1. Introduction

1.1 Background and Motivation

For several years fluid viscous dampers have been studied for their ability to reduce structural response through increased energy dissipation. Some of the past research has compared the performance of dampers with linear and nonlinear force-velocity relationships. Many researchers feel that a certain type of nonlinear damping is more suitable to reduce peak responses for structures subjected to near-field earthquakes. The conclusions made by several of these researchers are accurate for the conditions of the experiments they performed. However, the conclusions often do not give the complete picture of behavior for a system incorporating fluid viscous dampers.

For example, a study performed by Filiatrault et al. (2001) evaluated the performance of steel moment-resisting frames when seismically retrofitted with passive damping systems. One of the objectives was to determine if nonlinear viscous dampers could improve performance when a steel moment-resisting frame was subjected to near-field ground motions. In the study, the researchers used nonlinear viscous dampers with damping exponents of 0.3 and 0.5. Their study concluded that, in comparison to the linear dampers, the nonlinear dampers had higher peak displacements with lower peak damper forces. However, they were deemed ineffective because the braces used to connect them to the structure yielded in tension or would have undergone inelastic buckling, thus limiting the viscous damping system.

It is felt that the Filiatrault et al. (2001) study, while possibly appropriate for its own purposes, has a couple of shortcomings that may lead to conclusions about fluid viscous damping which are incomplete. One of these shortcomings is that the dampers used only had exponents less than unity. The damping exponent is a parameter of a damper's force-velocity relationship that determines the shape of the curve. When the exponent equals unity the curve is linear; when the exponent is less than unity, the curve softens; and when the exponent is greater than unity, the curve hardens. This is explained further, in detail, in Chapter 2. The current study expects to find that viscous dampers with exponents greater than unity may be best suited to improve the performance of steel moment-resisting frames subjected to near-field earthquakes. The other shortcoming to note is that the nonlinear dampers were deemed ineffective by Filiatrault et al. (2001) because the brace yielded. While the braces should not yield, it is felt that this is not a problem with the nonlinear dampers, but rather poor brace design. The shortcomings described and some additional concerns have served as motivation for the study presented in the following chapters.

1.2 Purpose and Objectives

The purpose of the current study is to provide a complete evaluation of the performance of a steel moment-resisting frame using linear and nonlinear fluid viscous dampers when subjected to different types of ground motions. To achieve this, the study used nonlinear dampers with damping exponents less than, equal to, and greater than unity. Each nonlinear damper was calibrated in such a way that a fair comparison can be made between the different damping types. A parameter used to calibrate the nonlinear dampers was varied to observe the sensitivity of the results to the calibration. The different types of damping were incorporated into a steel moment-resisting frame that was subjected to 12 different earthquakes, six of which are classified as near-field earthquakes. The earthquakes were applied to the structure using an approach called Incremental Dynamic Analysis (IDA) (Vamvatsikos and Cornell, 2002), where each ground motion is scaled to several different levels of intensity. The steel moment-resisting frame was then subjected to the different motions using nonlinear inelastic time history analysis in the program *RAM Perform 2D* (Powell, 2000). The IDA approach provides a means to observe the changes in structural response as the ductility demand changes. At the end of the analysis a complete picture of structural behavior was created with IDA curves, which are plots of intensity versus a response measure. A few response measures were chosen for the analysis, including interstory drift ratio, Park and Ang damage index, base shear, and residual displacement. Residual displacements are often the explanation for undesirable inelastic structural behavior and the study provides possible ways to reduce them. The following list is the objectives of this research:

- Determine if a certain damper type (nonlinear with softening force-velocity relationship, linear, or nonlinear with hardening force-velocity relationship) is best suited for use in a structure subjected to a certain ground motion (near-field or far-field)
- Compare response of a damper for a coefficient calibrated at 1 and 5% story drifts
- Determine if viscous dampers, more specifically a certain type of viscous damper, can decrease residual deformations
- Determine if viscous dampers, more specifically a certain type of viscous damper, can reduce the dispersion in the IDA curves
- Relate residual deformation to dispersion in the IDA curves
- Compare the results of the IDA method for the different damage indices
- Provide an assessment of the use of IDA as a seismic behavior evaluation tool

1.3 Overview of Thesis

A review of published research is presented in Chapter 2 to provide background information on fluid viscous damping and the method of analysis used in the study. Chapter 3 discusses how the method of analysis is applied in this study and describes the structural model that has been created for the analysis. This is followed by Chapter 4, which presents and discusses the results of the analysis, using several IDA curves that illustrate structural behavior. The conclusions, which address the objectives, are presented in Chapter 5 along with recommendations for further research. Appendix A provides a comparison of *Perform*, *SAP2000*, and *Drain-2DX,* which was completed to check the validity and accuracy of *Perform* because it is a new program. Appendix B displays all the IDA plots created for the different response measures including structural drift, base shear, residual displacement, and the damage index.