Chapter 5

Summary and Conclusions

5.1 Summary and Conclusions

An investigation into the experimental snap loading of synthetic fiber ropes was carried out in this thesis. When a rope transfers from a slack (loose) state to a taut (tight) state, energy is dissipated. The tension that builds up during the taut state is referred to as a snap load. Eleven different types (fiber content) of synthetic fiber ropes were tested under snap loading. These rope types were chosen based upon material properties and the amount of stretch that each rope possessed. It was desired to test ropes that have minimal elongation, yet were capable of dissipating much energy. All of the ropes tested contained one or a blend of the following fibers: polyester, polypropylene, polyethylene, LCP (Vectran), aramid (Kevlar), olefin, and high molecular weight polyethylene (HMPE). The high modulus characteristics of these fibers restrict the ropes from excessive elongation under load. All of the ropes tested had either single or double braided construction. The braided construction allows more friction to occur between individual strands under load than a twisted rope or parallel strand rope. All of the ropes that were tested had diameters of 3/8-inch, 1/2-inch, or 3/4-inch. Three of the ropes tested were seven feet in length, while the other thirty ropes were nine feet in length.

Two types of tests were investigated, which included static load tests and dynamic snap load tests. A total of 33 synthetic fiber ropes were tested; eighteen of these ropes were tested under both static and dynamic loading, while the remaining fifteen ropes were tested under dynamic loading only. The static tests subjected the ropes to incremental loads up to 200 lb in most of the tests. These tests were repeated several times on each rope in order to better understand the force vs. displacement characteristics. The force on each rope was obtained using a ten-kip load cell attached to the top plate of the drop tower, while the displacement of the end of each rope was obtained using a wire pot attached to the bottom of the drop plate.

A total of 282 dynamic tests were conducted on the 33 synthetic fiber ropes. The weight applied to the drop plate and the drop height was varied for the dynamic tests. Some of the ropes bottomed out under dynamic loading because of the elastic nature of the ropes combined with some of the ropes being longer than nine feet in length. Friction in the bearing blocks influenced the results of the dynamic tests to a large extent. For this reason, theoretical velocities had to be multiplied by a percentage in order to obtain accurate results. These percentages were based on tests that were conducted using the entire data collected during a test. Initial velocities and accelerations were zero in value when using the tests with the entire data set and could be integrated to get exact results. The trapezoidal or midpoint rule was used in integrating the acceleration data in order to obtain velocity and displacement values for the drop tests. The results from each test contain four plots that can be viewed in Appendix B.

Some interesting conclusions can be made from the test results. It seems that energy was dissipated in all of the dynamic tests that were conducted because the velocities immediately after the force on the ropes returned to zero were less than the velocities immediately prior to the snap loads. The amount of energy dissipated for each test will be calculated at a later date, which will require more research by another student. As was expected, the higher modulus ropes do not seem to dissipate as much energy (based on the velocity plots and the force vs. absolute displacement plots) as the lower modulus ropes. However, the higher modulus ropes do not have as much end displacement under load as the lower modulus ropes. Further research will determine which rope will provide the best combination of minimal end displacement and energy dissipation capacity.

As mentioned previously, in all of the ropes tested, the end displacement of the ropes did not return to zero once the force in the ropes returned to zero. Although the force in each rope was zero after a snap load occurred, each rope was stretched beyond its elastic elongation (immediately recoverable) limit and this caused some “permanent” elongation to occur. This would explain why the displacements did not return to zero at the same time the force in each rope returned to zero. The permanent elongation can be recovered to some extent after a rope is in a relaxed state for an extended period of time. All of the ropes experienced some permanent elongation that will never be recovered, but a good portion of the elongation that happened under the snap loads recovered shortly after the force in each rope returned to zero.

According to the dynamic test results, each rope became stiffer after every snap load. Each test caused the strands in each rope to be pulled closer together within the rope. As the strands were pulled tighter, the rope displaced less, thus causing the stiffness of each rope to increase. This conclusion could also be verified visually with each test. As more tests were conducted on the same rope, the amount of tower vibration increased. The drop tower's four steel rods would bow out at the instant the snap loads were taking place. As the stiffness of each rope increased, the amount of bowing that took place in each rod increased as well. This caused the tower to vibrate in a violent manner, but by the second snap load after the rebound, the tower had usually damped itself out.

On all of the ropes tested, there were no signs of extreme fatigue visible to the naked eye. Some of the ropes that were dynamically tested more times than other ropes began to show signs of individual fiber failure. Several of the outer fibers in the strands began to "feather" out from adjacent fibers. It is impossible to know if a number of the interior fibers were failing in the same manner as the exterior fibers. The only other sign of fatigue that was apparent on a few of the ropes was located at the connection of the drop plate or at the connection of the load cell. At the point where the ropes were bearing on the screw pin that connects to the anchor shackle, bearing fatigue was beginning to show. The constant compressive force that was being applied to the fibers on the inside part of each eye splice seemed to be causing some fatigue.

5.2 Need For Further Research

The experimental snap loading of synthetic fiber ropes is part of a multiple stage research project. More research is needed before these ropes can be utilized as a plausible method to mitigate earthquake forces in structures. The data that has been presented in this thesis can be used to create a mathematical model that describes rope behavior. Once this model is created, studies will be conducted on the utilization of snapping-cable energy dissipators in structures. These studies will include finite element analysis and physical testing of ropes in buildings. The physical testing will include a scale model of a building frame on a shake table where a variety of seismic forces will be applied.

There are many other options that may be explored on this research topic. Only braided ropes were tested for this thesis. Other types of ropes that may be tested include twisted ropes and parallel strand ropes. Within these two types of ropes, there are multiple subtypes of constructions. Also, lower modulus ropes may be explored for more energy dissipation. Only high modulus ropes were tested in this thesis in order to limit displacements, but more research may be done in which displacements are not considered to be a limiting factor. Larger diameter ropes and/or longer ropes could also be tested under similar loading. An effort could also be made to modify the drop tower so that multiple ropes could be tested in unison under dynamic loading. Multiple ropes at the same point in a structure may in fact be needed to handle large earthquake induced forces. If the drop tower is modified to handle multiple ropes under dynamic loading, more accurate tests could be achieved. Static tests could have been conducted after all of the dynamic tests had been performed in order to determine the effects of the dynamic tests. In order to reduce or eliminate the noise caused by the steel rods after the snap load has occurred, bracing could be provided to the drop tower. Bracing would also allow for larger loads to be applied to the ropes. A higher capacity load cell and accelerometer would also be required if larger loads were applied. A scan rate of 10,000 readings per second could be implemented using the System 6000, as opposed to 5,000 readings per second. An increase in scan rate may or may not prove to provide better results.

It is impossible for drop tests conducted using this drop tower or any other drop tower to be entirely frictionless. The amount of friction in the drop tower's bearing blocks is excessive. An effort could be made to eliminate some or most of the friction that is present in the bearing blocks. This friction greatly affected the results of the dynamic tests, but did not compromise the integrity of the research. Since all of the tests contained considerable and similar amounts of friction, the ropes and their properties can still be compared accurately to each other.