"The Seismic Retrofit of the City and County Building in Salt Lake City: A Case Study of the Application of Base Isolation to a Historic Building"

Theodore H. M. Prudon[1]

The protection of historic architecture against natural disasters has over the last decade, become more and more a concern for restoration architects and preservationists. This development comes at the same time as building codes, which have, for instance, extensive seismic strenghtening requirements, are being applied increasingly to existing and historic buildings. The restoration of the California State Capitol is one of the most celebrated case studies and represents a comprehensive example of the thinking of the last decade. The requirements of such codes as the Uniform Building Code (UBC) are being applied quite strictly with little or no opportunity to maintain the original fabric. The case study presented here represents a different approach and obtains seismic retrofit with optimum life safety and damage reduction factors.

The construction of the Salt Lake City and County Building was begun in 1891 after the designs of the architectural firm of Monheim, Bird and Proudfoot, who were the winners of a competition with 15 entries. The building was completed in 1893 and officially dedicated on December 28th of that year. The building designed in the Richardsonian Romanesque style has five stories and is topped by a large crossing tower (Figure 1). The building has a rectangular plan and is divided into four identical quadrants by two perpendicular corridors, which give access to suites of offices and courtrooms. A large monumental stair located in the center on the west side of the building, provides access to the upper floors. The building is located in a small park and can be entered from all four sides.

In construction, the building is typical for unreinforced masonry load

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bearing construction of that period. The exterior is made of a local sandstone with a brick back-up with a mortar bond providing the only connection between stone and back-up. The loadbearing interior walls are made of brick and partitions in structural clay block. Except for the second and third floor, which are made in the typical 19th Century fireproof floor construction consisting of steel beams with brick arches in between, all floors and roof structures are made of wood. Little or no anchoring between the floors, walls and roofs exists.[2]

The City and County Building is located in Salt Lake City, Utah, within 2 miles of the Wasatch Fault, in an area designated as Seismic Zone 3 by the Uniform Building Code, i.e., a "moderately high" seismic risk area. Although no seismographic records of significant earthquakes exist for this area, various studies have shown a recurrence interval for an earthquake with an Effective Peak Acceleration (EPA) of 20% gravity (0.2g) of 1400 years. This is the magnitude of earthquake for which the seismic retrofit has been designed.

Studies to seismic retrofit the building were begun in 1973. Some work to stiffen and reinforce the tower was started by the end of the 1970's. However, because of the major cost implications and other work necessary such as conservation of the exterior stone, upgrading of existing systems, life safety and general interior restoration, a more comprehensive restoration study was commissioned in 1983 and completed in 1984. These 1983 feasibility studies primarily addressed compliance with UBC requirements.

In 1984 a beginning was made with the design of the rehabilitation and a more detailed comparative analysis was prepared. Not only compliance with UBC was considered, but also the ABK method and base isolation were considered as basis for a seismic retrofit. The ABK method named for the three engineers who developed this method was based on a study specifically addressing unreinforced masonry, sponsored by the National Science Foundation.[3] Base isolation is a system whereby a horizontal shear medium is used to separate the building from the ground thus substantially reducing the energy transmitted to the building base.[4]

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[2]The construction detailing of the building is described in Dean L. Gustavson Associates/The Ehrenkrantz Group, "Salt Lake City and County Building Restoration Study," Salt Lake City and San Francisco. 1983.

[3]More completely, this study is titled: "Methodology for Mitigation of Seismic Hazards in Existing Unreinforced Masonry Buildings, ABK TR-08," prepared for the National Science Foundation under Contract No. CEE-8100532. One of the authors, John Kariotis, also served as a consultant on this project.

[4]For a general discussion of base isolation, see, Dynamic Isolation Systems, Base Isolation of Buildings, Berkeley, CA: Dynamic Isolation

The comparative analysis was based on several clearly established goals and criteria i.e., life safety, protection of the building, damage reduction, minimal intervention into the existing structure to obtain seismic retrofit and cost[5] At the end of the pre-design study, it was determined that base isolation was the most desirable solution because it offered similar or better protection for life safety and against damage to the building and its contents at little or no additional cost. Because the work was limited largely to the foundation, it offered the additional philosophical advantage that less original fabric would be disturbed and that fabric was more likely to be intact after an earthquake[6]. After approval, a detailed computer analysis was subsequently performed to establish the performance criteria for the design of the base isolators and the strengthening and anchoring required for the tower and the base building.[7]

Specific test conducted to determine the site specific response spectra. It was established that the site period was 1.4 seconds. To accomplish an effective and safe "de-coupling" of the model behavior of the site and masonry superstructure, the fundamental mode of the base-isolated system was to be not less than 2.0 seconds. Lead rubber bearings based upon a New Zealand patent were selected for that purpose. This system provided in a single unit, three basic requirements, i.e., vertical support, horizontal flexibility and energy dissipation. The bearings are very stiff in a vertical direction allowing only minimal settlement when fully loaded, but retain lateral flexibility. This is accomplished with a special rubber laminated horizontally with steel plates. The energy dissipation is obtained by a properly designed lead core which yields under shear but which provides enough rigidity to prevent lateral movement during minor earthquakes and wind loading. The effect of the system is to shift the fundamental period of vibration of the structure to a range outside the predominant energy content of the earthquake, avoiding resonance and reducing the level of force experienced by the

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[5]For a discussion of vulnerability assessment, see, Eric Elsesser, "Assessing the Seismic Vulnerability of Museums and Historic Structures," in: Barclay G. Jones, Protecting Historic Architecture and Museum Collections from Natural Disasters, London: Butterworth, 1986, pp. 131-173

[6]A more detailed discussion can be found in: "The City and County Building, Salt Lake City, Utah: Pre-Design Submittal," San Francisco, CA: The Ehrenkrantz Group, 1985.

[7]This report was prepared by The Ehrenkrantz Group, PC; Burtch W. Beall, FAIA; Edmund W. Allen Associates; Forell/Elsesser Engineers; SSD Inc., "Base Isolation Study for the Renovation of the Salt Lake City and County Building...," Salt Lake City and San Francisco.

building. In concept, the system works in much the same way as shock absorbers do in an automobile, isolating the car's occupants from road vibrations.

Utilizing extensive computer modeling, the design criteria of the base isolators were determined and the allowable horizontal displacement was established. A schematic design of the base isolation was analyzed in this same computer analysis to assure its feasibility. In addition, the design forces for the reinforcement of the masonry superstructure were calculated. The tower was to continue to be reinforced in a conventional manner utilizing a structural steel frame, which caused little disturbance to the building, as this area was both unoccupied and unfinished. Also anchoring of floors to walls, installation of diaphrams in floors and roofs were necessary. The impact of this structural work has minimal compared with the UBC requirements,which would require dismantling of original finishes such as door surrounds, panelling, wainscotting, and decorative plaster ceilings. Similarly, shearwall construction by adding several inches of reinforced concrete to the existing masonry was limited to a small section of an upper floor to allow for the transfer of tower loads to the base building.

Prior to conducting the computer analysis of the base isolation system, several other issues had to be resolved. The original pre-design concept was to construct a reinforced concrete beam under all masonry walls, which would transfer all loads to the isolators. The isolators were to be placed on a new reinforced concrete strip foundation, located underneath the existing foundation. This new foundation would be pre-loaded before the load of the building was to be transferred to avoid excessive and serious initial settlement. Upon selected investigation of the existing foundations, however, it was found that the existing foundation was wider and extended to a greater depth than anticipated from the original architectural drawings. To minimize the underpinning effort, it was decided that the isolators were to be placed on the existing foundations. While this resulted in cost savings, it also introduced a new problem. To provide sufficient clearance above the existing foundation to accommodate the isolator and the reinforced concrete beams, the level of the first floor was raised thirteen inches. More importantly, however, extensive testing of the existing structure also revealed that the sandstone used for the existing foundations was extremely hard and would only be cut with great difficulty. This necessitated another design modification. Rather than constructing a new beam directly underneath the existing masonry walls, requiring removal of large quantities of sandstone, the new system was to cinch the beams at either side of the wall and connect them by post tensioned rods to provide enough friction to support the masonry in addition to the small notches to be cut into the masonry. At the location of the isolator, an opening will be cut to install the isolator and to construct a cross beam connecting the two sidebeams in order to to transfer the load to the isolator and free the foundation from the rest of the building (Figures 2 and 3.) A single but minimal horizontal cut will be sufficient. Prior to the cut, however, the isolator will be preloaded by installing and then inflating flat jacks which have been placed on top of the isolators. These flat jacks will remain in place. In addition to the design of the system itself, it was also important to establish a detailed construction procedure. These procedures were to serve two purposes. First, it was necessary to maintain relative seismic safety during construction whereby one section of the building would not be fully isolated while another section had not yet been worked on. Secondly, it was necessary that no failure of the existing foundations or walls reoccur. As a result of this sequencing construction proceeds symmetrically along the two perpendicular axis thereby reducing the danger of undermining too large a section of the existing footing.

At the present time, the base isolation project has been under construction since February of 1987 with a scheduled occupation by the now fully unoccupied building by June of 1989. The work on the tower including the structural reinforcement was started in the spring of 1986 and is complete.

This project is the first restoration in the world, to our knowledge, to use base isolation as the system for seismic retrofit. Because the system appears to offer good protection against severe damage and because installation causes less disruption of the original fabric, it is a system which deserves study for application to many more buildings.

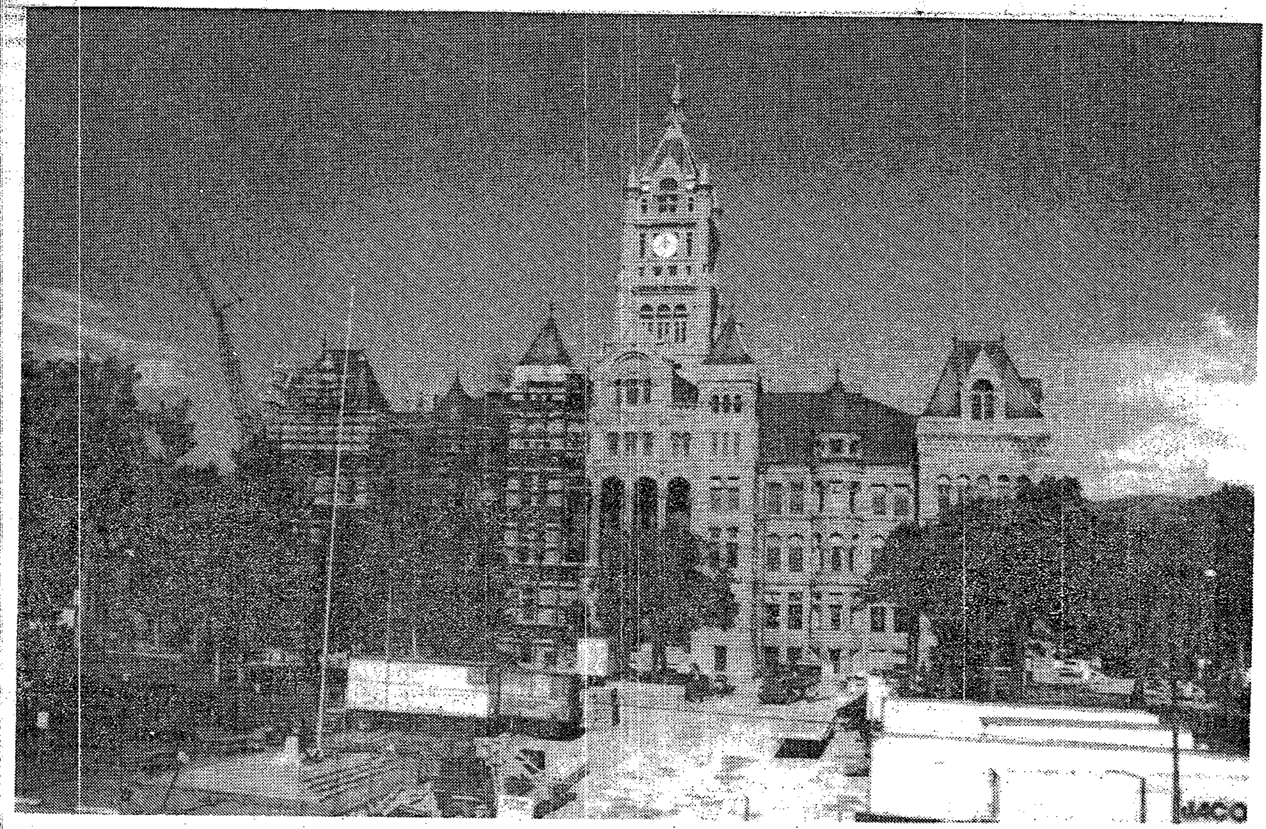

Figure 1: City and County Building, Salt Lake City, Utah, May 1987. General Restoration as well as installation of base isolation underway.

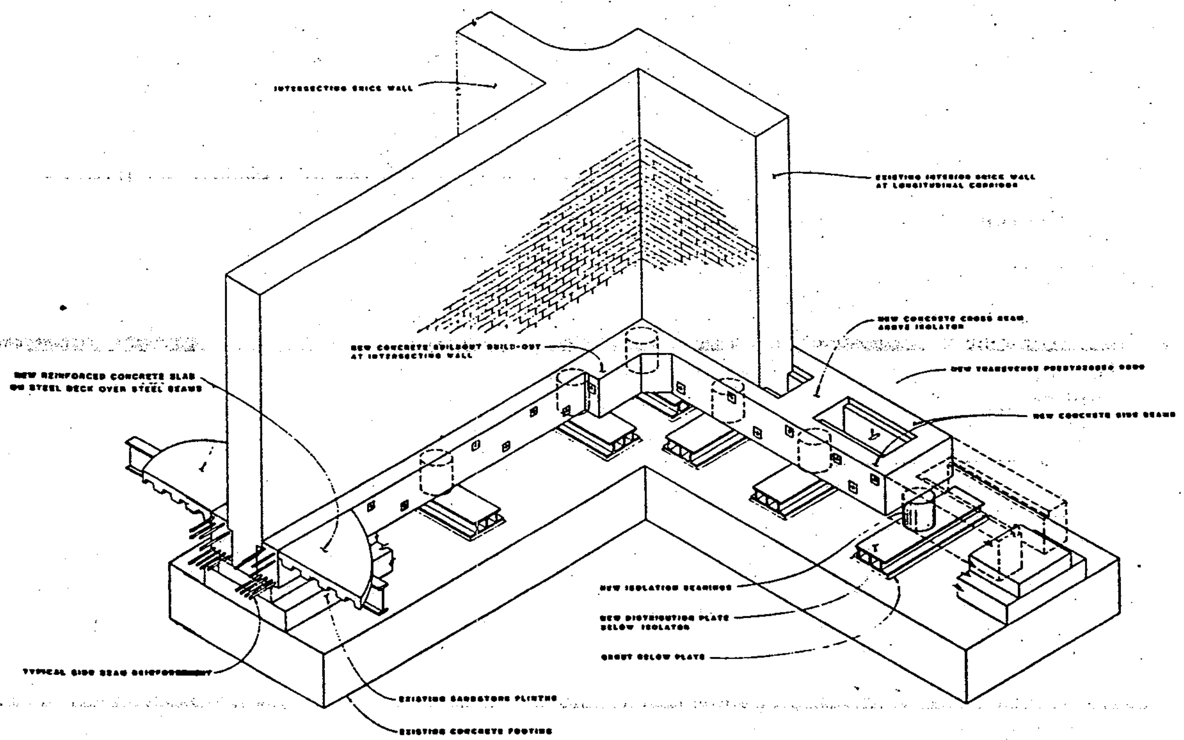

Figure 2: Isometric cutaway of typical wall intersection sharing existing foundations and masonry walls and the new cinch beams and spreader beams as well as the base isolators.

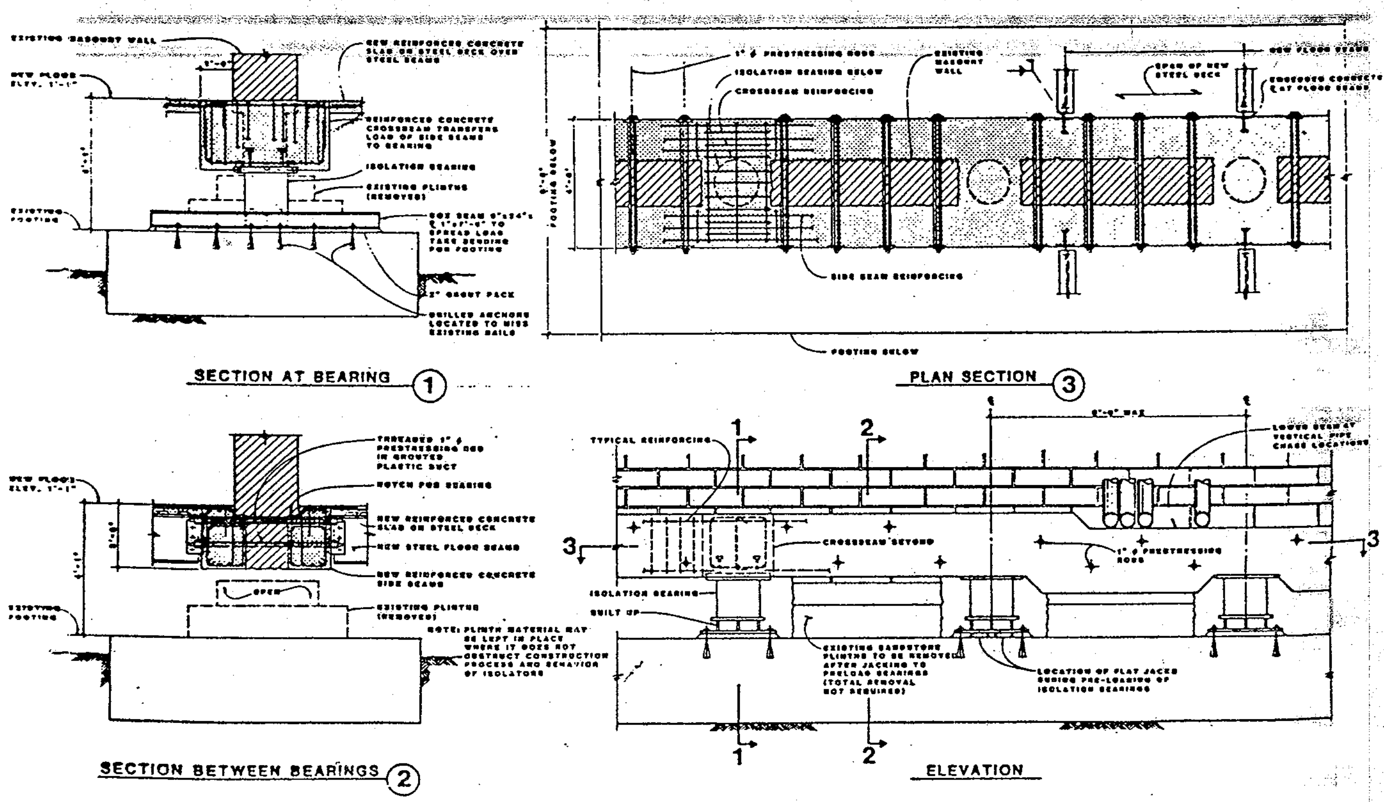

Figure 3: Typical details for base isolation installation.

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The seismic retrofit of the City and County Building, Salt Lake City, Utah, U.S.A. designed by architects Monheim, Bird, and Proudfoot 1891-1894 addresses the third sub-theme of the 8th ICOMOS General Assembly "Monuments in Relation To Their Natural and Built Environments and Their Historical Context". Because of the building's geographical location along the Wasatch fault line, Zone 3, i.e., an area with a "moderately high" seismic risk, earthquakes are a major concern and therefore the building, built prior to seismic design considerations, must be upgraded to meet contemporary codes.

Three methods of seismic reinforcement, Uniform Building Code (UBC), ABK, and Base Isolation, were studied, analyzed and compared to determine which would upgrade the building while retaining the greatest amount of historic fabric. Both the UBC and ABK methods take the approach of resistance to earthquake motion by assessing shear values of masonry walls. In the UBC method, no lateral resistance is assumed and in the case of the ABK method, a shear value is calculated. In both methods, resistance is achieved by introducing diaphragms of poured structurally reinforced concrete at floor levels and stiffening the existing walls with gunite in addition to anchoring of floor, walls, pinnacles and parapets, as well as stiffening of the tower. This work necessitates complete removal of architectural finishes with the resultant replacement of an old veneer onto a new frame.

Base Isolation on the other hand takes the approach of separation through which the building is isolated from ground motion by placing the building on "shock absorbers", rubber pads with steel plates between, at foundation level. This method was found to be more advantageous. While the required life safety could be provided, damage would appear to be less. Also, construction would be limited to the foundation, thereby not requiring removal of original materials and finishes. The system for base isolation selected is based on the original New Zealand patent and has been used for contemporary construction. This project, which is currently under construction, is the first example of the application of base isolation to a historic building.

"Adaptación Sísmica del Edificio Municipal en la Ciudad de Salt Lake: Un estudio sobre la aplicación del Aislamiento de Base a un Edificio Histórico"

Theodore H. M. Prudon

La adaptación sísmica del Edificio Municipal, Ciudad de Salt Lake, Utah, U.S.A. diseñado por los arquitectos Monheim, Bird, y Proudfoot 1891-1894 se aplica al tercer sub-tema del octavo ICOMOS Asamblea General "Relación de Monumentos a su Medio Ambiente y a su Contexto Histórico. Debido a la situación geográfica del edificio sobre la falla Wasatch, en una zona de riesgo sísmico "moderadamente alta" (Zona 3), los terremotos son causa de gran preocupación. El diseño original del edificio no toma en cuenta consideraciones sísmicas y debe, por tanto, ser remodelado para satisfacer código contemporáneo.

Tres métodos de refuerzo sísmico, Código de Construccioń Uniforme (CCU), ABK, y Aislamiento de Base, fueron estudiados, analizados, y comparados para determinar cual podría reforzar el edificio y al mismo tiempo retener la mayor parte de su constitución histórica. Ambos métodos el CCU y el ABK toman la posición de resistencia al movimiento de terremotos por medio de evaluación de fuerzas de corte de las paredes de piedra. En el método CCU, no se asume resistencia lateral y en el caso del método ABK, un valor para la fuerza de corte es calculado. En ambos métodos, la resistencia de la estructura se obtiene al introducir diafragmas de concreto estructural al nivel del piso y refuerzo de las paredes con gunite, además de sujeción de pisos, paredes, y parapetos y refuerzo de la torre. Para ejecutar este trabajo es necesario remover completamente los acabados arquitectónicos y consecuentemente reemplazar la vieja capa exterior sobre una nueva estructura.

Aislamiento de Base, por otro lado, utiliza el procedimiento de separación, aislando el edificio de movimientos de tierra al colocarlo en "amortiguadores," bloques de goma con platinas de acero entremedio, al nivel de la fundación. Este método fue encontrado más ventajoso. Además de lograrse el requerimiento de seguridad, el daño parecería ser menor. También, construcción sería limitada a la fundación, por tanto no demanda remover los materiales y acabados originales. El sistema para el Aislamiento de Base seleccionado esta basado en la patente original de Nueva Zelandia y ha sido utilizado en construcción moderna. Este proyecto, que está presentemente en construcción, es el primer ejemplo de la aplicación de Aislamiento de Base a un edificio histórico.