Chapter 4

Static and Dynamic Test Results

4.1 Static Tests

Static tests were performed on fifteen of the nine-foot ropes and on the three seven-foot ropes. As mentioned previously, different numbers of loading cycles were applied to different ropes. For ropes that were not loaded consecutively (i.e., loaded once or twice and then replaced with another rope before testing again), the displacements seemed to be larger for a majority of the ropes. Also, most of the 1/2-inch and 3/4-inch ropes, but not all, seemed to have larger displacements than the 3/8-inch ropes under identical load. Most of the higher modulus ropes had smaller displacements than the lower modulus ropes, which was expected. Figure 4.1 shows a QS Polytron rope cycled eight consecutive times. As the number of cycles increases, the amount of displacement draws closer to the previous cycle.

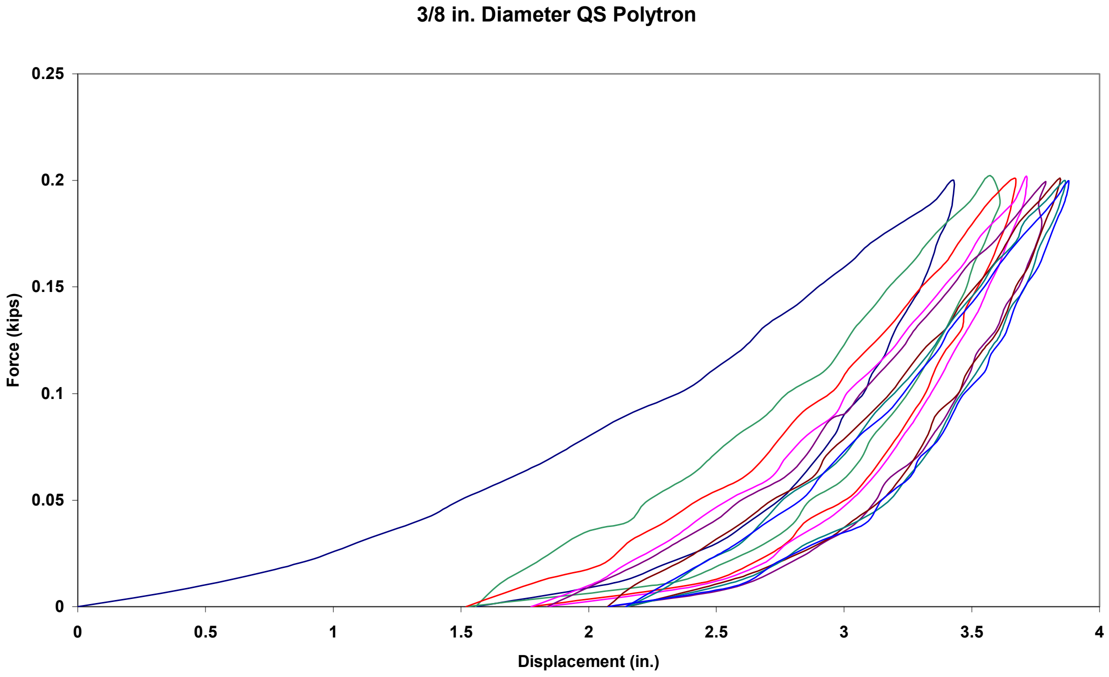

Figure 4.1 Static Test Plot – 3/8 in. Diameter QS Polytron Synthetic Fiber Rope

Figure 4.2 shows a 1/2-inch diameter QS Polytron rope cycled three consecutive times.

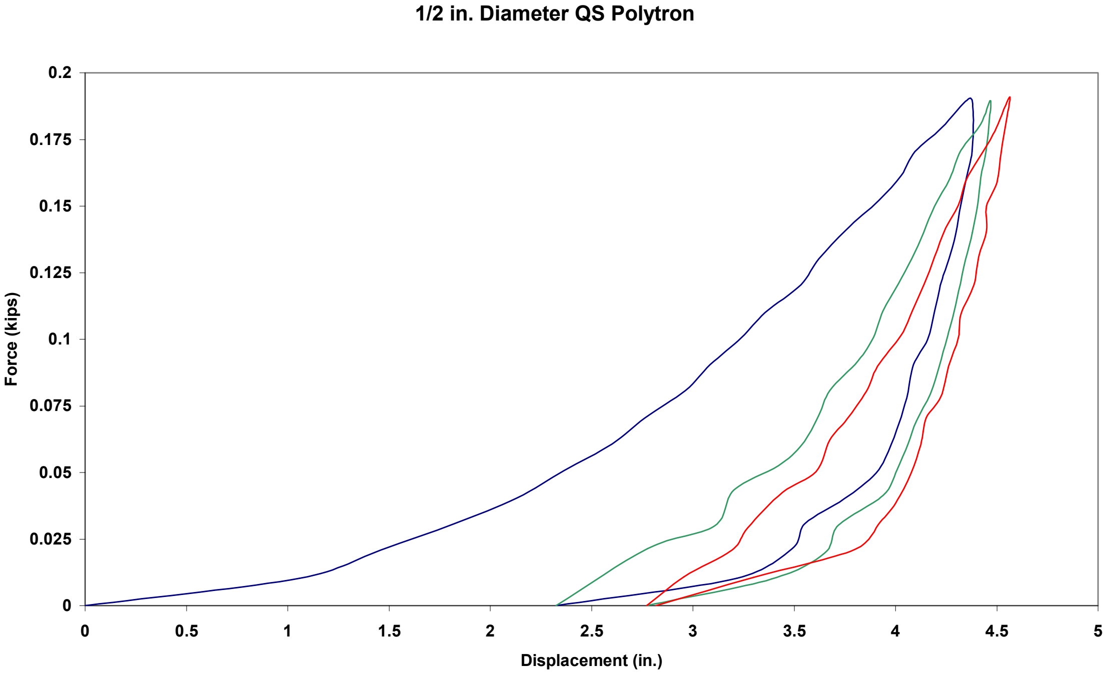

Figure 4.2 Static Test Plot – 1/2 in. Diameter QS Polytron Synthetic Fiber Rope

On all of the static test plots, the first cycle exhibits much more displacement than the following cycles. This "phenomenon" is often referred to as the initial construction elongation. As mentioned in previous chapters, upon initial load, the rope begins to constrict and pull the strands closer together. Once the strands have been pulled tightly together, they fill in a majority of the open space between strands and tend to stay in place or never fully recover. All eighteen static test plots can be found in Appendix A.

4.2 Dynamic Tests

A majority of this research was dedicated to the dynamic testing of synthetic fiber ropes. In excess of 325 dynamic tests were conducted during this research. A fraction of these tests had to be discarded for various reasons. In all, data was analyzed for 272 dynamic tests on 33 ropes.

A number of factors contribute to the elongation of a rope. One factor that has been mentioned numerous times is the modulus of elasticity. A higher modulus of elasticity usually results in a lower elongation under load. Another factor that can be seen in the static tests is the diameter size. Judging from test data, larger diameter ropes tend to exhibit larger displacements than smaller diameter ropes of the same material makeup. A tighter braided rope tends to elongate less than a looser braided rope of the same material and diameter size. If a rope is braided in a loose manner, the rope will contract into a tighter braid before the individual fibers begin to elongate. Many of the larger diameter ropes are braided loosely and tend to have more open space between strands, thus causing them to have larger end displacements under load.

All ropes were measured prior to testing (see Table 2.1 and Table 2.2). Although all the ropes are considered to be 9 ft in length, actual rope lengths ranged from 8’ 11” to 9’ 2.5”. This deviation from 9 ft in length actually made a difference in the dynamic tests. The drop tower was designed to accommodate the testing of ropes up to 9 ft in length. Some of the lower modulus ropes proved to have end displacements (elongations) up to 8 or 9 in. Adding this displacement to a rope that is already 2 in. longer than 9 ft resulted in the drop plate exceeding the clear height of the drop tower, which nullifies the test. When the drop plate exceeds the clear height and strikes the protective rubber pads on the base plate, the rope has essentially “bottomed out”. Many of the discarded dynamic tests were a result of the rope bottoming out. In an effort to continue testing ropes that were bottoming out, a smaller amount of weight was placed on the drop plate. This method proved to be acceptable for some of the ropes, but many of the ropes continued to bottom out and could not be further tested.

A problem associated with lowering the amount of weight applied to the drop plate is that the amount of friction in the bearings is too great to overcome, and the test data can be inaccurate. The ball bearing blocks that allow the drop plate to slide up and down the steel rods on the drop tower are 1 1/2 in. in diameter. This size block is typically used for applications that utilize weights much greater than 125 lb. Under a large amount of weight, the friction in the ball bearings is considered to be negligible because the weight’s momentum can overcome the friction without compromising the application to which the blocks are being used. The maximum weight used on any of the dynamic tests performed was 145 lb. Many of the tests did not exceed 85 lb in weight and had as little as 25 lb in weight. For this reason, the friction within the ball bearings had a significant influence on many of the dynamic tests.

All acceleration data was brought into a spreadsheet in g's. To obtain the velocity and displacement of the drop plate, the data had to be integrated. The velocity of an object is equal to the area under the acceleration vs. time plot, while the displacement of that same object is equal to the area under the velocity vs. time plot. The trapezoidal or midpoint rule was used to integrate accelerations and velocities. This rule is as follows:

$$\int_a^b f(x)dx = \left(\frac{b-a}{2n}\right)\left[f(x_o) + 2f(x_1) + 2f(x_2) + \ldots + 2f(x_{n-1}) + f(x_n)\right]$$

where: $[a,b]$ = time interval

n = number of equal subintervals (number of trapezoids)

After integrating the acceleration and velocity data for each test, plots were made in A spreadsheet in order to better understand and "see" the data. Several plots were made for each test. Among these plots are acceleration and force vs. time, force vs. velocity, force vs. the absolute value of displacement, and a combination of acceleration, force, velocity, and displacement vs. time. The latter three plots focus on only the time that the rope is initially taut, while the first plot (acceleration and force vs. time) displays the initial taut phase, the second taut phase, and the slack phase between the two taut phases. New ropes refer to ropes that have not been subjected to static testing prior to dynamic testing, while the precycled ropes have been statically loaded and dynamically loaded. The following four figures show an example of each of the four plots:

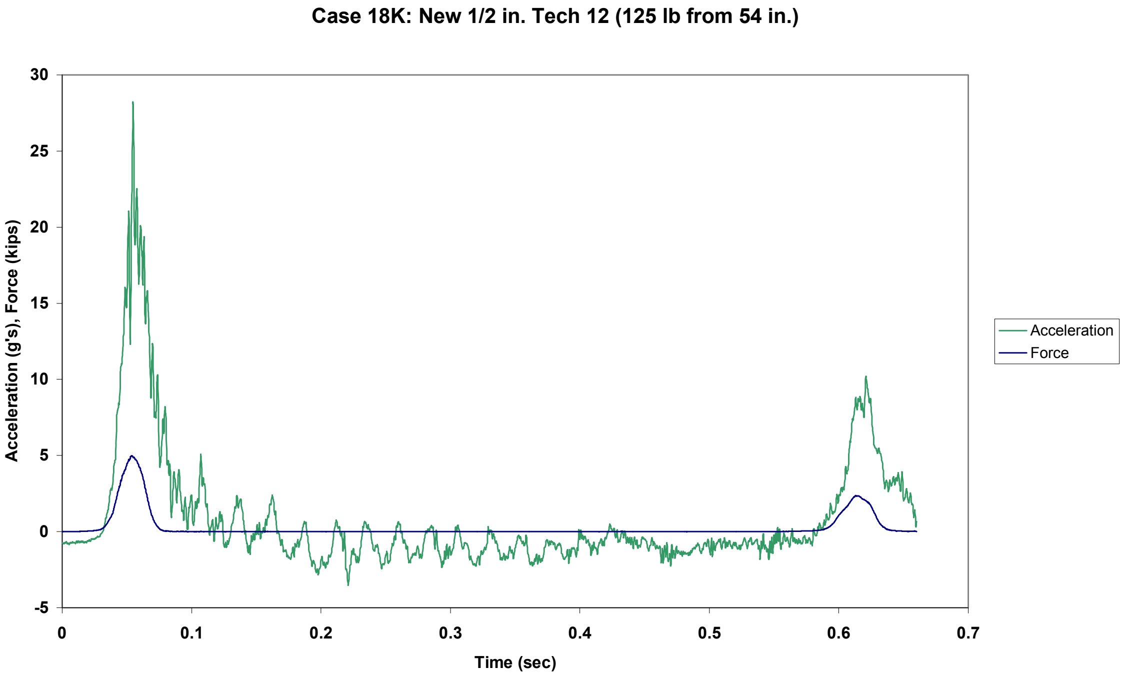

Figure 4.3 Case 18K: Force and Acceleration vs. Time

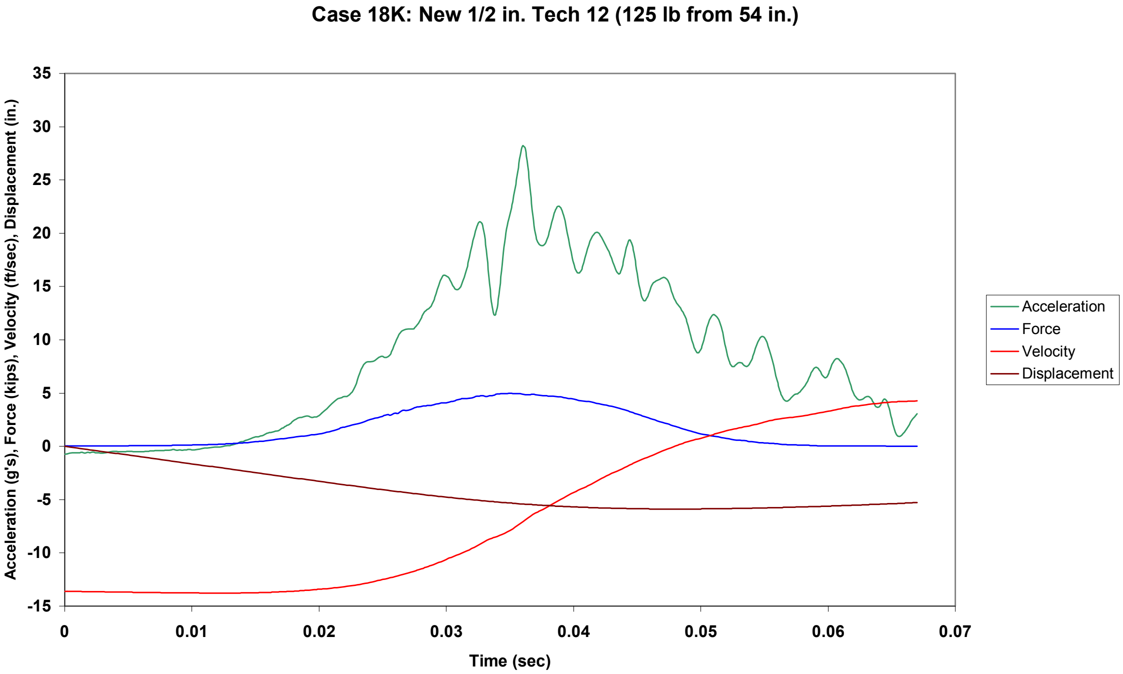

Figure 4.4 Case 18K: Combined Plot

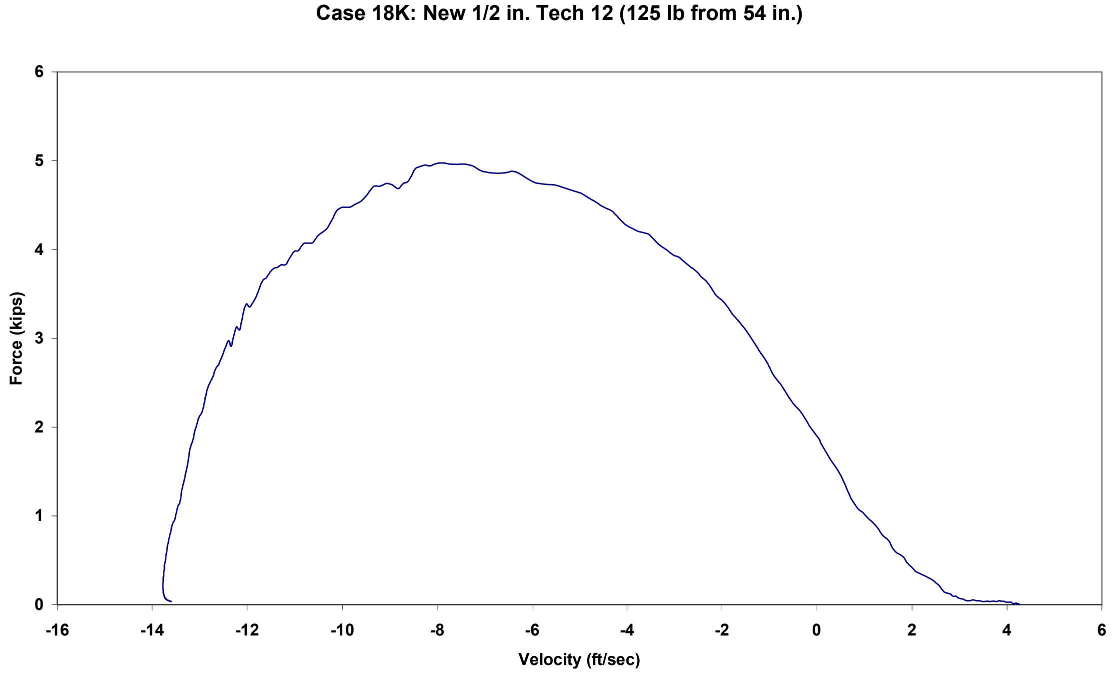

Figure 4.5 Case 18K: Force vs. Velocity

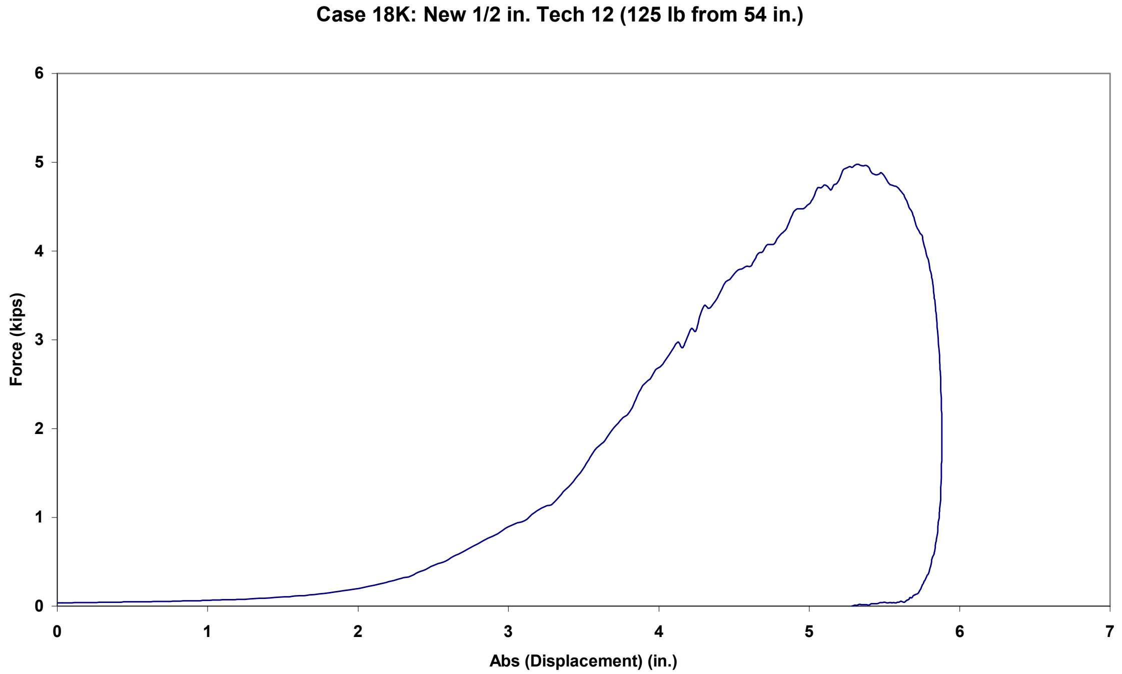

Figure 4.6 Case 18K: Force vs. Absolute Displacement

One problem that occurred during all of the drop tests was the accelerometer registering the added “noise” caused by the drop tower vibrating after the snap load. This occurrence was unforeseen prior to testing and thus unavoidable during testing. With the extreme slenderness of the drop tower (11 ft high and only 22 in. x 22 in. square), the impact of the snap load caused the four steel rods to vibrate. The accelerometer was extremely sensitive to even the smallest of vibrations, so the tower acceleration caused by the vibrations was added or subtracted from the drop plate acceleration. This caused multiple peaks and valleys in the acceleration data, especially after the initial snap load. The multiple peaks and valleys can be seen in Figure 4.3. Originally, the acceleration data was filtered to create a smooth acceleration plot. This approach was discarded for a couple of reasons. The filtered acceleration values often lowered the maximum acceleration value by five to ten g’s, which affected the test results and was considered to be unacceptable. Also, the number of filtered acceleration values was a fraction of the original number of values. The filtering process utilized a spreadsheet macro that would essentially perform a running average of the original acceleration data and reduce the amount of test data by a certain percentage. A higher reduction in test data would usually result in a smoother curve, but there were significantly less numbers in the data group, which made the results lose validity. The problem with having less numbers in a data group is that it can greatly affect the integration of that group. This was also considered to be unacceptable. It was decided to leave the raw data in its original form and perform the integrations without filtering the data.

During the drop tests, the data that is collected in the System 6000 has to be reduced and sent to a spreadsheet file. These files can be extremely large in disk space, so an effort was made to eliminate as much unneeded data as possible. For the drop tests, the only data that is crucial to this research is the initial taut phase. The second taut phase, as well as the slack phase between the two taut phases, could be crucial in future research and was taken into consideration. For these reasons, the raw data was cropped prior to converting the data to a spreadsheet file. The cropping took place immediately before the rope began to get taut initially and immediately after the rope began to get slack a second time. Cropping the data significantly reduced the size of the spreadsheet files and made them more manageable for integrating.

Another problem that was discovered once the drop tests had begun and the cropping had taken place was that the amount of friction in the bearing blocks had a significant effect on the tests. Once it was decided to crop the data, the idea was to assume that the initial velocity of the plate at the point when the rope starts to become taut is calculated as follows:

$$V = \sqrt{2gh}$$

where: V = velocity

g = gravitational constant (32.2 ft/sec^2)

h = drop height

The velocity equation does not consider the effects of air resistance on the drop plate or the friction associated with the bearing blocks. These two effects were not considered to be significant when the drop tests started. Once the data had been integrated and analyzed, it was found that the amount of friction in the bearing blocks significantly reduced the velocity of the drop plate and caused the initial velocity to be much greater than it actually was. In order to get true results, a percentage of initial velocity had to be determined. It was decided to use the velocity equation for initial velocity values, but the values were to be multiplied by a percentage to account for the friction in the bearing blocks. In order to do this, a series of tests were performed at various heights and weights in which the true initial velocity could be measured.

Various methods were attempted to measure the velocity of the drop plate prior to testing. One of these methods was using a laser provided by Dr. G. Park at the Center for Intelligent Material Systems and Structures at Virginia Tech. This laser measures the velocity of objects as they are approaching or retreating. The main problem that was found with using this laser was that it had a maximum velocity reading of 1 m/sec. Many of the drop tests that were performed reached velocities well above this limit, so the laser was not a valid instrument for measuring the initial velocity of the drop plate. Another method that was considered was the use of a police radar gun. Lieutenant W. R. Flinchum of the Virginia Tech Police Department allowed for a radar gun to be borrowed from the department in order to measure velocities. The radar gun proved to be an invalid instrument for measuring initial velocity because the reaction time for the radar gun was not fast enough to capture velocity of the drop plate. Another problem associated with the radar gun was the inability of the gun to measure velocity increments smaller than 1 mph.

Once these two methods failed, it was decided to run a series of drop tests with the accelerometer starting from zero velocity and zero acceleration. All data was kept for these tests and integrated using an initial velocity of zero. Approximately 25 tests were conducted using various weights and heights in which the velocity was measured. Based on averages for different weights and heights, a percentage of velocity was determined and applied to each of the 272 drop tests. This seemed to be the best approach to determining initial velocity for each test for which the data had been cropped.

In order for the idea of using snapping-cable energy dissipators as a passive control technique to work, a rope must be found that dissipates enough energy to dampen a structure, yet does not allow excessive drift of the structure. Excessive elongation proved to be a problem with almost all of the tested ropes. Among the highest elongated ropes under dynamic loading were the SSR 1200, Quick-Splice Polytron, and the Tenex ropes. These ropes elongated exceptionally and may not be a plausible means to safely dissipate energy from a structure. Polyester and olefin are the primary fibers that compose these ropes, which would account for much of the excessive elongation. The velocity of the drop plate for a majority of the tests was substantially higher than what would be expected under seismic loads. Lower test velocities could prove that many of the highly elongated ropes can provide sufficient stiffness to a structure. Further tests should be conducted using much lower velocities to determine if the elongations are excessive. All of the high molecular weight polyethylene fiber ropes performed relatively well under dynamic loading and should be examined in further tests as energy dissipating devices. The elongation associated with these ropes was considerably less than the aforementioned ropes. In particular, the Amsteel II double-braided rope and the Tech 12 single-braided rope both seem to have a good combination of energy dissipation and elongation capabilities.

The following figures will show some comparisons between the Amsteel II ropes and the Tech 12 ropes. As mentioned previously, one of the reasons that static tests were conducted on half of the 9 ft ropes and not on the other half was so that a comparison between precycled ropes and new ropes could be made. Test sequences were the same for both sets of ropes so that each rope would be subjected to the same dynamic loading. The results could then be compared with the only difference between tests being the initial condition of each rope (i.e., precycled or new). Figure 4.7 shows a comparison between a precycled 1/2 in. diameter Tech 12 rope and a new 1/2 in. diameter Tech 12 rope. The plots with the greater peak force are the results of the 65 lb from 78 in. dynamic tests. Comparing the new rope tests to the precycled rope tests, the displacements are slightly greater for the new ropes, however the peak forces are slightly lower. One reason for these occurrences could be that the precycled ropes are stiffer than the new ropes and consequently do not exhibit as much elongation as the new ropes. Also, because the precycled ropes are stiffer, the peak force tends to be slightly greater than the peak force for the new ropes. This is not the case for all of the ropes, but it is a general trend. Test 1 was conducted prior to test 2 for the precycled ropes and the new ropes. As a result of the ropes becoming stiffer with each test, the test 2 displacement

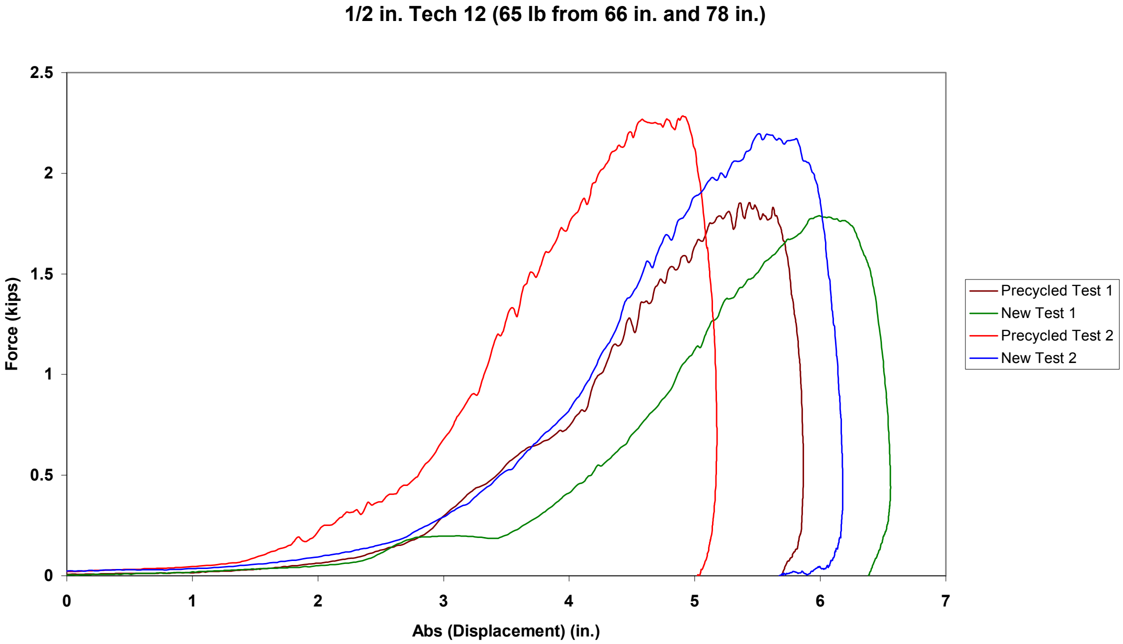

Figure 4.7 Comparison Between Precycled and New Ropes

values are less for both rope types. In addition to test 2 having lower displacement values, the peak force is greater for both rope types.

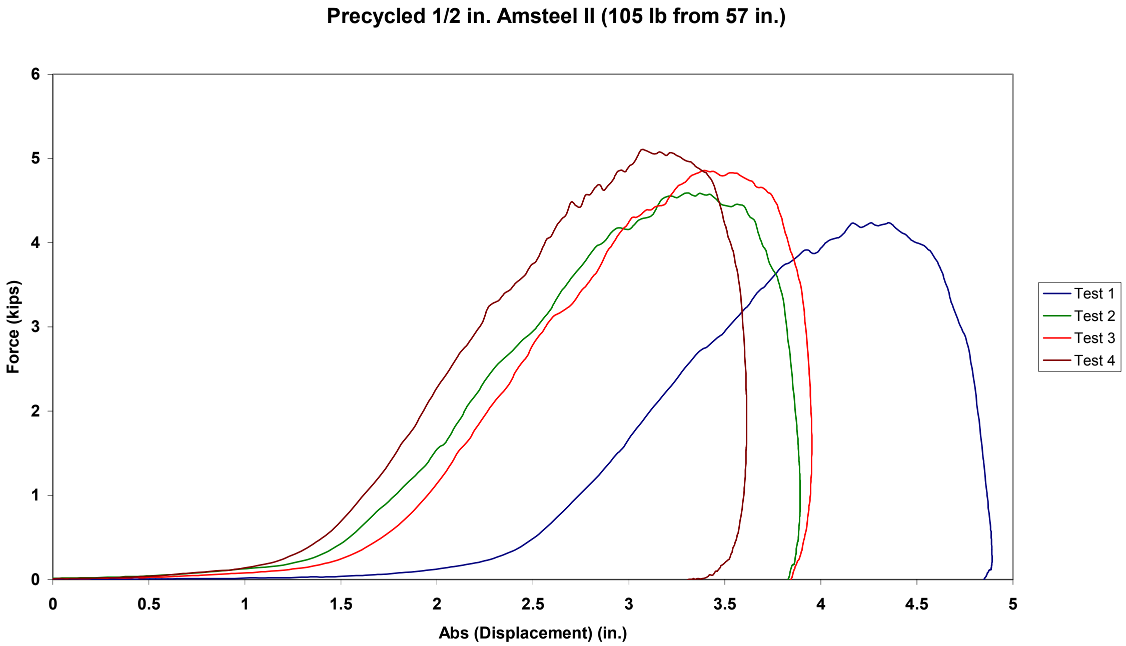

Figure 4.8 Comparison of Consecutive Tests

Figure 4.8 shows a comparison of consecutive tests for a precycled 1/2 in. diameter Amsteel II rope. These tests were conducted consecutively by dropping 105 lb from 57 in. Similar to many of the static tests, the first test cycle produced the greatest amount of displacement under loading. Also, the displacement decreased and the peak force increased with each subsequent test. Increasing stiffness of the rope could be one reason that these values are increasing and decreasing with each test cycle.

At any instant of time, the total energy of the drop plate is made up of two parts, which are kinetic energy of the falling plate and the potential energy resulting from the height that the drop plate was released from. Using data from the tests in Figure 4.8, some calculations of energy dissipation were tabulated for each of the test cycles. The following equation for kinetic energy was used to obtain these tabulations:

$$KE = \frac{1}{2}mv^2$$

where: KE = kinetic energy
m = mass
v = velocity

If the velocity of the drop plate just prior to the snap load is greater than the velocity of the drop plate just after the snap load, energy is dissipated (assuming the mass remains constant). For the precycled 1/2 in. Amsteel II rope loaded consecutively with 105 lb from 57 in., the velocity just prior to the snap load is considered to be equal for all four tests. The calculated kinetic energy at this point is approximately 280 lb-ft or 0.28 k-ft. The calculated kinetic energy just after the snap load for each test in ascending order is as follows: 2.2 lb-ft, 4.1 lb-ft, 7.2 lb-ft, and 20 lb-ft. By taking the difference between the total energy prior to the snap load and the total energy after the snap load, the amount of energy dissipation can be found. Since the amount of energy just after the snap load increases with each successive test, less energy is dissipated as the rope is subjected to more cycles. These numbers are not the total amount of energy dissipated because the potential energy was not calculated in conjunction with the kinetic energy. At the point that the kinetic energy was calculated, the potential energy is relatively small in comparison, but will affect the total amount of energy dissipated.

Some interesting observations were made with respect to the drop tests. Once a rope experienced a snap load and began to return to a slack state, the force applied to the rope was zero, yet the displacement of the end of the rope had not returned to zero. This was apparent in almost all of the ropes that were tested. It is reasonable to believe that this is valid because of the inelastic nature of these synthetic fiber ropes. Even though the force in the rope was zero, the rope had been stretched so much that it could not recover the displacement at zero force. Another observation that was made with respect to the drop tests was that the velocity of the drop plate after the snap load occurred was less than it was when the rope began to get taut. This would imply that the rope dissipated energy during the snap load. The amount of energy dissipated can be calculated as the area under the force vs. absolute displacement curve or the change in total energy during the snap load. A majority of the ropes tested experienced excessive elongation under dynamic loading. The amount of elongation that each rope experiences is very important to the success of using synthetic fiber ropes to dissipate seismic energy in a structure. For this fact, a majority of the ropes that were tested should be tested under lower velocities to determine if they will provide enough restriction to the lateral displacement of a structure under seismic loads.