Chapter 5

Results of the Static and Dynamic Tests

5.1 Static Test Results

Static Testing (also known as precycling) was performed on five Amsteel Blue and five Amsteel II ropes. Each rope was loaded in ten-pound increments from zero to 200 pounds and then back down to zero. The ropes were subjected to six of these cycles consecutively. All of the results that were obtained can be easily understood by looking at the load vs. displacement plots (hysteresis loops). An example of one of these plots can be found in Figure 5.1.1.

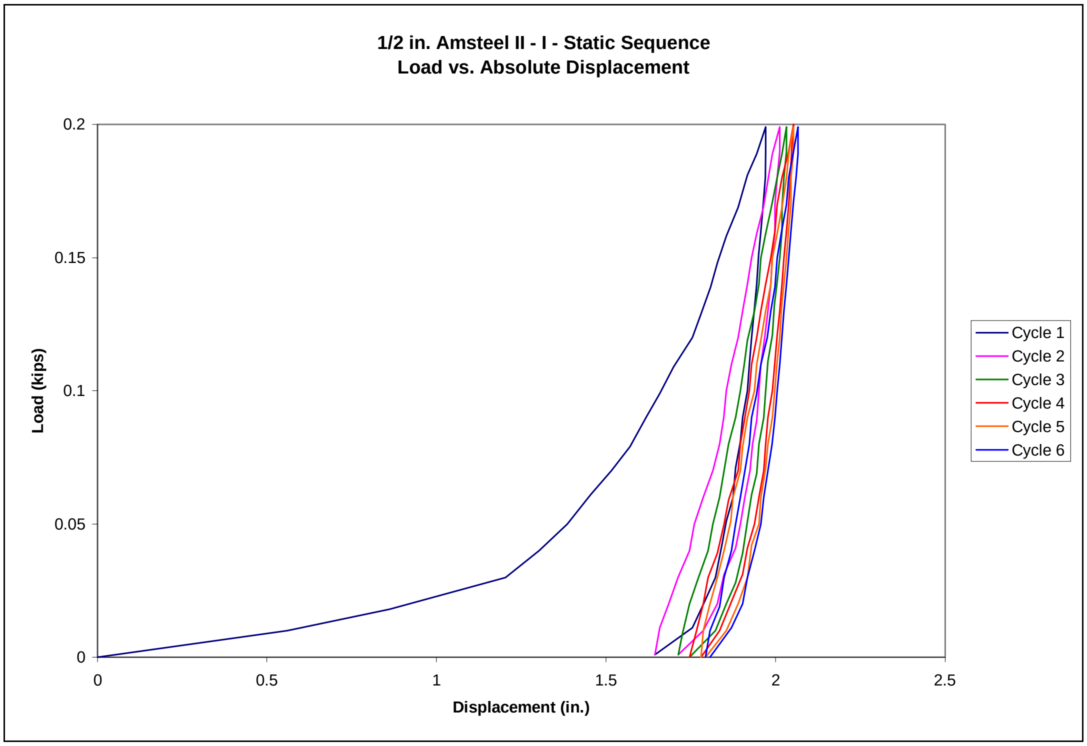

Figure 5.1.1: Static Load vs. Displacement Plot (Static Hysteresis Loops)

The most dramatic change to the ropes occurred in the first cycle. During this cycle, the largest elongation of the ropes occurred, which is evident from the large difference in the displacement readings between the beginning and end of the cycle. The next largest elongation occurs in the second cycle, but it is much smaller than that of the first cycle. The rope continues to elongate in the cycles that follow, but the amount the rope lengthens decreases as the static sequence progresses. This indicates that as the rope stiffens, less additional elongation will occur. The elongation data for the Amsteel II ropes can be found in Figure 5.1.2.

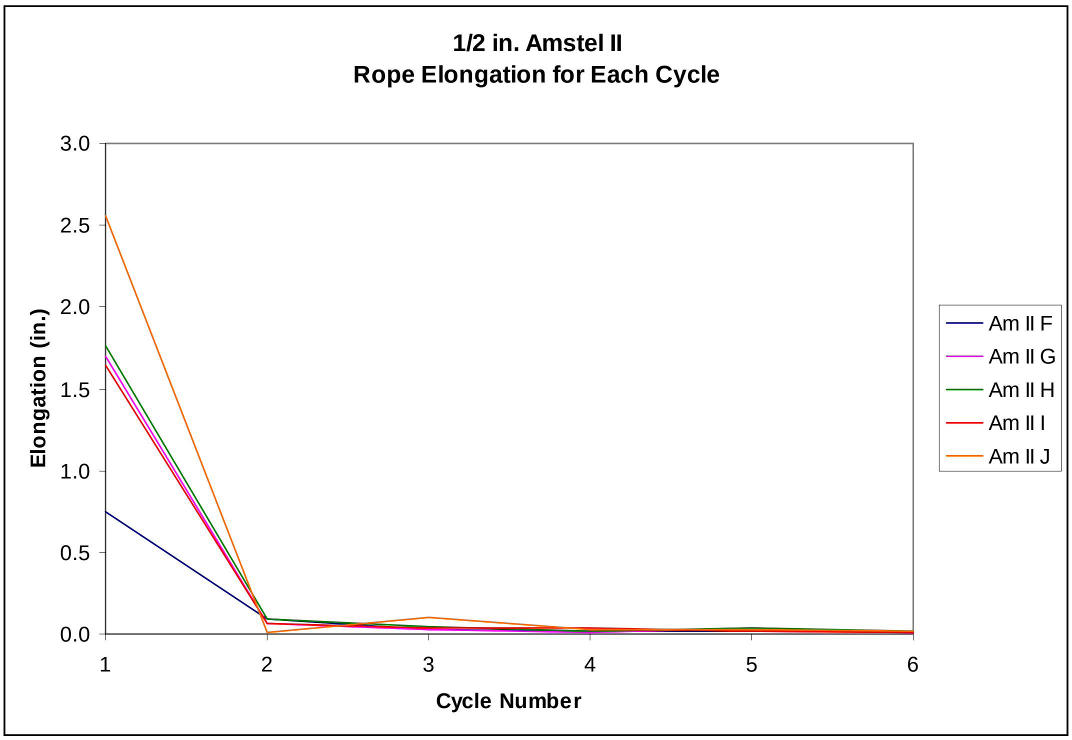

Figure 5.1.2: Rope Elongation Trend for Amsteel II Sequences

A different trend can be seen in maximum displacement data. A large displacement occurred during the first cycle and there was a slight increase in displacement during the second cycle, but after the second cycle the maximum displacement did not increase significantly. The maximum displacement trends for the Amsteel II ropes can be seen in Figure 5.1.3.

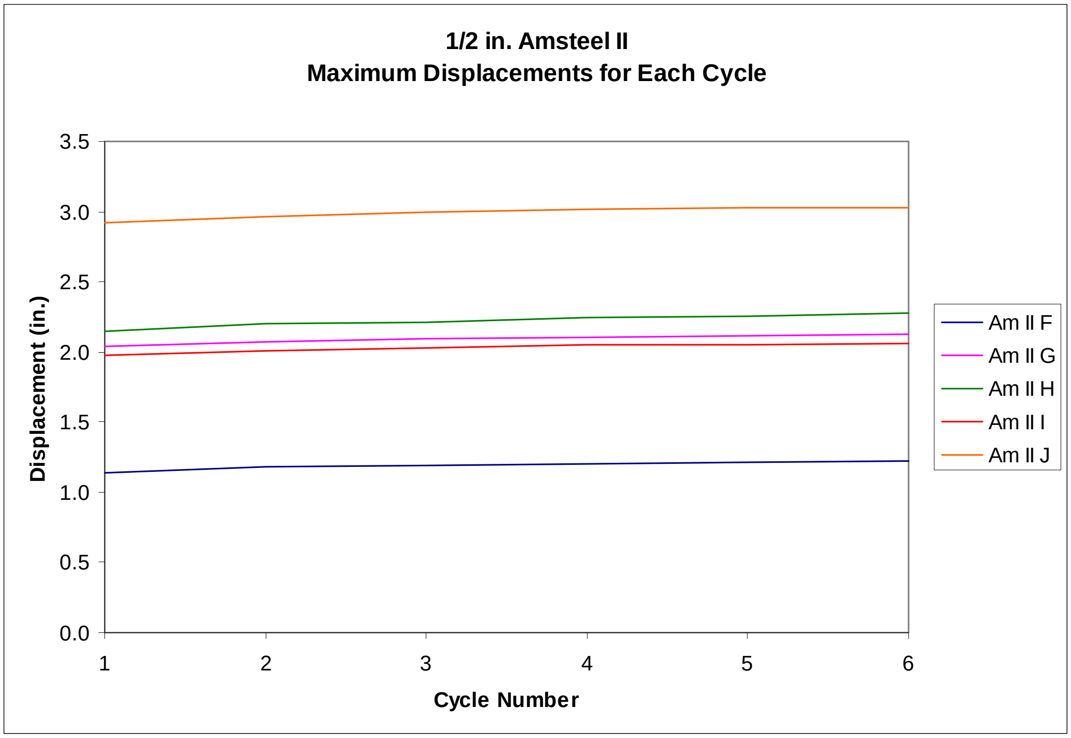

Figure 5.1.3: Maximum Displacement Trend for Amsteel II Sequences

There was some variance in the amount of elongation and the maximum displacement between the different types of ropes as well as between some ropes of the same type. As mentioned earlier, the Amsteel Blue ropes are constructed with a looser fiber configuration than the Amsteel II ropes. This causes more elongation to occur in those ropes than occurs for the Amsteel II rope. Hence, the Amsteel Blue ropes have larger values for both quantities in question. Excluding two sequences (one from each rope type) in which equipment error caused the first cycles not to be recorded, the Amsteel

Blue ropes elongated between 3 and 5 inches in the first cycle while the Amsteel II ropes elongated between 1.5 and 2.5 inches. The total static elongations were also close to these values. The maximum deflection of the ropes was between 3.5 and 6 inches for the Amsteel Blue and 2 and 3 inches for the Amsteel II. The Amsteel Blue ropes also have larger deflection values in cycles 2 through 6. Table 5.1.1 compares the total static elongation values that were found through the data analysis to those that were measured.

Amsteel Blue Ropes			
Rope	Analytical Elongation (in.)	Measured Elongation (in.)	Difference (in.)
Am Bl - A	6.04	4.5	1.54
Am Bl - B	3.93	4.0	0.07
Am Bl - D	3.77	3.5	0.27
Am Bl - E	5.08	5.0	0.08

Amsteel II Ropes			
Rope	Analytical Elongation (in.)	Measured Elongation (in.)	Difference (in.)
Am II - G	1.84	2.0	0.16
Am II - H	1.97	2.0	0.03
Am II - I	1.81	2.0	0.19
Am II - J	2.74	2.5	0.24

Table 5.1.1: Static Rope Elongation Comparison

The slope of the load vs. displacement curves (which was used to determine the stiffness of the rope) was more gradual for the first cycle than it was for cycles 2 through 6. There is a large increase in slope between the first and second cycle, but the slope of the subsequent cycles does not increase significantly. This behavior is consistent for all of the loading sequences and can be seen in Figure 5.1.4.

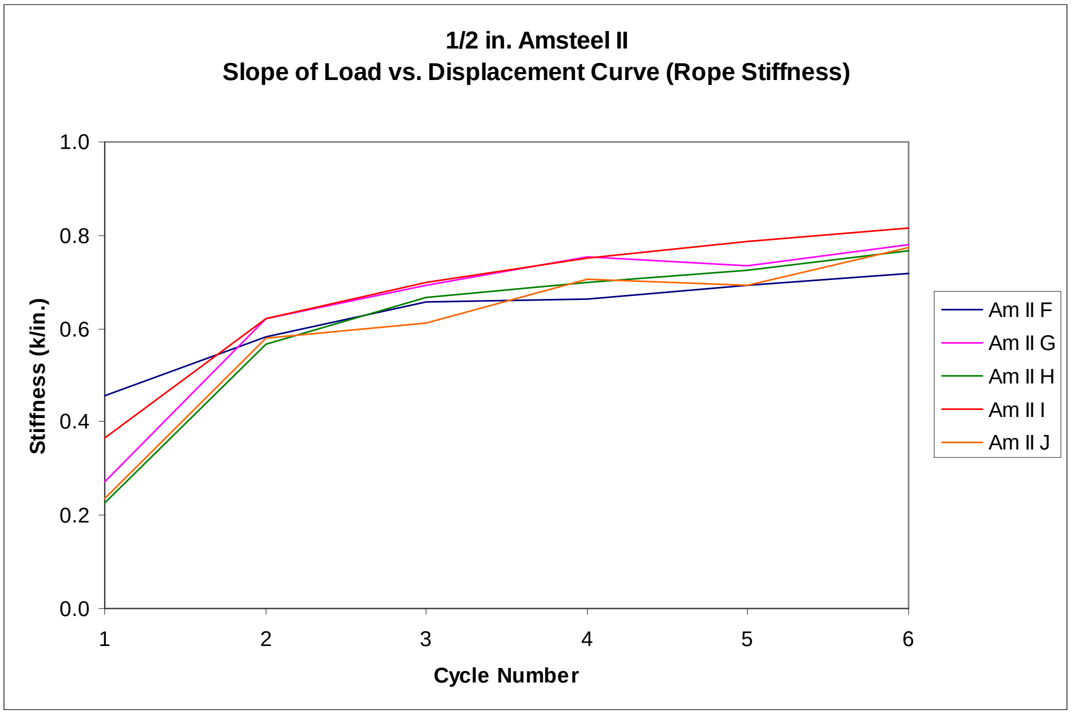

Figure 5.1.4: Stiffness Trend for Amsteel II Sequences

The average stiffness was calculated for each rope by averaging the slopes of the second through sixth cycles. These values were then averaged to find the average rope type stiffness. The average stiffness for the Amsteel Blue ropes was 0.380 kips/inch, while the average stiffness for the Amsteel II ropes was 0.694 kips/inch. This difference in values was expected since the Amsteel II ropes have a tighter strand configuration and therefore are stiffer ropes.

The behavior of the area under the static hysteresis loops (or the Static Area) is similar to that of the rope elongation. The area under these curves is much larger for the first cycle than it is for the subsequent cycles and the area remains fairly constant after the first cycle. This trend can be seen in Figure 5.1.5.

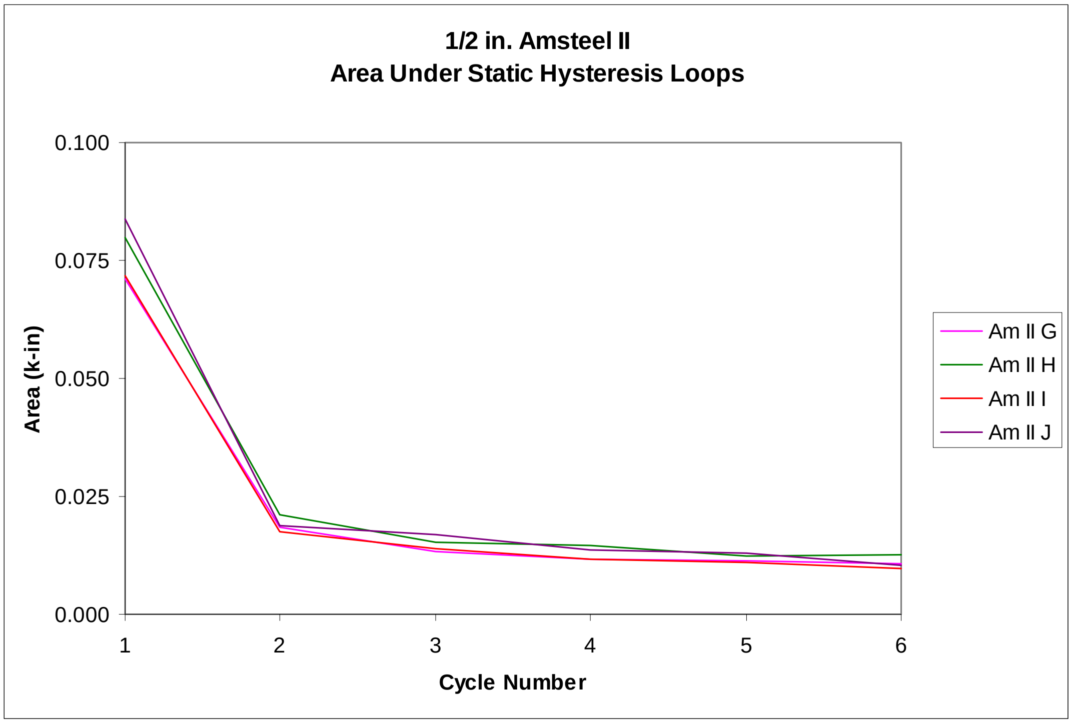

Figure 5.1.5: Static Hysteresis Area for Amsteel II Sequences

The area under the hysteresis loops is larger for the Amsteel Blue ropes because of the larger displacements that those ropes experience. This may indicate that more energy can be dissipated by these ropes. The total area is the combined area for all of the static hysteresis loops for a given rope. The average total area is the average of all of the total areas for each rope type. The average total area for the Amsteel Blue ropes was 0.524 kip-inches, while the average total area for the Amsteel II ropes was 0.146 kip-inches. All values of interest for the static tests can be found in Table 5.1.2.

Rope	Cycle 1 Elongation (in.)	Sequence Max. Disp. (in.)	Average Stiffness (k/in.)	Area Under Cycle 1 Curve (k-in.)	Total Area (k-in.)
Amsteel Blue - A	error	error	0.399	error	error
Amsteel Blue - B	3.359	4.353	0.378	0.311	0.481
Amsteel Blue - C	5.161	6.575	0.341	0.376	0.607
Amsteel Blue - D	3.086	4.208	0.402	0.301	0.485
Amsteel Blue - E	5.078	5.674	error	0.323	error
Amsteel II - F	error	error	0.663	error	error
Amsteel II - G	1.697	2.126	0.717	0.071	0.137
Amsteel II - H	1.766	2.271	0.684	0.080	0.155
Amsteel II - I	1.644	2.066	0.735	0.072	0.136
Amsteel II - J	2.557	3.026	0.673	0.084	0.157
Amsteel Blue	4.171	5.203	0.380	0.328	0.524
Amsteel II	1.916	2.372	0.694	0.077	0.146

Table 5.1.2: Static Test Results

5.2 Dynamic Test Results

The majority of the analyses that were conducted for this research and all of the data that was modeled came from the Taut Phase of the dynamic tests. Each rope was tested using a sequence that consisted of 20 drop tests from the same height and with the same weight. This was done in order to determine how the rope changed when it was subjected to consistent snap loadings. In addition, a pre-cycled and a new rope were tested from the same drop height in order to determine if statically loading the ropes before they are dynamically loaded produces any benefits.

5.2.1 Rope Stiffness

The first quantity that was examined was the stiffness. As more drop tests were conducted, the fibers in the ropes were pulled closer together and the ropes became more stiff. The behavior of all of the subsequent quantities is dependent on this occurrence and their values and trends will be related to the change in stiffness of the ropes.

It was expected that the ropes that were pre-cycled would produce higher stiffness values than the new ones. However, with the exception of the first few cycles, the new ropes produced stiffness values that were equal to or larger than those of the pre-cycled ropes. This behavior can be seen in Figure 5.2.1.1. The difference between the two values is small, but this was unexpected and is consistent for the majority of the ropes.

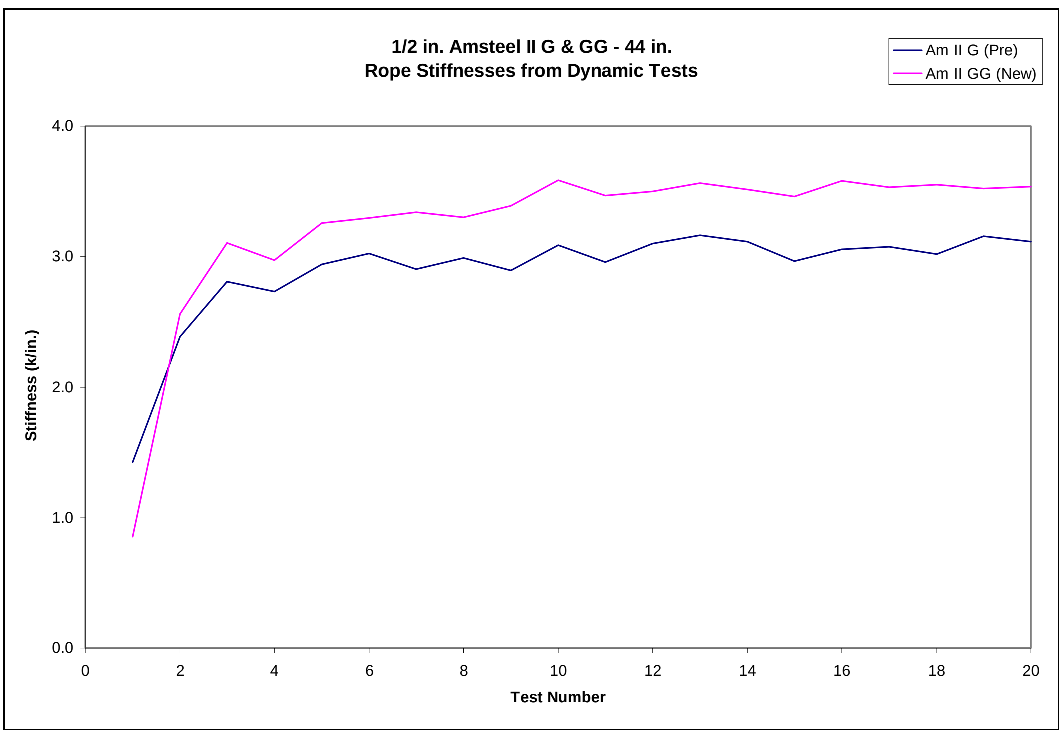

Figure 5.2.1.1: Stiffness Trends for a Pre-cycled and New Amsteel II Sequence

It is clear from this graph that for the Amsteel II ropes there is a large increase in stiffness in the first few cycles, but the curve levels out after several tests and the rope reaches a nearly constant stiffness. This indicates that the fibers in the ropes get to a point where they cannot be pulled any tighter and the rope is essentially stretched to its maximum length. However, the stiffness of the Amsteel Blue ropes tends to increase throughout the sequence and reaches its steady state value much slower than the Amsteel II ropes do. This can be seen in Figure 5.2.1.2.

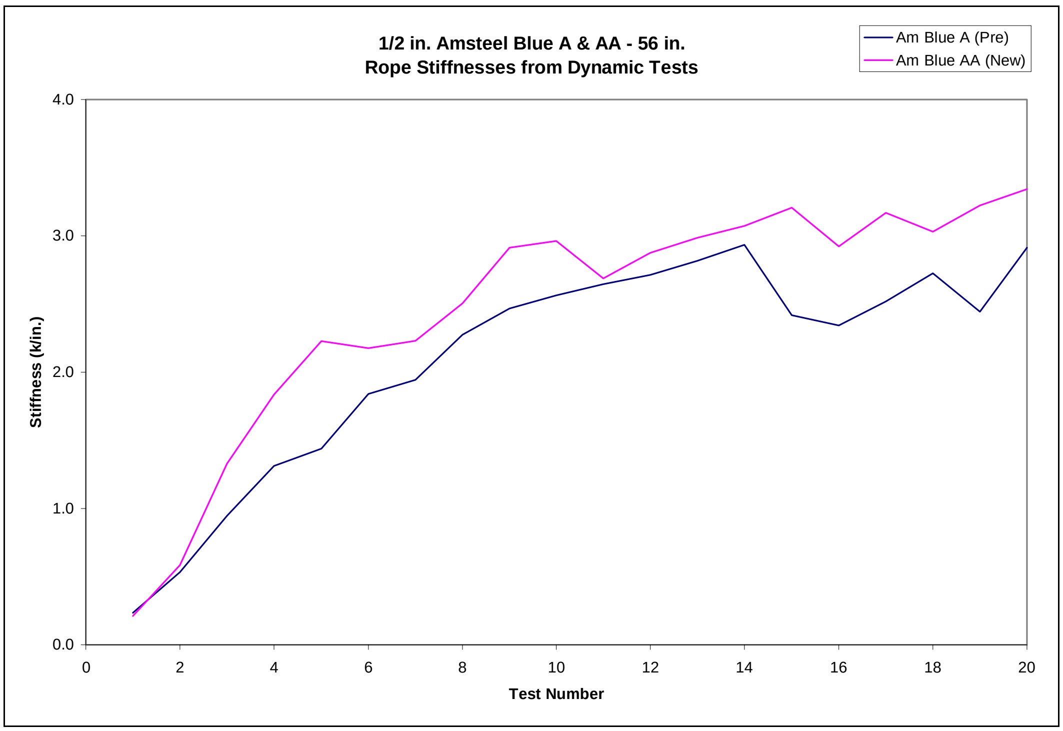

Figure 5.2.1.2: Stiffness Trends for a Pre-cycled and New Amsteel Blue Sequence

Figure 5.2.1.3 is a plot of the stiffness trends of the New Amsteel II ropes which shows how drop height affects the stiffness. The drop heights are listed in the legend next to the appropriate rope classification. In general, the higher drop heights produce stiffer ropes, but there is some variance in the data and the differences are not very large. This trend was the same for all of the ropes.

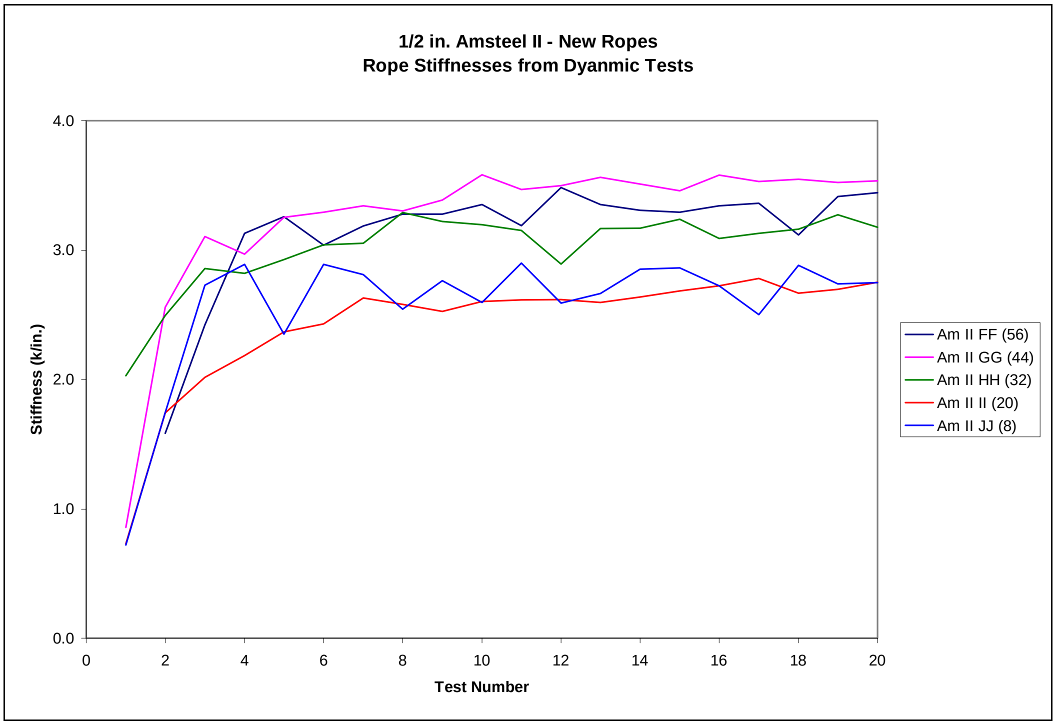

Figure 5.2.1.3: Rope Stiffness Trends for the New Amsteel II Ropes

5.2.2 Inherent and Integrated Data

The next set of quantities that were analyzed were those that were either obtained directly from the data acquisition devices or through integration of this data. The first of these quantities is the Pulse Duration. The Pulse Duration (or the length of the Taut Phase) decreases as more dynamic tests are conducted on a rope. After the first few drop tests, the pulse duration reaches a relative steady state value of between 0.05 and 0.06 seconds. For the most part, the higher drop heights seem to produce longer pulse durations, but the data series are slightly erratic and there are some variations. The results seem to indicate that the pulse duration is a function of the stiffness of the rope. When the fibers in the ropes are looser, the pulse durations are longer. As the sequence progresses and the ropes reach a nearly constant stiffness, the durations remain at a relatively constant length. The Pulse Duration trends for the Amsteel II ropes can be seen in Figure 5.2.2.1. The Pulse Duration trends for the Amsteel Blue Ropes look very similar and can be found in Figure 5.2.2.2.

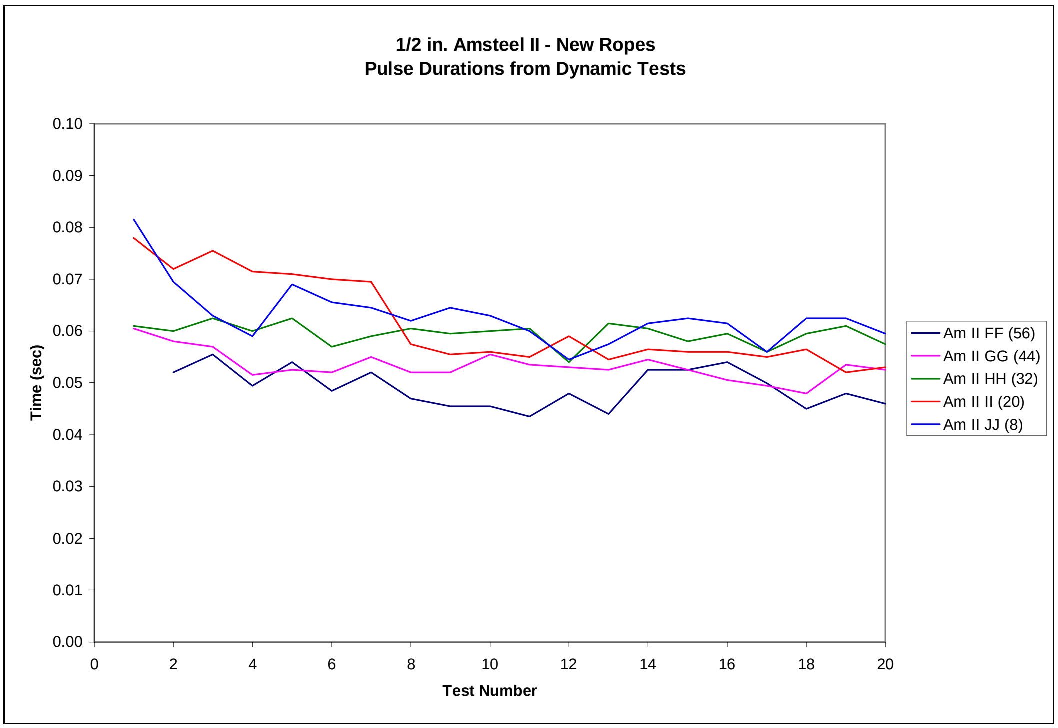

Figure 5.2.2.1: Pulse Durations for the New Amsteel II Dynamic Sequences

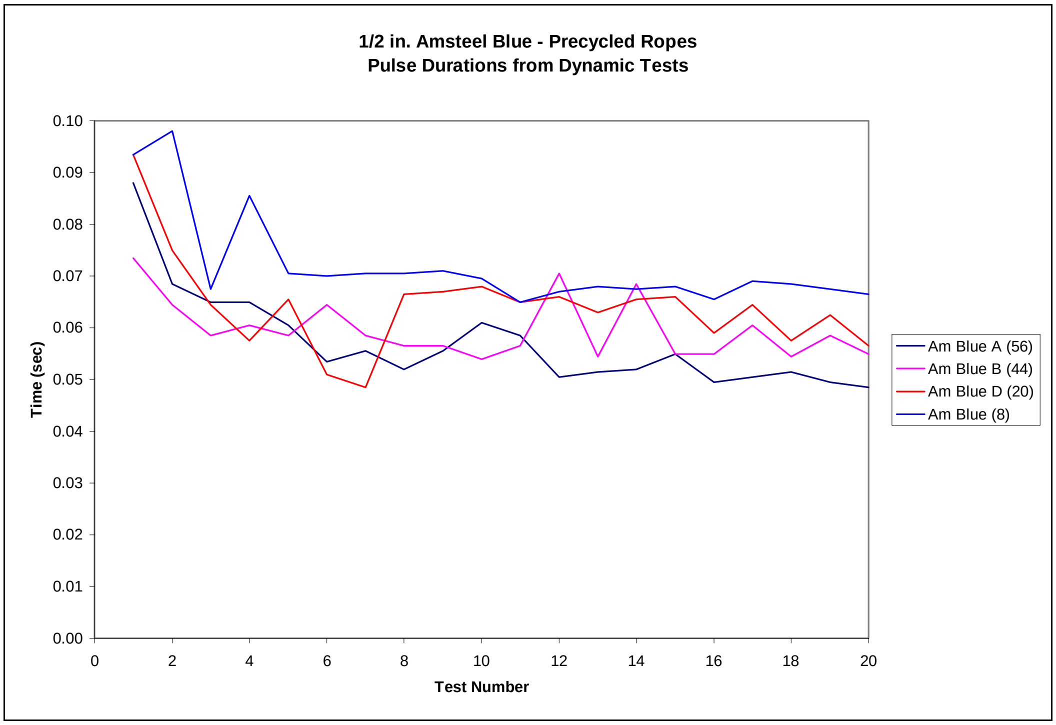

Figure 5.2.2.2: Pulse Durations for the Precycled Amsteel Blue Dynamic Sequences

The trends for the Maximum Forces and the Maximum Accelerations that were produced by the snap loads are very similar. For the Amsteel II ropes, the values increased in the first few cycles and then reached nearly constant values. This can also be attributed to the stiffening of the rope. When the fibers were loose, more energy could be dissipated through the friction that was produced when the fibers slid past each other as the rope was stretching. As more tests were conducted and the ropes tightened up, less of this slipping occurred and the Maximum Force values increased until they reached a steady state value. Since the Maximum Acceleration is related to the amount of force that is produced, these values followed the same trend. Figures 5.2.2.3 and 5.2.2.4 show this behavior.

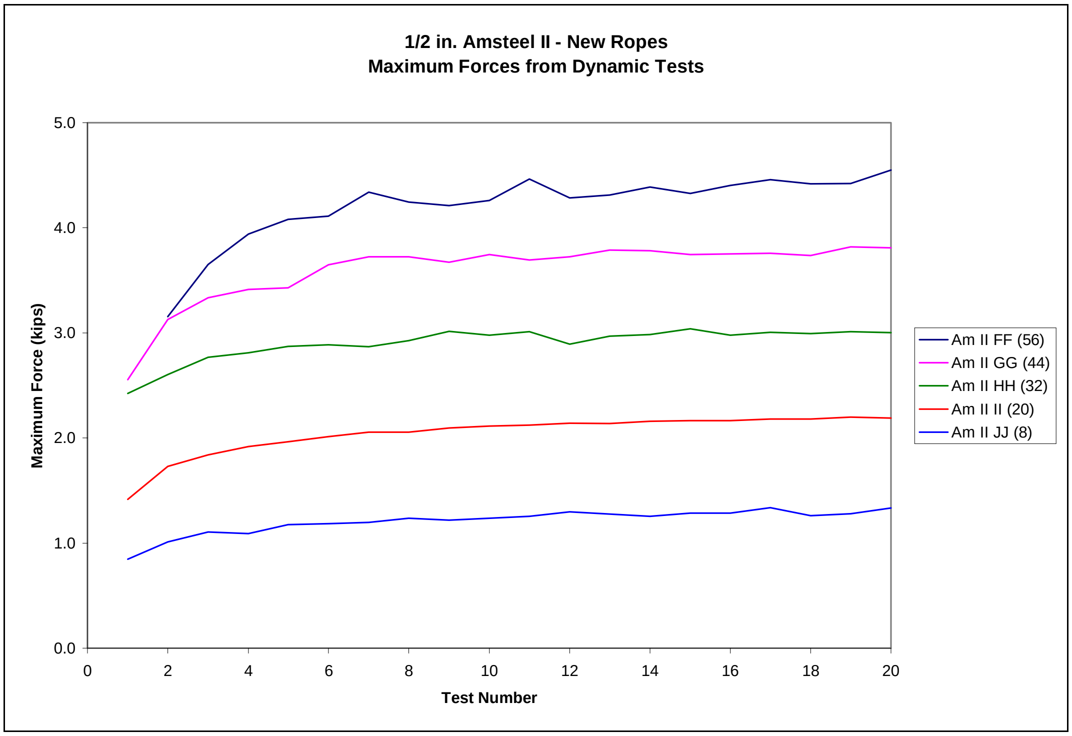

Figure 5.2.2.3: Maximum Forces from the New Amsteel II Dynamic Sequences

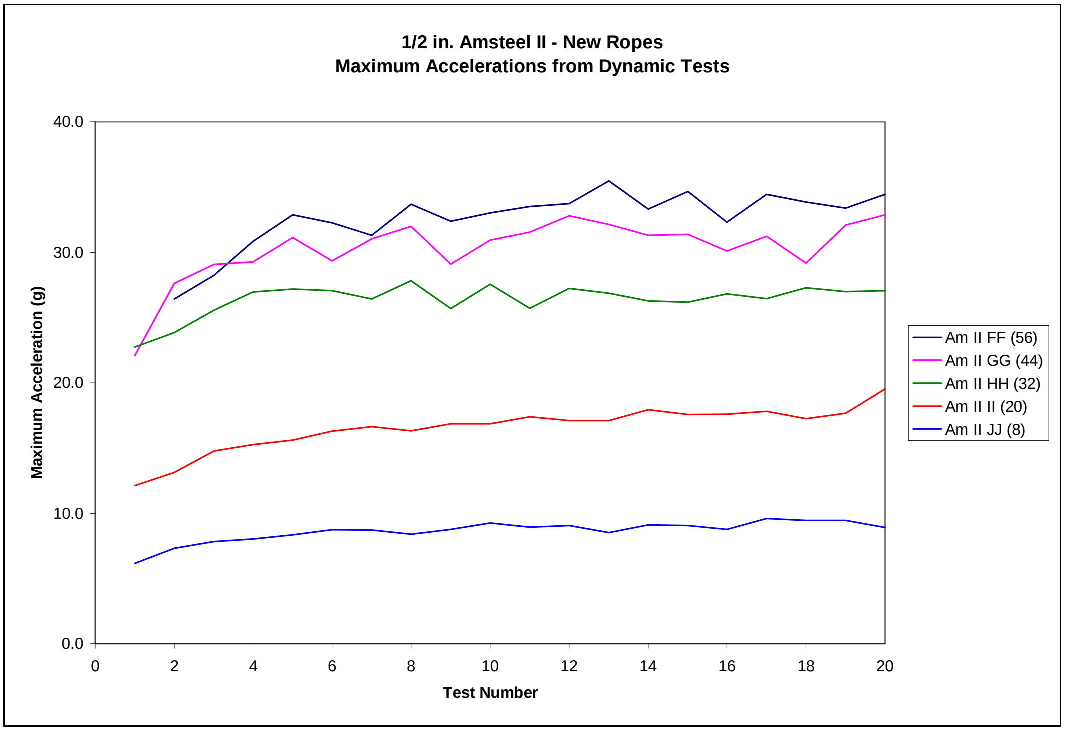

Figure 5.2.2.4: Maximum Accelerations from the New Amsteel II Dynamic Sequences

For the Amsteel Blue ropes, the same trends are seen for the Maximum Forces and Accelerations as for the Amsteel II ropes. However, the increase in the values was more gradual and did not level off at as high a value as the Amsteel II ropes. The Maximum Force trends for the Amsteel Blue ropes can be seen in Figure 5.2.2.5 and the trends for the Maximum Accelerations can be seen in Figure 5.2.2.6. For both the Amsteel Blue and Amsteel II ropes, there was no significant difference in the values of the New and Precycled Ropes.

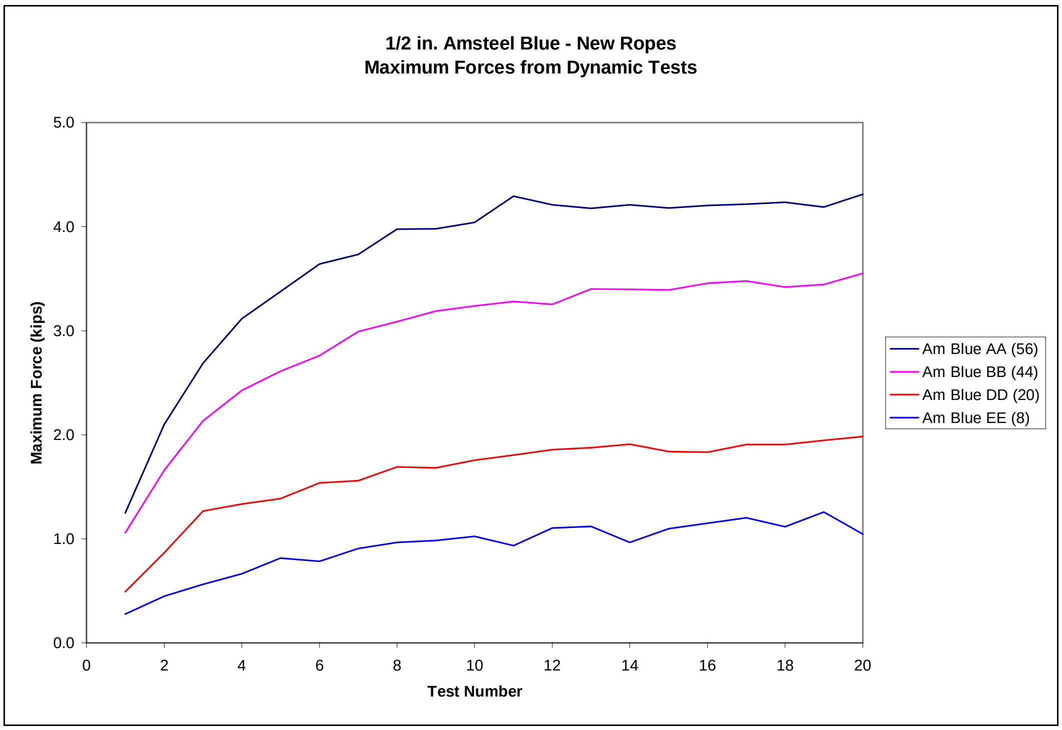

Figure 5.2.2.5: Maximum Forces from the New Amsteel Blue Dynamic Sequences

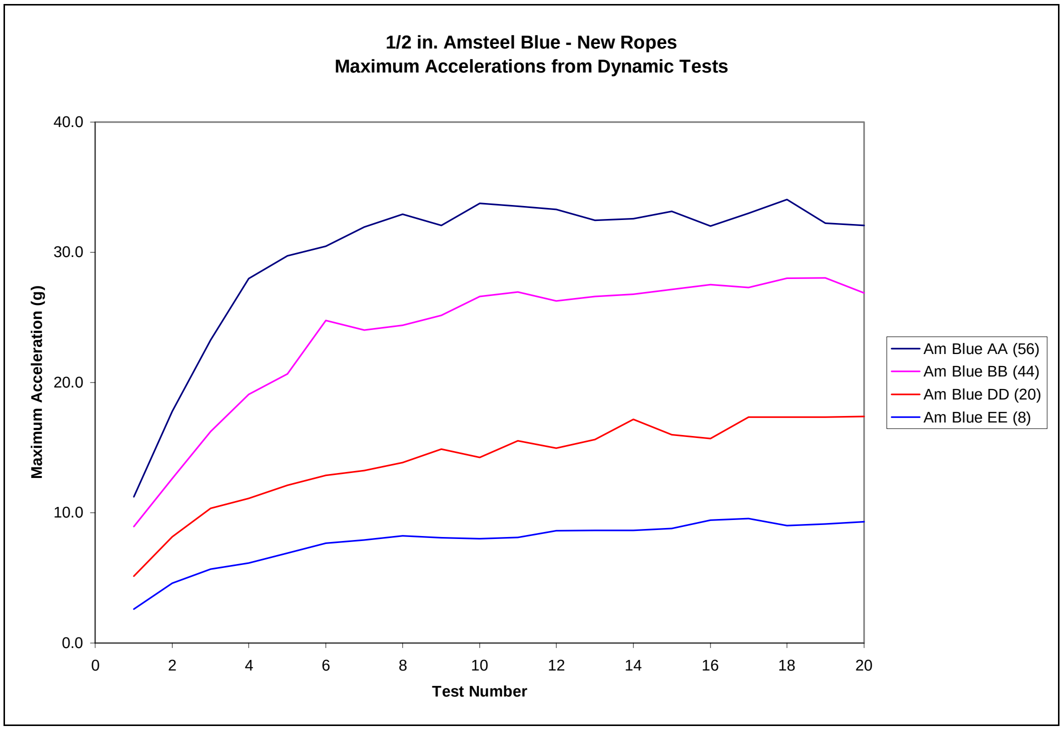

Figure 5.2.2.6: Maximum Acceleration from the New Amsteel Blue Dynamic Sequences

The Maximum Displacement trends are similar to those of the Pulse Duration. As the dynamic sequences progressed, the ropes were stretched out and therefore would not displace as far in the following cycles. Once the ropes were stretched to their maximum length, the Maximum Displacements remained fairly constant. What actually happens is that in the first few tests the rope is not displacing as much as it does later on because the fibers are still tightening up. When the rope reaches a constant stiffness, the displacement remains fairly steady. Some of the data is erratic, but that is the general data trend.

The Maximum Displacements for the Amsteel II ropes can be found in Figure 5.2.2.7 and those for the Amsteel Blue ropes can be found in Figure 5.2.2.8. As can be seen, the higher drop heights tend to produce larger displacements. In addition, the maximum displacements of the Amsteel Blue ropes are between 1 and 2 inches greater than those of the Amsteel II ropes.

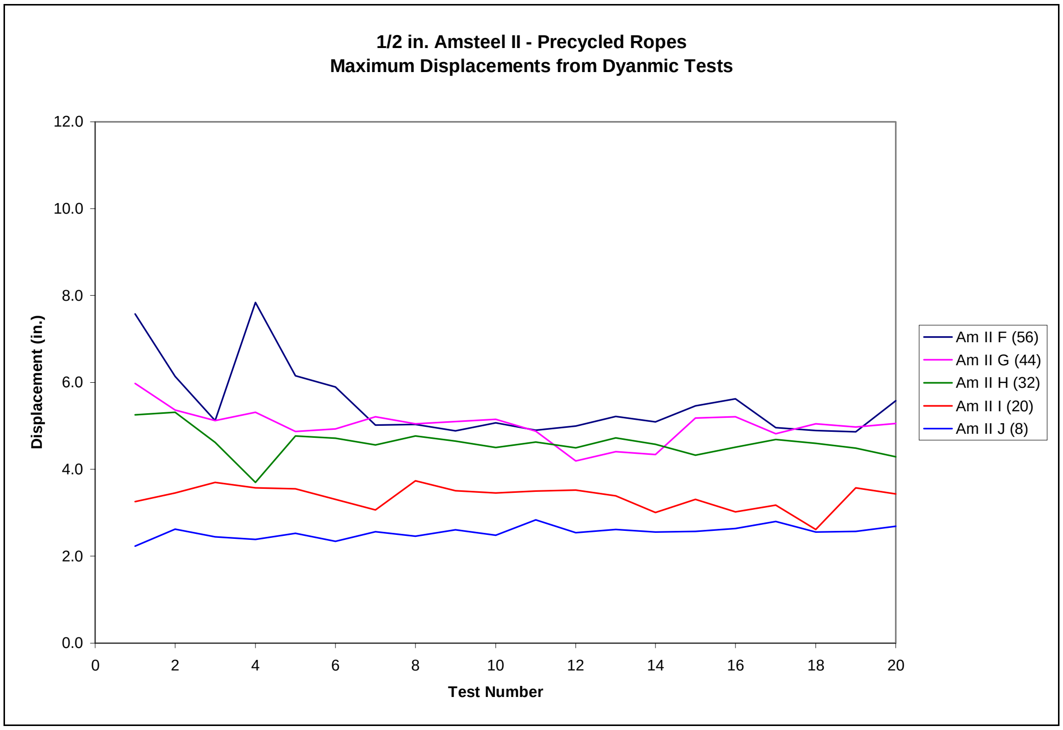

Figure 5.2.2.7: Maximum Displacements from the Precycled Amsteel II Dynamic Sequences

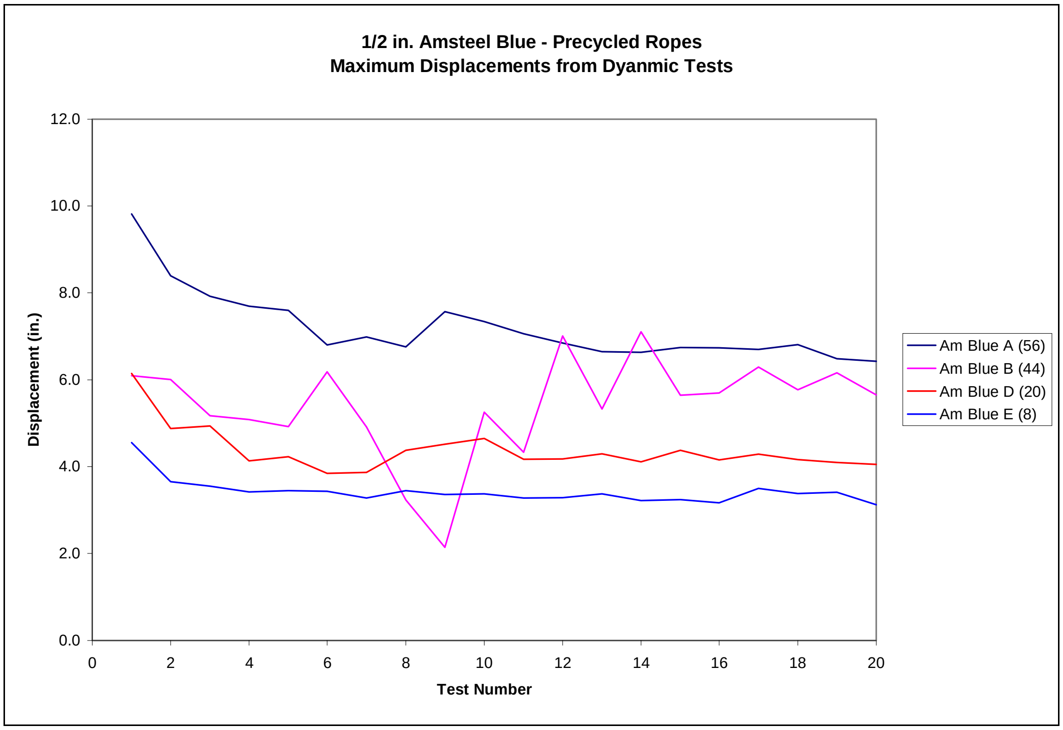

Figure 5.2.2.8: Maximum Displacements from the Precycled Amsteel Blue Dynamic Sequences

The Impact Velocity trends are similar for both the Amsteel Blue and Amsteel II ropes. In the first few cycles there is a slight increase in velocity before it reaches a constant level. However, the increase is small and therefore the Impact Velocity can be taken as constant throughout a test sequence for a given drop height. This behavior is seen in Figures 5.2.2.9 and 5.2.2.10. The Impact Velocities are slightly higher for the Amsteel Blue ropes, but the difference in the values is small.

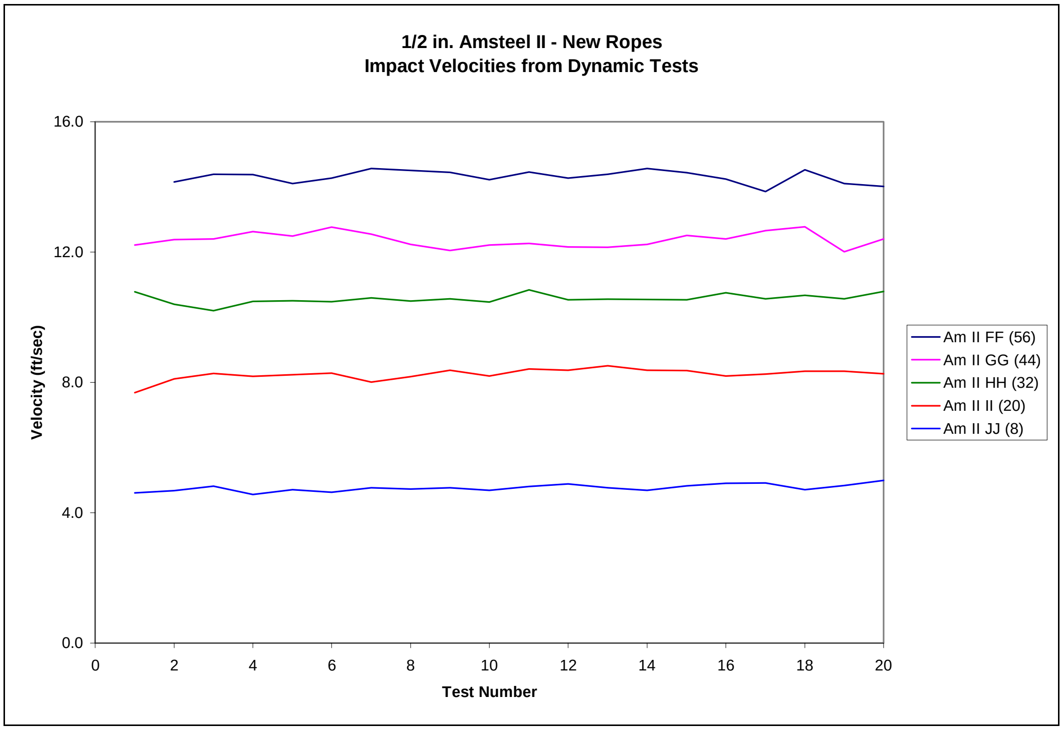

Figure 5.2.2.9: Impact Velocities from the New Amsteel II Dynamic Sequences

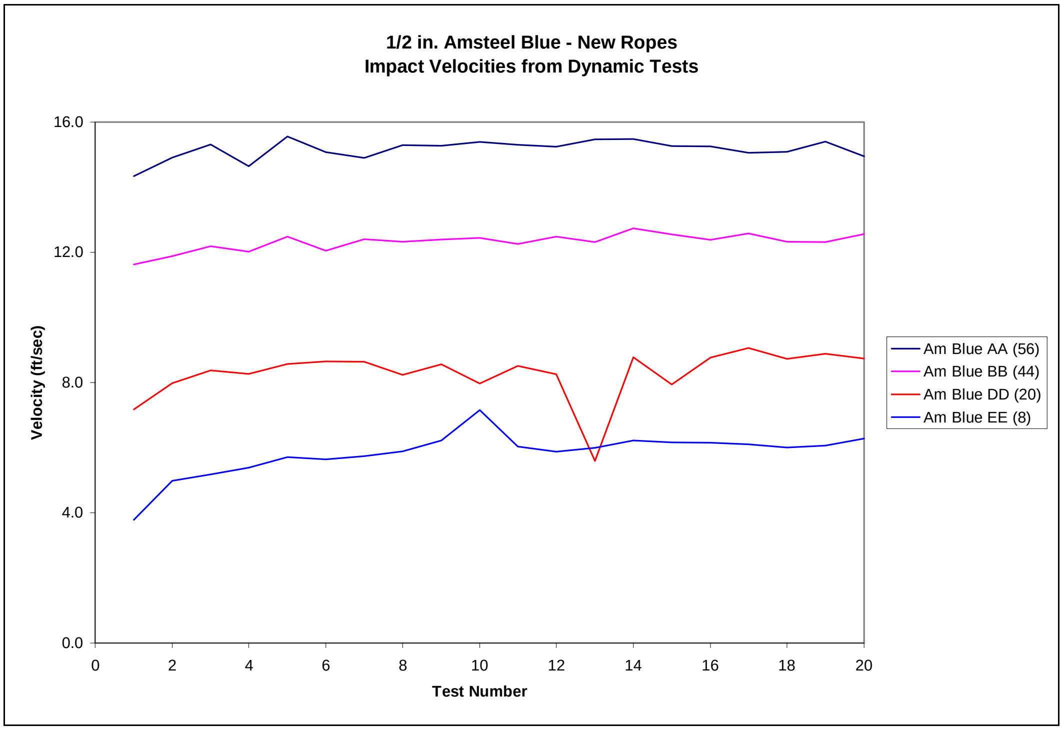

Figure 5.2.2.10: Impact Velocities from the New Amsteel Blue Dynamic Sequences

Figure 5.2.2.11 is a plot of the Pulse Duration, Maximum Force, Maximum Acceleration, Maximum Displacement, and Impact Velocity for an Amsteel II rope test sequence. Figure 5.2.2.12 is a plot of the same data for the Amsteel Blue rope sequence for the same drop height. These graphs show how each quantity changes throughout the test sequence and allows for a relative comparison between the trends and a comparison between the two ropes.

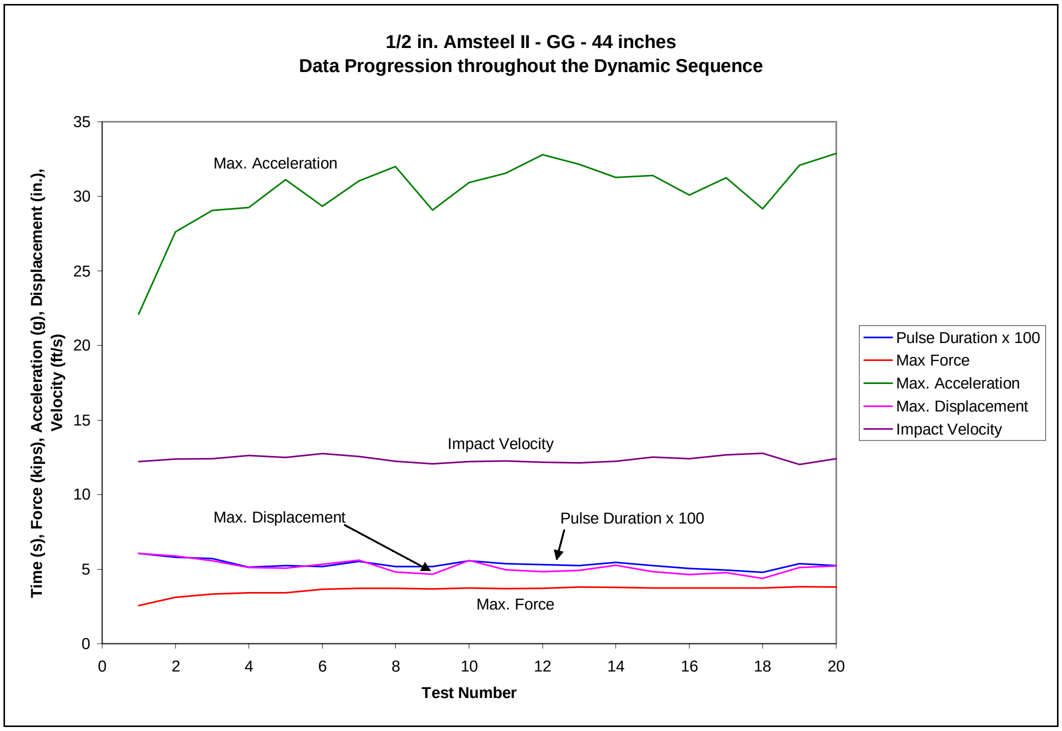

Figure 5.2.2.11: Data from an Amsteel II Dynamic Sequence

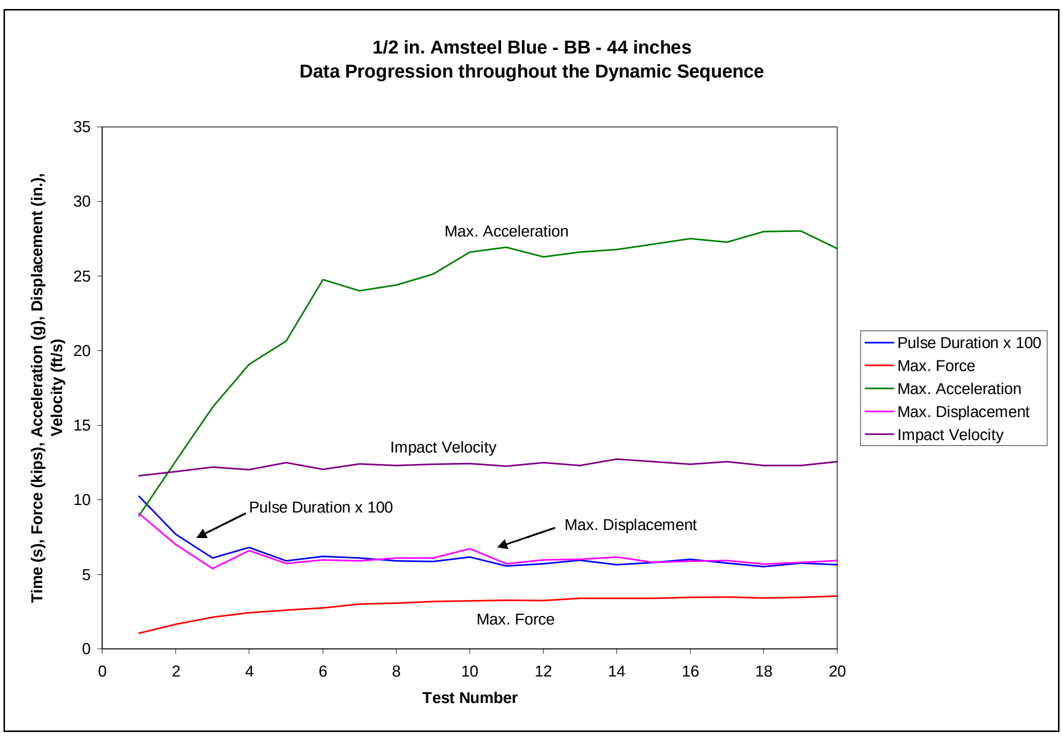

Figure 5.2.2.12: Data from an Amsteel Blue Dynamic Sequence

As mentioned earlier, as the test sequence progresses, the Maximum Force, Maximum Acceleration, and Maximum Displacement all increase up to a point and then stay at nearly constant values. In addition, the Pulse Duration decreases up to a point and then remains constant, and the Impact Velocity can be taken as constant for an entire sequence. This behavior occurred in every rope that was dynamically tested and is what can be expected from SCEDs that are used in buildings.

5.2.3 Rope Elongation Comparisons

As mentioned earlier, each rope was measured when it was new, after it had been statically tested, and after it had been dynamically tested. The values are found in Table 5.2.3.1.

Original Rope Lengths			
Amsteel Blue		Amsteel II	
Rope	Length (in.)	Rope	Length (in.)
A	107.0	F	108.5
B	108.0	G	108.5
C	107.0	H	107.5
D	108.5	I	108.0
E	109.0	J	107.5
AA	108.0	FF	109.5
BB	108.5	GG	109.0
CC	107.5	HH	108.5
DD	108.0	II	108.0
EE	108.5	JJ	108.5

Lengths After Precycling			
Amsteel Blue		Amsteel II	
Rope	Length (in.)	Rope	Length (in.)
A	111.5	F	110.5
B	112.0	G	110.5
C	112.5	H	109.5
D	112.0	I	110.0
E	114.0	J	110.0

Lengths After Dynamic Tests			
Amsteel Blue		Amsteel II	
Rope	Length (in.)	Rope	Length (in.)
A	116.5	F	111.5
B	117.0	G	112.0
C	116.5	H	111.0
D	116.5	I	111.5
E	118.5	J	111.0
AA	116.0	FF	111.5
BB	116.0	GG	111.0
CC	116.5	HH	111.0
DD	116.5	II	110.5
EE	116.5	JJ	111.5

Table 5.2.3.1 Measured Rope Lengths

These values were then compared to the elongation values that were found through the analysis of the static and dynamic tests to determine the accuracy of the analytical values. The comparisons are found in Table 5.2.3.2.

Static Rope Elongation Comparison			
Rope	Analytical Elongation (in.)	Measured Elongation (in.)	Difference (in.)
Am Bl - A	6.04	4.5	1.54
Am Bl - B	3.93	4.0	0.07
Am Bl - C	1.46	4.5	error
Am Bl - D	3.77	3.5	0.27
Am Bl - E	5.08	5.0	0.08
Am II - F	0.92	2.0	error
Am II - G	1.84	2.0	0.16
Am II - H	1.97	2.0	0.03
Am II - I	1.81	2.0	0.19
Am II - J	2.74	2.5	0.24

Dynamic Rope Elongation Comparison			
Rope	Analytical Elongation (in.)	Measured Elongation (in.)	Difference (in.)
Am Bl - A	4.75	4.0	0.75
Am Bl - B	4.76	5.0	0.24
Am Bl - C	error	4.0	error
Am Bl - D	4.94	4.5	0.44
Am Bl - E	4.40	4.5	0.10
Am Bl - AA	7.54	8.0	0.46
Am Bl - BB	7.41	7.5	0.09
Am Bl - CC	error	8.0	error
Am Bl - DD	8.02	8.5	0.48
Am Bl - EE	7.99	8.0	0.01

Dynamic Rope Elongation Comparison			
Rope	Analytical Elongation (in.)	Measured Elongation (in.)	Difference (in.)
Am II - F	0.52	1.0	0.48
Am II - G	1.69	1.5	0.19
Am II - H	1.50	1.5	0.00
Am II - I	1.64	1.5	0.14
Am II - J	1.49	1.0	0.49
Am II - FF	1.33	2.0	error
Am II - GG	1.83	2.0	0.17
Am II - HH	2.46	2.5	0.04
Am II - II	2.90	2.5	0.40
Am II - JJ	3.50	3.0	0.50

Table 5.2.3.2: Static and Dynamic Rope Elongation Comparisons

In most cases, the computed elongation of the ropes was within ½-inch of the measured value. Considering that the measured values were rounded to the nearest ½-inch, these results are very good.

Theoretically, the static elongations should be very consistent among a certain type of rope. Each rope was loaded the same way and experienced the same number of cycles, excluding the Amsteel Blue C and the Amsteel II F ropes. These two had a seventh cycle, but since the first cycle wasn't recorded, the elongation values are not accurate. However, even for the ropes for which no error occurred, there was a lot of variance in the elongation. The Amsteel Blue ropes elongated between 3.75 and 6 inches, while the Amsteel II ropes elongated between 1.75 and 2.75 inches. This variance most likely occurred due to differences in the individual ropes.

In the dynamic tests, the precycled ropes elongated less than the new ropes. This was expected since the ropes were stretched out quite a bit during the static tests. However, the drop height did not appear to play a large role in the amount of elongation. The elongation values vary, but they can be taken as fairly constant for a given rope type.

The ropes that were precycled had larger total elongation values than the new ropes did. This is seen in Table 5.2.3.3.

Amsteel Blue - All Tests				
Rope	Length (in.)		Δ Length (in.)	% Change
	Before	After		
A	107.0	116.5	9.5	8.9
B	108.0	117.0	9.0	8.3
C	107.0	116.5	9.5	8.9
D	108.5	116.5	8.0	7.4
E	109.0	118.5	9.5	8.7
AA	108.0	116.0	8.0	7.4
BB	108.5	116.0	7.5	6.9
CC	107.5	116.5	9.0	8.4
DD	108.0	116.5	8.5	7.9
EE	108.5	116.5	8.0	7.4

Amsteel II - All Tests				
Rope	Length (in.)		Δ Length (in.)	% Change
	Before	After		
F	108.5	111.5	3.0	2.8
G	108.5	112.0	3.5	3.2
H	107.5	111.0	3.5	3.3
I	108.0	111.5	3.5	3.2
J	107.5	111.0	3.5	3.3
FF	109.5	111.5	2.0	1.8
GG	109.0	111.0	2.0	1.8
HH	108.5	111.0	2.5	2.3
II	108.0	110.5	2.5	2.3
JJ	108.5	111.5	3.0	2.8

Table 5.2.3.3: Total Measured Elongation of the Ropes

While this seems to indicate that the new ropes perform better during the dynamic tests, the opposite is actually true. By looking back at Figure 5.2.3.2, it can be seen that the new ropes elongate about twice as much as the precycled ropes do during the dynamic tests. This is very important in the application of SCEDs. If a new rope were used as a SCED, a large amount of elongation would occur in the first few cycles and the structural frame might not sway far enough for the rope to become taut after that. Therefore, it is vital that the SCED have limited elongation under dynamic loading. With that in mind, the Precycled Amsteel II ropes performed the best during the dynamic tests, stretching about 1.5 inches. This is about half as much as the New Amsteel II ropes and about one-third as much as the Precycled Amsteel Blue ropes.

5.2.4 Energy Dissipation Trends and Comparisons

The amount of energy that is dissipated by the rope during the snap loads, the Energy Loss (ΔE), is compared to the Impulse (J) and the Dynamic Area (DA). The Impulse is the area under the dynamic force vs. time curve, the Energy Loss is the change in kinetic energy between the datum points of the Taut Phase, and the Dynamic Area is the area within the dynamic hysteresis loops. The Impulse trends for the Amsteel II ropes can be found in Figure 5.3.4.1, and the trends for the Amsteel Blue ropes can be found in Figure 5.2.4.2.

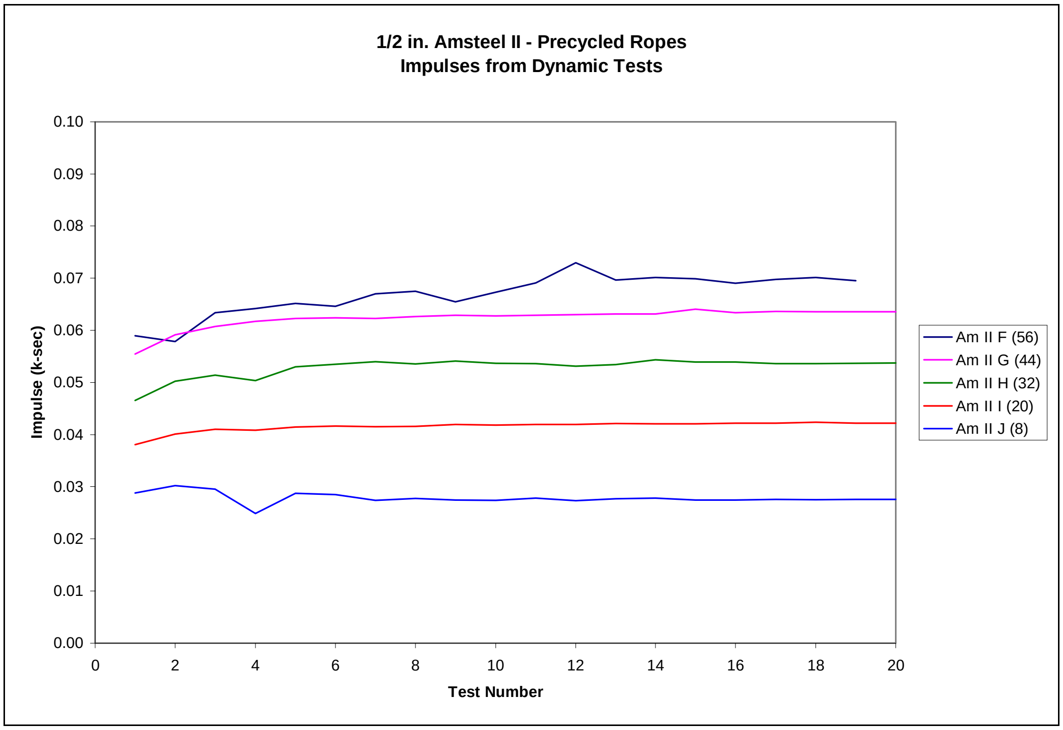

Figure 5.2.4.1: Impulses from the Precycled Amsteel II Dynamic Sequences

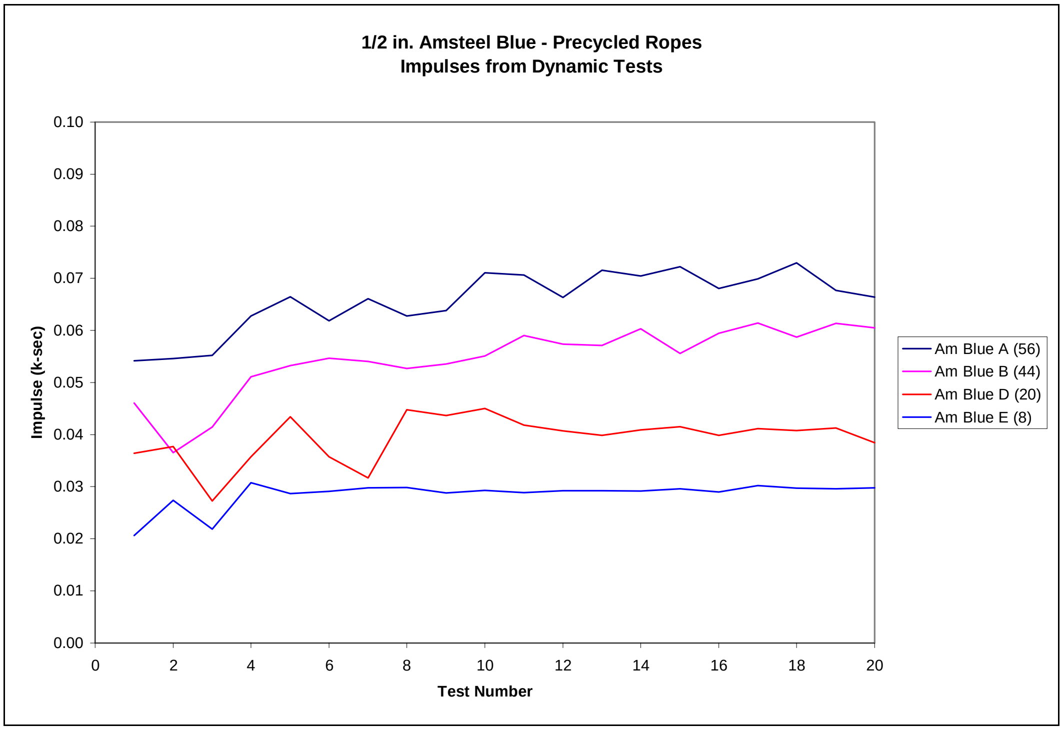

Figure 5.2.4.2: Impulses from the Precycled Amsteel Blue Dynamic Sequences

As before, there is a slight increase in the Impulse during the first few cycles for the Amsteel II ropes, but the areas become nearly constant after that. This occurs because during the beginning cycles, the force values are still increasing even though the Pulse Durations are higher then. Once both of these values level out, so does the Impulse. The increase for the Amsteel Blue ropes is again more gradual.

The Impulse values are dependent on the drop height because the force values increase when the plate has further to fall. However, there was no significant difference in the Impulse values between the pre-cycled and new ropes or the Amsteel II and Amsteel Blue ropes.

The trend for the Energy Loss was opposite to that of the Impulse. Even though the Impact Velocities don't change much throughout a sequence, the change in velocity is greater in the early cycles and therefore so is the energy loss. There is some variation in the data and several drop tests in the Amsteel Blue B sequence produced illogical values, but the Energy Loss generally decreases in the first few cycles before the values level off. The energy loss values are dependent on the drop height since it affects the velocity values, but there is little difference between the values for the precycled and new ropes. However, there is a noticeable difference between the values for the Amsteel Blue and Amsteel II ropes. The Amsteel Blue ropes on average dissipate between 0.25 and 0.5 k-in. more than the Amsteel II ropes do. This is due to the larger displacements that the Amsteel Blue ropes experience, which causes more friction to occur between the fibers in the ropes. The Energy Loss trends for the Precycled Amsteel II ropes can be found in Figure 5.2.4.3, and the trends for the Precycled Amsteel Blue ropes can be found in Figure 5.2.4.4.

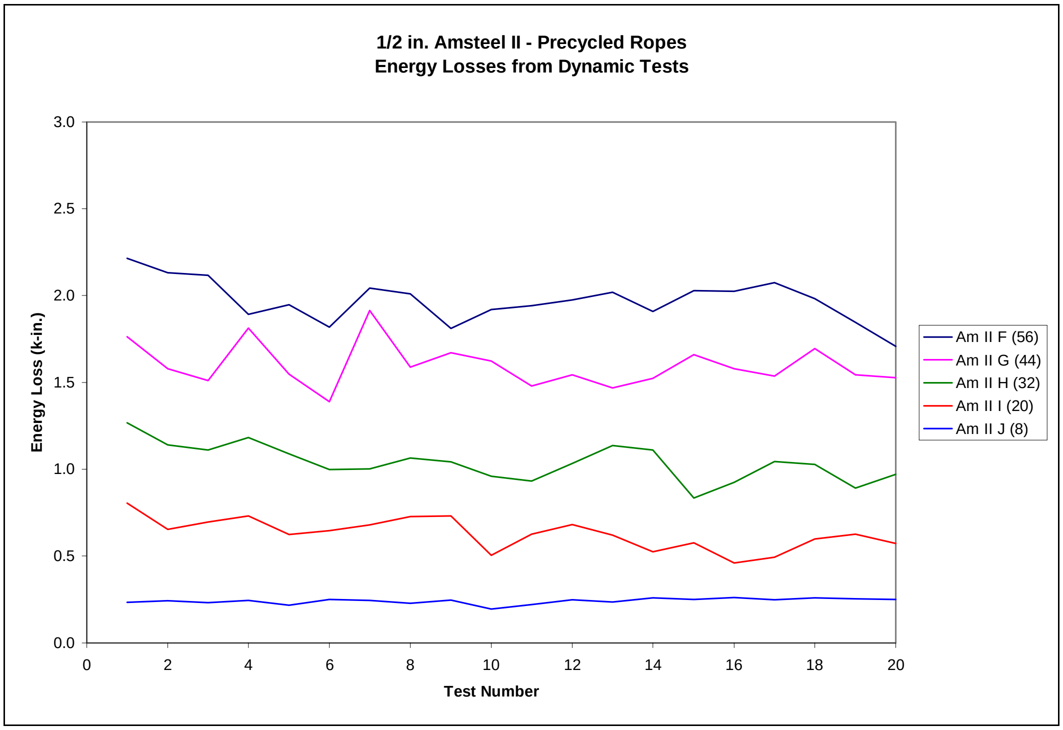

Figure 5.2.4.3: Energy Losses for the Precycled Amsteel II Dynamic Sequences

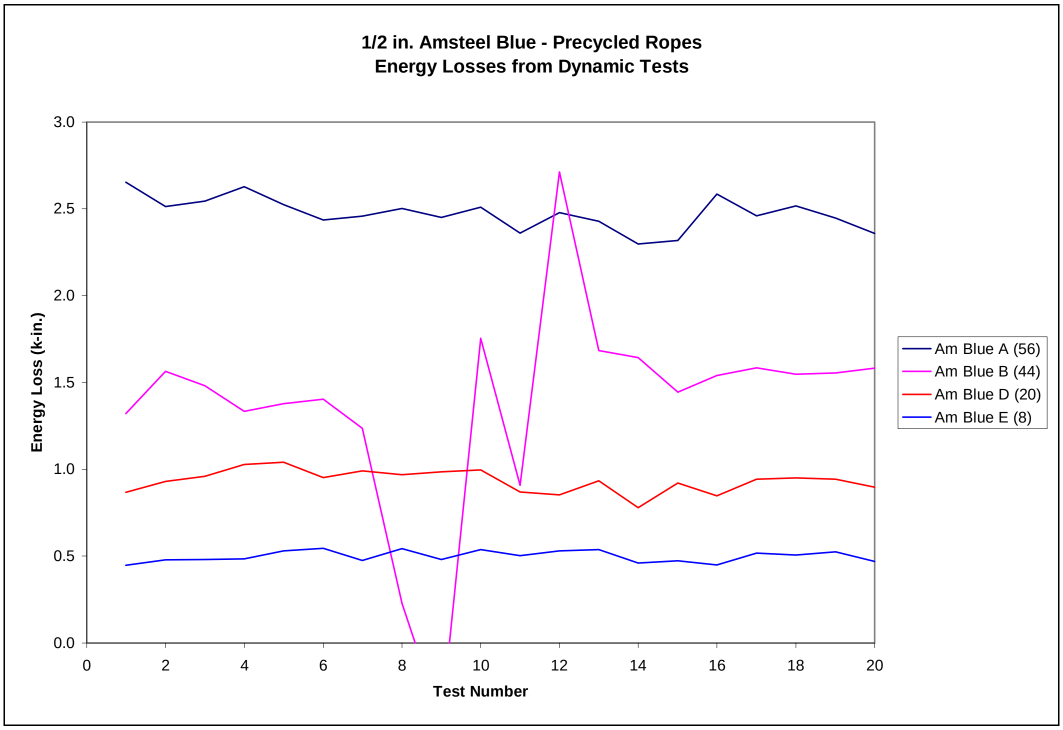

Figure 5.2.4.4: Energy Losses for the Precycled Amsteel Blue Dynamic Sequences

The Dynamic Area trends are similar to the Impulse trends. The values for the Amsteel II ropes increase in the first few cycles before leveling off. The values for the Amsteel Blue ropes once again increase more gradually until they reach a steady value. Graphs of this data can be found in Figures 5.2.4.5 and 5.2.4.6.

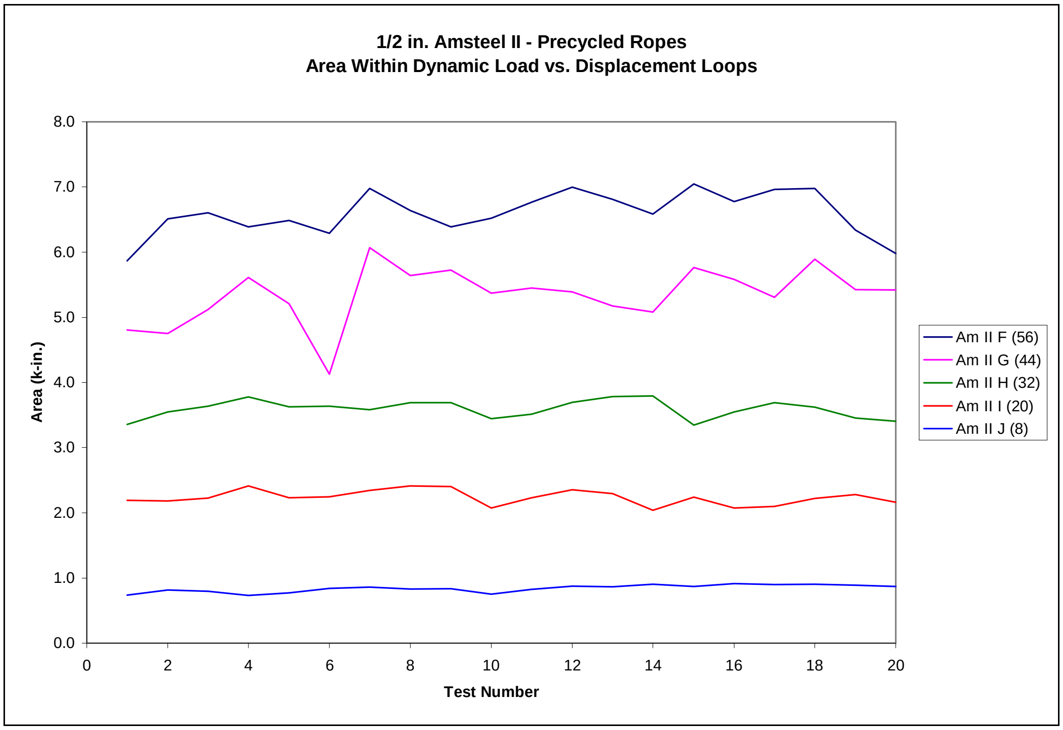

Figure 5.2.4.5: Dynamic Areas for the Precycled Amsteel II Dynamic Sequences

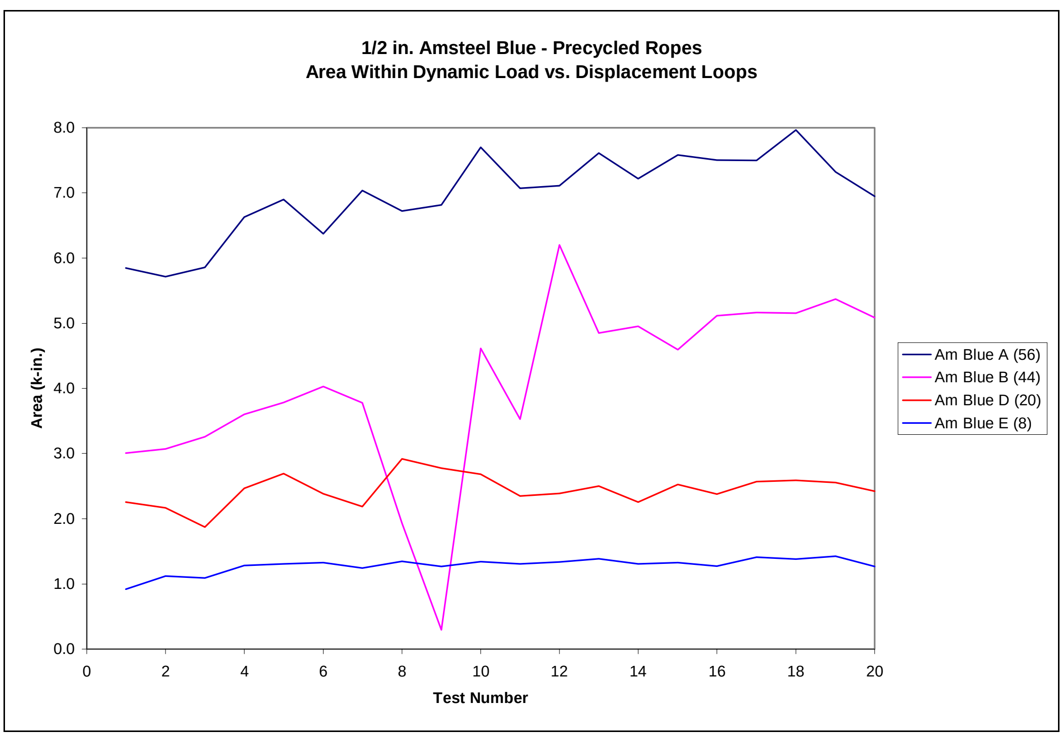

Figure 5.2.4.6: Dynamic Areas for the Precycled Amsteel II Dynamic Sequences

Even though the displacement values decrease in the early cycles before they become constant, the force values increase during those cycles and that has a greater effect on the Dynamic Area. The drop heights also affect these values, but there is little difference between the precycled and new ropes. Again, the Amsteel Blue ropes generally have larger values than the Amsteel II ropes.

There is no real way to compare the Static Area to the Dynamic Area because the forces are much higher in the dynamic tests and the displacement values were recorded continuously during each static sequence. However, the values were plotted against each to see if there was any correlation. An example of this can be found in Figure 5.2.4.7. As can be seen, the Dynamic Area values for the new and precycled ropes are very similar, but the Static Area is much smaller and follows a different trend. If there were a way to continuously monitor the displacements throughout a dynamic sequence (for all 20 drop tests), the Dynamic Area trends would look the same as the Static Area trends. However, that was not possible with this experimental setup.

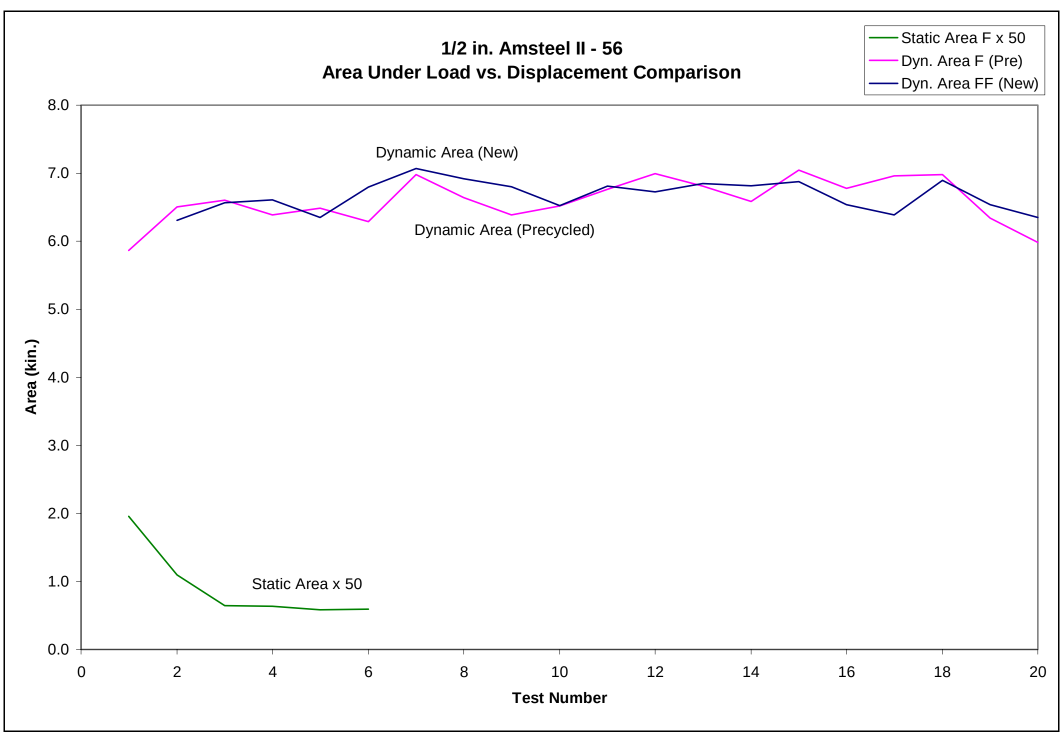

Figure 5.2.4.7: Dynamic Areas vs. Static Areas for Amsteel II F & FF

To show more clearly how the Dynamic Area values change as a test sequence progresses, several dynamic hysteresis loops were plotted on the same graph to demonstrate how the shapes change. Figures 5.23.4.8 and 5.2.4.10 compare the first five cycles for the Amsteel II and Amsteel Blue ropes, respectively. Cycles 1, 10, and 20 are compared for the same ropes in Figures 5.2.4.9 and 5.2.4.11.

As can be seen in these figures, the displacement values generally decrease and the force values increase as more cycles are conducted. The dynamic hysteresis loops for the Amsteel II ropes reach a uniform shape after several cycles. This is apparent since there is a noticeable change between the hysteresis loops for cycles 1, 2, and 3, but those for cycles 3, 4, and 5 are very similar. In addition, since the size and shape of the cycle 5 hysteresis loop are nearly identical to those of cycles 10 and 20, this indicates that there is little change in the hysteresis loops after the initial cycles. However, the dynamic hysteresis loops for the Amsteel Blue ropes are subject to a gradual change throughout a sequence as seen in its other quantities. This is apparent by looking at Figures 5.2.4.10 and 5.2.4.11. The shape of the hysteresis loops change between every cycle and the difference in shape between cycles 10 and 20 is much more pronounced than it is for the Amsteel II ropes.

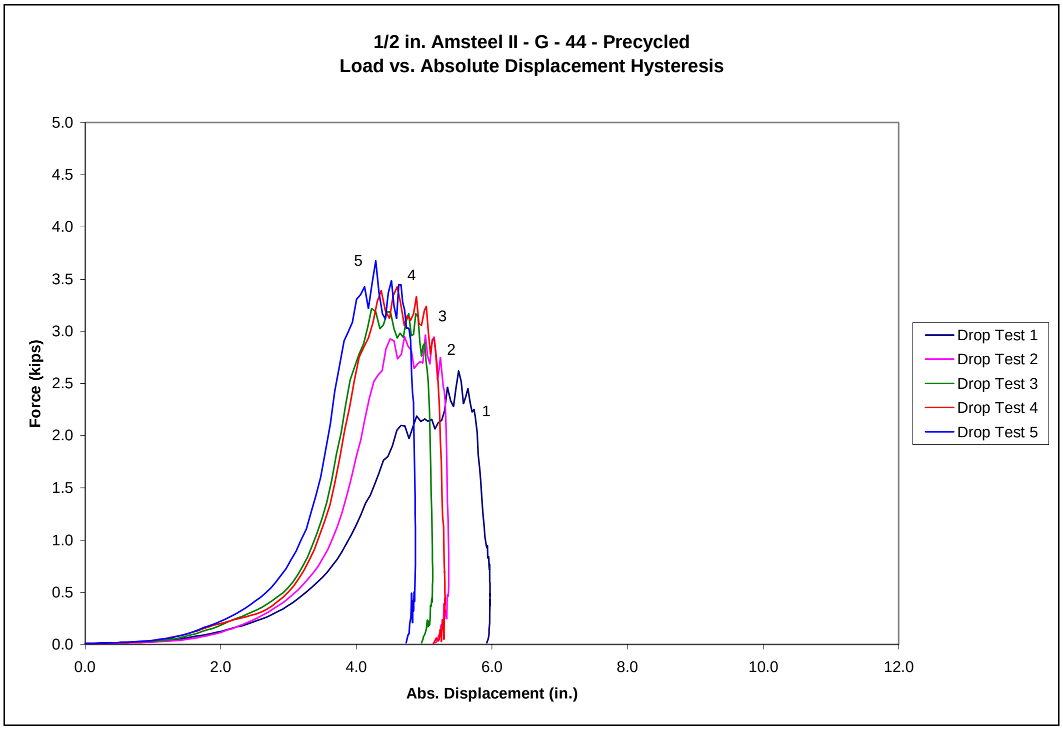

Figure 5.2.4.8: Changes in Dynamic Hysteresis - Amsteel II G (First Five Cycles)

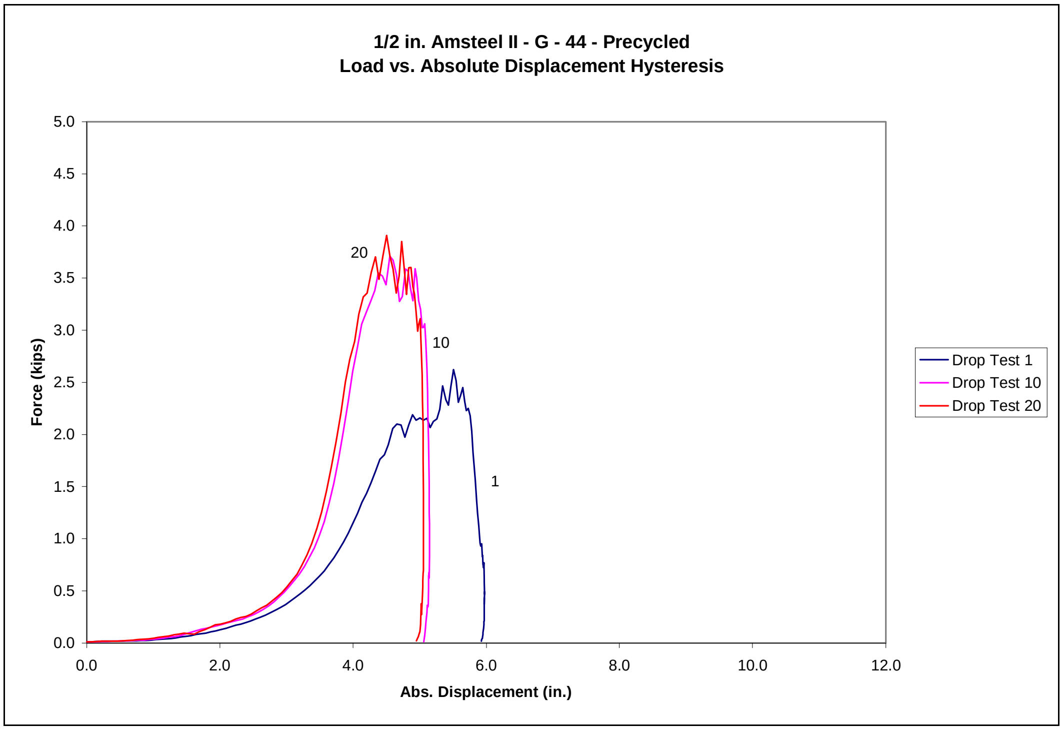

Figure 5.2.4.9: Changes in Dynamic Hysteresis - Amsteel II G (Cycles 1, 10, and 20)

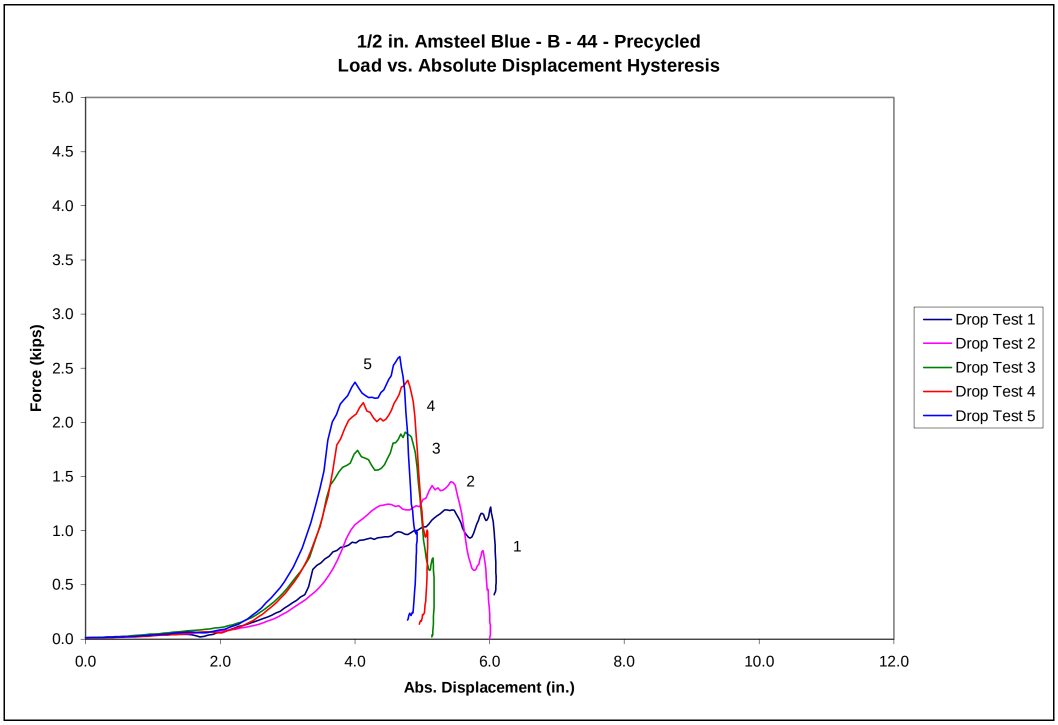

Figure 5.2.4.10: Changes in Dynamic Hysteresis - Amsteel Blue B (First Five Cycles)

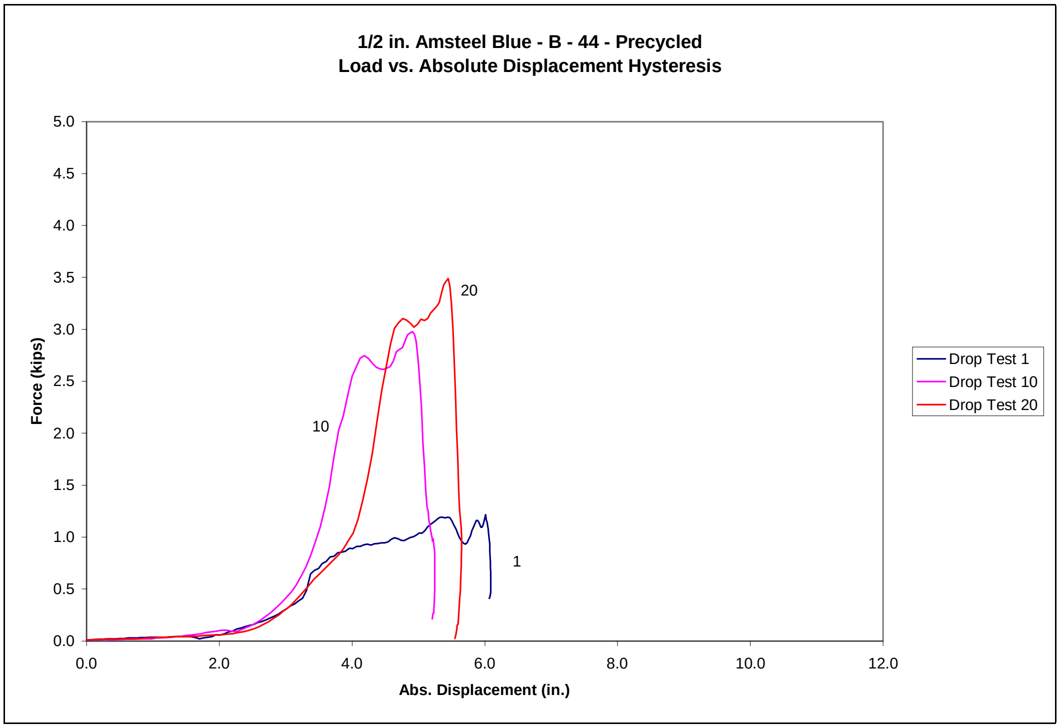

Figure 5.2.4.11: Changes in Dynamic Hysteresis - Amsteel Blue B (Cycles 1, 10, and 20)

The three quantities were compared to each other. An example of this for the Amsteel II ropes can be found in Figure 5.2.4.12, and Figure 5.2.4.13 shows these values for an Amsteel Blue rope.

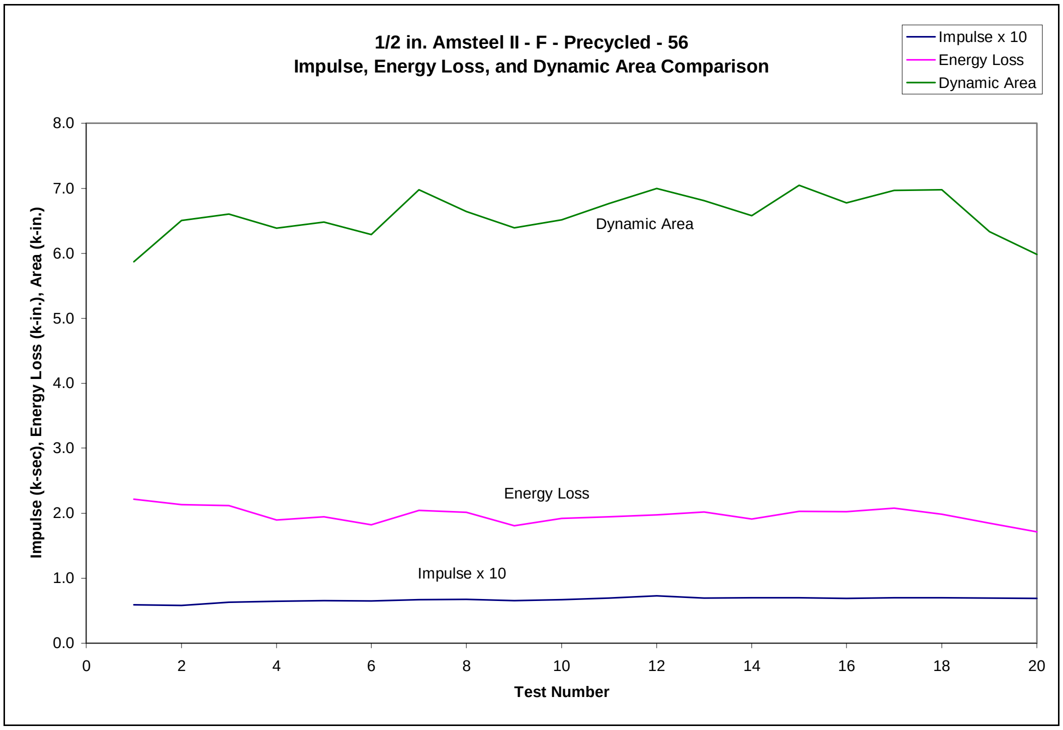

Figure 5.2.4.12: Impulse, Energy Loss, and Dynamic Area for Precycled Amsteel II F

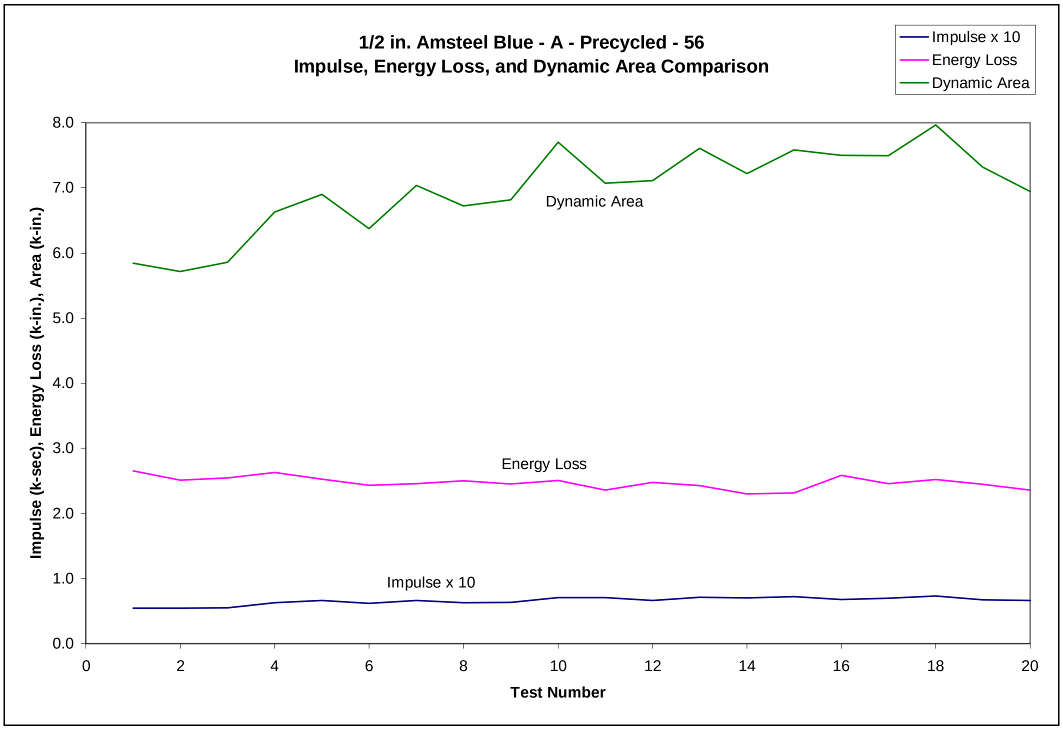

Figure 5.2.4.13: Impulse, Energy Loss, and Dynamic Area for Precycled Amsteel Blue A

The Impulse is much lower than the other two quantities, but since it is not in the same units as the Energy Loss and the Dynamic Area, comparing its value to these quantities is not appropriate. However, the other two quantities are in the same units and the Dynamic Area is consistently larger than Energy Loss. All three of these quantities (as well as the Maximum Force and Maximum Acceleration) were averaged for each sequence and the values can be found in Table 5.2.4.1. The average *DA/ΔE* ratio for the Amsteel Blue ropes was 2.73 and for the Amsteel II ropes it was 3.46. The *DA/ΔE* ratios for each individual rope did not vary much from the averages for each rope type, and this consistency indicates that a coefficient could be applied to the Dynamic Area in order to obtain the Energy Loss in future tests and models.

Rope	Drop Height (in.)	Average ΔE (k-in.)	Av. Dyn. Area (k-in.)	DA/ΔE	Av. Max. Accel. (g)	Av. Max. Force (kips)	Av. Impulse (k-sec)
Amsteel Blue - A	56	2.47	6.97	2.82	29.4	3.58	0.0657
Amsteel Blue - AA	56	2.45	6.64	2.71	30.0	3.71	0.0639
Amsteel II - F	56	1.97	6.59	3.35	32.0	4.17	0.0670
Amsteel II - FF	56	1.89	6.67	3.52	32.6	4.21	0.0700
Amsteel Blue - B	44	1.37	4.07	2.96	22.7	2.84	0.0545
Amsteel Blue - BB	44	1.61	4.91	3.05	23.7	2.96	0.0572
Amsteel II - G	44	1.60	5.34	3.35	27.3	3.64	0.0623
Amsteel II - GG	44	1.40	4.95	3.53	30.3	3.60	0.0618
Amsteel II - H	32	1.04	3.59	3.46	24.0	2.87	0.0529
Amsteel II - HH	32	1.05	3.63	3.46	26.4	2.90	0.0529
Amsteel Blue - D	20	0.93	2.45	2.62	16.2	1.74	0.0394
Amsteel Blue - DD	20	0.74	1.98	2.69	14.0	1.62	0.0377
Amsteel II - I	20	0.63	2.23	3.55	19.9	2.17	0.0415
Amsteel II - II	20	0.66	2.28	3.45	16.5	2.04	0.0419
Amsteel Blue - E	8	0.50	1.28	2.57	10.4	1.16	0.0285
Amsteel Blue - EE	8	0.44	1.05	2.39	7.8	0.92	0.0261
Amsteel II - J	8	0.24	0.84	3.47	8.7	1.17	0.0278
Amsteel II - JJ	8	0.24	0.82	3.42	8.6	1.21	0.0271

Amsteel Blue Average DA/ΔE =	2.73
Amsteel II Average DA/ΔE =	3.46

Table 5.2.4.1: Comparison of Average Energy Dissipation and Recorded Data Values

Figure 5.2.4.14 is a plot of the Average Energy Loss vs. the drop height for each type of rope. As can be seen, the greater the drop height, the more energy was dissipated. Also, the Amsteel Blue ropes generally dissipated more energy than the Amsteel II ropes, but there was not much difference between the new and precycled ropes of the same type.

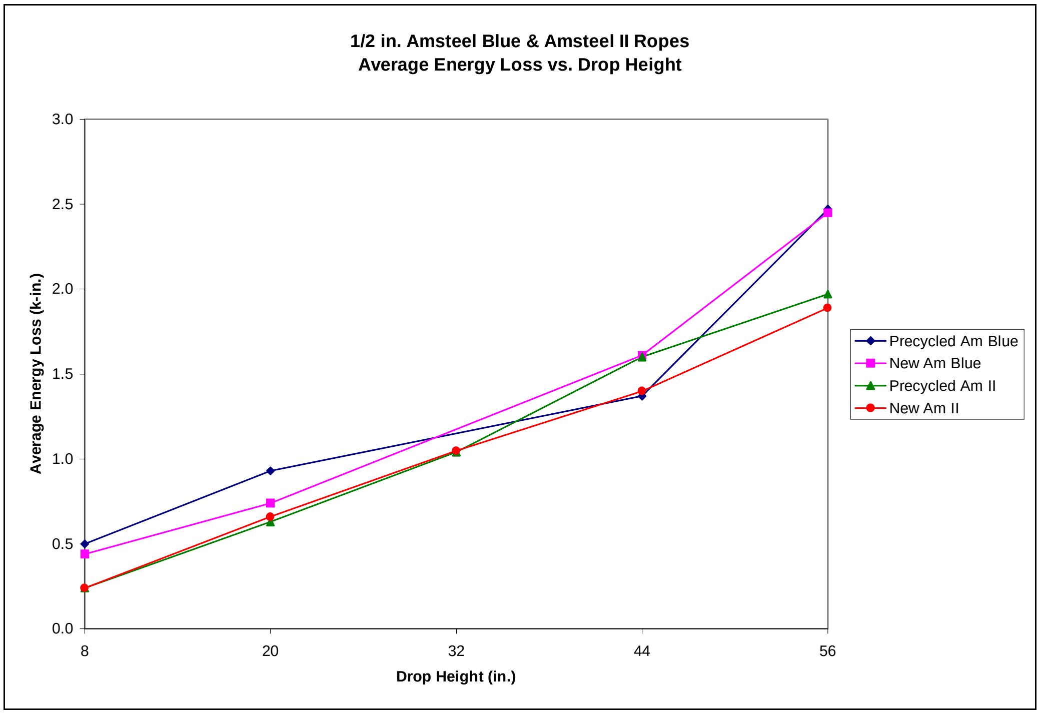

Figure 5.2.4.14: Average Energy Loss vs. Drop Height

5.2.5 Longitudinal Stress Waves

Several quantities were calculated that are related to the longitudinal stress waves that travel through the rope during the Taut Phase. The first quantity was the wave speed. The average wave speed for the Amsteel II ropes was around 6,250 ft/sec and the average for the Amsteel Blue ropes was around 4,100 ft/sec. This indicates that stress waves travel more quickly in stiffer ropes. The second quantity was the average Stress Wave Duration. This is the amount of time it took the wave to travel the length of the rope. For the Amsteel II ropes, this was 0.0015 seconds, and for the Amsteel Blue ropes it was 0.0025 seconds. The last quantity is the average number of waves that occur during the Taut Phase. For the Amsteel II ropes, the average was 36.5 waves, and for the Amsteel

Blue ropes it was 28.1 waves. These averages, along with the values for each individual rope, can be found in Tables 5.2.5.1 and 5.2.5.2.

1/2 in. Amsteel Blue - Longitudinal Stress Waves				
Rope	Approx. Drop Height (in.)	Wave Speed (ft/sec)	Stress Wave Duration (sec)	# Waves in Taut Phase
A	56	2720.4	0.0035	16.5
B	44	4455.4	0.0021	28.5
C	32	5733.1	0.0016	40.7
D	20	3464.4	0.0027	26.7
	Averages	4093.3	0.0025	28.1

Table 5.2.5.1: Longitudinal Stress Wave Data for the Amsteel Blue ropes

1/2 in. Amsteel II - Longitudinal Stress Waves				
Rope	Approx. Drop Height (in.)	Wave Speed (ft/sec)	Stress Wave Duration (sec)	# Waves in Taut Phase
F	56	6233.9	0.0015	32.2
G	44	8531.3	0.0011	44.0
H	32	4905.8	0.0019	32.2
I	20	6244.9	0.0015	35.2
J	8	5317.6	0.0017	39.0
	Averages	6246.7	0.0015	36.5

Table 5.2.5.2: Longitudinal Stress Wave Data for the Amsteel Blue ropes

5.2.6 Comparison of the Analytical and Theoretical Data

The analytical values were compared to theoretical values that were computed using the equations discussed in Chapter 4. The first quantity that was examined was the rope stiffness. The Static Stiffness, Dynamic Stiffness, and Theoretical Dynamic Stiffness are plotted in Figure 5.2.6.1 for an Amsteel Blue rope and in Figure 5.2.6.2 for an Amsteel II rope. The static rope stiffness value is taken as constant in these plots and is smaller than the dynamic stiffness in every case. However, the first dynamic stiffness value is very close to the static stiffness value, but it increases after that. The theoretical dynamic stiffness values from equation (4-10) follow the same trends as the experimental values, but are about twice as large. This difference is fairly consistent and was expected because the theoretical equation is based on a frictionless, linearly-elastic system, which is not the case here.

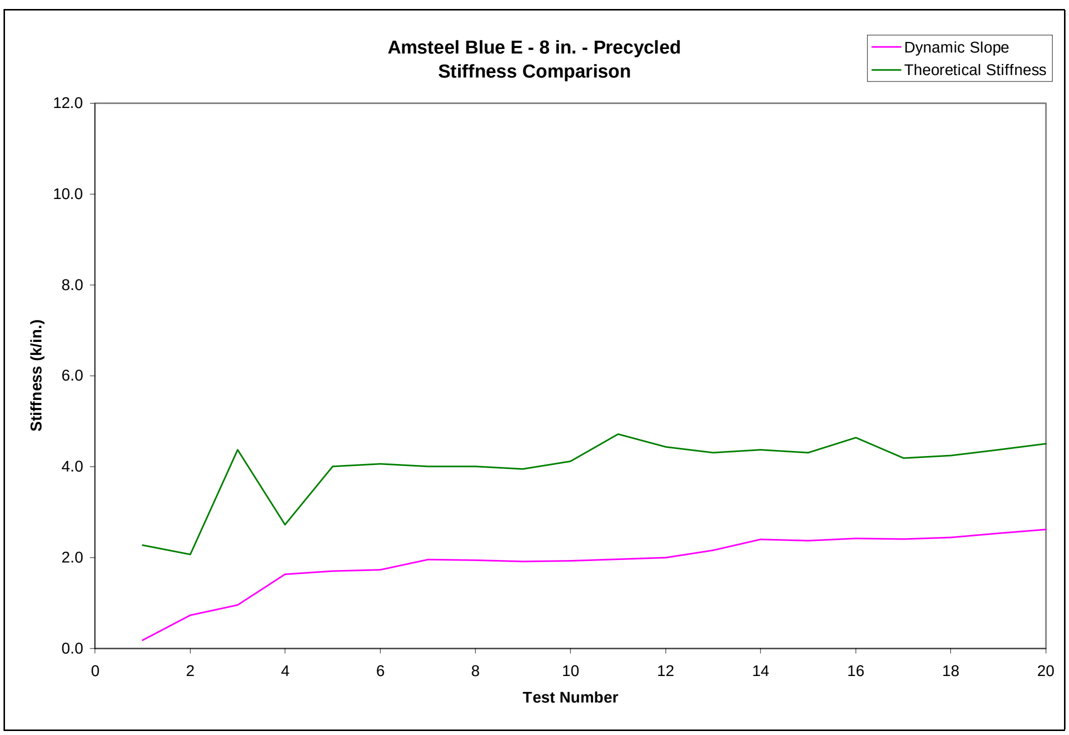

Figure 5.2.6.1: Stiffness Comparison for a Precycled Amsteel Blue rope

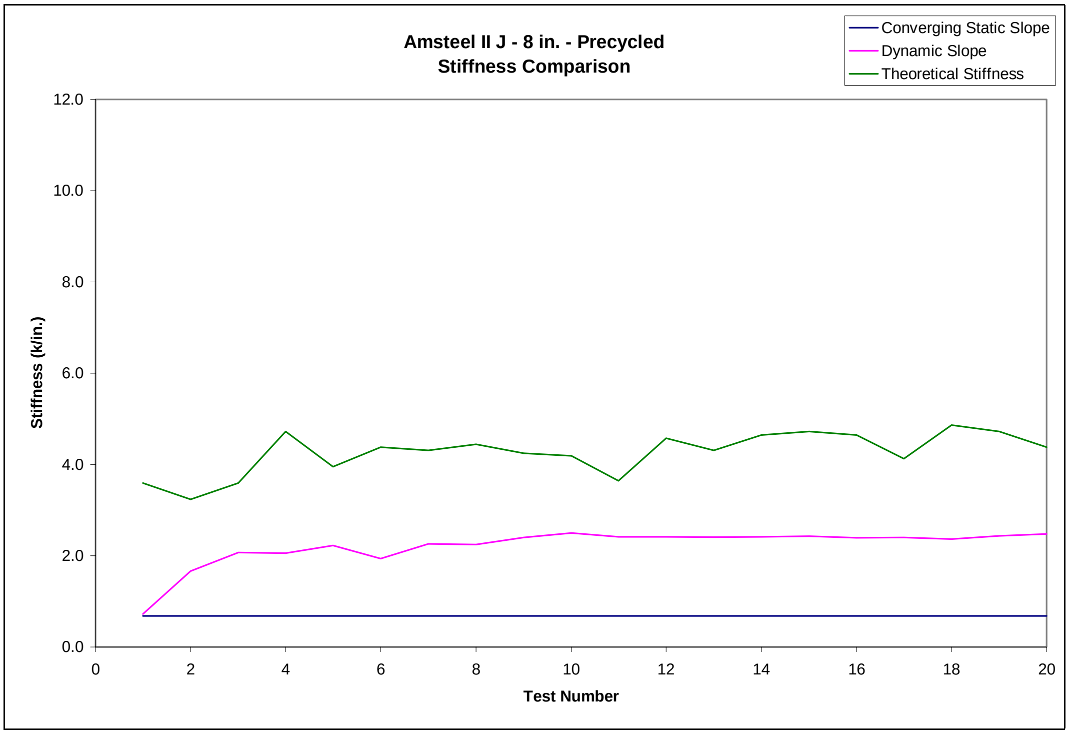

Figure 5.2.6.2: Stiffness Comparison for a Precycled Amsteel Blue rope

The next comparison is between the experimental and theoretical Impact Velocities. The theoretical values were computed using the free-fall equation (4-12) and the established drop height for a given sequence. It was known that there would be a large difference between the two values because of the friction and the air resistance of the sliding plate. The percent difference between the two is called the percent of velocity lost due to friction. The average percent velocity losses can be found in Table 5.2.6.1. There is no general trend for these values, but the average velocity loss for the Amsteel Blue ropes is 14.7%, and it is 18.1% for the Amsteel II ropes.

Precycled Ropes		
Rope	Average % Vel. Loss	Standard Deviation
A	12.4	1.93
B	25.6	11.42
D	13.0	2.95
E	13.5	3.33
F	17.3	1.51
G	15.9	1.88
H	19.0	1.68
I	20.0	2.51
J	24.6	1.88

New Ropes		
Rope	Average % Vel. Loss	Standard Deviation
AA	9.7	1.79
BB	17.0	1.76
DD	12.0	8.11
EE	-12.5	12.75
FF	16.9	1.17
GG	18.3	1.59
HH	16.9	1.18
II	14.4	2.20
JJ	17.4	2.20

Test Group	Average % Vel. Loss
Precycled Amsteel Blue	16.1
Precycled Amsteel II	19.3
New Amsteel Blue	12.9
New Amsteel II	16.8
All Amsteel Blue	14.7
All Amsteel II	18.1

Table 5.2.6.1: Average Velocity Loss values

The next comparison that was made was between the experimental and theoretical Maximum Displacement values. The theoretical equation (4-14) is based upon the experimental Impact Velocities and the experimental Stiffness values and therefore should compare well with the experimental values. Figures 5.2.6.3 and 5.2.6.4 are plots of both data series for an Amsteel Blue and Amsteel II rope, respectfully. These plots show that the two values are very close to each other and follow the same trends.

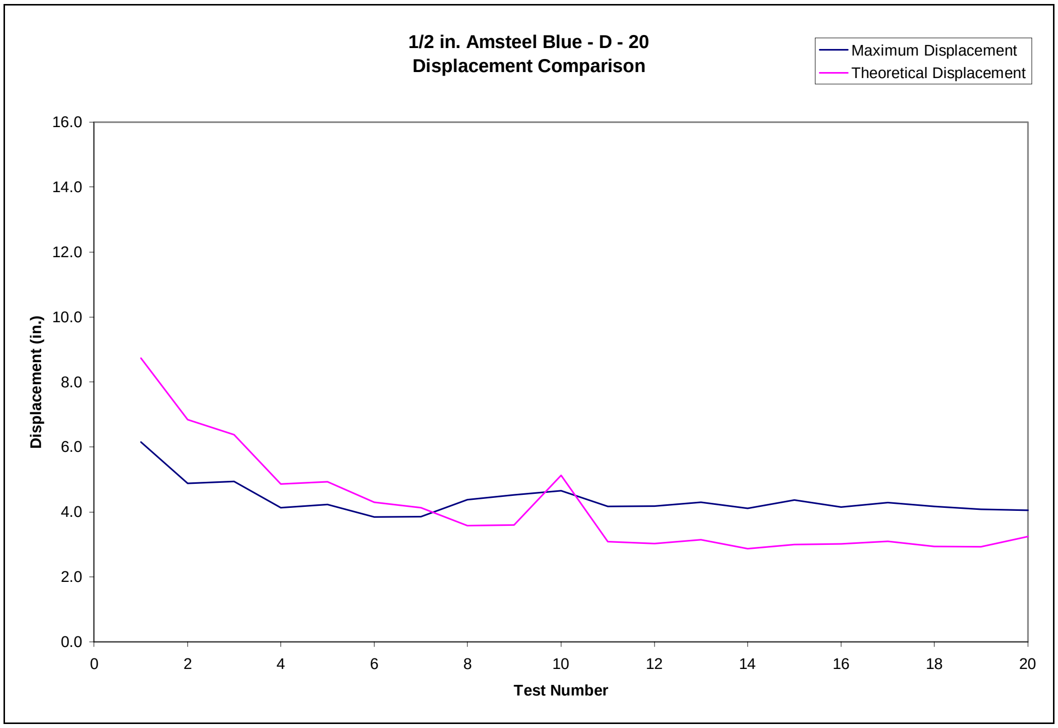

Figure 5.2.6.3: Maximum Displacement Comparison for a Precycled Amsteel Blue rope

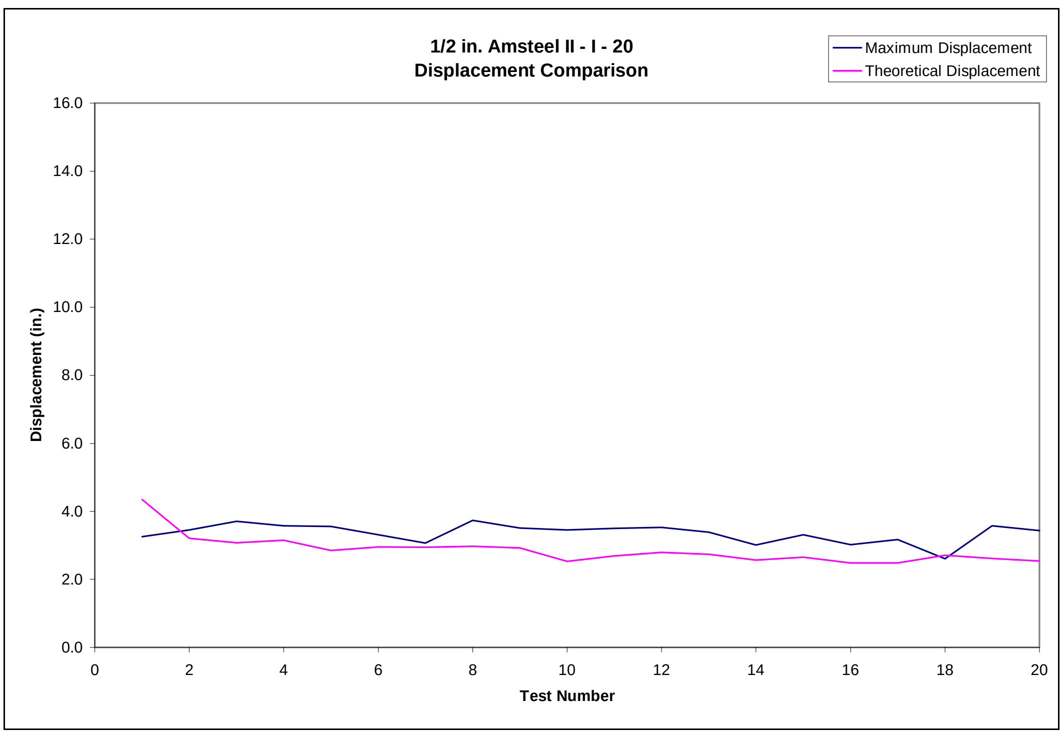

Figure 5.2.6.4: Maximum Displacement Comparison for a Precycled Amsteel II rope

The last comparison that was made was between the experimental and theoretical forces during the Taut Phase. The theoretical values were based on equation (4-15) and are the forces that were experienced at the bottom of the rope. However, the experimental forces were obtained from a load cell located at the top of the rope. Figure 5.2.4.5 shows a comparison of the two data series.

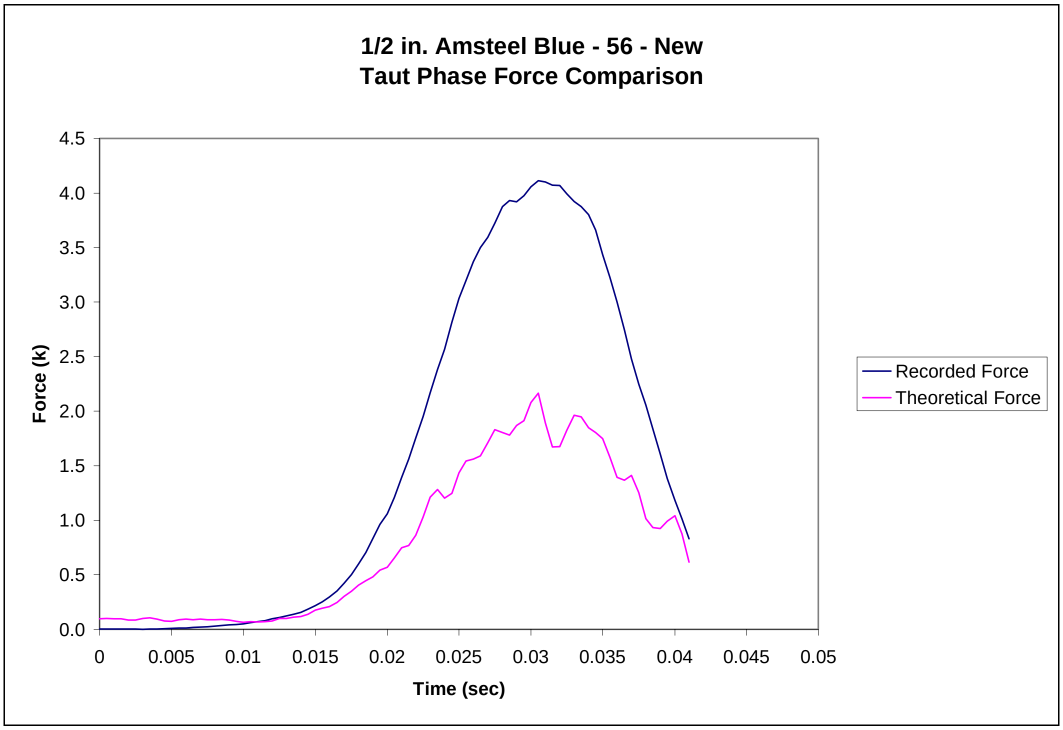

Figure 5.2.6.5: Force Comparison for a New Amsteel Blue rope

As can be seen, the recorded forces are about twice as large as the experimental forces for most of the Taut Phase. This trend was consistent for all of the comparisons that were made and can be explained. The longitudinal stress waves that are produced by the snap load cause the force at the top of the rope to be larger than the force at the bottom of the rope (Goldsmith 2001).