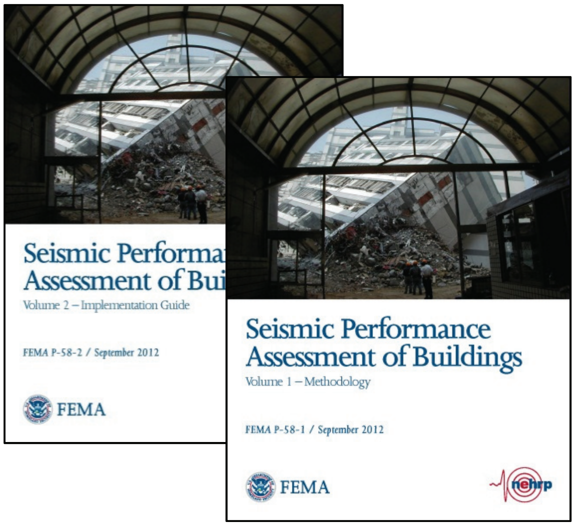

Background Document

FEMA P-58/BD-3.9.3

Seismic Fragility of Building Interior Doors

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Background Documentation

FEMA P-58 Background Documents are a series of reports documenting the technical background and source information for key aspects of the FEMA P-58 methodology and its implementation. These reports were developed over the course of the 10-year ATC-58/ATC-58-1 Projects funded under FEMA Contracts EMW-2001-RP-0056 and HSFEHQ-06-D-1105.

Background Documents were developed by consultants, serving at various levels within the project hierarchy, reporting the results of: (1) decisions on technical development protocols; (2) focused studies on the development of key aspects of the methodology; (3) documentation of recommended procedures; and (4) collection of available data for the development of structural and nonstructural fragilities. They were initially intended to serve as a record of the technical state-of-knowledge at the time they were produced, and as resources for the development of the eventual project reports. As such, they represent a snapshot in time, and may, or may not, match the technical content, recommended procedures, or data incorporated into the final methodology and its implementation.

This Background Document is intended for the purpose of providing supplemental knowledge to users of the FEMA P-58 methodology. Information contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology. Specifically in the case of certain nonstructural component fragilities, the NISTIR fragility classification numbering scheme was modified over the course of the project, and the fragility classification number assigned in this document might be different from numbers assigned in the final fragility database. Users of information in this document assume all liability arising from such use.

Notice

Cover illustration – Primary resource documents for the FEMA P-58 *Seismic Performance Assessment of Buildings, Methodology and Implementation* series of products: FEMA P-58-1, *Volume 1 – Methodology*, and FEMA P-58-2, *Volume 2 – Implementation Guide*.

SEISMIC FRAGILITY OF BUILDING INTERIOR DOORS

Prepared for ATC-58 by
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Introduction

The objective of this document is to summarize the development of fragility functions for interior doors used in building construction.

Sources of information

As part of the U.S.-Japan Cooperative Research Project a full-scale seven story reinforced concrete building was tested at the Building Research Institute (BRI) in Tsukuba, Japan (Kaminosono et al, 1984). The building had a height of 21.75 m (71.4 ft) with plan dimensions of 16 m (52.5 ft) by 17 m (55.5 ft) in plan. The story height was 3.75 m for the first story and 3.0 m for the second through seventh stories. The lateral resisting system consisted of a dual system of a shear wall and moment resisting frames. After pseudo-dynamic testing of the structure and subsequent repair nonstructural components were added to the building which included gypsum wallboard partitions and doors (Nakata et al., 1984). Damage was documented as various stages of subsequent pseudo-dynamic testing.

Arnold et. al 2003 Tested eleven full-scale wall specimens with wood studs and ½ in gypsum wallboard. Four of the six walls with an aspects ratio of three had double-hung windows, casement windows, and prehung doors installed.

Lang (Land and Restrepo 2006, Lang 2007), tested two identical specimens that were constructed in accordance with current practice including mudding and taping of the gypsum finish wallboard. The specimens represented full scale office rooms which were approximately 15 feet long, 12 feet wide, and 14 feet high. The specimen configuration included several characteristics common to partition wall construction including return walls, T-walls, a structural column wrap, utility cut-out, and door with a sidelight. Metal framing was erected in accordance with current construction practice, including 3-⅝ inch 20 gage studs spaced every 16 inches. Vertically slotted tracks (slip tracks) were used at the top of the walls; this is an industry standard to allow for vertical deflections. The studs were fastened to the tracks at the flanges with No. 8 by 9/16 inch self-tapping screws. Gypsum wallboard panel with a thickness of 5/8 inch were used as facing material on each side of the partitions. The wallboard was fastened with No. 8 self-tapping screws placed at 8 inches on center to the bottom track and every 8 to 10 inches (12 inch minimum) to the studs and were not screwed to the top track.

The two specimens were subjected to different loading protocols developed as part of the ATC-58 project. Bi-directional lateral displacements were imposed on the specimens in a crossshaped manner, with decoupled strong and weak axes. There was no bi-axial movement. The specimens were first loaded in the strong axis for two cycles, returned to zero displacement, loaded in the weak axis for two cycles, and then returned to zero displacement. The weak to strong axis ratio was 0.5. The loading history consists of step-wise, exponentially increasing drift ratio amplitudes. Two cycles per amplitude were performed. In the first test fasteners that attached the tracks to the concrete slabs fracture due to low cycle fatigue apparently due to the large number of cycles in the loading protocol, so the second specimen was subjected to a modified protocol with significantly smaller number of cycles (approximately one third).

Lee et al. (2006, 2007) tested various configurations of interior partitions with metal studs. One of the specimens included a door.

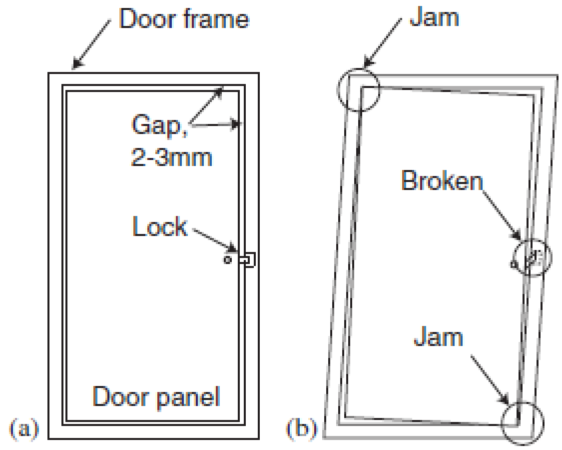

Figure 1. Door subjected to lateral deformations (after Lee et al. 2007)

Figure 2. Examples of specimens tested by Arnold et al 2003.

Figure 3. Example of door at large levels of deformation (After Arnold et al.).

Damage States

Two damage states were selected for the development of the fragility functions. Consistent with the approach developed by the Pacific Earthquake Engineering Research Center (Krawinkler and Miranda, 2004) damage states well selected in accordance to repair methods or consequences of damage. The first damage state, DS-1, consists of a door jam in which the door cannot be opened. This damage state has been reported to occur at interstory drift ratios as small as 0.001. Since the damage can be opened once the deformation is eliminated, then this damage state is considered to have occurred only when a permanent drift ratio exists.

The second damage state consists of damage to the door that prevents it from opening and one that leads to repairs. Typical damage occurs at the door lock and at the hinges.

Fragility functions

Fragility functions were developed by first identifying the level of lateral deformation imposed in the partition at which each damage level was first reported to occur. Table 1 summarizes this information for all specimens.

First a lognormal probability distribution was fitted on the ascending sorted data by using moment matching in which the median is computed as the geometric mean and the dispersion (β) is computed as the logarithmic standard deviation. Empirical cumulative distribution functions were also plotted using Hazen's plotting position given as

$$p_i = \frac{i - 0.5}{n}$$

where i is the rank of the sorted data and n is the sample size corresponding to each damage state.

Figure 4 shows the empirical cumulative distribution function corresponding to damage state 1. As shown in this figure doors were reported to be jammed in some specimens at very low values of interstory drift (0.001) while in others this damage state was not reported to occur until drift ratios reached 0.006. Also shown in the figure is the fitted lognormal distribution. The parameters of the lognormal probability distribution correspond to the geometric mean and the logarithmic standard deviation of the data. As shown in the figure the lognormal probability distribution provides a relatively good fit to the data.

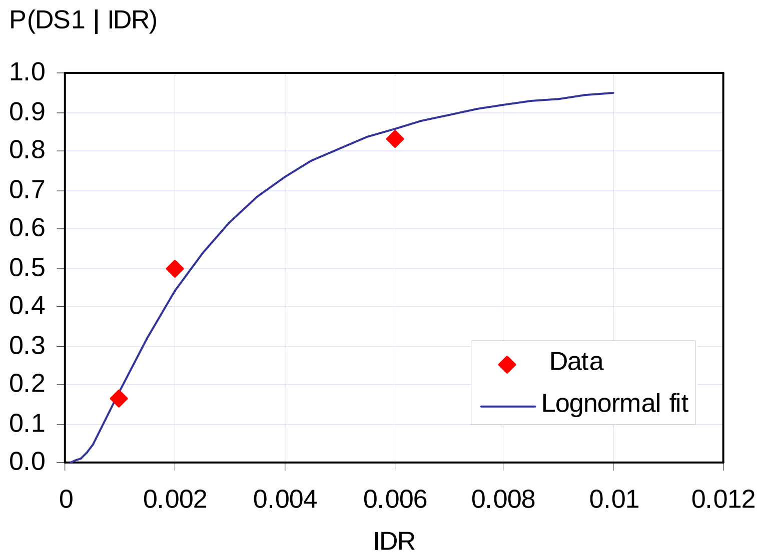

Figure 4. Fragility function corresponding to damage state 1.

Figure 5 shows cumulative distribution functions corresponding to damage state 2. The figure shows both the empirical cumulative distribution function and the fitted lognormal distribution. As shown in this figure this second damage state was reported to occur for interstory drift ratios ranging from 0.004 to 0.01.

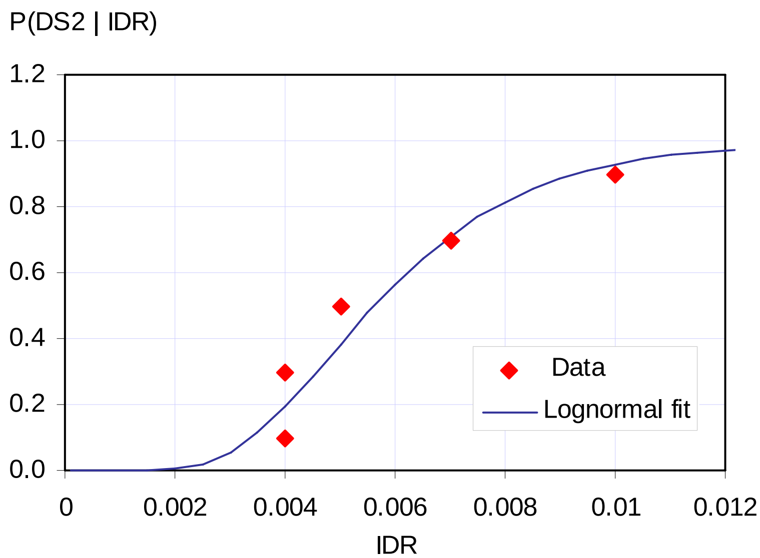

Figure 5. Fragility function corresponding to damage state 2.

Table 1. Interstory drift ratios in which each damage state was reported to have occurred.

Reference	**DS1**	**DS2**
Okamoto et al. 1985	0.002	0.004
Lang et al. 2007	0.001	0.004
Lee et al. 2007	0.006	0.010
CUREE EDA-02	-	0.005
Arnold et al 2003	-	0.007

Table 2. Parameters of lognormal distributions fitted to data in table 1.

Damage State	Description	Median IDR	Dispersion
DS1	Door gets jammed and cannot be opened	0.0023	0.90
DS2	Damage is produced to the door lock and/or hinges	0.0056	0.40

References:

Arnold, A., Uang, C.-M. and Filiatrualt, A. (2002) "Cyclic behavior and repair of stucco and gypsum sheated woodframe walls: Phase I, Report No. SSRP-2002/01, University of California, San Diego, La Jolla, CA.

Arnold, A., Uang, C.-M. and Filiatrualt, A. (2003) "Cyclic behavior and repair of stucco and gypsum sheated woodframe walls: Phase II, Report No. SSRP-2003/01, University of California, San Diego, La Jolla, CA.

Bersofsky, A.M, Restrepo J. and Filiatrualt, A. (2002) Progress report, Pacific Earthquake Engineering Center, University of California, Berkeley.

Bersofsky, A.M, (2004), Seismic performance evaluation of gypsum wallboard partitions, *MS Thesis*, University of California at San Diego.

Lang, A.F., Restrepo, J.I. (2006), "Seismic performance evaluation of gypsum wallboard partitions." *Proceedings of 8th U.S. National Conference on Earthquake Engineering*, EERI, San Francisco, California, U.S.A., 2006, Paper No. 1353.

Lang, A.F. (2007) "Seismic performance evaluation of gypsum wallboard partitions, *MS Thesis*, University of California at San Diego.

Lee, T.H., M. Kato, T. Matsumiya, K. Suita and M. Nakashima (2006), "Seismic performance evaluation of non-structural components: drywall partitions," *Annals of the Disaster Prevention Research Institute*, Kyoto University, No. 49 C, pp. 177–188.

Lee, T.H., M. Kato, T. Matsumiya, K. Suita and M. Nakashima (2007), "Seismic performance evaluation of non-structural components: drywall partitions," *Earthquake Engineering and Structural Dynamics*, Vol. 36, pp. 367–382.

Nakata, S., H. Itoh, A. Baba, and S. Okamoto, (1984) "U.S.-Japan cooperative research on R/C full-scale building test: Part 3 -- Installation on nonstructural elements and repair works, damage aspects and hysteretic properties after repair," *Proc. Eight World Conf. Earthquake Engrg.*, San Francisco, CA, Vol. VI, pp. 611-618.

Okamoto, S., et al., (1985). "Testing, Repair and Strengthening, and Retesting of a Full-Scale Seven-Story Reinforced Concrete Building," *SP-84,* Earthquake Effects on Reinforced Concrete Structures, U.S.-Japan Res., American Concrete Institute.