MATERIAL TESTING REPORT

1.4 MULTIPLIER TEST

GRAVITEC TESTING FACILITY
— BAINBRIDGE ISLAND, WA —

Prepared By,

Gravitec Systems Inc.

9453 Coppertop Loop NE

Bainbridge Island, WA 98110

1-800-755-8455

June 2006

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

Appendix A – Drop Test Force-Time Graphs

Appendix B – Energy Absorbing Lanyard Measured Data

EXECUTIVE SUMMARY

The purpose of this testing was to determine whether the existing 1.4 multiplier comparison between a human body and a rigid test weight for testing fall arresting equipment is suitable for current technology.

Reduction of the 1.4 multiplier to reflect current fall protection technologies entails increasing the weight of the rigid test weight used in dynamic performance drop tests on energy absorbing lanyards and other fall arresting devices. A major feature of this test was to gather test data using both human subjects and a rigid weight capable of being heavier or lighter to match each human subject's weight.

This test includes easily understood mathematics which outline the differences in the energy absorbed by a human during a fall versus absorbed energy by a rigid test weight. It concludes that the present 1.4 multiplier is inadequate to represent a human weight when using a rigid test weight. The data suggests a 1.10 multiplier may be more accurate when using a rigid test weight simulating a human for qualification testing, assuming a 6 ft free fall distance. This report recommends that the ANSI standard body should seriously review their current testing protocols.

Also included are tables and graphs outlining the comparisons between the rigid and human weights tested. The graphs contain a series of tests overlaid on each other and enlarged graphs focusing on the deployment of energy absorbers during a test.

1. INTRODUCTION

1.1. Scope

It is widely acknowledged that when personal protection equipment is activated during a fall some of the energy of the fall is absorbed by the human body. When conducting dynamic fall protection equipment tests using a rigid weight, there is a need to compensate for the fact that a human is not involved. Historically, a multiplier of 1.4 has been used to compensate for the energy absorbing qualities of the human body in rigid weight tests. This standard has been applied by all testing agencies, governing bodies, and standards organizations.

It has been suggested that innovations in personal fall protection equipment may have rendered the 1.4 multiplier inaccurate in comparing human to rigid weight drop tests. Through this report, Gravitec Systems has conducted testing to investigate whether the 1.4 multiplier is accurate. As such, this report presents data from the tests and suggest an updated multiplier to reflect current fall arrest technologies.

This test was funded and conducted by Gravitec Systems, Inc., for the purposes set forth by the ANSI Z359.1 committee chairman.

1.2. Background Information

The 1.4 multiplier mentioned in ANSI Z359.1-1992 is a multiplier used to designate the difference between using a human body or a rigid test weight during the performance test of fall arrest systems. In essence, a 220 lb rigid weight can be construed as a 310 lb person using the 1.4 multiplier when conducting dynamic performance tests of fall arrest systems, i.e., 220 lbs * 1.4 multiplier = 310 lbs (308 lbs). We understand the 1.4 multiplier was established during the era of waist belts when, during a fall, additional fall energy was absorbed by dynamic movements of the human body. As such, the multiplier was established because a solid rigid test weight does not account for the fall energy absorbed by a human wearing a waist belt during a drop test.

The onset of full-body harnesses has allowed the human to remain in an erect position with their head pointing upwards after a fall, not nose to toe as was the case when a waist belt was used. The use of the full-body harness distributes forces sustained during a fall to the sub-pelvic region of the body and allows the human torso to compress and expand in a vertical direction along the axis of the spine. With waist belts all fall forces were targeted to the waist of the human, creating the before-mentioned nose-to-toe position in addition to placing large impact loads on the spine. The 1.4 multiplier continues to be used for testing of personal fall arresting equipment although the differences between a rigid weight and human wearing a full body harness during a drop test are similar.

1.3. Definitions

For the purposes of this report, the following definitions apply:

Adjustable Rigid Test Weight
A cylindrical steel constructed test weight with the capabilities of changing weight by addition or removal of lead shot.

Human Weight
A fit human used as a test weight. The human weight has the ability to dampen the fall by compression of body tissue and the body's ability to expand and contract.

Energy Absorbing Lanyard
The type of equipment tested. A component of a fall arrest system, the main purpose of which is to absorb fall energy as it limits fall distances. Each energy absorbing lanyard was 6 ft in length and was exposed to a fall distance of 6 feet.

Free Fall Distance
The amount of distance fallen by either the human or the adjustable rigid test weight before any deployment of the energy absorbing lanyard.

Maximum Arrest Forces (MAF)
Maximum arrest forces sustained and measured by the load cell and Somat data collection system, by the human or adjustable rigid test weight during the fall.

EAL Energy Absorption
Fall energy absorbed by the energy absorbing lanyard.

EAL Deployment
The amount each energy absorbing lanyard elongated during testing.

1.4. ANSI Standard Z359.1-1992

To date, the American National Standards Institute stipulates the following for tests weights used in qualification testing of fall protection equipment:

> *4.1.2 Test Weight – Two test weights are required by this standard. The test weights shall be of a rigid steel construction in accordance with the dimensions set forth in Appendix B, Figure 17. Where dynamic performance testing is required (except where the test torso specified in 4.1.3 is used in conjunction with testing that involves a full-body harness) the test weight shall weigh 220 lbs plus or minus 2 lbs (100 kg plus or minus 1 kg). Where dynamic strength testing is required the test weight shall weigh 300 pounds plus or minus 3 pounds (136.4 kg plus or minus 1.4 kg).*

1.5. Testing Methods

1.5.1. General Procedures

Both humans and an adjustable rigid test weight were used during these tests. Three (3) tests were performed with each human wearing a new full-body harness – DBI model #1103321. Tests using the adjustable test weight preceded each human test.

1.5.2. Removal of Error Sources

Throughout the planning process before testing, multiple error sources were identified and corrected before testing began. The following items were examined and corrected.

1.5.2.1. Extension Cable

A 3/8" Type 302 7x19 stainless steel cable with snaphooks on either end (per ANSI Z359.1-1992 4.1.4) was used to attach the energy absorbing lanyard specimens to the drop test structure. The human subjects and the rigid test weight were then attached to the EAL pouch end at the energy absorbing lanyard. The extension cable was used to remove the possibility of the human striking any component of the drop test structure. Before testing, this cable was pulled to 25% of its breaking strength for a period of two (2) minutes to remove any constructional stretch and prevent elongation during drop testing.

1.5.2.2. EAL Measurements

A cloth tape graduated in US units (feet-inch) with an accuracy of 1/8" was used to perform measurements on the energy absorbing lanyard specimen. A total of four (4) measurements were made with each energy absorbing lanyard specimen: two (2) measurements to determine its initial length before testing, and two (2) measurements to determine its final length after testing.

1.5.2.3. Human/Test Weight Measurements

A floor scale with an accuracy of 1/2 lb was used to determine the weight of each human. These measurements were used to adjust the weight of the rigid test weight to match each human's weight.

1.5.2.4. Load Cells

A 5,000 lb capacity load cell with a maximum error of less than 0.5% (±25 lbs) certified by an independent testing agency was used to collect force data. The 5,000 lb load cell was hung vertically from the drop test structure and provided an attachment point for the energy absorbing lanyard specimen(s). Load cells were calibrated frequently.

1.5.2.5. Connecting Hardware

To prevent connecting hardware from slipping or creating a weak axis loading situation, crape tape and velcro straps were used to ensure connecting hardware remained oriented along its strong axis.

1.6. Testing Equipment

1.6.1. Drop Test Tower

Gravitec Systems drop test tower meets all requirements of ANSI Z359.1-1992, Section 4. A drop test structure made of solid steel members has been independently certified by the use of a bump test and accelerometer testing to have a natural frequency exceeding the minimum 200 Hz set forth in the standard (4.1.1).

1.6.2. Test Instrumentation

Per the requirements in ANSI Z359.1-1992 section 4.1.5, a specially made filter certified by an independent testing agency was used to adhere to the required 100 Hz (+ ½ dB, - 3 dB) corner frequency in collection of test data shown on Page 5, Figure 1. The filter's frequency range lies in the middle of the shaded region.

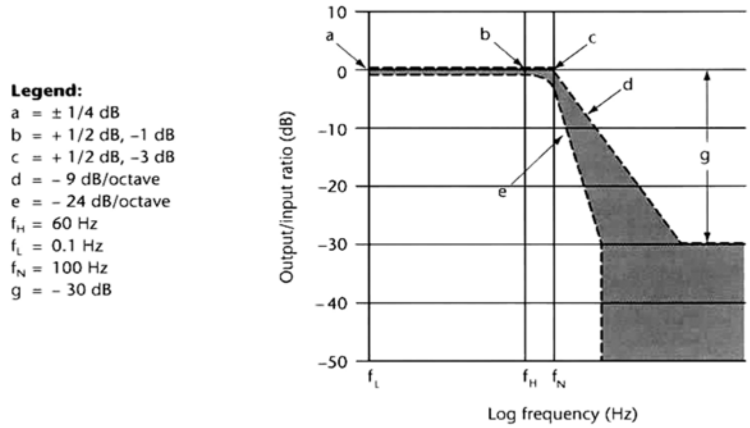


Figure 1 - Corner Frequency Graph

A data collection system certified by an independent testing agency in conjunction with a desktop computer was used to collect and view test data. A 1,000 cycles-per-second sampling rate (Hz) was used in the collection of test data using a 5,000 lb capacity load cell.

1.6.3. Quick Release Mechanism

An electric quick release mechanism was used to remotely release the human test specimen or rigid test weight starting each drop test.

1.6.4. Video Documentation

A high-speed video system was used to document each drop test. In addition, standard digital video was shot of each test.

1.6.5. Still Photographs

Still shot photographs were taken of each test during set-up of the test and the end result of each test specimen. Photographs were used for report documents in addition to providing test information.

1.7. Testing Equipment

The following equipment was used during these tests.

1.7.1. Test Subject Equipment

- Full-Body Harness - DBI model #1103321
- Energy Absorbing Lanyards
- Steel-toed boots
- Coveralls
- Safety goggles
- Safety helmets
- Mouth guards

1.7.2. Data Collection

- 5,000 lb capacity load cell & appropriate cords
- Desktop computer system
- Associated software
- Data Acquisition System meeting ANSI requirements
- Corner Frequency filter meeting ANSI requirements

1.7.3. Testing Hardware

- Quick-release mechanism with safety detent pin
- Electronic release switch
- Adjustable rigid test weight
- Test torso
- Columbia winch
- Associated carabiners
- Associated shackles

1.8. Safety Procedures

1.8.1. General Procedures

In order to establish a safe testing area, a safety zone was set up around the drop test structure protecting spectators. Those within the safety zone, testing personnel, etc., were required to wear steel-toed boots, safety glasses, and hard hats. Testing personnel working on the drop test tower were secured to the tower by use of ANSI-approved fall protection equipment.

1.8.2. Human Testing

Extensive measures were established to protect the welfare of each human. A new full-body harness was used for each drop test (DBI model #1103321). Each human wore a set of coveralls, steel-toed boots, safety goggles, hard hat with chin strap, and a mouth guard. Large gymnastics crash pads were set up at the base of Gravitec's drop test tower as an added safety barrier. A detent safety pin attached to a quick release mechanism provided security against any chance of unintentional release. Humans were protected at all times through the use of fall protection equipment. Self-retracting lifelines connected to beam clamps attached to the drop test structure were connected to each human until the test begun. A verbal communications system was established between drop test personnel to ensure all safety concerns were worked out before the test began. A safety monitor was on site at all times, as was a certified Emergency Medical Technician (EMT). Accident procedures were established and posted adjacent to the drop test structure. Before humans ascended the drop test structure, a safety check was performed in addition to a safety check before the human was hung from the tower winch.

1.8.3. Rigid Weight Testing

During the testing of the rigid test weight, large rubber mats were installed at the base of the drop test tower to prevent damage to the testing facility. As with the human testing, a special detent safety pin within the quick-release cargo hook was removed once the test was cleared to commence. Verbal communications were repeated until the test commenced.

2. TESTING PROCEDURES

A variation to the testing procedures outlined in ANSI Z359.1-1992 under the dynamic performance tests for energy absorbing lanyards (4.2.9) was followed for these tests. The procedures are outlined below.

1) Attach the 5,000 lb capacity load cell to the drop test structure. (The 5k lb load cell remained on the drop test for each test.)
2) Use a new energy absorbing lanyard test specimen for each test.
3) Attach one end of the energy absorbing lanyard to the load cell extension cable described in 1.5.2.1.
4) Use a 10 lb sandbag hanging from the other end of the energy absorbing lanyard to determine the initial length of the specimen. Measure to the bearing point on each snaphook or shackle using the hanging cloth tape and record each measurement.
5) To determine the initial lanyard length, subtract the upper measurement from the bottom measurement. Record this value on the lanyard spreadsheet.
6) Attach the quick release mechanism to either the rigid test weight or to the dorsal D-ring on the human's full-body harness. Place the safety detent pin into the quick release mechanism to prevent a premature release. (This safety detent pin is to be removed only when all test set up procedures have been completed. At any time a human or test weight is suspended, the safety detent pin is to be left in the quick-release mechanism preventing a premature release.)
7) Raise the rigid test weight or human and connect the snaphook of the energy absorbing lanyard to the test weight or the dorsal D-ring on the human's full-body harness.
8) Raise the rigid test weight or human to a predetermined height allowing a 6 ft free fall of the rigid test weight or human. (Using the bottom measurement found in step #4, subtract 6 ft from this measurement to determine the drop test height.)
9) Once the data collection device has been calibrated, zeroed, and initialized, the safety detent pin can be removed from the quick release mechanism.
10) Start the drop test.
11) Release the test weight (rigid or human) using the quick-release mechanism and trigger system.
12) Once the rigid test weight or human has come to a complete rest, measure and record the length of the energy absorbing lanyard test specimen from bearing point to bearing point while the rigid test weight or human is still suspended using the same procedures as in step #4 but without the 10lb sandbag.
13) Upload the test data to the desktop computer system.

14) Calculate the test specimen deployment. Take the initial length found in step #4 versus the final length recorded in step #12 and take the difference of those two numbers. The result is the deployment (stretch) of the energy absorbing lanyard test specimen.
15) Place the energy absorbing lanyard test specimen in its appropriate container and proceed with the next test.
16) Repeat steps #1-15 until all tests have been performed.

3. TEST OBSERVATIONS

3.1. Human Test Weights

The graph show in Table 1 below outlines the test weights for each human. Three human test weights were used in addition to a rigid test torso.

Table 1 - Weights of Human Test Subjects

HUMAN SUBJECT #1 (lbs)	HUMAN SUBJECT #2 (lbs)	HUMAN SUBJECT #3 (lbs)	HUMAN #4A TEST TORSO (lbs)
162.0	193.0	219.0	228.0

The adjustable rigid test weight was attuned to match the above weights.

Note: Unique for these tests was a specially designed rigid test weight adjustable from 100 lbs (45.5 kg) to 360 lbs (163.4 kg) by either adding or removing lead shot. For each human test, the rigid test weight using the floor scale was made heavier or lighter to match the weights of the human subjects.

3.2. EAL Specimen Data

Following the test procedures in Section 2, energy absorbing lanyard test specimens were measured before and after each test to determine their initial and final lengths. This data is shown below in Table 2 through Table 5.

Table 2 – Test Subject #1 EAL Test Data

	Item #	EAL Initial Length (in)	Final Length (in)	EAL Deployment (in)
TEST SUBJECT #1 162.0 LBS	1.4-TS1-H-L1	149.875	166.250	16.375
	1.4-TS1-H-L2	149.500	170.875	21.375
	1.4-TS1-H-L3	149.750	170.500	20.750
	1.4-TS1-W-L1	149.750	172.500	22.750
	1.4-TS1-W-L2	149.500	172.750	23.250
	1.4-TS1-W-L3	149.625	172.250	22.625

Table 3 - Test Subject #2 EAL Test Data

TEST SUBJECT #2 193.0 LBS	Item #	EAL Initial Length (in)	Final Length (in)	EAL Deployment (in)
	1.4-TS2-H-L1	150.250	177.000	26.750
	1.4-TS2-H-L2	150.125	175.500	25.375
	1.4-TS2-H-L3	149.875	176.000	26.125
	1.4-TS2-W-L1	150.000	178.750	28.750
	1.4-TS2-W-L2	150.000	178.875	28.875
	1.4-TS2-W-L3	149.875	179.125	29.250

Table 4 - Test Subject #3 EAL Test Data

TEST SUBJECT #3 219.0 LBS	Item #	EAL Initial Length (in)	Final Length (in)	EAL Deployment (in)
	1.4-TS3-H-L1	150.000	181.250	31.250
	1.4-TS3-H-L2	149.750	182.000	32.250
	1.4-TS3-H-L3	149.750	182.500	32.750
	1.4-TS3-W-L1	149.750	185.000	35.250
	1.4-TS3-W-L2	149.750	185.500	35.750
	1.4-TS3-W-L3	149.875	185.875	36.000

Table 5 - Test Subject #4 EAL Test Data

TEST SUBJECT #4 - TORSO - 228.0 LBS	Item #	EAL Initial Length (in)	Final Length (in)	EAL Deployment (in)
	1.4-TS4-H-L1	149.750	186.875	37.125
	1.4-TS4-H-L2	149.750	187.875	38.125
	1.4-TS4-W-L1	149.500	186.750	37.250
	1.4-TS4-W-L2	149.750	188.000	38.250

Energy absorbing lanyard test specimens and full-body harnesses were given their own designation. For example, 1.4-TS1-H-L1 is described as: test name = 1.4 multiplier test; test subject number = TS1; full-body harness (H) or rigid test weight (W); lanyard test number = L1. In addition, a similar code was placed on each full-body harness used with each human test.

A force-time graph was created by the data collection device outlining the forces sustained by the human test specimen and/or the rigid test weight during each test. These graphs are shown in Appendix A.

An expanded version of Tables 2 through 5 is shown in Appendix B.

In making comparisons with these tables of lanyard data, the average initial and final lengths were used for energy absorbing lanyards. At first glance, the rigid test weight appears to have caused the energy absorbing lanyards to deploy farther than the human's energy absorbing lanyards. With the three humans, this difference ranged an average of 0.33% to 14.75% as outlined in Table 6 on the next page.

Table 6 - EAL Deployment Comparisons

TEST SUBJECT #1 162.0 LBS		**EAL Deployments**	
		Individual Deployment (in)	**Average Deployment (in)**
HUMAN	1.4-TS1-H-L1**	16.375	21.063
	1.4-TS1-H-L2	21.375	
	1.4-TS1-H-L3	20.750	
RIGID WEIGHT	1.4-TS1-W-L1	22.750	22.875
	1.4-TS1-W-L2	23.250	
	1.4-TS1-W-L3	22.625	
Average difference between Human & Rigid Weight (in)			**1.813**
Average percent difference between Human & Rigid Weight (%)			**7.92%**

TEST SUBJECT #2 193.0 LBS		**EAL Deployments**	
		Individual Deployment (in)	**Average Deployment (in)**
HUMAN	1.4-TS2-H-L1	26.750	25.417
	1.4-TS2-W-L2	23.375	
	1.4-TS2-H-L3	26.125	
RIGID WEIGHT	1.4-TS2-W-L1	28.750	28.958
	1.4-TS2-H-L2	28.875	
	1.4-TS2-W-L3	29.250	
Average difference between Human & Rigid Weight (in)			**3.542**
Average percent difference between Human & Rigid Weight (%)			**12.23%**

** This test was removed from averaging due to the large discrepancy between this lanyard test and the rest of the tests performed with Test Specimen #1.

Table 6 - EAL Deployment Comparisons, continued

TEST SUBJECT #3 219.0 LBS		EAL Deployments	
		Individual Deployment (in)	Average Deployment (in)
HUMAN	1.4-TS3-H-L1	31.250	32.083
	1.4-TS3-H-L2	32.250	
	1.4-TS3-H-L3	32.750	
RIGID WEIGHT	1.4-TS3-W-L1	35.250	35.667
	1.4-TS3-W-L2	35.750	
	1.4-TS3-W-L3	36.000	
Average difference between Human & Rigid Weight (in)			**3.583**
Average percent difference between Human & Rigid Weight (%)			**10.05%**

TEST SUBJECT #4 - TEST TORSO - 228.0 LBS		EAL Deployments	
		Individual Deployment (in)	Average Deployment (in)
HUMAN	1.4-TS4-H-L1	37.125	37.625
	1.4-TS3-H-L2	38.125	
RIGID WEIGHT	1.4-TS4-W-L1	37.25	37.750
	1.4-TS4-W-L2	38.250	
Average difference between Human & Rigid Weight (in)			**0.125**
Average percent difference between Human & Rigid Weight (%)			**0.33%**

From the data shown in Table 6 above, it is clear that the humans absorbed more of the fall energy than the rigid test weight. Test specimen #4 shows very close similarities between a rigid test weight and the test torso in terms of the amount of deployment the energy absorbing lanyard sustained. Additionally, in terms of the test torso comparison to the rigid weight, the test torso did not dampen the fall like the human specimen's did. This is because the test torso is essentially a rigid test weight with a full-body harness. What the test torso does show is the full-body harness does not absorb any significant amount of the fall energy created during the fall.

In addition to deployment distance between energy absorbing lanyards used during the human tests and the rigid test weight tests, two additional factors, maximum arrest forces and energy absorption, were looked at to compare the difference between human and rigid test weight dynamic performance tests of an energy absorbing lanyard. Of these two factors, energy absorption is of utmost importance.

3.3. Energy Absorption Data

Energy absorption is the comparison between the energy created during the fall and the energy absorbed by the energy absorbing lanyard during arresting phase of the fall. Throughout the deceleration distance of the fall, the energy absorbing lanyard deploys and absorbs fall energy as it tears apart. This energy is a key factor in arresting the human's fall. During this time, energy is dissipated, or absorbed, by the energy absorbing lanyard. This figure is calculated by the average arrest force of the EAL multiplied by the deployment distance of the EAL whose product is in the units of energy.

In comparing the differences between tests performed with humans and rigid weights, the human fall energy is absorbed not only by the energy absorbing lanyard, but also by the human body itself (compression of human tissue, full-body harness adjusting itself to the human's physique, etc.). Tables 7 through 10 outline the energy absorption of each test. Percent differences compare the human test subjects against the rigid test weight. For example, in Table 7 the percent difference between human and rigid weight tests is 8.06%. This figure means the energy absorbing lanyard arresting the fall of the rigid weight is absorbing 8.06% more fall energy than the energy absorbing lanyard arresting the fall of the human not taking into account the energy absorbed by the full-body harness. However, the energy absorbed by the full-body harness is negligible, 0.45%, in comparison to the fall energy absorbed by the energy absorbing lanyard arresting the fall of the rigid test weight as shown in Table 10.

Table 7 - Energy Comparisons for Test Subject #1

TEST SUBJECT #1 162.0 LBS		EAL Energy Absorption			
		Average Deployment Force (lbs)	EAL Deployment (in)	Individual EAL Energy Absorption (in-lbs)	Average EAL Energy Absorption (ft-in)
HUMAN	1.4-TS1-H-L1**	574.494	16.375	9407.347	12,237.426
	1.4-TS1-H-L2	579.973	21.375	12,396.914	
	1.4-TS1-H-L3	582.069	20.750	12,077.937	
RIGID WEIGHT	1.4-TS1-W-L1	595.326	22.750	13,543.671	13,310.250
	1.4-TS1-W-L2	570.524	23.250	13,264.691	
	1.4-TS1-W-L3	579.995	22.625	13,122.388	
Average difference between Human & Rigid Weight (in-lbs)					1072.824
Average percent difference between Human & Rigid Weight (%)					8.06%

** This test was removed from averaging purposes due to the large discrepancy between this lanyard test and the rest of the tests performed with Test Specimen #1.

Table 8 - Energy Comparisons for Test Subject #2

TEST SUBJECT #2 193.0 LBS		EAL Energy Absorption			
		Average Deployment Force (lbs)	EAL Deployment (in)	Individual EAL Energy Absorption (in-lbs)	Average EAL Energy Absorption (ft-in)
HUMAN	1.4-TS2-H-L1	576.908	26.750	15,432.284	14,871.273
	1.4-TS2-W-L2	588.524	23.375	13,756.745	
	1.4-TS2-H-L3	590.423	26.125	15,424.790	
RIGID WEIGHT	1.4-TS2-W-L1	581.291	28.750	16,712.116	16,906.536
	1.4-TS2-H-L2	584.340	28.875	16,872.817	
	1.4-TS2-W-L3	585.801	29.250	17,134.673	
Average difference between Human & Rigid Weight (in-lbs)					**2035.263**
Average percent difference between Human & Rigid Weight (%)					**12.04%**

Table 9 - Energy Comparisons for Test Subject #3

TEST SUBJECT #3 219.0 LBS		EAL Energy Absorption			
		Average Deployment Force (lbs)	EAL Deployment (in)	Individual EAL Energy Absorption (in-lbs)	Average EAL Energy Absorption (ft-in)
HUMAN	1.4-TS3-H-L1	606.870	31.250	18,964.690	19,125.443
	1.4-TS3-H-L2	594.463	32.250	19,171.434	
	1.4-TS3-H-L3	587.487	32.750	19,240.205	
RIGID WEIGHT	1.4-TS3-W-L1	586.214	35.250	20,664.054	21,024.624
	1.4-TS3-W-L2	585.954	35.750	20,947.864	
	1.4-TS3-W-L3	596.165	36.000	21,461.954	
Average difference between Human & Rigid Weight (in-lbs)					**1899.181**
Average percent difference between Human & Rigid Weight (%)					**9.03%**

Table 10 - Energy Comparisons for Test Subject #4

TEST SUBJECT #4 - TEST TORSO - 228.0 LBS		EAL Energy Absorption			
		Average Deployment Force (lbs)	EAL Deployment (in)	Individual EAL Energy Absorption (in-lbs)	Average EAL Energy Absorption (ft-in)
TEST TORSO	1.4-TS4-H-L1	601.379	37.125	22,326.199	22,498.063
	1.4-TS3-H-L2	594.621	38.125	22,669.926	
RIGID WEIGHT	1.4-TS4-W-L1	605.551	37.250	22,556.777	22,600.734
	1.4-TS4-W-L2	592.018	38.250	22,644.691	
Average difference between Human & Rigid Weight (in-lbs)					102.671
Average percent difference between Human & Rigid Weight (%)					0.45%

Note: Energy was calculated as the average deployment force (lbs) multiplied by the EAL deployment (in) to reach a value in in-lbs or a unit of energy. The human, test torso, and rigid weight energy calculations were averaged to determine the percent difference between the three test weights.

In Table 10 above it is shown the percent difference between the energy absorbed by the energy absorbing lanyard arresting the fall of the test torso wearing a full-body harness and the energy absorbed by the energy absorbing lanyard arresting the fall of the rigid weight is less than 1%. Due to this finding, it is fair to conclude that the full-body harness does not significantly contribute to the fall arrest of the test torso. In other words, the energy absorbed by an energy absorbing lanyard arresting the fall of a test torso wearing a full-body harness is similar to the energy absorbed by an energy absorbing lanyard arresting the fall of a rigid test weight of equal weight. No significant additional fall energy is absorbed by the full-body harness.

4. CONCLUSIONS

4.1. Overview

The ANSI standard states that a 1.4 multiplier should be used to compare the differences between a human and a rigid test weight when performing qualification testing of fall-arresting equipment. Using this multiplier, a 220 lb test weight can be construed as equivalent to a 310 lb worker through the use of this standard. However, the 1.4 multiplier was established prior to the advent of current fall arresting equipment, most notably during the time period when waist belts were used for fall arrest applications.

4.2. EAL Deployment

From the results presented in this report, average differences between rigid weights and human test subjects when looking at deployment of the energy absorbing lanyard range from 7.92% to 12.23% with an average of 10%. To evaluate the possible energy absorbed by the full-body harness, tests using the test torso wearing a full-body harness as opposed to a rigid weight were done. These results were very similar with a difference of 0.33%. In short, it is fair to say the full-body harness plays no significant role when making comparisons between human weights and rigid test weights, and, in terms of deployment of the energy absorbing lanyard, there is a 10% difference when using a human weight as opposed to a rigid weight.

4.3. Energy Absorption

In looking at the energy absorption of energy absorbing lanyards arresting the fall of a human versus a rigid weight, a range of 8.06% to 12.04% was calculated with an average of 9.71% or 10%. Moreover, the tests conducted with the test torso wearing a full-body harness versus a matching rigid weight show negligible differences. As such, it is fair to state the following for an updated multiplier in relating human weights and rigid test weights for qualification testing of fall-arresting equipment:

Rigid Weight / Human Weight Multiplier = 1.10

Thus, to simulate a human weight for dynamic performance testing of fall-arresting equipment, the actual weight of a rigid test weight should be multiplied by 1.10 to equal the desired human weight. In other words, if a 310 lb worker was desired as a human test weight, then a rigid weight of 280 lbs should be used (280 lbs x 1.1 = 310 lbs).

4.4. General Conclusions

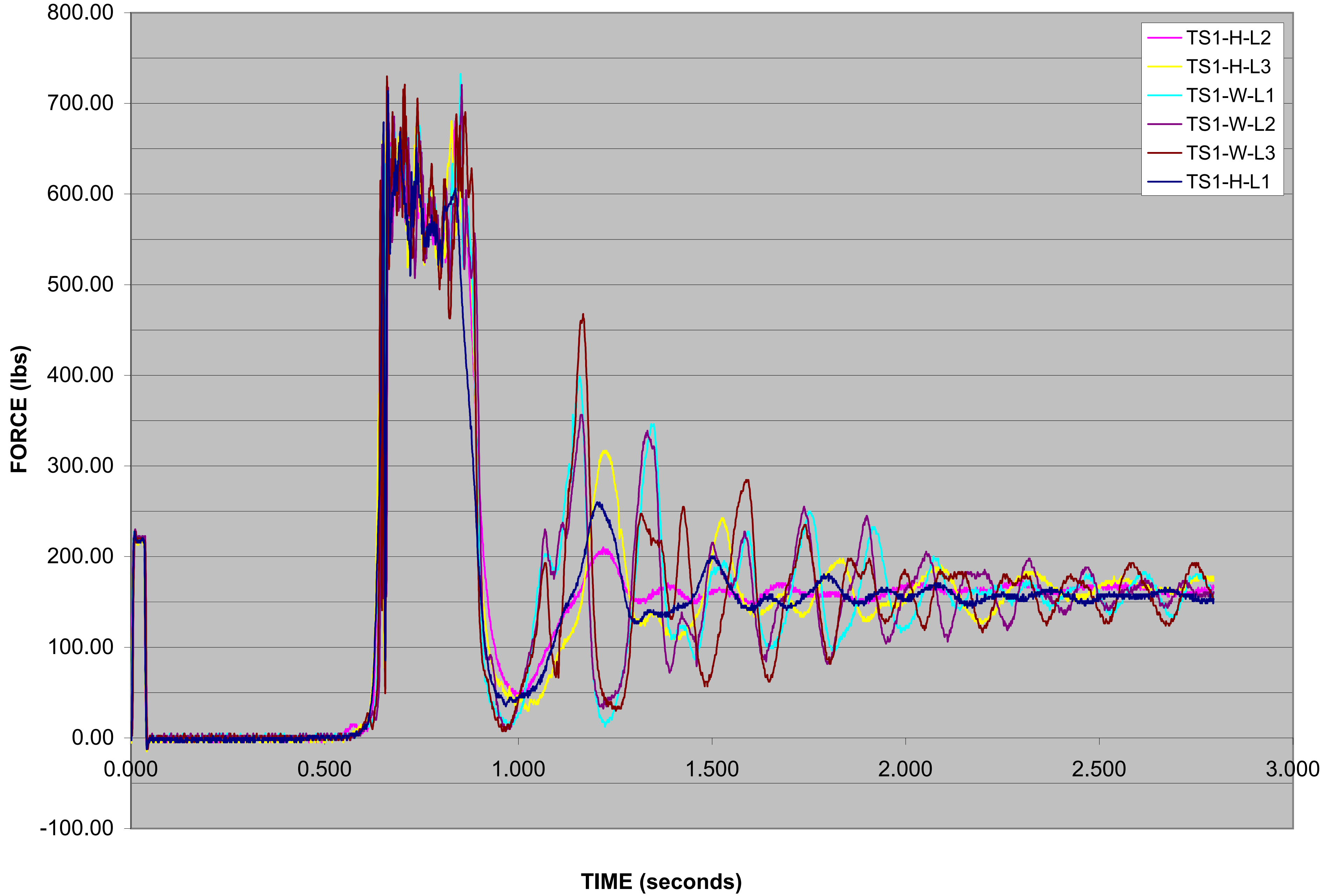
The results and recommendations presented in this report were derived from the three (3) trials performed comparing human and rigid weights and an additional test using a test torso to examine the performance of the full-body harness during a drop test. However, four (4) additional tests were performed by Gravitec Systems following similar testing protocol all producing results consistent with those presented in this report. Through these tests alone the updated multiplier was estimated. To solidify multipliers, further tests should be conducted to obtain averages and remove outliers (invalid data). On the other hand, subjecting humans to multiple drop tests can be harmful to their health and as such careful consideration must be made before arranging further tests involving humans.

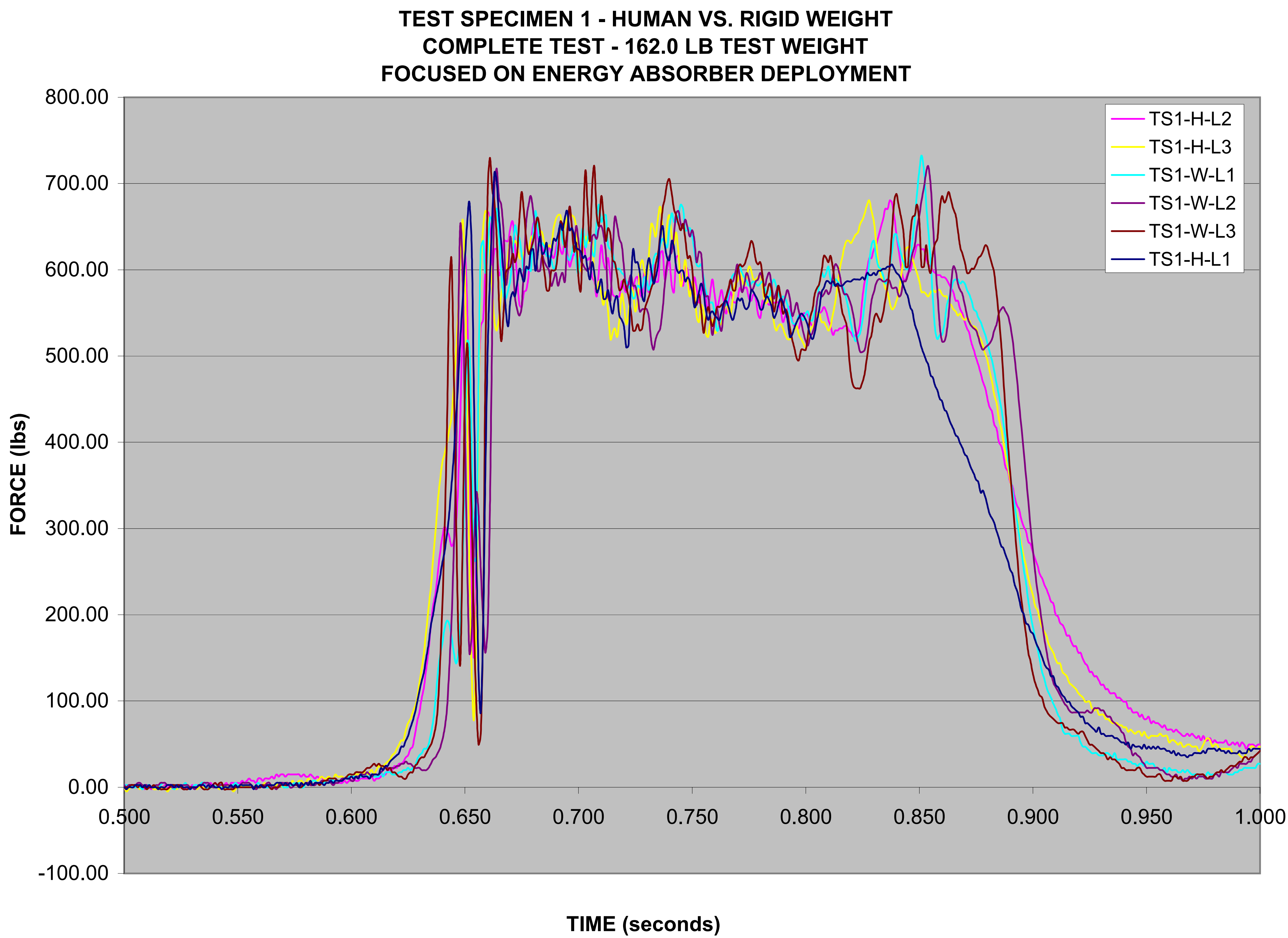
The tests performed during this study give a baseline for further testing to determine if the 1.10 multiplier will hold constant. On the contrary, previous testing by both individuals and manufacturers has been performed in looking at this issue. Even though those tests did not follow the strict testing protocol used by Gravitec System through this report by using a scientific approach to the situation, those test should not be discredited. In fact, results found through previous testing are similar to results found through this report. With this in mind, all testing performed by individuals and manufacturers looking at the 1.4 multiplier, not just the results contained within this report, should be analyzed to establish a multiplier.

APPENDIX A

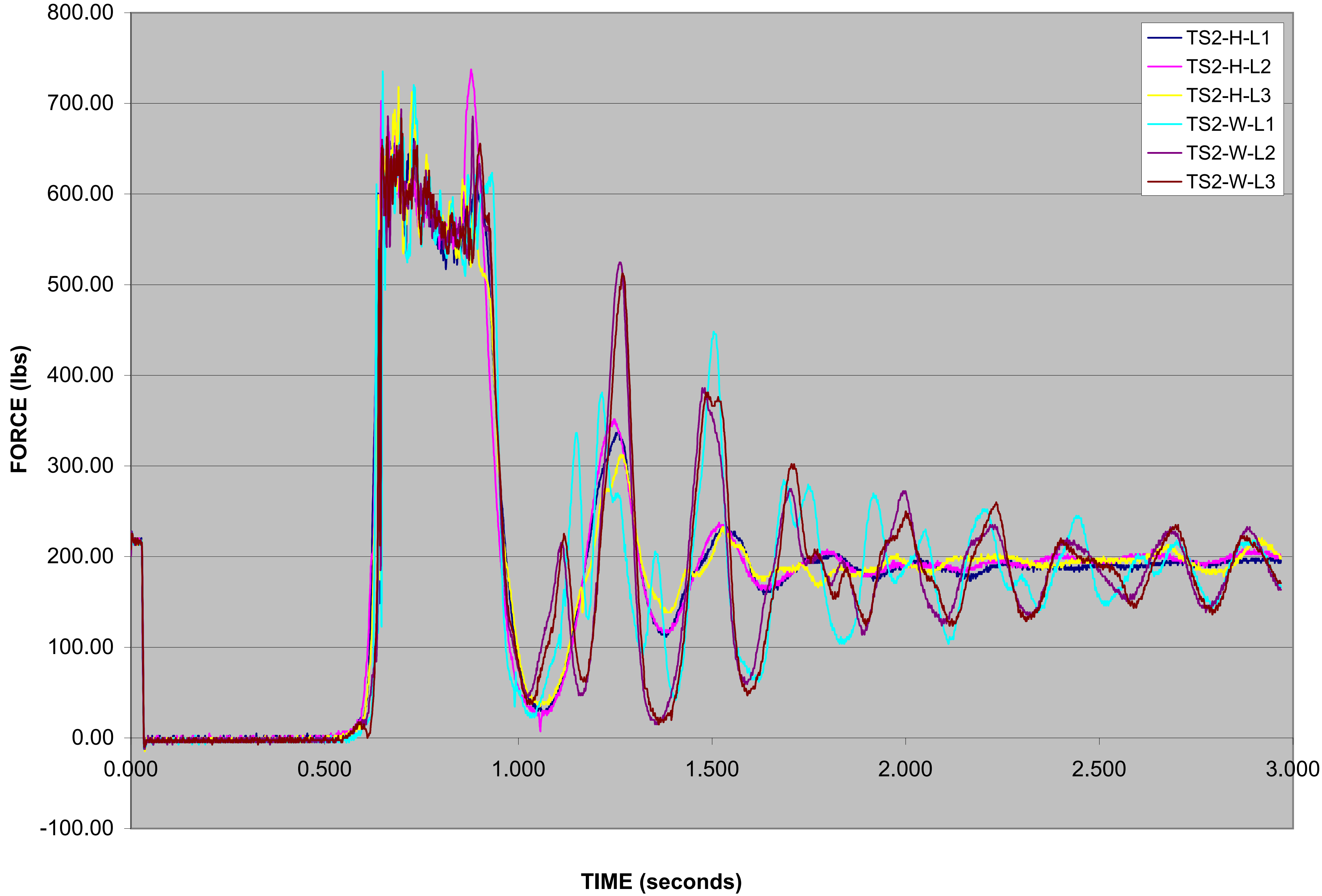
DROP TEST FORCE TIME GRAPHS

TEST SPECIMEN 1 - HUMAN VS. RIGID WEIGHT
COMPLETE TEST - 162.0 LB TEST WEIGHT

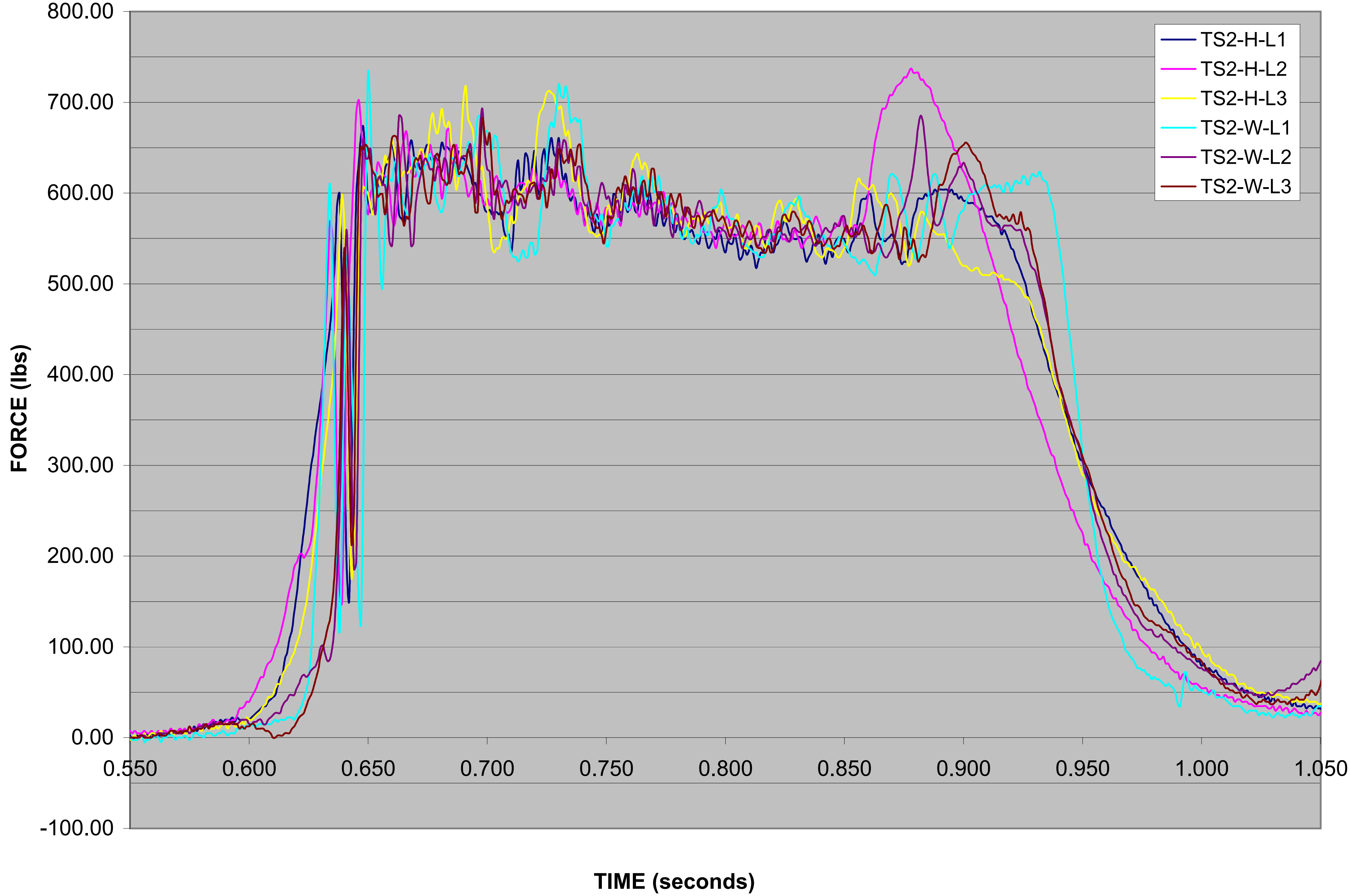


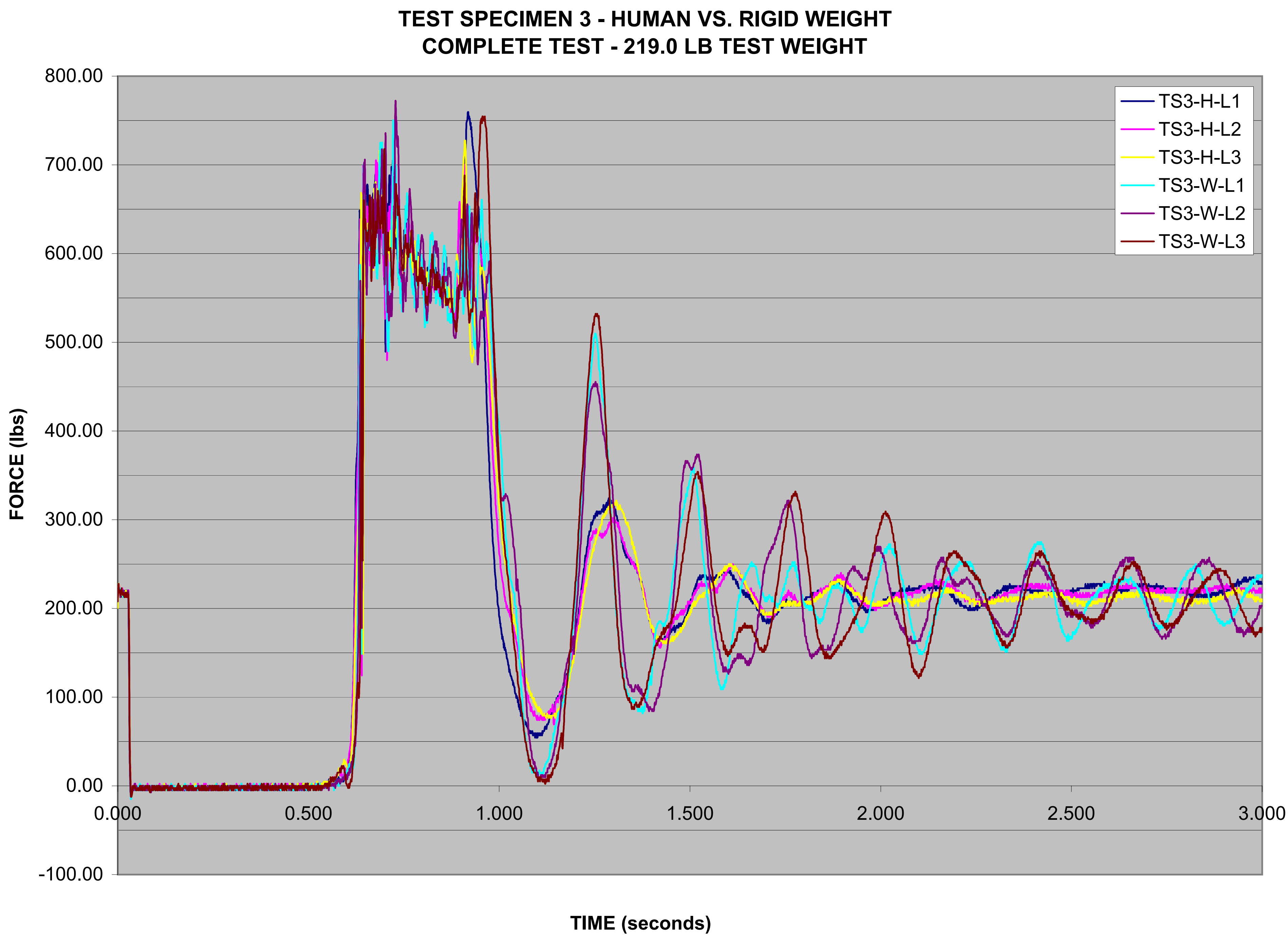

TEST SPECIMEN 1 - HUMAN VS. RIGID WEIGHT
COMPLETE TEST - 162.0 LB TEST WEIGHT
FOCUSED ON ENERGY ABSORBER DEPLOYMENT
FORCE (lbs)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
-100.00
0.500
0.550
0.600
0.650
0.700
0.750
0.800
0.850
0.900
0.950
1.000
TIME (seconds)
TS1-H-L2
TS1-H-L3
TS1-W-L1
TS1-W-L2
TS1-W-L3
TS1-H-L1

TEST SPECIMEN 2 - HUMAN VS. RIGID WEIGHT
COMPLETE TEST - 193.0 LB TEST WEIGHT

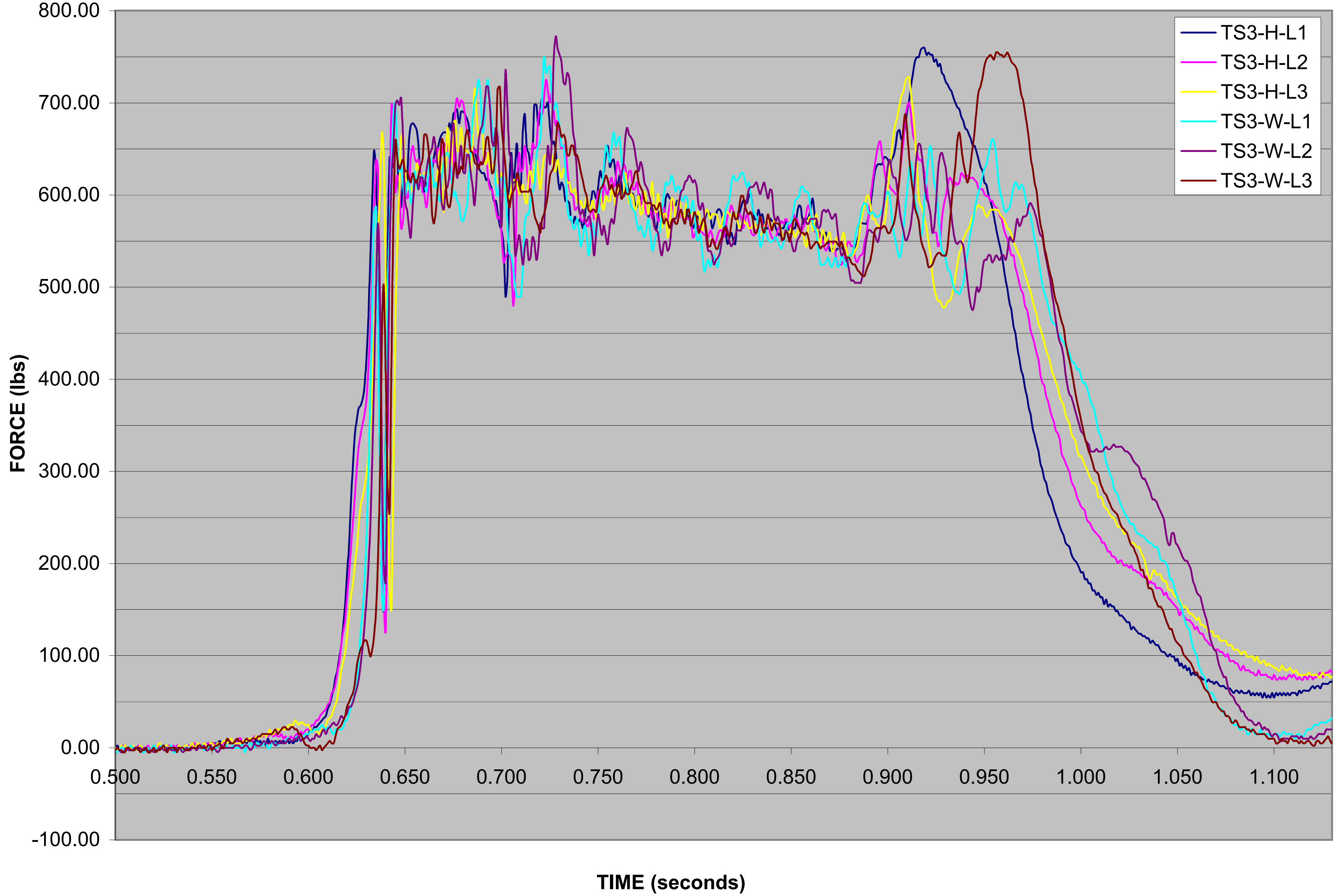


TEST SPECIMEN 2 - HUMAN VS. RIGID WEIGHT
COMPLETE TEST - 193.0 LB TEST WEIGHT
FOCUSED ON ENERGY ABSORBER DEPLOYMENT

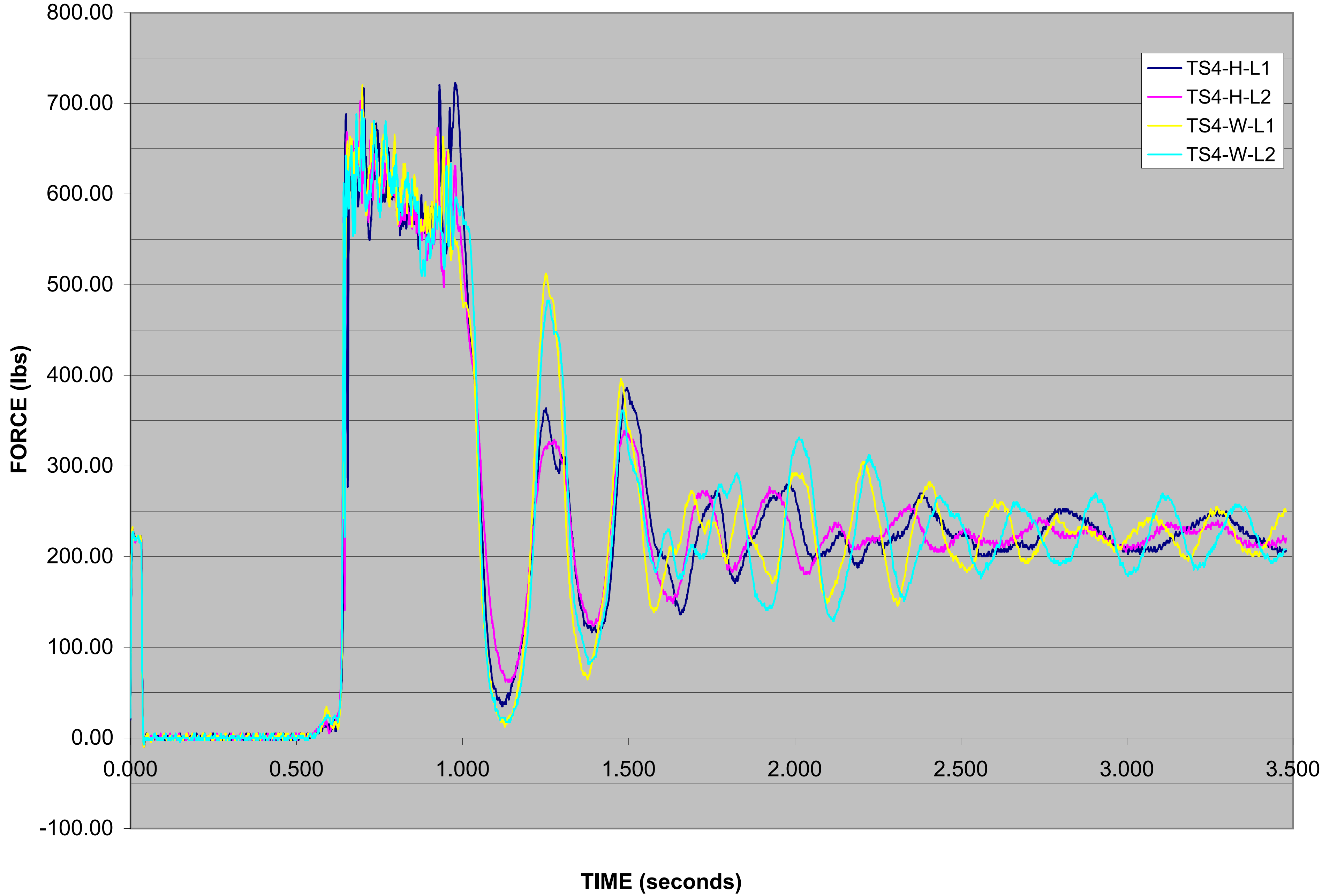


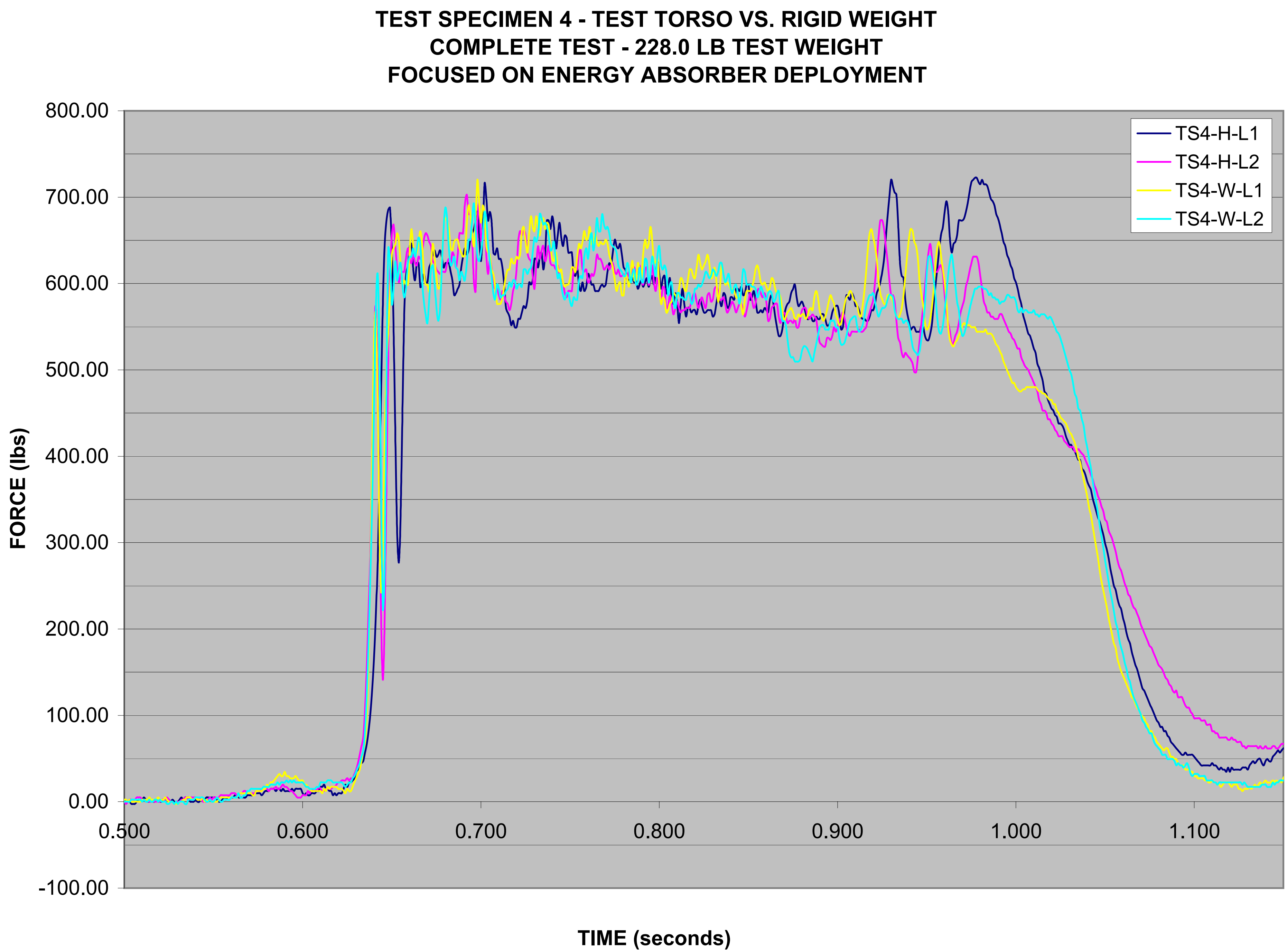

TEST SPECIMEN 3 - HUMAN VS. RIGID WEIGHT
COMPLETE TEST - 219.0 LB TEST WEIGHT
FORCE (lbs)
TIME (seconds)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
-100.00
0.000
0.500
1.000
1.500
2.000
2.500
3.000
TS3-H-L1
TS3-H-L2
TS3-H-L3
TS3-W-L1
TS3-W-L2
TS3-W-L3

TEST SPECIMEN 3 - HUMAN VS. RIGID WEIGHT
COMPLETE TEST - 219.0 LB TEST WEIGHT
FOCUSED ON ENERGY ABSORBER DEPLOYMENT



TEST SPECIMEN 4 - TEST TORSO VS. RIGID WEIGHT
COMPLETE TEST - 228.0 LB TEST WEIGHT




TEST SPECIMEN 4 - TEST TORSO VS. RIGID WEIGHT
COMPLETE TEST - 228.0 LB TEST WEIGHT
FOCUSED ON ENERGY ABSORBER DEPLOYMENT
FORCE (lbs)
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
-100.00
0.500
0.600
0.700
0.800
0.900
1.000
1.100
TIME (seconds)
TS4-H-L1
TS4-H-L2
TS4-W-L1
TS4-W-L2

APPENDIX B

ENERGY ABSORBING LANYARD MEASURED DATA

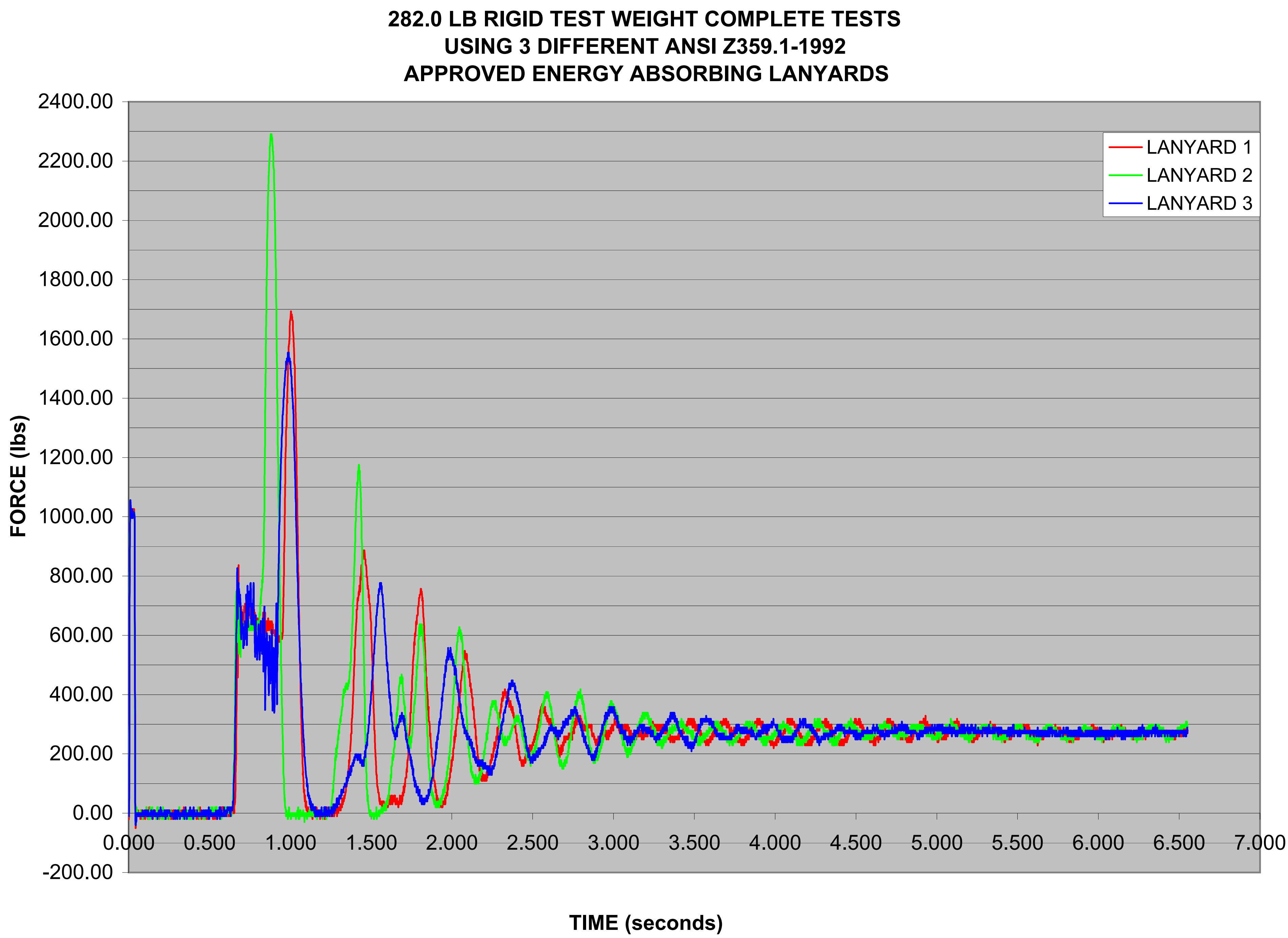
1.4 CONVERSTION TEST - INITIAL EAL LENGTHS & STARTING DROP HEIGHT - APRIL 7, 2006 DATA

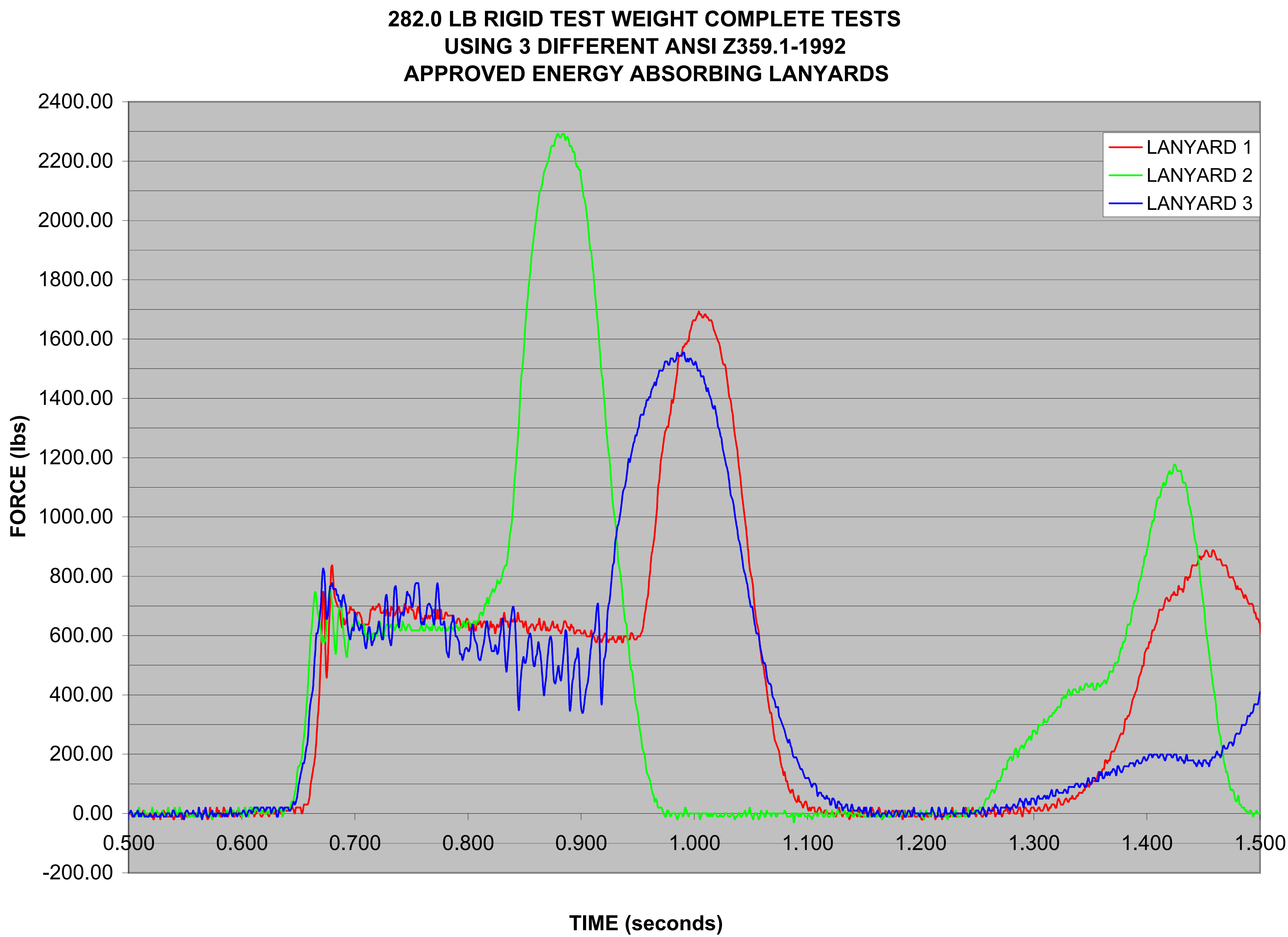
	Item #	Top (feet)	Top (in)	EAL Top Measure (in)	Bottom (feet)	Bottom (in)	EAL Bottom Measure (in)	EAL Initial Length (in)	Starting Drop Height (in)	Starting Drop Height (ft)	Starting Drop Height (in)	TEST STATUS	Top (feet)	Top (in)	Top Final Measure (in)	Bottom (feet)	Bottom (in)	Bottom Final Measure (in)	Final Length (in)	EAL Deployment (in)
TEST SUBJECT #1 - CHRIS - 162.0 LBS	1.4-TS1-H-L1	29.000	4.250	352.250	41.000	10.125	502.125	149.875	430.125	35.84375	10.125	GOOD	29.000	4.250	352.250	43.000	2.500	518.500	166.250	16.375
	1.4-TS1-H-L2	29.000	4.250	352.250	41.000	9.750	501.750	149.500	429.750	35.81250	9.750	GOOD	29.000	4.250	352.250	43.000	7.125	523.125	170.875	21.375
	1.4-TS1-H-L3	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	43.000	6.750	522.750	170.500	20.750
	1.4-TS1-W-L1	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	43.000	8.750	524.750	172.500	22.750
	1.4-TS1-W-L2	29.000	4.250	352.250	41.000	9.750	501.750	149.500	429.750	35.81250	9.750	GOOD	29.000	4.250	352.250	43.000	9.000	525.000	172.750	23.250
	1.4-TS1-W-L3	29.000	4.250	352.250	41.000	9.875	501.875	149.625	429.875	35.82292	9.875	GOOD	29.000	4.250	352.250	43.000	8.500	524.500	172.250	22.625

	Item #	Top (feet)	Top (in)	EAL Top Measure (in)	Bottom (feet)	Bottom (in)	EAL Bottom Measure (in)	EAL Initial Length (in)	Starting Drop Height (in)	Starting Drop Height (ft)	Starting Drop Height (in)	TEST STATUS	Top (feet)	Top (in)	Top Final Measure (in)	Bottom (feet)	Bottom (in)	Bottom Final Measure (in)	Final Length (in)	EAL Deployment (in)
TEST SUBJECT #2 - THOMAS - 193.0 LBS	1.4-TS2-H-L1	29.000	4.250	352.250	41.000	10.500	502.500	150.250	430.500	35.87500	10.500	GOOD	29.000	4.250	352.250	44.000	1.250	529.250	177.000	26.750
	1.4-TS2-H-L2	29.000	4.250	352.250	41.000	10.375	502.375	150.125	430.375	35.86458	10.375	GOOD	29.000	4.250	352.250	43.000	11.750	527.750	175.500	25.375
	1.4-TS2-H-L3	29.000	4.250	352.250	41.000	10.125	502.125	149.875	430.125	35.84375	10.125	GOOD	29.000	4.250	352.250	44.000	0.250	528.250	176.000	26.125
	1.4-TS2-W-L1	29.000	4.250	352.250	41.000	10.250	502.250	150.000	430.250	35.85417	10.250	GOOD	29.000	4.250	352.250	44.000	3.000	531.000	178.750	28.750
	1.4-TS2-W-L2	29.000	4.250	352.250	41.000	10.250	502.250	150.000	430.250	35.85417	10.250	GOOD	29.000	4.250	352.250	44.000	3.125	531.125	178.875	28.875
	1.4-TS2-W-L3	29.000	4.250	352.250	41.000	10.125	502.125	149.875	430.125	35.84375	10.125	GOOD	29.000	4.250	352.250	44.000	3.375	531.375	179.125	29.250

	Item #	Top (feet)	Top (in)	EAL Top Measure (in)	Bottom (feet)	Bottom (in)	EAL Bottom Measure (in)	EAL Initial Length (in)	Starting Drop Height (in)	Starting Drop Height (ft)	Starting Drop Height (in)	TEST STATUS	Top (feet)	Top (in)	Top Final Measure (in)	Bottom (feet)	Bottom (in)	Bottom Final Measure (in)	Final Length (in)	EAL Deployment (in)
TEST SUBJECT #3 - KEITH - 219.0 LBS	1.4-TS3-H-L1	29.000	4.250	352.250	41.000	10.250	502.250	150.000	430.250	35.85417	10.250	GOOD	29.000	4.250	352.250	44.000	5.500	533.500	181.250	31.250
	1.4-TS3-H-L2	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	44.000	6.250	534.250	182.000	32.250
	1.4-TS3-H-L3	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	44.000	6.750	534.750	182.500	32.750
	1.4-TS3-W-L1	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	44.000	9.250	537.250	185.000	35.250
	1.4-TS3-W-L2	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	44.000	9.750	537.750	185.500	35.750
	1.4-TS3-W-L3	29.000	4.250	352.250	41.000	10.125	502.125	149.875	430.125	35.84375	10.125	GOOD	29.000	4.250	352.250	44.000	10.125	538.125	185.875	36.000

	Item #	Top (feet)	Top (in)	EAL Top Measure (in)	Bottom (feet)	Bottom (in)	EAL Bottom Measure (in)	EAL Initial Length (in)	Starting Drop Height (in)	Starting Drop Height (ft)	Starting Drop Height (in)	TEST STATUS	Top (feet)	Top (in)	Top Final Measure (in)	Bottom (feet)	Bottom (in)	Bottom Final Measure (in)	Final Length (in)	EAL Deployment (in)
TEST SUBJECT #4 - TORSO A - 228.0 LBS	1.4-TS4-H-L1	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	44.000	11.125	539.125	186.875	37.125
	1.4-TS4-H-L2	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	45.000	0.125	540.125	187.875	38.125
	1.4-TS4-W-L1	29.000	4.250	352.250	41.000	9.750	501.750	149.500	429.750	35.81250	9.750	GOOD	29.000	4.250	352.250	44.000	11.000	539.000	186.750	37.250
	1.4-TS4-W-L2	29.000	4.250	352.250	41.000	10.000	502.000	149.750	430.000	35.83333	10.000	GOOD	29.000	4.250	352.250	45.000	0.250	540.250	188.000	38.250


282.0 LB RIGID TEST WEIGHT COMPLETE TESTS
USING 3 DIFFERENT ANSI Z359.1-1992
APPROVED ENERGY ABSORBING LANYARDS
FORCE (lbs)
2400.00
2200.00
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
-200.00
0.000
0.500
1.000
1.500
2.000
2.500
3.000
3.500
4.000
4.500
5.000
5.500
6.000
6.500
7.000
TIME (seconds)
LANYARD 1
LANYARD 2
LANYARD 3


282.0 LB RIGID TEST WEIGHT COMPLETE TESTS
USING 3 DIFFERENT ANSI Z359.1-1992
APPROVED ENERGY ABSORBING LANYARDS
FORCE (lbs)
2400.00
2200.00
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
-200.00
0.500
0.600
0.700
0.800
0.900
1.000
1.100
1.200
1.300
1.400
1.500
TIME (seconds)
LANYARD 1
LANYARD 2
LANYARD 3