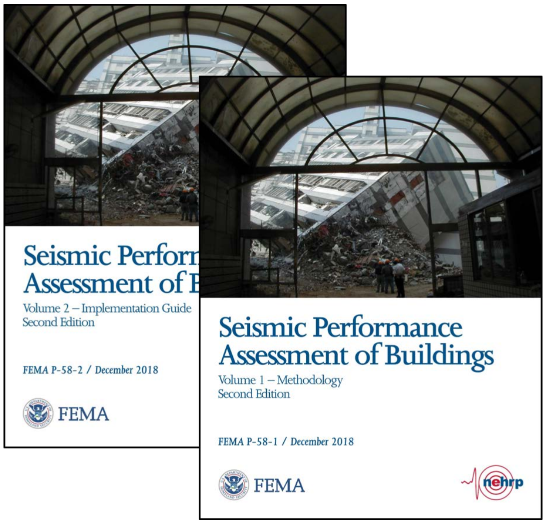

Background Document

FEMA P-58/BD-3.9.32

Interior Cold-Formed Steel Framed Gypsum Partition Walls

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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. This report was developed over the course of the 5-year ATC-58-2 Project funded under FEMA Contract HSFE60-12-C-0243.

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contained herein has not been independently verified for accuracy as a stand-alone document, and may have been superseded in its final implementation within the methodology.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 photograph – 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, Second Edition*, and FEMA P-58-2, *Volume 2 – Implementation Guide, Second Edition*.
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REVISION OF SEISMIC FRAGILITY FUNCTIONS FOR BUILDING INTERIOR COLD-FORMED STEEL FRAMED GYPSUM PARTITION WALLS

Prepared by

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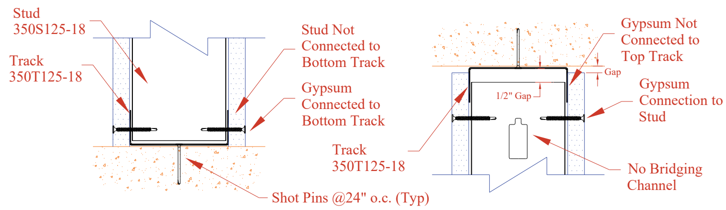
December 17, 2015

INTRODUCTION

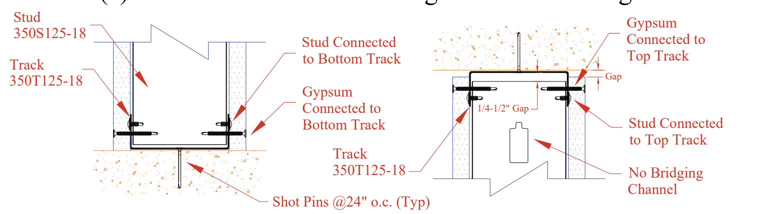
The seismic behavior of light gauge steel studded gypsum partition walls has been extensively studied through various experimental research programs, with over 140 individual specimens tested to date. Some previous research studies proposed seismic fragility functions from the individual test program data considering various damage states and construction details. Fragility functions were developed as part of the FEMA P-58 project (FEMA 2013A) by Miranda and Mosqueda (2011) that considered available test data at that time to best assess the various types and distribution of damage at a given drift.) The recommended fragility parameter values were included in the PACT software (FEMA 2013B). These partition wall fragilities are based primarily on test data and constitute one of the most extensively tested and documented nonstructural components. However, loss estimation studies using PACT have been problematic in the sense that losses attributed to partition wall damage have far exceeded observations during past earthquakes. These discrepancies can likely be attributed to the combined conservatism built into the fragility functions and even more the interpretation of damage states into consequence and repair actions. Initiation of damage as reported in research studies could be relatively insignificant at times, such as a barely visible hairline crack that would otherwise not be reported in post-earthquake investigations. While a field team may be tasked with examining several furnished and/or occupied buildings in their entirety following an earthquake, a research team may focus on a single unobstructed wall specimen in a well-lit laboratory and more likely to report barely visible damage.

In light of recent studies reporting larger than expected monetary loss contributions from partition walls using PACT, the fragility functions and definitions of damage states for partition walls as reported by Miranda and Mosqueda (2011) were revisited within the context of the consequence functions provided in PACT. The data was reexamined to consider the level of damage that triggers a particular damage state to better quantify the level of repair required. Data that has become available since the 2011 study was also considered in revising the fragility functions.

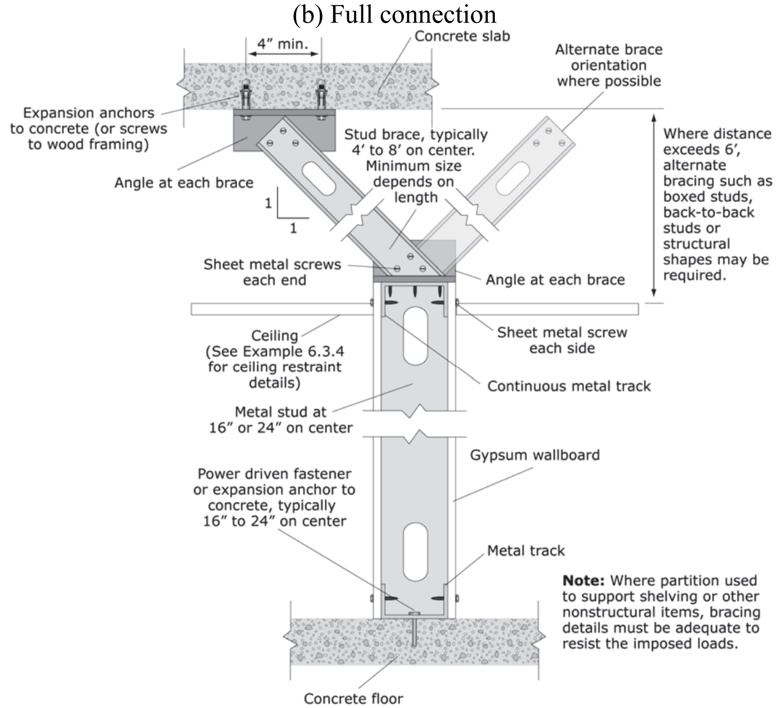
The types of walls considered here are interior non-load-bearing gypsum wallboard partitions. The walls consist of vertical C-shaped cold formed metal studs connected to horizontal cold-formed metal tracks attached directly to the building floor slabs at the top and bottom. Gypsum wallboard, typically in one layer of 1/2 inch and 5/8 inch thickness is screwed to the metal studs and finished with mud taping at the joints then painted for the finish. A more detailed description of the wall types examined here and variations in construction is available in Miranda and Mosqueda (2011). For the purposes of this study, the walls are categorized into the following groups depending on details of the connections between the gypsum wallboard and the studs to the top tracks. Connection details are illustrated in Figure 1:



(a) friction connection allowing horizontal sliding



(b) Full connection



(c) partial height wall (FEMA-77, 2011)

Fig. 1. Connection details for cold-formed steel indoor partition walls

- **Full Connection** with screws connecting studs and gypsum wallboard to bottom and top tracks
- **Friction Connection/Horizontal Slip Track** with no direct connection between wallboard and studs to top track allowing the wall to slip relative to the top track. Return walls may limit the free movement of the walls.
- **Friction Connection/Horizontal Slip Track With No Returns** with no direct connection between wallboard and studs to top track allowing the wall to slip relative to the top track. Only the boundary studs are typically connected to the top track.
- **Partial Height Walls** with diagonal bracing connecting the top track to the slab above

SOURCE OF DATA

The same set of data used by Miranda and Mosqueda is used here with additional data from two recent projects that have tested partition walls since 2011. However, only data with the required information to identify the drifts at the damage states of interest was considered in the development of the fragility functions. Most of the test data is from cyclic testing in which the specimens are subjected to a predetermined loading patters with pauses at select amplitudes to inspect and document damage. The maximum drift to which the specimen was subjected to was reported by the research teams. Some of the more recent data includes observations from partition walls installed within a complete structural model or structural framing subjected to base earthquake ground shaking. In this case, damage was only reported after the simulated earthquake event considering the peak drift imposed on the test specimen. Data from the following test series was considered in these studies.

- **JAB**: John A. Blume and Associates (John A. Blume and Associates 1966, 1968, Freeman 1971, 1974, 1979) tested fifty-four interior wall panel specimens. Only specimens consisting of gypsum wallboard on metal studs are considered here and include 13 fixed and 9 friction connection with no returns. Two damage states were defined and described as 1) 'first indication of noticeable damage' and 2) 'real damage' with descriptors such as 'failure of wallboard at screws', 'cracks extend'. These appear to be consistent with Damage States DS0 and DS1 respectively as defined later for this study.
- **Rihal** (Rihal, 1982; Rihal, and Granneman, 1984) tested fourteen 8 ft by 8 ft interior wall partition specimens of which 11 were considered fixed for these studies. Two damage states were defined and described as 1) 'first indication of noticeable damage' and 2) 'failure/significant damage' with descriptors that appear to be consistent with Damage States DS0 and DS2 respectively as defined later for this study.
- **ABM**: Bersofsky, A.M, (2004) tested sixteen 16-feet long by 8-feet tall specimens Return walls were installed perpendicular to the plane of the main wall at opposite ends, creating an I-wall cross section. Fourteen of the test specimens are considered as having fixed connections. This report provided detailed descriptions of defined damage states and photos of the corresponding damage.
- **Lang** (Land and Restrepo 2006, Lang 2007), tested two identical specimens representing full scale office rooms which were approximately 15 feet long, 12 feet wide, and 14 feet high under bi-directional loading. The two specimens are considered fixed. Data are included for calculating fragilities using Method A (Actual Demand Data) but not for Method B (Bounding Demand Data).
- **Lee** et al. (2006, 2007) tested various configurations of interior partitions with metal studs. The partitions tested were built without screwing studs to the horizontal tracks as in the seismic slip-track. One test included returns, but these were not properly braced to restrict the motion at the intersection of the sliding walls. Data are included for calculating fragilities using Method A (Actual Demand Data) but not for Method B (Bounding Demand Data).
- **NEESR UB**: As part of the NEES Nonstructural Grand Challenge project, 36 in-plane partition walls were tested at the University at Buffalo (Retamales et al. 2010), of which 13 fixed, 8 slip track, 5 slip track with no returns, and 3 partial height walls were considered. A very detailed description and photos of damage for each specimen are provided in this report.
- **NEESR UNR**: NEES Nonstructural testing at UN Reno (Rahmanishamsi et al. 2014) included several configurations of partition walls installed in a two story steel frame subjected to base excitation. In total, 13 fixed, 8 slip track, 5 slip track with no returns, and 3 partial height walls were considered.
- **BNCS**: Interior partition walls were included in the BNCS project at UC San Diego (Chen et al. 2013). In these tests the walls were installed inside a 5 story concrete building tested on a shake table. Partition walls where installed in each story of the building, with only one 17 ft. segment installed in-plane at each story. In total, 5 walls, corresponding to each in-plane wall per story, are considered here. Following a test, damage was reported and categorized as one of the defined damage states with the corresponding drift taken as the maximum drift to which the story was subjected.

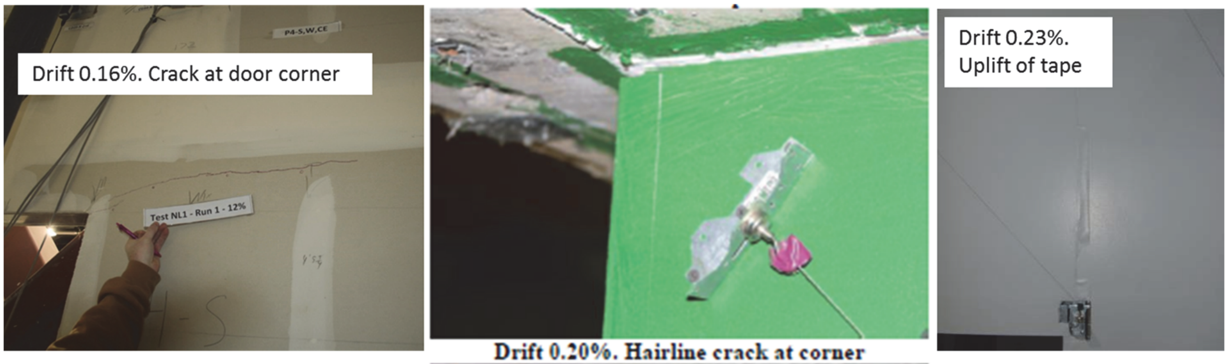
REVISED DEFINITION OF DAMAGE STATES

For the original fragility functions, Miranda and Mosqueda defined three damage state for partition walls based on the level of repair required following the approach of Taghavi and Miranda (2003). These three damage states were defined as follows:

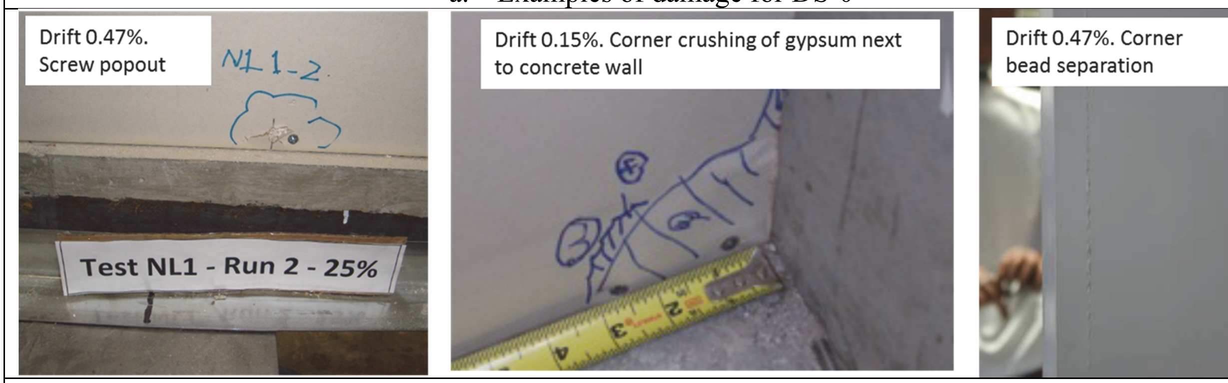
- DS-1 consists of minor damage which can be repaired by patching, re-taping, sanding and painting of the gypsum wallboard. Examples of this type of damage include minor cracking of the gypsum wallboards or the tape, warping of the tape, minor damage around the screw heads, etc. For partial height walls, DS-1 can also include buckling or local failure of the braces.
- DS-2 consists of severe cracking, crushing or out of plane buckling of the gypsum wallboards such that replacement of the wallboards becomes necessary. Repair would involve removing the damage wallboards and subsequent taping, pasting, sanding and painting. DS-2 also includes damage to boundary studs that can be easily replaced.
- DS-3 involves severe damage to the partition including not only severe damage to the gypsum wallboards and the screws connecting them to the studs and tracks but also damage to the steel framing such that replacement of the partition becomes necessary. This type of damage typically involves local buckling and/or fracture of the metal studs.

Following recommendations from an ATC-58-2 meeting (May 2015), the definition of damage states for gypsum partition walls were revised. Based on photos for each damage state, it was determined that the first damage state DS-1 corresponding to the first visible damage can, at times, be rather minor. More importantly, the repair action for DS-1 required repair and painting of 50% of the wall. In many cases, this type of damage could be considered to be within the range or normal wear and tear from daily use. Such damage includes hairline cracks or slight uplift of screws or tape at joints. Repair of this type of damage will be at the discretion of the building owner and thus there should be an options to account for this low level damage in loss assessment studies.

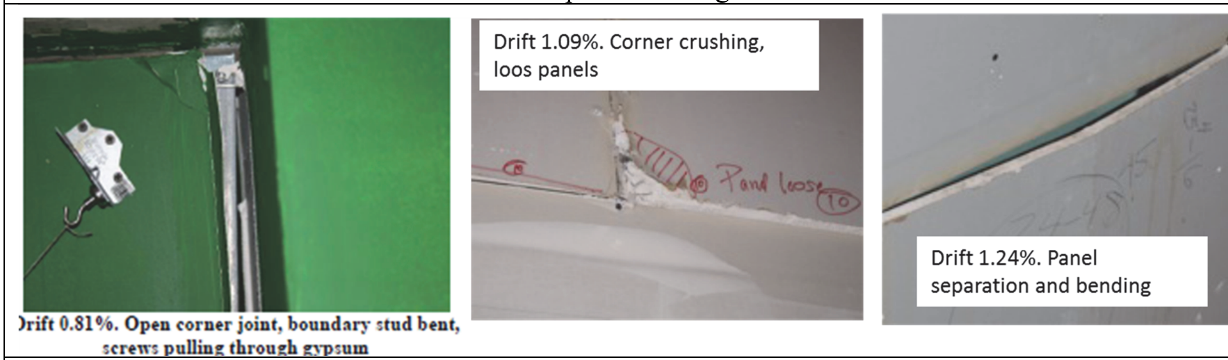
To address this concern, a preliminary damage state was defined as DS-0 to account for the drift demand at which visible damage initiates. This corresponds to the first observation of damage as reported in many past research studies. Consequently, the actual damage associated with the three damages states DS-1, DS-2 and DS-3 were increased in severity. The definition of damage states were revised as shown in Fig. 2 and Table 1 to include the optional DS-0 and redefine the remaining three damage states to better correlate to the required repair actions. Partitions with full or friction connections had similar failure modes and thus use the same definition of damage states and repair actions. Partial height walls showed a different sequence of failure, requiring different definitions for damage states and repair actions as defined in Table 2. Following this revision to the damage state definitions, the experimental data had to be sorted to define the corresponding drift at which the newly defined damage state were observed. This was accomplished by reviewing photographs of the reported damage where available for each specimen or by the description of damage provided by previous testing programs.



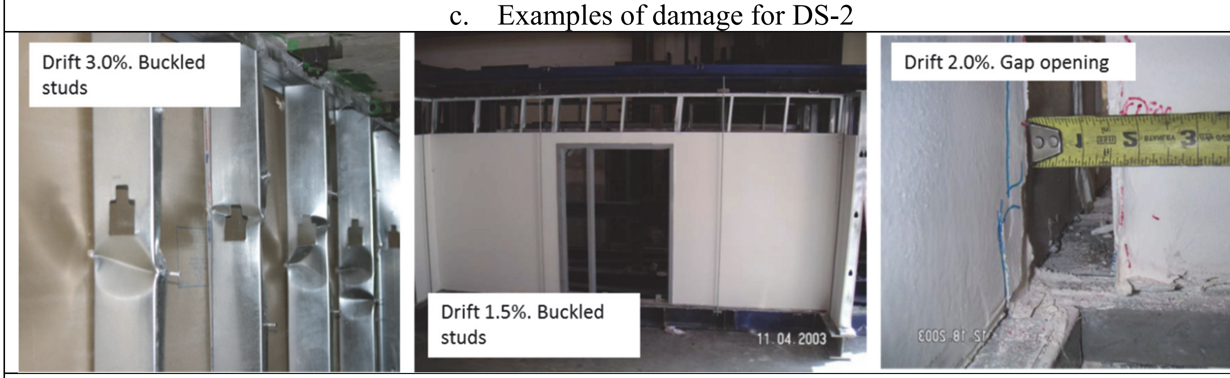
a. Examples of damage for DS-0



b. Examples of damage for DS-1



c. Examples of damage for DS-2



d. Examples of damage for DS-3

Fig. 2. Images of damage triggering a damage state for full and friction connection partition walls (Photos collected from various report from which data was obtained)

Table 1. Revised damage states for full and friction connection partition walls.

Damage State		Description of Damage	Repair Action
DS-0	Localized visible damage to the upon close inspection	Hairline cracking of wall board or joints, visible screw pop out, light warping or cracking of tape. Damage could be taken for normal wear and tear	Localized repair mainly around corners and edges of wall. May require light pasting and repainting.
DS-1	Local damage to the walls	Significant screw pop-out, cracking of wall board, warping or cracking of tape, slight crushing of wall panel at corners	Retape joints, past and repaint. May require cutting and replacing corner sections of board. Repair 5% wallboard, 10% retape, 25% paint
DS-2	Local damage of gypsum wallboards and/or steel frame components	Moderate cracking or crushing of gypsum wall boards (typically in corners). Moderate corner gap openings, Bending of boundary studs	Remove and replace 10% of wall board (both sides), re-tape and paste 25% of wall, paint 50% of wall. Replace boundary studs ~ 5 intersections per 100 ft of wall.
DS-3	Severe damage to walls	Buckling of studs and tearing of tracks. Tearing or bending of top track, tearing at corners with transverse walls, large gap openings, and walls displaced.	Remove and replace 50% length of metal stud wall, both sides of the gypsum wall board and any embedded utilities, and tape, paste and repaint. 50% wall replacement, 100% paint

Table 2. Revised damage states for partial height walls.

Damage State		Description of Damage	Repair Action
DS-0	Localized visible damage to the walls upon close inspection	Slight twisting or bending of braces, especially at connection point, rocking of whole wall	Localized repair mainly around corners and edges of wall
DS-1	Local damage to the walls	Buckling or connection failure of diagonal braces. Significant screw pop-out, cracking of wall board, warping or cracking of tape	Replace brace diagonals about 5 intersections per 100 ft of wall Retape and paste 10% of joints, paint 25% of wall surface
DS-2	Local damage of gypsum wallboards and/or steel frame components	Significant screw pop-out, cracking of wall board, warping or cracking of tape	Repair from DS1 plus possible replacement of top track and boundary studs.
DS-3	Severe damage to walls	Damage to top track, separation at joint, significant rocking of wall, bottom track uplifts – nail fasteners fail transverse walls, large gap openings, and walls displaced.	Remove and replace 50% length of metal stud wall, both sides of the gypsum wall board and any embedded utilities, and tape, paste and repaint. 50% wall replacement, 100% paint and repaint. 50% wall replacement, 100% paint

DERIVATION OF FRAGILITY PARAMETERS

Previously, the gypsum wallboard fragility functions were derived using Method A with “Actual Demand Data” from experiments following the procedure in section H.2.1 of FEMA P58-1. This approach requires the value of the demand at each test at which a damage state was initiated. In experiments, however, cyclic testing is performed in incremental loading steps followed by a pause for inspection. While the occurrence of damage is typically only reported at the end of each loading cycle, the damage could have actually occurred anywhere in between the loading increment from the previous loading cycle. A correction was applied by subtracting one half of the deformation increment at the cycle in which each damage state was reported to have occurred. Anecdotal checks with some of the data found that this approach can be conservative in estimating damage, but it seems unlikely to have a significant effect on estimated repair costs. Particularly for cyclic loading tests, damage inspections were carried out after small increments of loading.

The available test data provides the peak drift imposed on the partition wall specimen that resulted in a given damage state, but not the instance it was initiated. Especially for the walls installed within actual building frames in recent shake table tests, an alternative approach using Bounding Demand Data, (referred to as Method B) was considered. Method B requires the maximum value of the demand to which the specimen was subjected to and if a particular damage state occurred. The detailed formulation for this approach can be found in section H2.2.2 of FEMA P-58-1. In the sections that follow, the available data is presented for each type of partition wall considered and the fragility parameters are calculated using both Method A: Actual Demand Data and Method B: Bounding Demand Data. The organization of data for Method B is presented for one of the fragility functions to demonstrate the process.

DATA AND CALCULATION OF FRAGILITY FUNCTION PARAMETERS

Fragility functions were developed by first identifying the level of lateral story drift imposed in the partition at which each damage level was first reported to occur. Considering the revised definition of damage states, the drift was identified from photos of damage where available. For earlier experiments, descriptors of damage identified in reports was used to categorize the damage state at which drifts were reported.

Full Connection Partitions

In total 64 specimens are considered from seven test programs. The data available to derive the fragility function parameters is listed in Table 3.

Table 3. Full connection data: drifts reported for each damage state

Research Program	Specimen	Story Drift Ratio at DS			
		DS0	DS1	DS2	DS3
JAB	A-4	0.0026	0.0078	-	-
	A-12	0.0026	0.0052	-	-
	A-12R	0.0026	0.0052	-	-
	A-30	0.0052	0.0078	-	-
	X-33	0.0026	-	-	-
	A-5	0.0052	0.0104	-	-
	A-15	0.0026	0.0052	-	-
	A-15R	-	0.0052	-	-
	A-31	0.0026	0.0052	-	-
	A-31R	0.0007	0.0026	-	-
	A-11	0.0026	0.0052	-	-
	A-11R	0.0013	0.0052	-	-
	A-27	0.0026	0.0052	-	-
Rihal	P2A	0.0039	-	0.0083	-
	P3A	0.0039	-	0.0063	-
	P4	0.0026	-	0.0104	-
	P5	0.0046	-	0.0110	-
	P6	0.0052	-	0.0078	-
	P7	0.0046	-	0.0104	-
	P8	0.0039	-	-	-
	P8A	0.0039	-	-	-
	P9	0.0039	-	0.0111	-
	P10	0.0039	-	0.0073	-
	P11	0.0039	-	0.0073	-
AMB	2A	0.0030	0.0100	0.0150	0.0300
	2B	0.0030	0.0100	0.0150	0.0300
	3A	0.0005	0.0030	0.0100	-
	3B	0.0030	0.0050	0.0150	-
	4A	0.0030	0.0050	0.0100	0.0300
	4B	0.0030	0.0075	0.0150	0.0300
	5A	0.0030	0.0075	-	0.0150
	5B	0.0050	0.0075	-	0.0200
	6A	0.0030	0.0075	0.0100	0.0200
	6B	0.0010	0.0050	0.0100	0.0200
	7A	0.0030	0.0050	0.0100	0.0200
	7B	0.0010	0.0030	0.0100	0.0200
	8A	0.0010	0.0075	0.0150	0.0200
	8B	0.0030	0.0030	0.0150	0.0200
Lang	1	0.0025	-	0.0082	-
	2	0.0028	-	0.0077	-

Research Program	Specimen	Story Drift Ratio at DS			
		DS0	DS1	DS2	DS3
Lee	GBM-2	0.0020	-	0.0080	-
NEESR UB	4	0.0040	0.0062	0.0116	0.0215
	5	0.0040	0.0062	0.0116	0.0266
	6	0.0040	0.0040	0.0157	0.0300
	7	0.0040	0.0062	0.0100	0.0215
	8	0.0040	0.0062	0.0081	0.0215
	9	0.0040	0.0040	0.0062	0.0199
	10	0.0020	0.0062	0.0135	0.0266
	23	0.0020	0.0040	0.0184	0.0282
	24	0.0040	0.0062	0.0199	0.0282
	25	0.0040	0.0062	0.0100	0.0215
	26	0.0040	0.0062	0.0215	0.0300
	27	0.0040	0.0062	0.0116	0.0266
	28	0.0040	0.0062	0.0116	0.0232
NEESR UNR	P2-F -NL1	0.0047	-	-	0.0264
	P2-F -NL2	-	0.0074	0.0161	0.0213
	P2-F -NL3	-	-	0.0097	0.0229
	P1-S-NL1	-	0.005689	-	0.0207
	P1-S-NL2	-	0.0123	0.0123	0.0186
	P1-S-NL3	-	0.0181	-	-
BNCS	1	-	-	0.0075	0.0264
	2	-	-	0.0094	0.0275
	3	-	-	0.0067	0.0208
	4	-	-	0.0109	-
	5	-	-	0.0066	-

The procedure used to determine the fragility function parameters including the median and dispersion for Method A is described in Miranda and Mosqueda using the data for each damage state in the table above. Note that the updated table presented here includes new test data and the previous data examined by Miranda and Mosqueda has been reorganized considering the newly defined damage states. Method B requires further arrangement of the data. For each test program, the drift at which each experiment was paused for inspection is identified and the number of positive observations for each damage state is considered. The data for DS-0 is show in Table 4. Note that for the NEESR UNR data, only one of test runs with two specimens is considered with only one of the walls having observed DS-0. The data from Lang and the data from Lee are not considered in Method B.

Table 4. Number of observations for DS-0 at each drift at which wall were inspected by test program

	Drift at Inspection	# Samples DS Observed	
		Yes	No
Rihal	0.0013	0	9
	0.0026	1	8
	0.0039	6	3
	0.0046	8	1
	0.0052	9	0
ABM	0.0005	1	13
	0.001	4	10
	0.003	13	1
	0.005	14	0
NEESR UB	0.002	4	9
	0.004	13	0
NEESR UNR	0.0016	1	2
	0.0022	1	2
	0.0029	1	2
	0.0042	2	1
	0.00509	2	1
JAB	0.0013	1	11
	0.0026	10	2
	0.0052	12	0

The data in Table 3 is then sorted into bins following the procedure specified in FEMA P58-1 (See Table H-1 for explanation of the variable and calculations). For DS-0, j=5 bins are considered with the lower bound value of each bin a_j identified in the second column.

Table 5. Table for calculation of fragility parameters using Method B: Bounding Data Analysis for DS-0

j	a_j	$r_j$bar	M_j	m_j	x_j	y_j	x_j-xbar	y_j-ybar	$(x_j\text{-xbar})^2$	(x_j-xbar) (y_j-ybar)
1	0.0005	0.000986	49	6	-6.922	-1.080	-0.934	-1.431	0.872	1.336
2	0.0015	0.001968	19	6	-6.231	-0.385	-0.242	-0.736	0.059	0.178
3	0.0025	0.002771	38	25	-5.889	0.431	0.100	0.080	0.010	0.008
4	0.0035	0.003988	25	21	-5.524	1.020	0.464	0.669	0.215	0.310
5	0.0045	0.004625	51	49	-5.376	1.769	0.612	1.418	0.375	0.868
SUM			182		-5.988	0.351			1.530	2.701

From this table, the dispersion is calculated as

$$\beta_r = \frac{\sum_{j=1}^{5}(x_j - \bar{x})^2}{\sum (x_j - \bar{x})(y_j - \bar{y})}$$

And the median is calculated as

$$\theta = e^{(\bar{x} - \bar{y}\beta_r)}$$

This procedure is repeated for the remaining damage states and similarly applied to the data for two other wall configurations. The resulting data is presented in the Summary section of this report.

Friction Connection/Horizontal Slip Track Partitions

The data for specimens with friction connection was gathered from the NEESR test program testing at both UB an UNR as shown in Table 6. In this case only 4 bins of data were considered for implementation of the fragility analysis using Method B.

Table 6. Friction Connection/Horizontal Slip Track data: drifts reported for each damage state

Research Investigation	Specimen	Story Drift Ratio at DS			
		DS0	DS1	DS2	DS3
NEESR UB	1	0.0020	0.0020	0.0062	0.0184
	2	0.0020	0.0040	0.0116	0.0199
	3	0.0020	0.0040	0.0081	0.0184
	20	0.0020	0.0040	0.0116	0.0199
	21	0.0040	0.0062	0.0100	0.0199
	22	0.0040	0.0062	0.0100	0.0199
	31	0.0020	0.0062	0.0135	0.0199
	32	0.0040	0.0062	0.0135	0.0199
NEESR UNR	P3-S		0.0157	0.0207	
	P5-S			0.0142	

Friction Connection/Horizontal Slip Track Partitions with no Returns

The data for specimens with friction connection with no returns was gathered from several test programs and listed in Table 7. The drift at the first reported damage was closer to the description of DS-1 and categorized in this fashion. Typically the next failure mode involved the steel framing boundary studs, which coincides with DS-2. In this case only 4 bins of data were considered for implementation of the fragility analysis using Method B.

Table 7. Friction Connection/Horizontal Slip Track with No Returns data: drifts reported for each damage state

Research Program	Specimen	Story Drift Ratio at DS		
		DS0	DS1	DS2
NEESR UB	14	-	0.0013	0.0130
	15	-	0.0056	0.0245
	16	-	0.0027	0.0104
	29	-	-	-
	30	-	-	-
LEE	1	-	-	0.0150
	2	-	0.0050	0.0100
	4	-	-	0.0100
Rihal	P2	-	-	-
	P3	-	-	-
JAB	A-3	-	0.0078	0.0104
	A-10R	-	-	-
	A-10RR	-	-	-
	A-19	-	-	0.0078
	A-29	-	0.0104	0.0104
	A-2	-	0.0039	0.0052
	A-14	-	0.0039	-
	A-23	-	0.0039	0.0078
	A-23R	-	0.0039	0.0052
	A-28	-	0.0026	-
	A-28R	-	0.0007	0.0078
NEESR UNR	P2-S	-	0.0207	0.0207
	P6-S	-	-	0.0207

Partial Height Wall Partitions

The data for specimens with partial height walls was also mainly gathered from the NEESR test program at both UB an UNR (Table 8). In this case up to 4 bins of data were considered for implementation of the fragility analysis using Method B. Only two bins were used for the damage states with few data points.

Table 8. Partial Height Walls: drifts reported for each damage state

Research Program	Specimen	Story Drift Ratio at DS			
		DS0	DS1	DS2	DS3
NEESR UB	17	0.0062	0.0081	0.0135	0.0199
	18	0.0062	0.0081	0.0157	0.0184
	19	0.004	0.0100	0.0116	0.0199
NEESR UB (Dynamic)	48		0.0126		
	49		0.0093		
	50		0.0134		
NEESR UNR	P10-S		0.0211		

SUMMARY OF FRAGILITY PARAMETERS

Considering the data with damage states as defined in this report, the calculated parameters for fragility functions are provided in Table 8 for Method A and Method B. Recommended values based on fit to the data are also provided in the table for each type of wall considered and each damage state. Note that the fitted lognormal distribution should ideally sit on top of the test data since the y-scale indicates the percent of specimens that achieved a damage state for a given drift. The recommended values were adjusted to improve this fit. Fragility functions using the recommended parameters are plotted in Figures 3 through 6 on top of the raw experimental data.

Table 9. Summary of calculated and recommended fragility parameters

		Previous values		Bounding Demand Parameters		Actual Demand Data		Recommended Values	
		Median	Disper.	Median	Disper.	Median	Disper.	Median	Disper.
Full	DS0	0.0021	0.60	0.0021	0.57	0.0029	0.50	0.0021	0.60
(a)	DS1	0.0071	0.45	0.0045	0.38	0.0059	0.38	0.0050	0.40
	DS2	0.0120	0.45	0.0094	0.40	0.0106	0.31	0.0100	0.30
	DS3			0.0205	0.25	0.0234	0.18	0.0210	0.20
Partial	DS0			0.0040	0.30	0.0054	0.36	0.0050	0.35
(b)	DS1	0.0064	0.30	0.0088	0.41	0.0112	0.34	0.0100	0.30
	DS2	0.0110	0.30	0.0100	0.35	0.0140	0.30	0.0130	0.30
	DS3	0.0180	0.30	0.0160	0.28	0.0200	0.25	0.0180	0.30
Slip	DS0			0.0017	0.41	0.0026	0.44	0.0020	0.30
(c)	DS1	0.0020	0.70	0.0030	0.43	0.0052	0.56	0.0040	0.45
	DS2	0.0050	0.40	0.0085	0.36	0.0114	0.33	0.0110	0.35
	DS3	0.0090	0.60	0.0170	0.28	0.0195	0.25	0.0190	0.25
Slip NR	DS0								
(d)	DS1	0.0035	0.70	No Change				0.0035	0.70
	DS2	0.0093	0.45	No new or sufficient data				0.0095	0.45
	DS3								

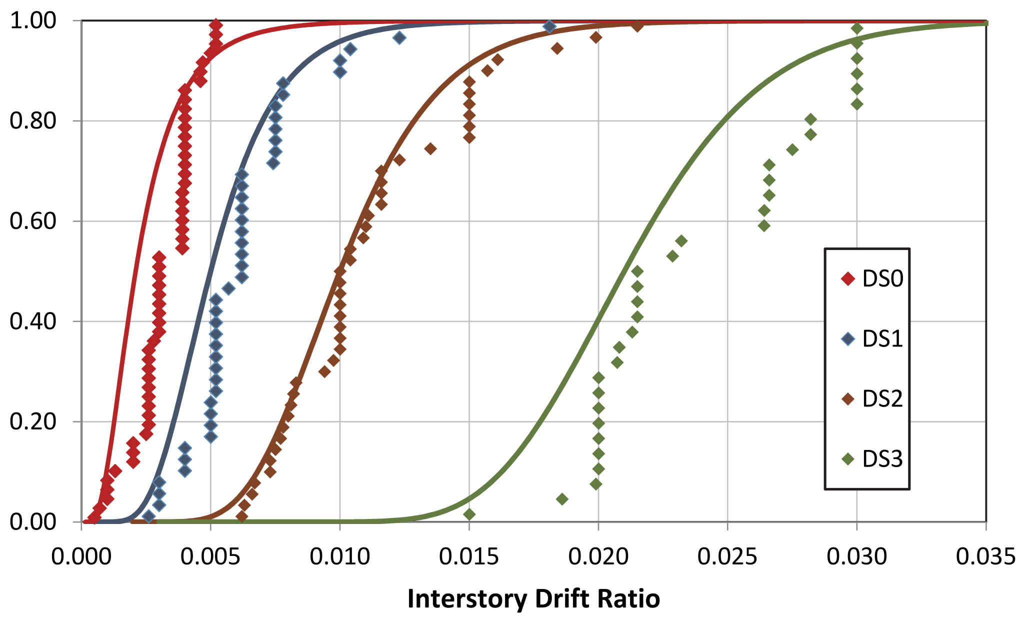


Fig. 3. Fragility functions with recommended parameters compared with experimental data for full connection partition walls

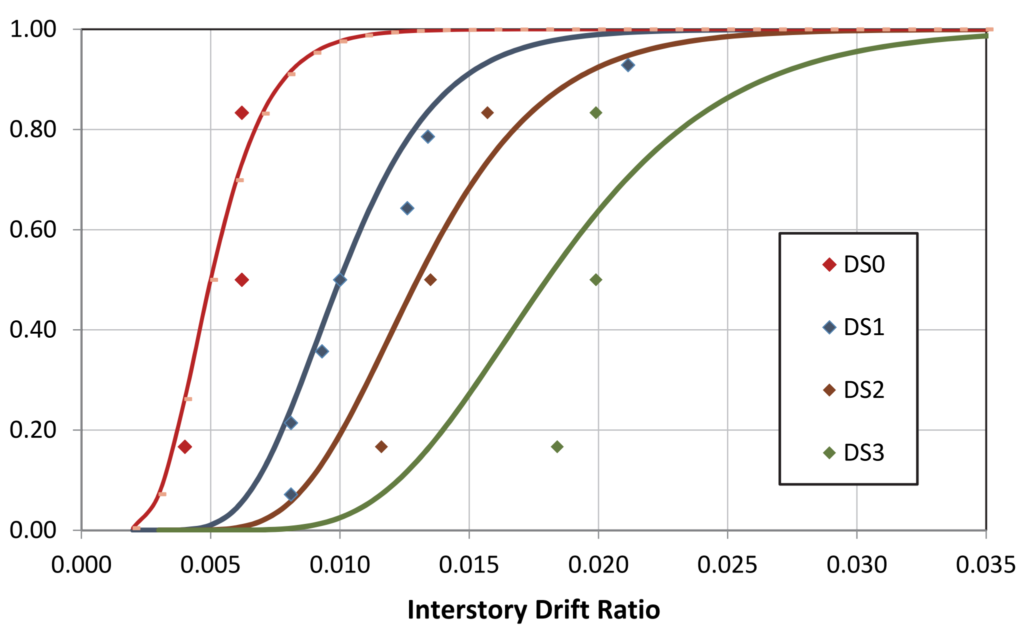


Fig. 4. Fragility functions with recommended parameters compared with experimental data for partial height partition walls

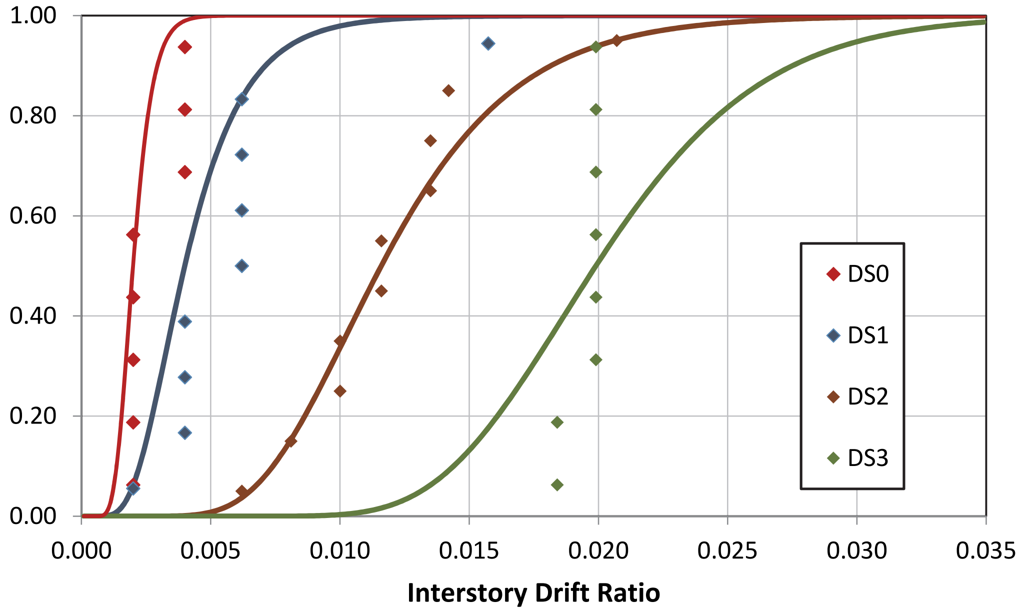


Fig. 5. Fragility functions with recommended parameters compared with experimental data for friction connection partition walls with returns

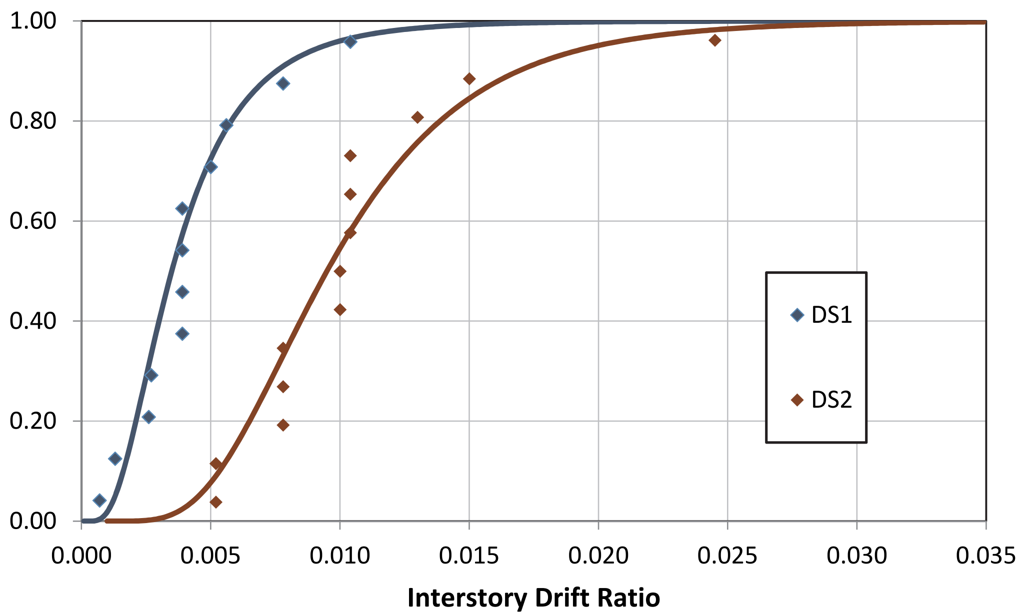


Fig. 5. Fragility functions with recommended parameters compared with experimental data for friction connection partition walls with no returns

REFERENCES

Bersofsky, A.M, (2004), Seismic performance evaluation of gypsum wallboard partitions, *MS Thesis*, University of California at San Diego.

Chen, M. C., Pantoli, E., Wang, X., Astroza, R., Ebrahimian, H., Mintz, S., ... & Kim, J. K. (2013). BNCS Report# 1: Full-scale structural and nonstructural building system performance during earthquakes and post-earthquake fire—specimen design, construction, and test protocol. SSRP, 13(09).

Federal Emergency Management Agency (FEMA), 2011. *FEMA E-74 Reducing the Risks of Nonstructural Earthquake Damage, A Practical Guide, Fourth Edition*, Applied Technology Council.

Federal Emergency Management Agency (FEMA), 2012B. *FEMA P-58-1: Seismic Performance Assessment of Buildings, Volume 1- Methodology*, Applied Technology Council.

Federal Emergency Management Agency (FEMA), 2012A. *FEMA P-58-2: Seismic Performance Assessment of Buildings, Volume 2- Implementation Guide*, Applied Technology Council.

Freeman, S.A., (1971). “Third Progress Report on Racking Tests of Wall Panels,” John A. Blume and Associates Research Division, *Report JAB-99-54*, San Francisco, Calif., Nov 1971.

Freeman, S.A., (1974). “Fourth Progress Report on Racking Tests of Wall Panels,” John A. Blume and Associates Research Division, *Report JAB-99-55*, San Francisco, Calif., Sep 1974.

Freeman, S.A., (1976). “Racking Tests of High-Rise Building Partitions,” *Journal of the Structural Division, Proceedings of the American Society of Structural Engineers*, Vol. 103, No. ST8, pp. 1673-1685.

John A. Blume and Associates, (1966). “First Progress Report on Racking Tests of Wall Panels,” John A. Blume and Associates Research Division, *Report NVO-99-15*, San Francisco, Calif., Aug 1966.

John A. Blume and Associates, (1968). “Second Progress Report on Racking Tests of Wall Panels,” John A. Blume and Associates Research Division, San Francisco. *Report JAB-99-35*, Jul. 1968.

Lang, A.F., Restrepo, J.I. (2006), “Seismic performance evaluation of gypsum wallboard partitions.” *Proceedings of 8th U.S. National Conference on Earthquake Engineering*, EERI, San Francisco, California, U.S.A., 2006, Paper No. 1353.

Lang, A.F. (2007) “Seismic performance evaluation of gypsum wallboard partitions, *MS Thesis*, University of California at San Diego.

Lee, T.H., M. Kato, T. Matsumiya, K. Suita and M. Nakashima (2006), “Seismic performance evaluation of non-structural components: drywall partitions,” *Annals of the Disaster Prevention Research Institute*, Kyoto University, No. 49 C, pp. 177–188.

Lee, T.H., M. Kato, T. Matsumiya, K. Suita and M. Nakashima (2007), “Seismic performance evaluation of non-structural components: drywall partitions,” *Earthquake Engineering and Structural Dynamics*, Vol. 36, pp. 367–382.

Rahmanishamsi, E., S. Soroushian, and M. Maragakis. (2014) "System-Level Experiments on Ceiling/Piping/Partition Systems at UNR-NEES Site." In Tenth US National Conference on Earthquake Engineering. July 2014.

Retamales, R., Davies, R., Mosqueda, G., and Filiatrault, A. (2010). “Experimental seismic fragility of light gauge steel studded gypsum partition walls.” 9th US National and 10th Canadian Conference on Earthquake Engineering, July 2010.

Rihal, S.S. (1982). “Behavior of non-structural building partitions during earthquakes” *Seventh Symposium on Earthquake Engineering*, Sarita Prakashan, Meerut, India, , Vol. 1, pp. 267-277.

Rihal, S.S., Granneman, G. (1984), “Experimental investigation of the dynamic behavior of building partitions and suspended ceilings during earthquakes”, *Report No. ARCE R84-1*, Architectural Engineering Dept., California Polytechnic State Univ., San Luis Obispo

Taghavi, S. and Miranda, E. (2003), “Response Assessment of Nonstructural Building Elements,” *Report No. PEER 2003/05*, Pacific Earthquake Engineering Research Center, University of California, Berkeley.