Chapter 7

Summary and Conclusions

7.1 Summary and Conclusions

This research focused on the analysis of the experimental test data obtained from the static and dynamic testing of synthetic fiber ropes, and the modeling of the dynamic tests in order to characterize how the ropes behave under dynamic loading. When a rope quickly transfers from a slack state to a taut state, a snapping action occurs and produces a very large tensile force which is known as a snap load. Energy is dissipated during this snap loading. It is proposed to use synthetic fiber ropes as a type of passive earthquake damper to take advantage of this phenomenon. This thesis is the second phase of a multi-stage research project whose goal is to investigate and develop what will be known as Snapping-Cable Energy Dissipators (SCEDs).

The analyses were conducted on all of the test data obtained in the previous research, "Experimental Snap Loading of Synthetic Fiber Ropes," as well as, from a round of follow-up tests that were conducted on a selection of the ropes from that research, and a round of new tests conducted on brand new ropes as part of this research. In the previous research, a number of different ropes with varying material properties, lengths, and diameters were tested from many different drop heights and with varying amounts of weight. This was done in order to determine what properties are most desirable in a rope that is to be used as a SCED. After all of these ropes were analyzed and compared, two ropes were chosen for a follow-up round of tests that were conducted with a constant weight and from lower drop heights than the previous round of tests. These ropes were chosen because they were originally tested in a similar sequence in which the weight was constant and the drop height varied.

Based on the results of these two rounds of tests, a third round was conducted to eliminate some of the variables that were present in the earlier tests, and to expose the ropes to conditions that are more like what they would experience if they were used as SCEDs. Two ropes were selected for these tests, the 1/2-inch-diameter Amsteel Blue rope and the 1/2-inch-diameter Amsteel II rope, both of which were 9 feet in length. These ropes have contrasting material properties and behaved differently under static and dynamic loadings. By testing these two different types of rope, it was possible to develop an accurate idea of what properties are most essential in order to develop a SCED that dissipates a significant amount of energy, but only exhibits a limited amount of dynamic elongation.

The new dynamic tests were conducted in sequences that consisted of 20 consecutive drop tests from a constant height and with a constant weight. By conducting so many consecutive tests with identical parameters, it was possible to observe how the behavior of the rope changed throughout a loading sequence. Two ropes of each type were tested from each drop height. One of these ropes was statically tested (or precycled) before it was tested dynamically, and the other was not. This was done to determine if there were any advantages to pre-stretching a rope before it was subjected to snap loading.

The behavior of the ropes was very dependent on how stiff they became due to the repeated snap loads. As more drop tests were conducted, the individual components of the ropes were pulled closer together and the ropes became stiffer. The Amsteel Blue ropes were manufactured with a loose braid, while the Amsteel II ropes were constructed with a tight braid. As a result, the Amsteel Blue ropes continued to gain stiffness throughout the loading sequence, while the Amsteel II ropes experienced a large increase in stiffness in the first few cycles and after that the stiffness remained at a nearly constant value. This indicates that the fibers in the Amsteel II ropes get to a point where they cannot be pulled any tighter and the rope is essentially stretched to its maximum length. The behavior of the other analytical quantities is dependent on this occurrence.

The elongation of a rope under dynamic loading is of particular importance. If a SCED experiences too much elongation, the frame may not sway far enough to allow the rope to become taut throughout a seismic event. Therefore, the amount of dynamic elongation must be limited. The loosely braided Amsteel Blue ropes experienced more than twice as much dynamic elongation than the tightly braided Amsteel II ropes. In addition, the precycled ropes exhibited about half as much elongation as the new ropes. Therefore, in order to minimize the elongation of a SCED under dynamic loads, a tightly braided and precycled rope should be utilized.

The amount of energy that was dissipated during the snap loads is called the Energy Loss. The Energy Loss values are larger for the first few drop tests and their values decrease with each subsequent drop test until they reach a steady value. The values are larger in the first few drop tests because the rope is still elongating during this time and the additional friction that this causes between the components of the rope dissipates more energy. There is little difference between the values for the precycled and new ropes, but the Amsteel Blue ropes dissipate slightly more energy than the Amsteel II ropes. However, this is due to the additional elongation that the Amsteel Blue ropes experience, which is not desirable.

The force, velocity, and displacement values from the Taut Phase of each dynamic test were then used to create a mathematical model to accurately characterize the behavior of a rope during snap loading. The model equation was revised several times until an equation was developed that was both accurate and practical in application. The final model is based on a nonlinear equation that includes a series of coefficients that act either as constants or multipliers of the velocity and displacement terms. These coefficients were determined by conducting regression analyses on the data from each sequence of drop tests. These coefficients were chosen because they were applicable to all of the drop tests from an individual sequence and produced theoretical force values that showed around a 96% correlation with the recorded force values for the Amsteel II ropes.

It was determined that in order for SCEDs to function the way they are intended to, a tightly braided rope should be utilized, such as the Amsteel II rope. In addition, the ropes should be precycled so that there is not an excessive amount of dynamic elongation. When a SCED is mounted in a structural frame, it should be in a straight, but slightly slack configuration so that even small vibrations will cause the rope to become taut.

7.2 Need for Further Research

The analysis and modeling of snap loads on synthetic fiber ropes is part of a multi-stage research project whose goal is to verify the benefits that Snapping Cable Energy Dissipators can provide and to implement them as a way to mitigate the forces that an earthquake applies to a structure. Now that the behavior of a rope during a series of snap loads is better understood, a specific type of rope has been selected for use as a SCED, and a mathematical model has been developed that can accurately predict the dynamic response of a rope during the Taut Phase, the research can progress to a more macroscopic analysis of a system that includes SCEDs.

The mathematical model that was developed in this research will be applied to a finite element analysis of a structural system to simulate a system of SCEDs under a seismic loading. In addition, a small structural frame or possibly a scale model will be built on a shake table so that tests can be conducted that will closely simulate the conditions to which an actual system of SCEDs will be subjected.

Since the ropes that will be used as SCEDs will be longer and probably of a larger diameter than the ones that were tested for this research, another round of drop tests may be necessary to determine the proper coefficients for the mathematical model. The coefficients that were obtained from the Model 4 Sequence Equation for the Precycled

Amsteel II rope J are accurate, but it is unclear how altering the rope diameter and length will affect these coefficients.

Other applications of Snapping Cable Energy Dissipators should also be considered. For example, SCEDs could be used to connect adjoining spans of a bridge deck to prevent the unseating and failure of a span during an earthquake (e.g., the San Francisco-Oakland Bay Bridge during the Loma Prieta Earthquake in 1989). Also, they could be used in the structural framework of bridges to restrain movements and dissipate energy during a seismic event.