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3D modeling of an historic masonry structure for rehabilitation planning and seismic retrofit design

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Abstract

The Lyceum building is the central building on the campus of the University of Mississippi and dates to the founding of the University in 1848. A major renovation is currently being planned to upgrade the interior facilities to suit the present day needs of the University's administration housed by the building. The renovation has been complicated by the need to satisfy conflicting demands of current building codes which now include seismic provisions and those of the State of Mississippi's Department of Archives and History and Bureau of Buildings. This paper highlights the modeling which has been performed of the 3D seismic response of the 3-story brick masonry wall system. The utility of the response analysis is then demonstrated for the renovation planning, both historic and technical, and, in particular, the seismic retrofit design being performed by a consulting engineer contracted by the State.

Introduction

The primary buildings on the campus of the University of Mississippi were completed in 1848 with the central position being occupied by the Lyceum building shown in Figure 1. The original Lyceum was a 3-story brick masonry construction having a rectangular plan and an architecture and interior design that has come to exemplify the cultural style of the Old South in the last century. The neoclassical facade with tall white columns and the interior

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corridors with their high ceilings provide a simple elegance. It is that elegance which has become endeared the Lyceum to the many students and alumni of the University and indeed to the entire State.

The importance of the building in the history of the State may also be observed in the fact that the original Lyceum and the major additions made in 1903 were designed by the same architects and constructed at the same time, respectively, as the original State capitol building and the current one which houses the State government in Jackson, Mississippi. The 1948 designs were made by the architect Nichols, while the 1903 designs were made by the architect Theo Link.

Figure 1. Lyceum building- view from the south.

The current day Lyceum houses several key University functions including those of the Chancellor and his administrative support staff, Admissions, the Registrar, and the Bursar. Space constraints and the need for modern equipment and facilities more most of those functions have motivated the planned major renovation which will involve moving some of the functions out of the Lyceum and reorganizing others within it.

A survey of the current day structure of the Lyceum revealed that much of the original Lyceum is still in tact including the central brick masonry wall system, many of the primary wood truss elements of the roof, and many of the primary wood floor system elements. It is the desire to maintain this original fabric of the building which soon became of importance to the State of Mississippi's Bureau of Buildings and Department of Archives and History as plans to renovate the structure were begun.

While the desire to preserve the original content of the building was clear to all planners, the severe seismic hazard to which it is exposed also has to be faced. The Department of Civil Engineering has been performing 3D dynamic finite element analysis of the primary University buildings for the Mississippi Emergency Management Agency to evaluate vulnerability of these buildings to a major seismic event which is expected on the nearby New Madrid fault. The Lyceum is one the buildings being evaluated.

The timing of the seismic analysis has proven to be beneficial to both the renovation planning and the seismic retrofit design by virtue of the graphic and quantitative results provided by the response predictions. This paper will present some of the preliminary findings of this analysis emphasizing the impact of 3D dynamic analysis in depicting the effects of major loadings of historic structures and evaluating the improvements made by a proposed retrofit strategy. The retrofit design is still underway, so the potential of the interaction between analysis, planning, and retrofit design is still unfolding.

Lyceum wall structural system

The present day brick masonry wall structure shown in Figure 1 represents the primary bearing support system for the building. The exterior walls are comprised of five wythes loosely connected by mortar which in some cases has deteriorated completed leaving gaps between the wythes. Several interior walls also exist which are comprised of varying numbers of wythes. The ABAQUS [1] finite element model of this wall system is shown in Figure 2 below.

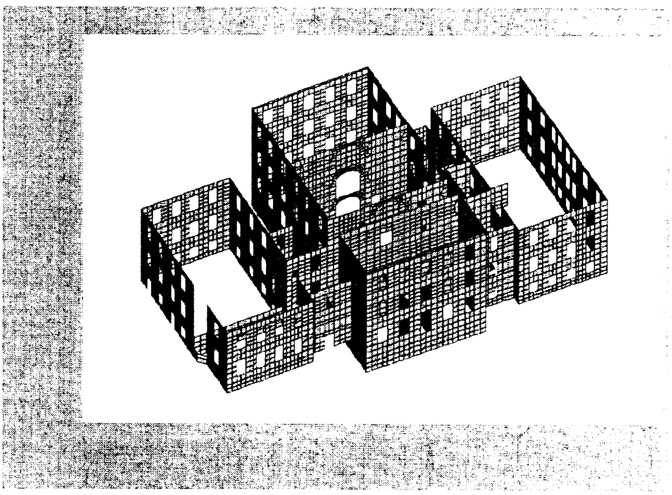

Figure 2. Finite element model of present day wall system.

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The roof and floor systems are comprised of wood and have virtually no positive connections to the walls as the need for seismic lateral load resisting systems was not recognized by the designers despite the occurrence of Richter magnitude 8 events in 1811 and 1812. In fact, only recently have building authorities in northwest Mississippi begun to adopt regional codes [2] for seismic resistance that in turn adopt national provisions [3]. The seismic analysis of the present day Lyceum building without retrofit has therefore been performed assuming no contribution of these wood systems to the stiffness or mass of the vibrating structure. The model in Figure 2 was used as shown for the dynamic response analysis using the dead load from the wood systems to define the initial conditions.

The masonry walls are of varying age with two major additions having been made to the original 1848 structure. In 1858 the central wall system was extended to the north, and in 1903 the two east and west wall systems were added. These additions were not given any positive connections to the original wall system. In modeling the combined system shown in Figure 2, gap elements were used to allow contact interaction during dynamic response.

Brick masonry properties

The properties of the masonry wall system will eventually be measured *in situ* according to static and dynamic procedures similar to ones applied on the Brooklyn Bridge [4]. For the preliminary analysis described in this paper, values of the elastic modulus of the brick, E_B, and masonry, E_M, were assumed to be typical ones for clay brick and lime mortar [5] and an equivalent strain approach was used to obtain the composite modulus, E , to be used in the model.

A reduction was applied to the values of the composite modulus in the older central wall system relative to those in the newer additions to account for the effects of age and degradation. The degradation is expected not only because of typical environmental effects but also the fact that the original Lyceum was subjected to a Richter magnitude 6.8 event in 1895 before the newer additions were constructed.

In addition, it was the observation of the consulting structural engineer on the renovation that the practice at the time of construction that the bricks in the exterior wythes were kiln fired to a higher performance grade than the interior wythes. In the modeling of the walls as continuous plate elements, a 50 percent reduction was in the equivalent plate thickness to account for the nonuniform distribution of elastic modulus. This reduction maintains the average membrane rigidity while accounting for the reduced bending rigidity.

3D seismic response to a moderate event

Current probabilistic hazard estimates for the New Madrid fault zone call for a better than 90 percent chance that an event exceeding a Richter magnitude 6 will occur in the next 50 years [6]. This moderate event scenario is analyzed here using a measured eastern United States event, the Saguenay earthquake of 1984, having magnitude 6 that has been intensity scaled to account for the distance of the Lyceum from the New Madrid fault. The input ground acceleration time history applied to the Lyceum model is shown below in Figure 3.

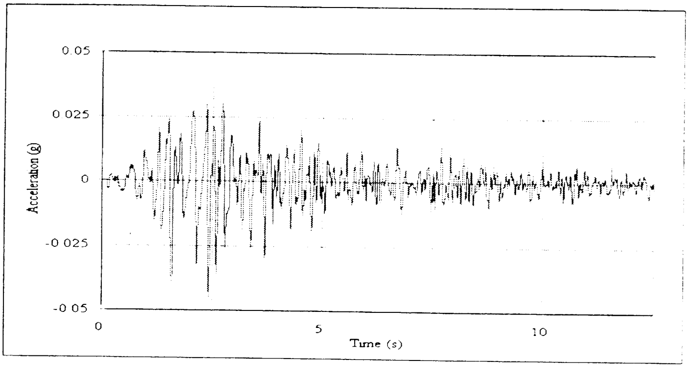

Figure 3. Input motion for moderate seismic event.

The fixed base response of the wall system model was computed to this input motion and produced a rather complex motion which can only be visualized through animation procedures that cannot be presented in this paper. These animations indicate the predominance of out-of-plane flexural modes which are depicted in the snapshot shown in Figure 4. The time of this snapshot corresponds to the peak normal (membrane plus bending) stress observed in the time history plots shown in Figure 5.

In order to evaluate the structural integrity of the wall system under this loading, 3D submodels were constructed from the dynamic model and the mesh was refined around the corners of the window openings. The cut-boundary displacement method was then implemented in which all displacement components at common nodes of the overall and submodel were extracted from the overall model results file and applied statically to the submodel as a prescribed displacement loading. Stresses from the refined submodel would form the basis of establishing failure modes relative to the estimated material strengths.

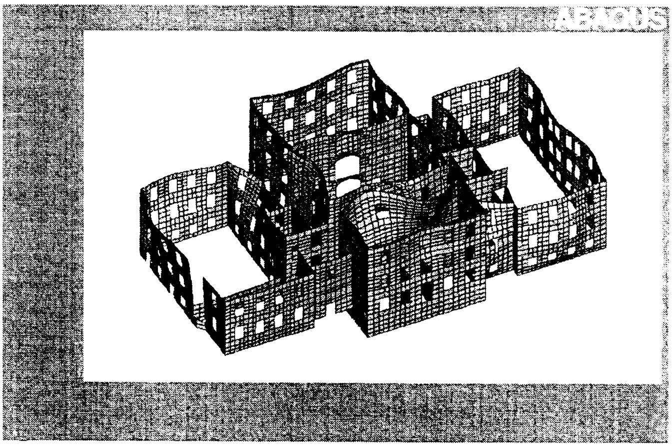

Figure 4. Deformed shape at time of peak response to M=6 event.

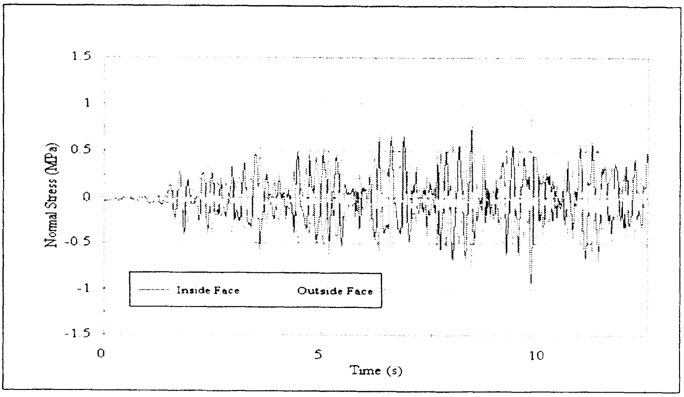

Figure 5. Stress time history at top of south exterior wall.

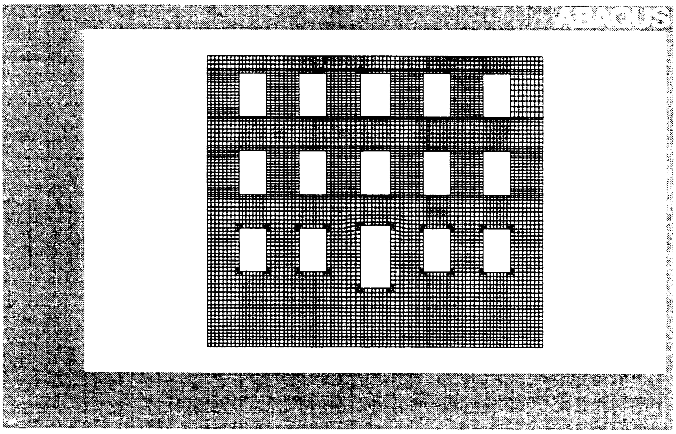

Figure 6. Normal stress plot in south exterior wall submodel.

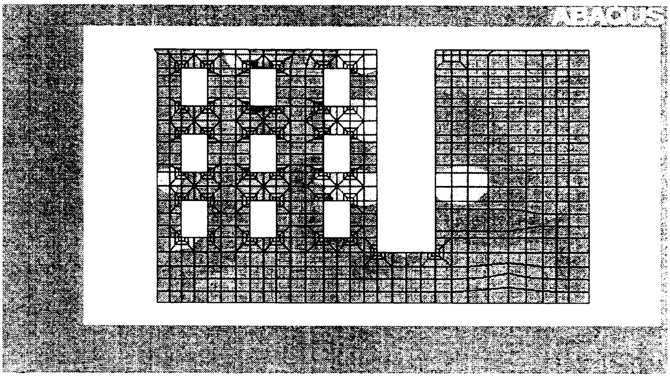

Figure 7. Normal stress plot in central west exterior wall submodel.

Evaluation of results for moderate seismic event

The submodel analyses indicate typical hotspots that arise in the current day configuration of the Lyceum building. The intensities of these stresses indicate that some localized cracking and possibly minor crushing would occur in these hotspots under the moderate event based on typical strengths for concrete and mortar assumed to apply here. Nevertheless, the overall integrity of the wall appears to be satisfactory.

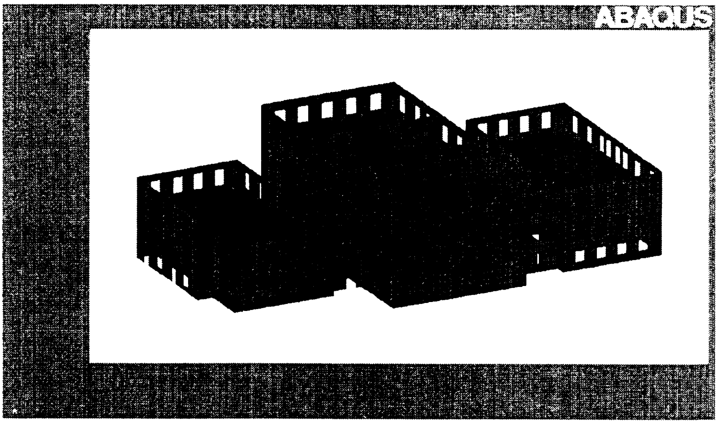

Figure 8. Basic retrofit model connecting floor and wall systems

The true utility of the analysis is really somewhat more qualitative. First, the observed modes of response indicate that localized modes of relatively high frequency dominate the response to this earthquake. Should the connections between wall and floor system be established as indicated in the model shown in Figure 8, the dominance of these wall flexure modes will be substantially reduced.

This type of influence will be computed using the model incorporating the retrofit designs proposed by the consulting structural engineer. The basic retrofit plan tying floor systems to the wall system will introduce new more global mode shapes at lower frequencies and potentially increase the level of contact between the additions. The model will permit quantitative evaluation of these effects.

It appears that straightforward retrofit measures will be effective in maintaining the structural integrity of this historic structure during a moderate event. This conclusion is consistent in fact with an evaluation of the response of an historic two-story brick masonry fire station [7] in California which experienced the 1989 Loma Prieta earthquake, a moderate event.

Conclusions

The 3D dynamic analysis of an historic brick masonry building on the campus of the University of Mississippi has been performed demonstrating the expected vulnerability to a moderate level seismic event occurring on the nearby New Madrid fault. The analysis is of interest both to state emergency planning personnel and the team planning the renovation of the structure. The seismic analysis is being provided to the consulting engineer as well as those interested in the historic preservation of the basic physical elements of the building. The interaction among the various groups will enable the implementation of a seismic retrofit strategy that is acceptable to all parties concerned.

Acknowledgement

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