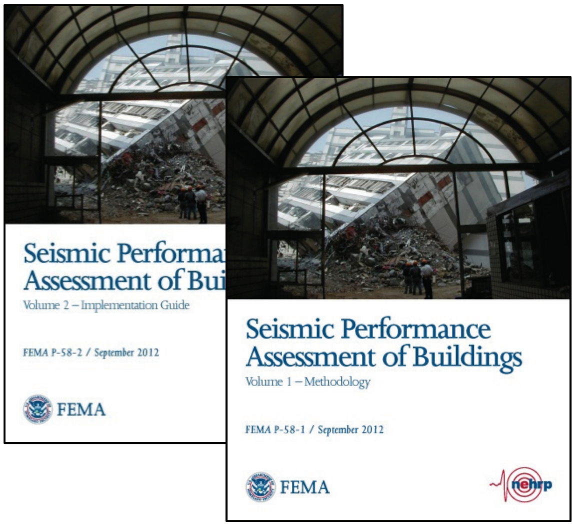

Background Document

FEMA P-58/BD-3.9.17

Fragility of Engine 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
U.S. Department of Homeland Security
500 C Street, SW
Washington, D.C. 20472

October 5, 2009

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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

Keith Porter (10/05/2009)

Table 1. Summary results

Fragility, damage measures, and consequences for	
Component category:	D5092.030, engine generator, avg. or unknown conditions D5092.031, engine 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 D5092.032, engine generator, 1 deficiency (typ. no anchorage) D5092.033, engine generator, 2+ deficiencies (typ. no anchorage + interaction concerns)
Basic composition:	Electrical cabinet. See Figure 1.
Units:	ea
Number of damage states:	1
If multiple damage states:	□ ordered; □ mutually exclusive; □ simultaneous
Author and date:	Keith Porter 5 Oct 2009
Damage states, fragilities, and consequences for D5092.030, 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):	1.6g
Data dispersion (β_d)(2)	0.6
Uncertainty (β_u)(2)	
Total dispersion (β)(1):	0.6
Probability(1):	
Correlation:	
Repairs required:	Repair fracture pipes & damaged nozzles (70%), overhaul because of drive shaft misalignment (10%), minor electrical repair (10%), reconnect exhaust line (10%)
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. EPRI (1991) did not offer GERS data for engine generators	
Number of specimens tested:	157 from data set 1 (EPRI + EQE data) 141 with known PMFs from data set 2 (EPRI)
Construction quality:	□ exceeds □ meets □ does not meet requirements of: varies
Seismic installation conditions:	varies
Loading protocols applied:	13 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 engine generators (data set 1: EQE + EPRI)

r, *g*	Units, *M*	Failed, *m*	*w* =*M*/Σ*M*	*y* = *m*/*M*	Φ
0.12	1	1	0.006	1.000	0.000
0.14	1	0	0.006	0.000	0.000
0.20	24	0	0.153	0.000	0.000
0.23	4	0	0.025	0.000	0.000
0.25	47	4	0.299	0.085	0.000
0.26	1	0	0.006	0.000	0.000
0.30	21	5	0.134	0.238	0.000
0.35	5	0	0.032	0.000	0.000
0.37	3	0	0.019	0.000	0.000
0.40	18	1	0.115	0.056	0.000
0.42	6	2	0.038	0.333	0.000
0.50	5	0	0.032	0.000	0.000
0.55	1	0	0.006	0.000	0.001
0.56	1	0	0.006	0.000	0.001
0.60	18	0	0.115	0.000	0.001
0.85	1	0	0.006	0.000	0.016
Sum	157	13			

Table 4. Failure data for engine generators with 0 installation deficiencies (from EPRI data set)

r, g	Units, M	Failed, m	Comment
0.12	1	1	Broken wire at the terminal connection serving the solenoid valve controlling oil flow to the Woodward governor mounted atop the diesel engine. The technician described the wire connection as having "burst". The wiring was described as old, possibly near failure. The technician could not determine if the wire failure was related to the earthquake vibration within the diesel, to an electrical current surge through the wire, or to a random failure that happened to be noticed at the time of the earthquake. The station manager reported that the diesel is tested about every two weeks and had not previously shown a history of problems.
0.14	1	0	
0.20	3	0	
0.20	17	0	
0.20	4	0	
0.25	13	0	
0.25	3	0	
0.25	15	0	
0.25	14	3	Rod hung piping motion cracked cast steel nozzles
0.26	1	0	
0.30	1	0	
0.30	6	0	
0.30	1	0	
0.30	1	0	
0.37	3	0	
0.40	4	0	
0.40	2	0	
0.40	2	0	
0.40	1	0	
0.40	6	0	
0.42	1	0	
0.50	1	0	
0.50	3	0	
0.50	1	0	
0.60	18	0	
0.85	1	0	
Sum	124	4	

Table 5. Failure data for engine generators with 1 installation deficiency (typ. unanchored, from EPRI data set)

r, g	Units, M	Failed, m	
0.23	4	0	
0.25	1	1	One week after the quake, the diesel burned its outboard pillow block bearing. Damage was attributed to seismically-induced misalignment (units are aligned to .003 inch). Bearing is supported on a different base from the diesel-generator unit.
0.30	8	5	Settlement caused line breaks and shaft misalignments
0.42	1	1	The unit's exhaust line disconnected at its expansion bellows.
0.42	2	1	Failed relay in the adjacent wall-mounted control panel. A maintenance contractor serviced the diesel and replaced the failed relay. The cause of the relay's failure was never discovered. Electrical burnout is considered the most likely source.
0.55	1	0	
Sum	17	8	

Table 6. 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 ≤ *β* ≤ 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 0.2 to 6.8 here. Discrepancy at low end perhaps attributable to Johnson's HCLPF approach, which relies on one data point, vs. method B3 used here. Discrepancy at high end perhaps attributable to Johnson not separating out specimens with no deficiencies, assuming average ≈ best. Re believing 10% failure probability, curve goes through data cloud.			

Table 7. Extrapolation to other detailed conditions and to average conditions

Condition (describe)	From tests?	DS1		J99	
		θ	*β*	θ	*β*
Best: anchored; no isolator concerns; no rigid attachment concerns; no driver-generator differential displacement concerns	Y	6.8	0.6		
Moderate: one deficiency, typ.unanchored	Y	0.31	0.6		
Worst: 2 or more deficiencies	N	0.20	0.6		
Average or unknown	Y	1.2	0.6		
Do not use fragility functions for PFA > 1.5 times maximum value in the observations. Basis for extrapolation. For moderate, average, and best conditions, from data shown above. For worst conditions, take 2/3rd x moderate 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

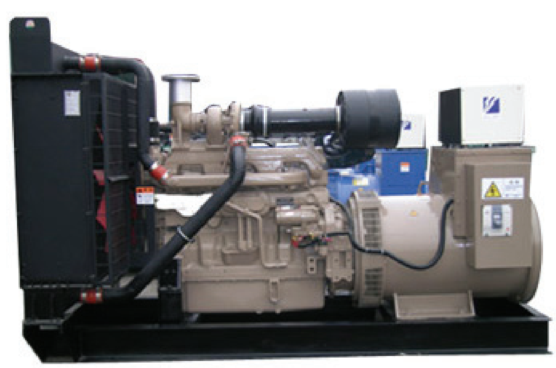

Figure 1. Engine generator

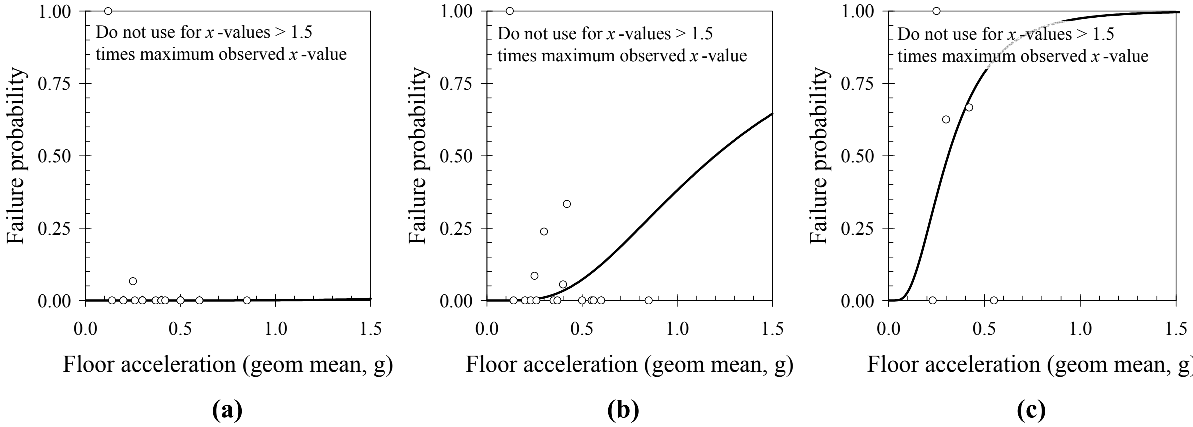

Figure 2. Engine generator fragility: (a) well anchored, snubbers on isolators, flexibly attached conduit, driver and motor mounted on same skid, no large nearby items that could fall on generator, (b) average or unknown conditions, and (c) 1 deficiency, typ. unanchored.

REFERENCES CITED

(EPRI) Electric Power Research Institute, 1991. *Generic Seismic Ruggedness of Power Plant Equipment. EPRI NP-5223-SL Revision 1*. Oakland, CA, 248 pp.

(EPRI) Electric Power Research Institute, 2007. *Seismic Experience Database WWW Version 2.3*. http://www.epriq.com/esqug/

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. Approved Aug 2009 for publication in *Earthquake Spectra*.