Roble Hall at Stanford University:
A Case Study in the Evolution of Seismic Rehabilitation Standards

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ABSTRACT

Roble Hall is a historic, three-story dormitory housing 310 students on the Stanford University campus. Discovered in 1987 to be a non-ductile concrete frame with hollow clay tile infill, it was deemed to be a high seismic risk, students were moved out during the middle of the school year, and a fast-track seismic rehabilitation project was completed in 1988. The goal for that work was to significantly reduce the risk to life safety (primarily from collapse) at a reasonable cost. Rehabilitation of the 1918 building involved new concrete shear wall towers (see Figure 1) in selected rooms and attic diaphragm strengthening designed using standard static lateral force methods. Some seismic deficiencies—such as the poor ties between wings—were not addressed due to the associated cost and disruption and a perceived lack of benefit. The 1989 Loma Prieta Earthquake produced moderate levels of shaking at the site, and the retrofitted building suffered minimal damage.

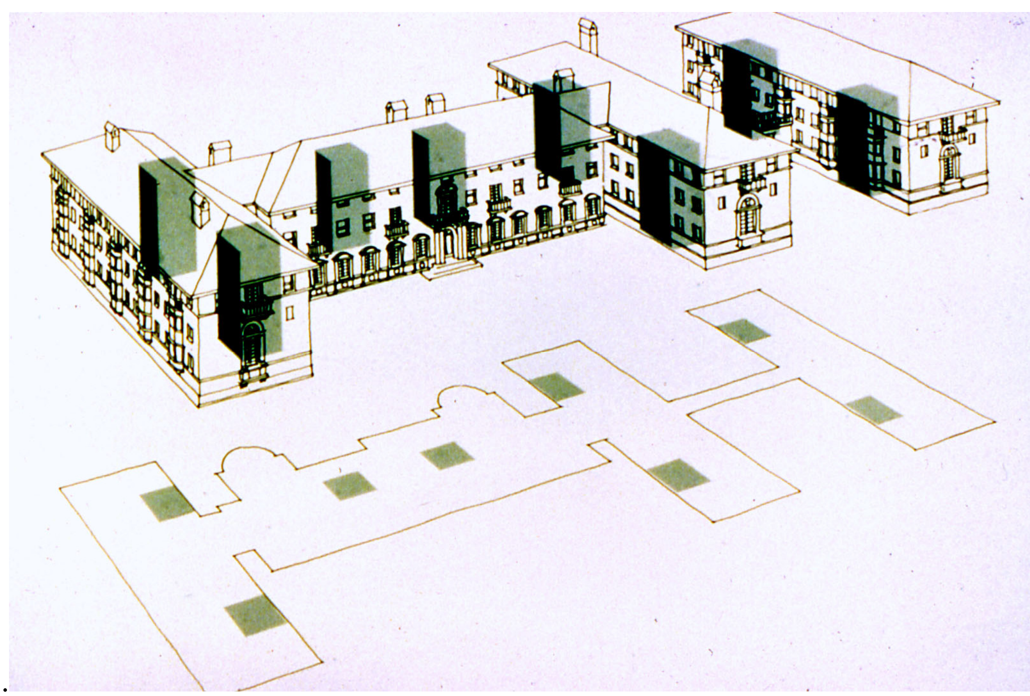

Figure 1. Concrete shear wall tower locations in the 1988 seismic rehabilitation.

As part of a comprehensive mitigation program begun after the 1989 earthquake, Roble Hall was reevaluated in 2005 to a new set of performance-based campus standards, where the target for performance was similar to the FEMA 356/ASCE 41 Basic Safety Objective. FEMA 356/440 nonlinear static analyses were the evaluation focus, but linear static, linear dynamic, and nonlinear dynamic analyses were also conducted. Modeling included diaphragm and soil flexibility. The 1988 concrete towers were found to have sufficient strength and displacement capacity, but several seismic deficiencies were identified. These deficiencies included insufficient connecting ties to prevent damaging out-of-phase movement between wings; a weak, flexible diaphragm in the one linking structure that the University chose not to strengthen in 1988; inadequate out-of-plane ties at the roof-to-wall interface; and clay tile parapets found to be insufficiently reinforced.

As part of a major capital improvement project, a second seismic rehabilitation was completed to address the deficiencies in the 2005 study. Several retrofit schemes were considered for the link structures, including a complete seismic separation for the full height of the building, ties that would connect the wings together either rigidly or with a fuse that would yield at a defined level, or a supplementary vertical support system at the anticipated location of damage in out-of-phase movement. A steel supplementary vertical support system was eventually selected based on the relative cost, the elimination of waterproofing concerns with the jointing schemes, the preservation of redundancy in moderate seismic events, and the inability of the existing concrete floors to provide the capacity needed to reliably tie the wings together.

The multiple seismic evaluations and rehabilitations at Roble Hall over a period of nearly 20 years provide an excellent case study in the evolution of seismic analysis procedures, performance-based thinking, and rehabilitation techniques. The paper will describe the criteria, analyses, performance objectives, and key decisions in each rehabilitation project, and explore the challenges and opportunities that complicated, historic structures can present in providing practical, cost effective seismic rehabilitation solutions.