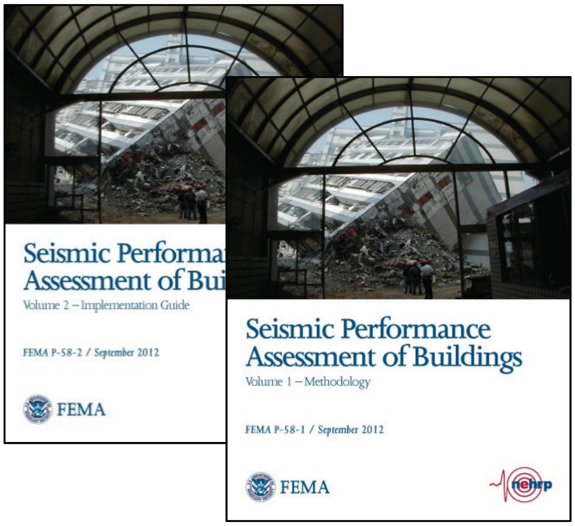

Background Document

FEMA P-58/BD-3.9.30

Fragility of China and Art on Shelves

Prepared by

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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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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.

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*.

Fragility of china and art on shelves

Keith Porter (08/21/2008)

Table 1. Summary of results

Fragility, damage measures, and consequences for			
Component category:	E2022.010, China and art on shelves E2022.011, Ditto, all w/ high friction coeff, secured cabinets E2022.012, Ditto, some with high friction coeff, etc. E2022.013, Ditto, few to none with high friction coeff, etc.		
Basic composition:	china and art on shelves, including china cabinets		
Units:	ea item		
Demand parameter:	peak diaphragm acceleration		
Number of damage states:	1		
If multiple damage states:	□ ordered; □ mutually exclusive; □ simultaneous		
Author and date:	Keith Porter 21 Aug 2008		
Damage states, fragilities, and consequences			
	DS1	**DS2**	**DS3**
Description:	Object falls off shelf or shelf overturns and object breaks		
Illustration:			
Median demand (θ)(1):	0.25g		
Dispersion (β)(1):	0.5		
Probability(1):			
Correlation:	0		
Repairs required:	Replace object		
Possible consequences:			
Repair cost (Y/N/?):	Y		
Death or injury (Y/N/?):	Y		
Inoperative facility (Y/N/?):	N		
Red tagging (Y/N/?)	N		
Comments:	Injury only from china cabinet or heavy object falling from above waist level		

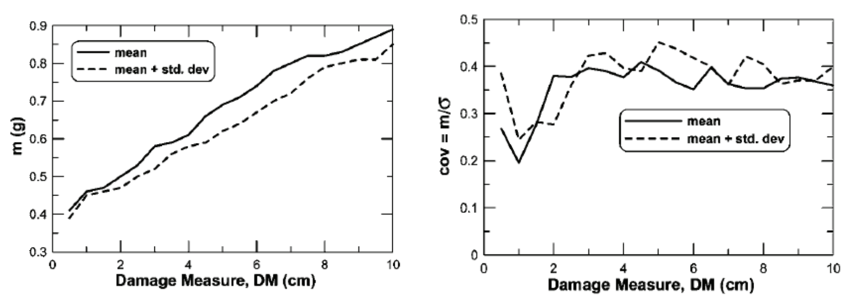
(1) If ordered damage states, leave "probability" blank. If mutually exclusive or simultaneous damage states, provide parameters in DS1 column only, and probabilities of each damage state in "probability."

Table 2. Summary supporting information template

Literature summary

Saeki et al. (2000). These authors performed an empirical study of the fragility of household property, including a category labeled "large self-standing furniture mainly used for storage" and another labeled "tableware." They performed a questionnaire-based survey of damage to household property experienced in the 1995 Kobe earthquake. A total of 1,450 questionnaires were sent out over a wide area centering on Hyogo and Osaka Prefectures, with 965 responses. They created fragility functions in the form of Gaussian cumulative distribution functions with JMA intensity as the EDP. The damage state for large self-standing furniture was overturning; with m = 6.3 and σ = 0.9. The damage state for tableware was falling to the floor, with m = 5.0 and σ = 0.4.

Hutchinson and Chaudhuri (2003). These authors report on recent shake-table tests of bench-mounted, unrestrained laboratory equipment subjected to horizontal excitation. The authors provide functional relationships between the distance that components slid (to which they refer as a damage measure) and the peak diaphragm acceleration (PDA) imposed. They categorize components by coefficient of static friction between the base of the equipment and the surface on which it rests, from a low value of 0.35 to a high of 0.85. Their distance-PDA relationship for low coefficient of static friction is shown in Figure 1. Note that the coefficient of base friction between china and wood would probably be substantially lower than 0.35.



(a) Category 1: Low Base Resistance

Figure 1. Results of shake-table tests of bench-mounted laboratory equipment with coefficient of base friction of approximately 0.35 (Hutchinson and Chaudhuri 2003). In the figure, *m* denotes mean sliding distance and σ denotes the standard deviation of sliding distance. The coefficient of base friction between china and wood would probably be substantially lower than 0.35.

Filiatrault (2006). This author reports on laboratory testing of tall unanchored bookcases, which might be equivalent to china cabinets. Filiatrault offers two fragility functions derived from these data, shown in Figure 2.

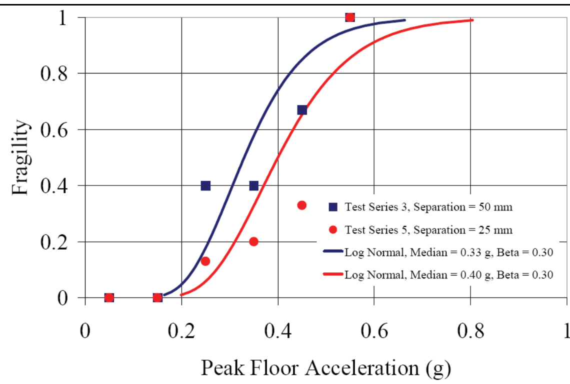


Figure 2 – Overturning Fragilities of Bookcases.

Figure 2. Fragility function for overturning of tall unanchored bookcases (Filiatrault 2006)

ANALYSIS

It is worthwhile to convert the Saeki et al. (2000) fragility functions from a JMA-intensity basis to a PDA basis for present purposes. To perform the conversion, consider the intensity maps for the 1995 Kobe earthquake offered by Yamaguchi and Yamazaki (2001), shown in Figure 3. It appears that JMA intensity 6+ equates approximately with peak ground acceleration (PGA) = 1.0g, suggesting a median value of peak diaphragm acceleration (PDA, taken here as approximately 2xPGA) for overturning of china cabinets of 2.0g, which seems high. It also appears that JMA intensity 5 equates approximately with PGA = 0.15g, or approximately θ = 0.15g for ground-floor locations or 0.3g for upper-story locations, when the EDP is PDA. A value of σ = 0.4 for a Gaussian fragility function in terms of JMA intensity equates approximately with β = 0.5 for a lognormal fragility function in terms of PGV, which is assumed to apply equally to PDA (see Porter 2006 for support).

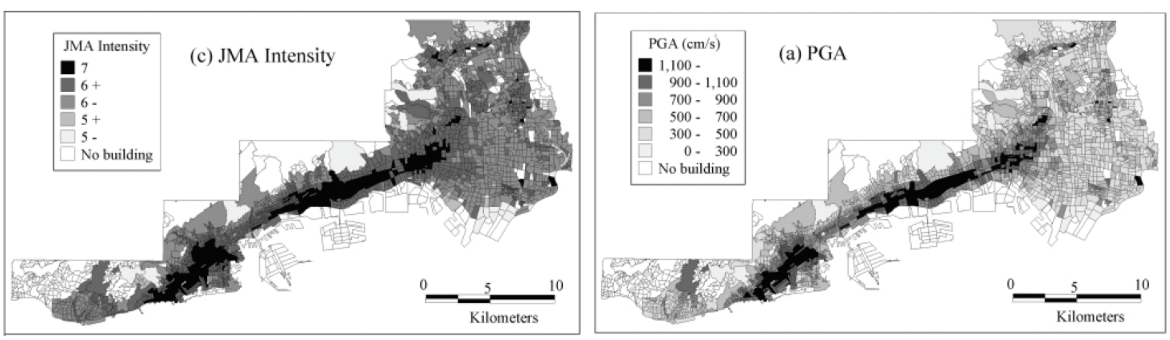


Figure 3. Kobe earthquake shaking intensity estimates (Yamaguchi and Yamazaki 2001)

Hutchinson and Chaudhuri's tests can be approximately converted to fragility functions in the ATC-58 sense by assuming a coefficient of static friction between the equipment base and the surface on which it rests, and the sliding distance that would result in the china falling to the floor. If the china or other art objects must slide 3 inches before falling, Figure 1 implies $\theta \approx$ 0.8g. Increasing the distance to 12 in (30 cm) produces θ = 1.9g. Overturning of the china cabinet is not reflected in these figures. Note that the coefficient of friction between china and wood is probably significantly below 0.35; perhaps on the order of 0.2 to 0.25, so these figures, $\theta \approx$ 0.8 to 1.9g, would probably be substantially greater than what one would expect if Hutchinson and Chaudhuri had tested ceramics on wood surfaces.

Fitting a lognormal CDF to all the data in Figure 2 suggests that overturning of tall

unanchored bookcases (and by inference china cabinets) occurs with θ = 0.4g and β = 0.4. The present analysis of the Saeki et al. (2000) fragility functions suggests that, including both objects sliding off shelves and cabinets overturning, $\theta \approx$ 0.15 to 0.3g, with β = 0.5. By judgment, take an approximate midpoint for capacity and the larger of the two betas, i.e., θ = 0.25g and β = 0.5.	
Number of specimens tested:	Saeki et al. (2000): an unknown number of objects in up to 965 homes. Filiatrault (2006): 1 specimen tested under 3 installation conditions in a total of 180 tests
Construction quality:	□ exceeds □ meets □ does not meet requirements of: ____
Seismic installation conditions:	Unsecured objects in unsecured cabinets
Loading protocols applied:	Filiatrault: Various. Saeki et al.: Kobe earthquake at various locations
Method for observing demand:	Filiatrault: Input excitation Saeki et al.: survey respondent's address geolocated, overlain with JMA intensity map of Kobe earthquake
Method for observing damage:	Filiatrault: Direct observation Saeki et al.: Survey of residents

Table 3. Table of test results

Specimen	DS1		DS2		DS3		Comment
	Data type: B		Data type:		Data type:		
	demand	***f***	***demand***	***f***	***demand***	***f***	
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
add as req							

Table 4. Quality tests

Quality test	DS1	DS2	DS3
Passes Lilliefors goodness of fit test? (Type A only)	NA		
Are θ and β within 20% of past results? If not discuss.	NA		
Are $0.2 \leq \beta \leq 0.6$? If not discuss.	Y		
Discussion.			

Table 5. Extrapolation to other detailed conditions and to average conditions

Condition (describe)	From tests?	DS1		DS2		DS3	
		θ	*β*	θ	*β*	θ	*β*
Best: objects on shelves have high coefficient of static friction, e.g., because of museum putty, or cabinet doors have latches. Cabinets are secured to the wall.	N	1.0g	0.5				
Moderate: some objects have museum putty or some cabinets have latches. Cabinets are secured to the wall.	N	0.6	0.6				
Worst: no objects have museum putty and no cabinets are secured to the wall.	Y	0.25	0.5				
Average: some objects have museum putty or some cabinets have latches. Some cabinets are secured to the wall.	N	0.4	0.6				
Basis for extrapolation. What factors affect θ and *β*? For objects sliding off shelves, coefficient of static friction and the presence of latched cabinet doors would seem to dominate θ. For tall china cabinets, θ would be affected primarily by whether the cabinet is secured to the building frame and secondarily by the distance between the wall and the cabinet. Results based on Saeki and Filiatrault are assigned to "worst" conditions, based on the assumption that few Japanese protected their tableware with museum putty or cabinet door latches, and on the observation that Filiatrault's tests did not include bookcases secured to the wall. Fragility functions for best, moderate, and average conditions are based on judgment of their capacity relative to "worst."							

"From tests" means that the tests reported here are believed to represent this condition level

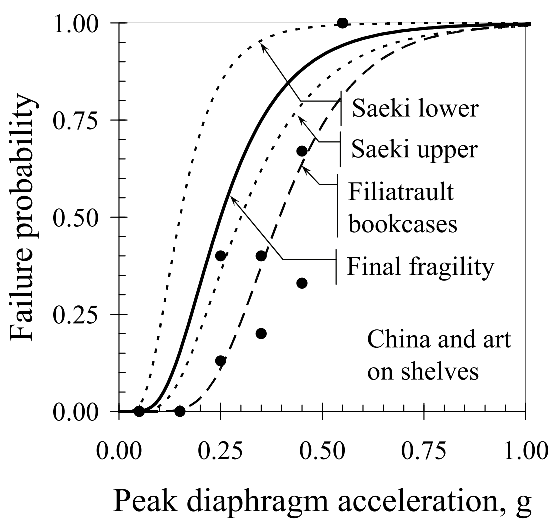


Figure 4. Fragility of china and art on shelves. "Saeki lower" refers to lower fragility function interpreted from Saeki et al. (2000) results. Black dots are Filiatrault's (2006) series 3 and 5 data. "Filiatrault bookcases" refers to curve fit to these latter data.

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Revision history

1.0	21 Aug 2008	Initial release