BAREPP

BAY AREA REGIONAL EARTHQUAKE PREPAREDNESS PROJECT

HAZARDOUS BUILDINGS

Case Study

Seismic Retrofit of a Wood Frame Building

The structure selected for the Wood Frame Retrofit Case Study is a single-family dwelling built in the 1850s and located in the Western Addition of San Francisco. Structural upgrading, including seismic bracing, was required by the lending institution as a condition of approval for remodeling financing. Wood frame structures constructed before the 1930s constitute a significant portion of the historic wood frame architecture in the Bay Area, and this house is typical of the retrofit problems encountered in wood frame buildings. This Case Study describes the original structure and the approach taken to seismically upgrade the building.

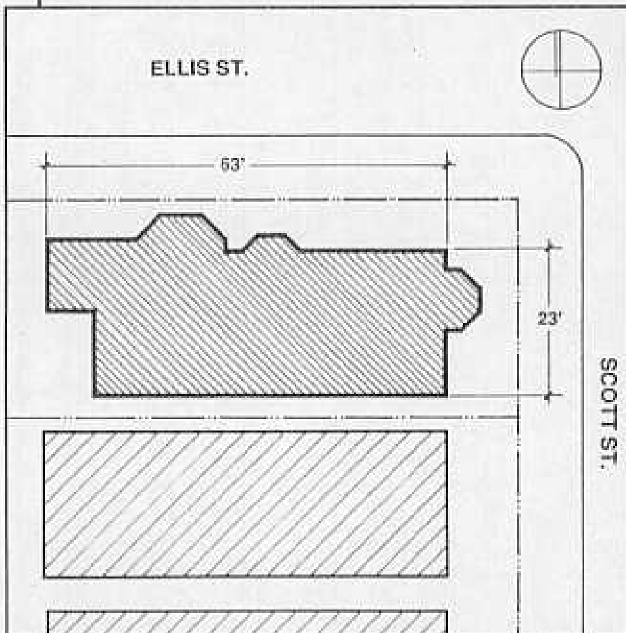
DESCRIPTION OF BUILDING

This two-story wood frame structure is located on a corner lot at 1249-51 Scott Street in San Francisco's Western Addition. The building is rectangular in plan, measuring 54 feet by 24 feet, and presents a typical configuration for a building located on a corner in that two sides front on the street.

The building was constructed using a balloon framing system typical for the period of construction. This framing system consists of exterior walls constructed of one-piece wooden studs that extend the full height of the wall—from the foundation sill plate to the top plate. At the second floor a ledger or "ribbon strip" is notched into the studs to support the floor joists. The second floor joists are nailed to both the ledger and the wall studs. Straight wood sheathing, consisting of 1×12 boards laid at right angles to the studs, was used to cover exterior walls and for construction of the subfloors.

Built-up corner posts run the full height of the building. Nailed to the posts are the walls' end studs, supporting the ends of the top plates and providing backing at the corners for wooden lath.

On the gable end walls, studs extend from the foundation sill to the top plate. (The foundation sill plate transfers the weight of the building from the wooden framing system to an unreinforced brick foundation wall.) Gable studs extend from there



Site Layout and Project Summary

Configuration:	Rectangular plan
Structure:	Balloon frame, one-piece wooden studs from foundation to rafter A ledger or "ribbon strip" ties the studs and supports the joists Wood beams and joists support the floor; straight wood sheathing covers exterior walls, floors, and roof
Problems:	Inadequate resistance to lateral forces House did not meet San Francisco building code structural requirements
Retrofit Approach:	Replace existing foundations Add shear strength Replace termite damage
Retrofit Costs:	Approximately $19.25/sq. ft.

to the end rafters. Use of gable studs was necessary because studs of adequate length to extend from the foundation sill plate to the rafters were not readily available. Studs are continuous from the foundation to the rafters, and there are no overlapping doubled top plates at the second floor as there are in a platform frame system.

The floors consisted of horizontal sheathing and joists. The roof was constructed of wood framing members (rafters) resting on the top plate and connected by a "collar tie." Spaced wood sheathing was used as the base for wood shingles.

The dwelling lacked an adequate system to resist earthquake forces and did not the meet the structural requirements of the San Francisco building code.

BACKGROUND

In 1978, the owners of the building wanted to remodel their home. Their lending institution required full structural upgrading, including seismic strengthening, as a condition for loan approval.

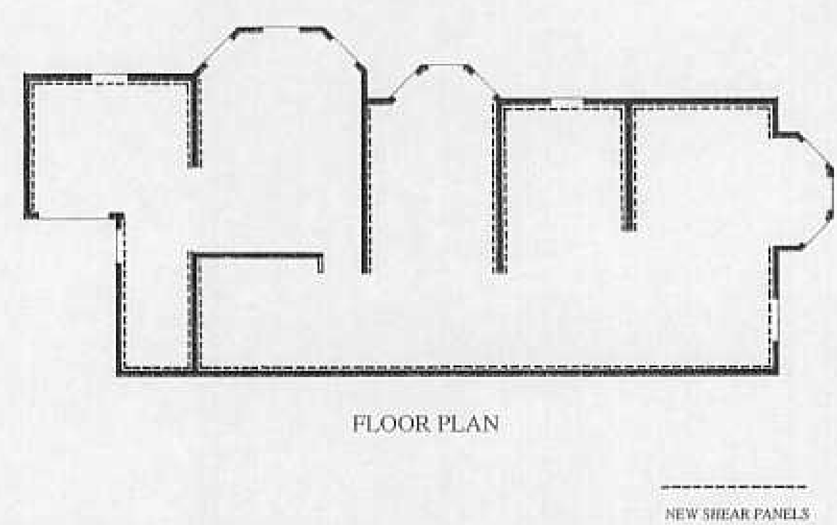
In order to comply with these requirements, the owners sought assistance from the San Francisco Redevelopment Agency, which is in charge of the majority of Western Addition remodeling projects, including seismic strengthening. Seismic retrofit was engineered by Shapiro, Okino, Hom and Associates, a San Francisco structural engineering firm.

METHOD OF STRENGTHENING

An analysis of the building showed the following seismically related problems: weak masonry foundations; no reliable soil information available; lack of earthquake force resistance (shear walls or bracing) in the north-south direction; termite damage to the lower structure; and, the lack of adequate bracing of floors and walls (the original 1 × 12 sheathing for the walls and floor diaphragms was laid at right angles to the joists, which does not provide the lateral stiffness needed in an earthquake.)

Replacement of Existing Foundations

The first step in the retrofit was to lift the existing building with jacks to permit removal of the faulty unreinforced concrete foundations. The old foundations were replaced with new reinforced concrete foundations and pads for posts. A concrete slab-on-grade was constructed in the basement and garage. Anchor bolts and tie-downs were set in the foundation to tie the wood frame to the new foundation. A new basement retaining wall was also constructed.



FLOOR PLAN

Addition of Shear Strength

Earthquake-resisting lateral force bracing was improved in the building by adding plywood sheathing to some of the inside walls on the first and second floors, creating shear walls. On long walls and floor diaphragms where the existing straight sheathing was adequate, renailing was provided. Steel bracing was added around the garage door in the basement to strengthen the door opening, and to the entry foyer in order to avoid sagging or distortion from the newly-imposed vertical wall loads above these openings.

Glue-laminated wooden beams were added throughout the building to strengthen the floor system. Additional support was provided for the joists by adding an intermediate beam and post consisting of one steel pipe in the basement and a timber post in the first floor living room. New blocking and bracing was added to support walls in parallel with the floor joists.

The roof structure underwent major strengthening by nailing a new rafter to each old one, creating double rafters. The collar tie was raised and renailed to new rafters to create more head room in the attic. The roof did not require resheathing.

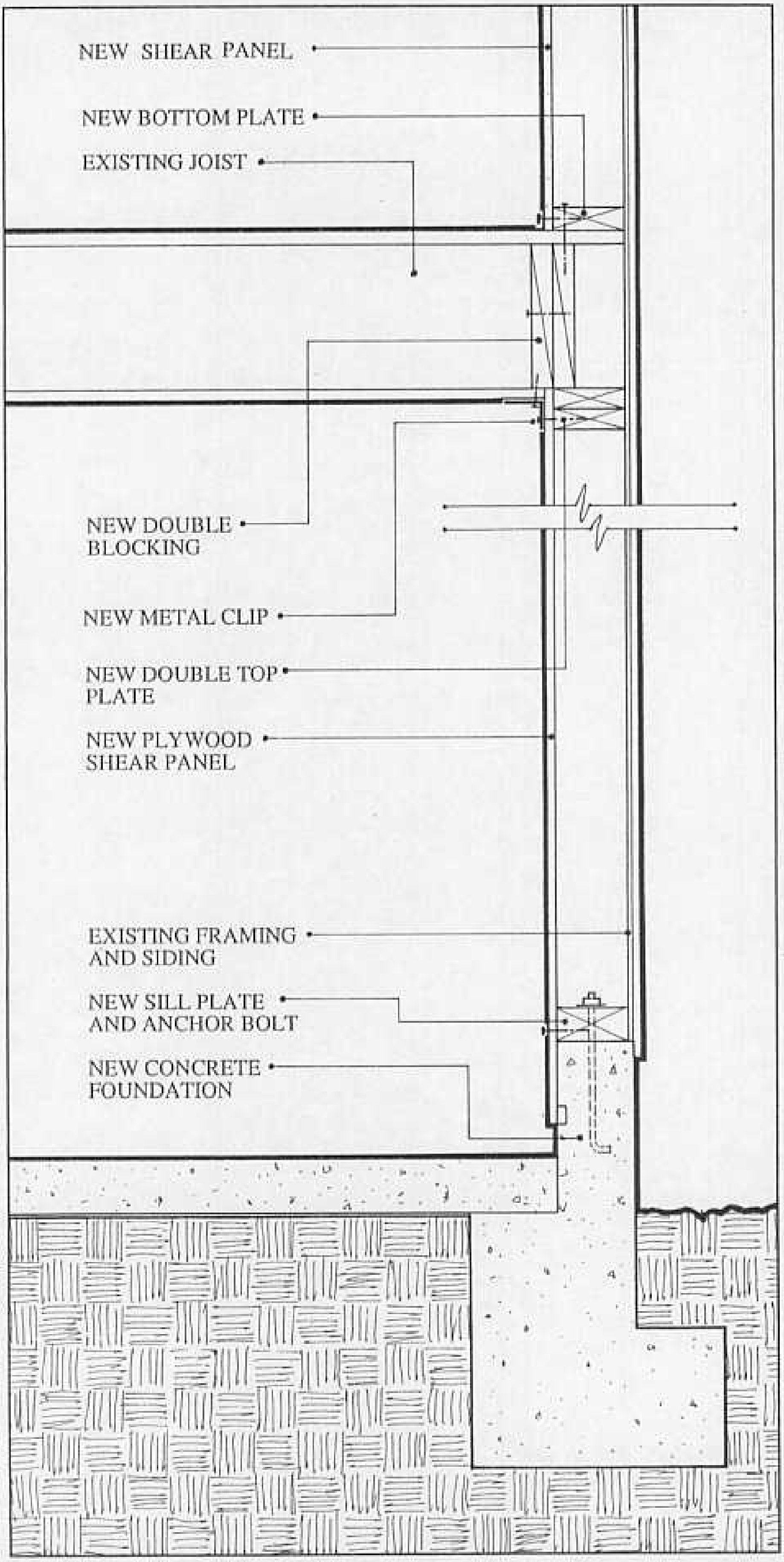
Additional Work

Where termite or dry rot damage was found the wood framing was replaced. Extensive termite damage required that the perimeter stud wall under the first floor be reframed and sheathed with plywood. In addition, the original ceiling in the front living room was removed to increase the height and architectural quality of the room.

SUMMARY AND COSTS

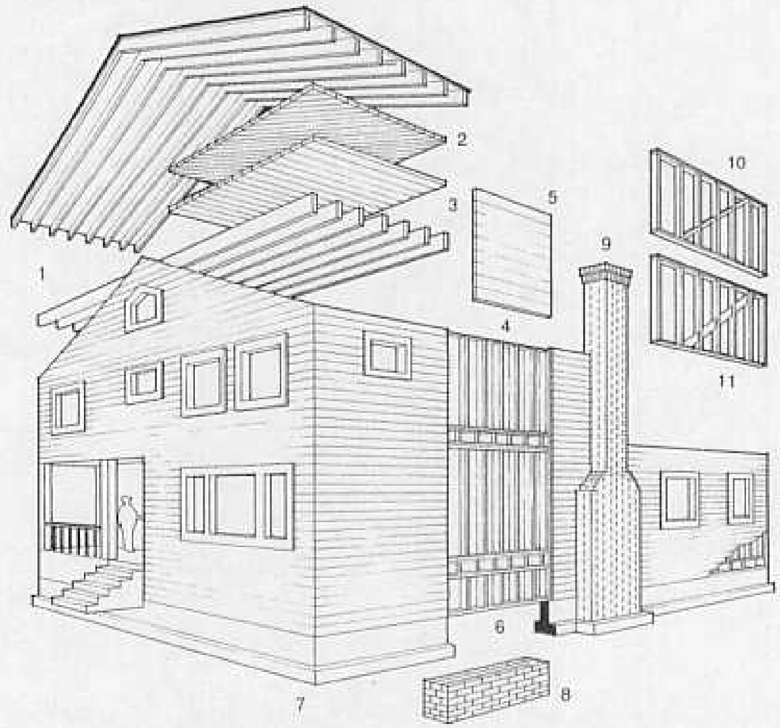
The design of this house is typical of those built in the 1850s in the Bay Area. The problems encountered and their structural solutions are typical of wood frame structures built before the introduction of seismic building codes.

The rehabilitation of this house comprised both structural upgrading and architectural remodeling. Costs for seismic strengthening, including engineering design, were estimated at $69,685 or about $19.25 per square foot.



Reducing Hazards in Wood Frame Buildings

Reference



DESCRIPTION OF TYPICAL BUILDINGS

Roof/ floor span system:
1. wood joist and rafter
2. diagonal sheathing
3. straight sheathing

Wall systems:
4. stud wall (platform or ballon framed)
5. horizontal siding

Foundation/ connections:
6. unbraced cripple wall
7. concrete foundation
8. brick foundation

Bracing and Details:
9. unbraced brick chimney
10. diagonal blocking
11. let-in brace
12. non-bearing wood stud partitions

modified graphics from Lagorio, Friedman, & Wong, *Issues for Seismic Strengthening of Existing Buildings: A Practical Guide for Architects*, 1986

WHAT ARE WOOD FRAME BUILDINGS?

Wood frame buildings are constructed of light wood elements. They are used primarily as residential and small commercial buildings. Their principal structural elements are vertical 2×4 or 2×6 wood studs for walls, wood beams and joists for floors, and beams and rafters for the roof. These elements are spaced closely together to support the weight of the building and its contents. Sheathing is nailed directly to the wall studs. Horizontal sheathing connects joists (or rafters) into a rigid horizontal beam or diaphragm. Structurally, diaphragms transfer horizontal loads to shear walls. Plywood or diagonally placed 1×12 boards are generally used for sheathing to brace walls, floors, and roofs, and give the building rigidity. The Uniform Building Code specifies the type and spacing of nails required for proper diaphragm construction. Overlapping wood plates (sills) are used to connect wall sections and join walls to ceiling, roof joists, and rafters.

In recently constructed wood frame buildings, horizontal loads are carried by shear walls and transmitted to the foundation by floor and roof diaphragms and by the shear walls themselves. These shear walls resist lateral forces created by wind or by earthquakes and transmitted to them by the roof and floor diaphragms. Shear walls can be located on the exterior or the interior of the building. Appropriately sized, constructed, and anchored, horizontal diaphragms and shear walls make the building function as a rigid box.

WHAT ARE TYPICAL WEAK LINKS IN WOOD FRAME BUILDINGS?

Wood frame construction is considered to be the safest type of building in an earthquake. However, this is true only if the building was designed and constructed to resist the horizontal forces of earthquakes. Frequently, in older, pre-1940 construction, this is not the case. Common weak links in wood frame buildings are:

1. *The wood frame structure is not tied to the foundation.* Without anchor bolts tying the wood structure to the foundation, older wood frame buildings often slide sideways off their foundations in earthquakes.
2. *Cripple walls are not braced.* Many houses have a crawl space below the first floor, with a short perimeter cripple wall supporting the first floor joists. If this cripple wall is not braced, it may fail, in which case the building will slide sideways in an earthquake even if it is bolted to the foundation.
3. *Lack of rigidity and resistance to lateral forces.* Where large window

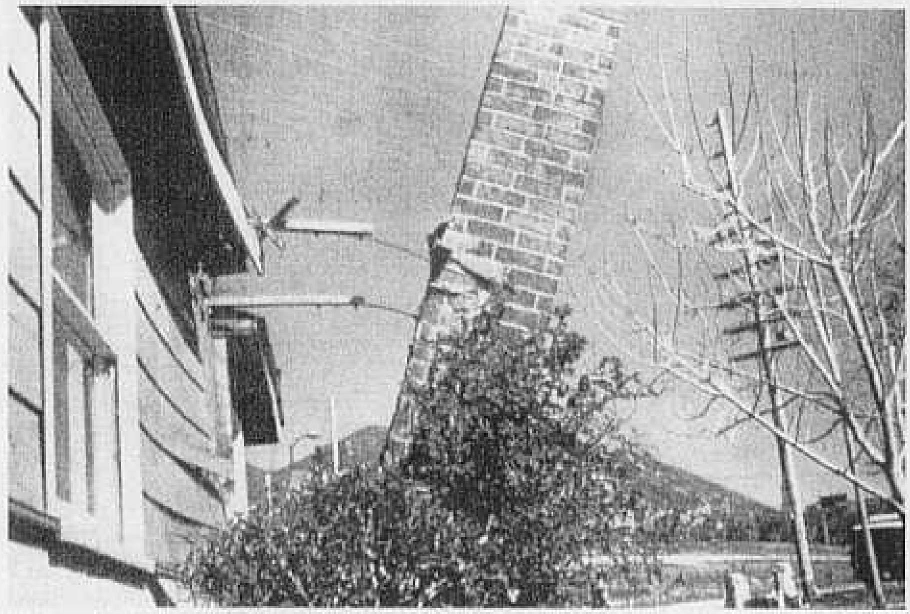
and door openings are present, there is often not enough horizontal wall length capable of acting as shear walls to resist lateral seismic forces. Existing floor or roof diaphragms are often not stiff enough, and not nailed sufficiently, which will cause the building to lack rigidity and collapse under earthquake forces.

4. *Unreinforced masonry chimneys are not tied to the building.* Combining tall, stiff, brittle masonry fireplaces and chimneys with more flexible wooden structures can result in severe damage if connections between the two types of materials are not properly designed. A tall and stiff chimney, and a shorter and more flexible wood frame building will behave as two separate structures during an earthquake. As a result, chimneys frequently snap off at the roof, or foundation line, dropping brick through the roof into the house or onto the ground, causing damage and, potentially, injury or loss of life.

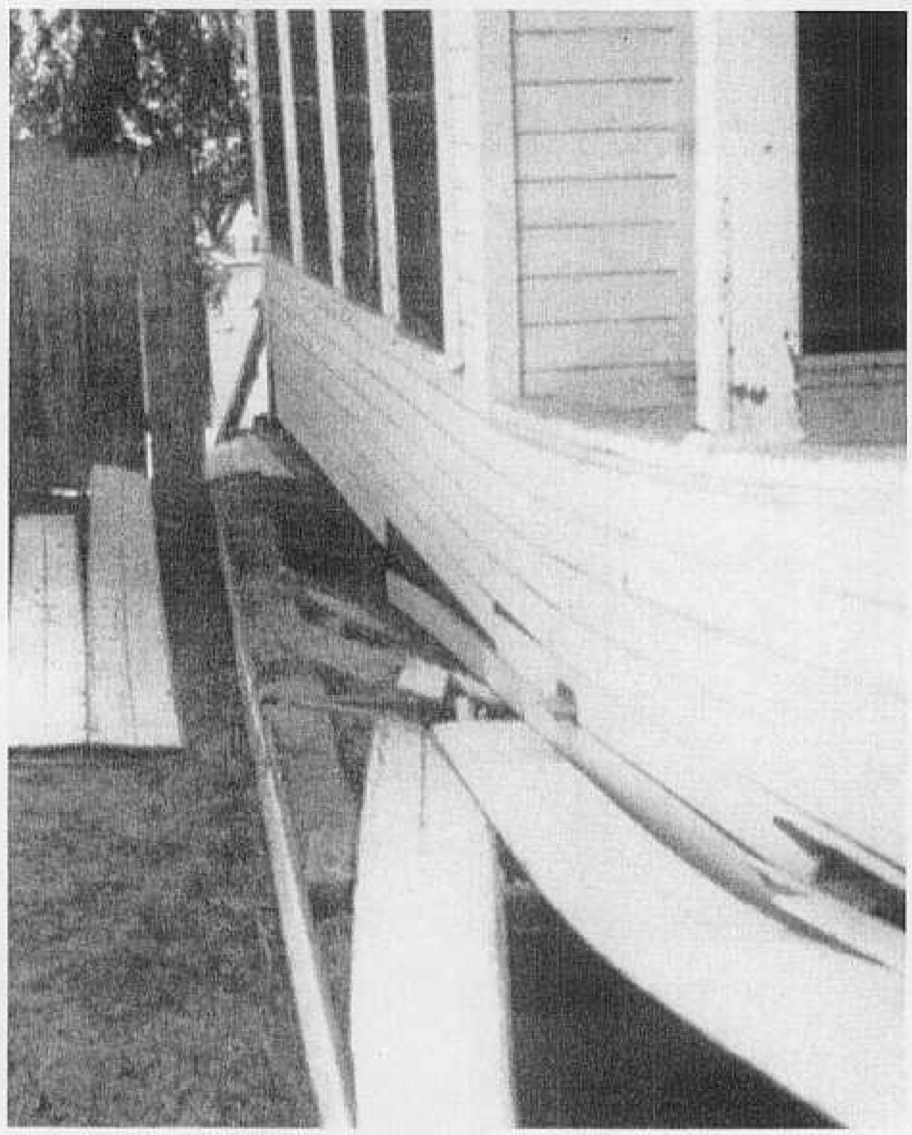
HOW CAN WE MITIGATE THE HAZARDS OF WOOD FRAME BUILDINGS?

Although wood frame buildings are generally the safest building category in terms of life loss during earthquakes, they are potentially hazardous if not constructed properly. Their structural weak links have been noted above. Seismic requirements for this type of building were adopted in building codes in the 1940s. However, despite building codes, wood frame buildings are frequently improperly constructed. For example, during the moderate 1984 Morgan Hill earthquake several recently constructed wood frame homes were seriously damaged and had to be demolished.

It is in the interest of all property owners to make sure that their wood frame building is properly bolted to its foundation, that cripple walls are braced, that adequate shear walls and diaphragms exist, and that chimneys are reinforced and securely fastened to the building. With proper construction, wood frame houses can resist earthquake forces and damage to the building can be minimized.



Failure of a chimney tie caused this chimney to fall away during the 1983 Coalinga earthquake.



Failure of unbraced cripple walls caused this building to slide to the right and collapse downward in the 1983 Coalinga earthquake.