Seismic straps protrude from this panel, which is ready for placing concrete.

Tilt-up in seismically active areas

Earthquakes leave well-engineered tilt-up buildings standing tall

BY D. L. FROHMADER

Earthquakes teach hard but valuable lessons. The 1971 Sylmar quake in California was no exception. In the wake of the destruction, owners and builders of reinforced concrete tilt-up structures unearthed valuable information that has allowed them to make a good concrete construction method even better.

Tilt-ups, even those built before the Sylmar quake, have done well in seismically active areas. In fact, structural engineer Hugh Brooks, author of The Tilt-up Design and Construction Manual, says there's "not a single known instance of an in-service failure of the estimated 10 million tilt-up panels constructed to date." This excellent record persists for several reasons:

1. The large monolithic panels inherent to tilt-ups are strong and often capable of surviving seismic forces.

2. The shape and size of typical panels promotes efficient transfer of shear forces and provides good shear resistance.

3. Large panels have few joints or weak areas that are prone to failure.

The Sylmar quake taught lessons that added to these strengths. Keep-

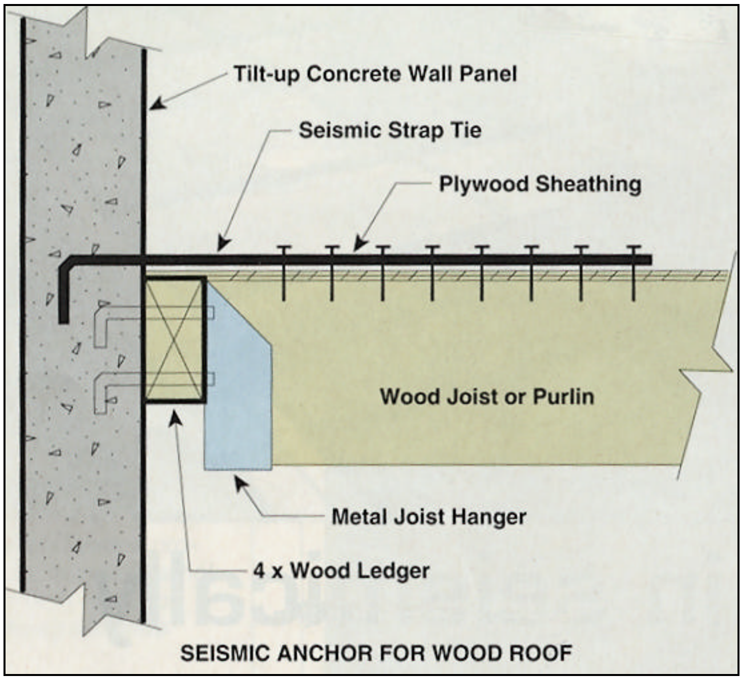

Figure 1. Floor and roof framing is directly anchored to the wall panels independent of the ledger.

ing tilt-up seismically safe is particularly important as the use of tilt-up construction increases and the variety of building uses expands to include more than the traditional warehouse. Today, a tilt-up structure is likely to be a stylish office building serving large numbers of people—all deserving adequate earthquake protection.

Wall to diaphragm anchoring

"Connection of the upper portion of the panel to the roof diaphragm is critical," says Brooks. "A number of failures of this connection occurred during the 1971 Sylmar quake. Codes were subsequently revised to require positive connection with steel straps and to prohibit connections consisting only of plywood nailed to wood ledgers. In this and other earthquakes there were many examples of the roof structure pulling loose from the wall panels and collapsing while the walls remained in place."

In the past, wall panels were anchored to roof and floor diaphragms by bolting ledgers to the tilt-up panels, hanging diaphragm framing members to the ledgers, and nailing sheathing to the ledger and framing. Under earthquake stress, wood ledgers tended to split across the grain and fail, leaving the walls and diaphragms unattached. Walls pulled away from the diaphragms, leaving no support, and floors and roofs could collapse. Other roof systems, when inadequately anchored to wall panels, experienced similar failures.

To correct this problem, floor and roof framing is now directly anchored to the wall panels independent of the ledger (Figure 1). When the framing is perpendicular to the wall panels, individual framing members are anchored using straps nailed to the member and anchored in the wall panels. When framing is parallel to the wall, a similar strap anchor is used but extends over several blocked joists or rafters. The strap is nailed to the blocking as well as the framing.

Anchoring in this way not only helps prevent the walls and diaphragms from pulling away from each other, but aids in transferring seismic forces from walls perpendicular to the movement of the earth to parallel walls that can better accept the shear forces.

Floor to wall connections are equally important for both ductility and energy transfer within the structure. "Panels are customarily tied to the floor slab by means of dowels from the panel into the closure strip and from there into the main floor slab to effect the tie," says Brooks. "Additional connection of the panel to the footing, although required by current ACI code, is controversial and an effort is underway to have this requirement repealed—proponents are arguing that a properly designed connection to the floor slab is adequate."

Diaphragm continuity

In many structures, roof framing is done in sections that lie both on exterior walls and interior walls or support beams. Under seismic stress, areas where the sections meet are subject to failure and collapse. By adding metal anchors between the framing members on either side, the diaphragm is made continuous in its capacity to transfer force across its entire surface area. Because a diaphragm is only as strong as its weakest part, anchoring in this manner is equally as important as the wall anchoring in maintaining overall structural integrity.

Panel engineering

Now that tilt-up structures are being designed with more attention to sophisticated architectural and aesthetic values required by office and retail structures, panel engineering has become increasingly important. Where panels are large and solid, as was most often the case when tilt-up was used primarily for single-story warehouse-type structures, shear forces are readily transferred. Thin walls are both safe and economical in this context. However, special engineering is required when large open areas are required for door and window openings.

During an earthquake, a fixed amount of shear can be expected to affect a wall area. If the wall is composed primarily of large, solid panels, the stress over the entire panel is relatively low because it's expressed over a large area.

When the panels have large openings, the shear force is concentrated on the narrow areas between openings which tend to act as columns rather than wall sections. These columns are difficult or impossible to engineer as shear structures. However, engineering solutions can be found in at least three ways.

The first is to redesign the building so that it incorporates large solid panels adequate to accept the predicted shear forces. Although this is often the best way, architectural values must be reckoned with and this technique may not always be acceptable. The solutions found in these cases should be the result of a cooperative effort between the architect and engineer.

The second is to design columnar wall sections as columns rather than as walls. These columns are often designed to accept earthquake force as a result of their ductile qualities. The columns will tend to flex and deform but not completely fail. To accomplish this, special attention to engineering detail including reinforcement and anchoring between wall members and foundations is required. The depth of the columns is often greatly increased to accept the higher amount of reinforcement needed to achieve the required ductility.

Spandrel beams or similar horizontal structures also must be designed for ductile capacity compatible with the vertical columns so they function as a unit. Engineer continuous grade beams or large footings to function as a unit too.

A third method is to provide additional interior shear structures that can accept shear forces in unison with the exterior structure. This method redistributes the shear stress generated by earthquake activity, putting less stress on the relatively weak exterior wall panels and more on relatively strong interior walls.

Study Shows Tilt-up Advantage

The Whittier Narrows quake that occurred October 1, 1987, provided much information on the earthquake performance values of tilt-up concrete structures. Although more than 10,000 buildings of all types were damaged in the 5.9 intensity quake, the Agbabian study indicates that tilt-ups fared extremely well.

The study, prepared under a National Science Foundation grant, considered a sampling of 81 tilt-up structures and assessed the extent of damages as representative of all area structures. Although more research is being conducted and will continue into the foreseeable future, three major observations can be made so far:

1. Survey evidence indicates that of some 2,000 tilt-up structures in the affected area, more than 1,900 suffered no major structural or nonstructural damage. This is an impressive indicator of the safety and integrity of tilt-up construction. In fact, of the 81 surveyed buildings, 52 sustained virtually no damage, 22 showed minor to moderate structural or nonstructural damage, and only 7 buildings were found to have major structural or nonstructural damage.

2. Current building codes and techniques represent a distinct improvement over the pre-1971 (San Fernando quake) standards, and current engineering reflects additional advances in building performance under earthquake conditions. Specifically, structures engineered and built using the Uniform Building Code (UBC) standards adopted in 1976 performed substantially better than those built before the code's enforcement.

3. Increased understanding of how earthquake stresses affect tilt-up construction will result in additional improvements in construction methods, engineering designs, and building codes. Historically, each earthquake experience has provided impetus and data that resulted in substantial gains in earthquake safety and endurance capacity.

For more information, order the survey report "Survey of Tilt-Up-Wall Structural Systems Affected by the Whittier Narrows Earthquake of October 1, 1987," prepared by Agbabian Associates, structural engineers, Pasadena, California (815-441-1060), $27.

Anchoring between panels

"Tilt-up panels must also be joined end-to-end to transfer inplane forces (that is, forces parallel to their length)," Brooks says. "Connections are typically made near the roof line and are termed chord connections. Connections are accomplished either by spliced welding of reinforcing bars in the panels or by splicing steel ledgers. In either case, the purpose is to provide a continuous tie along the length of a series of panels."

Anchoring thus between panels allows seismic forces to transfer efficiently from the roof diaphragm through the wall panels and into the floor slab. It further increases resistance to diaphragm chord forces.

Retrofitting

Tilt-up buildings that were not originally designed with the above considerations should be retrofitted. Fortunately, retrofitting tilt-ups is easier and less expensive than retrofitting other building types.

Connections between panels, when necessary, can be simply made by attaching lap plates with expansion anchors. Wall-to-diaphragm anchors are made by using a number of different proprietary units that are installed just as when used in new construction. Interconnections between framing members are equally straightforward in most cases. The nature of the tilt-up method and the prevailing construction techniques commonly allow simple access to the areas where the retrofitting must be done—another advantage of tilt-up buildings.

The one area of difficulty is where a structure was designed with large openings in thin-wall panels. Under these circumstances, additional wall or column construction is often required to emulate the current engineering designs. Replacing weakened panels with solid panels is again the simplest way to gain shear resistance, but other methods may be considered that preserve functional or architectural values. To best determine how to retrofit under these conditions, each building must be appraised by a qualified engineer to determine alternatives for improving seismic performance.

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