EARTHQUAKE BEHAVIOR OF COMMERCIAL-INDUSTRIAL BUILDINGS IN THE SAN FERNANDO VALLEY

by

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SYNOPSIS

One area of construction that has had little coverage in engineering publications following the February 9, 1971 San Fernando, California Earthquake is the single story masonry walled or concrete tilt-up commercial-industrial building having a wood roof diaphragm. This type of structure represents a significant dollar value in the areas of the San Fernando Valley that were affected by strong ground motion. They are often used for purposes of public occupancy such as markets, bowling alleys and other uses where questions of public safety must be raised. Review of the codes governing this type of construction and observation of many damaged buildings strongly suggest that changes be made in current practice.

INTRODUCTION

The commercial-industrial category of buildings is broad and encompassing; however, specific reference is made to a type of construction prevalent not only in the San Fernando Valley but in most urban areas throughout California. Following the February 9, 1971 San Fernando earthquake, high rise buildings, large structures of major importance, dams, freeway bridges, and other major structures have been the object of considerable study, research, the subject of code committee meetings and countless articles. Relatively little, however, has been written about the earthquake behavior of the commercial-industrial category of buildings. These unglamorous buildings, generally one and two story shear wall structures, are often constructed of tilt-up concrete, concrete block, or reinforced brick masonry walls, and have roofs of plywood sheathing sup-

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ported on wood framing affording a flexible diaphragm. Fifty to sixty foot clear spans are common for the roof carrying members which are usually glued laminated Douglas Fir or tapered steel girders. The particular usage and occupancy load of these buildings varies considerably. Bowling alleys, supermarkets, liquor stores, warehouses and light manufacturing buildings in industrial parks are some examples. The usual occupancy of this type of building may vary from only a few employees as in the case of a warehouse to hundreds of patrons as in the case of a retail store.

The importance of this type of building is further indicated by the large dollar value represented in Southern California and elsewhere. Available figures for the western states including Alaska indicate the 1972 cost of commercial-industrial (non-residential) construction was $2,700 million. This can be compared with the 1972 total dollar volume (non-residential) of $5,000 million for all building construction for the same survey area. (Reference 1) Some types of construction other than the masonry walled-wood roof type referred to is necessarily included in the former figure. Another significant factor to be held in focus is the fact that the commercial-industrial building in most cases represents the product of "recent" construction utilizing "modern" methods, materials, and Building Codes.

DISCUSSION

An in depth discussion of the geologic settings and soil amplification of specific building sites is beyond the scope of this paper. Damaged buildings in the Sylmar area examined shortly after the February 9th ground disturbance and its attending aftershocks suffered from moderate damage to total collapse due to the seismic activity experienced in the area. Few of the sites observed had experienced significant surface offsets of the ground as in the case of the Olive View Hospital, Pacoima Dam site and others.

The closest building, of the type discussed, to the established epicenter is approximately six miles (10 km) with the majority in the six to eight mile (10 to 14 km) range. The initial jolt of February 9 measured 6.6 on the Richter Scale with a ground level peak acceleration of 27%g horizontal and 17%g vertical as recorded at the Holiday Inn on the corner of Roscoe Boulevard and Orion Avenue, approximately six miles south-west of Sylmar. (Reference 2) It is unfortunate that no strong motion seismographs were located close enough to provide actual ground acceleration information relative to the buildings in the area discussed. There is general agreement among engineers that horizontal ground accelerations experienced by some of these damaged structures closest to the epicenter developed lateral forces at least two times minimum code design forces.

The building codes governing the construction in the San Fernando-Sylmar-Newhall area are the Los Angeles City Building Code for the areas within the Los Angeles City boundarys, the Los Angeles County Building Laws, and the Uniform Building Code. These codes require plans to be signed by a registered Architect, Civil or Structural Engineer. Soil investigations made by soil engineers are not required if soil bearing values used in design do not exceed those provided for by code based on arbitrary soil classification. As a result, relatively few of these building sites have a thorough soils investigation. Deeper subsoil conditions that may adversely affect the seismic behavior of structures are seldom known. The soil depths underlying the buildings discussed range from 30 and 60 feet which qualifies them as stiff sites due to the relatively shallow alluvium.

The category of buildings referred to generally conforms to the code requirements of a "box system" or a structural system without a complete vertical load carrying space frame which is assigned a K value of 1.33. In California and other seismic zone 3 areas, the K factor is combined with a Z = 1.0 and a C = 0.1 to provide a seismic force design level of 13.3% of gravity.

DAMAGE OBSERVED

The types of commercial-industrial building failures observed following the San Fernando earthquake can be typified in numerous respects. One of the most common failures was the separation of plywood roof diaphragms and the supporting wood wall ledgers. These resulted in the collapse of all or portions of the wall followed by the immediate collapse of the adjacent section of the roof structure (Fig. 1, 2 and 3.) Another almost universal failure among notably damaged buildings was the separation of the roof girders and the tops of wall columns or pilasters. In these cases, it was often observed the pilaster ties did not adequately confine the concrete or grout around the girder anchor bolts, and the girders were either displaced or fell to the ground. Both of these two common modes of failures were "tension" type failures of the "brittle" variety affording little warning of impending collapse. Ranking less common but none the less serious is the failure to provide adequate continuity for roof diaphragm chord stresses by not providing proper doweling and lapping of chord reinforcing. In other common failures, the corners of the buildings separated above the roof line because of inadequate reinforcing continuity around the corners (Fig. 4 and 5.) It was observed in buildings having re-entrant corners that roof drag forces commonly were not accounted for by an adequate transfer into the connecting shear walls (Fig. 6). Buildings of unusual configurations were observed to have sustained considerably more damage than those having more regular shapes. A continuous stress path should be provided to transmit lateral shear forces from the building roof to the ground.

The effects of unsupervised masonry construction are evident in Figures 7 and 8 which indicate complete lack of continuous wall reinforcement. The plans for this building called for #4 bars at 24" o.c. vertically.

As has been mentioned, perhaps the single most common mode of failure was the roof diaphragm to wall connection involving a bolt-on wall ledger. As indicated by Figure 9, the nails often pulled through the edge of the 1/2" or 3/8" plywood sheathing and/or the ledger split longitudinally along the bolt line. In a few cases, the nails pulled out of the ledger. A method of attachment which performed considerably better was the so called "joist anchor". See Figure 10. Note that codes to date do not require a similar positive tie at the first interior girder line where many diaphragms separated. One study made of joist anchors vs. wall ledgers immediately after the San Fernando earthquake indicated the anchors to be remarkably effective. (Reference 3) In all buildings covered in the study, there was no case of wall to roof separation where joist anchors were properly installed. The Los Angeles City Building Department now requires joist anchors at wall ledgers spaced at not over 4'-0" o.c. and capable of transferring a minimum of 200 lbs/foot of lateral wall load to the roof diaphragm. Los Angeles City Code changes enacted since the February 9, 1971 earthquake also specify closer spacing of pilaster or column ties in the area immediately below the girder seat. (Reference 4) The tie lap bend has been defined as a bend of 135 degrees around the common vertical bar. Three-eighths inch diameter minimum ties are now required. Additionally, the embedment requirement of beam or girder anchor bolts has been increased by 2 inches. Also, maximum allowable Code shear values for use in design of masonry shear walls have been reduced to fifty percent of the previous table values. To date, these are the principal Los Angeles City adopted code changes that apply to this category of buildings. The need for additional code changes should be apparent. In areas of severe ground movement it was obvious that the 13.3% of gravity requirement for lateral force design was not adequate for the accelerations experienced. Study is needed to determine at what level of lateral force it becomes economically impractical to design for earthquakes, and indeed if arbitrarily increasing the lateral force design requirements is the best answer for designing buildings.

SUMMARY

Numerous damaged buildings in the commercial-industrial classification were inspected and reviewed by the author. With few exceptions these buildings were in general conformance with the minimum requirements for structural adequacy as expressly stated by the governing Building Codes. Herein lies the fallacy and this, in the author's opinion, cannot be over emphasized - the Building Codes are intended to serve as minimum standards for the design profession and construction industry and should not and cannot take the place of sound engineering judgment. It is generally agreed by the engineering fraternity that sound engineering judgment cannot be codified nor should this be attempted. It is clear from this earthquake that the codes cannot be relied upon as the guardian of public safety. The problem is further aggravated by the reticence of some owners to pay for engineering which goes beyond the express minimum requirements of the building code even when it is in their best interests to do so. Recent history can point to cases

where structural engineers have had suits brought against them by owners for alleged overdesign of a project. If the public is to be reasonably safeguarded from the inherent dangers of a proliferation of the same type of questionable construction exposed in the debris following that February morning in 1971, there must be instituted more well studied changes in both Building Codes and general practice than have been made to date. The author feels existing laws should be changed to require the signature on the structural drawings of a licensed Civil, Structural, or Professional Engineer for this type of building. The same engineer of record may then better recognize his responsibility for minimal field supervision and review of shop drawings to assure that the construction documents bearing his name are being correctly interpreted and followed. Most surely changes must be made in the fees presently paid consulting engineers in order to make this possible, or provide a separate contract for these services. This is a must if we are to take our places as true professionals in improving the "state of the art".

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