Chapter 8

Conclusions

Concrete is a material that exhibits complex behaviors, including a strong dependence on its multiaxial load state. It has long been recognized that it is necessary to confine concrete in order to have the required strength and ductility for structural use. However, due to its heterogeneous composition, even the most basic properties of concrete, such as its compressive strength, can vary widely from specimen to specimen. This combination of complex behavior and varying properties makes concrete a difficult material to accurately model. Despite these challenges, this thesis seeks to model the multiaxial behavior of concrete. The concrete model defined in this thesis defines the backbone monotonic loading curves for concrete. It can then be combined with existing finite element codes that account for other concrete behaviors, including cracking, shear sliding, and creep, to fully model this complex material.

Current plasticity theory provides an ideal framework to model concrete. Basic ideas of failure surfaces and plastic flow are adapted to represent the behaviors exhibited by concrete. A complex, work hardening failure surface is defined in the stress invariant space. This failure surface is composed of three fixed loading surfaces that correspond to the uniaxial yield, peak, and residual stresses. The current failure surface travels between these three fixed loading surfaces based on the accrual of damage in the material. The damage level is related to the amount of plastic strain accumulated in the specimen. The plastic strain is determined through the use of a non-associated flow rule. The full plasticity model is then coupled to finite element theory to create a computer program capable of predicting the behavior of concrete.

The full plasticity model contains twenty-four parameters, which must be defined using experimental concrete data and knowledge of fundamental concrete behavior. For this purpose, twenty-five experimental data sets were obtained from published works. These data sets included results from tests on a wide variety of concrete mixes and strengths, specimen shapes, confinement configurations, and load paths. Some of these variables are explicitly taken into account by the concrete model, while others deemed to be less significant are not accounted for. The concrete model parameters were then fit to the data. In the scope of this thesis, the data utilized for the fit are consistent with the loading of confined concrete columns. If a different use is required of the program, these parameters can be fit to data more closely representative of the problem being considered.

The finite element (FE) model is utilized to predict the experimental results of concrete. Five experimental data sets were obtained representing the variety of problems that this model is designed to solve. Four data sets are results of axial loading of confined columns. Two utilized steel rebar as a confinement material, and two used a fiber reinforced polymer (FRP) for confinement. The fifth data set tested a steel confined column under combined axial load and moment. When these data sets were initially modeled, a problem with the residual surface led to premature termination of the program for steel confined sections. It is desirable to determine the issue with this model that leads to the problem. However, a simple workaround was utilized by defining the tensile meridian to be equal to the compressive meridian, creating a round residual surface. The FE model predictions, using a round residual surface for steel confined sections only, are compared to the results obtained from the experiments. While the data contains large scatter, the program exhibited no consistent or systematic error in predicting the experimental results. Overall, the FE model was quite successful at accounting for a wide variety of testing variables, including shape, confining material, and confinement layout.

A concrete model of this type can be utilized as both a design and analysis tool. A study is performed to determine the effects of confining material and cross sectional shape. Concrete confined by FRP is shown to be capable of much greater increases in strength. However, this increase in strength can be accompanied by a significant decrease in the ductility of the failure mode. This is a significant point for designers to consider when using this confining material. In general, circular shaped cross sections show a larger increase in strength and ductility than comparable square sections. This performance increase comes at the cost of higher stresses in the confining material. This exploration of these two design variables is useful information when designing structures.

In this thesis, a detailed concrete model is designed, its parameters are estimated using test data, the identified model is validated, and then it is used to explore certain aspects of concrete behavior. Comparisons to test data are shown to be favorable, making the predictive results of this model useful for understanding how concrete will perform under a particular loading configuration. The potential uses of such a program are quite extensive. It can be applied as a simple design tool for use in capacity calculations. New confining materials can be explored, and the resulting concrete behavior compared to existing confinement techniques. A deeper understanding of concrete behavior can be gained through careful examination of the stress distribution in the material in many different types of loading configurations. Implementing this model into existing code that would account for cyclic loading effects (including cracking, shear sliding, etc.) would allow a complete time history analysis of a concrete structure undergoing dynamic loading such as an earthquake. The concrete model presented in this thesis presents a powerful and flexible tool for the future analysis of concrete behavior under loads.