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SEISMIC FRAGILITY ASSESSMENT OF RESIDENTIAL ANCHORED BRICK VENEER WALLS

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ABSTRACT

The out-of-plane seismic fragilities of single-story brick veneer walls built over a wood frame backup were evaluated analytically. Two-dimensional (2-D) finite element (FE) brick veneer wall strip models were developed, based in part on earlier experimental findings, and nonlinear time history analyses were then carried out by subjecting these FE models to synthetic earthquake ground motions representing the seismic characteristics of the central and eastern U.S. Onset of damage at key tie connection locations was used to evaluate the damage limit states of brick veneer walls; the two damage limit states evaluated in this fragility study were onset/accumulation of wall tie damage (described as repairable damage), and brick veneer wall instability/collapse. Throughout the analytical fragility study, brick veneer wall panel component properties were assumed to be deterministic, therefore mainly focusing the work on wall damage uncertainty due to seismic loads. Sensitivity of wall damage probabilities to variability in the ultimate capacities of the tie connections was reviewed afterwards. Three types of tie connection properties and two distinct tie layouts were represented in the FE wall models; the influence of typical wood frame house backup properties on out-of-plane seismic performance of brick veneer walls was also reviewed. Seismic fragility functions were computed to represent both current design standards and common practice for residential brick veneer construction.

Introduction

Wood frame structures with anchored brick masonry veneer are a common type of residential construction throughout the United States, Canada, Australia, and other regions of the world. This type of construction typically comprises an interior wood frame backup structure and an exterior masonry wall (separated by an air cavity), with regularly spaced corrugated sheet metal ties used to connect the brick masonry to the backup. In recent years, brick veneer wall damage (including cracking, relative movement, and collapse) has been observed resulting from moderate earthquakes. Damage of brick veneer walls has mainly been attributed to their vulnerability to out-of-plane loading, as the brick veneer moves away from the wood backup, placing a high demand on the tensile force and displacement capacity of the tie connections. In such cases, tie connections typically ultimately exhibit one of three types of failure: tie fracture, tie pullout from the mortar joint, or tie fastener (nail) pullout from the wood backup. Veneer

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wall damage has often been explained by improper material use and/or poor workmanship during construction, particularly as relates to installation of the tie connections.

Experimental and analytical studies have been undertaken at the University of Illinois to investigate the out-of-plane seismic performance of brick veneer wall systems over wood framing, representing typical U.S. construction practice (Choi and LaFave 2004, Reneckis et al. 2004, LaFave and Reneckis 2005, Reneckis and LaFave 2005). As part of the final phase of the project, finite element (FE) models, developed based on test results from brick veneer tie connection and single-story wall panel experimental studies, have been utilized to evaluate the seismic fragility of this form of construction (Reneckis and LaFave 2009). Seismic fragility functions were computed to represent both current design standards and common practice for residential brick veneer construction, as described herein.

Brick Veneer Wall Design and Construction Parameters

Prescriptive requirements for brick veneer over wood frame backup wall design and construction are specified in the Masonry Standards Joint Committee (MSJC) Code (2008), the International Residential Code (IRC) for One- and Two-Family Dwellings (ICC 2003), and the Brick Industry Association (BIA) Technical Notes (2002, 2003). Brick masonry with Type N mortar is usually used in veneer wall construction, which is adequate for carrying the self-weight, transferring loads to the tie connections, and limiting flexural cracking of the brick veneer. For anchoring brick veneer to a wood frame backup, the minimum tie thickness is specified as 22 ga., installed with a maximum bend eccentricity of 1/2 in. (12.7 mm) (with the exception of IRC, which does not specify tie bend eccentricity limits), and attached to the wood backup studs with at least 8d nails, as shown in Fig. 1(a). Furthermore, the maximum wall area to be supported by the ties is limited to 2.67 ft^2 (0.25 m^2) for construction in seismic design categories C and below, reduced to 2 ft^2 (0.19 m^2) in higher seismic design categories (among several other requirements for those higher design categories); respectively, these wall areas correspond to tie grid spacings of 24 in. x 16 in. (610 mm x 406 mm), and 16 in. x 16 in. (406 mm x 406 mm), in actual construction. Furthermore, MSJC (2008) and IRC (ICC 2003) require that ties be provided within 12 in. (305 mm) of wall edges near openings; this dimension is reduced to 8 in. (203 mm) in BIA (2003), where the maximum edge distance is recommended for tie placement near openings and at other discontinuities in brick veneer walls (such as at wall edges, expansion joints, or shelf angles).

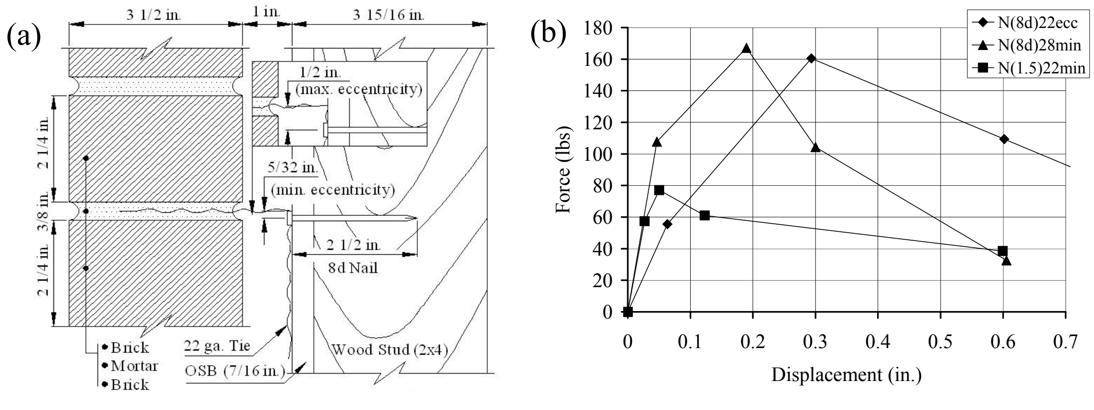

Figure 1. Tie connection details: (a) section view of installation, and (b) idealized force-displacement behavior in tension. (1 in. = 25.4 mm; 1 lb = 4.45 N)

In actual construction practice, however, tie installation in brick veneer walls frequently deviates from these requirements; 28 ga. ties and/or shorter roofing nails are commonly used as substitutes, with a variety of tie layouts. The seismic performance and damage of brick veneer walls has been attributed to the performance of the corrugated sheet metal tie connections; therefore, brick veneer wall fragilities were evaluated as a function of three representative types of tie connection properties: (1) code compliant 22 ga. ties with 1/2 in. maximum bend eccentricity, attached to the wood stud by an 8d nail (N(8d)22ecc); (2) thinner 28 ga. ties without a bend eccentricity, also attached by an 8d nail (N(8d)28min); and (3) 22 ga. ties without a bend eccentricity, attached by a 1.5 in. roofing nail (N(1.5)22min), representing poor workmanship during tie installation. The idealized tensile force-displacement relationships for these tie connections is shown in Fig. 1(b), from experimental tie subassembly test results by LaFave and Reneckis (2005). (The predominant failure mode observed in the monotonic tension tests of these tie connections was nail pullout from the wood stud; tie fracture and yield around the tie hole was also noted during some of the cyclic tests.) In this analytical study, a horizontal tie spacing of 16 in. (406 mm) with a vertical tie spacing of 24 in. (610 mm) (labeled as wall type A), was assigned for walls with all three types of tie connections, representing the maximum supported brick veneer wall area (per tie) requirement in seismic design category C or lower per MSJC (2008). Then, two additional walls were studied, with N(8d)22ecc and N(1.5)22min types of ties and the vertical spacing reduced to 16 in. (406 mm) (labeled as wall type D), representing a maximum supported wall area requirement for seismic design category D or higher. These tie connection properties and layouts were meant to represent typical brick veneer walls built in accordance with prescriptive construction and design requirements per MSJC (2008), IRC (ICC 2003), and BIA (2003), as well as per methods employed in actual construction practice (which do not always meet the prescribed requirements).

Brick Veneer Wall Performance Limit States

According to the ASCE 41-06 Standard for Seismic Rehabilitation of Existing Buildings (ASCE 2006), the seismic performance objectives for buildings can be described qualitatively in terms of: the safety afforded to building occupants during and after the event; the cost and feasibility of restoring the building to its pre-earthquake condition; the length of time the building is removed from service to effect repairs; and economic, architectural, or historic impacts on the larger community. These performance characteristics are directly related to the extent of damage that would be sustained by the building. It appears that the primary objectives for the seismic performance of residential anchored brick veneer will be related to maintaining occupant safety, along with cost and feasibility of repairs.

In terms of safety objectives, ASCE 41-06 requires that anchored brick veneer wall components satisfy three performance levels, including: Immediate Occupancy (IO), Life Safety (LS), and Hazards Reduced (HR). Qualitative descriptions of these performance levels for architectural cladding components (most closely applicable to anchored brick veneer) are summarized in Table 1. Brick veneer wall damage can also be evaluated in terms of cost and feasibility of repairs. Repairable damage will typically involve re-anchoring, as well as some tuckpointing or crack repair of the brick veneer; at the ultimate limit state, collapse will require partial or full reconstruction of the brick veneer. Overall, it can be expected that "repairable damage" will result in repair costs of approximately several hundred dollars (perhaps up to a few thousand dollars). Reconstruction of collapsed walls, on the other hand, might result in a few thousand and maybe up to tens of thousands of dollars worth of repairs (a significant portion of the total cost of a single-family home). This type of information can be utilized by building owners, as well as insurance companies, to estimate probable financial losses of residential brick veneer construction during earthquakes.

Table 1. Performance levels for architectural cladding components per ASCE 41-06.

Immediate Occupancy (IO)	Life Safety (LS)	Hazards Reduced (HR)
Connections yield; minor cracks (< 1/16 in. width) or bending in cladding.	Severe distortion in connections. Distributed cracking, bending, crushing, and spalling of cladding components. Some fracturing of cladding, but panels do not fall.	Severe distortion in connections. Distributed cracking, bending, crushing, and spalling of cladding components. Some fracturing of cladding, but panels do not fall in areas of public assembly.

During experimental studies of brick veneer wall panels, it was noted that the overall veneer wall response depended primarily on the tensile performance of the tie connections. At the onset of tie damage in brick veneer walls, peak measured tie elongations were found to be closely related to elongations determined for ultimate loading during tie subassembly tests (Reneckis et al. 2004). Different ranges of brick veneer wall behavior (including *elastic*, *intermediate*, and *ultimate*) and related damage limit states were then identified and evaluated analytically with 3-D FE models by focusing on the tensile performance of key tie connections, without explicitly evaluating for cracking of the brick veneer (LaFave and Reneckis 2005, Reneckis and LaFave 2009). Based on the observed performance, a simplified 2-D brick veneer wall strip model has been developed for fragility assessment of this form of construction. With this simplified model, two damage limit states are evaluated: *(i-ii)* onset/accumulation of tie failure at the top of the wall (a combination of the first two damage limit states evaluated earlier experimentally and analytically with 3-D models), and *(iii)* tie failure at the lower rows from the top (representing brick veneer wall instability/collapse). In general, both IO and LS performance levels can therefore be related to limit state (*i-ii*), and the HR performance level can be related to limit state (*iii*). In terms of repair costs, these two damage limit states can generally be described as: (*i-ii*) repairable damage, and (*iii*) collapse (possibly requiring major reconstruction).

Brick Veneer Wall Finite Element Model

Brick Veneer Wall Strip Model Geometry and Material Properties

For analytical fragility assessment of brick veneer walls, 3-D solid single-story brick veneer wall panel models, which were developed, calibrated, and validated per an experimental wall setup and behavior, were reduced to a 2-D wall strip. The analysis software *ABAQUS* (Abaqus Inc. 2006) and the pre- / post-processor software *MSC.Patran* (MSC 2005) were utilized. As shown in Fig. 2(a-b), the model consisted of the wood frame wall, the brick veneer, and the corrugated sheet metal tie connections; other surrounding "boundary" components of the wall structure were implemented as spring support conditions. This wall strip was set up to be 16 in. (406 mm) wide, representing the tributary width of a wall system with a wood backup stud spacing of 16 in. on center. The brick veneer and wood frame backup FE models were linked along their vertical centerline by axial bar elements representing the tie connections. The 2x4 stud beams were assigned dimensions of 1.5 in. x 3.5 in. (38 mm x 89 mm), and the OSB was modeled as 7/16 in. (11 mm) thick shells. The brick veneer was also modeled using shell elements, with its reference plane at the shell mid-surface and assigned a thickness of 3.5 in. (89 mm). Material properties for wood and masonry components were assumed to be linear elastic and deterministic; median modulus of elasticity and density values were assigned, as listed in Table 2, based on those utilized in modeling of the experimental wall specimens.

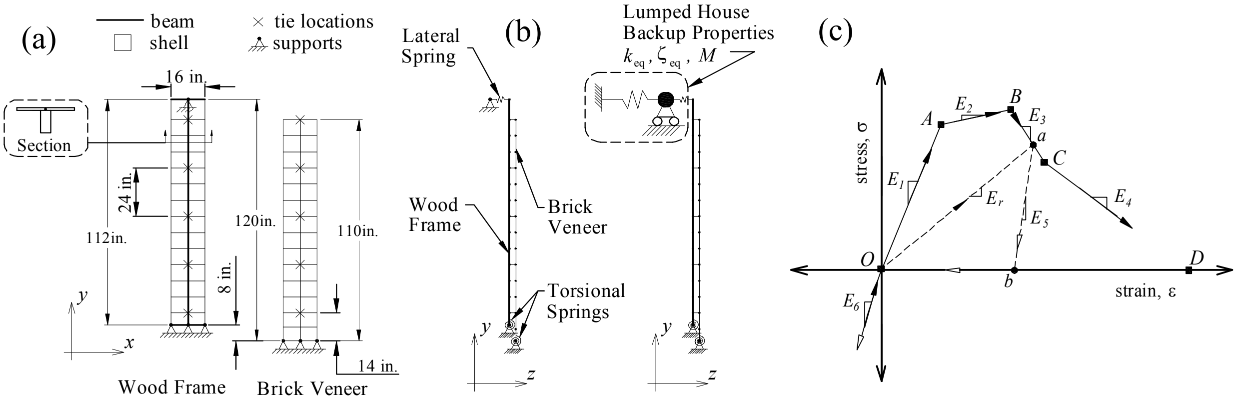

Figure 2. (a) Front view of simplified 2-D wall strip model representing a single-story solid brick veneer wall panel. (b) Side view of wall strip without and with lumped properties representing a house backup structure. (c) Tie connection hysteresis model.

Table 2. FE wall model material properties.

Material	Modulus of Elasticity, E (ksi)	Poisson's Ratio, ν	Density, ρ (pcf)
Wood Studs[a]	1,200	0.4	26.2
OSB Sheathing[a]	930	0.4	31.2
Gypsum Wallboard	-	-	41.2[b]
Brick Masonry	2,000[c]	0.2	115[b]

[a] Modulus of elasticity and density from NDS (2001).

[b] Density from wall specimen material weight.

[c] Modulus of elasticity determined from masonry prism tests.

The experimental brick veneer walls generally exhibited more rigid body rotation (rocking about their base) than bending when subjected to out-of-plane static and moderate dynamic loading. Experimental results also indicated that wall response, up to and including ultimate cracking and collapse of the veneer, was most closely associated with the performance of the tie connections. Therefore, the experimental load vs. displacement behaviors of the tie connections, evaluated both during tie subassembly and brick veneer wall panel testing, were implemented in unique nonlinear “material” constitutive models for the axial tie connection elements. As shown in Fig. 2(c), the behavior in tension was nonlinear inelastic (based on the average idealized monotonic tensile force-displacement relationship from subassembly test results, shown in Fig. 1(b)), and linear elastic in compression (based on both subassembly and wall test results), to combine the effects of the ties and excess mortar within the wall cavity.

Brick Veneer Wall Strip Model Support Conditions

The FE brick veneer wall models employed in this fragility study were generally based on the experimental brick veneer wall specimens and their observed behavior. The experimental wall specimens were designed and constructed to represent the various details of actual brick veneer wall systems, including their boundary conditions; however, due to limitations of the shake table size and capacity, the mass and dynamic response of an entire house were not captured in the test setup (Reneckis et al. 2004). In the FE model, the cumulative effects of the surrounding wood backup components (such as the concrete foundation, floor and roof/ceiling framing, and rafter ties and other nail connections to the wall frame) on the brick veneer wall system were incorporated into elastic rotational springs along the bottom of the wall (assigned 1,000 k-in./rad [110 kN-m/rad]) and translational spring supports along the top (assigned 1.4 k/in. [250 kN/m]). Furthermore, a pin support with a nonlinear elastic rotational spring was implemented at the base of the brick veneer wall model, representing a rigid body rocking response (based on the self-weight and geometry of the brick veneer). A viscous damping ratio of 4% was assigned to the brick veneer wall strip model. Preliminary time history analyses were then conducted by subjecting the FE wall strip model to out-of-plane seismic loads, to validate its performance against earlier 3-D analytical and experimental results, effectively capturing different ranges of wall behavior and defined damage limit states (Reneckis and LaFave 2009).

It is difficult to estimate a fixed set of properties to characterize a typical wood frame home structure because they are highly variable. Therefore, to model the amplification to the dynamic response of brick veneer walls by a backup structure, a simple one degree of freedom lumped backup model, with a weight of 32 kips (corresponding to mass of 14,500 kg) and viscous damping of 5%, was introduced at the top support of the brick veneer wall strip model, as shown in Fig. 2(b). The stiffness properties of the lumped backup model were then varied, in relation to the first natural period of vibration of the brick veneer wall panel T_{wall}. In general, a model without the lumped backup structure (i.e., with T_{backup}/T_{wall} = 0.0, such as in the experimental test setup) was an effective upper bound for evaluating the out-of-plane dynamic performance of brick veneer walls, capturing the minimal amplification effects of both very rigid and flexible backups. The highest response would then occur for a wall strip with T_{backup}/T_{wall} equal to 1.0 (i.e. $T_{backup} = T_{wall}$), providing a conservative lower bound for out-of-plane wall capacity. In this study, both types of lumped backup models were represented for brick veneer walls with ties spaced 24 in. vertically (wall type A), and the worst-case scenario backup properties were utilized for walls with ties at 16 in. vertically (wall type D). It was assumed that the backup response would primarily be dominated by linear behavior.

Seismic Fragility Analysis Procedure and Results

The seismic fragility of a structure and its components is generally identified as the failure probability of meeting their strength and/or serviceability performance objectives, as a function of seismic demand. Aleatory and epistemic sources of uncertainty have to be considered during seismic hazard analysis of structures. Aleatory uncertainty has been identified as the inherent randomness, generally characterized by uncertainty in seismic demand and structural capacity. The seismic excitation uncertainty usually dominates the vulnerability of structures because the uncertainty in seismic excitation is typically much larger than that of the structural capacity (Wen and Ellingwood 2005). Therefore, in the current study all of the brick veneer wall system components were simply assumed to be deterministic, assigned average material properties based on experimental observations and standard published values. On the other hand, epistemic or knowledge-based uncertainty is generally characterized by modeling error. This type of uncertainty was not evaluated in the current study because alternate prediction models were not investigated.

To evaluate the seismic fragility, a structural and/or component damage analysis has to be conducted, with the earthquake intensity measure as the input and the damage limit state as the output. The damage limit state can be described by a system response variable D_j exceeding a deterministic threshold *d*. Therefore, a fragility function is the probability of exceeding a damage limit state at a given excitation intensity measure *X*, as follows:

$$F_R(x) \equiv P[D_j \geq d \,|\, X = x] \;. \tag{1}$$

This relationship has been idealized by a lognormal distribution as:

$$F_R(x) = \Phi\left(\frac{\ln(x/m_R)}{\beta}\right), \tag{2}$$

where Φ denotes the standard normal (Gaussian) cumulative distribution function, m_R is the median value of the distribution, and β is the logarithmic standard deviation (Porter et al. 2007).

A total of twenty synthetic earthquake records generated by Wen and Wu (2001) (ten records with a hazard level of 10%, and another ten with a hazard of 2%, in 50 years) for representative soil conditions in Memphis, Tennessee, were selected for the current study. The seismic excitation intensity measure *X* was characterized by the earthquake input peak ground accelerations (PGAs), normalized and scaled at 0.1g increments. The occurrences and sequences of tie damage were assessed with the FE models to evaluate the defined damage limit states of brick veneer walls. Tie connection damage in the FE models was determined from the maximum computed tie elongations D_j; at a stage when these elongations exceeded the opening displacements at ultimate load capacity *d* found from the tie subassembly tests, the tie connections in the FE models were considered to be damaged. Damage limit state *(i-ii)* was identified with the top row tie D_A exceeding *d*, and *(iii)* was identified with the second row tie D_B and third row tie D_C exceeding *d*, respectively, in walls with vertical spacings of 24 in. (610 mm) and 16 in. (406 mm). The likelihood of each damage limit state was then computed for the known earthquake excitation PGA intensity increment by:

$$P_f = \frac{m+1}{M+1}, \tag{3}$$

where *m* is the number of walls that experienced damage for a particular PGA increment, and *M* is the total number of analyses (equal to twenty). (This probability function, as presented by Porter et al. (2007), generally provides a conservative estimate of the failure probability when a relatively small sample is available.) Lognormal distribution parameters were then computed from the damage probabilities and the natural logarithm of the earthquake input PGAs, by utilizing probability paper; these parameters were the seismic demand uncertainty $\beta\,(=\beta_{D|X})$ and median m_R. Fragility curves based on these analysis results are shown in Figs. 4 and 5, and the lognormal distribution parameters are summarized in Table 3.

Following the time history analyses, the sensitivity of brick veneer wall damage to variability in tie connection capacity β_C was then evaluated by combining the seismic uncertainty with that of the tie connection strength by letting $\beta = \sqrt{\beta_{D|X}^2 + \beta_C^2}$. The uncertainty in brick veneer tie connection strength β_C was characterized by the coefficient of variation of their ultimate strength capacities, which were 0.36, 0.13, and 0.17, respectively for N(8d)22ecc, N(8d)28min, and N(1.5)22min types of ties (based on subassembly test data).

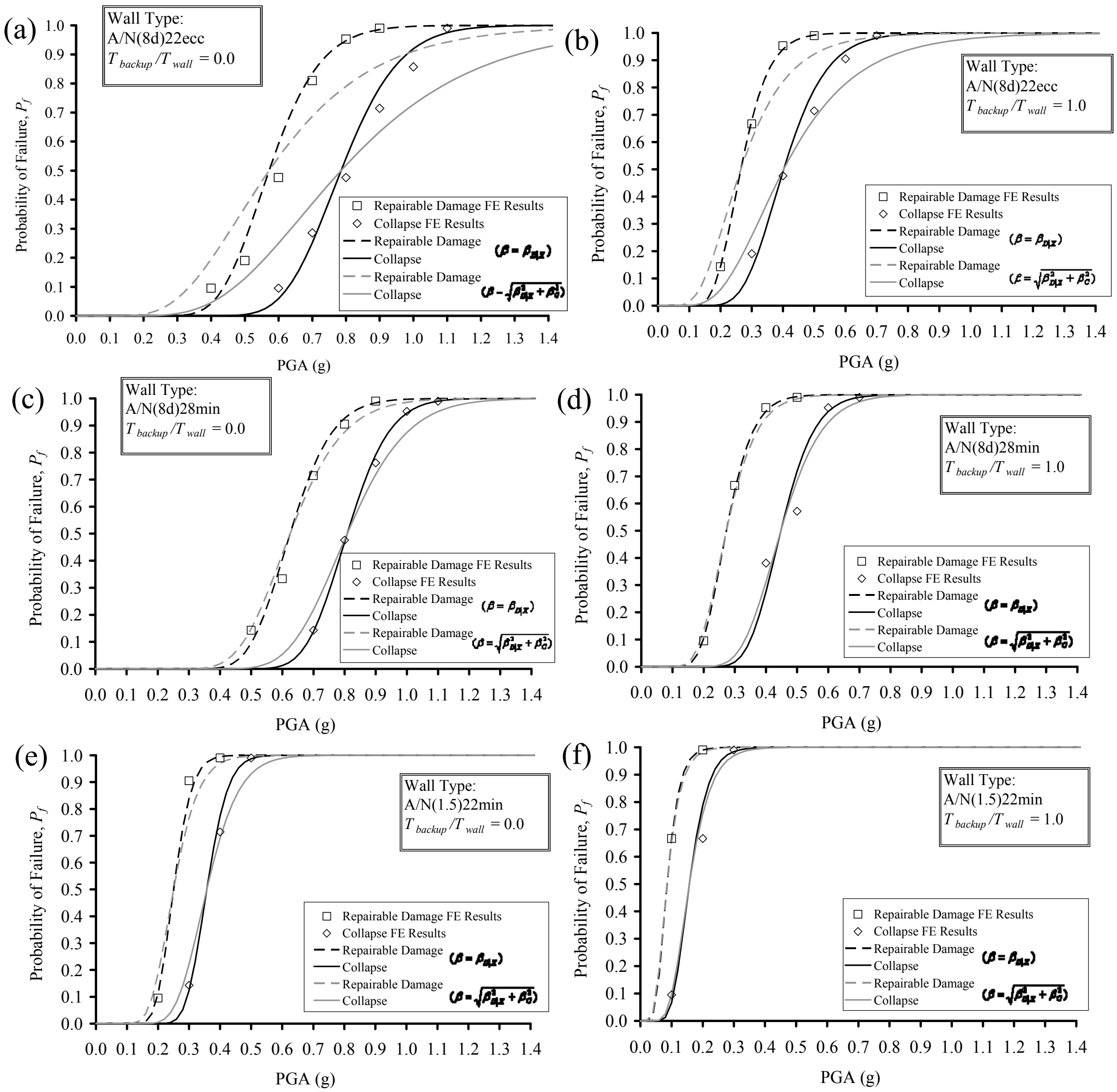

Figure 4. Seismic fragility curves for brick veneer walls with (a-b) N(8d)22ecc, (c-d) N(8d)28min, and (e-f) N(1.5)22min types of tie connections spaced 24 in. vertically.

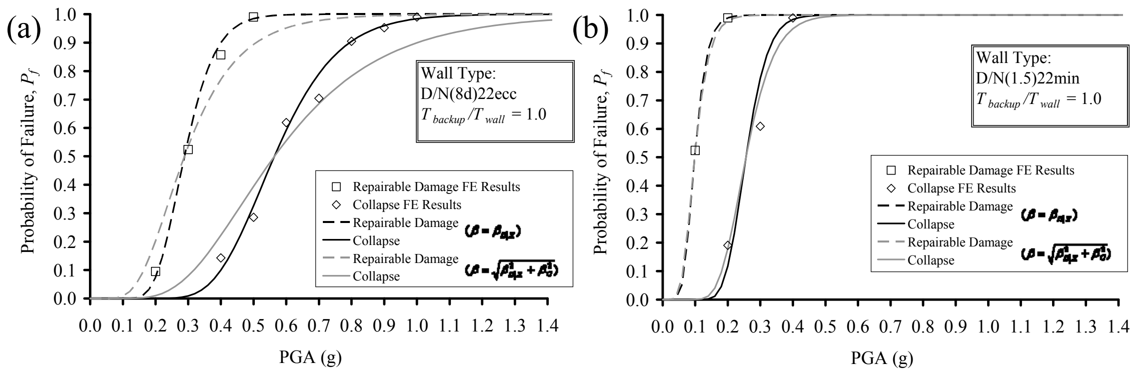

Figure 5. Seismic fragility curves for brick veneer walls with (a) N(8d)22ecc and (b) N(1.5)22min types of tie connections spaced 16 in. vertically.

Table 3. Summary of lognormal distribution parameters.

Wall Type	Wall Natural Period of Vibration, T_{wall} (sec)	Properties of Lumped Backup Structure, T_{backup}/T_{wall}	Damage Limit States			
			Repairable Damage (*i-ii*)		Collapse (*iii*)	
			Mean, m_R	St. Dev., $\beta_{D\|X}$	Mean, m_R	St. Dev., $\beta_{D\|X}$
A/N(8d)22ecc	0.139	0.0	-0.558	0.207	-0.242	0.172
		1.0	-1.328	0.264	-0.910	0.267
A/N(8d)28min	0.126	0.0	-0.470	0.170	-0.213	0.132
		1.0	-1.298	0.247	-0.803	0.190
A/N(1.5)22min	0.127	0.0	-1.386	0.184	-1.029	0.150
		1.0	-2.460	0.366	-1.851	0.301
D/N(8d)22ecc	0.138	1.0	-1.242	0.255	-0.573	0.267
D/N(1.5)22min	0.126	1.0	-2.321	0.306	-1.363	0.208

Summary and Conclusions

The out-of-plane seismic fragilities of brick veneer walls built over a wood frame backup were evaluated analytically, in terms of two damage limit states, as a function of earthquake excitation PGAs. Key findings from this study can be summarized as follows:

- On average, brick veneer walls with 22 ga. and 28 ga. ties attached by 8d nails exhibited similar fragilities at both damage limit states, and walls with 22 ga. ties attached by short roofing nails (representing poor workmanship during tie installation) experienced damage at significantly lower PGAs. For walls with reduced tie spacings, the fragility curves exhibited a slight shift to the right, as compared to the curves for walls with larger tie spacings. Damage to brick veneer walls was also affected by the amplification of the lumped backup structure model, with the damage limit state PGAs nearly two times lower for walls with the worst-case backup stiffness defined by T_{backup}/T_{wall} equal to 1.0.

- The uncertainty in seismic loading dominated the vulnerability of brick veneer walls; however, brick veneer walls utilizing tie connections with higher variability in their ultimate strength resulted in a noticeable effect on the fragility curves. By increasing the lognormal standard deviation, the slope of the fragility curves was reduced, generally causing them to rotate about the mean damage PGAs. Brick veneer walls with N(8d)22ecc type tie connections exhibited the largest variation.

- This set of fragility functions provides a more accurate estimate of brick veneer wall seismic vulnerabilities, compared to the expert opinion based fragilities available to date for unreinforced masonry buildings, which may only act as a baseline case for fragility assessment of residential brick veneer construction. Ultimately, fragility analysis results for anchored residential brick veneer can be compared with the acceptable seismic performance levels established in ASCE 41-06. These results can be utilized in conjunction with the seismic hazard maps from USGS to identify the feasibility of this form of construction in certain U.S. regions.

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References

Abaqus, Inc. (2006). *ABAQUS 6.6-2,* Providence, R.I.

ASCE. (2006). "Seismic Rehabilitation of Existing Buildings." *ASCE 41-06*, New York, N.Y.

Brick Industry Association (BIA). (2002). "Technical Notes 28 - Anchored Brick Veneer, Wood Frame Construction." *Technical Notes on Brick Construction,* Reston, Va.

BIA. (2003). "Technical Notes 44B - Wall Ties for Brick Masonry." *Technical Notes on Brick Construction,* Reston, Va.

Choi, Y.H. and LaFave, J.M. (2004). "Performance of Corrugated Metal Ties for Brick Veneer Wall Systems." *Journal of Materials in Civil Engineering,* 16(3), 202-211.

International Code Council (ICC). (2003). *International Residential Code for One- and Two-Family Dwellings,* Falls Church, Va.

LaFave, J.M. and Reneckis, D. (2005). "Structural Behavior of Tie Connections for Residential Brick Veneer Construction." *The Masonry Society Journal,* 23(1), 9-24.

Masonry Standards Joint Committee (MSJC). (2008). *Building Code Requirements for Masonry Structures. ACI 530-08/ASCE 5-08/TMS 402-08,* ACI, Farmington Hills, Mich.; ASCE, Reston, Va.; TMS, Boulder, Colo.

MSC.Software Corporation (2005). *MSC Patran 2005 r2,* Santa Ana, Calif.

National Design Specification for Wood Construction (NDS). (2001). American Forest and Paper Association, Washington, D.C.

Porter, K., Kennedy, R., and Bachman, R. (2007). "Creating Fragility Functions for Performance-Based Earthquake Engineering." *Earthquake Spectra,* 23(2), 471-489.

Reneckis, D., LaFave, J.M., and Clarke, W.M. (2004). "Out-of-Plane Performance of Brick Veneer Walls on Wood Frame Construction." *Engineering Structures,* 26(8), 1027-42.

Reneckis, D. and LaFave, J.M. (2005). "Analysis of Brick Veneer Walls on Wood Frame Construction Subjected to Out-of-Plane Loads." *Construction and Building Materials,* 19(6), 430-47.

Reneckis, D. and LaFave, J.M. (2009). *Seismic Performance of Anchored Brick Veneer,* Newmark Structural Laboratory Report Series No. 016, < http://www.ideals.illinois.edu/handle/2142/13670> University of Illinois at Urbana-Champaign, Urbana, Ill.

Wen, Y.K. and Wu, C.L. (2001). "Uniform Hazard Ground Motions for Mid-America Cities." *Earthquake Spectra,* 17(2), 359-384.

Wen, Y.K. and Ellingwood, B.R. (2005). "The Role of Fragility Assessment in Consequence-Based Engineering." *Earthquake Spectra,* 21(3), 861-877.