Earthquake Engineering, Tenth World Conference © 1992 Balkema, Rotterdam. ISBN 90 5410 060 5

Rehabilitation of the Mackay School of Mines, Phase III, with base isolation

Douglas Way
Base Isolation Consultants Inc., San Francisco, Calif., USA

Jack Howard
Jack Howard Associates, Reno, Nev., USA

ABSTRACT: The original Mackay School of Mines Building was constructed in 1908. Being one of the original buildings of University of Navada, it is situated at the north end of the main quadrangle within the campus. Prominent in its location at University of Nevada and in appearance, the building is designated as a national historic monument. During the years of 1926 and 1956, significant structural alterations were made to the original building. Phase III work at the original Mackay School of Mines Building involves adding a library at the basement, with the balance of the building being remodeled for similar-type functions. Constructed mainly of unreinforced masonry, the seismic rehabilitation of the structure warrants careful attention. During the schematic phase of the work, both conventional strengthening and Base Isolation were explored as potential techniques with which to mitigate damage from earthquakes. Cost estimate of both schemes were also developed. From a preservationist point of view, there were definite advantages in the isolation design. Since the isolation system could filter out most of the damaging forces associated with earthquakes, none of the unreinforced masonry walls required strengthening. As a result, many of the original architectural features of the original building can be salvaged, maintaining the original quality of the building and its identity. For these reasons the Base Isolation option was selected as the seismic retrofit scheme. This paper illustrates the Base Isolation design for the Mackay School of Mines, a historical structure constructed of unreinforced masonry.

The isolation system consists of high-damping rubber bearings in combination with sliding elements.

PROJECT DESCRIPTION

Originally planned and built in 1908, the Mackay School of Mines was one of the first structures to be built on the campus of the University of Nevada, Reno. It is a contributing building to the University of Nevada, Reno quadrangle Historic District Places. The building served as a model for all University of Nevada, Reno campus buildings prior to 1940. It may be the only remaining example of the work of the New York architectural firm of McKim, Mead and White west of Kansas City, Missouri.
The Mines building occupies a prominent position on the UNR campus, located at the north end of the quadrangle that forms the heart of the campus. The building's dramatic Neo-Classic design makes it a striking focal point for the area. The campus design was first proposed by Stanford White of McKim, Mead and White after his involvement in 1898 with the restoration and completion of the campus quad at the University of Virginia at Charlottesville. White revived the campus plan first developed by Thomas Jefferson and convinced his friend and associate, Clarence Mackay, to use the concept for the new campus in Nevada.

Clarence Mackay, together with his mother, funded the design and construction of the building memory of his father, John, one of America's foremost mining, railroad and communications entrepreneurs and capitalists.

The Mackay School of Mines has developed into a world renowned college and the campus buildings of the School have developed with it. A major remodel, designed by Fredrick DeLongchamps, was constructed in 1926 and more than doubled the size of the facility. This added second floor space to the entire building and produced the rectangular shape that exists today. Several minor, insensitive remodels have occurred in various parts of the building since the 1950's.

Being constructed of local bricks in the early 1900's, the structure is entirely unreinforced masonry (URM) with wood joist floors and roof throughout. This method of construction has presented many problems in recent times in regard to earthquake design. The building is presently not used as a classroom facility so that the occupancy loads can be restricted. Many studies have been done and many remodels have taken place that have significantly altered the original design of the building.

In 1975 a master plan for the Mackay School of Mines was developed that proposed the expansion of the School with the construction of an entirely new facility as well as remodel of the original Mines building. In this plan it was proposed to strengthen all of the URM walls of the building by adding reinforcing steel and gunite concrete. The remodeling work was put off until now and construction of the new facility proceeded. Phase I and II were completed in 1984 and 1989 respectively.

In 1987 the architectural firm of Casazza, Peetz and Hancock was commissioned by the state of Nevada to undertake the work of Phase III, rehabilitation of the Historic Mackay School of Mines Building. This project was to include the structural rehabilitation of the building so that it could meet the seismic requirements of the current codes.

The primary scope of the contract to rehabilitate the building was to incorporate the Engineering/Mines Library into the space of the building. The solution to accomplish this scope of the project was to remove a portion of the first and second floor and replace them with three floors in the same area. Structurally, this is to be accomplished with the use of post-tensioned concrete floor slabs. As part of the floor removal, one bearing wall will also be removed. This process requires the installation of a steel truss to support the existing wood trusses that make up the roof structure.

To obtain the necessary square footage for the future needs of the library, the basement had to be expanded to the full foot print of the building. Originally, only a small portion of the building had a basement, but over the years a basement has been constructed by ''mining'' out the areas under the building. In no case did the basement extend to the outside walls. To expand the basement, an underpinning operation will occur below all of the remaining URM walls. Additionally, all interior posts which currently support the first floor level had to be removed. Steel beams are to take their place and will be supported by the new underpinning walls.

In reviewing the 1975 study and its proposed strengthening operation, it was quickly determined that the gunite solution would be impossible given the fact the building is on the List of Historic Places. Alternative methods to seismically strengthen the building were investigated. The relatively new concept of base isolation was discussed and Base Isolation Consultants, Inc. (BIC) was consulted to pursue this idea. This process had to be ''sold'' to many people, but it was readily apparent that this system could be built relatively inexpensively, satisfy the seismic requirements of the structure and not require the ''destruction'' of the historic nature of the building. Since all of the primary URM bearing walls would be underpinned any way it proved to be a very short step to incorporate base isolation into the design of the building.

ISOLATION SYSTEM

The building rests on 67 high-damping rubber bearings. High-damping rubber is becoming prevalent as an isolation medium not only in United States [3], but also in Japan. The advantage in such a system is it's simplicity. Rather than incorporating wind fuses and damping gadgets, the rubber does everything. It exhibits high stiffness at low strains, a characteristic that is suitable for windloads, and a median damping value of approximately 15%. At low strains the damping is higher.

Three different types of bearings were designed to accommodate varying vertical loads, ranging from 45 to over 300 Kips. See Figure 3. for Plan of Isolators.

A suspended concrete flat slab serves as the basement floor and the structural tie above the isolation system. For economy the slab is poured on top of cardboard forms. This method of isolating the slab was first proposed for the isolation design of the Masonic Building. [2] To provide support for the flat slab so that the spans become manageable, teflon sliders (42 total) with rubber retainers for the protection of the teflon surfaces are incorporated. The sliders, targeted at coefficient of friction value of 0.10, will also add additional damping to the system.

The sequence of construction is first the underpinning concrete walls and footings are constructed with pockets left open for the bearings. A steel shim plate is placed between the wall and the footing. Flat jacks on top of the bearings are subsequently installed. After all the bearings and flat jacks are in place, the building is jacked up. In the process, the vertical load is transferred from the steel shim plates to the bearings, after which the steel shim plates are removed. The flat jacks are grouted and are left in place. See Figure 4. for Detail of Bearing.

ANALYSIS

3-D time history analysis were performed to analyze the behavior of the structure. Since the unreinforced masonry wall had in-place ultimate capacities which would be reached at around .25-.30G, it was important to filter the forces associated with the maximum credible earthquake below this threshold to avoid collapse. With a hybrid isolation system of high-damping rubber bearings in combination with teflon sliders, the analytical tool used had to accurately depict the contribution in response due to these two elements. N-PAD was selected as the analytical tool for the project. The program was first used for the analysis of the Foothill Communities Law and Justice Center, the first building in the United States to be base isolated. [1]

The analysis involved the use of two programs, SAP-81 and N-PAD. [4] The latter program, which is designed to work in conjunction with SAP-81, introduces non-linear degrees of freedom at the base of an elastic superstructure. The SAP-81 program is used to model the elastic superstructure, which model is then combined with the non-linear isolator base modeled on N-PAD. Before execution of N-PAD, some of the SAP-81 programs - SAP, FRAME, PLANE, SOLVE, TABS - need to be executed to establish the stiffness matrix of the superstructure. After completion, N-PAD will generate the complete stiffness, mass, and damping matrix of the Base Isolation system and combine it with the superstructure matrix. Each isolator is considered as having two translational and one vertical degree of freedom (d.o.f.). The vertical d.o.f. is elastic and independent; the two translational d.o.f.'s are coupled and can be non-linear. For each time step, the stress and strain of every pad is calculated and the program establishes the assembled stiffness of the pads at the rigid base center. The building is assumed to have a rigid diaphragm at the base and at every floor level and the horizontal d.o.f.'s are reduced to three - 2 translational and 1 rotational - at every story. The stiffness of the superstructure is elastic and generated by TABS. The base system - 3 horizontal d.o.f.'s - is non-linear and iterations are carried out to calculate the instantaneous stiffness for every time step. Newmark's method is used for time-history analyses.

Bi-linear elastic elements were used to model the high-damping rubber bearings and hysteretic elements were used to model the sliders.

Three synthetic design time histories representing the maximum credible event were developed by Geospectra of Richmond, California as a basis of design, and are summarized as follows (See also Figure 5.): Discussion of the derivation of these time histories and the general seismic risk in the Reno area is not within the scope of this paper.

Name of Record	Max. Acceleration
UNR9S	.58G
UNR9S1	.53G
UNR6SSC2	.55G

N-PAD analytical results are shown in Figures 6 and 7. The record that produced that highest response was the UNR6SSC2 record which possessed high energy content in the long period range. Maximum displacement at the corner was 6.3 inches and 5.9 inches at the geometric center. Maximum transmitted base shear was .15G. At the roof level, most of the spikes were less than .20G with one spike reaching .22G. The monitored accelerations up the building in no instance reached the .25G to .30G area, which is the ultimate threshold representing the force level that could cause potential out-of-plane failure of the unreinforced masonry walls.

From the transmitted base shear time histories, one can calculate the equivalent viscous damping value of the hybrid isolation system. That value was 26%.

CONCLUSION

The fact that Base Isolation can be a viable alternative to conventional guniting as a strategy for the mitigation of earthquake damage associated with unreinforced masonry structures is the significant outcome of this project. In the case of buildings of historical significance such as the Mackay School of Mines, seismic retrofitting with Base Isolation has the potential of saving the interior fabric of the building and thereby its original character.

REFERENCES

[1] A. G. Tarics, D. Way, and J. M. Kelly, "The Implementation of Base Isolation for the Foothill Communities Law and Justice Center", AReport to the National Science Foundation (CEE-821758C) (1984)

[2] J. M. Kelly, D. Way, "The Seimic Rehabilitation of Existing Buildings Using Natural Rubber Bearings," Proceedings of International Conference on Natural Rubber for Earthquake Protection of Buildings and Vibration Isolation (1982)

[3] A. G. Tarics, J. M. Kelly, D. Way, R. Holland, "Quality Assurance and Control of Fabrication for a High-Damping-Rubber Base Isolation System," Third U.S. National Conference on Earthquake Engineering (1986)

[4] D. Way, V. Jeng, "N-Pad, A Three-Dimensional Program for the Analysis of Base-Isolated Structures," Proceedings of American Society of Civil Engineers, Structural Congress (1989)

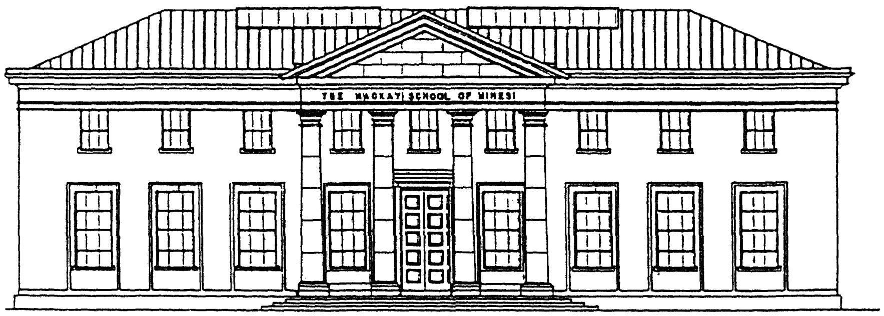

FIGURE 1. SOUTH ELEVATION

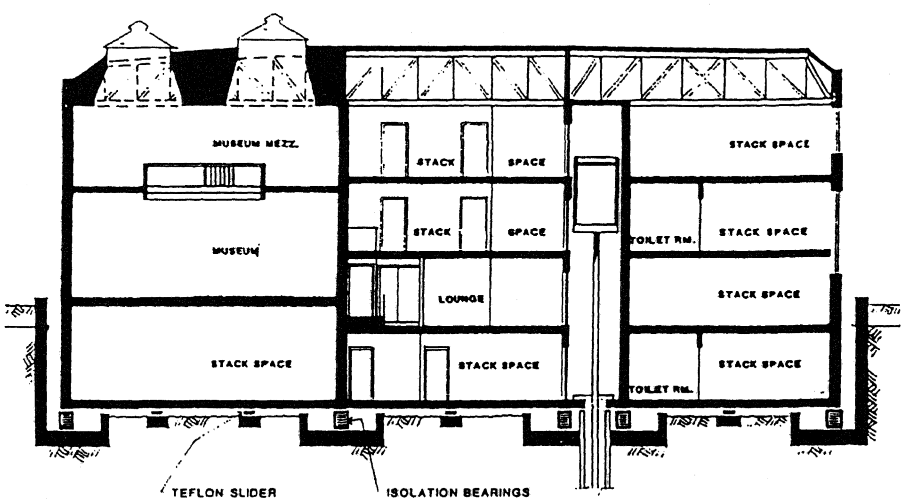

FIGURE 2. BUILDING SECTION

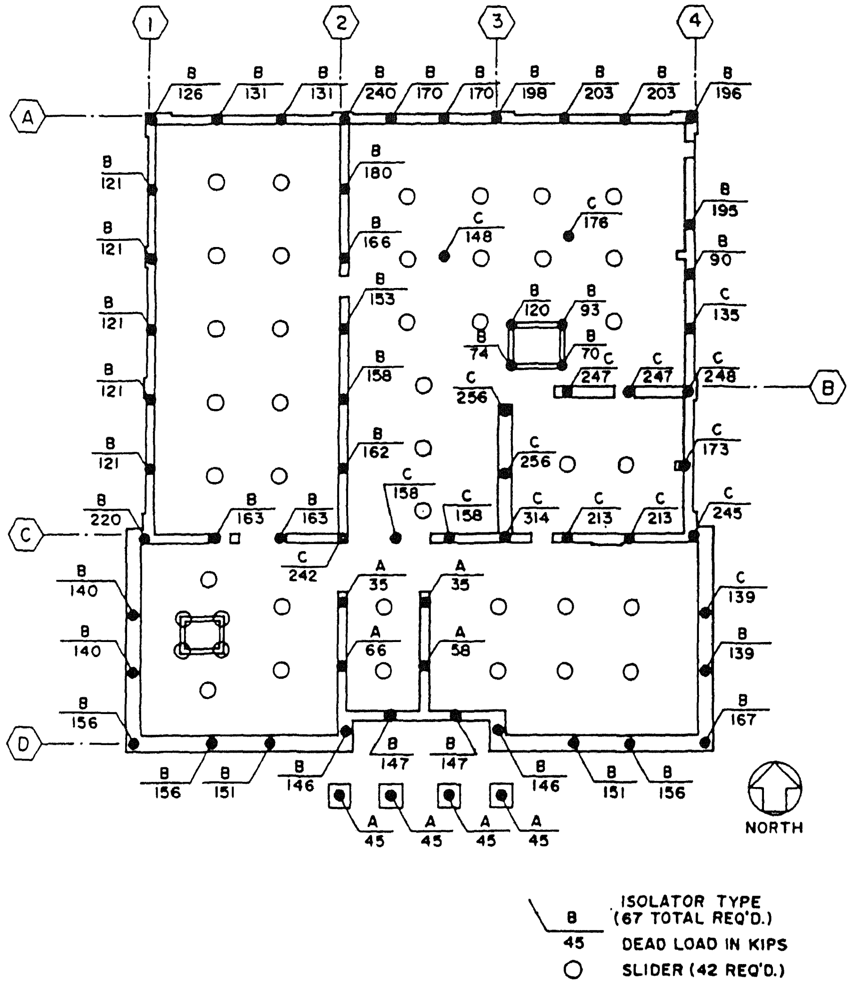

FIGURE 3. PLAN OF ISOLATORS

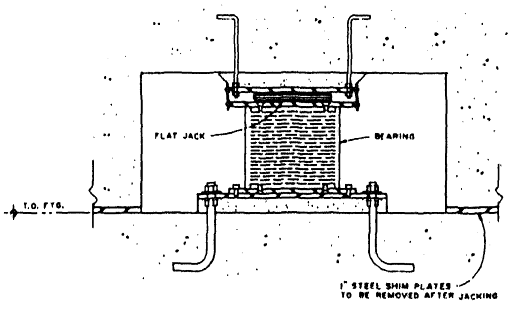

FIGURE 4. DETAIL OF BEARING

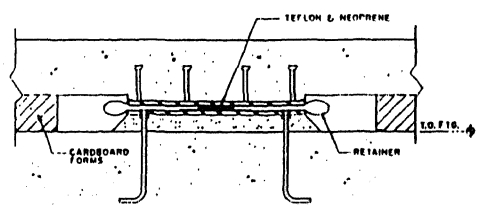

FIGURE 4a. DETAIL OF SLIDER