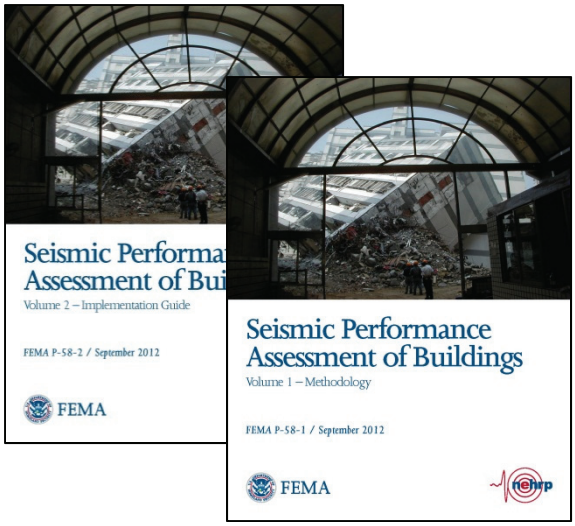


# Background Document

## FEMA P-58/BD-3.9.20

# Fragility of Air Compressors

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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

**Keith Porter (10/05/2009)**

**Table 1. Summary results**

| **Fragility, damage measures, and consequences for** | | |
|---|---|---|
| Component category: | D3032.011, compressor, well anchored to slab, isolators have snubbers; pipes and conduits are all flexibly attached; no large items that could fall on compressor<br>D3032.012, compressor, deficient installation (in 9 of 11 cases isolators without snubbers; in 2 of 11 cases, unanchored w no isolators) | |
| Basic composition: | Air, gas fuel, or ammonia compressor, sometimes mounted on air tanks. See Figure 1 for example. | |
| Units: | **ea** | |
| Number of damage states: | **1** | |
| If multiple damage states: | simultaneous | |
| Author and date: | Keith Porter 9 Oct 2009 | |
| **Damage states, fragilities, and consequences for** | | |
| | **D3032.011: well installed** | **D3032.012: deficient install** |
| Description: | Inoperative | Inoperative |
| Illustration: | NA | NA |
| Demand parameter | Peak floor acceleration (geom mean, g) | Peak floor acceleration (geom mean, g) |
| Median demand (θ): | 2.6 | 0.9 |
| Data dispersion ($\beta_d$): | 0.6 | 0.6 |
| Uncertainty ($\beta_u$): | | |
| Total dispersion ($\beta$): | 0.6 | 0.6 |
| Probability: | | |
| Correlation: | | |
| Repairs required: | Replace motor (2 of 3 cases), repair hose (1 of 3 cases). | Replace motor (2 of 3 cases), repair hose (1 of 3 cases). |
| 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 = 0.65g, so do not use for PFA > 1.0g. | Max observed PFA = 0.5g, so do not use for PFA > 0.75g. |

**Table 2. Summary supporting information template**

| | |
|---|---|
| Literature summary<br>See Porter et al., ND. Fragility of mechanical, electrical, and plumbing equipment. Note that EPRI (1991) has no GERS for compressors, and considers them "inherently rugged" (p 5-1). | |
| Number of specimens tested: | 116 from EPRI (2007) SQUG database with known installation conditions |
| Construction quality: | □ exceeds □ meets □ does not meet requirements of:<br>varies |
| Seismic installation conditions: | varies |
| Loading protocols applied: | 14 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 air compressors without installation deficiencies**

| r, g | Units, M | Failed, m | |
|---|---|---|---|
| 0.20 | 5 | 0 | |
| 0.20 | 4 | 0 | |
| 0.20 | 2 | 0 | |
| 0.23 | 8 | 0 | |
| 0.24 | 4 | 0 | |
| 0.26 | 6 | 0 | |
| 0.26 | 4 | 0 | |
| 0.26 | 4 | 0 | |
| 0.27 | 4 | 0 | |
| 0.27 | 7 | 0 | |
| 0.31 | 2 | 2 | Burnt windings possibly from offsite electrical supply (single-phase event) |
| 0.31 | 7 | 0 | |
| 0.31 | 5 | 0 | |
| 0.31 | 4 | 0 | |
| 0.31 | 2 | 0 | |
| 0.31 | 4 | 0 | |
| 0.33 | 3 | 0 | |
| 0.36 | 2 | 0 | |
| 0.41 | 7 | 0 | |
| 0.43 | 7 | 0 | |
| 0.51 | 6 | 0 | |
| 0.57 | 2 | 0 | |
| 0.61 | 6 | 0 | |
| Sum | 105 | 2 | |

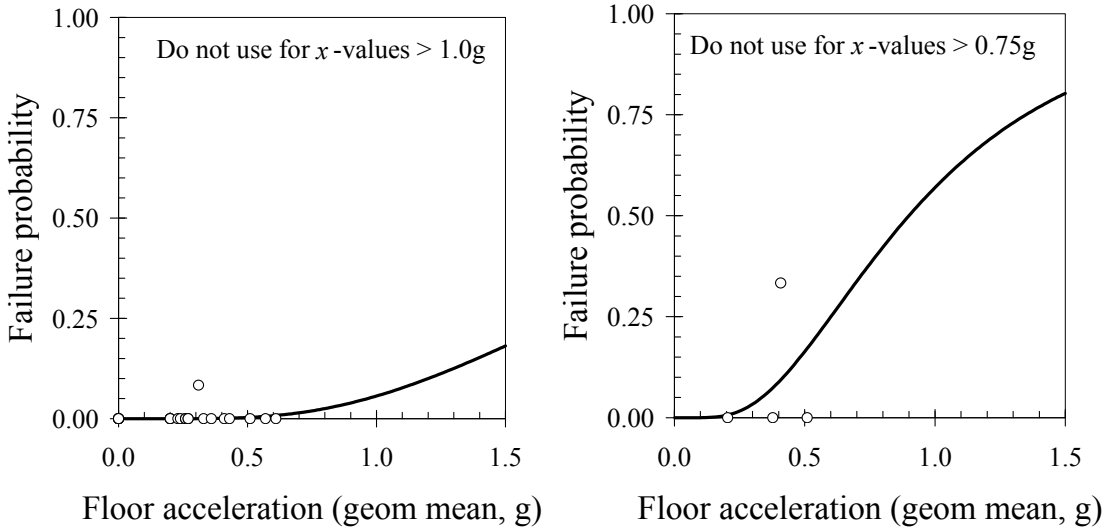
**Table 4. Failure data of compressors with installation deficiencies**

| r, g | Units, M | Failed, m | |
|---|---|---|---|
| 0.20 | 3 | 0 | Isolators w/o snubbers; did not fail |
| 0.38 | 3 | 0 | Isolators w/o snubbers; did not fail |
| 0.41 | 1 | 1 | Cracked air line, maybe aggravated by compressor rocking on its spring mounts |
| 0.41 | 2 | 0 | Isolators w/o snubbers; did not fail |
| 0.51 | 2 | 0 | Welded to tanks which are welded to unanchored skid, did not fail |
| Sum | 11 | 1 | |

**Table 5. Quality tests**

| **Quality test** | |
|---|---|
| Passes Lilliefors goodness of fit test? (Type A only) | NA |
| Are θ and $\beta$ within 20% of past results? If not discuss. | θ: Y, $\beta$: N |
| 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 2.5 (vs. 0.9 and 2.6 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, given 2 sites with 5-10% failure at lower excitation. | |

**Figure 1. Compressor**



(a) (b)

**Figure 2. Air compressors**: (a) D3032.011, compressor well anchored to slab, isolators have snubbers; pipes and conduits are all flexibly attached; no large items that could fall on compressor, (b) D3032.012 compressor with deficient installation, typically isolators without seismic restraint. 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.

## REFERENCES CITED


(EPRI) Electric Power Research Institute, 2007. Seismic Experience Database WWW Version 2.3.

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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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