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SEISMIC REHABILITATION OF THE SALT LAKE CITY & COUNTY BUILDING USING BASE ISOLATION

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SUMMARY

This paper presents very briefly the methods used to seismically strengthen a historical building (100 years old) using base isolation. Anchoring walls to floor diaphragms, anchoring appendages and ornaments, construction of new wood roof and attic diaphragms, and constructing a new steel braced frame on the inside of the tower are all portions of the seismic strengthening.

Base isolation is shown to be an effective method for the seismic strengthening of existing buildings of this type.

INTRODUCTION

The Salt Lake City & County Building was constructed of unreinforced masonry and sandstone in 1890-1894.

The masonry has a thickness up to 2.5m at the base of the tower. Masonry walls throughout the main part of the building have thicknesses up to 0.6m on the interior and 0.9m on the exterior.

The building is monumental and highly ornamented. It is approximately 81m x 39m in plan. The building is approximately 30m high with a central stone and masonry tower extending to 76m high. The architecture can be described as Richardsonian Romanesque Revival style.

The Wasatch Fault runs through Salt Lake City approximately 2 km east of the building. The length of the fault is more than 370 km. Salt Lake City has been classified as a Uniform Building Code (UBC) Zone 3. Zone 3 is considered a zone of major damage - corresponds to intensity VII and higher on the Modified Mercalli Scale.

The building is being restored and seismically strengthened because it is a community treasure and provides a sense of stability and continuity with the past. When the restoration is completed, the building will stand as an enduring witness to a city's commitment to the past and the future.

STRUCTURAL HISTORY

The largest earthquake experienced by the building occurred in 1934, which prompted the removal of the four statues over the main building entrances and the statue atop the clock tower. The March 12, 1934, Hansel Valley earthquake had an approximate Richter magnitude of 6.1. Hansel Valley is about 80 miles from Salt Lake. Accelerations felt by the building at its base were likely not greater than .05 G.

A modest study, with Henry J. Degenkolb and Associates, San Francisco, as consultants to E.W. Allen, was undertaken in 1975 to determine the best way to strengthen the clock tower.

The study concluded that a steel space truss within the tower was the best solution, primarily because it would not add significant weight to a building which had already shown some signs of settlement distress.

Tower overturning would be counteracted by embedding the four corner steel columns at a distance sufficient to mobilize the dead weight of the massive 8-foot by 13-foot, L-shaped tower support piers below the main roof.

The city decided in 1984 to go ahead with the project. The design team consisted of The Ehrenkrantz Group, project architects; Burtch Beall, associate architect; and E.W. Allen and Associates, structural engineer.

STRUCTURAL ANALYSIS AND DESIGN

Two leaders in the field of structural engineering, knowledgeable in new technology, were hired as consultants to E.W. Allen & Associates (EWA) to investigate alternative approaches to seismic upgrade. These people were John Kariotis of Kariotis and Associates, Pasadena, and Eric Elsesser of Forell/Elsesser (F/E) in San Francisco.

Preliminary analyses were done to arrive at seismic retrofit schemes using the UBC, the ABK Method and base isolation.

Although, the base isolation solution exceeded ABK in cost by over $1 million, based on rough schematic estimates, it was still considerably less expensive and architecturally disruptive than the UBC solution, which would require total demolition and reconstruction of the interior of the building.

Calculations also indicated that the base-isolated building stayed well within the elastic range (.08 G, vs. .55 G for a non-isolated building) so that predicted damage would be minimized for the design earthquake.

These findings were presented to the Salt Lake mayor and city council, with a recommendation to proceed with base isolation. A decision was made to conduct a detailed analytical study, which would include dynamic time history analyses on a detailed building computer model. F/E was hired by EWA to act as the consultant to perform this study. The extensive computer work was done by SSD, Berkeley, acting as consultants to F/E.

BASE ISOLATION CONCEPT

Although no seismograph records for major earthquakes in Salt Lake exist, earthquake records in other areas with characteristic similar to what might be expected in Salt Lake, indicated that the City and County Building might be subjected to amplified force levels as high as .55 G. Resisting these forces using such approaches as the UBC and ABK methodologies would require significant construction throughout the building, such as shotcreting or replacing most of the unreinforced brick bearing walls, and extensive anchorage of floor diaphragms to exterior and interior walls.

Base isolators are very stiff in the vertical direction in order to transfer gravity loads, but are flexible in the horizontal direction, thus isolating the building from the horizontal components of seismic forces. Base isolation of the structure would shift the fundamental period of vibration of the structure to a range outside of the predominant energy content of the design earthquake.

A typical bearing used on this project is approximately 17 inches square by 15 inches tall. It consists of a sandwich of alternating steel and rubber layers with a lead core.

A retaining wall is being constructed around the building's exterior with a 12-inch seismic gap, so that the building is free to translate horizontally relative to the ground.

Computer runs indicate that the maximum deflection that the building will experience relative to the ground during the design earthquake is about 5 inches. The additional clearance is provided as a factor of safety in the extremely rare event of a larger earthquake.

BASE ISOLATION DESIGN

Working together, EWA and F/E found a method of installing the isolators on top of the existing footings. However, because of isolator installation clearances, it would also be necessary to install the new first floor 1 foot, 2 inches higher than the old floor.

It was necessary to cut hundreds of slots through existing walls above the footings in order to install the isolators.

Dames & Moore, project geo-seismic and geo-technical consultant on the project, conducted additional dynamic soil tests at the site and determined that the building site period was 1.4 seconds. This is different enough from the base-isolated fundamental building period of 2.5 seconds to preclude any resonance between the isolators and the ground.

The final design, on which construction documents were based and construction has proceeded, consisted of 447 bearings placed on top of the original spread footings, with a new concrete structural system built above the bearings to distribute loads to the isolators. This new structure contains the following elements:

1) New concrete side-beams poured on each side of all masonry walls. The walls are notched in 4 inches on each side to receive these beams, and post-tensioning rods are drilled through the walls and tightened to clinch the masonry material between the new beams.

2) At isolator locations, all wall material is removed to accommodate the bearings themselves, and a new concrete cross beam is poured over the top of the isolator and to connect the two side beams. The cross beam acts as a double cantilever in transferring the wall load from the side beams onto the isolator.

3) Below the isolators, several small wide flange beams are welded together to form a grillage, that distributes vertical loads from the isolator to the existing footing so as not to overstress it.

4) A new concrete floor is located above the isolators to act as a rigid

diaphragm, connecting all of the new side beams and linking all of the isolators so they will act together as a system.

5) After the four steps are completed, the mortar joint directly below the new side beams would be removed, transferring the building weight onto the isolators and completing the isolation process.

OTHER SEISMIC STRENGTHENING MEASURES

In addition to base isolation, the following seismic strengthening measures are being done:

1) Construction of a structural steel space truss within the clock tower to stabilize it and transfer seismic forces down into the main building.
2) Creation of a structural plywood diaphragm in the fifth floor attic to stabilize the top of exterior masonry walls.
3) Structural plywood shear walls within the attic to laterally stabilize the main building roof structure. The new walls will be located above the existing interior masonry walls.
4) Anchorage of all exterior masonry walls to floor and attic diaphragms.
5) Anchorage of diaphragms to interior masonry walls for shear and to provide a tension tie through the walls.
6) Lightweight reinforced concrete topping over existing floor diaphragms to increase their stiffness and strength.
7) Anchorage of all exterior seismic hazards, such as chimneys, statues, dormers, ballustrades, parapets and cornices.

CONSTRUCTION

The method chosen by general contractor Jacobsen Construction Co. for a large portion of the stone cutting was a wire saw. Manufactured in Spain, the saw consists of a 1/2-inch diameter, diamond-studded steel wire, guided by a series of pulleys adapted to each cutting situation, with a control panel mounted on a track that maintains a predetermined wire tension. The wire is kept cool with a steady stream of water.

Also, large diamond-blade rotary saws up to 4 feet in diameter were used to make the vertical cuts. Overcutting at corners could not be permitted, so this method would leave a considerable amount of partially cut stone within the holes which would then have to be broken out later. Both line drilling and wire saw cutting were used to make the horizontal cuts across the top of the slots.

Another major concern was building settlement and potential cracking at the time of mortar joint removal. It was decided to pre-load the isolators to take up any slack in the isolator assemblage before cutting the mortar joints between isolators. The isolator vertical stiffness is considerable (3000 kips/in.). It was decided to pre-load to two-thirds of the estimated dead load, rather than the entire dead load. This would lower the risk of cracking the walls above, which might occur if too much pre-load was applied.

Pre-loading was accomplished using Freyssinet flat jacks in a shim space provided for this purpose below each isolator. The particular flat jack used is 16 inches in diameter by 1 1/4 inches thick, with a rated load of 380 kips. Two workmen could easily pre-load three isolators in an hour.

The procedure goes as follows:

1) Place flat jack with circular shims in space between isolator and spreader beam. The shims are fabricated to fit in the two dished areas located

in the center of each side of the flat jack.

2) The flat jack comes with two valve stems. Epoxy is pumped into one of the stems until all air is bled through the second stem, at which time it is locked off. As pressure increases, the central dished out area of the flat jack expands as it fills with epoxy and presses against the two nested shims.

3) The hydraulic jack for pumping the epoxy is a double-acting type, where the hydraulic fluid, gauge and assorted hoses are kept separate from the epoxy, allowing the hydraulic jack to be re-used. A solvent is used to clean the fittings and the top cylinder, which comes in contact with the epoxy. When the gauge reading indicates the desired pre-load, the flat jack valve stem is locked off.

The remaining space between the 24-inch square plates not occupied by the flat jack is shimmed tight with steel shim plates, and the four corner bolts are tightened down.

5) Once the epoxy has cured, temporary safety screw jacks are removed and used elsewhere on the job.

CONSTRUCTION STAGING

Also believed to be of critical importance is the staging of mortar joint removal once all isolators are in place and pre-loaded. It would be unwise to allow the contractor to proceed at will with mortar joint removal since parts of the building might be cut loose while other parts are still rigidly attached to the ground. Therefore, the contractor had to meet the following requirements:

First, the new first-floor diaphragm had to be in place so that the isolation system would act as a unit.

Second, all mortar joints were removed in as short a time as possible so that one part of the building did not become isolated for an extended period of time while another part of the building was still tied down.

It must be realized that the building is in great seismic danger during the whole isolator installation process, as significant portions of wall must be removed to install the isolators. An earthquake of any significant size during isolator installation could be catastrophic to the building.

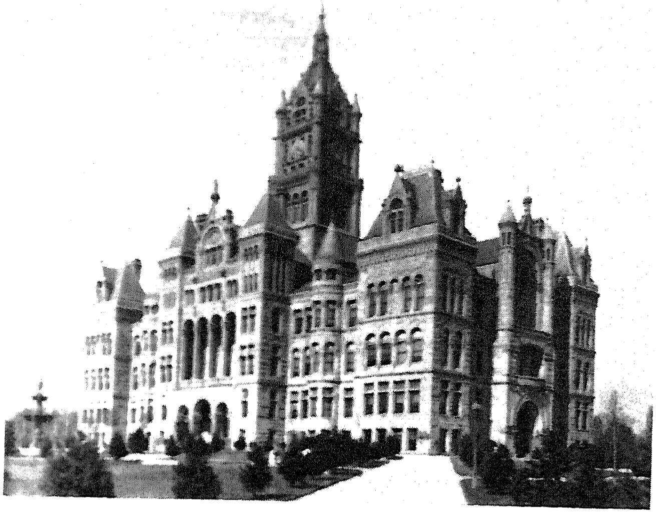
CONCLUSIONS

The experience of designing and constructing a seismic isolation system for the Salt Lake City and County Building has proved the feasibility of this seismic mitigation technique for existing buildings. It is an approach that offers the possibility of preserving as much of the original architectural fabric as possible while providing a greater degree of protection from non-structural damage than conventional strengthening.

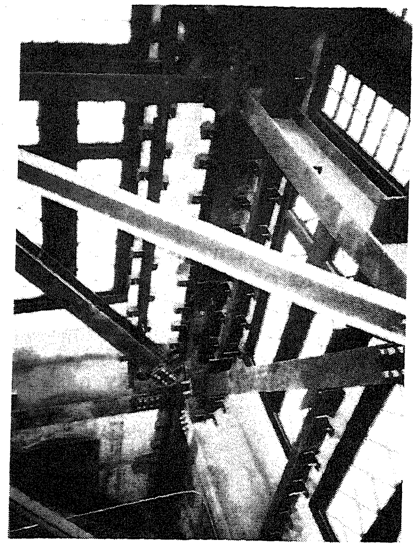
REFERENCES

(1) Allen, Elsesser, Hollings, and others, "Base Isolation Study of the Salt Lake City & County Building", 1986

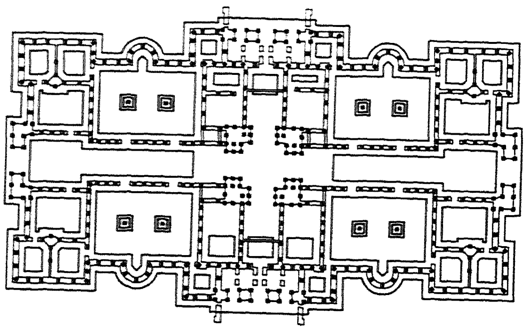
(2) Dynamic Isolation Systems Inc., "Base Isolation of Buildings", 1985



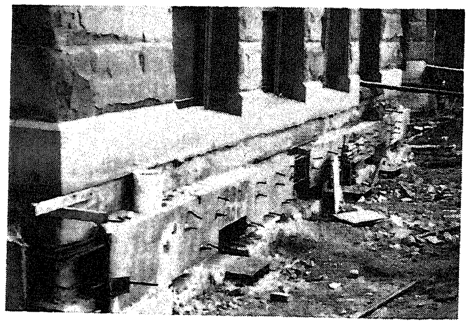
Building after completion.
(Circa 1900)



Clocktower
Space Truss

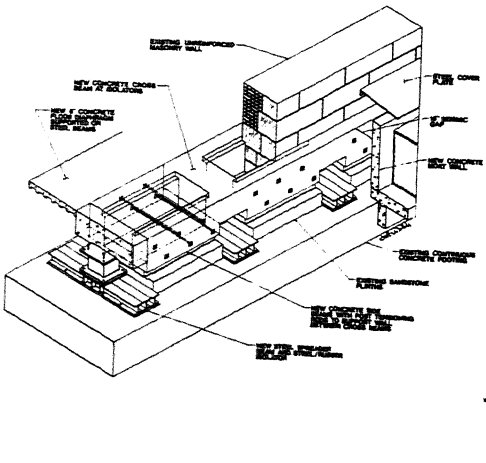


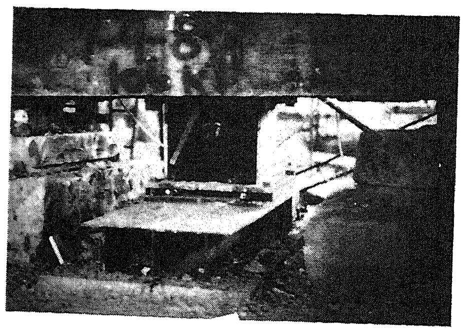
SCHEMATIC BASE ISOLATOR LOCATIONS



Typical Exterior Condition

Plan of Isolators





Typical Isolator as
installed.

Detail of Typical Isolator
installation.