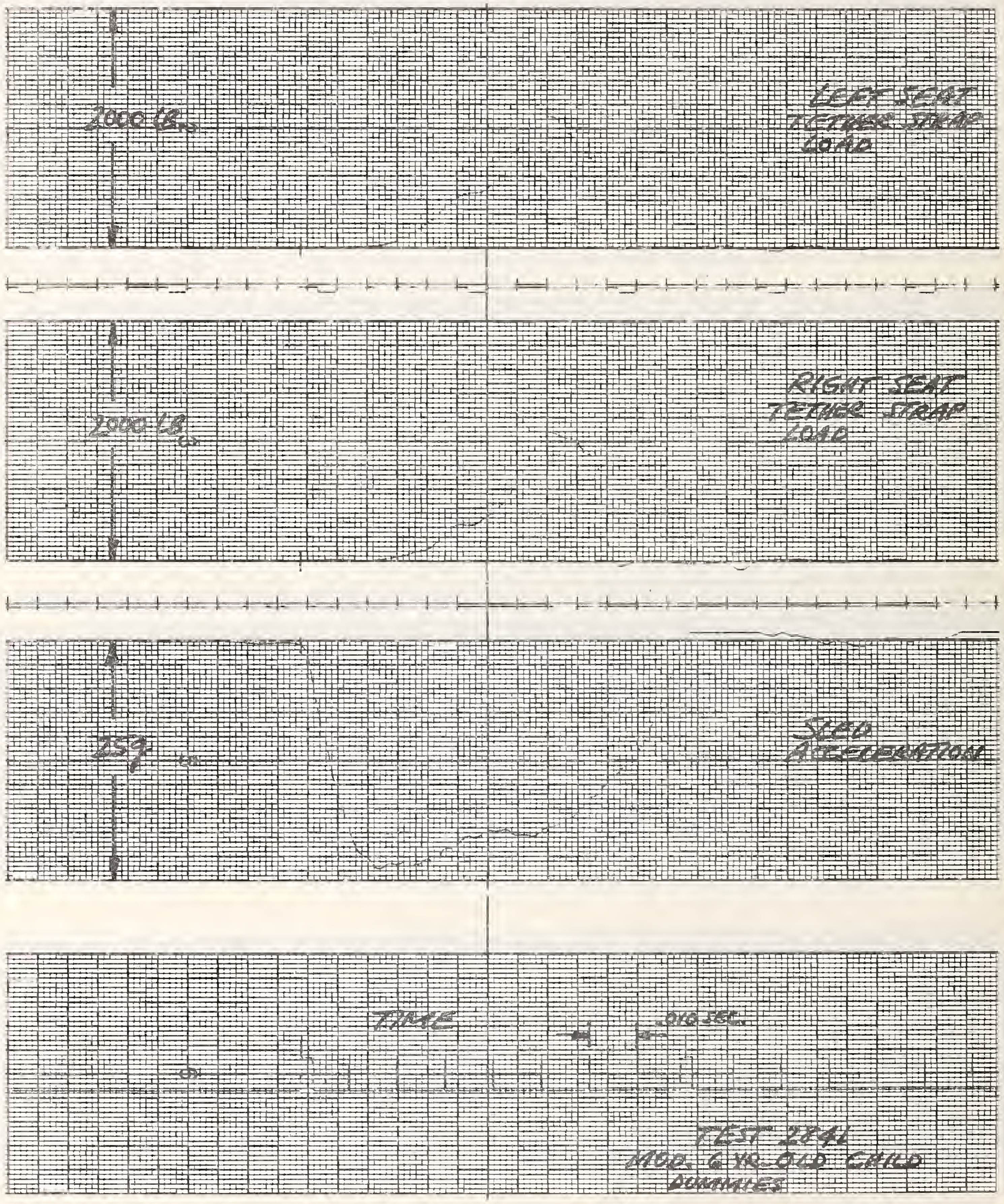


Figure A-3: Test 2841 of Modified 6-Year-Old Child Dummies

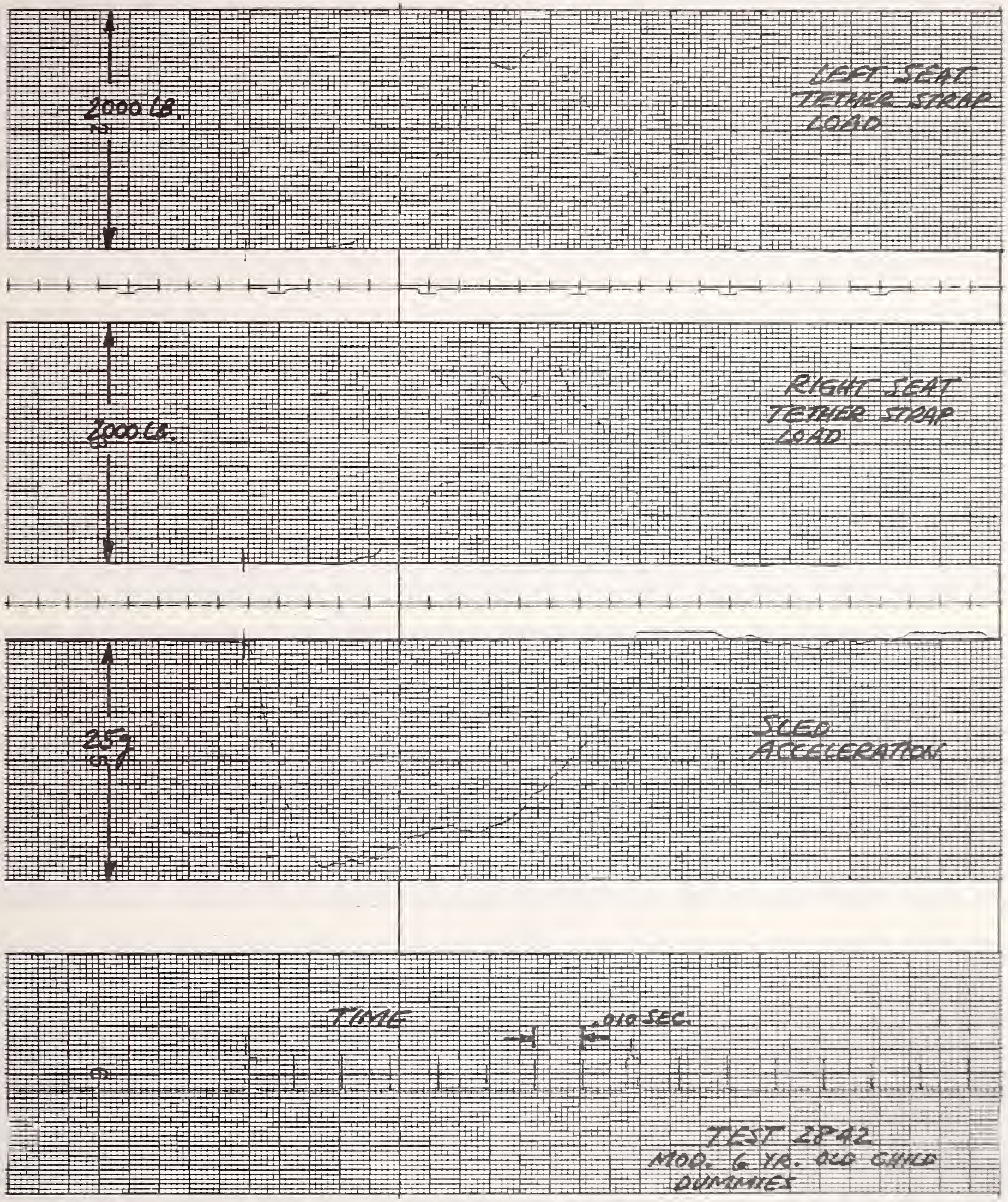


Figure A-4: Test 2842 of Modified 6-Year-Old Child Dummies

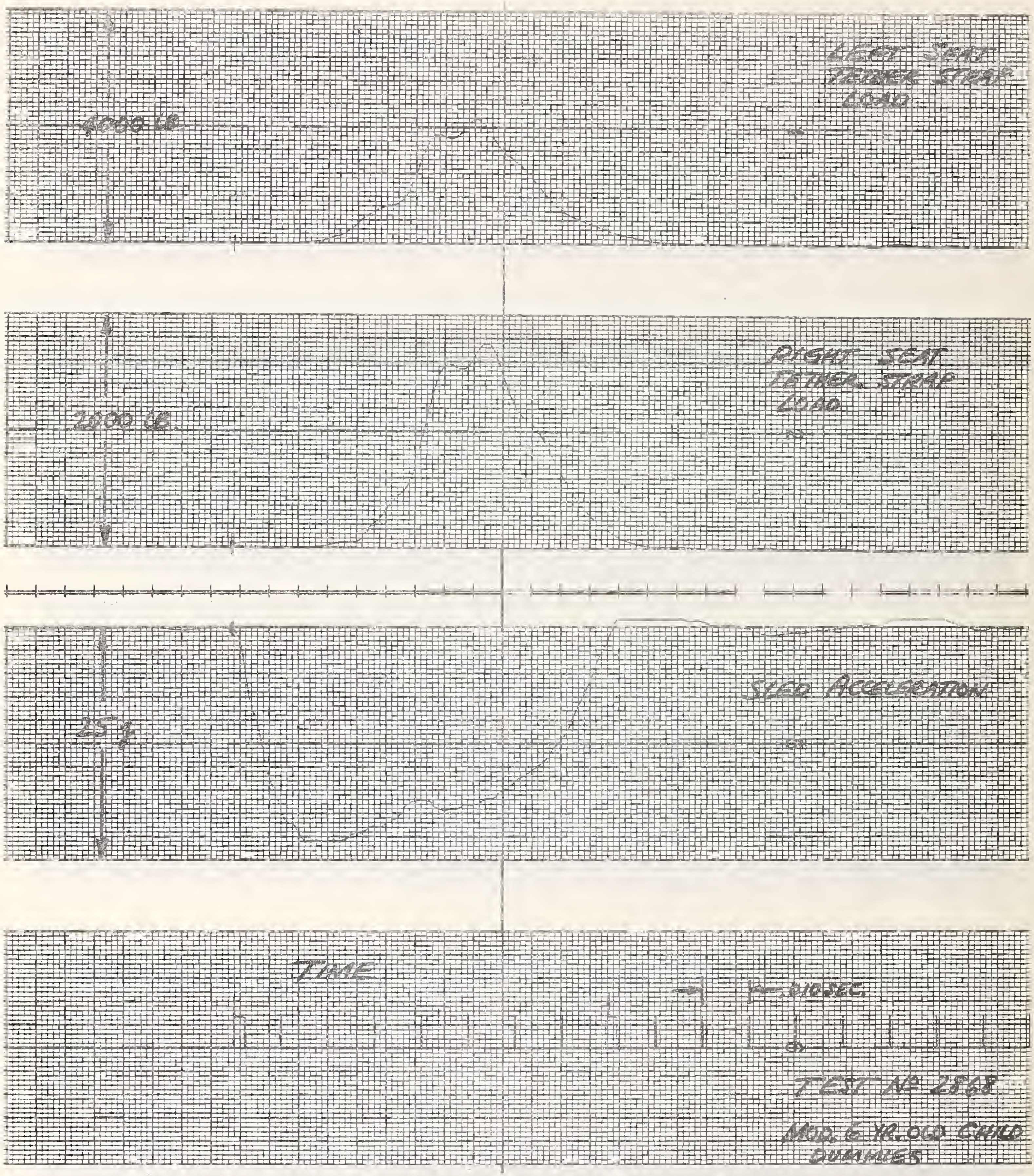


Figure A-5: Test 2868 of Modified 6-Year-Old Child Dummies

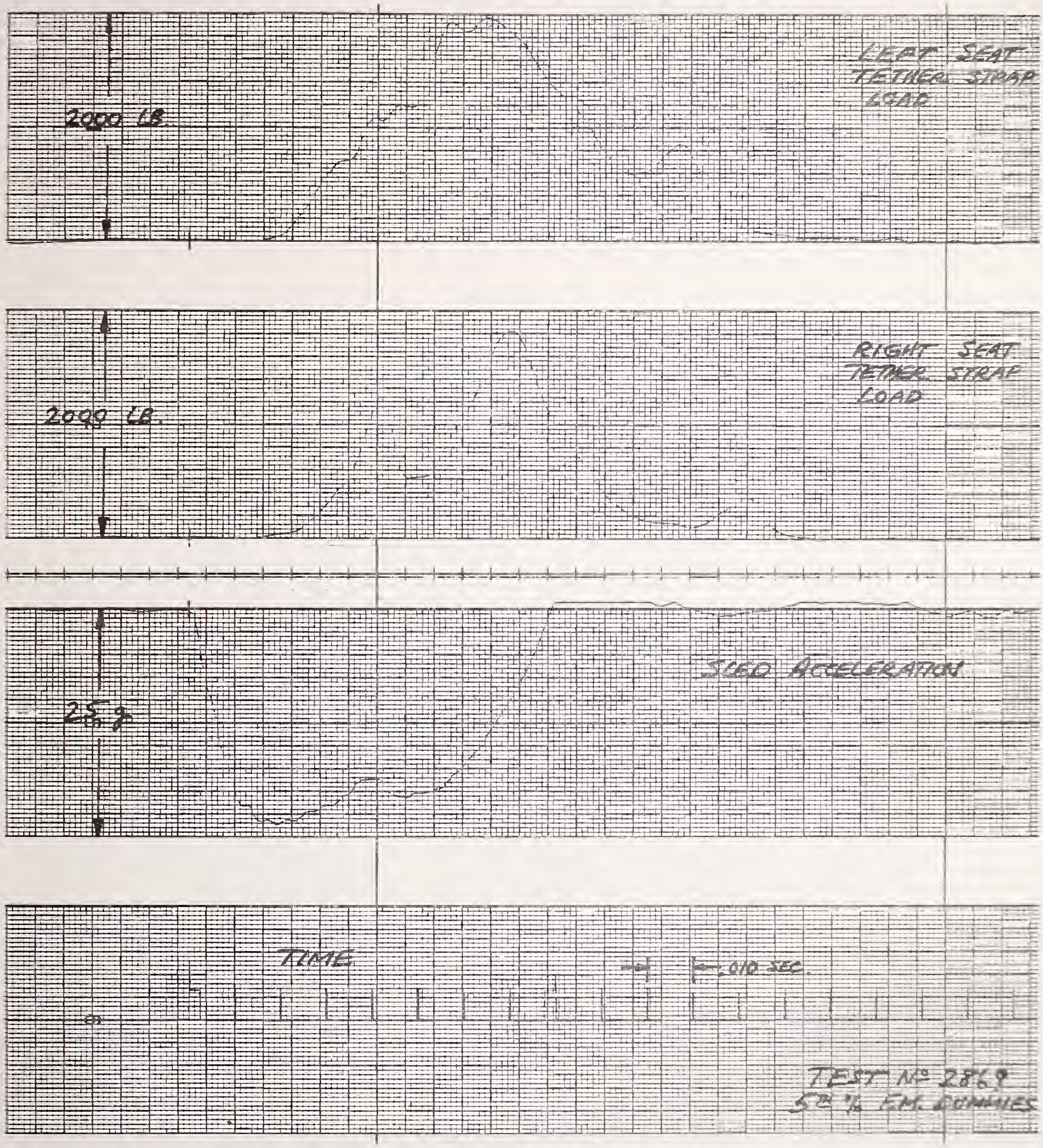


Figure A-6: Test 2869 of 5th Percentile Female Dummies