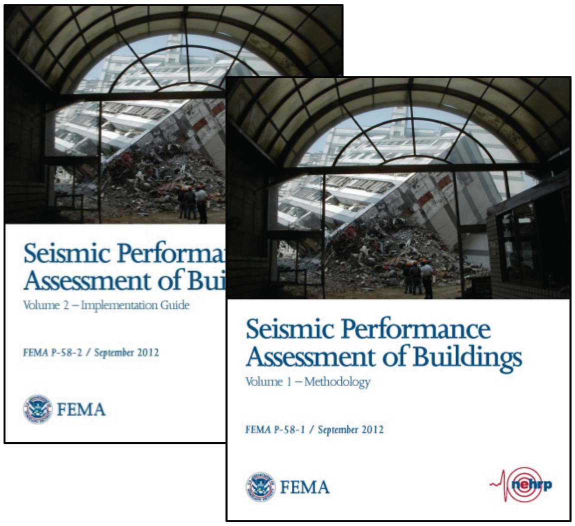

Background Document

FEMA P-58/BD-3.9.24

Fragility of Transformers

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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

Keith Porter (09/12/2009)

Table 1. Summary results

Fragility, damage measures, and consequences for	
Component category:	D5011.010 Transformer, unknown installation D5011.011 Transformer, well anchored, cabinets within ½ inch are bolted together, strong load path to floor, no large nearby items that could fall on generator, internal coils firmly restrained D5011.012 Transformer unanchored but restrained by adjacent equipment D5011.013 Transformer, 1 deficiency (typ unanchored)
Basic composition:	Varies; see Figure 1
Units:	ea
Number of damage states:	1
If multiple damage states:	□ ordered; □ mutually exclusive; □ simultaneous
Author and date:	K Porter 05 Oct 2009
Damage states, fragilities, and consequences for D5011.010, average or unknown installation conditions. For other conditions see Table 7.	
	DS1
Description:	Inoperative
Illustration:	
Demand parameter	Peak floor acceleration (geometric mean, g)
Median demand (θ)[(1)]:	1.3g
Data dispersion (β_d)[(2)]	0.6
Uncertainty (β_u)[(2)]	(none added)
Total dispersion (β)[(1)]:	0.6
Probability[(1)]:	
Correlation:	
Repairs required:	Typically, service and reinstall existing transformer
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). EPRI (1991) offers tests of 4 specimen and recommends GERS ZPA = 1.5g for dry-type transformers of 7.5 to 225 kVA with single-phase or 3-phase ratings at 120/480 VAC, either floor-mounted or wall-mounted.	
Number of specimens tested:	245; see Porter et al. (ND)
Construction quality:	☐ exceeds ☐ meets ☐ does not meet requirements of: varies
Seismic installation conditions:	Varies. Some pad-mounted, some small units on top of switchgear or pole-mounted. Of 245 specimens, 169 had known anchorage conditions: 100 anchored, 69 unanchored, from EPRI (2007). In many cases transformer is installed between anchored switchgear, so even if the transformer itself is unanchored or its anchorage is unknown it is restrained.
Loading protocols applied:	18 earthquakes at 46 sites, mostly industrial facilities
Method for observing demand:	Nearby strong-motion instruments.
Method for observing damage:	Combination of: interviews with facility operators, examination of facility records, & 1st-hand observations by engineers of EQE International, EPRI, or both.

Table 3. Failure data for all transformers (data set 1: EQE + EPRI 2007); data type B

r, g	**Units, *M***	**Failed, *m***	$w = M/\Sigma M$	$y = m/M$	**Φ**
0.20	22	0	0.090	0.000	0.001
0.23	1	0	0.004	0.000	0.002
0.24	7	0	0.029	0.000	0.002
0.25	57	2	0.233	0.035	0.002
0.26	12	0	0.049	0.000	0.003
0.30	42	0	0.171	0.000	0.006
0.35	3	0	0.012	0.000	0.012
0.37	4	0	0.016	0.000	0.016
0.40	57	1	0.233	0.018	0.021
0.42	14	0	0.057	0.000	0.026
0.47	9	1	0.037	0.111	0.039
0.50	6	0	0.024	0.000	0.049
0.56	2	0	0.008	0.000	0.071
0.60	7	1	0.029	0.143	0.088
0.64	2	0	0.008	0.000	0.107
Sum	245	5			

Table 4. Performance of anchored transformers (0 installation deficiencies; data set 2: EPRI 2007)

r, g	Units, M	Failed, m	Comment
0.20	1	0	EPRI (2007) UNO
0.20	2	0	
0.20	3	0	
0.20	3	0	
0.20	1	0	
0.20	1	0	
0.20	1	0	
0.20	2	0	
0.20	1	0	
0.24	1	0	
0.24	1	0	
0.24	1	0	
0.25	1	0	
0.25	1	0	
0.25	1	0	
0.25	1	0	
0.25	1	0	
0.25	20	0	
0.26	1	0	
0.26	2	0	
0.26	3	0	
0.26	2	0	
0.26	2	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	1	0	
0.30	2	0	
0.35	1	0	
0.37	1	0	
0.40	4	0	
0.40	1	0	
0.40	4	0	
0.40	1	0	
0.40	1	0	
0.40	1	0	
0.40	1	0	
0.40	1	0	
0.40	2	0	
0.40	1	0	
0.40	1	0	
0.42	1	0	
0.42	1	0	
0.42	3	0	
0.42	2	0	
0.42	2	0	
0.42	1	0	
0.47	1	0	
0.47	2	0	
0.47	2	0	
0.50	1	0	
0.56	1	0	
0.56	1	0	
0.60	1	0	
0.60	1	1	The anchorage failed at the clip welds to the transformer casing. Unit shifted about 3 inches, fracturing conduit at the base of the transformer. The transformer initially remained operational following restoration of power to the site. However, several months after the earthquake, a ground fault developed in the unit during the winter rains, apparently due to damage to cables in the fractured conduit. Failure ignored for ATC-58, to be treated separately.
0.60	1	0	

3.2	3	0	Schneider Electric 600V and below seismic qualification certificate
1.7	3	0	Eaton Cutler-Hammer Dry-Type Distribution Transformers – EP, EPT, DS-3, DT-3 seis qual cert
1.0	3	0	GE Consumer & Industrial Electrical Distribution QB, IP and QMS Series Transformers seis qual cert
0.2	2	0	EPRI (1991)
1.0	1	0	Ditto
1.7	1	1	Ditto. Coil layer spacers came out and coil support anchor broke away from the support bracket. The support was repaired and the transformer qualified for lower input motion level
Sum	113	2	

Table 5. Performance of unanchored transformers (data set 2: EPRI 2007); data type B

r, g	Units, M	Failed, m	Comment
0.25	3	0	
0.25	1	0	
0.25	1	0	
0.25	1	0	
0.25	1	0	
0.25	1	0	
0.25	2	1	Transformer dismounted from its concrete pedestal. Another, identical transformer remained in place. The toppled transformer was not seriously damaged and was restored to operation.
0.25	20	1	Ground fault, caused by paper insulation, help in place only by friction, slipped from between a live and a grounded bus connection.
0.26	2	0	
0.30	1	0	
0.30	2	0	
0.35	1	0	
0.40	3	0	
0.40	1	0	
0.40	1	0	
0.40	20	0	
0.42	2	0	
0.47	3	2	Two of three shifted off one side of the platform but were restrained from toppling to the ground by the steel truss bracing in the enclosing transmission tower. Units were uprighted after the earthquakes and restored to service.
0.47	1	0	
0.60	1	0	
0.60	1	0	
Sum	69	4	

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.	~Y		
Are $0.2 \le \beta \le 0.6$? If not discuss.	Y		
Do you believe the demand with 10% failure probability?	Y		
Discussion. θ ≈ 0.8 x that of Johnson et al. (1999) but $\beta \approx 1.5$ x Johnson et al.'s. Re believing 10^{th} percentile, yes; the curve seems to run through the cloud okay. See Figure 2b			

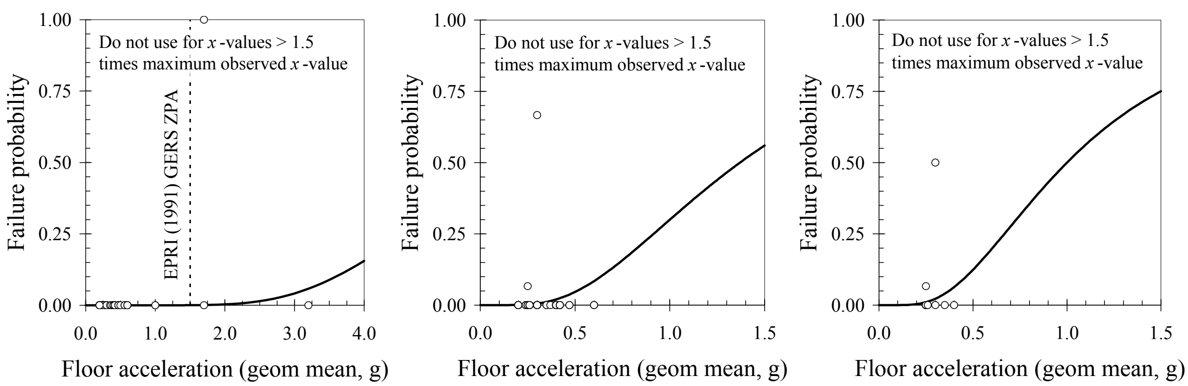
Table 7. Extrapolation to other detailed conditions and to average conditions

Condition (describe)	From tests?	Points		J99	
		θ	*β*	θ	*β*
Best: anchored	~Y	6.0	0.4		
Moderate: unanchored but restrained by attached, anchored equipment e.g., switchgear	N	1.3	0.6		
Worst: unanchored	Y	1.0	0.6		
Average or unknown	Y	1.3	0.6		

Do not use fragility functions for PFA > 1.5 times maximum value in the observations.
Basis for extrapolation. What factors affect θ and *β*?

- Median θ seems affected by anchorage, restraint from attached components (conduit, switchgear), and internal deficiencies such as the paper insulators without positive connection to conductor.
- *β* probably affected by the diversity of transformers and installation conditions.

Figure 1. Some varieties of transformer: (a) 100 lb, 480/120V column-mounted, (b) 2400/480V transformers and attached switchgear



(a) (b) (c)

Figure 2. Fragility of transformers: (a) anchored, (a) average or unknown conditions, and (c) unanchored

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