Seismic Retrofit

Strengthening Tilt-Up Structures

By David L. McCormick

Introduction

Tilt-up buildings first became popular in California after World War II. Their popularity is in part due to the fact that they are relatively economical to construct. In addition, an ability to accommodate attractive designs and historically minimal maintenance requirements add to the attractiveness of tilt-up wall panels.

Tilt-ups received their name based on how they are constructed. The tilt-up wall panels are cast on the concrete floor slab and then tilted into place after curing. The panelized wood roof *(Figure 1)* is assembled in large, pre-manufactured panels that are lifted into place with a crane. It is the use of these two different construction materials, and the lack of adequate connections to tie them together, that has led to poor performance of tilt-ups in past earthquakes.

"…older tilt-ups have proven to be among the worst performing building types in an earthquake."

Along with unreinforced masonry buildings, older wood frame buildings with parking below, and older concrete frame buildings, older tilt-ups have proven to be among the worst performing building types in an earthquake.

The Structural Engineers Association of California (SEAOC) has recently developed two documents that can be used by engineers to reduce the vulnerabilities in existing tilt-ups: *Guidelines for Seismic Evaluation and Rehabilitation of Tilt-up Buildings (Guidelines)*, and Chapter 2 of *Guidelines for Seismic Retrofit of Existing Buildings (GSREB)*. The GSREB is an appendix to the 2003 International Existing Building Code. Both the *GSREB* and the *Guidelines* are based on extensive research, by SEAOC members, of tilt-ups in past earthquakes including the 1994 Northridge Earthquake. Both of these documents can be purchased from the International Conference of Building Officials (ICBO), www.icbo.org.

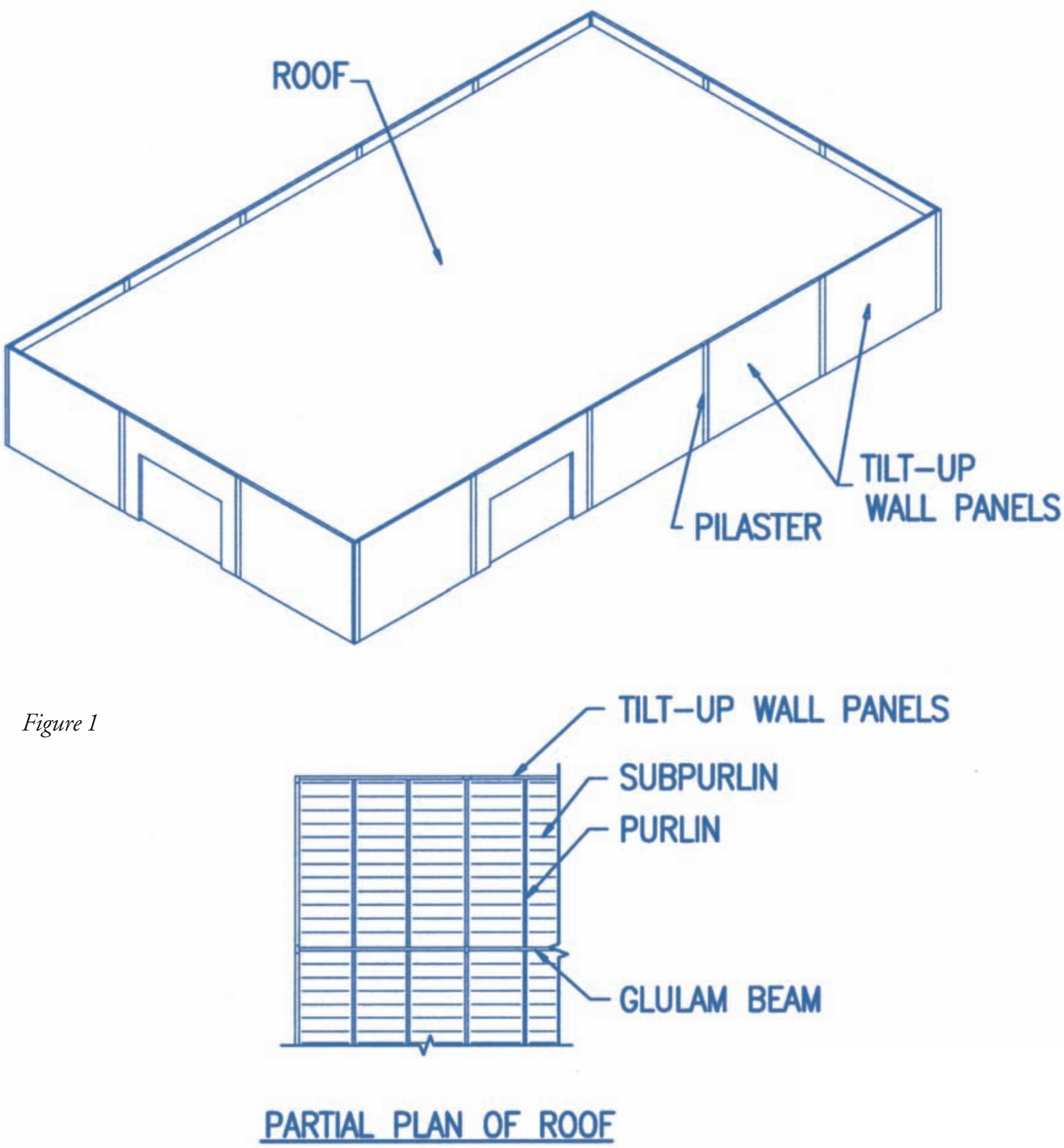
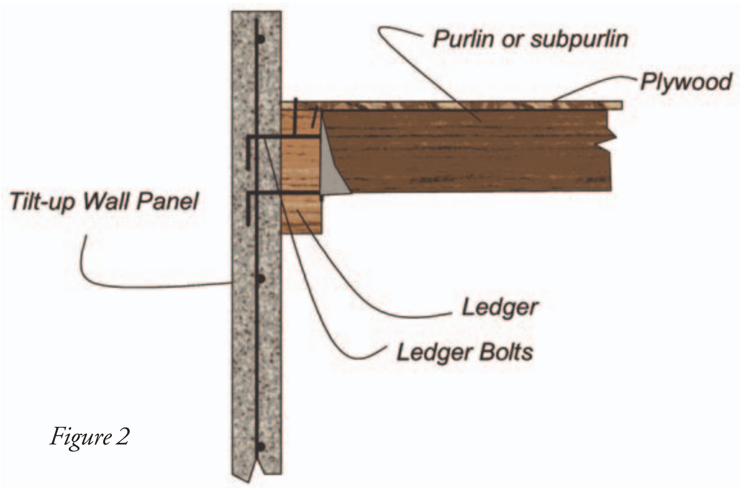


Figure 1

Isometric view and partial plan of roof

History

Prior to the 1971 San Fernando earthquake, the connections between the concrete walls and the wood roof were typically not engineered. The plywood roof was nailed to 3-inch or 4-inch thick wood members called *ledgers*, which were in turn, bolted to the *wall panels (Figure 2)*. When an earthquake occurs, forces perpendicular to the walls must be resisted at the base and the top of the walls *(Figure 3)*. In the San Fernando earthquake, it was demonstrated that the connection in Figure 2 was too weak to provide support at the top of the walls, and the walls and roof separated, leading to building collapses *(Figure 4)*.

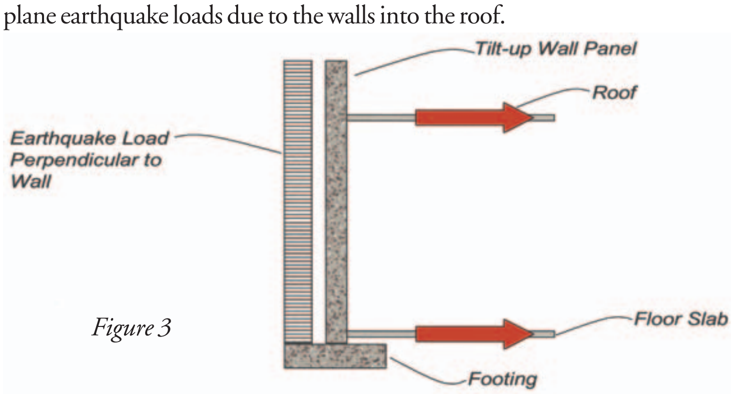


Lack of wall anchorage in old tilt-ups can lead to roof collapse

Collapsed Tilt-Ups.

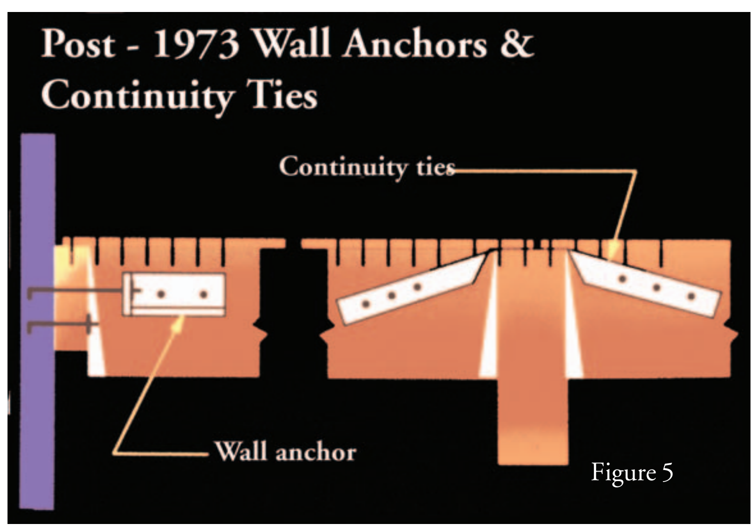
After the San Fernando earthquake, provisions were introduced into the *Uniform Building Code (UBC)* that required steel hardware to connect the walls and the beams supporting the plywood, referred to as a *wall anchor (Figure 5)*. In addition, it was understood that simply tying the walls and beams together would probably not be sufficient to prevent building collapse. There had to be a way to transfer the earthquake loads from the walls far enough into the plywood roof so that the failure location was not simply relocated to the other end of the beams. Thus the practice of providing additional hardware *(continuity ties) (Figure 5)* to make the beams continuous across the building was codified. Together the wall anchors, the continuity ties, the beams, and portions of the plywood adjacent to the walls (called *subdiaphragms*) that receive closer nailing, make up what is called the *wall anchor system*. The components of the wall anchor system work together to transfer the out-of-plane earthquake loads due to the walls into the roof.

> "…simply tying the walls and beams together would probably not be sufficient to prevent building collapse."



Walls are supported against earthquake loads by roof and floor slab

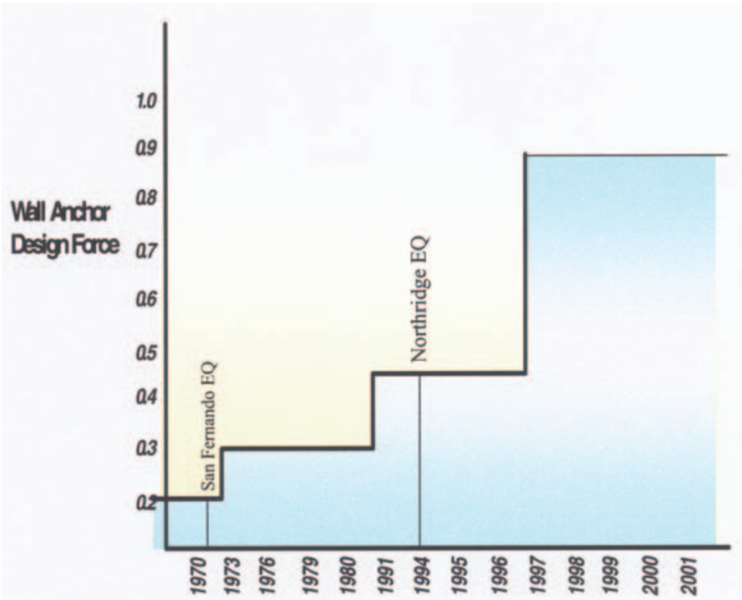
After the 1994 Northridge Earthquake, when approximately 400 tilt-up buildings were badly damaged, it was noted that even tilt-ups designed using newer code provisions are relatively high risks. Thus many new code provisions, and larger design forces, were introduced into the 1997 UBC. As can be seen in *Figure 6*, the forces used for designing the wall anchor system have increased by approximately a factor of four since the early 1970s. This increase in wall anchor design forces, accompanied with stricter detailing and inspection requirements, means that tilt-ups designed and built today should perform much better than those constructed prior to the early 1990's.



Example of wall anchors and continuity ties.

Guidelines for Retrofit

What does this mean to the tilt-up owner? Depending on the age of the tilt-up and the type of wall anchors provided, a pre-Northridge earthquake tilt-up has anywhere from a high to a moderately-low chance of partial collapse during the strong ground shaking associated with even a nearby, moderate earthquake (i.e., magnitude less than 7). This may even be true if the building was retrofitted prior to 1994.



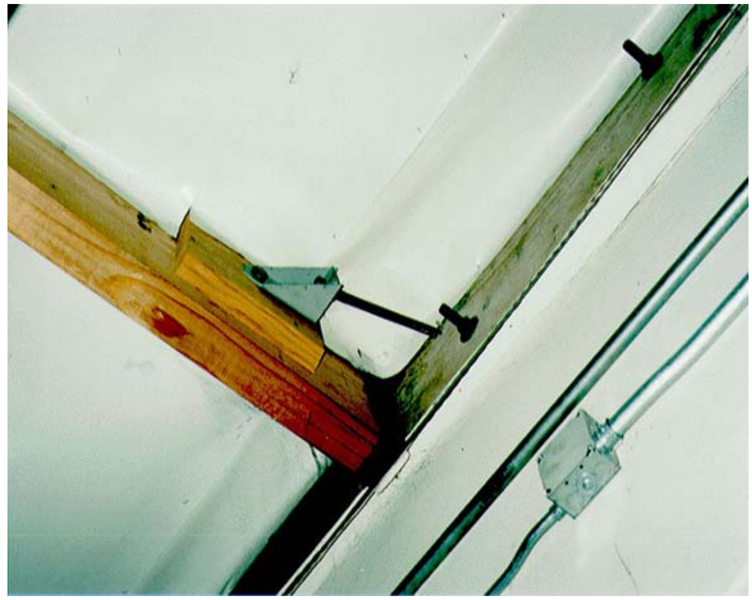
History of design forces in building code for steel portion of wall anchor

Fortunately, tilt-ups are relatively easy and inexpensive to retrofit. Typical retrofit construction costs for large warehouses with minimal access problems are as low as $1 to $2 per square foot. In offices and other buildings with suspended ceilings or operations that make access difficult, costs can be substantially higher.

"Factors that increase the likelihood that seismic upgrade is needed..."

As discussed above, pre-Northridge tilt-ups should be evaluated to determine whether they provide life-safety protection for occupants. Factors that increase the likelihood that seismic upgrade is needed include:

- Age – the older, the more likely retrofit is necessary
- Location within 5 miles of a major fault – higher seismic forces likely
- Irregular configuration in plan or elevation (e.g., L-shape in plan, or two or more roof levels) – concentration of damage at irregularities
- Poor construction quality of wall anchors
- Flexible wall anchors – wall anchors that consist of flat or twisted straps are less effective than stiffer wall anchors, such as hold-downs
- Eccentric wall anchors – wall anchors applied on one side only of smaller (2-inch wide) beams called *subpurlins* can lead to splitting of subpurlins in an earthquake
- Large beams (i.e., glulam beams) sitting on top of pilasters with beam seat hardware only – cracking of top of pilaster



"Many jurisdictions have, or are considering adopting, tilt-up ordinances…"

To date, deficiencies in the wall anchorage system have resulted in most of the tilt-up damage observed in earthquakes. Consequently, most of the effort and retrofit should be focused on the wall anchorage system. This approach is taken in various documents intended for retrofit, including Chapter 2 of the GSREB, as well as mandatory tilt-up retrofit ordinances by jurisdictions such as the California cities of Los Angeles and Fremont *(see on-line article)*. These documents address issues encountered in existing construction, and thus are more applicable for retrofit than the current Building Code. However, there are other deficiencies that can result in major damage. Other possible deficiencies that should be evaluated include:

- Wall panels with large openings that are not properly reinforced
- Irregular features like buttress walls or skewed corners
- Roofs weakened due to past roof leaks or infestation
- Mezzanines or heavy canopies that may impact the walls and result in damage
- Contents that may interact with the building

Many jurisdictions have, or are considering adopting, tilt-up ordinances similar to the provisions of the *GSREB* that use reduced evaluations forces. However, if the wall anchor system is determined deficient and *strengthening* is required, it is recommended that design forces comparable to those in the current Building Code be used. The consequences of wall anchor failure are high, and the costs associated with providing additional capacity are relatively small.

> "…generating an effective retrofit design is more complex than it once was."

One of the intended uses of the *Guidelines* is to help the engineer and owner in prioritizing retrofits when limited retrofit dollars are available, especially when there are multiple buildings concerned. Chapter 4 of the *Guidelines* lists possible deficiencies and prioritizes them. Hiring an engineer that is familiar with tilt-ups is important, because generating an effective retrofit design is more complex than it once was.

Understanding the motivation behind code requirements and past seismic performance are crucial in understanding how much of the existing wall anchor system can be used in the retrofit design. It is also important that the owner provide the engineer with sufficient budget to make visits to the site at several phases during the retrofit construction. While at the site the engineer can verify that as-built conditions agree with the drawings, that the structure is in good condition, and the retrofit work is done in accordance with the drawings. Good quality control assures that the money spent on the retrofit is money well spent.

Conclusions

There are many benefits to retrofitting tilt-ups:

- Reduced risk to life safety
- Reduced damage and business interruption costs after a major earthquake
- Reduced refinance costs (lower interest rates will be available as more lenders will be willing to provide loans for buildings with lower seismic risks)
- Reduced earthquake insurance costs

Strong ground shaking has the potential to damage many tilt-up structures beyond use until they are repaired. Due to the demands for contractors following a major earthquake, such repairs could take months. During this time, a business could lose its competitive advantage or even fail to remain viable. Existing tilt-up buildings should be evaluated and retrofitted using the provisions of Chapter 2 of the *GSREB* as a minimum. The *Guidelines* may be used to help prioritize fixes, especially if limited retrofit dollars are available.

David L. McCormick is a Senior Staff Engineer at Simpson Gumpertz & Heger Inc. (SGH). David's work includes seismic risk assessment, design and retrofit of buildings, and post-earthquake assessment, with specialized knowledge of tilt-up building performance. (415-495-3700)

Tilt-up Retrofit Ordinances in California

The City Council of Fremont adopted the Tilt-up Concrete and Reinforced Masonry Building (TRM) Ordinance (Ordinance No. 2405) in October 10, 2000. The intent of this mandatory program is to promote public welfare and safety, and to improve the performance of TRM buildings in the event of an earthquake. Through research (historical files, plans and site visits), about 160 buildings were identified as having been constructed prior to adoption of the 1973 UBC. After several public meetings, an ordinance was developed that requires mandatory retrofit of buildings within a certain timetable. The compliance timetable is based on the number of building occupants and the hazard level of the building. Buildings with a lower level of hazard, or with fewer occupants, were allowed a longer time for compliance. For example, group III buildings have between 49 and 16 occupants, and were allowed 24 months for obtaining a permit and 60 months for completion of construction. Thus the deadline for permits for the Group III buildings, which represents a large portion of the buildings, was October of last year.

The provisions of Ordinance No. 2405 are modeled after Chapter 2 of the *GSREB*. (The provisions actually reference the 1997 *Uniform Code for Building Conservation (UCBC)* or its successor, and the 2000 GSREB is the successor.) Previously retrofitted buildings shall be evaluated according to the provisions of the Ordinance, and will be ordered to be modified to comply with this Ordinance if the wall anchor system was not completely retrofitted, or if design loads were less than 75% of those included in the current Building Code (1997 UBC). The City does provide some financial assistance to the building owners by refunding the plan check and building permit fees when the retrofit is completed within the required time frame.

Other jurisdictions have also adopted ordinances. In 1990, the City of Fullerton adopted a mandatory program requiring pre-1976 tilt-ups to be retrofitted using 1976 UBC requirements for wall anchors. All buildings were in compliance prior to 1995. The City of Hayward had a similar program. The City of Los Angles adopted a mandatory program (Division 91) for pre-1976 tilt-ups soon after the 1994 Northridge Earthquake. The requirements are similar to those of Chapter 2 of the *GSREB*. There is also a voluntary program (Division 96) for newer structures that becomes mandatory for certain changes in use, or major remodels. Recently, the City of San Leandro adopted the *GSREB* as a minimum retrofit ordinance voluntary retrofit for tilt-ups, tuck under parking buildings, and nonductile concrete buildings.

A recent survey by the Association of Bay Area Governments (ABAG) indicated that 11 San Francisco Bay Area cities, and 1 county, have adopted either mandatory or voluntary seismic retrofit standards for tilt-ups. Phone calls by SEAOC Existing Committee members to some of these and other jurisdictions revealed there is a general lack of appreciation for the risk associated with existing tilt-ups, as well as a lack of awareness of available documents like the *GSREB* and the *Guidelines*. The Existing Building Committee recognizes the need to assist building departments in this regard. In 2002, members of the committee presented a seminar in Southern California and Sacramento. Other means of informing building departments and the public are being considered, including offering to make presentations to building departments and/or City Councils.