SEISMIC Retrofit

of the Wallace F. Bennett Federal Building

(Left)Fig.1.a. View of existing Wallace F. Bennett Federal Building from NW corner. (Top)Fig. 1.b. Architectural rendering of seismically-upgraded building.

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Fig. 3.b. Shear transfer assembly and brace connection during construction.

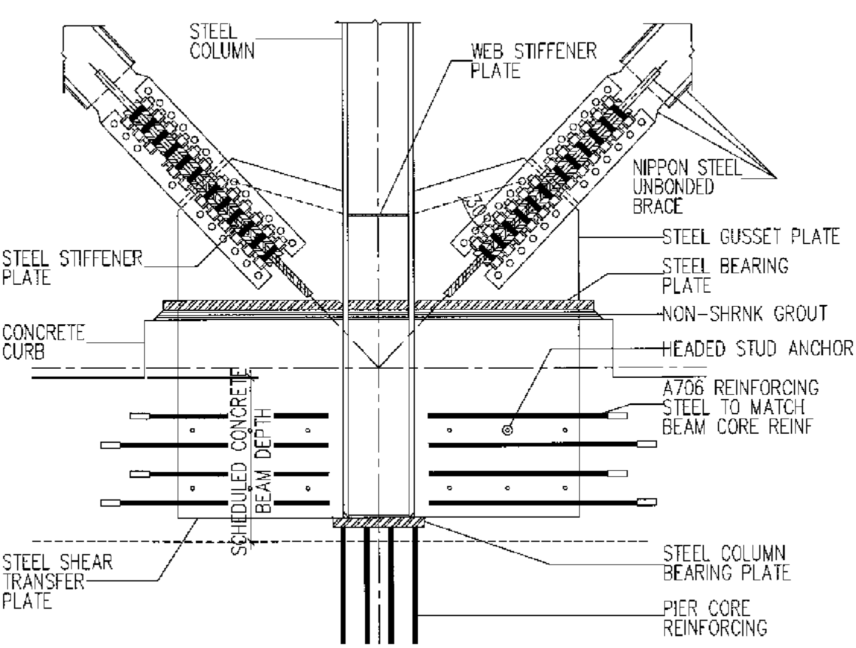

Fig. 3.a. Exterior shear transfer assembly and brace connection details along grid line 7′.

It took a collaborative effort between the property owner, contractor, material supplier, architect and structural engineer to devise a high-tech solution to seismically retrofit the Wallace F. Bennett Federal Building. A total of 344 buckling-restrained braces, called "Unbonded Braces," manufactured by Nippon Steel Corporation of Tokyo, Japan, are used to provide an attractive, economical and high-performance seismic retrofit. The Bennett Building is among the first few buildings in the U.S. and the first federal building project to use buckling-restrained brace technology.

The Wallace F. Bennett Federal Building stands prominently at the southeast corner of 100 South and State Streets in downtown Salt Lake City, UT (Figure 1.a). This eight-story, 300,000 sq. ft. office building has been a community landmark since it was constructed in the early 1960s. The reinforced-concrete structure is constructed of 8″ thick two-way flat plate floors, spirally-reinforced rectangular columns and pile foundations. It was well designed and constructed for its time and has been carefully maintained over its life. Nonetheless, the Bennett Building lacks the many advances in seismic resistant design that have been incorporated into building codes since the time of its design and construction and would not be capable of resisting the large magnitude earthquake that the nearby Wasatch Fault is capable of generating.

Salt Lake City is located within the Intermountain Seismic Belt and has been designated Seismic Zone 3 by the Uniform Building Code since about the time the Bennett Building was constructed. Recent studies suggest that the potential exists for more frequent, large magnitude earthquakes in the region than previously understood. According to the most recent USGS/NEHRP seismic contour maps, the Wastach Fault portion of the Intermountain Seismic Belt that includes the Salt Lake City area has the potential to generate Maximum Considered Earthquake (MCE) responses at short to moderate period ranges equal to or greater than many portions of the high seismic regions of the California coast. A general awareness of the potential for damaging earthquakes in Salt Lake City made the seismic upgrade of the Bennett Building a high priority.

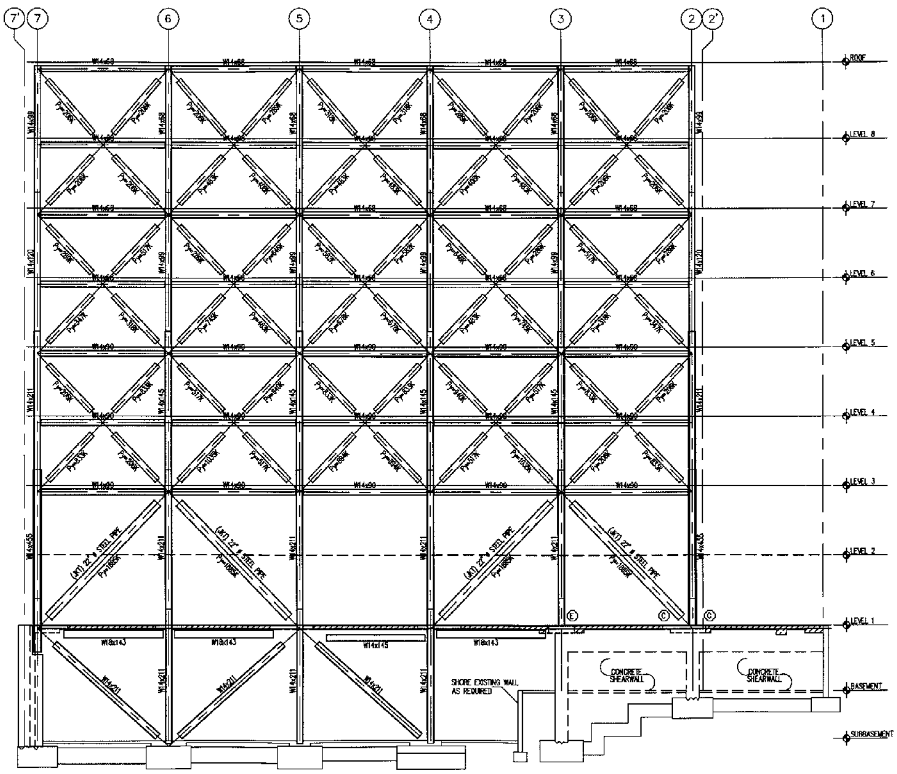

Fig. 2. Braced frame elevation at grid line C (N-S direction, E-end of building).

The Role of the GSA

The General Services Administration (GSA) is the largest single-entity property owner in the U.S. As the general real estate arm of the Federal Government, the GSA is responsible for acquiring, maintaining, updating and managing tens of millions of square feet of various types of buildings across the country. Its primary mission is to provide high-quality lease space at reasonable rates to a large number of different federal agencies. As a competitive landlord, the GSA must be cost conscious and value minded while providing quality lease space to their tenants.

The GSA also takes safety very seriously. It systematically conducts seismic, blast, gravity load capacity and other types of evaluations on its inventory of buildings to assess their capabilities to resist potentially catastrophic events. Life safety is the primary concern. A number of seismic vulnerability studies of the Bennett Building have been performed since 1988. These evaluations became more detailed and sophisticated over time, but they all shared a common conclusion: serious deficiencies existed in the seismic force resisting systems of the structure.

Seismic safety was the primary driving force when the GSA announced the Bennett Building seismic upgrade project. It was also understood from the outset that aesthetics would be a very important aspect of the upgrade. Reaveley Engineers & Associates, Inc. and Gillies Stransky Brems Smith, P.C., Architects, assembled a team of design consultants that were awarded the upgrade design contract in the fall of 1998. The project was included in the GSA "Design Excellence" program, which provides for enhanced levels of government scrutiny and independent peer review. In addition to the seismic strengthening, the $23.5 million construction budget includes abatement of PCB contaminates, upgrading electrical grounding, the installation of blast-resistant windows and a "first impressions" renovation of the main entrance and lobby.

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The first order of business was to determine the standard and performance level required for the seismic upgrade. Based on the recommendation of the design team, the GSA accepted the performance-based "NEHRP Guidelines for the Seismic Rehabilitation of Buildings," or FEMA-273, as the most appropriate standard for the design. The minimum performance level was determined to be consistent with the FEMA-273 Basic Safety Objective, which is "Life Safety" performance for the BSE-1 intensity earthquake and "Collapse Prevention" for the BSE-2 intensity earthquake.

The design team undertook a comprehensive study of a broad range of different approaches to meeting the upgrade design goals. The project budget could not afford the temporary relocation of the building tenants, and thus all viable solutions had to consider a construction process that would impose minimal disruption to the buildings' approximately 550 tenants who would remain in the facility throughout the construction period.

At the beginning of the study, the favored solution involved the addition of four seismic buttress "modules," each about 25′ by 50′ in plan and extending over the height of the building, attached to the exterior of the building. This solution would have met the budget requirements; however, site restrictions and aesthetic issues were problematic. Also, the GSA had determined that it did not require the additional floor space that would be contained in the modules. More than a dozen other options and variations were systematically explored. However, the seismic retrofit solution quickly converged on introducing a new steel braced frame system around the exterior of the building. The braced frame scheme was selected for its strength, rigidity, economy, constructability and minimal construction disruption to the building occupants. The economy of this scheme also opened the door to replace the existing pre-cast exterior cladding with a modern, attractive and energy-efficient curtain wall system (Figure 1.b).

The Unbonded Brace

Buckling restrained brace technologies have been under development, principally in Japan, for the last 17 years. The Unbonded Brace has been used in more than 160 buildings in Japan, at least 90 of which are greater than 15 stories in height. However, only recently has Nippon Steel begun exploring interest in the Unbonded Brace in the U.S. Structural peer reviewer for the project, Degenkolb Engineers of San Francisco, suggested during a design charrette/peer review workshop at the schematic design phase that this new technology be considered. This proprietary, foreign-manufactured product had to clear substantial hurdles in order to be accepted by a federal government agency mandated to "Buy American" and avoid single-source products.

A structural steel framework interconnects the diagonal braces to form the seismic lateral force resisting system for the upgraded building. This framework is constructed of vertical and horizontal steel wide-flange members attached to the exterior of the building (Figures 2 to 4). The structural steel framework, to which the buckling-restrained braces connect, must be designed to remain safely below the yield stress level for the maximum forces deliverable by the buckling-restrained braces, thus ensuring that yielding will be limited to the braces and not occur in the structural steel framework. Load test results indicate that Nippon Steel Unbonded Braces can be expected to withstand many more cycles of full seismic deformation than they would be expected to experience in a major earthquake. Because the "damage tolerant" buckling-restrained brace system has predictable and ductile behavior with a large capacity for plastic deformation in both tension and compression, large amounts of seismic energy can be absorbed by the structure. This is important, because although the building may sustain significant damage during an earthquake, it is expected to remain stable and capable of withstanding large aftershocks or possibly additional earthquakes without collapse.

Upon completion of Schematic Design, Big-D Construction, Salt Lake City, UT, was brought on board as a construction manager/general contractor with a guaranteed maximum cost of construction contract. Big-D prepared direct cost comparisons of two detailed braced frame designs: a conventional Concentrically Braced Frame and a scheme using buckling-restrained braces. The $1.96 million cost to import the Unbonded Braces was mostly offset by direct reductions in the tonnage of the structural steel framework possibly due to the better post-yield and energy dissipating characteristics of the braces. Extensive modifications to the existing pile foundations that would have been required for the Concentrically Braced Frame scheme were essentially eliminated with the buckling-restrained brace system. Including savings achieved in the foundations, Big-D's estimates indicated a net savings to the structural system in excess of $2 million. Also, the bolt-in-place Unbonded Braces saved about two months of construction time compared with field-welded conventional braces, making it possible to meet the GSA's extremely tight

BUCKLING-RESTRAINED BRACES

The Unbonded Brace is one type of buckling-restrained brace and is a simple but yet remarkably effective configuration of steel and concrete producing a tension-compression load-carrying brace element capable of stable yielding behavior without buckling. The basic concept of the Unbonded Brace is the prevention of compression buckling of a central steel core by encasing it over its length in a steel tube filled with concrete or mortar (Figure 6). A slip interface, or "unbonding" layer, between the steel core and the surrounding concrete is provided to ensure that compression and tension loads are carried only by the steel core. The materials and geometry of the slip layer must be carefully designed and constructed to allow relative movement between the steel core and the concrete due to shearing and Poisson's effect, while simultaneously inhibiting local buckling of the core as it yields in compression.

Tests of Unbonded Braces conducted at the University of California, Berkeley, and extensive testing in Japan, have shown the braces to produce repeatable symmetric behavior in tension and compression, up to post-yield ductilities in the range of 15-20. The symmetric behavior has particular design advantages for chevron or V configurations, and the well-defined elastic-plastic bilinear characteristic allows for rational capacity design methods for the connections, surrounding structural elements and foundations.

Fig. 4.b. Brace connection assembly ready for installation at grid line Q′-2′.

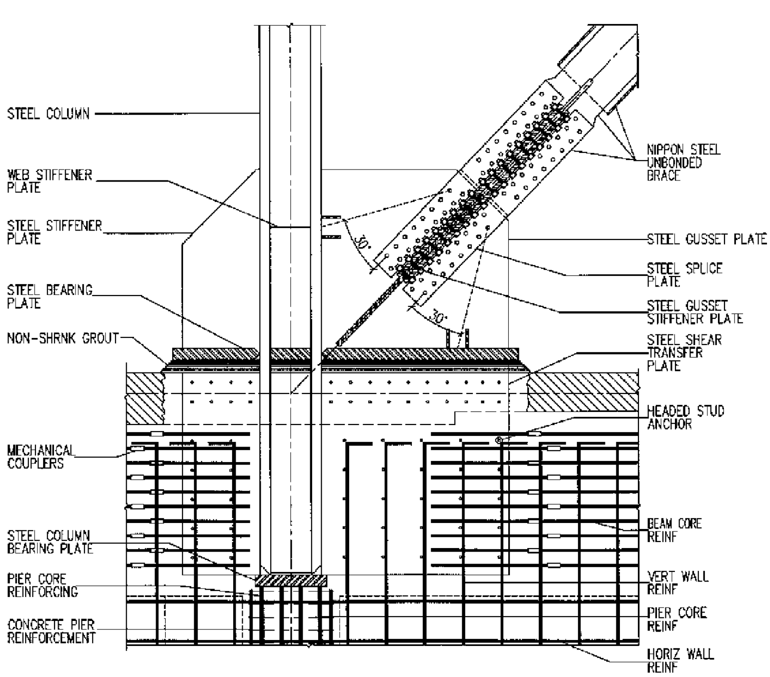

Fig. 4.a. Brace connection detail at grid lines Q′-2′.

14-month construction schedule requirement.

As a diligent owner, the GSA still needed additional assurance to justify spending public funds on such a new concept. Key members representing the contractor, the design team and the owner made one trip to the San Francisco area and two trips to Japan to observe projects using Unbonded Braces and gather important information concerning the design, fabrication and installation of the system. Close tolerances were required to ensure that brace members fabricated to metric dimensions halfway around the globe would fit when shipped to the U.S. and bolted into place. The exceptional quality of the Japanese braces, coupled with compelling technical information that included extensive full-scale testing conducted in Japan and also at the University of California, Berkeley, resulted in a unanimous decision for the use of this innovative technology.

Since the beginning of 2000, AISC's Seismic Design Task Committee and the Structural Engineers' Association of California (SEAOC) have had a joint task group developing standard design provisions for buckling restrained braced frames (BRBFs). The joint task group's draft provisions were utilized for the design of the brace system for the Bennett Building. Extensive analyses of the building and the buckling-restrained braces were performed as part of the upgrade design. For the building lateral system design, both linear analyses and nonlinear push-over analyses were performed using the RAM Frame and SAP2000 nonlinear structural analysis programs.

To validate the design and performance of the Unbonded Brace itself, 3-D nonlinear finite element analyses of several of the largest braces for the project were performed (Figure 7). These analyses involved the application of an increasing amplitude displacement loading history based upon the loading protocol for moment-resisting frames developed in the SAC Steel Project. The analysis results confirmed the Unbonded Brace designs, showing not only that the braces did not buckle,

Fig. 5. Unbonded braces at fabrication plant, Chino, Japan.

but also that stable and predictable hysteretic behavior was achieved. The brace analyses were performed by Nippon Steel using the general-purpose nonlinear finite element analysis program, MARC.

The Bennett Building is the first federally owned building to use buckling-restrained brace technology, and to date, it is also the largest such project in the U.S. The braces used in the Bennett Building range from 206 to 1905 kips yield force and from 11′-2″ to 29′-1″ in length, making them the largest yet applied in the U.S. The braces were manufactured at a fabrication facility in Chino, Japan, which is about 150 miles northwest of Tokyo (Figure 5). The first shipment of braces was delivered on schedule at the beginning of June 2001. Two additional shipments, coordinated to match site construction requirements, will follow in mid-July and at the end of August.

The Wallace F. Bennett Federal Building joins an elite group of projects leading the way to provide seismically safe structures using buckling-restrained brace technology in the U.S.. Other projects in the U.S. using Unbonded Braces include the Plant and Environmental Sciences Building at the University of California at Davis, the seismic upgrade of the Frank Lloyd Wright-designed Marin County Civic Center Hall of Justice in San Rafael, CA, and the Broad Center for the Biological Sciences at the California Institute of Technology, in Pasadena, CA. Additional projects are to follow in the near future.

Buckling-restrained brace technology was a perfect fit for the Bennett Federal Building seismic upgrade project, and it allowed the project to exceed the defined seismic performance goals while meeting strict budget constraints. The benefits of improved seismic performance, reliability and lower costs resulted in a win-win solution.

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General Services Administration, Region 8, Denver, CO

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ARCHITECT:
Gillies Stransky Brems Smith, P.C., Salt Lake City, UT

CONTRACTOR:
Big-D Construction, Salt Lake City, UT

STEEL FABRICATOR:
Mountain States Steel, Lindon, UT (AISC member)

STEEL ERECTOR:
Western Construction Specialties, West Jordan, UT

STEEL DETAILER:
Detail Design Drafting Service, Ltd., Parksville, B.C., Canada

BRACE MANUFACTURER:
Nippon Steel Corporation, Tokyo, Japan

SOFTWARE:
Linear dynamic: RAM Frame,

RAM International

Nonlinear static pushover:
SAP2000 Nonlinear, CSI

Nonlinear finite element analysis:
MARC, MSC.Software

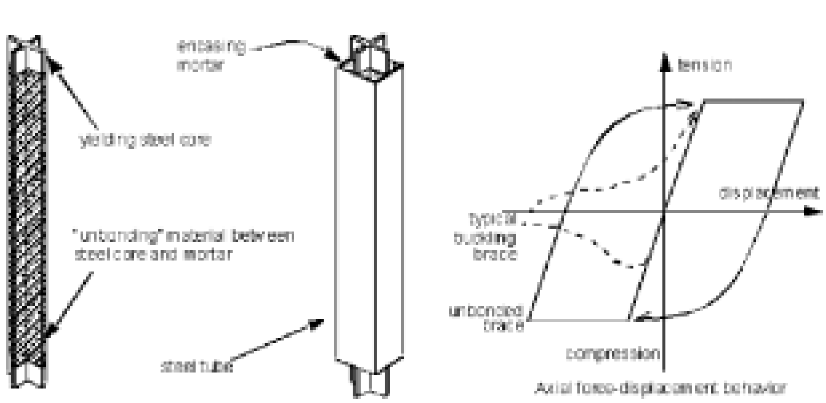

Fig. 6. Unbonded brace concept and typical hysteretic behavior.