SEISMIC DESIGN AND CONSTRUCTION FOR SINGLE-FAMILY DWELLINGS

by

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SYNOPSIS

This paper presents results of research carried out by the Applied Technology Council (ATC), San Francisco, California under the sponsorship of the U.S. Department of Housing and Urban Development. The objective of this project was to develop a "Manual of Seismic Design and Construction for Single-Family Dwellings." The Manual contains architectural layouts, design guides, types of construction, and features recommended or to be avoided. It also contains a cost impact study for dwellings located in Seismic Zones 2 and 3. The Manual was prepared for engineers, builders, building officials, field inspectors and house designers. It emphasizes the advantages of shear walls in single-family dwellings as prime elements to resist lateral forces.

1. INTRODUCTION

During the San Fernando Earthquake of February 9, 1971, single-family dwellings sustained considerable damage. The U.S. Department of Housing and Urban Development (HUD) took several steps to provide better and safer housing.

Together with the Department of Commerce, HUD initiated and supported a study, "Performance of Single-Family Dwellings in the San Fernando Earthquake of February 9, 1971" (1). The report clearly shows design and construction deficiencies which resulted in considerable damage to single-family dwellings.

HUD then awarded a contract in June 1974 to the Applied Technology Council, San Francisco, California, to develop a "Manual of Seismic Design and Construction for Single-Family Dwellings." To our knowledge this manual stands alone in its field. The work was performed by Ralph W. Goers, Structural Engineer, Los Angeles, California.

This paper concentrates on improvements in design and construction of single-family dwellings as recommended in the Manual.

2. SCOPE OF RESEARCH PROJECT

The total research project consisted of the following seven tasks:

Task 1: Review Existing Damage Literature
Task 2: Review HUD Minimum Property Standards (2) and Building Code Earthquake Requirements.

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Task 3: Develop Construction Details
Task 4: Prepare Manual and Supplementary Engineering Analysis Report
Task 5: Slide Presentation
Task 6: Present to Builder Organizations and Related Groups
Task 7: Prepare Cost Impact Analysis

Tasks 1, 2 and part of Task 3 were presented in a paper at the Seventh Joint Meeting of the U.S.-Japan Panel on Wind and Seismic Effects in Tokyo, Japan, May 1975 (3). Under Tasks 3 and 4 the Contractor has assembled in the Manual all pertinent information, including tables, graphs and illustrations, as well as requirements not presently incorporated in building codes or engineering design procedures in common use.

3. SCOPE OF MANUAL

The scope of the Manual is shown in the following "TABLE OF CONTENTS."

PART I INTRODUCTION

Purpose
Coverage
Types of Design and Construction Materials
Earthquake Damage
Use of the Publication
Limitations
New Concepts and Procedures
Organization

PART II BASIC SEISMIC ANALYSIS FOR SINGLE-FAMILY RESIDENCES

Principles of Seismic Design
Locating shear walls and determining tributary areas
Determining seismic and other loads
Wood frame shear wall design
Design of Masonry exterior walls
Miscellaneous structural considerations
Non-structural items

PART III RECOMMENDED GENERAL DESIGN REQUIREMENTS

Methodology and Definitions
Determination of Shear Wall Locations
Tributary Areas
Determination of Seismic Loads
Wind Loads
Design of Wood Frame Construction
Design of Masonry Construction
Miscellaneous Structural Considerations
Miscellaneous Non-Structural Items

PART IV CONSTRUCTION DETAILS

Commentary on details
Details

PART V GUIDELINES FOR PLAN-CHECKERS AND INSPECTORS

Plan-Checking
Checking Calc forms
Checking the plans
Inspection
New construction requirements

Due to the technical nature of the subject, the information in the Manual contains some technical terminology. However, technical terms were kept to a minimum and descriptions are in semi-technical language familiar to housing designers and builders. The section on "Principles of Seismic Design " Part II introduces most technical terms and discusses each in detail.

4. GENERAL PHILOSOPHY

The approach used in the Manual is that houses, like other structures, shall conform to the design requirements of the Uniform Building Code (UBC), 1973 Edition (4). However, exceptions in the UBC for single-family framed structures are not permitted unless justified by a thorough structural analysis as outlined in the Manual.

The intent of the Manual is to minimize the degree of damage rather than to prevent all damage. Even though this approach will probably add to the cost of home construction, there is little doubt that the additional cost would be the least expensive earthquake insurance available.

Virtually all homes built recently in the United States have wood framed second floors or roofs. Current engineering analysis generally assumes wood-frame diaphragms to be flexible. Therefore, lateral loads are distributed to shear walls on a tributary area basis. Field observations of houses damaged by the 1971 San Fernando earthquake indicate that this assumption is not correct. Calculations show that the second floor diaphragm is approximately ten times as rigid as the longest wood-framed shear wall. Therefore, lateral loads would be distributed to the walls based on relative rigidities.

Split-level houses received severe damage, including complete collapse, during the San Fernando earthquake. Analysis of a typical split-level house by the "tributary area" method predicts that the wall between the garage and family room would receive around three-quarters of the total lateral load. If the house is analyzed by using relative rigidities, the interior wall would receive almost all of the lateral load. It was obvious that traditional tributary area analysis techniques had to be evaluated and revised.

Another associated problem is that analysis indicates that shears generated in the first story walls of small split-level and two-story houses are in excess of allowable values for many of the shear resisting materials specified by Section 2518(f)5

of the UBC. Proposed requirements will therefore either result in use of plywood shear panels or in much longer shear panels of other materials for two-story and split-level homes.

An important clarification is needed concerning tributary areas as used in the Manual. Because of rigid diaphragm action, interior walls are subjected to higher loads than loads associated with one-half distances to the next walls. The Manual therefore introduces a multiplying factor (Figure 1) based on the ratio of effective lengths of walls. However, shears associated with outside walls are not reduced.

One other item concerns the "effective length" of shear walls to determine overturning stability. The effective length of the wall depends on size and number of openings. Shaded areas in Figure 2 "Determination of Effective Length of walls for Overturning" indicate portions of walls considered to resist overturning. To avoid confusion, this "effective length" is used only in determining stability against overturning and not for computing shear in these walls.

5. DESIGN AND CONSTRUCTION

Part III of the Manual covers seismic design provisions. As stated above, shear walls are the main lateral force resisting elements. A considerable portion of this part deals with shear walls: determination of their location, tributary areas associated with these walls, and special CALC FORMS to be used in designing dwellings. Two alternate design provisions (one for Seismic Zone 2, and one for Seismic Zone 3) are also provided.

One section presents several tables and graphs to facilitate design of shear walls in wood frame houses. Design parameters for masonry dwellings are provided in another section. An engineering design is required for two-story dwellings with full-height exterior masonry walls. In this case, only masonry walls are considered as shear walls. Here again the author makes use of several tables and graphs.

In the opinion of the author of the Manual, the largest responsibility created by promulgation of the Manual falls upon the plan checker. Checking of plans to determine adequacy to satisfy seismic requirements is divided into two parts. First, calculations and actual design are checked for correctness and completeness. Second, plans are reviewed to determine that proper details are used and all required details have been referenced. Since there are over a hundred details, this is not a simple task. To help accomplish it two special check lists are provided.

Finally, the last stage is construction of a dwelling. Proper design and careful checking will not produce a structure capable of resisting seismic forces if that structure is not built in accordance with the seismic design requirements.

Special details constructed properly can make a regular dwelling earthquake resistant. The Manual provides a great number of these details which can be considered its most valuable asset. (Figures 3 & 4).

This paper was prepared from a review of the final draft of the Manual as submitted by Mr. Goers to the Applied Technology Council, which in turn will publish the final documen later in 1976.

During the work on the Manual, it was discovered by Mr. Goers that there is a great need to clarify and correlate shear values of different building materials and combinations thereof. It is HUD's intent to proceed in this direction by sponsoring research to determine allowable shear values of all wall materials and combinations and to develop uniform testing procedures that may be correlated. This we believe will facilitate implementation of the Manual.

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Interpretations stated in this paper are solely that of the authors and does not necessarily reflect the official position of the U.S. Department of Housing and Urban Development, the Applied Technology Council, or Mr. Goers.

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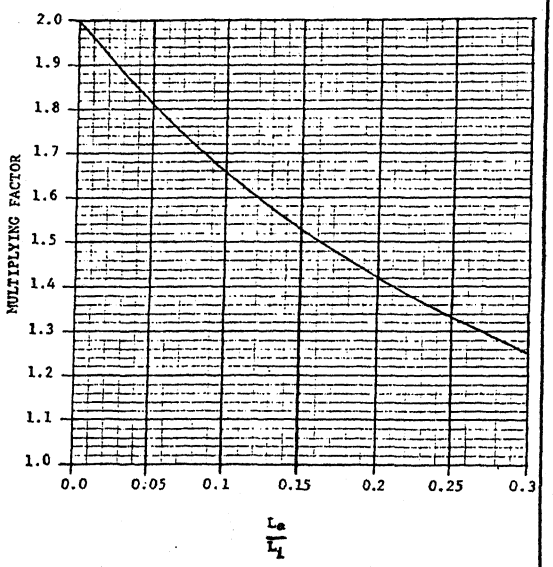
BIBLIOGRAPHY

(1) McClure, Frank E., "Performance of Single-Family Dwellings in the San Fernando Earthquake of February 9, 1971," National Oceanic and Atmospheric Admin. and U.S. Dept. of HUD, May 1973

(2) U.S. Department of Housing and Urban Development, HUD Minimum Property Standards, "One and Two-Family Dwellings," 1973 Edition

(3) Fuller, G. Robert, "Improved Earthquake Resistive Design and Construction of Single-Family Residential Dwellings," Seventh Joint Meeting, Panel on Wind and Seismic Effects, (UJNR) Tokyo, Japan, May 1975

(4) International Conference of Building Officials, "Uniform Building Code," 1973 Edition



L_e = total effective length of shear wall at the parallel exterior wall.

L_I = total effective length of interior shear wall.

FIGURE 1 MULTIPLYING FACTORS FOR TRIBUTARY WIDTH ADJUSTMENT

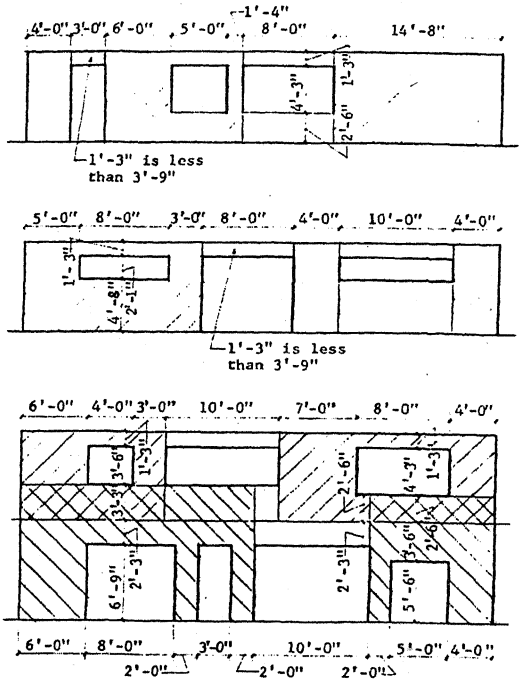
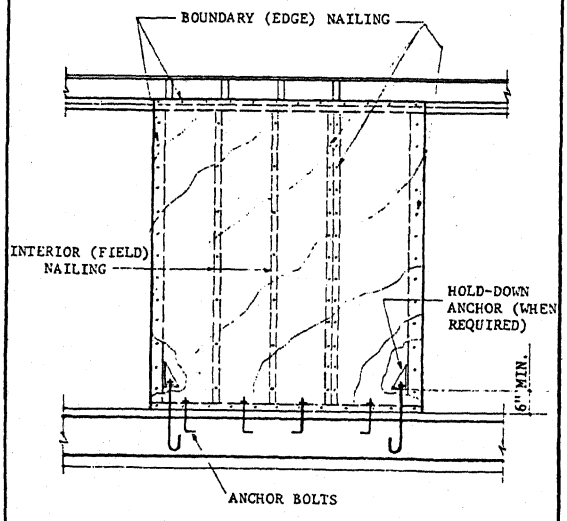
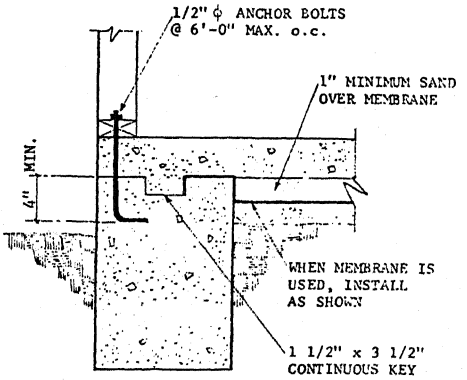


FIGURE 2 DETERMINATION OF EFFECTIVE LENGTH OF WALLS FOR OVERTURNING



TYPICAL SHEAR WALL INSTALLATION

FIGURE 3



TYPICAL CONTINUOUS FOOTING WITH SLAB ON GRADE

FIGURE 4