LA-UR -91-133

CONF-910306--1

Received ...

FEB 08 1991



LA-UR--91-133

DE91 007390

TITLE: LOW-RISE SHEAR WALL FAILURE MODES

AUTHOR(S): Charles R. Farrar
Philip S. Hashimoto
John W. Reed

SUBMITTED TO: ASCE
Pittsburg, PA
March 1991



Los Alamos Los Alamos National Laboratory
Los Alamos, New Mexico 87545

LOW-RISE SHEAR WALL FAILURE MODES

Charles R. Farrar[1],Member, ASCE
Philip S. Hashimoto[2], Member, ASCE
John W. Reed[3], Member, ASCE

## Abstract

A summary of the data that are available concerning the structural response of low-rise shear walls is presented. This data will be used to address two failure modes associated with the shear wall structures. First, data concerning the seismic capacity of the shear walls with emphasis on excessive deformations that can cause equipment failure are examined. Second, data concerning the dynamic properties of shear walls (stiffness and damping) that are necessary to compute the seismic inputs to attached equipment are summarized. This case addresses the failure of equipment when the structure remains functional.

## Introduction

The purpose of this paper is to document the available data concerning the seismic capacity and the dynamic properties (stiffness and damping) of low-rise reinforced concrete shear walls. This paper will point out where analyses unsupported by experimental verification with their inherent engineering judgements are being used and where data-based procedures for

---

[1]Staff Member, Los Alamos National Laboratory, MS J576, Los Alamos, NM 87545
[2]Technical Manager, EQE Engineering Inc., 3150 Bristol Street, Suite 350, Costa Mesa, CA 92626
[3]Associate, Jack R. Benjamin and Associates, Inc., 444 Castro Street, Suite 501, Mountain View, CA 94041

estimating structural behavior are being used. The information discussed in this paper is used for fragility analysis associated with seismic probabilistic risk analysis (PRA) and for seismic margin assessment.

Two issues are of interest: (1) seismic capacity of the shear wall with emphasis on excessive deformations of the structure that indirectly fails equipment, and (2) direct failure of the enclosed equipment from inertial loading. Because of their heavy construction, nuclear power plant low-rise shear wall structures are typically considered to have very large capacities against seismic-induced collapse. Therefore, in seismic PRA, structural failure is defined to occur when structural deformations are sufficient to impair the functionality of supported equipment. These deformations are usually much lower than motion levels that would cause collapse of the structure.

A building may respond in such a manner that it remains functional but with motion levels that cause equipment failure. This response can be either elastic or inelastic with the shear wall's stiffness and damping being the structural properties that control the motion levels. Because the full range of motions must be considered in seismic PRA, the relationship between the shear wall's dynamic properties and the ground motion input is required.

## Seismic Capacity Of Low-Rise Shear Walls

Quantities related to seismic capacity of low-rise shear walls that are evaluated in structural fragility analysis for seismic PRA include (1) structure deformation limits, (2) structure strength, and (3) structure nonlinear displacements.

Structure deformation limits corresponding to loss of function of supported equipment are typically estimated using engineering judgement. Median estimates of interstory drifts corresponding to equipment failure are typically in the range of about 0.5% to 1.5% of the wall height. For example, in the Diablo Canyon PRA [1], the median drift limit for the turbine building shear walls was estimated to be 0.7%. Only limited test data [2 through 4] were available to derive this estimate.

Determination of structure strength for seismic fragility evaluations requires estimates of material strengths and element strengths. Median material strengths are determined from plant-specific data to the extent possible. The resulting median compressive strength typically exceeds the specified design strength by a factor ranging from about 1.4 to 2.0. Median reinforcement yield strengths typically exceed the specified design strength by a factor ranging from about 1.1 to 1.3.

The American Concrete Institute (ACI) Code provides equations for design ultimate strengths of shear walls loaded by in-plane shear and moment (Reference 2-5). These equations were shown to provide conservative strength capacities based upon testing of shear wall specimens with overall height-to-length ratios ranging from 1.0 to 3.4. Testing by Barda, et al [2] has indicated that the ACI design equations are very conservative for low-rise shear walls (height-to-length ratios less than 1.0) with boundary elements.

Several past fragility evaluations have evaluated median shear strengths of low-rise shear walls using an equation that is based on Barda's work [2]. Figure 3-2 in [6] compares this equation with available test data from [2, 5, 7, and 8]. The nominal concrete shear stress permitted by the ACI code is also plotted in this figure. As shown, the ACI code is very conservative in comparison to the available test data.

The effective flange width provided by shear walls in transverse directions and load redistribution that results from cracking of the shear walls are estimated based on engineering judgement.

. Fragility evaluation must consider nonlinear structural response because initial yielding of nuclear plant shear walls will typically occur at deformations well below levels necessary to damage attached equipment components. There are only limited examples of nonlinear structural analyses that have been performed in support of seismic PRAs. One such example is described in [1].

As an alternative to explicit nonlinear analysis, an inelastic energy absorption factor, $F_u$, has been used in past fragility evaluations. Simplified procedures used to estimate the inelastic energy absorption factor have been correlated against analytical data generated by nonlinear analyses. These analyses used nonlinear structure models with hysteresis characteristics that attempt to match the results of cyclic loading tests of shear wall specimens. Correlation of the simplified procedures against actual dynamic test data has not been performed.

Simplified procedures for estimating nonlinear structure response from elastic analysis results have been investigated for nuclear plant application in [9] and the Diablo Canyon turbine building fragility evaluation [1]. These procedures include (1) a spectral averaging method [9] and (2) a modified Riddell-Newmark method [10,11].

## Low-Rise Shear Wall Structural Properties

Stiffness and damping of shear wall elements must be estimated in order to calculate the input to attached equipment housed in these structures. Typically, stiffness values are determined from a strength-of-materials analysis procedure with a stiffness reduction factor sometimes applied. Although there are numerous static and dynamic tests of shear wall elements [4,12 through 18], the majority of these were ultimate strength tests. When these tests are examined to determine stiffness values, the values range from almost exact agreement with strength-of-material theory to almost 90% below theory. Data from dynamic tests have shown significant reductions in stiffness at very low stress levels. There is little dynamic data that quantifies the change in stiffness as the structure's response becomes nonlinear.

Equivalent viscous damping ratios used in the analysis of nuclear power plant structures are based on the recommendations in Regulatory Guide 1.61 [19]. References [4,14,20,21] provide experimental estimates of damping from tests on full size structures and on scale model shear wall elements. It is difficult to determine if these tests are measuring the damping of the shear wall or of a system that includes the shear wall and the base connection of the test specimen. The experimental data is somewhat scattered and tests on full size shear wall structures that are responding in the nonlinear response region does not exist.


Summary

There is substantial data in the open literature that verifies the conservatism of the equations used to determine the ultimate strength of low-rise shear walls. However, deformations levels that could cause failure of attached equipment more often determine the seismic capacity of these walls. In this regard, both the deformation limits and the analytical procedures used to calculate deformations are based on engineering judgement These analytical procedures have only been indirectly correlated with experimental data.

Guidance for determining the stiffness and damping of low-rise shear walls which will be used to calculate inputs to attached equipment is given in [22]. There is little experimental data available with which to verify the recommendations in these guidelines. The data that exists are inconsistent even in the linear response region as discussed in [23]. Data concerning these dynamic properties in the nonlinear response region and how these properties change as response goes from the linear to nonlinear region are particularly sparse.


References


1 Kennedy, R.P., D.A. Wesley, and W.H. Tong, "Probabilistic Evaluation of the Diablo Canyon Turbine Building Seismic Capacity Using Nonlinear Time History Analyses", prepared for Pacific Gas and Electric Company, December, 1988.

2 Barda, F., J.M. Hanson, and W.G. Corley, "Shear Strength of Low-Rise Walls with Boundary Elements", ACI Symposium, Reinforced Concrete Structure in Seismic Zones, SP-53, American Concrete Institute, Detroit, Michigan, 1976.

3 Shiga, T., "Hysteretic Behavior of Reinforced Concrete Shear Walls", Proceedings of the U.S.-Japan Cooperative Research, The Safety of School Buildings,Hawaii, 1975.

4. J. G. Bennett et al., "Seismic Category I Structures Program: Final Report, FY 1983-84, Los Alamos National Laboratory report LA-11013-MS, (Sept. 1987).

5 Cardenas, A.E., et al., "Design Provisions for Shear Walls", ACI Journal, Volume 70, No. 3, March, 1973.

6 Wesley, D.A. and P.S. Hashimoto, "Seismic Structural Fragility Investigation for the Zion Nuclear Power Plant", prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-2320, October, 1981.

7 Oesterle, R.G., et al, "Earthquake Resistant Structural Walls - Tests of Isolated Walls - Phase II", Construction Technology Laboratories,Skokie, Illinois, October, 1979.

8 Shiga, T., A. Shibata, and J. Takahashi, "Experimental Study on Dynamic Properties of Reinforced Concrete Shear Walls", Fifth World Conference on Earthquake Engineering, Rome, Italy, 1973.

9 Kennedy, R.P., et al, "Engineering Characterization of Ground Motion - Task I: Effects of Characteristics of Free-Field Motion on Structural Response", prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-3805, Volume 1, May, 1984.

10 Riddell, R. and N.M. Newmark, "Statistical Analysis of the Response of Nonlinear Systems Subjected to Earthquakes", SRS 468, Department of Civil Engineering, University of Illinois, Urbana, August, 1979.

11 Kennedy, R.P., R.H. Kincaid, and S.A. Short, "Engineering Characterization of Ground Motion - Task II: Effects of Ground Motion Characteristics on Structural Response Considering Localized Structural Nonlinearities and Soil-Structure Interaction Effects", prepared for the U.S. Nuclear Regulatory Commission, NUREG/CR-3805, Volume 2, of Free-Field Motion March, 1985.

12. V. Bertero, "The Response of Shear Walls Subjected to Dynamic Loads," Doctoral Dissertation, Dept. of Civil and Sanitary Eng., M.I.T., (1957).

13. J. Antebi, "Model Analysis Of The Response Of Shear Walls To Dynamic Loads," Doctoral Dissertation, Dept. of Civil and Sanitary Eng., M.I.T., (1961).

14. J. Aristizabal-Ochoa, "Cracking and Shear Effects on Structural Walls," *Am. Soc. Civ. Engrs. Proc. (J. Structural Div.),* 109, No. 5, pp. 1267-1277 (May 1985).

15. E. G. Enderbrock, R. C. Dove, and W. E. Dunwoody, "Analysis and Test on Small-Scale Shear Walls, FY-82 Final Report," Los Alamos National Laboratory report LA-10443-MS, (Sept. 1985).

16. J. G. Bennett et al., "Simulated Seismic Tests on 1/42- and 1/14-Scale Category I, Auxiliary Buildings," Los Alamos National Laboratory report LA-11093, (Oct. 1987).

17. J. G. Bennett et al., "The Seismic Category I Structures Program: Results for FY 1985," Los Alamos National Laboratory report LA-11117-MS, (Dec. 1987).

18. J. G. Bennett et al., "The Seismic Category I Structures Program: Results for FY 1986," Los Alamos National Laboratory report LA-11377-MS, (Sept. 1988).

19. Division of Nuclear Regulatory Standards, "Damping Values for Seismic Design of Nuclear Power Plants, Reg. Guide 1.61," United States Nuclear Regulatory Commission, Washington D.C., 1973.

20. T. Shiga, A. Shibata, and J. Takahashi,"Experimental Study of Dynamic Properties of Reinforced Concrete Shear Walls," Proc. World Conference on Earthquake Engineering, 5th, Rome, 1973, 1, pp.221-241.

21. J.D. Stevenson, "Structural Damping Values As A Function of Dynamic Response Stress and Deformation Levels," Nuclear Eng. and Design, 60, pp. 211-238, (1980).

22. Committee on Nuclear Standards, Seismic Analysis of Safety-Related Nuclear Structures, (ASCE, New York, 1987).

23. J. P. Moehle, M. A. Sozen, and H. T. Tang, "Concrete Wall Stiffness: Calculation VS. Measurement," in Current Issues Related To Nuclear Power Plant Structures, Equipment and Piping, A. K. Gupta Ed. (North Carolina State University, Raleigh, NC,1990).

# END

# DATE FILMED

03 / 20 / 91