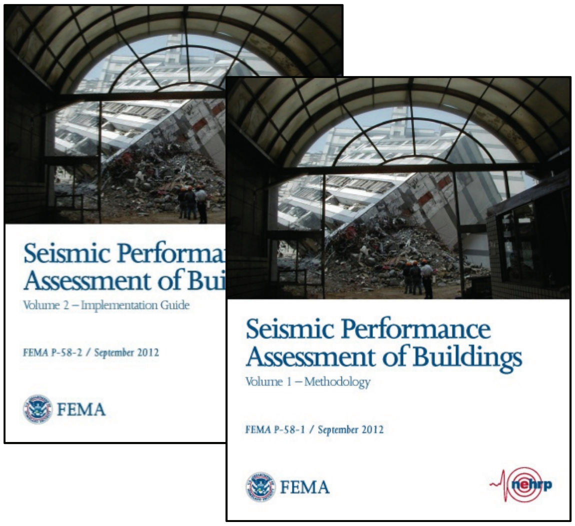



# Background Document

## FEMA P-58/BD-3.9.22

# Fragility of Fans

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

September 12, 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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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.



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 fans

**Keith Porter (09/12/2009)**

**Table 1. Summary results**

| **Fragility, damage measures, and consequences for** | |
|---|---|
| Component category: | D3041.010, Fan, average or unknown conditions<br>D3041.011, Fan, well anchored, vibration isolators have snubbers, motor and fan anchored to same pad or skid, attached ducting is supported, bellows supported on both sides, flexible connection between fan and duct, no large nearby nonstructural components that could fall on fan<br>D3041.012, Fan, one deficiency, typ. vibration isolators without seismic restraint or motor and fan are anchored to different pad or skid<br>D3041.013, Fan, 2+ deficiencies, typ. rigid attachment between fan and duct and either vibration isolators without seismic restraint or motor and fan are anchored to different pad or skid |
| Basic composition: | Fan inside ductwork and attached drive motor. See Figure 1 |
| Units: | **ea** |
| Number of damage states: | **1** |
| If multiple damage states: | □ ordered; □ mutually exclusive; □ simultaneous |
| Author and date: | Keith Porter 12 Sep 2009 |
| **Damage states, fragilities, and consequences for D3041.010, average or unknown installation 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): | 1.4 |
| Data dispersion ($\beta_d$)(2) | 0.6 |
| Uncertainty ($\beta_u$)(2) | |
| Total dispersion ($\beta$)(1): | 0.6 |
| Probability(1): | |
| Correlation: | |
| Repairs required: | Typ. remount fan on isolators, add snubbers |
| 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 $\theta$ to 2 significant figures and $\beta$ to nearest 0.05.
(2) For methods A and B only, provide $\beta_d$ and $\beta_u$ and explain in the "comments" row any $\beta_u$ value that differs from recommendations in Appendix C.

**Table 2. Summary supporting information template**

| Literature summary<br>See Porter et al., ND. Fragility of mechanical, electrical, and plumbing equipment. | |
|---|---|
| Number of specimens tested: | Avg condition: 402 from data set 1 (broader EQE data set)<br>Known deficiencies: 154 from data set 2 (EPRI database) |
| Construction quality: | ☐ exceeds ☐ meets ☐ does not meet requirements of:<br>varies |
| Seismic installation conditions: | varies |
| Loading protocols applied: | 16 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 of all specimens (data set 1: EQE + EPRI)**

| *r, g* | Units, *M* | Failed, *m* | *w* =*M*/Σ*M* | *y* = *m*/*M* | Φ |
|---|---|---|---|---|---|
| 0.35 | 58 | 8 | 0.144 | 0.138 | 0.000 |
| 0.42 | 5 | 0 | 0.012 | 0.000 | 0.000 |
| 0.44 | 64 | 5 | 0.159 | 0.078 | 0.000 |
| 0.46 | 26 | 0 | 0.065 | 0.000 | 0.000 |
| 0.53 | 112 | 0 | 0.279 | 0.000 | 0.000 |
| 0.56 | 4 | 0 | 0.010 | 0.000 | 0.001 |
| 0.61 | 6 | 3 | 0.015 | 0.500 | 0.002 |
| 0.65 | 2 | 0 | 0.005 | 0.000 | 0.002 |
| 0.70 | 40 | 20 | 0.100 | 0.500 | 0.004 |
| 0.74 | 30 | 4 | 0.075 | 0.133 | 0.006 |
| 0.82 | 6 | 0 | 0.015 | 0.000 | 0.013 |
| 0.88 | 21 | 4 | 0.052 | 0.190 | 0.020 |
| 1.05 | 23 | 3 | 0.057 | 0.130 | 0.054 |
| 1.12 | 5 | 0 | 0.012 | 0.000 | 0.074 |
| Sum | 402 | 47 | | | |

**Table 4. Failure data of specimens with no deficiencies (data set 2, EPRI)**

| r, g | Units | Failed | Comment |
|---|---|---|---|
| 0.35 | 5 | 0 | |
| 0.35 | 2 | 0 | |
| 0.35 | 1 | 0 | |
| 0.35 | 12 | 0 | |
| 0.42 | 2 | 0 | |
| 0.44 | 1 | 0 | |
| 0.44 | 5 | 0 | |
| 0.44 | 2 | 0 | |
| 0.45 | 2 | 0 | |
| 0.45 | 2 | 0 | |
| 0.53 | 1 | 0 | |
| 0.53 | 1 | 0 | |
| 0.53 | 14 | 0 | |

| | | | |
|---|---|---|---|
| 0.53 | 20 | 0 | |
| 0.53 | 2 | 0 | |
| 0.56 | 3 | 0 | |
| 0.56 | 1 | 0 | |
| 0.61 | 1 | 0 | |
| 0.70 | 2 | 0 | |
| 0.70 | 2 | 0 | |
| 0.70 | 2 | 0 | |
| 0.70 | 2 | 0 | |
| 0.70 | 9 | 0 | |
| 0.73 | 2 | 0 | |
| 0.73 | 2 | 0 | |
| 0.82 | 3 | 0 | |
| 1.05 | 1 | 0 | |
| Sum | 102 | 0 | |

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

| ***r*, g** | **Units, *M*** | **Failed, *m*** | **Comment** |
|---|---|---|---|
| 0.35 | 4 | 0 | |
| 0.35 | 1 | 0 | |
| 0.42 | 1 | 0 | |
| 0.42 | 1 | 0 | |
| 0.44 | 1 | 0 | |
| 0.44 | 1 | 0 | |
| 0.44 | 1 | 1 | Isolation-mounted fan shifted off its mounts. The fan was otherwise undamaged and operable once it was remounted. |
| 0.53 | 1 | 0 | |
| 0.65 | 1 | 0 | |
| 0.70 | 7 | 7 | Failed their spring supports and dismounted. Six of the seven fans were operable once remounted. One unit that was in operation at the time "self-destructed" upon dismount and contact of the impeller with the fan enclosure. |
| 0.70 | 6 | 0 | |
| 0.70 | 1 | 0 | |
| 0.70 | 2 | 2 | Two axial fans, mounted in sheet metal enclosures attached to circular ducting and mixing boxes, shifted off their spring mounts. One unit remained operable. The other unit displayed excessive vibration upon restart, apparently due to shaft misalignment, most likely caused by the imposed distortion of the fan enclosure as it shifted against the adjacent ducting. Eventually this misalignment increased to a degree that the impeller contacted the enclosure, damaging the fan blades. |
| 0.70 | 6 | 6 | Bouncing of the fans on their spring supports during the earthquake caused them to dismount, although all fans remained atop their steel stands and none were damaged. Displacement of the fans tore the elastic seals that join the fan housing to the vertical ducting. Isolation mounts also had to be replaced when the fans were remounted. All fans were operational once they were repositioned. |
| 0.88 | 3 | 0 | |
| 0.88 | 5 | 0 | |
| 0.88 | 6 | 0 | |
| 0.88 | 1 | 1 | Vibration isolator failed. |
| 0.88 | 3 | 0 | |
| Sum | 52 | 17 | |

**Table 6. Quality tests**

| Quality test | DS1 | DS2 | DS3 |
|---|---|---|---|
| Passes Lilliefors goodness of fit test? (Type A only) | NA | | |
| Are θ and $\beta$ within 20% of past results? If not discuss. | θ: Y, $\beta$: ~Y | | |
| Are $0.2 \le \beta \le 0.6$? If not discuss. | Y | | |
| Do you believe demand with 10% failure probability? | Y | | |

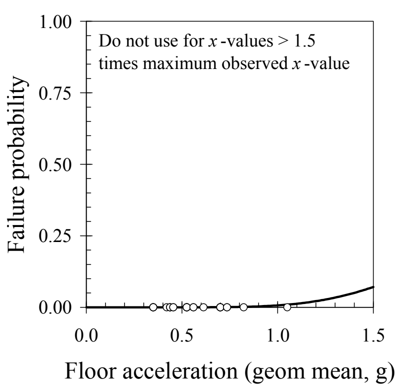
Discussion. Prior functions: Johnson et al. (1999) basic conditions; see below. Re believing 10% failure probability, yes. Plenty of data with r ~ 0.3 to 1.1g, much around 10% failure probability; fragility function seems to pass through the cloud & is fairly close to the value of r where the 1-point fragility function passes through 10% failure probability. Re $\beta$ within 20% of past results, compare w/J99, shown below.

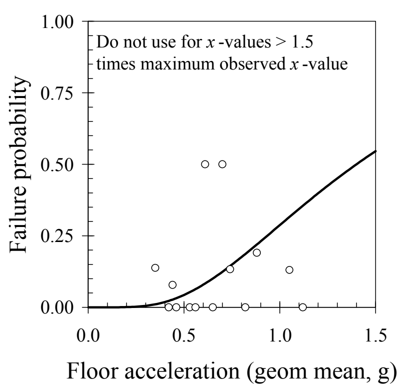
**Table 7. Extrapolation to other detailed conditions and to average conditions**

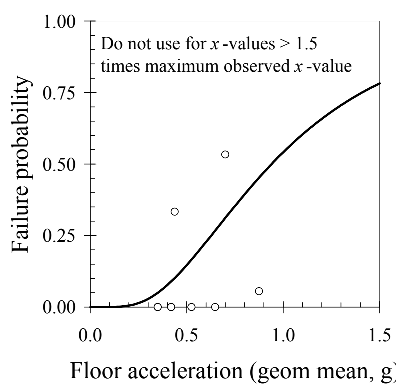
| Condition (describe) | From tests? | DS1 | | J99* | |
|---|---|---|---|---|---|
| | | θ | $\beta$ | θ | $\beta$ |
| Best: no deficiencies | Y | 2.7 | 0.4 | | |
| Moderate: 1 deficiency, typ. vibration isolator w/o subbers or fan and motor mounted on separate skids or pads | Y | 0.94 | 0.6 | 0.6-1.1 | 0.5 |
| Worst: 2+ deficiencies: no snubber + rigid att to duct? | N | 0.6 | 0.6 | 0.6 | 0.5 |
| Average or unknown | Y | 1.4 | 0.6 | 1.6 | 0.5 |

*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 $\beta$? See "best" conditions.

**Figure 1. Fan (background) and drive motor (foreground, EPRI)**



(a) (b) (c)

**Figure 2.** Fan seismic fragility: (a) well anchored, vibration isolators have snubbers, motor and fan anchored to same pad or skid, attached ducting is supported, bellows supported on both sides, flexible connection between fan and duct, no large nearby nonstructural components that could fall on fan, (b) average or unknown conditions, (c) 1 deficiency, typ. vibration isolators without seismic restraint or motor and fan are anchored to different pad or skid.

## REFERENCES CITED

(EPRI) Electric Power Research Institute, ND. *Seismic Experience Database*. www.epriq.com/esqug/main.html

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 Aug 2009 for publication to *Earthquake Spectra*.