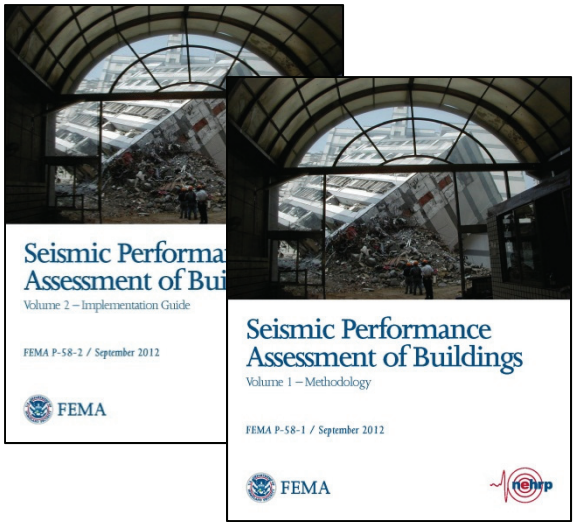

Background Document

FEMA P-58/BD-3.9.21

Fragility of Air Handling Units

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Submitted to

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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

Keith Porter (10/05/2009)

Table 1. Summary results

Fragility, damage measures, and consequences for		
Component category:	D3063.011 AHU with good installation: well anchored, restraints on isolators, well supported attached ducting w flexible bellows connection, no rigidly attached pipe, no large nearby items that could fall & impact AHU, no other impact concerns D3063.012, AHU with deficient installation: unanchored, or on isolators without sufficient seismic restraint, or with unsupported attached ducting without flexible bellows connections	
Basic composition:	Packaged air handling unit. See Figure 1.	
Units:	**ea**	
Number of damage states:	**1**	
If multiple damage states:	simultaneous	
Author and date:	Keith Porter 11 Oct 2009	
Damage states, fragilities, and consequences for		
	D3053.011, AHU with good installation	D3063.012, AHU with deficient installation
Description:	Broken attached piping or duct	Broken attached piping or duct
Illustration:	N/A	Figure 2
Demand parameter	Peak floor acceleration (geom mean, g)	Peak floor acceleration (geom mean, g)
Median demand (θ):	2.9	1.5
Data dispersion (β_d):	0.6	0.6
Uncertainty (β_u):		
Total dispersion (β):	0.6	0.6
Probability:		
Correlation:		
Repairs required:	Repair piping or duct	Repair piping or duct
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:	Max observed PFA ≈ 0.9g, so do not use for PFA > 1.4g	Max observed PFA ≈ 0.8g, so do not use for PFA > 1.2g

Table 2. Summary supporting information template

Literature summary. See Porter et al., ND. Fragility of mechanical, electrical, and plumbing equipment. EPRI (1991) has no GERS information related to air handling units.	
Number of specimens tested:	96 with known PMFs (EPRI 2007)
Construction quality:	□ exceeds □ meets □ does not meet requirements of: varies
Seismic installation conditions:	varies
Loading protocols applied:	7 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 specimens without installation deficiencies

r, g	Units, M	Failed, m	Comment
0.39	4	0	
0.46	1	0	
0.57	3	0	
0.62	2	0	
0.62	1	0	
0.65	2	0	
0.87	2	0	
0.93	6	0	
Sum	21	0	

Table 4. Failure data for specimens with installation deficiencies

r, g	Units, M	Failed, m	Comment
0.31	3	1	A threaded water line within the air handler was reported to have cracked at its attachment to one of the water coils. The most likely cause appears to have been insufficient flexibility in the water line to accommodate displacement between the spring-mounted air handler and the relatively inflexible water lines exterior to the assembly.
0.39	3	0	
0.62	2	0	
0.62	4	1	PVC cooling water line developed a leak at an elbow over one air handler. Overstress in the PVC line may have been aggravated by bouncing of the air handler on its spring mounts.
0.62	6	6	The air conditioner units shifted several inches, exposing the duct penetrations, allowing water intrusion in the rainstorm three days after the earthquake. Conduit attached to the units pulled apart due to the imposed displacement. The attached gas lines yielded with shifting of the unit. It was not apparent whether the gas lines had been breached, since the gas had been turned off and the units had not been repositioned or tested at the time of the site visit.
0.62	4	4	Sheet metal ducting was reported to have pulled apart at several seams near the

			air handlers; this may have been aggravated by rocking of the air handlers on their isolation mounts. The insulated PVC water lines serving the air handlers were reported to have fractured in four different locations on the roof. The cause of fracture (repaired at the time of the site visit) was not apparent, although shifting of the air handlers on their spring mounts may have been a factor. The air handlers themselves were reported as undamaged.
0.62	1	0	
0.65	2	2	Rocking of the rod-hung air handler during the earthquake caused a small tap valve on the attached water line to impact a concrete beam in the ceiling. The impact snapped off the tap, resulting in a water leak from the insulated line.
0.78	54	0	The AHU anchorage, which consisted of vibration isolators, were damaged during the earthquake. The shaking caused most of the AHUs to fall from their supports. In some cases, the AHUs shifted enough to dislodge attached piping and ducts. These failures are ignored for present purposes and their fragility reflected in a separate isolator fragility function.
Sum	79	14	

Table 5. Quality tests

Quality test	
Passes Lilliefors goodness of fit test? (Type A only)	NA
Are θ and β within 20% of past results? If not discuss.	NA
Are $0.2 \leq \beta \leq 0.6$? If not discuss.	Y
Do you believe the demand with 10% failure probability?	Y
Discussion. Johnson et al. (1999) propose θs between 0.6 and 1.9 (vs. 1.5 and 2.9 here), but are not directly comparable. J99 includes isolator overturning, and does not offer a zero-deficiency fragility function. Re believing 10% failure probability, yes. In the 1+ deficiency group there are several data points near the curve where it reaches 10% failure probability.	

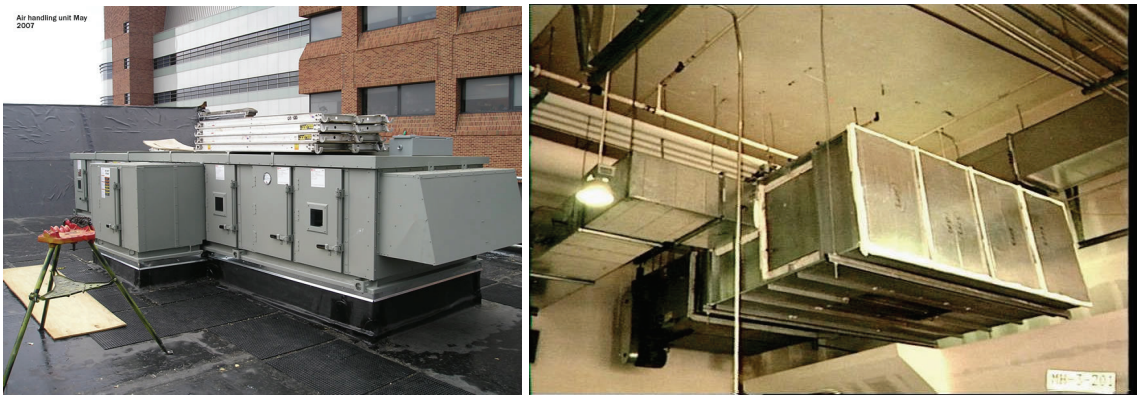

Figure 1. Roof mounted and rod hung air handling units

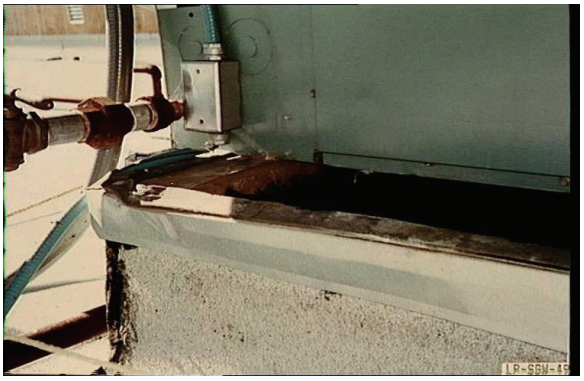

Figure 2. AHU shifted from duct (EPRI 2007)

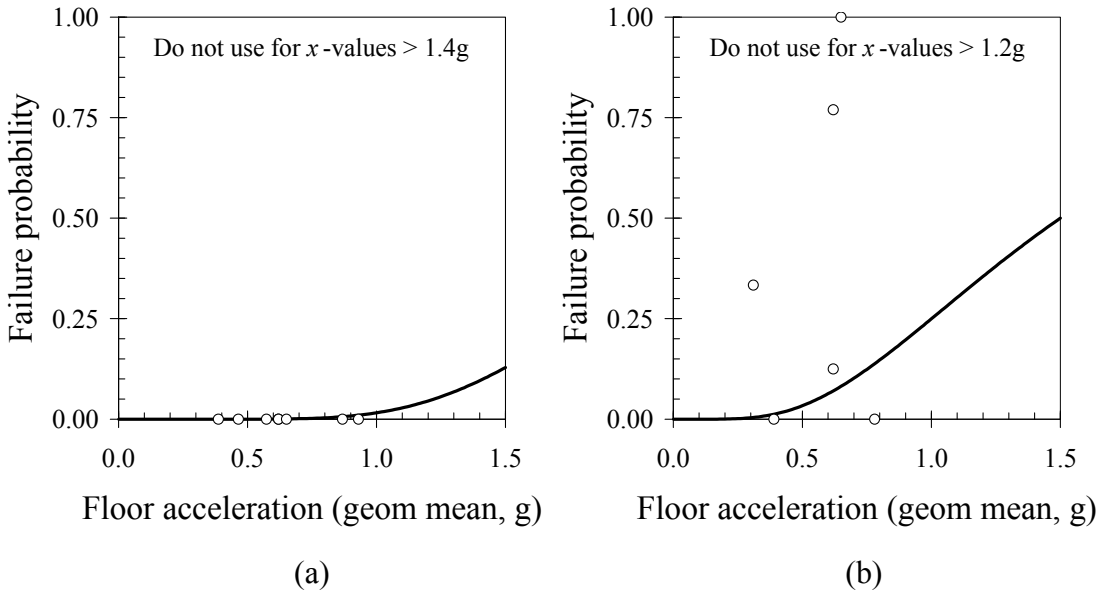

Figure 3. Air handling unit fragility (a) well anchored, restraints on isolators, well supported attached ducting w flexible bellows connection, no rigidly attached pipe, no large nearby items that could fall & impact AHU, no other impact concerns (b) 1 or more installation deficiency. Failures exclude anchorage pullout and isolators overturning. They *do* include breakage of attached piping because of excessive motion that did not result from isolators overturning.

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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.

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