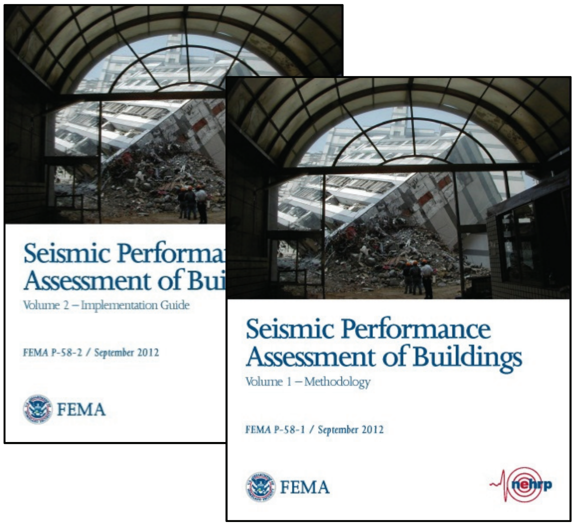

Background Document

FEMA P-58/BD-3.9.19

Fragility of Motor Control Centers

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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

Keith Porter (10/05/2009)

Table 1. Summary results

Fragility, damage measures, and consequences	
Component category:	D5010.010 Motor control center, avg or unknown conditions D5010.011 Motor control center, equipment well anchored to floor, strong continuous load path from components to floor, adjacent cabinets are attached to each other or are more than ½ inch apart, no nearby large items can fall and impact MCC D5010.012, Motor control center, installation inspected but not tested, one deficiency (typ. unanchored or poorly anchored) D5010.013, Motor control center, installation inspected but not tested, 2+ deficiencies
Basic composition:	Metal cabinet or assembly of cabinets bolted together; Fig 1
Units:	**ea**
Number of damage states:	**1**
If multiple damage states:	□ ordered; □ mutually exclusive; □ simultaneous
Author and date:	Keith Porter 05 Oct 2009
Damage states, fragilities, and consequences for D5010.010, average or unknown conditions. For other conditions see Table 7.	
	DS1
Description:	Damaged, inoperative
Illustration:	NA
Demand parameter	Peak floor acceleration (geometric mean, g)
Median demand (θ)(1):	1.8
Data dispersion (β_d)(2)	0.6
Uncertainty (β_u)(2)	
Total dispersion (β)(1):	0.6
Probability(1):	
Correlation:	
Repairs required:	Typically, upright and anchor or re-anchor
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 MEP equipment. EPRI (1991) offers data on 15 specimens and recommends a GERS ZPA = 1.0g. Several of these had relay chatter, contact chatter, and other minor damage modes that are ignored here.	
Number of specimens tested:	Avg condition: 283 from data set 1 (EQE set) Known deficiencies: 216 from data set 2 (EPRI 2007) Tested anchorage conditions: approximately 24 from data set 3: seismic qualification tests from 3 manufacturers GERS data: 15 tests (EPRI 1991)
Construction quality:	□ exceeds □ meets □ does not meet requirements of: varies
Seismic installation conditions:	varies
Loading protocols applied:	12 earthquakes (data sets 1 & 2), unknown shake-table excitation (data set 3)
Method for observing demand:	Nearby strong-motion instruments (data sets 1 & 2), shake-table instruments (data set 3)
Method for observing damage:	Data sets 1 & 2: 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 all specimens (data set 1: EQE + EPRI)

r, g	Units, *M*	Failed, *m*	$w = M/\Sigma M$	$y = m/M$	Φ
0.24	37	0	0.131	0.000	0.000
0.27	5	0	0.018	0.000	0.001
0.30	68	2	0.240	0.029	0.001
0.31	6	0	0.021	0.000	0.001
0.35	49	0	0.173	0.000	0.003
0.38	9	0	0.032	0.000	0.004
0.41	12	0	0.042	0.000	0.006
0.44	3	0	0.011	0.000	0.008
0.47	35	0	0.124	0.000	0.012
0.50	11	0	0.039	0.000	0.014
0.56	10	2	0.035	0.200	0.023
0.59	19	1	0.067	0.053	0.029
0.66	4	0	0.014	0.000	0.044
0.71	15	0	0.053	0.000	0.056
Sum	283	5			

Table 4. Failure data of specimens with no deficiencies (data set 2, EPRI 2007, + data set 3, qualification tests, + EPRI 1991 GERS report tests)

r, g	Units	Failed	Comment
0.24	2	0	NIST (2007) UNO
0.24	1	0	
0.24	5	0	
0.24	1	0	
0.24	1	0	

0.24	1	0	
0.24	2	0	
0.24	1	0	
0.24	6	0	
0.24	1	0	
0.24	1	0	
0.24	1	0	
0.24	1	0	
0.24	1	0	
0.24	1	0	
0.24	1	0	
0.24	1	0	
0.30	1	0	
0.30	12	6	Three of 12 MCC assemblies pulled their anchorage and overturned. *These failures are ignored here*. Some remaining MCCs were also damaged. Deformation of the cabinet framing in the longitudinal direction sheared the 1/4-inch screws that attach the sheet metal panels to the rear of the MCC. Shear deformation wedged some of the removable motor controller cubicles (buckets) into their enclosures. Deformation of the MCC framing buckled the sheet metal cubicles of some motor controllers. In a few cases buckling of the motor controller cubicles cracked the insulated casings of internal components such as contactors. The end sections of the MCCs contain a stack of 480V circuit breakers. Cracking of internal components was also found in this end section in 6 out of 12 MCCs. In the busbar in the rear of the switchgear section, small cracks were found in fiberglass insulators that hold the vertical busbars in position. The cracks were discovered after the MCCs had been replaced and were undergoing startup testing.
0.30	2	0	
0.30	1	0	
0.30	5	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	2	0	
0.30	4	0	
0.30	2	0	
0.30	2	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	2	0	
0.31	1	0	
0.31	1	0	
0.31	1	0	
0.31	1	0	
0.31	1	0	
0.31	1	0	
0.35	1	0	
0.35	1	0	
0.35	1	0	
0.35	1	0	
0.35	2	0	
0.35	2	0	
0.35	1	0	

0.35	1	0	
0.38	4	0	
0.38	2	0	
0.41	5	0	
0.41	4	0	
0.41	12	0	
0.41	1	0	
0.44	1	0	
0.47	1	0	
0.47	2	0	
0.47	2	0	
0.47	2	0	
0.47	4	0	
0.47	1	0	
0.47	1	0	
0.47	1	0	
0.47	1	0	
0.47	1	0	
0.47	1	0	
0.47	1	0	
0.47	1	0	
0.47	1	0	
0.50	1	0	
0.50	1	0	
0.50	1	0	
0.50	1	0	
0.50	1	0	
0.50	1	0	
0.50	1	0	
0.55	1	0	
0.55	4	0	
0.59	1	0	
0.59	1	0	
0.59	2	0	
0.59	6	0	
0.59	7	0	
0.59	5	0	
0.59	2	0	
0.59	1	0	
0.66	2	0	
0.66	2	0	
0.71	1	0	
0.24	2	0	
1.7	8	0	Qualification tests
2.0	8	0	Qualification tests
2.4	8	0	Qualification tests
0.50	1	0	EPRI (1991) non-failure data
0.80	1	0	Ditto
1.00	1	0	Ditto
1.10	1	0	Ditto
1.40	1	0	Ditto
1.70	1	0	Ditto
1.75	1	0	Ditto
2.80	1	0	Ditto
0.75	1	0	EPRI (1991) failure data: de-energized; chatter, but this failure ignored
1.50	1	0	Ditto: chatter

1.60	1	0	Ditto, auxiliary contact chatter
2.00	1	0	Ditto, chatter, deenergized, internal mounting bolt failure
2.30	1	0	Ditto, auxiliary contact chatter
3.20	1	0	Ditto, minor structural damage
4.00	1	0	Ditto, chatter
Sum	219	6	

Table 5. Failure data of specimens with 1 deficiency, typ. unanchored or poorly anchored (data set 2, EPRI)

***r*, g**	**Units**	**Failed**	**Comment**
0.30	1	0	
0.30	1	0	
0.30	6	1	MCC overturned, striking 2400-volt switchgear across the walkway. Overturned MCC was eventually uprighted and finding no serious damage, restored to operation.
0.35	2	0	
0.35	6	0	
0.35	2	0	
0.41	2	0	
0.41	1	0	
0.41	1	0	
0.41	1	0	
0.41	1	0	
0.41	1	0	
0.44	1	0	
0.47	1	0	
0.47	1	0	
0.47	2	0	
0.55	1	1	Unanchored MCC overturned against a steel conveyor rack located across the aisle way. The toppled MCC was later uprighted and restrained at top with steel cables into the ceiling rafters. Repairs were not required to the motor controllers.
0.55	1	1	Sprayed by a ruptured overhead fire line. Soaked cabinet was dried & reenergized.
0.59	1	0	
0.71	1	0	
0.71	2	0	
Sum	36	3	

Table 6. Quality tests

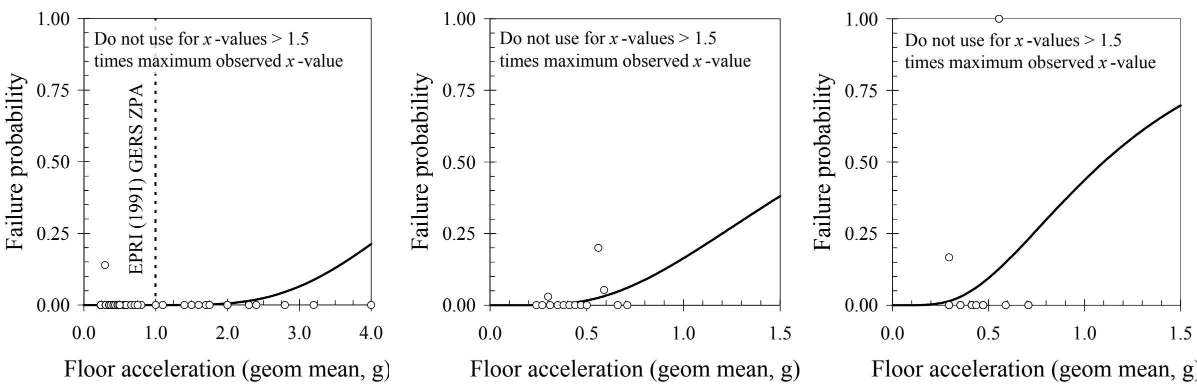
Quality test	**DS1**	**DS2**	**DS3**
Passes Lilliefors goodness of fit test? (Type A only)	NA		
Are θ and β within 20% of past results? If not discuss.	θ: Y, β: ~Y		
Are $0.2 \le \beta \le 0.6$? If not discuss.	Y		
Do you believe demand with 10% failure probability?	Y		
Discussion. Past results: Johnson et al. (1999), with θ shown below. Re believing 10% failure probability, yes, though hard to say. Curve seems to go through the cloud, and some of the data have 5-20% failure rate, but 10th percentile on curve has higher demand than the data.			

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

Condition (describe)	**From tests?**	**DS1**		**J99***	
		θ	***β***	**θ**	***β***
Best: equipment well anchored to floor, strong continuous load path from components to floor, adjacent cabinets are attached to each other or are more than ½ inch apart, no nearby large items can fall and impact MCC. Used	Y	5.5	0.4		

Method C.					
Moderate: 1 deficiency, typ poor anchorage or unanchored	Y	1.1	0.6	0.8-0.9	0.5
Worst: 2 or more deficiencies: poor anchorage and interaction?	N	0.7	0.6	0.8	0.5
Average or unknown	Y	1.8	0.6	1.5	0.4
*J99: Johnson et al. (1999), for comparison. *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, 2/3rd x moderate. What factors affect θ and β? See "best" conditions.					

Figure 1. Motor control center (EPRI)



(a) (b) (c)

Figure 2. Motor control center seismic fragility: (a) no deficiencies, (b) average, (c) 1 deficiency. Solid line is fit to the individual data points (circles). Triangles show the overall failure rate at the weighted excitation. Dashed line is fit to the overall failure rate and $\beta = 0.4$

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