User Significance Statement

This report addresses the development of simplified methods of analysis and seismic assessment for shear wall type building structures with nonrigid diaphragms.

Masonry is a widely used material for building construction. According to Shing (1998), approximately 70 percent of the building inventory in the United States employs masonry walls in some capacity as lateral-load resisting elements. French and Olshansky (2000) categorize 33 percent of the essential facilities within a study area of the New Madrid fault zone as unreinforced masonry (URM), while eight percent of the essential facilities within this area are categorized in their research as reinforced masonry. On this basis, an early decision of the Mid-America Earthquake (MAE) Center Essential Facilities Program was to focus on masonry building construction, particularly unreinforced masonry. The purpose of the specific research addressed in this report is to develop and apply simplified analytical models for seismic assessment of low-rise buildings with nonrigid floor and/or roof diaphragms. A key focus of this work is on the modeling of low-rise masonry buildings. However, the approaches investigated have some potential for other low-rise building types as well.

The work focuses on low-rise wall-type buildings with rectangular plan geometry. A three-dimensional linear and nonlinear analysis approach is created to allow for accurate and rapid seismic assessment for these types of buildings. The suggested approach is efficient enough for the rapid evaluation of physical buildings or test designs, and for conducting large numbers of analyses within simulation studies. The approach utilizes new diaphragm and wall elements developed in this project. The diaphragm element is based on a flexibility (equilibrium) based formulation to calculate its stiffness and overall nonlinear force deformation response. Strength and hysteretic properties of the diaphragm element are estimated from the results of experimental tests conducted in previous research. The wall element involves a simple shear spring idealization. In order to most accurately estimate the initial stiffness coefficients of shear walls, a flexibility approach is recommended using the results of plane stress finite element analysis. Simple equations based on mechanics of materials are also considered for calibration of the wall stiffnesses.

Unreinforced masonry is a major construction material in existing essential facilities in mid America. Thus, an early decision of this research was to focus on the nonlinear characteristics of these types of buildings. The hysteretic properties of the structural components of these buildings are approximated in this work based on previous experimental tests. The wall and diaphragm elements are implemented with computer graphics visualization, as a post-processing tool, to manage the massive analysis outputs for better understating of the behavior of these buildings.

The MDOF model discussed above can be used for simplified three-dimensional nonlinear time history analysis of low-rise shear wall rectangular building structures. Comparisons of analytical studies to experimental tests can be valuable for understanding the seismic response of these types of buildings and for determining the qualities and limitations of simplified models. To this end, the proposed simplified MDOF analysis approach is applied to a two-story unreinforced masonry historic building with interior walls and multiple diaphragms in each story, and to a half-scale single-story reinforced masonry test building with a single diagonally-sheathed diaphragm. The two-story building was instrumented within the California Strong Motion Instrumentation Program (CSMIP) and withstood the Loma Prieta earthquake in 1989. This building, which is referred to as the Gilroy Firehouse, was previously studied extensively by Tena-Colunga and Abrams (1992). The single-story building was constructed and tested on the shaking table at the United States Army Construction Engineering Research Laboratory (CERL), and was subsequently studied by Cohen (2002). The structural properties of the Gilroy Firehouse are calculated based on extensions to various current methods prescribed in FEMA 273 (FEMA 1997) and 356 (ASCE 2002a) as well as other publications and developments from this research. The structure is analyzed based on these properties, and modifications necessary to obtain improved predictions relative to the field test data are discussed. For the single story test building, a model calibration process is performed in this work to determine the required structural properties based on the elastic and inelastic test responses. This approach is necessary since it is difficult to determine accurately the in-plane and out-of-plane stiffness, strength, and hysteresis using simplified equations specified in current seismic codes and standards. The comparison between the structural properties obtained by this calibration process and by various simple strength of materials type procedures are discussed.

Lastly, a simplified linear static procedure is proposed for low-rise buildings with flexible diaphragms. This method involves the consideration of the individual diaphragms and the associated out-of-plane walls within a building via separate idealized single degree of freedom models. The shear forces calculated from the separated models are combined to obtain wall shear forces. The final forces and displacements determined using this simplified linear static procedure are compared with linear time history analysis results for the one- and two-story buildings discussed in this research, and conclusions regarding the use of this approach are discussed.