Chapter 2

Overview and Analysis of the Previous Research

2.1 Scope of the Previous Research

The scope of the previous research was to develop a method for collecting experimental data for the snap loading of synthetic fiber ropes and to study their behavior through a series of cyclic loadings. A number of ropes with different material properties, lengths, and diameters were tested to identify which ropes had the best performance under the set parameters of the research. In all, 19 different types of ropes were tested under a combination of static and dynamic loadings.

2.2 Original Drop Tower

To conduct the desired tests, an 11-foot-tall drop tower was constructed at the Virginia Tech Structures and Materials Research Laboratory. The details of this drop tower are shown in Figure 2.2.1.

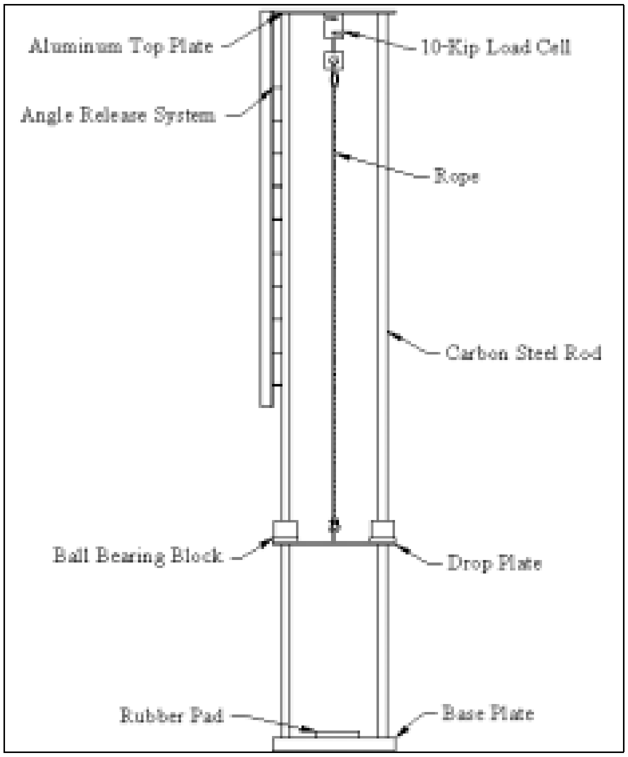

Figure 2.2.1: Diagram of the Original Drop Tower

The tower is made of four vertical carbon steel rods that connect the steel base plate and the aluminum top plate. An aluminum stabilizing plate (or drop plate) that is equipped with four ball-bearing blocks slides up and down along these rods. Other components of the drop plate include four threaded rods that allow for additional weight to be added to the plate, three eye bolts, and a screw pin anchor shackle that connects one of the eye bolts to the bottom of the rope. The other two eye bolts connect the drop plate to a pulley system which is used to raise the plate to its desired drop height. Figure 2.2.2 is a photograph of the drop plate.

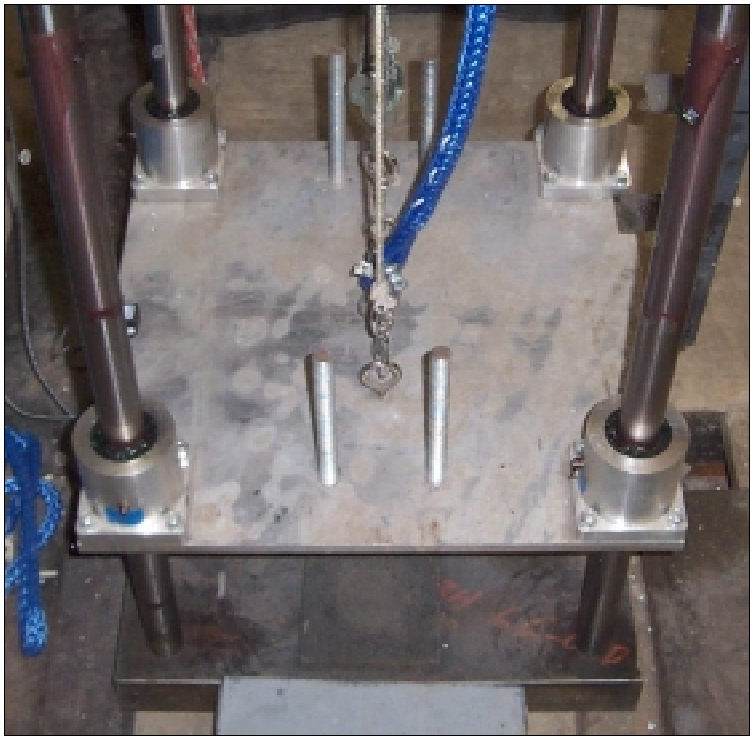

Figure 2.2.2: Photograph of the Drop Plate

The rope that is being tested is attached to the top plate by means of a load cell assembly. A 10-kip capacity load cell is bolted to the top plate at one of its ends and connected to a threaded rod at the other. The threaded rod is welded to an eye piece that attaches to another screw pin anchor shackle, which then attaches to the rope.   Figure 2.2.3 is a photograph of this assembly.

Figure 2.2.3: Photograph of the Load Cell Assembly

An angle release system (referred to as the drop angle) is attached via a hinge to one side of the top plate and hangs down beside the tower. The angle is equipped with smaller pieces of angle material (referred to as angle seats) that were welded onto it at 6-inch increments. To perform a dynamic test, the drop plate must first be raised and placed on the desired angle seat. The pulley system is then detached from the plate and the drop angle is pulled away from the tower, allowing the plate to fall.

2.3 Data Acquisition

The instrument that was used to obtain the data from the static and dynamic tests was the System 6000, manufactured by Vishay Measurements Group. The System 6000 recorded all of the data that was obtained from the tests and converted the analog output into digital data that was imported to a personal computer. Using a program called Strain Smart, the data was cropped, stored, and reduced so that it could be converted into a spreadsheet format. The data was then exported to Microsoft Excel, which was used to perform all of the subsequent analyses.

All of the force data from the tests was obtained from an S-shaped 10-kip load cell manufactured by Sentran, Inc. For the static tests, the displacement data was recorded using a direct current wire pot manufactured by Celesco. For the dynamic tests, the acceleration data was recorded with a $\pm$ 100 g accelerometer that was manufactured by Analog Devices. All of these devices were wired to the System 6000, which took readings throughout the tests.

2.4 Static and Dynamic Tests

In most cases, two ropes of each type were tested in the previous research. The static tests were conducted on one of the two ropes and the dynamic tests were conducted on both of them.

The static tests were performed to examine how the ropes behaved under a controlled cyclic loading sequence and how precycling would affect the subsequent dynamic tests. The static loading sequence is also known as the precycling process since the ropes were pre-loaded and therefore elongated before they were tested dynamically. For classification purposes, a rope that was tested statically before it was tested dynamically is called a Precycled Rope and a rope that was not tested statically is called a New Rope.

Each precycled rope was tested in a continuous sequence that consisted of three to eight cycles. This was done by allowing the drop plate and the rope to hang from the load cell assembly and adding 10-pound plates to increase the weight on the plate. In most of these cycles, the ropes were step loaded up to 200 pounds and then unloaded in the same fashion. At each step, the amount the rope stretched from its original length was also recorded.

The dynamic tests (or drop tests) were conducted to observe how the ropes behaved under snap loadings. The dynamic tests mimic the conditions that a SCED will be subjected to if it is placed in a building that experiences an earthquake. These tests were conducted on both the precycled and new ropes in order to determine if the two behave differently during the snap load. The dynamic tests were conducted in sequences that varied the height from which the plate was dropped and the weight added to the plate. The drop heights ranged from 98 inches to 56 inches, and the plate weights ranged from 25 pounds (the approximate weight of the drop plate with no additional weights) to 125 pounds. The following is a list of the different test sequences that were used:

1) Constant Height and Weight
2) Constant Height with Increasing Weight
3) Constant Height with Decreasing Weight
4) Increasing Height with Constant Weight
5) Decreasing Height with Constant Weight

Each type of rope was subjected to a different set of loading sequences. For the most part, the precycled and new ropes of each type were tested using the same sequences, but for some of the ropes this was also varied.

2.5 Ropes that were Tested

The ropes that were tested in both the previous and current research were obtained from Samson Rope Technologies in Ferndale, Washington. This company was chosen because they had the ability to manufacture the ropes and construct the end terminations (or eye splices) that were necessary for these tests. The ropes that were tested were composed of different combinations of nylon, polyester, polypropylene, polyethylene, Vectran, and Kevlar fibers. These fibers have different material properties and, therefore, each rope type has a unique modulus of elasticity, strength, and displacement characteristic. The reason why so many different types of ropes were tested for this research is that no earlier work was done that dealt with synthetic fiber ropes in this manner. As a result, a wide variety of data was desired.

Table 2.4.1 is a list of all the ropes that were tested. This table includes the diameter of the ropes, the lengths, and the types of tests conducted on them.

Rope Type	Diameter (in.)	Length (ft)	Tests Conducted
Amstee Blue	3/8	9	Precycled & New
Amstee Blue	1/2	9	Precycled & New
Amsteel II	3/8	9	Precycled & New
Amsteel II	1/2	9	Precycled & New
Amsteel SLV	3/8	7	Precycled
Amsteel SLV	3/8	9	Precycled & New
Amsteel SLV	1/2	9	Precycled & New
DB Nylon	3/8	7	Precycled
Dura Plex	3/8	9	Precycled & New
QS Polytron	3/8	9	Precycled & New
QS Polytron	1/2	9	Precycled & New
RP Polyester	3/4	9	Precycled & New
RP Ultra Blue	3/4	9	Precycled & New
SSR 1200	3/4	9	Precycled & New
Tech 12	3/8	9	Precycled & New
Tech 12	1/2	9	Precycled & New
Tenex	3/8	9	Precycled & New
Tenex	1/2	9	Precycled & New
XLS Yacht Braid	3/8	7	Precycled

Table 2.5.1: Rope Types Tested in the Previous Research

2.6 Results and Conclusions from the Previous Research

The results and conclusions from the previous research are as follows. In the static tests, the largest amount of un-recovered lengthening occurred in the first loading cycle. This is referred to as the initial construction elongation. As more cycles were conducted, the amount of additional elongation decreased until there was almost no lengthening in the later cycles. This seems to indicate that once the fibers in the rope are pulled tightly enough together, they will stay in that configuration and not elongate any further. However, only three cycles were conducted on most of the precycled ropes, so this behavior could not be confirmed for all of the ropes.

Several trends were noted in the static tests. First of all, the ropes with a high modulus of elasticity displace and elongate less than the ropes with a low modulus of elasticity. Second, the ropes that are constructed with a tighter braid displace less than those with a looser braid. Finally, the ropes with a smaller diameter displace less than the same ropes with a larger diameter. The last trend occurs because there is more empty space between the individual components of larger ropes than the smaller ropes. This was more characteristic of the ropes with a loose braid. However, since the ropes that will be used as SCEDs may be several inches in diameter, even if tightly braided ropes are utilized, this is an occurrence that could potentially affect their performance. Based on these observations, in order for a rope to be effective as an SCED it must be a high modulus rope with a tight braid construction and suffer as little permanent elongation as possible.

There were also some noticeable trends in the dynamic test data. It is clear that energy was dissipated during the dynamic tests because the velocities immediately after the force in the rope returned to zero were less than the velocities that preceded the snap load. Based on the velocity comparisons and force vs. displacement plots, the higher modulus ropes didn’t appear to dissipate as much energy as the lower modulus ropes. This is because the lower modulus ropes displace more during the snap load, allowing for more inter-component friction to occur in the ropes. The displacement trends that were noted for the static tests were also present in the dynamic tests. As more drop tests were conducted, the ropes appeared to become stiffer and the amount of additional rope elongation decreased. However, because there were so many different types of loading sequences in many different orders, a realistic idea of how the ropes behaved during a sequence of snap loads could not be established.

2.7 Continuation of the Dynamic Test Sequences

When Nicholas Pearson's research was presented, a concern was expressed that when a SCED is used in an actual building, the velocity that the rope experiences due to the swaying frame would not be as large as the velocity that it experiences due to the drop tower. This is because the rope would be in a slightly slack state in the building and the frame would only have to move a few inches in order to produce the snap load. In the dynamic tests, however, the drop plate is released from a much greater height and this results in much higher velocities.

To address this issue, another round of drop tests was conducted to initiate the present investigation. Nicholas Pearson assisted in these tests. The ropes that were selected for what is referred to as the Follow-Up Tests were the precycled and new 1/2-inch diameter Amsteel Blue ropes and the precycled and new 3/8-inch diameter Amsteel II ropes. These ropes were selected because they had been tested with a sequence of decreasing drop heights and a constant weight of 65 pounds. To conduct these tests, the drop angle had to be lengthened because the lowest angle seat produced a drop height of 56 inches. The modification of the angle release system will be further discussed in Chapter 3. Ten drop tests were conducted on each rope, using a sequence of decreasing heights in 6-inch increments (from 56 inches to 2 inches) and a constant weight of 65 pounds.

2.8 Analysis of Dynamic and Static Tests

As mentioned earlier, the data that was recorded for the static tests was the load and displacement at each load step, and data that was recorded for the dynamic tests was the load and acceleration at each time step. For the dynamic tests, the velocity and the displacement of the plate during the snap load were also determined analytically. Several different types of plots were constructed using a combination of the above data in order to determine how the ropes behaved under these conditions. While these steps did produce meaningful results and some interesting trends were taken from them, the work was not thorough enough to make any definite conclusions. As a result, the first step of the current research was to expand upon the analyses that were already conducted.

For the static tests, the maximum displacements, rope stiffness, and areas beneath the load vs. displacement plots (hysteresis loops) were calculated and compared. The processes that were used to find this data and the data from the dynamic tests are explained in detail in Chapter 5.

For the dynamic tests, several different comparisons and analyses were performed. The maximum recorded force and the time length of the snap load were documented for all of the tests. In addition, the area beneath the load vs. time curve was calculated. This value is known as the Impulse and was intended to be used as a way to predict the amount of energy that was dissipated by the snap load. The maximum forces and impulses for each sequence that was conducted on a particular rope were plotted to determine if any consistencies existed. However, because of the variance in the sequences that were conducted on each rope, it was difficult to establish any trends. Therefore, two additional comparisons were conducted. All of the sequences in which multiple dynamic tests were run from a constant drop height and with a constant weight were compared, as well as those sequences that had a constant drop height with a varying weight.

More analyses were originally to be conducted on this data, but during the Follow-Up tests, a major flaw was found in the way the original tests were conducted. This mistake was that the recorded data from the dynamic tests was cropped just before the snap load occurred. Therefore, no acceleration data was available for the time when the plate was falling and therefore, the velocity of the plate just before the snap load had to be estimated. As a result, all of the subsequent velocities and displacements that were calculated have a residual error in them. Even though there is some inaccuracy in the values of some of these quantities, the trends that were established in these tests are still assumed to be correct. This problem was corrected for the Follow-Up tests, but because of the uncertainty that arose due to the oversight, an additional round of static and dynamic tests was conducted as part of the current research. These tests are explained in detail in Chapter 3.

The data that was obtained from the Follow-Up tests was analyzed in the same way as the data from the previous research and was grouped with it due to the similarities between them. However, since the error in the data collection method had been corrected, it was possible to calculate the loss of kinetic energy during the snap load for these tests. These values will be compared to those of the new tests.

2.9 Results of Analyses

All of the data tables and figures that were generated during the analysis of these tests can be found in Appendix A. Not all of the precycled ropes were tested up to the same load or with the same number of cycles, so comparing the values for displacement, stiffness, and area under the hysteresis loops is not entirely accurate. However, a rope that has a low modulus of elasticity and a loose braid construction (such as the Amsteel Blue, Amsteel SLV, QS Polytron, RP Polyester, RP Ultra Blue, SSR 1200, and Tenex ropes) will displace more during the static cycles, have lower stiffness values, and have more area underneath the hysteresis loops than a rope with a high modulus of elasticity and a tight braid construction (such as the Amsteel II or Tech 12 ropes).

As for the dynamic tests, the maximum forces and impulses are larger for the higher drop heights and for the heavier plate weights. This is logical since an increase in either of these variables will cause a larger force to be present during the snap load. Therefore, decreasing the drop height or weight will decrease the maximum force and impulse values. Figure 2.9.1 is a plot of several test sequences in which the drop heights remain constant, but the weights are changed. As can be seen, the trends for the maximum forces and impulses are almost linear when the weight is changed in set intervals.

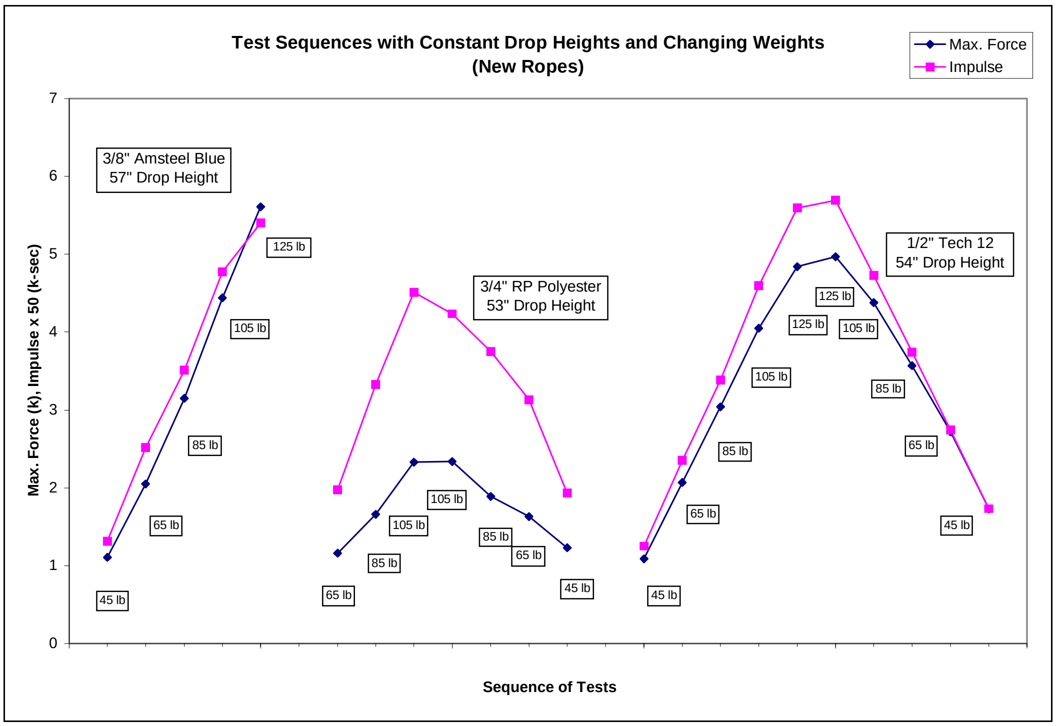

Figure 2.9.1: Maximum Force and Impulse Trends – Constant Height and Changing Weight Sequences

Figure 2.9.2 is a plot of several test sequences in which the drop height and the weight of the plate remained constant. The expected outcome from such tests would be rather steady trends for both the maximum force and the impulse. However, some of the sequences did not follow this trend at all. As a result of these findings, it was determined that the force values must undergo some type of change while the rope is elongating under the repeated snap loads. By that logic, all of other quantities probably go through some sort of change as well. It was difficult to determine how the trends change as the rope lengthened, but it appears that as a sequence progresses and the ropes stiffen, the forces and impulse tend to increase. This can also be seen in Figure 2.9.3.

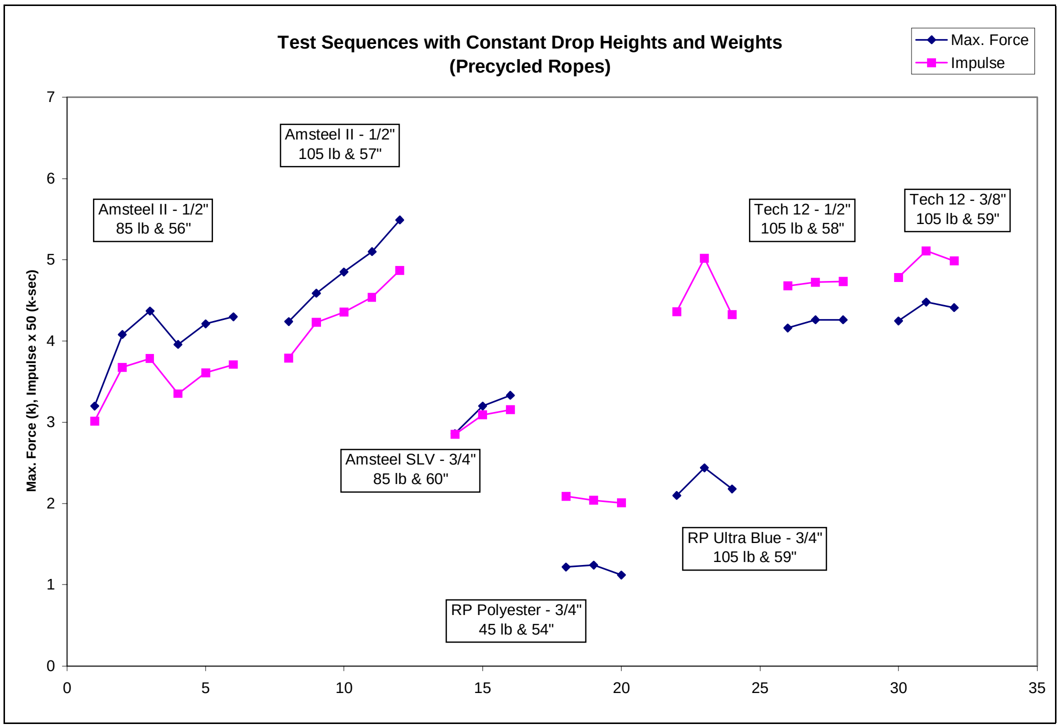

Figure 2.9.2: Maximum Force and Impulse Trends – Constant Height and Weight Sequences

The results of the Follow-Up tests follow the same trends as the results of the previous research. The tests were conducted with a constant weight and a decreasing drop height and, for the most part, the maximum force and impulse values decreased as the sequences progressed. In addition, the calculated energy loss values followed the same trend. However, the first few drop tests (which represent the highest drop heights) saw an increase in maximum force and impulse. This supports the theory that the maximum force and impulse values will increase until the rope has reached a certain stiffness. Figure 2.9.3 demonstrates this. Sequence 1 was the constant weight, decreasing height sequence conducted during the previous research and Sequence 3 was done in the Follow-Up tests. Both sequences show an increase in the maximum force and impulse values before they level off and start to decrease.

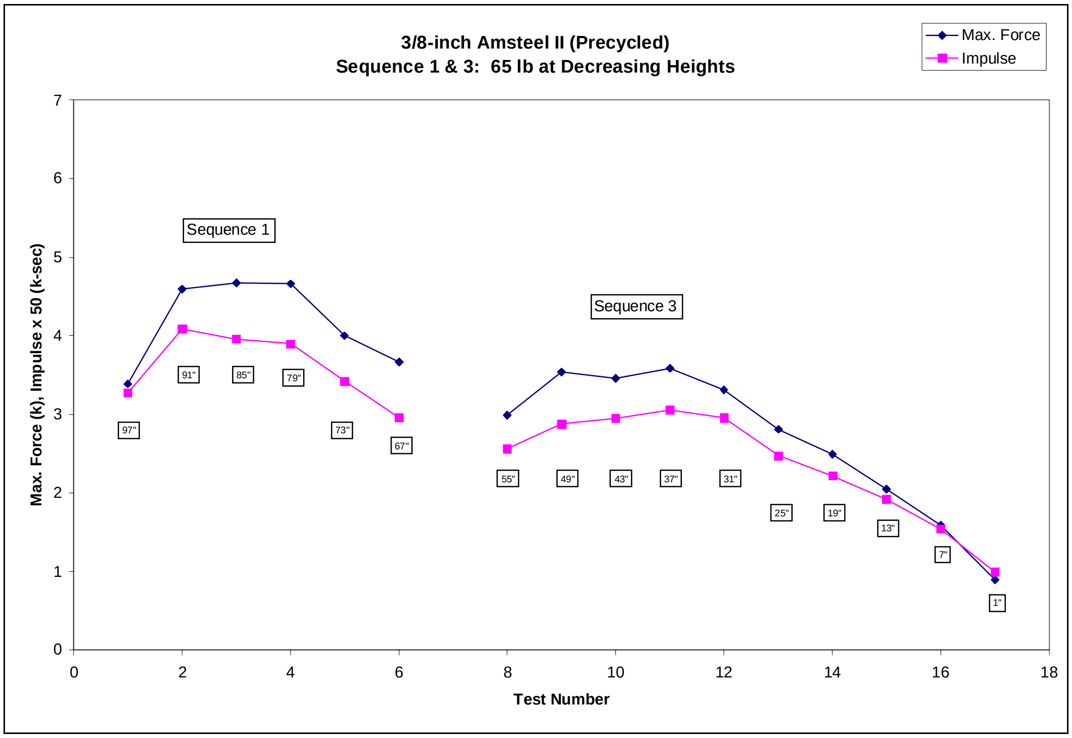

Figure 2.9.3: Constant Height and Weight Dynamic Loading Sequences

Figure 2.9.4 shows the energy loss trends for the Follow-Up tests. As can be seen, the energy loss increases as the drop height increases and there doesn't seem to be much difference between the high modulus Amsteel II rope and the low modulus Amsteel Blue rope. In addition, there is not much difference between the precycled and new ropes. The energy loss properties and the effect of rope elongation will be covered in detail in Chapter 5.

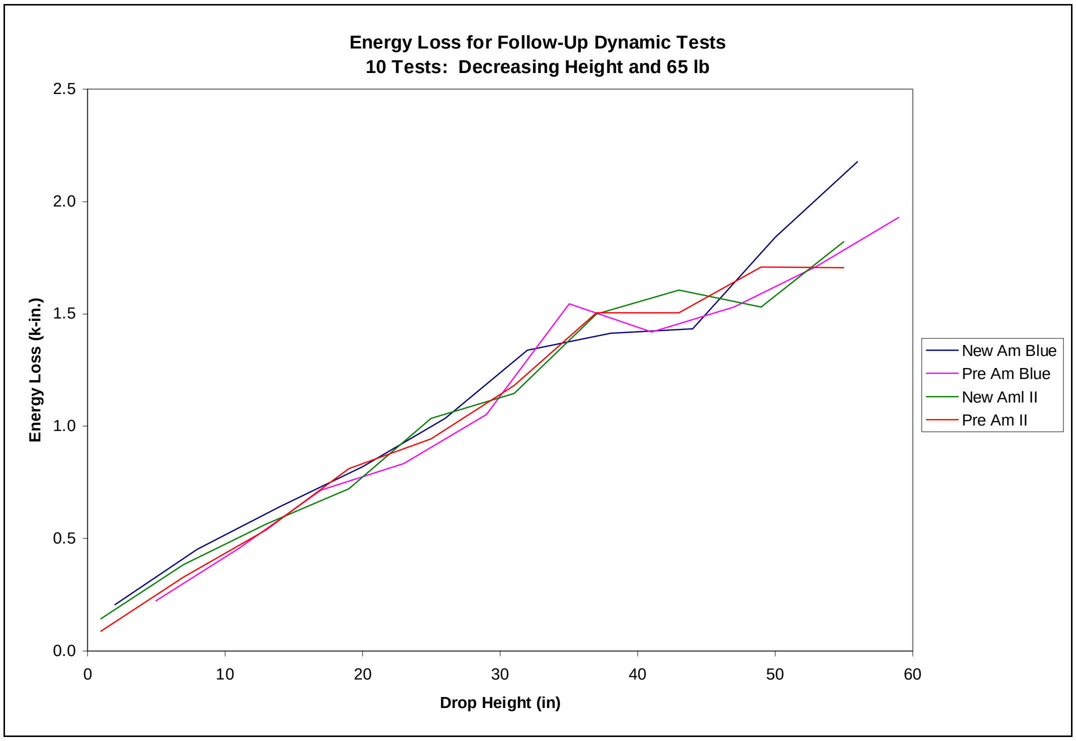

Figure 2.9.4: Energy Loss vs. Drop Height – Follow-Up Dynamic Tests