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Shake Table Seismic Experimentation of a Three-Story Apartment Building With Tuck-Under Parking



Berkeley

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The work described here is Task 1.1.2 of the CUREE-Caltech Woodframe Project.

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Research Motivation: Thousands of woodframe, multi-unit residential buildings have been constructed with tuck-under parking at the ground level, which can create a soft story configuration that may lead to severe damage and even collapse under strong earthquake shaking. Several buildings of this structural type, typically constructed in the 1960s or 1970s, experienced ground story collapses in the 1994 Northridge, California Earthquake, including the Northridge Meadows apartment complex where 16 people died. A commonly recommended approach to seismic retrofit is to provide a steel frame around garage openings to resist horizontal forces. However, no large-scale experimentation has been conducted to verify the effectiveness of introducing such steel frames as retrofits to existing buildings.



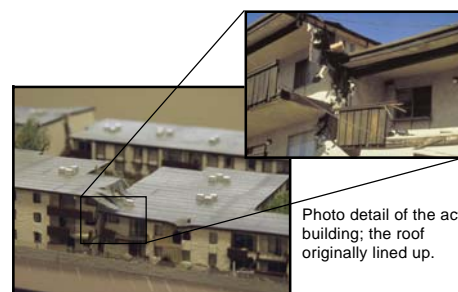
Ground story near-collapse of an apartment building in the 1971 San Fernando Earthquake. The structural problem is the same as surfaced in the 1994 Northridge Earthquake: Inadequate ground story earthquake resistance on the side where the parking stalls are located.



This view of an apartment building that leaned over but did not quite collapse in the 1994 Northridge Earthquake illustrates the excessive sidesway at the ground story parking area, which in combination with the large weight from stories above, can cause the ground story to collapse.

Research Objectives: Investigate the effectiveness of the kind of retrofit most commonly considered by engineers for reducing the life safety hazard of older apartment or condominium buildings with tuck-under parking. The scope of the research in the Woodframe Project on this building configuration does not include wood buildings with ground story parking garages made of concrete or masonry. Provide substantiation for the provisions in building retrofit ordinances now being considered by a number of local jurisdictions in California. Study whether this layout should be allowed in new construction. Experimental data on the seismic response of a complete woodframe structure for comparison with analytical model predictions will also be provided. Collect extensive data for use in development and verification of computer based analytical studies.

Phases of Experimentation: The full-scale experimentation carried out by UC Berkeley has six construction phases: (1) cable pull-and-release vibration testing of the full-scale apartment building model in its one-story state; (2) similar vibration testing in its two-story state; (3) forced vibration of the three-story building, using a portable shaker installed inside the building by Caltech researchers; (4) shake table earthquake simulation of the three-story building without steel frame retrofit and without stucco and drywall finish materials; (5) shake table testing of the three-story building with retrofit steel frame and with wall finish materials; (6) shake table testing of the three-story building with finish materials, but without the retrofit steel frame. Also included in the project are component tests of wood diaphragm-to-header connections and glue-laminated header beams and steel frame sub-assembly.



Model of Northridge Meadows apartment complex. All of the sections of the building were three stories tall.

Photo detail of the actual building; the roof originally lined up.



Ground story collapse, 3-story apartment building, 1994 Northridge Earthquake

CUREE-Caltech Woodframe Project

The Project is funded by the Federal Emergency Management Agency (FEMA) through a Hazard Mitigation Grant Program award administered by the California Office of Emergency Services (OES) and is supported by non-Federal sources from industry, academia, and state and local government. California Institute of Technology (Caltech) is the prime contractor to OES. The Consortium of Universities for Research in Earthquake Engineering (CUREE) organizes and carries out under subcontract to Caltech the tasks involving other universities, practicing engineers, and industry.





View of Full-Scale Apartment Building Model Prior to Installation of Stucco on Exterior and Gypsum Board on Interior

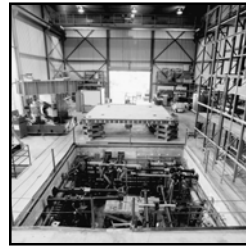


2 by 4 studs sheathed with plywood, with nailing and plywood details as per the 1964 Uniform Building Code.

The cables are part of the test set-up. If the structure reaches the point of collapse as it is shaken, the cables prevent it from crashing down.

Round steel columns (pipe columns) simulate original 1960's construction; they are "gravity load columns" (they were not designed to resist seismic forces).

The red steel "outriggers" allow the structural model to be longer than the shake table platform.



Computer-controlled hydraulic actuators ("pistons") underneath the UC Berkeley shake table platform play back with high fidelity the horizontal and vertical shaking of the ground that was recorded at a particular site in a past earthquake. Records from the 1994 Northridge Earthquake are used in the experimentation with the apartment building model.



By intent, inelastic behavior (when the steel becomes permanently bent) is designed to take place in the beam rather than column. If the damage were concentrated in the column, it could buckle under its gravity load and collapse. One technique for ensuring a "strong column-weak beam" design is to reduce the beam's strength near the joint by cutting out material from the flange.

There are various welded or bolted details used at the interface of the column and beam (that are not shown here) to connect the two together. In a "moment-resisting frame," the connection of column to beam is rigid enough to allow this angle to remain virtually 90 degrees as the building sways. The connection is able to resist the tendency of the beam to rotate relative to the column. The engineering term for "resistance to rotation" is "moment resistance," hence the term "moment-resisting frame." If the connections in a frame are not moment-resisting, then other forms of seismic resistance—diagonal braces or solid walls—are needed.

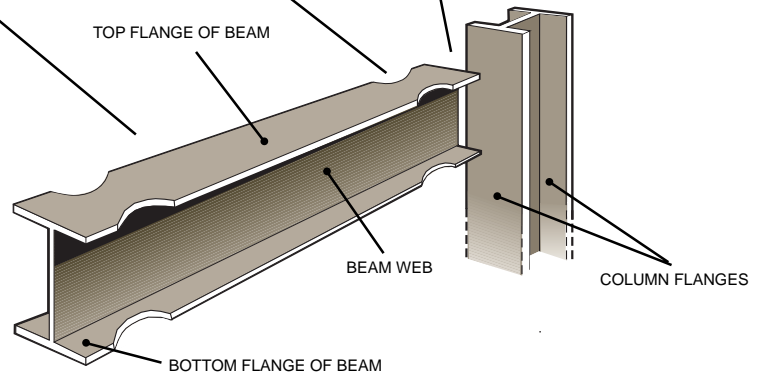
RETROFIT STEEL FRAME BEAM

TOP FLANGE OF BEAM

COLUMNS OF RETROFIT STEEL FRAME

BEAM WEB

COLUMN FLANGES



BOTTOM FLANGE OF BEAM

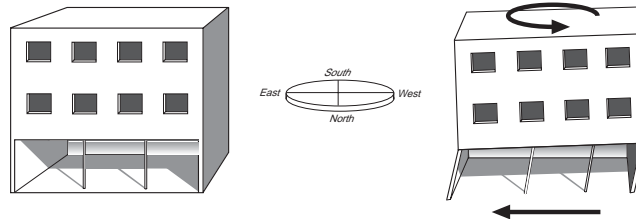
A new steel frame, designed to resist seismic forces, has been installed to simulate how the original building would be retrofitted. The steel beam is bolted to the wooden beam that is part of the original construction.

Steel moment-resisting frames provide earthquake resistance in a variety of buildings. They are extensively used in high-rise steel buildings but can also be used in combination with woodframe shearwalls as in this retrofit.

3-D Drawings of the Full-Scale Apartment Building Model

The front face of the ground story has no solid walls, because of the need for auto access into "tuck-under" parking stalls. The steel pipe columns were designed to only resist gravity loads and are not able to withstand lateral loads.

The other three sides of the ground story have solid wall areas. All four sides of the upper stories, although not built up to current construction standards, have relatively extensive amounts of solid wall area.



Viewed from above, the building twists (torsion occurs) as the front face displaces much farther than the rear wall on the same East-West axis.

As the ground moves Eastward, the building sways toward the West, excessively so, at the front face of the ground story.

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