Chapter 3

Test Set-Up and Procedure

3.1 Testing Methods

All experimental static tests and dynamic tests were conducted at the Virginia Tech Structures and Materials Facility (Structures Lab). Multiple pieces of equipment were used to carry out these tests. Many different methods of performing the snap load tests were explored prior to running the tests. Initially, the proposed idea was to use a drop tower provided by the Adhesions Laboratory at Virginia Tech. This tower is approximately six feet in clear height and consists of a small rectangular plate sliding on two steel rods. A high-speed camera was going to be used to gather displacement data. After talking with Dr. R. Chou of Samson Rope Technologies, it was decided that the snap load tests would need a larger drop tower with a greater clear distance to conduct the tests. In many of the synthetic fiber ropes tested, the length of the eye splice is substantially long (sometimes two or three feet into the rope) compared to the overall length of the rope. For this reason, the six-foot drop tower would not be adequate to fully test the "true" rope but the eye splice instead. In addition to the height limitations, there was not an easy way to apply different weights to the sliding plate. Since the drop tower in the Adhesions Laboratory does not belong to the Civil and Environmental Engineering Department at Virginia Tech, lab time with the tower would have to be shared with other academic departments.

Another method explored to perform the snap load tests was simply attaching one of the ropes to a beam in the lab, with the other end attached to a weight. The weighted end of the rope could be raised to a certain height and then dropped to perform a test. It was decided that this method would not be feasible because of the difficulty in capturing the displacement of the end of the rope. Under this method, the rope would most likely swing out-of-plane after becoming taut and not allow the displacement data to be collected. Also, there was not a clear way to attach a weight to the end of the rope without compromising the rope's strength or the integrity of the test. Some tests were conducted at Southern Illinois University's Carbondale campus using a method similar to this one. Professor Serge Abrate presented the results of snap load tests on two types of ropes that simulate the effects of parachute chords becoming taut upon deployment ("Nonlinear dynamic behavior of parachute static lines"). This presentation occurred at the 14th U.S. National Congress of Theoretical and Applied Mechanics at Virginia Tech during the summer of 2002. This test set-up used a crane with a load cell attached to a hook on the crane. A rope could be attached to the load cell at one end and have a weight attached to the other end. Eight-foot ropes were used in these tests, with the dropping weight varying from 320 lb to 400 lb. The load cell registered the amount of force on the rope at regular time intervals. The possibility of the rope swinging out-of-plane after the snap load took place was not a problem because no displacement data were recorded in these tests.

After careful consideration of all options and sources, it was decided that a drop tower would need to be built specifically for the snap load drop tests. The tower was modeled after the small drop tower located in the Adhesions Laboratory. The drop tower used for the snap load tests is now located in the Structures Lab at Virginia Tech.

3.2 Drop Tower

As mentioned previously, the drop tower used in the static and dynamic tests for snap loading was modeled after the small drop tower located in the Adhesions Laboratory. That drop tower has two steel rods on which the stabilizing plate can slide vertically up and down. The drop tower used in the snap load tests, which will be called the drop tower thus forth, has four steel rods on which a square stabilizing plate can slide vertically up and down. A preliminary sketch of the drop tower was given to Brett Farmer, who is a technician at the Structures Lab. Dr. Thomas Murray and Brett Farmer handled the drop tower details including material choices and design. A total height of eleven feet was decided upon so that ropes up to nine feet in length could be tested. This length can be increased slightly if a smaller load cell is used for testing. A sketch of the drop tower is shown in Figure 3.1.

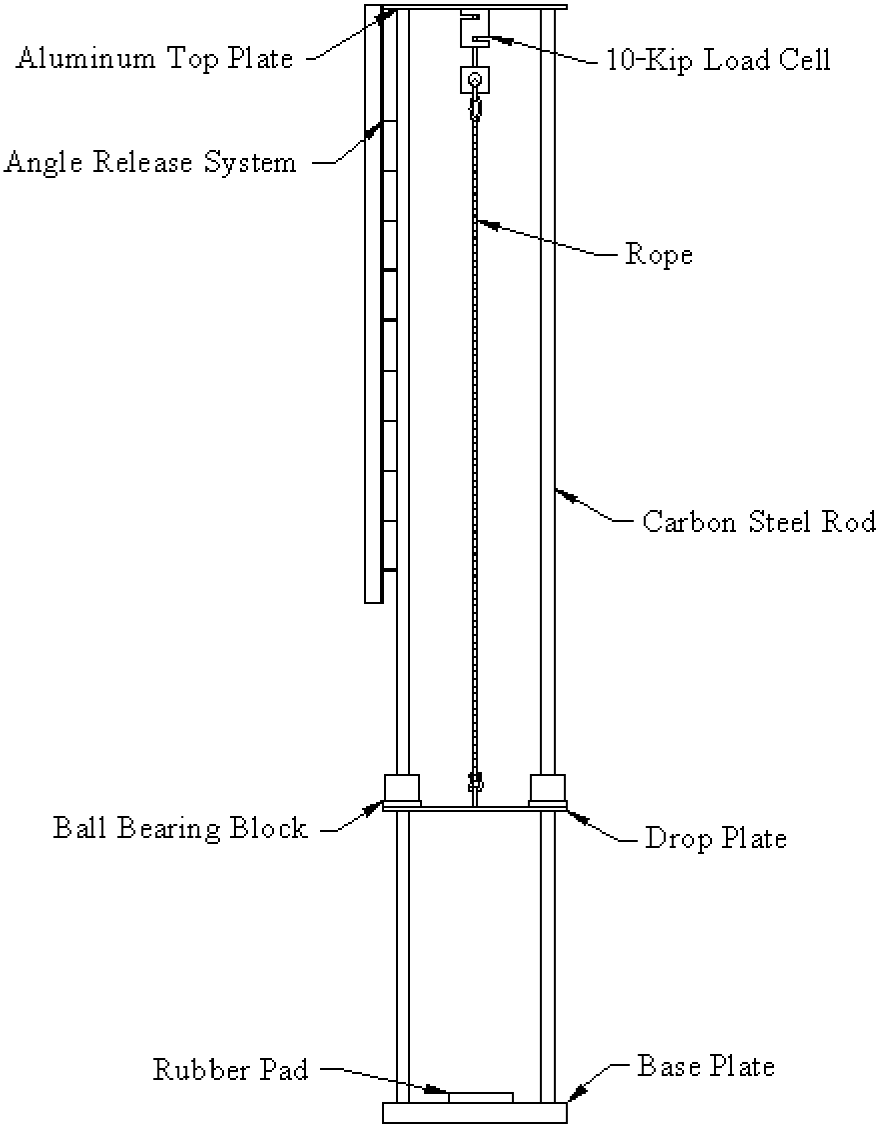

Figure 3.1 Drop Tower with Labeled Components

The main components that make up the drop tower are two 22 in. x 22 in. x 1/2 in. aluminum plates, one 22 in. x 22 in. x 2.5 in. steel plate, and four 1.5 in. diameter 1566 carbon steel rods. One aluminum plate is used as the stabilizing or drop plate to which one end of the rope can be attached. This plate also serves as a support to add various amounts of weight (in ten pound increments) to the rope. Two threaded bolts are attached to two sides of the plate so that ten-pound weighted plates can be placed evenly on each side. Each weight has two holes through the center to accommodate the threaded bolts. Nuts can be screwed onto the bolts so that the weights stay connected to the drop plate. The other aluminum plate is used as the top plate of the tower. This plate is essential not only for supporting the load cell but also for connecting and stabilizing the four steel rods. Aluminum was used for the drop plate and the top plate because it possesses high strength with a fraction of the weight of steel. The larger steel plate is used for the drop tower's base plate. With a weight of 408 lb, the base plate stabilizes the slender drop tower and prevents it from tipping over. The four steel rods have a core that is surrounded by a case. The core is made of carbon steel and hardened to 18-25 Rockwell C, while the case is also made of carbon steel and hardened to 60 Rockwell C.

Some of the smaller components that make up the drop tower are four 1.5 in. diameter Super Smart Ball Bushing Linear Bearing Pillow Blocks by Thomson Industries Inc., two 3/4 in. screw pin anchor shackles, a four-pulley lift system, a segmented angle release system, and a ten-kip load cell. The ball bearing blocks allow the drop plate to slide up and down the steel rods with a limited amount of friction. These blocks also help to stabilize the plate and prevent it from wobbling down the steel rods. The two screw pin anchor shackles are vital to the drop tests. One shackle connects the load cell to one end of the rope while the other shackle connects the drop plate to the other end of the rope. The screw pin fits through an eye splice and is fastened into the shackle.

Many different methods were considered for raising the drop plate to a desired release position. Among these methods were using one of the lab cranes, raising the plate by hand, and a pulley system. After much consideration, it was decided to use a four-pulley lift system to raise the drop plate. The lab crane method was ruled out because of constraints associated with the crane and drop tower. Raising the plate by hand would be a difficult task for anyone to accomplish and also quite dangerous. The pulley system is contained completely within the drop tower. Three pulleys are attached to the top plate of the drop tower, while the fourth pulley is attached to a clip that supports the drop plate. The pulley that is attached to the drop plate can be unclipped so that the drop test is not influenced by friction in the pulley system. Weights can be added to the drop plate at a low level, and then the drop plate can be lifted to a desired drop height using the pulley system. Since the pulley system is a combination of simple machines, the amount of work or strength required to raise the drop plate under load is a fraction of the actual weight.

Another aspect of the drop tower that had to be decided upon was the manner in which the drop plate could be placed at regular height intervals and released. Brett Farmer, the Structures Lab technician, proposed a release system that employs a hinged angle (2 in. x 2 in. x 1/8 in.) with welded tabs placed at regular intervals. A six-foot section was cut and assembled to make the release system. Ten smaller pieces of the angle were welded to one face of the angle at six-inch intervals so that multiple drop heights could be utilized. A hinge was welded to one end of the angle and screwed into the top plate of the drop tower. This hinge allows the angle to swing in and out from the tower. As the drop plate is raised up to a desired position, the angle can be pulled away from the tower to allow the plate to pass by the protruding smaller angles. Once the desired drop height is reached, the angle can be brought back into the plane of the drop tower so that the plate can rest on one of the smaller welded angles. A ten-kip load cell is attached to the center of the tower's top plate. This load cell serves not only as a way to fix the rope to the top of the tower, but also as a device to register the amount of force the rope is experiencing at a fixed time rate. Originally, a two-kip load cell was used for testing, but as the amount of weight added to the drop plate increased, it was decided that a larger load cell should be used.

As mentioned previously, the height of the drop tower is approximately 11 ft. The total clear span length or drop test length is approximately 9 ft 7 in. The top plate of the tower is 1/2 in. thick, and the load cell with the load plate is ten inches in length. Two protective rubber pads that protect the drop plate from the base plate are one inch thick, while the drop plate is one half inch thick. The screw pin and shackle apparatus connected to the drop plate are four inches in length, and the screw pin and shackle connected to the load cell adds an extra one inch in length to the load plate.

The following figures show photographs of the actual drop tower as well as some close-up shots of the individual components associated with the tower.

Figure 3.2 Side View - Drop Tower

Figure 3.2 illustrates the drop tower with the angle release system. As is apparent in the figure, the individual angles have been welded to the hinged release angle. Also shown in this figure are the ten-pound plates that can be applied to the drop plate to add more weight. Two nuts can be screwed down to each plate to secure them to the drop plate. The four-pulley lift system is also shown in this figure with the testing rope attached to the drop plate.

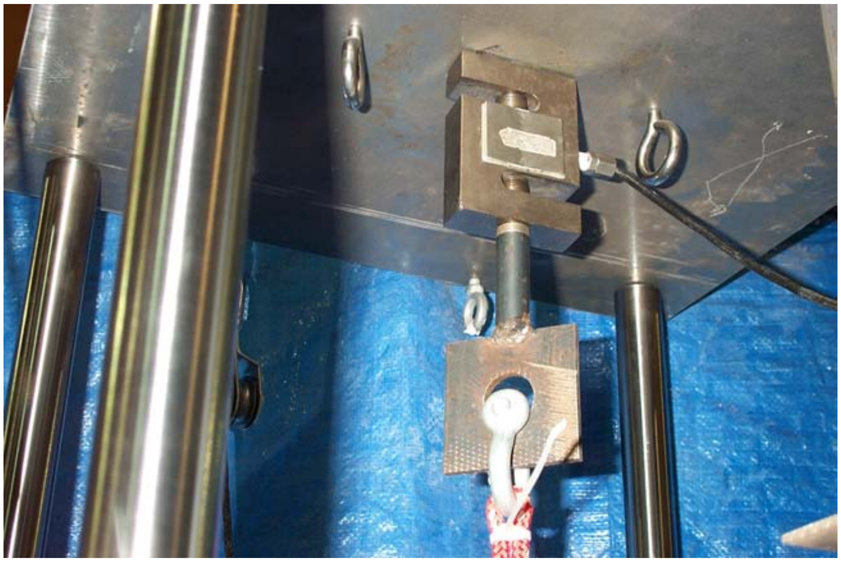

Figure 3.3 Ten-kip Load Cell with Attached Rope

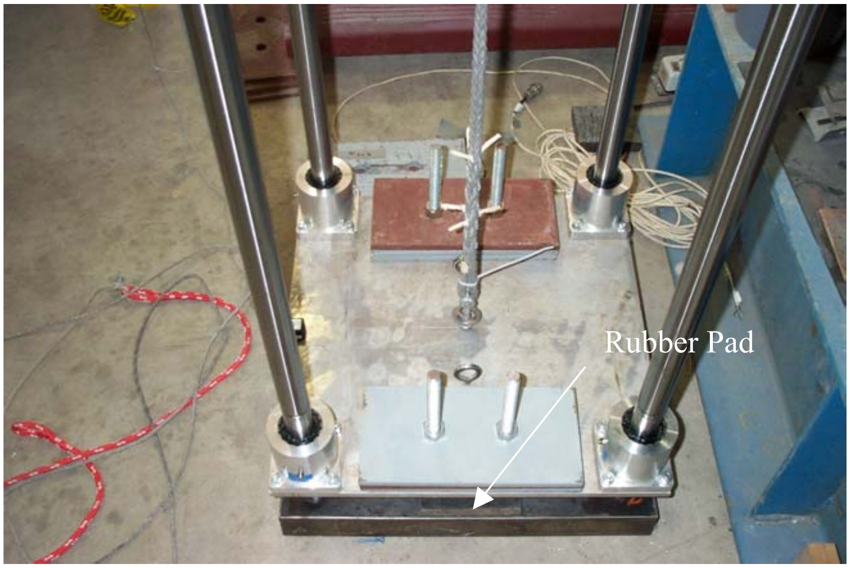

Figure 3.4 Drop Plate with Attached Rope

Figure 3.3 shows a synthetic fiber rope attached to the 10-kip load cell with a cable tie used to stabilize the rope splice. Cable ties were used to tightly fasten the ropes to the shackles on the load cell and drop plate, so that excess slip would not occur during the drop tests. Figure 3.4 shows the drop plate with an attached rope and weights. The protective rubber pads are sitting on top of the base plate. One of the pads is visible at the bottom of Figure 3.4.

3.3 Data Acquisition System

One of the most important instruments used in both the static tests and the dynamic tests was the System 6000 data acquisition system. The System 6000 is manufactured by Vishay Measurements Group and is part of the Strain Smart Data Systems group. A unique characteristic of the System 6000 is its ability to measure both static and dynamic signals. It can also store, reduce, and display data using the Strain Smart software. The dual signal processing allowed both static and dynamic tests to be conducted using the same acquisition system. The system converts analog output into digital output, which can be displayed in a number of different software programs. The system itself is attached to a personal computer where the data can be stored on the hard drive. All data obtained from the static and dynamic tests were brought into Excel for further experimental study.

The System 6000 has a maximum scan rate of 10,000 samples per second per channel (20 available channels). Each channel has an individual input card that is unique to the type of sensor being used for data acquisition. Two types of cards are used for the System 6000 in the Structures Lab at Virginia Tech. Strain gage cards and high level cards are the only cards available for testing in the lab. For the static tests, the load cell used a strain gage card and the wire pot (used to measure displacement) utilized a high level card. A scan rate was not needed for the static tests because measurements were taken at various points that were not time-dependent. A strain gage card was used for the load cell under dynamic loading, and a high level card was used for the accelerometer during the dynamic tests. Under dynamic loading, the scan rate was set for 5,000 readings per second for the accelerometer and the load cell. The System 6000 can supply a voltage to the equipment that is being used for data acquisition and receive a return voltage. This return voltage can be converted from an analog signal to a digital signal and viewed as raw data. Various digital filters can be used for signals up to 4 kHz as well.

3.4 Static Test Procedure

As mentioned previously, half of the 9 ft long ropes and the three 7 ft long ropes were tested under static loading prior to loading them dynamically. Not all of the static tests were performed in the same manner. Some of the ropes were subjected to higher forces than others, and the number of testing cycles was varied for different ropes as well. Some of the ropes were loaded and unloaded continuously, while some of the ropes were loaded and unloaded and isolated for a period of time before being cycled again. Rope displacements were measured using a wire pot that was powered by the System 6000. Linear displacement transducers measure deflections using an extendible wire that spins on a spool. A linear displacement transducer was placed directly under the drop plate so that vertical displacements of the tested ropes could be measured. As is the case with both the static and dynamic tests, the rope being tested was attached to the load cell at the top of the drop tower and to the drop plate at the other end of the rope.

Once the rope being tested was secured to the load cell and the drop plate, the pulley system was used to relieve the weight of the drop plate (approximately 25 lb) from the rope and the load cell was set at zero force. The wire pot was attached to the bottom of the drop plate prior to relieving the weight of the drop plate where it was set at zero displacement. After both measuring devices were “zeroed” out, the static tests were initiated. The general test procedure was the same for all of the static tests with some variances in the number of cycles, maximum force, and time between tests. The number of cycles ranged between three and eight, while the maximum force ranged between approximately 100 lb and 200 lb. Time between tests ranged between less than a minute to a day. A majority of the tests, especially on the nine-foot ropes, were cycled consecutively, so there was very little time between cycles for the rope to recover. On tests where the rope was allowed to recover for a day before recycling, the amount of total displacement was exaggerated because much of the elongation that was recovered over a period of 24 hours was elongated again with the amassing of additional elongation. The variance in test procedure allows for a better understanding of rope behavior under static loading. Multiple static tests were not conducted on each rope for various reasons. One of these reasons is that once the rope has been cycled, the rope will never fully recover to its original length, so the data collected on the first set of cycles are unique and unable to be repeated. Another reason for not conducting multiple static tests on each rope is that numerous static tests have been conducted by manufacturers on synthetic fiber ropes, so there is an abundance of information on this testing procedure.

Each rope started with an initial displacement of zero inches at zero force. The force was increased in ten-pound increments by adding ten-pound plates to the drop plate, and data were recorded at each incremental increase. As mentioned previously, the force was increased to a maximum of approximately 100 lb to 200 lb (approximately 1% of average breaking strength) depending on the test. Each rope was loaded and unloaded in the same manner.

3.5 Dynamic Test Procedure

Ropes were attached to the load cell and the drop plate for the dynamic tests in the same manner as they were for the static tests. The wire pot used in the static tests was replaced with an accelerometer that was bolted to the drop plate. Once a rope was attached to the load cell and the drop plate via the screw pin anchor shackles, cable ties were used to eliminate any space between the eye splice and the screw pin. The pulley system was then used to raise the drop plate to a desired testing height, where the angle release system secured the plate until the test was initiated. Before the plate was raised to the appropriate test height, weighted plates were added to the drop plate and secured with nuts. The load cell and the accelerometer were zeroed at this time, and the scan rate was set at 5,000 samples per second. Drop tests were initiated by pulling the angle release system out from under the drop plate, which allowed the drop plate to fall freely. The System 6000 measured load and acceleration throughout the test procedure.

The accelerometer used for the dynamic tests is manufactured by Analog Devices and packaged by Crossbow. Analog Devices donated the accelerometer for this research free of charge because it would be used in academia. Crossbow takes the accelerometer (dimensions 0.2 in. x 0.5 in. x 0.4 in.) and places it in a protective plastic case (dimensions 0.75 in. x

1.875 in. x 1 in.) with a lead wire attached to the accelerometer inside. The accelerometer and plastic casing as a whole is called an ADXL190 Evaluation Module, but it will be referred to as an accelerometer for simplicity. The accelerometer is a 3-axis, single chip accelerometer that has an acceleration span of +/- 100 g's (1 g = 32.2 ft/sec^2). This makes it suitable for shock and vibration measurement. It can withstand a 2,000 g shock if it does not have a power source connected to it at the time of the shock. The accelerometer is precalibrated with a sensitivity of approximately 20 mV/g, and it offers very low noise levels. A 5-volt DC power supply (2.0 mA current) is needed to operate the accelerometer.

The accelerometer was bolted to the drop plate so that the acceleration of the drop plate during testing could be obtained. Under the earth's gravitational pull, the accelerometer experiences an acceleration of 1 g. Once the accelerometer is zeroed at rest, it should experience 1 g of acceleration under "perfect" freefall, which would not be affected by wind resistance, friction, etc.

A variation in test sequence was desired to capture a complete analysis of each rope. Essentially, both the new ropes and the precycled ropes of the same fiber type and diameter were tested under the same conditions (i.e., weight, height, and drop sequence). The variation occurred between different rope types and diameters. Multiple drop tests were run under the following categories:

- Same weight and same height
- Increased weight and same height
- Decreased weight and same height
- Increased height and same weight
- Decreased height and same weight
- Increased height and increased weight
- Decreased height and increased weight
- Increased weight and decreased height
- Decreased weight and decreased height

The focus of the dynamic tests was to simulate different varieties of loading on the ropes and determine the response for each load. In order to accomplish this, the different sequences had to be implemented. Earthquake loading is random in direction and often impulsive in magnitude, thus the different weights and heights were used for the dynamic tests. The minimum amount of weight used in the drop tests was approximately 25 lb, which is the weight of the drop plate with no additional weighted plates added to it. The maximum amount of weight used in the drop tests was 145 lb. The maximum test height was 98 inches, while the minimum test height was 48 inches. Most of the ropes were tested repeatedly for several tests and then disconnected from the drop tower to be tested at a later date. This procedure may help to determine what the effects, if any, are if a rope is recycled at a later time.