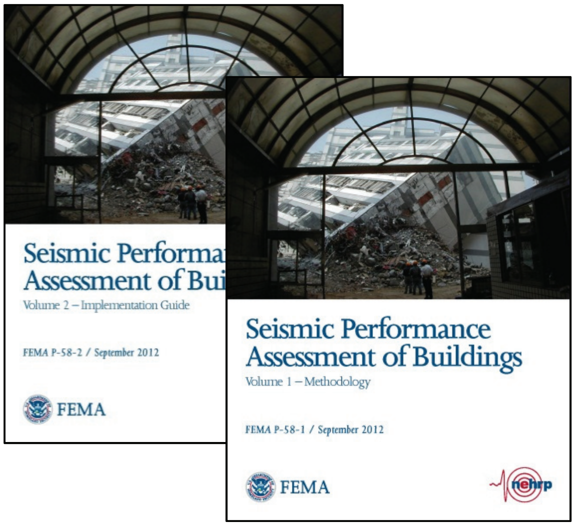


Background Document

FEMA P-58/BD-3.9.25

Fragility of Battery Chargers

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 18, 2009

FEMA

nehrp

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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

Keith Porter (10/18/2009)

Table 1. Summary results

Fragility, damage measures, and consequences for		
Component category:	D5092.021, charger, well installed: solid state, wall- or floor-mounted, in NEMA-type enclosure; well anchored, strong load path D5092.022, charger, deficient installation, typ unanchored	
Basic composition:	Floor- or wall-mounted cabinet; see Figure 1	
Units:	**ea**	
Number of damage states:	**1**	
If multiple damage states:		
Author and date:	Keith Porter 18 Oct 2009	
Damage states, fragilities, and consequences for:		
	D5092.021, Battery chargers, well installed	**D5092.022, Battery chargers, deficient install**
Description:	Damaged, inoperative	Damaged, inoperative
Illustration:	NA	NA
Demand parameter	Peak floor acceleration (geometric mean, g)	Peak floor acceleration (geometric mean, g)
Median demand (θ):	4.1g	1.3g
Data dispersion (β_d):	0.4	0.4
Uncertainty (β_u):		
Total dispersion (β):	0.4	0.4
Probability:		
Correlation:		
Repairs required:	Service for intermittent voltage or replace	Same
Possible consequences:		
Repair cost (Y/N/?):	Y	Y
Death or injury (Y/N/?):	N	N
Inoperative facility (Y/N/?):	Y	Y
Red tagging (Y/N/?)	N	N
Comments:		

Table 2. Summary supporting information template

Literature summary Johnson et al. (1999) present fragility functions for battery chargers under various conditions, based in large part the post-earthquake observations of the seismic performance of MEP equipment in commercial and industrial facilities during 1971-1991. Much of the data is shown in tables in Porter et al. (1993), and also appears in EPRI's eSQUG database (EPRI 2007). See Porter et al. (ND) for discussion of the Johnson et al. (1999) fragility functions. EPRI's eSQUG database (EPRI 2007) includes detail about individual specimens that does not appear in Porter et al. (1993) or Porter et al. (ND), particularly details about installation conditions, component elevation, manufacturer, model number, weight, photographs, etc. EPRI (2007) does not offer fragility functions. ANCO Engineers (EPRI 1991) offers generic equipment ruggedness spectra (GERS) for a number of equipment classes, based on shake-table tests of small numbers of specimens. The purpose of the report is to propose simplified response spectra that a generic piece of equipment can be assumed to survive, if it meets a set of constraints proposed by the author, even if that particular model has not been tested. The GERS generally includes a zero-period acceleration associated with the response spectrum, although there is some concern about using the ZPA. Reason is that the tests were performed using equipment that produced higher-than-natural levels of high frequency motion relative to 5%-damped spectral acceleration response near the resonant frequency of the equipment (denoted here by $S_a(T_1)$, where $T_1 \approx$ 5-15 Hz). Consequently, a capacity based on ZPA will overestimate the capacity in terms of $S_a(T_1)$. To address this problem without throwing out the tests reported in EPRI (1991), the values of ZPA were recalculated, as follows. Each response spectrum shown in EPRI (1991) and used here was interpreted by estimating by eye an approximate average S_a(5-15 Hz), which was then divided by 2.5 to estimate an equivalent "natural" ZPA. A second concern with the GERS data is that it can include only a subset of equipment that fit into the ATC-58 category. For each equipment category, the GERS report sets out checklists of equipment characteristics that a specimen must satisfy to be considered represented by the tests. The GERS criteria can be narrower than the ATC58 criteria. In an October 2009 ATC-58 FRP meeting, Bob Kennedy recommended that the GERS data be used only to check that the medians using the EPRI data are not too high, unless the GERS checklists correspond exactly with the "well installed" conditions to be used for ATC-58. This approach has produced some median capacities that look too low. In this and other fragility specifications, therefore, Kennedy's recommendation is followed with some flexibility, leaving open the possibility of including the GERS data, even if there are more constraints, based generally on 3 questions: a. How significant are the additional constraints in the GERS report, relative to the well-installed conditions? For example, what fraction of the failures in the eSQUG well-installed dataset occurred in specimens that seemed not to meet the GERS constraints? Do the additional constraints seem to be as important in preventing failures as the other conditions for well-installed equipment? b. If the GERS data are not used to create the fragility function, does the well-installed fragility function lie close to the deficient-installation function, and if so does the fragility function with the GERS data look more realistic? c. Do the eSQUG data seem consistent with the GERS tests, e.g., with few if any failures at

low levels of excitation where the GERS data show success at much higher levels?

Where answers to these questions suggest the GERS data can be used, the resulting median capacity is compared with the median calculated without GERS, and the average of the two is then offered. This essentially discounts the GERS data to some extent without ignoring it entirely.

In the case of the present equipment class, for the well-installed equipment (zero deficiencies), EPRI (1991) recommends a "ruggedness level" of 1.3g ZPA. This ruggedness level is defined as "The response to input motion at the base or support point for which equipment of a given class have been demonstrated, on the basis of test experience, to have sufficient ruggedness to perform as required" (EPRI 1991 pg 2-9). Performing as required means the equipment is operable during and after earthquake motion, or else survives the earthquake and operates afterwards, without gross deformation or fracture of its structural elements.

The tests of battery chargers in the GERS report indicated T1 ≈ 8 – 20 Hz. It only included solid-state units with SCR power controls, wall- or floor mounted within NEMA-type enclosure; specified voltage and amperage requirements, well anchored with good load path, heavy components located in the lower half and supported on the base or rear panel; with all door latches or other door fasteners secured. This is more restrictive than the conditions for our zero-deficiency fragility functions, so I examined the effect of removing the tests reported in the GERS report from the fragility function for well installed battery chargers. Doing so reduced the median from 4.0g to 1.6g, because of the lower maximum demand observed. The lower θ seems too low, too similar to the unanchored category whose θ = 1.3g, and very low compare with the GERS ruggedness level of 1.3g. The EPRI (2007) eSQUG data seem fairly consistent with the GERS data, i.e., no failures at low ZPAs to conflict with the successes in the GERS data.

The failure at low excitation in the eSQUG data does not seem to be related to the additional requirements in the GERS dataset. The fragility function for well-installed specimens presented here therefore includes the GERS tests, despite the narrower requirement in the GERS report.

Number of specimens tested:	122: 106 from eSQUG data (EPRI 2007) + 16 from EPRI (1991) GERS test data
Construction quality:	□ exceeds □ meets □ does not meet requirements of: <u>varies</u>
Seismic installation conditions:	varies
Loading protocols applied:	18 earthquakes
Method for observing demand:	Nearby strong-motion instruments for data set
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 of battery chargers with no deficiencies

r, g	Units, M	Failed, m	
0.20	2	0	EPRI (2007) data UNO
0.20	5	0	
0.20	2	0	
0.20	2	0	
0.24	6	0	
0.26	1	0	
0.26	2	0	
0.26	1	0	
0.26	6	0	
0.26	2	0	
0.27	1	0	
0.31	1	0	
0.31	6	0	
0.31	4	0	
0.33	3	0	
0.36	3	0	
0.36	1	0	
0.36	8	0	Blown fuses in one specimen. A loose sail switch that served the internal fan had come loose and apparently during the earthquake this loose item of metal shifted onto the capacitors, creating a short circuit. Site technicians suspected that the sail switch had come loose prior to the earthquake. Fuse replacement is too minor to consider a failure here.
0.41	4	0	
0.41	2	0	
0.41	2	0	
0.41	4	0	
0.43	2	0	
0.51	3	0	
0.51	3	0	
0.51	2	0	
0.51	1	0	
0.57	2	0	
0.87	3	0	
1.3	1	0	EPRI 1991 pg C-22 (GERS data): S_a(8-20 Hz) ≈
1.4	3	0	Ditto
1.9	2	0	Ditto
2.0	3	0	Ditto; one specimen with tripped breaker or post-test surge suppressor blown
2.1	1	0	Ditto
2.6	4	1	Ditto; one specimen with intermittent voltage output. Note that the fragility function is virtually unchanged whether this failure is included, using method B3, or excluded, using method C.
2.9	2	0	Ditto; one specimen with blown fuse
Sum	100	1	

Table 4. Failure data of battery chargers with deficient installation

r, g	Units, M	Failed, m	
0.20	2	0	EPRI (2007) UNO
0.20	2	0	
0.20	2	0	

0.26	1	0	
0.26	2	0	
0.26	2	0	
0.26	2	0	
0.31	1	0	
0.41	2	1	Pulled expansion bolts anchoring the corners of base channels to the concrete pads. The bolts appeared to have inadequate distance to the edge of the supporting pads, since concrete fractured at the pad corners as the expansion bolts pulled out. For ATC-58, this failure is ignored, to be treated using anchorage fragility.
0.43	2	0	
0.51	1	0	
0.61	3	0	
Sum	22	1	

Table 5. Quality tests

Quality test	D5092.021	D5092.022
Passes Lilliefors goodness of fit test? (Type A only)	NA	NA
Are θ and β within 20% of past results? If not discuss.	NA	θ: Y, β: Y
Are $0.2 \leq \beta \leq 0.6$? If not discuss.	Y	Y
Do you believe the demand with 10% failure probability?	Y	Y
Discussion. Prior vulnerability functions for equipment with installation deficiencies are from Johnson et al. (1999), whose θs ~ 0.9 to 1.9. Compare with θ = 1.3 here. Re believing 10% failure probability, yes.		

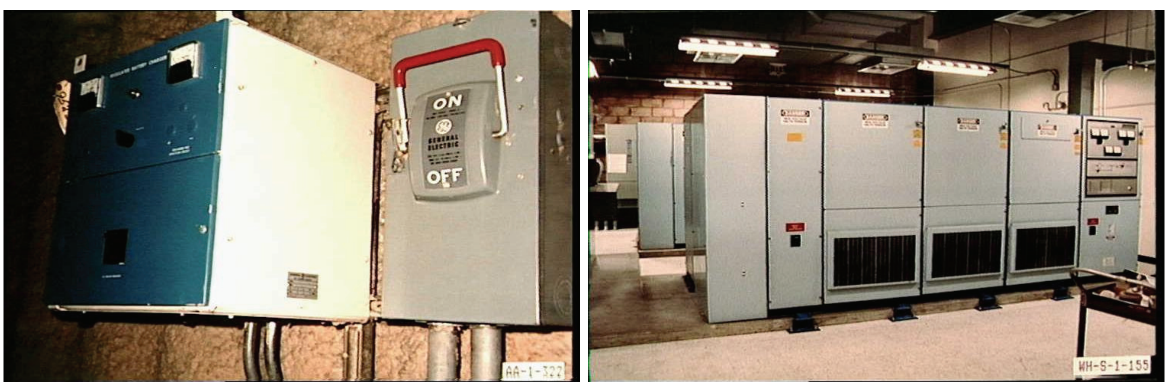
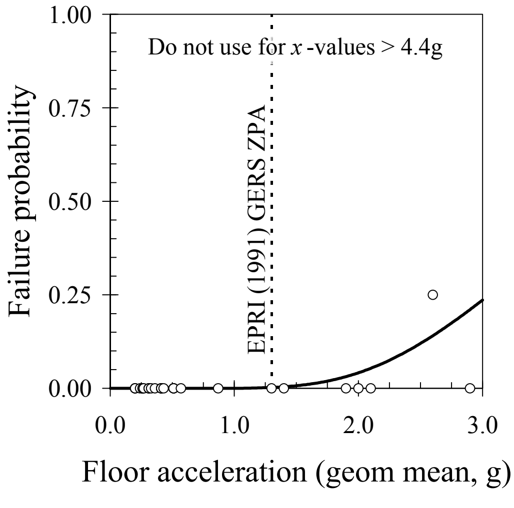


Figure 1. Battery chargers (EPRI 2007)



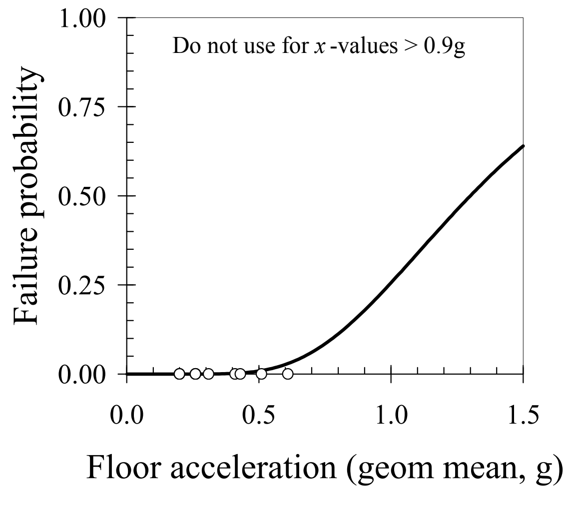


Figure 2. Battery chargers (a) well anchored, strong load path, no nearby large items that could fall on the charger, (b) with deficient installation, typically either unanchored or poorly anchored.

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*.

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. Accepted for publication by *Earthquake Spectra*.