RENOVATING CONCRETE

Structural steel moment resisting frames are proving to be an attractive alternative for retrofitting concrete structures in seismic areas

Shown at top is the SFSU Administration prior to renovation; shown above is the building after the renovation was completed.

By Hratch Kouyoumdjian, S.E.

RETROFITTING CONCRETE STRUCTURES FOR IMPROVED SEISMIC PERFORMANCE has long been a challenge. Traditionally, the retrofitting scheme for concrete-framed buildings has been the introduction of new concrete shear walls at selected locations within existing spaces and connecting new walls to existing elements to develop a new lateral-load resisting system.

Such solutions generally concentrate resistance to earthquake forces in the new walls and require new members to collect and deliver forces to the new walls. New foundations also are generally required to resist large sliding and overturning forces. In addition, columns and joints often need to be jacketed or improved by other means, or drifts need to be significantly reduced to limits that prevent the failure of existing members.

An attractive alternative recently adopted to retrofit existing concrete-framed buildings is the introduction of structural steel moment resisting frames to provide lateral resistance to earthquake forces and augment existing frames. Such steel frames can be proportioned to resist high levels of seismic forces based on the favorable ratio of E_{steel} to $E_{concrete}$, and can easily be proportioned by the engineer to limit building horizontal drifts to within shear capacities of existing concrete columns.

The gravity load resisting system generally remains unchanged.

Project Team

Owner:
San Francisco State University

Structural Engineer:
Hratch Kouyoumdjian & Associates

Architect:
Hratch Kouyoumdjian & Associates

Mechanical Engineer:
Bryan Brauer, P.E., Consulting Engineer

Electrical Engineer:
Pacific Engineering Associates

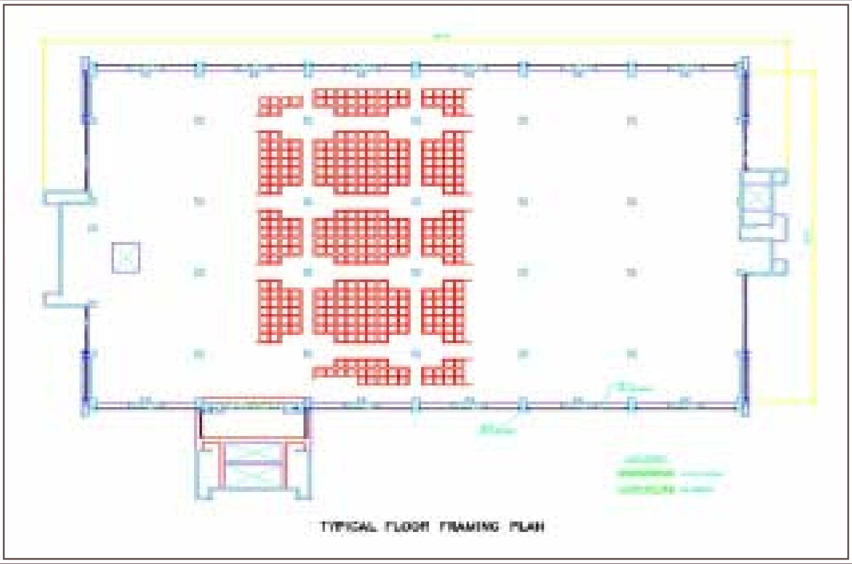
Contractor:
S.J. Amoroso Construction Company, Inc.

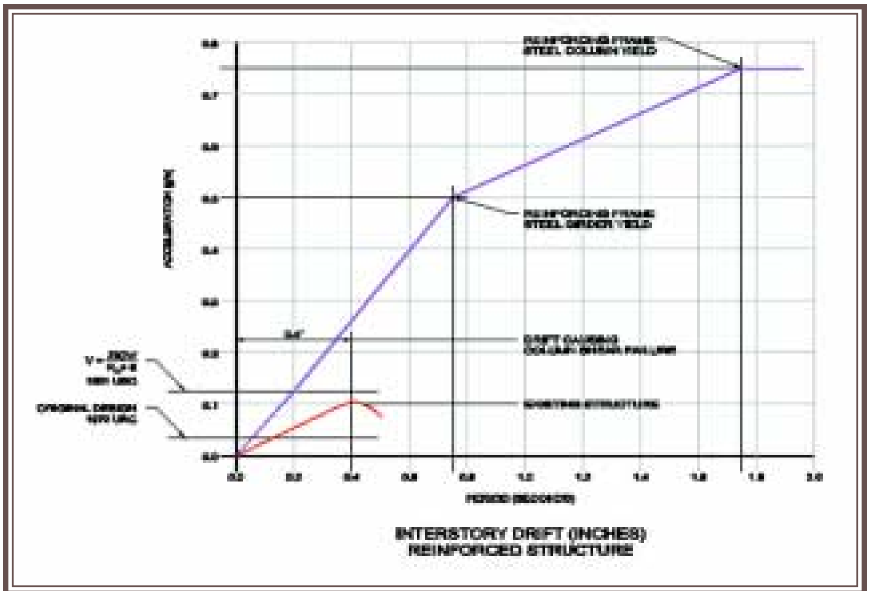
Steel Fabricator:
Hirschfeld Steel Company, Inc. (AISC Active Member)

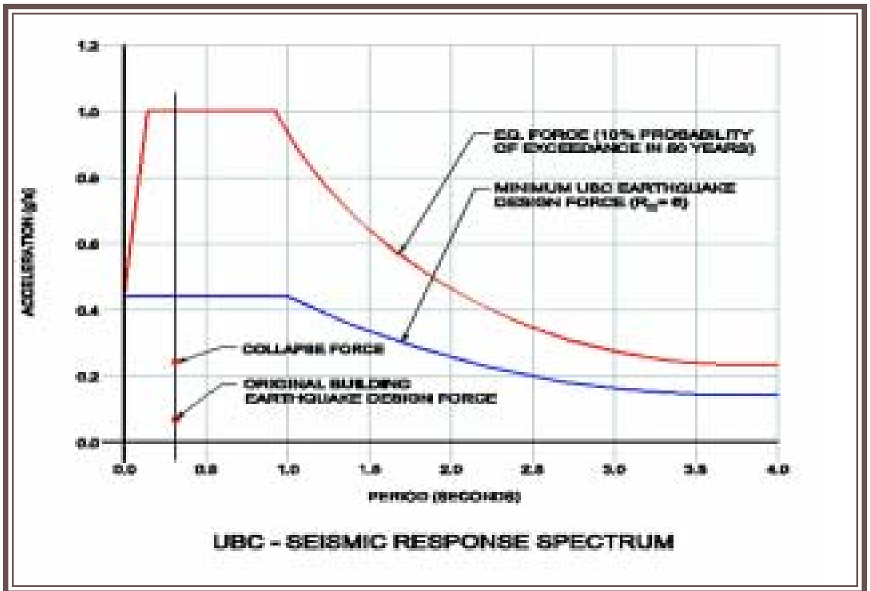
Existing Conditions

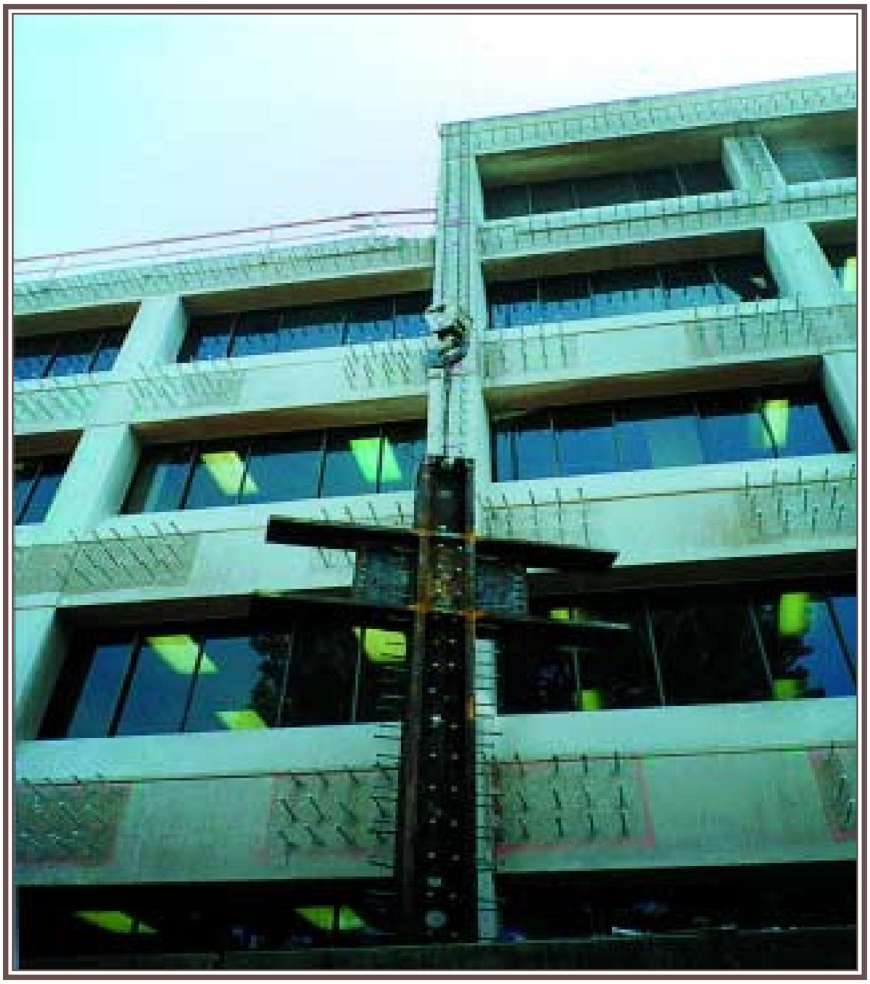
Recently, the application of structural steel moment resisting frames to economically retrofit an existing building was used for the Administration Building at San Francisco State University. The Administration Building is a six-story, 130,000-square-foot, concrete-framed building that was constructed in early 1970. It has a rectangular-shape and is approximately 218' long and 113' wide. The structure was originally designed with concrete waffle slabs for all floor and roof levels and concrete moment resisting frames along grid lines in both directions augmented with a few limited capacity shear walls.

The original lateral design was based on the codes of the late 1960s and accounts for approximately five percent of the building mass. Details of existing reinforcement followed gen-









Pictured on top is a prefabricated column-connection assembly being lifted into position.

Pictured on bottom, is the steel retrofitting in place on the SFSU Administration Building.

eral practices prevalent at the time of construction. Existing columns and girders were reinforced for conventional gravity loads but had limited lateral resistance. Early shear failures in columns, due to lack of closely spaced closed ties, were the most likely mode of failure during a strong earthquake and a potential building collapse could not be ruled out.

This structure was surveyed and analyzed as part of a campus-wide evaluation shortly after the Loma Prieta Earthquake in October 1989 and was noted as one of the most seismically hazardous buildings in the California State University (CSU) system. In 1992, Hratch Kouyoumdjian & Associates (HK&A) was retained to implement a retrofit program.

The current seismic requirements adopted by CSU stipulate a resistance to at least 0.4g ground accelerations for the San Francisco campus. Early analysis verified that if the building were subjected to 0.4g ground accelerations, the resulting drifts would be large and cause exterior column failures, thus subjecting the occupants to very high and unacceptable risks.

Determining A Retrofit Scheme

Early retrofitting concepts by others proposed utilizing several new concrete shear walls at various locations as the retrofitting system, along with jacketing of columns to prevent shear failures and improving column-girder connections to prevent girder failures. Upon detailed evaluation of more than 15 different concepts by HK&A, a structural steel moment resisting frame was selected as the most effective seismic retrofit solution for this concrete-framed building.

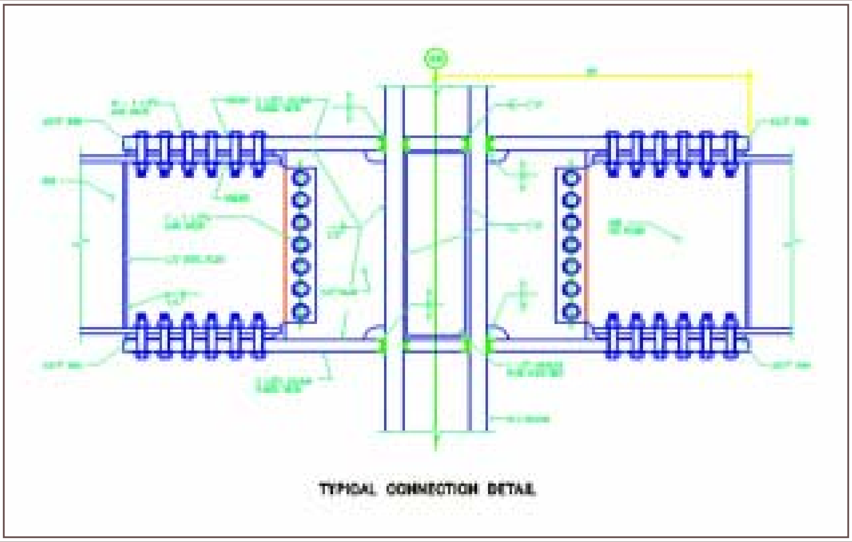
The steel frames alone could provide the necessary lateral resistance, as well as eliminate column failures and address the concerns mentioned previously. Additionally, the frames could be placed along the building exterior only, thereby leaving interior spaces unaffected and without disruptions. Steel moment frames also eliminated the obstruction of windows, and retained and spread out the lateral resistance to various elements along the length of the buildings, thereby increasing redundancy and reducing overturning effects.

Additionally, rolled steel sections were also used to improve capacities of a few existing concrete walls. Steel frames were designed for the full lateral loads prescribed by CSU criteria and proportioned so that expected drifts under design loads would be less than existing column failure loads. Frames were proportioned to maintain building stability and prevent collapse should design seismic loads exceed postulated limits. By limiting drifts to small amounts within existing concrete columns and joint capacities, costly jacketing of existing columns and joints were eliminated. In addition, there were no disruptions to tenants and interior spaces.

Typical frames included W14 x 426 column sections and W36 x 170 girders to provide the necessary strength, stiffness and ductility. Materials specified for columns were ASTM A572, and for girders ASTM A36. Connection bolts were specified as 1-1/2-inch diameter A490 SC, and all penetration welds were to be made with E7018 rods. Several "push-over " analyses verified that the retrofitted structure could resist seismic forces well in the range of 1.0g and could undergo large drifts while remaining stable, thereby fully satisfying CSU's Seismic Safety Program.

New Connection Tests

In the course of this work, a new moment connection was developed by HK&A reflecting many of the lessons learned from Northridge, Kobe and other earthquakes. This new connection is shop fabricated and welded into a tree-shaped assembly,



Shown top left is a typical connection detail.

The photo below, left, shows a connection test.

and girders are field-bolted into a standard and repetitive connection, thereby eliminating many previous concerns associated with field welding of heavy moment sections as in pre-Northridge earthquake designs.

A representative full-scale assembly of the new moment connection developed by HK&A was tested at the ATLSS Lab at Lehigh University prior to construction. It was used to verify joint stability and satisfactory inelastic performance of the assembly – which proved to be completely satisfactory. This connection delivered the necessary strength and inelastic rotations of more than 7 radians without any joint overstress, degradation, or yielding in the joint, and every bolt and weld remained intact. The project was completed early in 1998, well below budget, and the building is in full use today.

While concrete-framed buildings have been successfully retrofitted by a variety of systems and materials, there are opportunities where an effective retrofitting option is to use structural steel moment resisting frames to retrofit concrete structures as demonstrated at San Francisco State University and elsewhere.

Hratch Kouyoumdjian is president of Hratch Kouyoumdjian & Associates, which has offices in San Francisco and Oakland, CA.