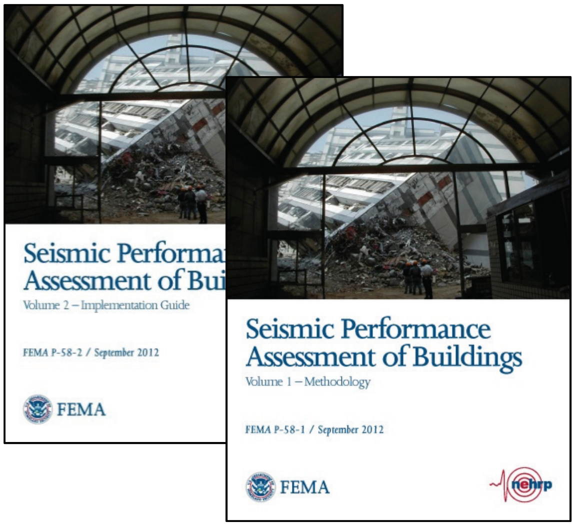

Background Document

FEMA P-58/BD-3.9.23

Fragility of Motor Generators

Prepared by

Keith Porter
Dept of Civil, Environmental & Architectural Engineering
University of Colorado
Boulder, Colorado 80309

Submitted to

APPLIED TECHNOLOGY COUNCIL
201 Redwood Shores Parkway, Suite 240
Redwood City, California 94065
www.ATCouncil.org

Prepared for

FEDERAL EMERGENCY MANAGEMENT AGENCY
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500 C Street, SW
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FEMA

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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

Fragility of motor generators

Keith Porter (09/12/2009)

Table 1. Summary results

Fragility, damage measures, and consequences for	
Component category:	D5012.010, motor generator, avg. or unknown conditions D5012.011, motor generator, well anchored, snubbers on isolators, flexibly attached conduit, driver and motor mounted on same skid, no large nearby items that could fall on generator D5012.012, motor generator, 1 deficiency (e.g., no snubbers) D5012.013, motor generator, 2+ deficiencies (e.g., no snubbers + interaction concerns)
Basic composition:	Motor generator set. See Figure 1.
Units:	ea
Number of damage states:	1
If multiple damage states:	□ ordered; □ mutually exclusive; □ simultaneous
Author and date:	Keith Porter 12 Sep 2009
Damage states, fragilities, and consequences for D5012.010, average or unknown conditions. For other conditions, see Table 7.	
	DS1
Description:	Inoperative
Illustration:	Not available
Demand parameter	Peak floor acceleration (geometric mean, g)
Median demand (θ)(1):	1.5g
Data dispersion (β_d)(2)	0.4
Uncertainty (β_u)(2)	
Total dispersion (β)(1):	0.4
Probability(1):	
Correlation:	
Repairs required:	Unknown
Possible consequences:	
Repair cost (Y/N/?):	Y
Death or injury (Y/N/?):	N
Inoperative facility (Y/N/?):	Y
Red tagging (Y/N/?)	N
Comments(2):	

(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." Round θ to 2 significant figures and β to nearest 0.05.
(2) For methods A and B only, provide β_d and β_u and explain in the "comments" row any β_u value that differs from recommendations in Appendix C.

Table 2. Summary supporting information template

Literature summary See Porter et al., ND. Fragility of mechanical, electrical, and plumbing equipment.	
Number of specimens tested:	41 from data set 1 (EPRI + EQE data) 38 with known PMFs from data set 2 (EPRI)
Construction quality:	□ exceeds □ meets □ does not meet requirements of: all available data are for well anchored motor generators
Seismic installation conditions:	varies
Loading protocols applied:	12 earthquakes
Method for observing demand:	Nearby strong-motion instruments
Method for observing damage:	First-hand observations by EQE International (e.g., DL McCormick, Nancy Horstman, Sam Swan, Peter Yanev, etc.) and by the Electric Power Research Institute (EPRI), e.g., Bob Kassawara. The investigators also examined facility engineers' records or interviewed them. Observations made during post-earthquake facility surveys on behalf of EPRI, with the intention of documenting failures *and* non-failures, with installation conditions, etc.

Table 3. Failure data for all motor generators (data set 1: EQE + EPRI data)

r, g	Units, M	Failed, m	$w = M/\Sigma M$	$y = m/M$	Φ
0.21	4	0	0.098	0.000	0.000
0.25	2	0	0.049	0.000	0.000
0.26	11	0	0.268	0.000	0.000
0.27	3	0	0.073	0.000	0.000
0.31	6	0	0.146	0.000	0.000
0.42	3	0	0.073	0.000	0.000
0.44	1	0	0.024	0.000	0.000
0.49	6	0	0.146	0.000	0.000
0.52	3	0	0.073	0.000	0.000
0.59	2	0	0.049	0.000	0.000
Sum	41	0			

Table 4. Failure data for motor generators with 0 installation deficiencies (EPRI data)

r, g	Units, M	Failed, m
0.21	4	0
0.25	2	0
0.26	2	0
0.26	4	0
0.26	2	0
0.26	2	0
0.27	1	0
0.27	2	0
0.31	3	0
0.31	1	0
0.31	2	0
0.42	2	0
0.42	1	0
0.44	1	0
0.49	6	0
0.52	3	0
Sum	38	0

Table 5. 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.	θ: N, β: Y		
Are $0.2 \leq \beta \leq 0.6$? If not discuss.	Y		
Do you believe demand with 10% failure probability?	Y		
Discussion. Prior vulnerability functions are from Johnson et al. (1999), whose θs vary from 0.8 to 2.0; compare with 0.8 to 1.5 here. Discrepancy between the best or average conditions developed here and that of Johnson et al. (1999) is explained by the fact that those developed here use Method C, which postdates Johnson's approach. It is unclear how he derived his fragility functions for this component, perhaps some HCLPF approach. Re believing 10% failure probability, seems reasonable, though a higher median is certainly possible.			

Table 6. Extrapolation to other detailed conditions and to average conditions

Condition (describe)	From tests?	DS1		DS2		DS3	
		θ	β	θ	β	θ	β
Best: anchored; isolators have snubbers; no driver-generator differential displacement concerns, no rigid attachment concerns; no interaction concerns	Y	1.5	0.4				
Moderate: one deficiency, perhaps poorly anchored	N	1.3	0.5				
Worst: 2 or more deficiencies, (isolators w/o snubbers + perhaps piping support concerns)	N	0.8	0.5				
Average or unknown	Y	1.5	0.4				
Do not use fragility functions for PFA > 1.5 times maximum value in the observations. Basis for extrapolation. Data shown above for average and best conditions (basically the same). Values for moderate and worst conditions taken from Johnson et al. (1999). What factors affect θ and β? Those listed under "best" conditions.							

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

Figure 1. Motor generator

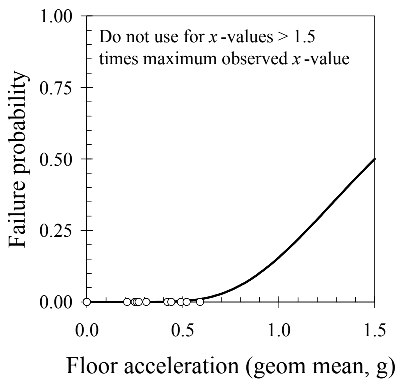

Figure 2. Motor generator fragility, average and 0 deficiencies (anchored; isolators have snubbers; no driver-generator differential displacement concerns; no rigid attachment concerns; no interaction concerns).

REFERENCES CITED

Johnson, G.S., R.E. Sheppard, M.D. Quilici, S.J. Eder, and C.R. Scawthorn, 1999. *Seismic Reliability Assessment of Critical Facilities: A Handbook, Supporting Documentation, and Model Code Provisions, MCEER-99-0008*, Multidisciplinary Center for Earthquake Engineering Research, Buffalo, NY, 384 pp.

Porter, K.A., G. Johnson, R. Sheppard, and R.E. Bachman, ND. Fragility of mechanical, electrical, and plumbing equipment. Submitted to *Earthquake Spectra*.