Chapter 3
Design Examples Appendix Chapter A2 Earthquake Hazard Reduction in Existing Reinforced Concrete and Reinforced Masonry Wall Buildings with Flexible Diaphragms

Figure 1. Damage from the 1971 San Fernando Earthquake, Feb 9, 1971
Credit: Department of the Interior/USGS
Photo ID: Castle, R.W. 103

Foreword

Many tilt-up buildings have suffered severe structural damage in past earthquakes, particularly during the 1971 San Fernando (M6.6), California, and 1994 Northridge (M 6.7), California, events. The most common problem was inadequate out-of-plane anchorage (especially twisted straps) resulting in wall-roof separation with subsequent partial roof collapse. The prime cause for the inadequacy was the method used for connecting the wall panel to the roof or floor for out-of-plane loading. This was achieved by nailing the diaphragms to wood ledgers and bolting the wood ledgers to the walls. This method of connection allowed the wall panels to separate from the roof or floor by failure of the ledger in cross-grain bending, by nail pullout from the ledger, or by nail pullout through the edge of the wood structural panel. Other causes for tilt-up failures include inadequate girder-to-pilaster connections; lack of continuous ties across the full depth of the diaphragm that allow cross-grain tension failures of the framing members at continuous joints in the wood-structural-panel sheathing; and lack of tension ties at glulam hinge locations, with loss of support for suspended girders.

In response to poor performance over the years, the building code provisions have improved significantly. Appendix Chapter A2 specifically addresses the most vulnerable risks to this building class with the intent to significantly reduce but not necessarily eliminate the likelihood of damage that will threaten the life safety of the occupants. The provisions in this chapter are targeted retrofits and do not address all deficiencies as otherwise required by the current building code. The expected performance of a building retrofitted only to the minimum recommendations of this chapter would be less than the performance of a building with a full retrofit based on provisions for new construction. Six examples follow. The first two use a building similar to that used in past seismic design manuals.

Design Example A2-1
Tilt-up Building Retrofit

Overview

This example presents the voluntary seismic retrofit design of the wall anchorage and collector components of a tilt-up building. The emphasis in this retrofit design example is on the seismic design of the wall-anchorage system, the collector members, and the collector connections. Deficiencies in other structural components have not frequently contributed to significant damage in past earthquakes and thus are not addressed in Appendix Chapter A2 or this example.

The engineer is warned that other damage modes associated with walls weakened through the introduction of door openings without localized strengthening and deterioration of roof diaphragms through leakage have also been observed but are not addressed in Chapter A2. Further, examples of tilt-up buildings with a substantial number of large wall openings (rendering the walls more like frames than walls) subjected to strong ground shaking is currently limited. There is some concern that such panels constructed prior to the inclusion of current detailing code requirements for wall piers may be more susceptible to damage. Finally, the provisions of this chapter originated after the the response of buildings was studied in regions where seismic design was required for many years so that complete load paths and elements designed for seismic loads exist. In low seismic areas where complete load paths may be missing, it may be appropriate to extend the structure assessment to establishing adequate load paths. Most tilt-ups in need of retrofit in the west are ones with wood diaphragms.

Problem Description

This example building is a warehouse, shown in Figure 2, which has tilt-up concrete walls and a panelized wood roof system. The roof consists of a panelized plywood system including 2×4 sub-purlins and plywood sheathing supported on 4x timber purlins and glue-laminated beams (glulam beams). The building's roof framing plan is shown in Figure 3, and a typical section through the building is given in Figure 4. A voluntary seismic retrofit is required following the procedures in the 2009 IEBC Appendix Chapter A2.

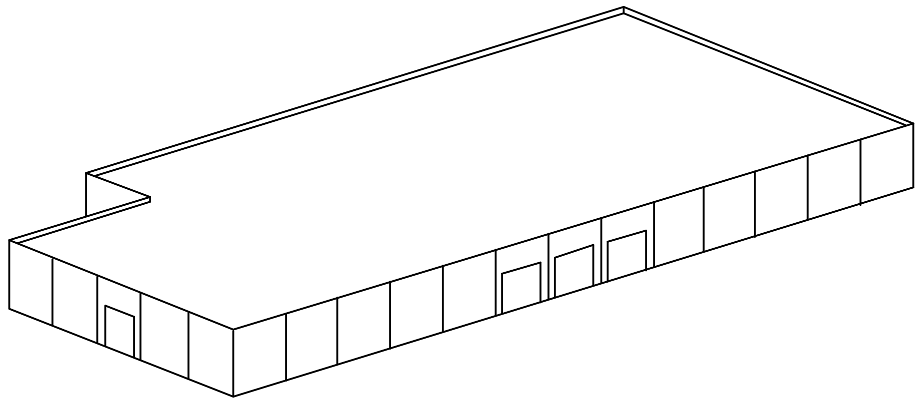

Figure 2. Tilt-up building

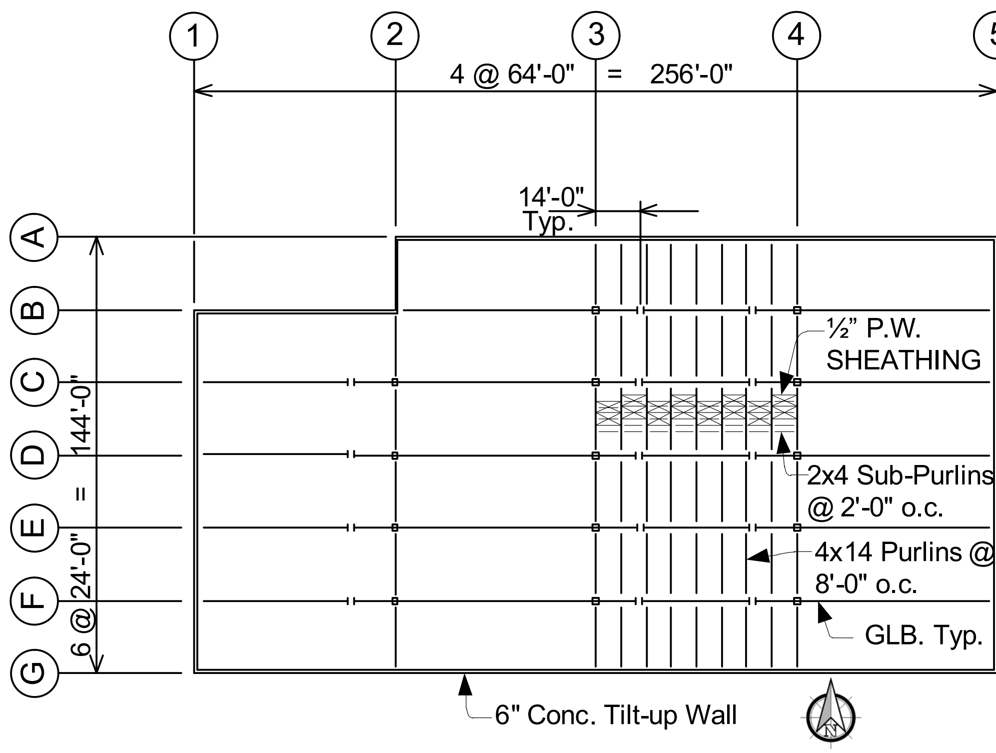

Figure 3. Roof framing plan of tilt-up building

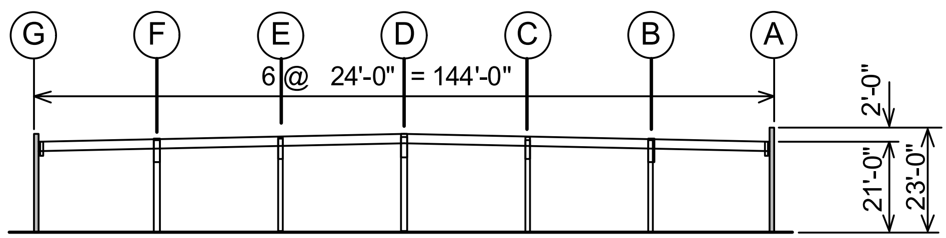

Figure 4. Typical cross-section

Outline

This example will illustrate the following parts of the retrofit design process:

1	**Calculation of base shear coefficient.**
2	**Calculation of diaphragm loads.**
3	**Evaluation of collector along line B between lines 2 and 3.**
4	**Retrofit design of the collector connection at lines B and 2.**
5	**Retrofit design of the wall-roof anchorage for north-south loads.**
6	**Retrofit design of the wall-roof anchorage for east-west loads.**
7	**Retrofit design for a typical east-west loaded subdiaphragm.**
8	**Retrofit design for a typical north-south loaded subdiaphragm.**

The loads developed in this example will be used in subsequent examples rather than re-deriving them. To the extent possible, the focus is on issues related to existing buildings.

Given Information

The following information was obtained from the design drawings:

Date built

1967

Roof

Dead load	= 14 psf
Live load (roof)	= 20 psf (reducible)

Walls

Thickness	= 6 in.
Total height	= 23 feet
Normal weight concrete	= 150 pcf
f'_c	= 3,000 psi

Roof Sheathing

Structural – I sheathing (wood structural panel, see layout Figure 3)

Roof diaphragm nailing, 10d at 4/6/12 pattern

Roof Structure

6¾ × 31½ glulam beam girders – 24F-V4 DF/DF. In 1967 the glulam grade designation was 24F-V8 DF/DF. This example is based on assuming grade 24F-V4 DF/DF.

4 × 14 purlins – Doug Fir, Select Structural

2 × 4 subpurlins – Doug Fir, No. 1

4 × 8 ledger – Doug Fir, No. 1

Wall Anchorage

Subpurlins – none

Purlins – none

Glulam beam – steel seat, see Section 6

Collector Connections

Line B – steel bucket

Line 2 – none

Seismic Force-Resisting System

Bearing wall system consisting of tilt-up concrete shear walls

The following information was obtained from the current ASCE 7:

Seismic and Site Data

Mapped spectral accelerations for the site

S_s = 1.5 (short period)

S_1 = 0.6 (1-second period)

Occupancy Category = II (warehouse occupancy) (ASCE-7, T 1-1)

Site Class = D

Wind

Not considered (typically will not govern in moderate and high seismic areas)

In addition, the owner has stated that the roof membrane is relatively new, and that it is intended that the retrofit be accomplished with no reroofing.

Calculations and Discussion

1 Calculation of base shear coefficient

The base shear coefficient is necessary for determining the roof diaphragm loads for the collector design. The design base shear will not be used to check the adequacy of other parts of the building as part of this design example because such checks are not in the scope of Appendix Chapter A2.