LATERAL LOADS ON BRICK VENEER RESIDENTIAL STRUCTURES

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ABSTRACT

In North American residential construction, brick veneer is typically used as a cladding system over wood stud wall systems. The brick veneer of these wall systems is normally assumed to act only as a cladding and any contributory resistance is not accounted for in the design of the lateral load resisting system of the structure.

As more building and national design codes require greater resistance to lateral loads, wind and seismic resistance are of growing concern. For a seismic analysis of a residential structure clad in brick veneer, the accelerated weight of the brick becomes a significant component of these lateral loads. In fact, the new International Residential Code has prescriptive limitations and requirements in higher seismic design categories that have resulted in brick veneer being restricted to one-story structures in many parts of the United States.

To evaluate the performance of brick veneer residential structures, a multiphase research program was proposed. In the first phase of this program the lateral loads applied to residential structures by code defined wind and seismic designs were determined for typical residential configurations. These loads were compared over a range of wind speed zones and seismic design categories. The result of this analysis indicates that typically wind forces are significantly higher than the calculated seismic forces and should be the governing lateral design load. In addition, there appears to be a significant difference in the code requirements of wood shear walls for wind versus seismic loading. This paper summarizes the findings of the first phase of this investigation and discusses the ramifications of the apparent inconsistencies in load versus resistance provisions.

Keywords: Lateral Loads, Light-Framed Residential Construction, Seismic, Wind, International Residential Code, Brick Veneer, Empirical Design, Rational Design

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INTRODUCTION

Light wood-framed construction has been, and currently is, the predominate technique for residential construction in the United States. Conventional light wood-framed residential construction has evolved throughout the 20th century. This evolution has included changes in member size (e.g., actual size vs. nominal size), plywood sheathing panels and oriented strand board replacing board sheathing, changes in nailing techniques and growing use of metal plate-connected wood trusses.

Conventional construction has historically been based on an empirical rationale as opposed to rational engineering analysis [HEW, 1931]. Subsequently, conventional residential construction practice typically occurs without the services of a design professional but uses prescriptive requirements that have been incorporated into building codes. In 1971, the Council of American Building Officials (CABO) first published the *One-and Two-Family Dwelling Code*. The intent of this code was to provide prescriptive requirements for the construction of residential structures. In recent times, the International Code Council (ICC) developed the *International Residential Code for One- and Two-Family Dwellings* (IRC). This code was published for the first time in 2000. The intent of this code was also to provide prescriptive requirements for the construction of residential structures that would be adopted throughout the United States.

The United States' National Earthquake Hazard Reduction Program (NEHRP) has developed the Recommended Provisions for Seismic Regulations for New Buildings. The 1997 NEHRP provisions included the development of new seismic acceleration maps for use in design as well as new structural design procedures [NEHRP, 1997 (a and b)]. Further, the American Society of Civil Engineers (ASCE) publishes a standard, *Minimum Design Loads for Buildings and Other Structures* (ASCE7-98), for which the NEHRP document serves as a basis for the seismic provisions [ASCE, 1999].

The International Residential Code (2000 edition) uses these aforementioned NEHRP maps as a basis to prescriptively define Seismic Design Categories. These categories are designated as A, B, C, D_1, D_2 and E. [International Residential Code, 2000 edition]. These new seismic maps have resulted in significant portions of the United States having substantially greater seismic building code requirements than in previous adopted codes (including residential). It is noteworthy that these newer seismic maps are a subject of significant controversy [Newman et al., 1999][Tomasello et al. 2001]. This controversy includes questions related to whether the risk of earthquakes is significantly overstated and result in higher lateral loads. In addition, the controversy questions whether there is a uniform treatment of life-safety issues across fire, wind and seismic concerns. Consequently, the economic justification of the higher seismic requirements becomes questionable.

The International Residential Code defines prescriptive requirements and limitations for specific Seismic Design Categories. These requirements and limitations include lateral resistance criteria for wood framing. These criteria are prescriptive and require consideration of both seismic and wind loads when determining requirements. In addition, the International Residential Code currently limits the use of brick veneer with wood backing to one story in Seismic Design Categories D_1 and D_2 and provides other requirements for some applications within Categories C. The fundamental basis of this limitation was that the governing lateral load produced from the design seismic event would exceed the shear and overturning capacities of a typical wood-frame configuration when the weight of the brick veneer is included in the seismic analysis.

This paper presents the results of the first phase of the investigation relative to the evaluation of lateral loads for typical residential building configurations. Also discussed are the prescriptive provisions in the code and whether these provisions are appropriate and/or consistent.

ANALYTICAL MODELING

To evaluate the relative effects of calculated wind and seismic loads on typical one and two story residential structures, the analytical investigation was conducted as follows: 1) prototype models of building geometry and cladding types were selected; 2) design wind and design seismic loads were identified; 3) design load analyses of the configurations for design wind speeds and design seismic categories were performed; and 4) the shear at diaphragm and base levels for the design wind and seismic loading were determined.

Prototype Models

Typical one and two story rectangular building structures having dimensions of 7.62 meters (25 feet) by 15.24 meters (50 feet) were selected for analysis. Figures 1 and 2 depict the one and two story analytical models, respectively. An interior floor to floor height of 2.74 meters (9 feet) was assumed and resulted in a diaphragm to diaphragm distance of 3.05 meters (10 feet)).

Three cladding types were assumed in the analysis, including two brick veneer types and one “other” (non-brick veneer). The brick veneer were assumed to be either a standard (or modular) unit having a thickness of 92 mm (3-5/8 inches) or a smaller unit having a thickness of 76 mm (3 inches). The “other” cladding type was assumed to have a weight of 0.479 kN/m^2 (10 lbs/ft^2).

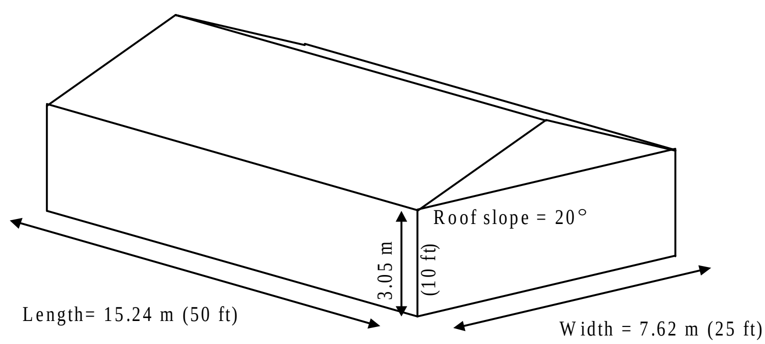

Figure 1: One Story Building Configuration

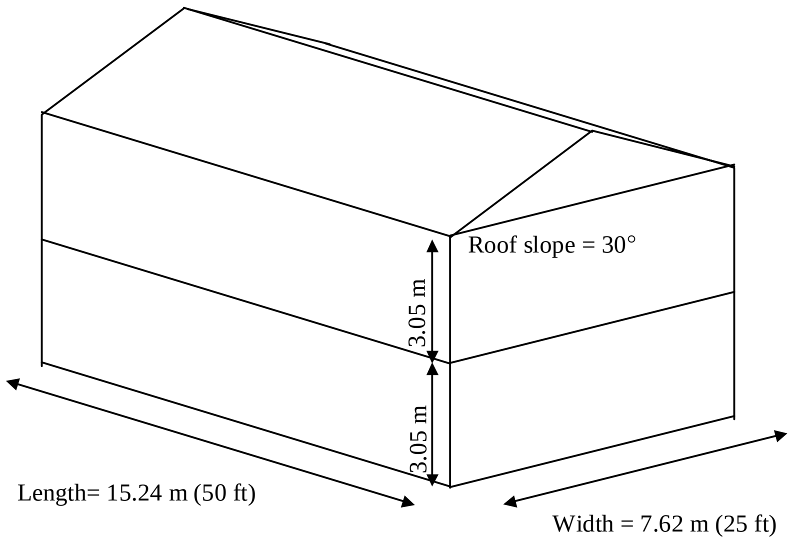

Figure 2: Two Story Building Configuration

Building Weight Assumptions

Dead loads produced by the weights of building components are fairly well defined and available from numerous sources. Building weights were selected using the Residential Design Guide 2000 [HUD, 2000] as follows:

Roof:	0.716 kN/m^2 (15 lbs/ft^2)
Floor:	0.479 kN/m^2 (10 lbs/ft^2)
Exterior Walls (92 mm Brick Unit):	2.156 kN/m^2 (45 lbs/ft^2)
Exterior Walls (76 mm Brick Unit):	1.867 kN/m^2 (39 lbs/ft^2)
Exterior Walls (“Non” Brick Siding):	0.479 kN/m^2 (10 lbs/ft^2)
Interior Braced Wall:	0.479 kN/m^2 (10 lbs/ft^2)
Interior Partition Walls:	0.287 kN/m^2 (6 lbs/ft^2)

Exterior wall weights were reduced by 15% for the brick veneer cases to account for the effect of openings.

IDENTIFYING DESIGN WIND AND SEISMIC LOADINGS

Design Wind Loadings

The 2000 International Residential Code references ASCE7-98 for determining design wind speeds. Based on these wind speeds, the vast majority of the continental United States uses a Basic Design Wind Speed of 40 m/s (90 mph), although the majority of the west coast states use a Design Wind Speed of 38 m/s (85 mph). States bordering oceans have design speeds that increase from 40 m/s (90 mph) incrementally up to 67 m/s (150 mph). However, the International Residential Code cannot be used for wind speeds exceeding 49 m/s (110 mph). Therefore, the design wind speeds selected for the analyses were 38 m/s (85 mph), 40 m/s (90 mph), 45 m/s (100 mph), and 49 m/s (110mph).

For all load calculations, an Importance Factor of 1.0 was selected. Exposure Categories of both B and C, as defined in ASCE7-98, were evaluated. Further discussion of these exposure selections is provided later in this paper. The topographic factor K_{zt} was assumed to be unity. Since the K_{zt} value will only be higher in hilly terrain, variation in wind loads due to this factor was not addressed in this investigation. Where applicable, this factor can have significant effects and would increase loads. Wind loads were evaluated both parallel and perpendicular to the roof ridge. However, wind loads that are perpendicular to the roof ridge are higher than those parallel to the roof ridge and only those values are reported since they produce the critical loading on the shorter gable end walls.

Design Seismic Loadings

The 2000 International Residential Code utilizes information in ASCE7-98 to prescriptively determine Seismic Design Categories for residential structures. These Seismic Design Categories include A, B, C, D_1, D_2 and E and each have a listed spectral acceleration response in the 0.2-second frequency range. Maximum spectral acceleration responses for A, B, C, D_1, D_2 are given as 0.17, 0.33, 0.50, and 0.83, and 1.17, respectively. Seismic Design Category E is highly dependent on site conditions and is not provided with a maximum spectral response.

This investigation limited itself to evaluating Seismic Design Categories C, D_1 and D_2. As with wind, an Importance Factor of 1.0 was used for the seismic load calculations. The default Site Class D per the International Residential Code was selected. In addition, a Response Modification Coefficient (R factor) for the analysis was selected from ASCE7-98. This document defines an R factor for the wood-framed construction of 6.5 and since the main resisting system in the residential structures was assumed to be the wood shear walls, this value was selected for all the building configurations.

ANALYSIS

Wind Loads

The velocity pressure evaluated at a given height is evaluated by the formula:

$$q_z = 0.613 K_z K_{zt} K_d V^2 I \quad (N/m^2) \quad (q_z = 0.00256 K_z K_{zt} K_d V^2 I \quad (lb/ft^2)) \tag{1}$$

where

K_z = velocity pressure exposure coefficient
varys from 0.57 to 0.649 for Exposure B
varys from 0.85 to 0.929 for Exposure C
K_{zt} = topographic factor
K_d = Directional Factor, 0.85
V = Design Wind Speed
I = Importance Factor

For the purpose of the analysis, an enclosed building analysis was used. Uplift was not addressed but it is acknowledged that uplift may increase any overturning moment requirements. Also, this analysis assumed the small portion of the triangular load distribution on the windward wall face was transferred to the roof diaphragm level. This simplification will have a relatively minimal effect on overturning moment produced but will not affect the base shear determined.

For purpose of this analysis, the main force resisting system pressure, p, was calculated using the following equation:

$$p = qGC_p - q_i(Gc_{pi}) \tag{2}$$

(Values of above variables are provided in ASCE7-98)

A strength design methodology was used for this analysis per ASCE7-98. Consequently, a load factor needs to be applied as appropriate. An example wind pressure analysis is provided below for the 2nd floor diaphragm level of a two-story structure using a 40 m/s (90 mph) wind speed and an Exposure Category C.

For 0- 4.6 meters (0-15 feet):

$q_z = 0.613(0.85)(1)(0.85)(40)^2(1) = 709\ N/m^2$

Load at 2nd floor diaphragm level:

Windward:

$p = (709)(0.85)(0.8) – 774(0.18) = 343\ N/m^2$ positive internal pressure

$p = (709)(0.85)(0.8) – 774(-0.18) = 621\ N/m^2$ negative internal pressure

Leeward:

$p = (774)(0.85)(-0.5) – 774(0.18) = -468\ N/m^2$ positive internal pressure

$p = (774)(0.85)(-0.5) – 774(-0.18) = -190\ N/m^2$ negative internal pressure

Net: $p = 343\ N/m^2 + 468\ N/m^2 = 811\ N/m^2$

Load = $811\ N/m^2$ (3.05m x 15.24m) = 37700 N = 37.7 kN

Factored Load = (1.6)(37.7kN) = 60.3 kN

Seismic Loads

Using a conventional seismic analysis, the weight acting at each of the diaphragm levels was determined and summed to determine a total seismic weight. From this total seismic weight, W, the total base shear was determined by the following equation:

$$W = S_{DS}\ (I)\ (W)/(R) \tag{3}$$

Where S_{DS} = Short Period Response Acceleration

I = Importance Factor

W = Total Seismic Weight

R = R Factor

Again, a strength design methodology was used for this analysis per ASCE7-98. For the case of seismic, the load factor is unity and is not shown.

This total base shear was distributed vertically at the diaphragm levels as follows: 1) the weight at that diaphragm level is multiplied by the height 2) this value is divided by the sum of these values for each diaphragm, 3) this value is then multiplied by the V_{base} previously obtained.

An example analysis is provided for a two-story, standard or modular-sized brick veneer structure in Seismic Design Category D_1. The vertical distribution methodology is provided in Table 1.

Weight acting at roof diaphragm = 225 kN (50,600 lbs)
Weight acting at second floor diaphragm = 339 kN (76,200 lbs)
Total Seismic Weight = 564 kN (126,800 lbs)
V_{base} = (0.83)(1)(564)/(6.5) = 72.0 kN (16,200 lbs)

Table 1: Vertical Distribution of Seismic Lateral Load

	Weight(W) (kN)	Height(H) (m)	W x H (kN-m)	$(WxH)^i/\Sigma(WxH)$	V_{shear} (kN)
Roof	225	6.10	1373	0.570	41.0
2nd floor	339	3.05	1034	0.430	31.0
			Σ = 2407	Σ = 1.000	Σ = 72.0

RESULTS

The results of the analysis are summarized in Table 2 through Table 7. Note that any small discrepancies in column summations are due to rounding and/or conversions.

Table 2: Wind Analysis Exposure B - Lateral Load - One Story Configuration
(Values given are in kN (kips))

	38m/s (85mph)	40m/s (90mph)	45m/s (100mph)	49m/s (110mph)
Total	33.3 (7.48)	37.3 (8.39)	46.3 (10.4)	55.6 (12.5)

Table 3: Wind Analysis Exposure B - Lateral Load - Two Story Configuration
(Values given are in kN (kips))

	38m/s (85mph)	40m/s (90mph)	45m/s (100mph)	49m/s (110mph)
Roof	36.8 (8.28)	41.3 (9.29)	51.2 (11.5)	61.8 (13.9)
2nd fl.	37.1 (8.34)	41.6 (9.35)	51.2 (11.5)	62.3 (14.0)
Total	73.8 (16.6)	82.7 (18.6)	102 (23.0)	124 (27.8)

Table 4: Wind Analysis Exposure C - Lateral Load - One Story Configuration
(Values given are in kN (kips))

	38m/s (85mph)	40m/s (90mph)	45m/s (100mph)	49m/s (110mph)
Total	49.8 (11.2)	55.6 (12.5)	68.5 (15.4)	83.2 (18.7)

Table 5: Wind Analysis Exposure C - Lateral Load - Two Story Configuration
(Values given are in kN (kips))

	38m/s (85mph)	40m/s (90mph)	45m/s (100mph)	49m/s (110mph)
Roof	53.4 (12.0)	59.6 (13.4)	73.8 (16.6)	89.0 (20.0)
2nd fl.	54.3 (12.2)	60.9 (13.7)	75.2 (16.9)	91.2 (20.5)
Total	108 (24.2)	121 (27.1)	149 (33.5)	180 (40.5)

Table 6: Seismic Analysis - Lateral Load - One Story Configuration
(Values given are in kN (kips presented in parenthesis below))

	Category C			Category D_1			Category D_2		
	Other	Brick[1]	Brick[2]	Other	Brick[1]	Brick[2]	Other	Brick[1]	Brick[2]
Total	10.1 (2.26)	17.3 (3.89)	16.0 (3.60)	16.7 (3.75)	28.7 (6.46)	26.6 (5.97)	23.5 (5.29)	40.5 (9.11)	37.5 (8.42)

[1] 92 mm (3-5/8 inch) thick brick unit
[2] 76 mm (3 inch) thick brick unit

Table 7: Seismic Analysis - Lateral Load - Two Story Configuration
(Values given are in kN (kips presented in parenthesis below))

	Category C			Category D_1			Category D_2		
	Other	Brick[1]	Brick[2]	Other	Brick[1]	Brick[2]	Other	Brick[1]	Brick[2]
Roof	13.7	24.7	22.8	22.8	41.1	37.8	32.1	57.8	53.4
	(3.09)	(5.56)	(5.12)	(5.12)	(9.23)	(8.50)	(7.22)	(13.0)	(12.0)
2nd fl.	7.87	18.6	16.7	13.1	30.9	27.7	18.5	43.6	39.1
	(1.77)	(4.19)	(3.75)	(2.95)	(6.95)	(6.23)	(4.15)	(9.80)	(8.78)
Total	21.6	43.4	39.5	35.9	72.1	65.4	50.7	101	92.5
	(4.86)	(9.75)	(8.87)	(8.07)	(16.2)	(14.7)	(11.4)	(22.8)	(20.8)

[1] 92 mm (3-5/8 inch) thick brick unit
[2] 76 mm (3 inch) thick brick unit

Summary of Results

Tables 8 and 9 summarize the analysis for one and two story building configurations, respectively. The tables present a comparison of total base shear loads for the various designs and configurations. A design wind speed of 40m/s (90mph) in Exposure B is used as the base, or 100% of the total base shear.

Table 8: One Story Building Configuration
Percentage Comparisons of Total Base Shear
(Using Exposure B and 40 m/s (90 mph) as the base or 100%)

Wind:		38m/s (85 mph)	40m/s (90 mph)	45m/s (100 mph)	49m/s (110 mph)
	Exp. B	89%	100%	124%	149%
	Exp. C	134%	149%	184%	223%
Seismic:		C	D_1	D_2	
	Other	27%	45%	63%	
	Brick[1]	46%	77%	109%	
	Brick[2]	43%	71%	101%	

[1] 92 mm (3-5/8 inch) thick brick unit
[2] 76 mm (3 inch) thick brick unit

Table 9: Two Story Building Configuration
Percentage Comparisons of Total Base Shear
(Using Exposure B and 40 m/s (90 mph) as the base or 100%)

Wind:		38m/s (85mph)	40m/s (90mph)	45m/s (100mph)	49m/s (110mph)
	Exp. B	89%	100%	123%	150%
	Exp. C	131%	146%	180%	218%
Seismic:		C	D_1	D_2	
	Other	26%	43%	61%	
	Brick[1]	52%	87%	122%	
	Brick[2]	48%	79%	112%	

[1] 92 mm (3-5/8 inch) thick brick unit
[2] 76 mm (3 inch) thick brick unit

DISCUSSION

As indicated in Tables 8 and 9, the code defined wind loads would generally produce higher lateral loads for the gable end walls of light framed residential construction. For Seismic Design Category C, wind produces the highest design load for all wind design speeds. For the majority of the geographic area of the continental United States, the design wind speed is 40 m/s (90mph), or above, and the highest lateral design load is produced by wind in Seismic Design Categories A through D_1. At the maximum 49 m/s (110 mph) design wind speed covered by the IRC, wind again produces the highest lateral design load even in Seismic Design Category D_2. It is noteworthy that in the IRC, the vast majority of the geographic area designated to be within the D Seismic Design Categories are in fact in Category D_1 and not in Category D_2. Furthermore, the wall-bracing table within the IRC prescriptively combines wind and seismic design criteria. Specifically, D Seismic Design Categories are combined with wind speeds up to but not including 49m/s (110mph). However, in Exposure B, the design lateral wind load for these criteria will exceed the design lateral seismic load by at least 72% in D_1 and at least 23% in D_2. For Exposure C, the design wind loads will exceed the design seismic loads by 151% and 79% for D_1 and D_2, respectively. Furthermore, it is not evident that this wall bracing table is exclusively for Exposure B and/or C. Thus, it appears that wind is likely to produce the critical lateral in-plane loads on the gable end walls of the investigated building configurations for virtually all, if not all, areas falling under the IRC code.

As indicated, the determination of the appropriate Exposure Category is of utmost importance and drastically affects the final wind loads. However, it is not always evident whether a given structure should be classified as Exposure B or Exposure C. In many suburban areas of the continental United States, as well as many urban areas, the terrain varies or flat open country is present. In these cases, classification of a structure as Exposure B is not necessarily appropriate. Furthermore, ASCE7-98 dictates, "*For a site located in the transition zone between categories, the category resulting in the* *largest wind forces shall apply*." Clearly, Exposure C is the more conservative classification for use in many residential applications and this exposure generates even larger wind forces than the code default Exposure B. With these factors taken into account, it would appear that wind loads would be even more likely to be the governing lateral design load for the shorter gable end walls in residential construction.

Furthermore, the lateral load resisting system in light framed residential construction is typically some form of relatively ductile, sheathed, wood stud, shear wall or a braced wall section. These lateral load resisting systems usually experience seismic forces that are relatively low when this ductility is taken into account. However, the lateral resisting system does not change whether the residence is covered in siding, or brick. The same ductile behavior of the lateral support system is expected. Although the brick veneer may experience isolated cracking during a severe seismic event, as long as the tie systems are present, provided in sufficient strength and frequency and adequately fastened, the veneer should not collapse. The following is an excerpt from the APA, the Engineered Wood Association publication (Wood Design Concepts – Introduction to Lateral Design) [APA, 1999]: "*Earthquakes and hurricanes both have vertical and horizontal force components. Therefore, the structure must be designed for the horizontal components acting along both horizontal axes, as well as from the vertical axes. From a design perspective, once the forces along all three axes of the structure have been determined, the actual building design proceeds identically to accommodate both wind and seismic loads.*" Thus, if wind is demonstrated to produce the greater loads, it should be the governing design load.

When developing prescriptive code provisions, the most critical conditions should serve as the basis of design for a given structure, system or component. For most residential system configurations, the lateral load resisting wall systems that have the highest loads, with respect to wind loads, would generally be the gabled end walls. These would likely serve as the basis of design since the seismic loads will be the same in either of the orthogonal directions and would therefore produce critical effects in these same shorter end wall systems. Since it has been shown that in most, if not all cases, winds produce higher lateral loads on these walls, even for the brick veneered residences, the critical design conditions used for the basis of the prescriptive provisions for lateral load resisting systems for light framed residential systems should generally address loads produced by wind.

Wind does not appear to have been the governing loading condition used to develop the prescriptive provisions for the IRC code for the lateral load resisting systems of light wood framed residential structures covered with brick veneer. These provisions limit the height of brick veneer structures in Seismic Design Categories D_1 and D_2. This appears to be inconsistent since the previous analysis indicates that the critical lateral loads are still produced by wind for a brick veneer structure and, logically, there should be no difference between the provisions required for a sided house and that clad by brick. There are less restrictive limits placed on residential structures clad in other than brick veneer even though the wind loads govern and do not vary with wall covering type. It should be noted that ASCE7-98 and the National Building Code of Canada do not restrict the use of brick veneer in two story residences [NBC, 1999].

Generally, prescriptive code provisions are designed to limit risk and protect life safety. However, some effort must be made to ensure that equal risk is maintained, and that the economic justifications are addressed. In addition, provisions that may limit the effect of one type of severe event may cause a reduction in the resistance of the system to another (e.g., wind and fire). For instance, brick veneer has been shown to be more resistant to wind-borne debris damage [McGinley et al., 1996] and thus provides greater severe wind event resistance. Further, the greater weight of the brick veneer tends to increase the overturning resistance of the structure.

In addition, whole building tests have been performed to better understand actual structural performance of residential structures [HUD, 2000]. Some of this research has indicated that brick veneer can resist a significant portion of the wind loads with proper design and detailing [HUD, 2000]. This contributory resistance of the brick veneer is not accounted for in either wind or seismic design. Furthermore, in the typical seismic analysis presented, the total accelerated weight of the veneer is assumed to be transferred to the wood support structure. It is likely that the veneer in the out-of-plane orientation will transfer load to the backing system. However, it is unlikely the veneer in the in-plane orientation will transfer all, if any significant, load to the wood shear walls since the brick is stiff relative to the wood system, has relatively good strength in this orientation, and the two systems are connected by relatively flexible tie systems. Thus, for the investigated prototype models, up to one-sixth of the accelerated seismic loading may not be applied to the wood shear walls systems in a seismic event.

SUMMARY AND CONCLUSIONS

To evaluate the performance of brick veneer residential construction, a multiphase research program was proposed. The goal of this phase of the research was to evaluate lateral loads on typical residential building configurations. The results of this evaluation will serve as a basis for further phases with the ultimate goal of accounting for the contributory resistance of brick veneer in light-framed, wood stud residential construction.

This investigation has determined that wind is the governing lateral load for typical residential construction in virtually all, if not all, cases. The analysis has also identified apparent technical inconsistencies in the prescriptive bracing requirements of the International Residential Code. These inconsistencies need to be addressed and rectified.

REFERENCES

[APA, 1999] Introduction to Lateral Design, Wood Design Concepts, APA The Engineering Wood Association, Revised September 1999

[ASCE, 1999] *Minimum Design Loads for Buildings and Other Structures*, ASCE Standard 7-98 American Society of Civil Engineers, Reston, Virginia, 1999

[HEW, 1931], *Light Frame House Construction*, Vocational Division Bulletin No. 145, U.S. Department of Health, Education, and Welfare (HEW)(GPO: Washington, DC), 1931 (reprinted 1956)

[HUD, 2000] Residential Structural Design Guide: 2000 Edition, National Association of Home Builders (NAHB) Research Center, Inc., February, 2000

[IRC] International Residential Code for One- and Two-Family Dwellings (2000 edition)

[McGinley, Samblanet, Subasic, 1996] *An Investigation of the Effects of Hurricane Opal On Masonry*, A report by the TMS Disaster Investigation Team, The Masonry Society, 1996

[NBC, 1999] The National Building Code of Canada, The Canadian Standard Association, Rexdale, Ontario, 1999

[NEHRP, 1997] *Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, *Part 1: Provisions* (FEMA 302), prepared for the Federal Emergency Management Agency by the Building Seismic Safety Council, Washington, DC, 1997a

[NEHRP, 1997] *Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, *Part 2: Commentary* (FEMA 303), prepared for the Federal Emergency Management Agency by the Building Seismic Safety Council, Washington, DC, 1997b

[Newman, A. et al.] "Slow Deformation and Lower Seismic Hazard at the New Madrid Seismic Zone," Science, Vol. 284, April 23, 1999, 619-621

[Tomasello, Stein, Gavin, Fanning, 2001] *Assessment of the National Institute of Building Sciences 1997 Edition NEHRP Recommended Provisions For The Madrid Seismic Zone: An Alternative View, Revision 1*, March, 2001