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Lintel Testing for Reduced Shear Reinforcement in Insulating Concrete Form Systems

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Notice

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Introduction

Historically, cast-in-place concrete for residential construction has been primarily limited to below grade applications such as footings and foundation walls. Such construction was relatively labor intensive, and, therefore was not considered a viable alternative for other parts of the building. However, the recent advent of insulating concrete form (ICF) wall construction and the *Prescriptive Method for Insulating Concrete Forms in Residential Construction (Prescriptive Method)* [1] has resulted in a competitive and energy efficient alternative for above grade walls in residential construction.

The purpose of this test program is to investigate the structural capacity and performance of the concrete lintels typically used in ICF construction. Lintels are reinforced concrete structural elements that support loads above openings in concrete walls. In the *Prescriptive Method* lintel spans were calculated using the *Building Code Requirements for Reinforced Concrete (ACI 318-95)* [2]. According to *ACI 318-95*, shear reinforcement is required for all ICF lintels in the *Prescriptive Method*. Shear reinforcement is generally difficult to install in ICF systems and, therefore, adds to the construction costs.

The major goal of the testing program is to support the development of economical lintel designs for ICF construction by eliminating shear reinforcement when feasible. An analysis was conducted to evaluate the current lintel design provisions in *ACI 318-95*. Experimental studies, on various configurations of ICF lintels, were conducted to further evaluate existing design provisions and determine whether certain restrictive provisions could be waived for ICF lintels in typical residential construction applications.

Results from this research program indicate that shear reinforcement for the ICF lintels in the *Prescriptive Method* is overly conservative and may be eliminated without sacrificing performance in span less than about 4 ft. (1.2 m). Consequently, future modifications to the *Prescriptive Method* and *ACI 318-95* should be considered to result in more efficient utilization of ICFs in residential construction. Additional experimental and analytical work is recommended to expand this cost-effective benefit to ICF lintels that are longer in span.

Existing Design Methodology for Shear Reinforcement

The design of bending members for shear is based on the assumption that the concrete resists part of the shear, and any excess over and above what the concrete is capable of resisting has to be resisted by shear reinforcement. The basic rationale for the design of shear reinforcement is to provide steel that bridges across diagonal tension cracks. Diagonal tension cracks are indicative of a shear failure in concrete beams and lintels. Shear reinforcement, commonly known as stirrups in concrete beams, prevents the diagonal tension cracks from propagating across the depth of the member and provides for continued capacity subsequent to concrete cracking.

For members that are subject to shear and flexure only, the amount of shear force that the concrete alone, unreinforced for shear, can resist is V_c,

$$V_c = 2\sqrt{f'_c}\, b_w d \qquad \text{ACI 318-95 Equation (11-3)}$$

where,

f_c' = compressive strength of concrete (psi)
b_w = web width, equivalent to b for rectangular beams (in.)
d = effective depth (in.)

Some research studies indicate that Equation (11-3) overestimates the influence of f_c' and underestimates the influence of the tensile reinforcement ratio and the span-to-depth ratio [3][4]. For example, the most significant conclusion from the 133 beams tested by Kani was that the shear strength of rectangular, reinforced concrete beams does not strongly depend on concrete strength [3]. He determined that the tensile reinforcement ratio and the span-to-depth ratio had the greatest impact on the shear strength [3].

A strength reduction factor, ϕ, of 0.85 is applied to the nominal shear strength of concrete. Theoretically, no web reinforcement should be required when the following condition is met:

$$V_u \leq \phi V_c$$

where,

V_u = design shear force
ϕ = strength reduction factor of 0.85
V_c = concrete shear force

According to *ACI 318-95* commentary, the formation of inclined cracks may lead to sudden failure in unreinforced concrete beams. However, the ACI Code requires that a minimum area of shear reinforcement be provided in reinforced concrete flexural members except where V_u is less than $\phi V_c/2$. Shear reinforcement increases the ductility and provides a warning of failure. In cases where the minimum area of shear reinforcement is required, the amount necessary is determined using the following equation:

$$A_v = 50\frac{b_w s}{f_y} \qquad \text{ACI 318-95 Equation (11-14)}$$

where,

A_v = total cross sectional area of shear reinforcement within a distance s (in.^{2})
b_w = web width = b for rectangular beams (in.)
s = center-to-center spacing of shear reinforcement in a direction parallel to the longitudinal reinforcement (in.)
f_y = yield strength of shear reinforcement steel (psi)

Experimental Program

A total of 18 ICF lintels were constructed and tested to evaluate their performance with no shear reinforcement. Eight of the lintel specimens were fabricated using flat ICF wall systems. Six were constructed using waffle-grid ICF wall systems. The remaining four lintel specimens were fabricated using screen-grid ICF wall systems. An overview of the test specimens is given in Table 1. The cross sections of the ICFs used in this study are shown in Figure 1. Additional specimens spanning 12 ft (3.66 m) were cast but not tested due to time and budget constraints.

Table 1
Specimen Specifications

Test Specimen	Width, b_w (in.)	Depth, d (in.)	Span (in.)	Tension Reinforcement
FLAT1_4x12	4	10	43	1 - #4
FLAT2_4x12	4	10	43	1 - #4
FLAT1_4x24	4	22	43	1 - #4
FLAT1_8x12	8	10	43	1 - #4
FLAT2_8x12	8	10	43	1 - #4
FLAT1_8x24	8	22	43	1 - #4
FLAT1_4x12a	4	10	40	2 - #5
FLAT1_8x12a	8	10	40	2 - #5
WAFFLE1_6x8	2	6	36	1 - #4
WAFFLE2_6x8	2	6	36	1 - #4
WAFFLE1_6x16	2	14	36	1 - #4
WAFFLE2_6x16	2	14	36	1 - #4
WAFFLE1_8x16	2	13.75	36	1 - #4
WAFFLE2_8x16	2	13.75	36	1 - #4
SCREEN1_6x12	0	10	38	1 - #4
SCREEN2_6x12	0	10	38	1 - #4
SCREEN1_6x24	0	22	38	1 - #4
SCREEN2_6x24	0	22	38	1 - #4

For SI: 1 inch = 25.4 mm.

ICFs used to fabricate the lintel specimens were provided by three different manufacturers. The 18 forms were cast off the ground and enclosed with oriented strand board (OSB) on both ends and the bottom. The ICF systems utilize the integral form ties to support the horizontal reinforcement. Holes were also cut at the appropriate height in the OSB end panels to support the ends of the horizontal reinforcement. Shear reinforcement was not used in any of the specimens.

The concrete mix utilized to fabricate the test specimens was selected based on the *Prescriptive Method*. The selected mix had a minimum design 28-day compressive strength of 2,500 psi (17.2 MPa) and utilized No. 67 gravel (90-100% of material passing ¾ in. (19 mm) sieve) for the coarse aggregate. Quantities of materials incorporated in the selected concrete mix is given in Appendix A.

Figure 1
Cross Section of ICF Forms

The concrete was supplied by a local ready-mix company and, after certain adjustments were made to optimize workability, had a measured on-site slump of 6 in.(152 mm) according to ASTM C143 [5].

Concrete was placed in the forms in layers (lifts) of a depth equal to approximately 1 ft. (0.30m). Each lift was manually consolidated using a ½ in. (12.7 mm) steel rod. The total time duration of the cast was approximately 1-1/2 hours for all specimens. OSB and insulation were removed prior to testing over a duration of several weeks. Although no cracks were observed on the exposed concrete specimens, localized “honeycombing” was evident in a few specimens.

Cylindrical concrete specimens were also formed during the casting of the lintels. The procedures of ASTM C39 [6], ASTM C31 [7], and ASTM C192 [8] were followed. Twenty 6 x 12 in. (152.4 x 304.8 mm) cylinders were filled in three equal lifts, each lift consolidated 25 times, representing the concrete incorporated in the test specimens. After 48 hours the cylinders were split into two batches. The first batch was moist cured, while the second batch was field cured. The cylinders were tested at 7, 28 and 56 days to determine the compressive strength of the concrete. Table 2 summarizes the results. According to *ACI 318-95* the compressive strength, f_c', shall be determined from the laboratory cured specimens. The field cured specimens are used to check the adequacy of curing and protection of concrete exposed to field conditions. An average value of 2,795 psi (19.3 MPa) for the 28-day and 56-day laboratory cure time was used as the concrete compression strength (f_c'). This average is representative of the concrete compressive strength during the testing period.

Table 2
Concrete Compression Tests

Test Specimens	7 day (psi)	28 day (psi)	56 day (psi)
Laboratory Cured			
Specimen 1	2,252	2,701	2,775
Specimen 2	2,309	2,692	2,829
Specimen 3	2,091	2,887	2,891
AVERAGE	**2,217**	**2,760**	**2,831**
COV	**0.051**	**0.040**	**0.020**
Field Cured			
Specimen 1	2,090	2,625	2,690
Specimen 2	2,160	2,614	2,710
Specimen 3	2,050	2,619	2,640
AVERAGE	**2,100**	**2,619**	**2,680**
COV	**0.027**	**0.002**	**0.013**

For SI: 1 psi = 6.9 kPa.

Two different sizes of Grade 40 reinforcing steel were used in fabricating the lintel specimens. Tension tests performed at the University of Maryland revealed yield strengths closer to Grade 60 steel. Table 3 lists the results.

Table 3
Rebar Tension Tests

Test Specimens	f_y (ksi)
#4 Rebar	
Specimen 1	60.1
Specimen 2	66.8
Specimen 3	67.2
AVERAGE	**64.7**
COV	**0.062**
#5 Rebar	
Specimen 1	60.1
Specimen 2	58.0
Specimen 3	59.1
AVERAGE	**59.1**
COV	**0.018**

For SI: 1 psi = 6.9 kPa.

Test Procedure

Tests on the lintel specimens commenced at a concrete age of 28 days and continued over a duration of four weeks. Each specimen was tested in accordance to ASTM C78 [9]. The NAHB Research Center's Universal Test Machine (UTM) applied the load to the specimens at a rate of 0.05 in. (1.27 mm) per minute to failure. A linear variable differential transformer (LVDT) was used to measure the displacement at midspan. Third-point loading was applied to the lintel specimens using a steel I-beam attached to the UTM crosshead. The lintels were simply supported at both reactions on rollers. Leather shims were placed between the bearing plate and the concrete at the load points and reactions to minimize the effect of surface roughness. Specific details of the test apparatus and setup are shown in Figures 2 through Figure 5.

Figure 2
Flat 4x12 Specimen in Universal Test Machine

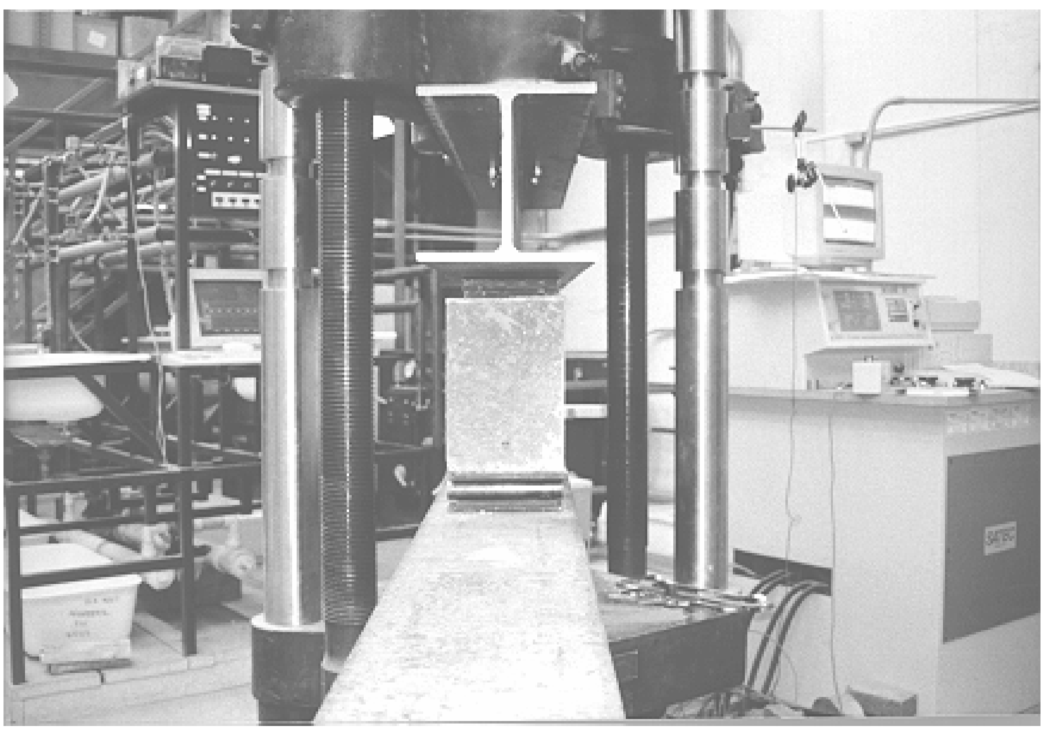

Figure 3
Side View of Flat 8x12 Specimen

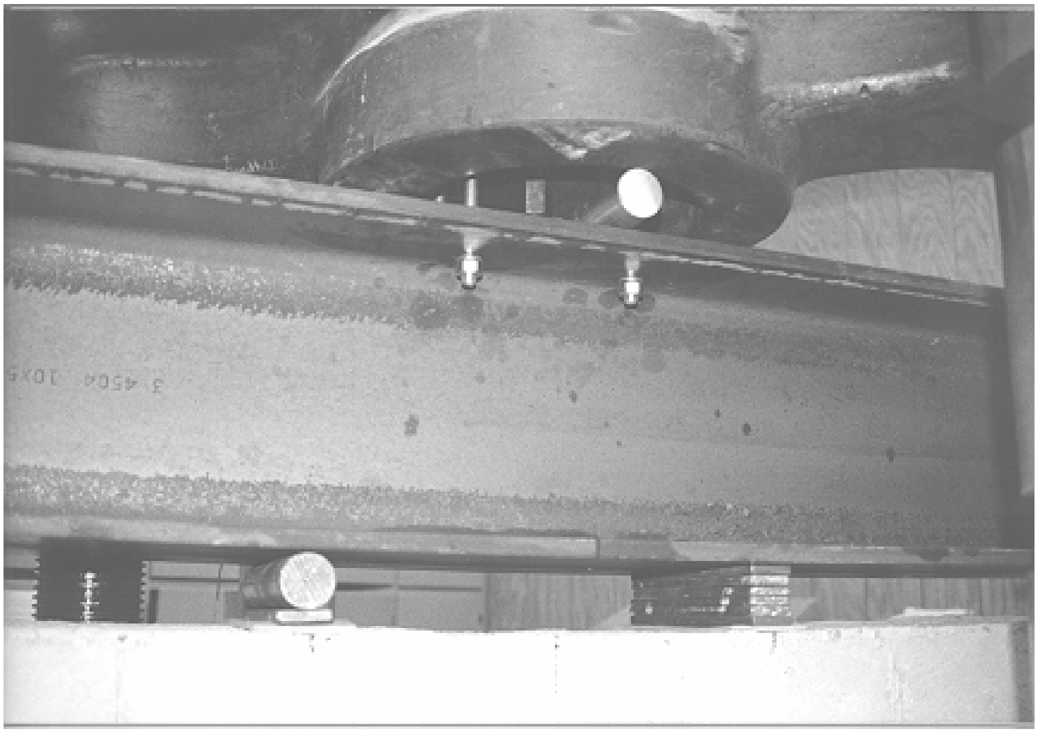

Figure 4
Steel I-Beam and Loading Points

Figure 5
Typical Simple Support

Results

The responses of all ICF lintel specimens to the third-point loading are shown in Table 4. The calculated ultimate load is based on the shear capacity of the section based on the ACI Equation (11-3). All of the specimens outperformed the calculated ultimate.

Table 4
Results of ICF Lintel Tests

Test Specimen	Predicted Ultimate[1] (lbs.)	Tested Ultimate (lbs.)	Ratio Tested/Predicted
FLAT1_4x12	8,459	17,172	2.03
FLAT2_4x12	8,459	17,830	2.11
FLAT1_4x24	18,609	37,170	2.00
FLAT1_8x12	16,917	21,030	1.24
FLAT2_8x12	16,917	22,600	1.34
FLAT1_8x24	37,219	44,210	1.19
FLAT1_4x12a	8,459	N/A[2]	N/A[2]
FLAT1_8x12a	16,917	64,750	3.83
WAFFLE1_6x8	2,538	12,130	4.78
WAFFLE2_6x8	2,538	11,980	4.72
WAFFLE1_6x16	5,921	31,260	5.30
WAFFLE2_6x16	5,921	31,820	5.37
WAFFLE1_8x16	5,815	35,620	6.13
WAFFLE2_8x16	5,815	37,120	6.38
SCREEN1_6x12	0[3]	6,498	-
SCREEN2_6x12	0[3]	7,052	-
SCREEN1_6x24	0[3]	30,460	-
SCREEN2_6x24	0[3]	31,520	-

For SI: 1 foot = 0.3048 m; 1 inch = 25.4 mm; 1 lb = 4.45 N.
[1]Ultimate load calculations are based on the ACI Equation (11-3).
[2]A tested value of 16,750 lb was recorded. Premature failure was experienced due to the severe honeycombing caused by the two-#5 rebar which restricted the flow of the concrete into the bottom of the form.
[3]ACI 318-95 does not provide a method to analyze beam cross sections with voids.

<u>Flat Specimens</u>

The ACI code under predicted the capacity of the flat specimens. The tested ultimate for the narrow sections was at least two times that of the predicted capacity in all cases. Failure of the flat specimens was due to tensile stresses induced in the beam by shearing forces that caused cracking inclined at 45° to the horizontal (Figure 6). Cracking also occurred between the form ties. This cracking occurred late in the testing.

Figure 6
Typical Failure Mode for the ICF Flat Lintel

Waffle-Grid Specimens

The predicted ultimate capacity was considerably lower than the tested ultimate loads for the waffle-grid specimens. The tested ultimate capacity was at least 4.7 times the capacity predicted by the ACI code. The disparity between the calculated and tested loads could be attributed to the use of the smallest web thickness in the calculated capacity. This provides for a conservative estimate in the ultimate capacity of the section. More sophisticated analysis, such as finite element modeling should be performed to determine the validity of this presumption. As in the flat sections, the failure mode was characterized by 45° cracking and crushing of the concrete at the load points (Figure 7).

Screen-Grid Specimens

There are currently no predicted values for the shear capacity of screen-grid lintels. The screen-grid sections have no effective web width, therefore zero shear capacity according to the ACI equations. Testing confirms the adequacy of the 24 in. (609.6 mm) deep sections in lintel applications. Failure was similar to that of the waffle-grid specimens in that the cracking was at 45° angle with the horizontal (Figure 8). The lack of concrete web resulted in a lower capacity than that of the waffle-grid sections. Again, more sophisticated analytical methods, such as finite element modeling, may be capable of explaining the performance of the screen-grid lintels. Such analysis could lead to appropriate design methods for incorporation in future editions of *ACI 318-95*.

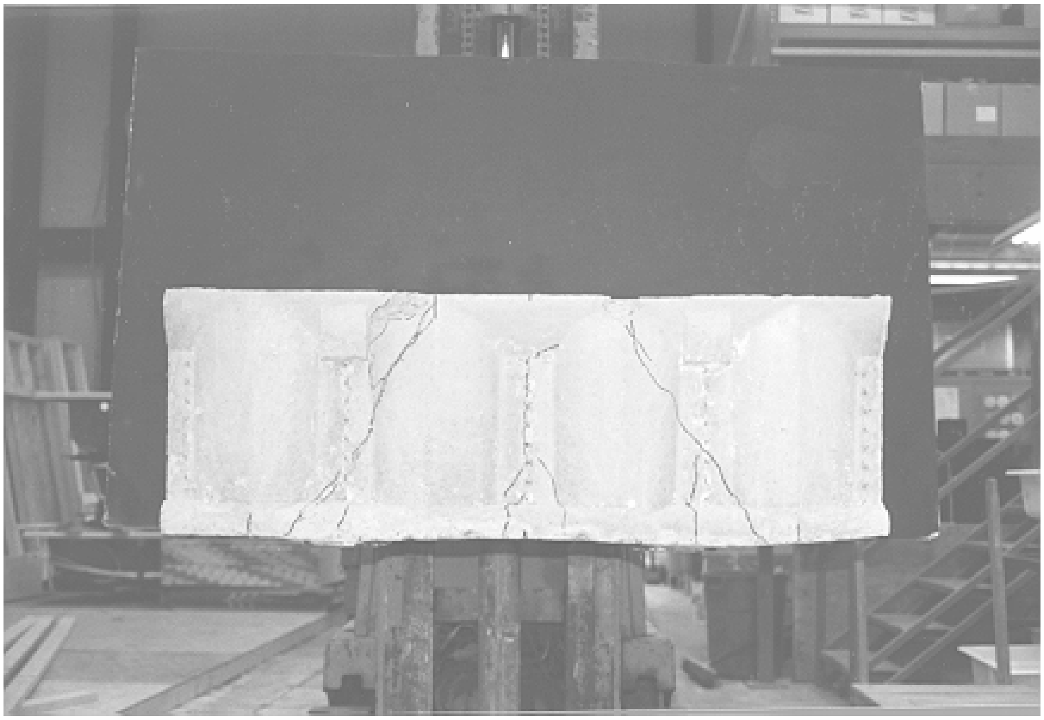

Figure 7
Typical Failure Mode for the ICF Waffle-Grid Lintel

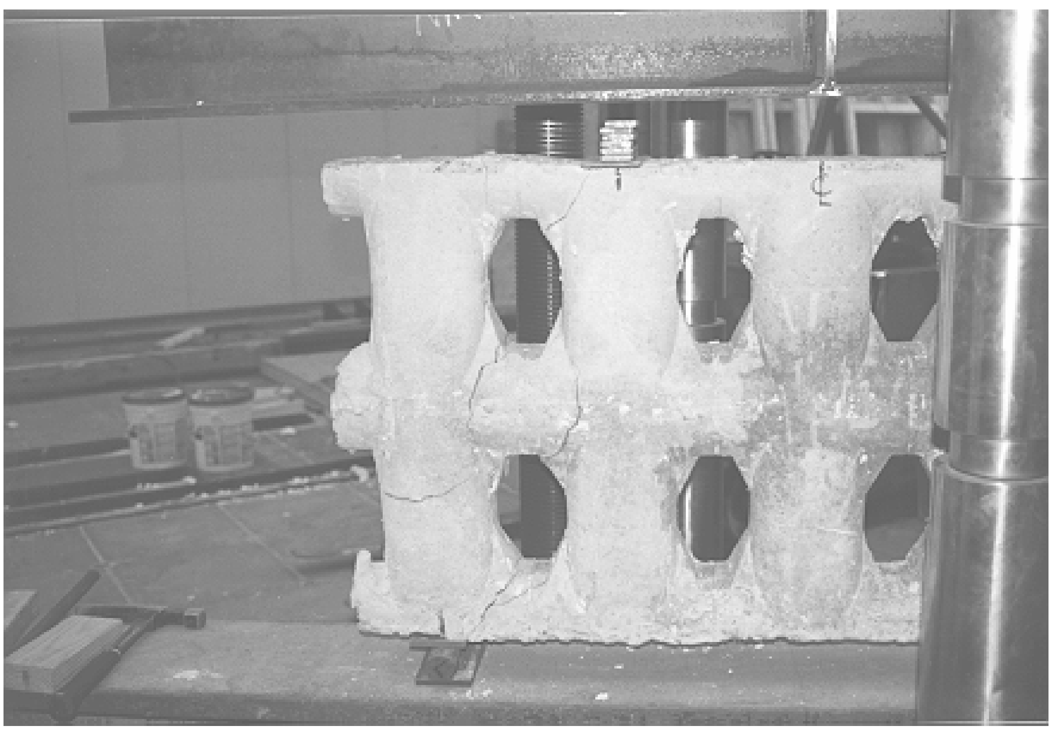

Figure 8
Typical Failure Mode for the ICF Screen-Grid Lintel

Conclusions

The major goal of this testing program was to support the development of more economical lintel designs for ICF construction. In all cases the tested capacity of the ICF lintels without shear reinforcement outperformed the *ACI 318-95* predicted capacities. All three types of lintels tested (flat, waffle-grid, and screen-grid) experienced a shear failure characterized by 45° degree incline cracking. "Honeycombing" only affected the capacity of the FLAT1_4x12a with 2-#5 reinforcing bars. The additional steel prevented the flow of concrete to the bottom of the specimen. For this reason, single horizontal reinforcement bars are recommended for ICF lintel construction. The findings from these tests support the conclusion that shear reinforcement is not necessary for the ICF lintels in the *Prescriptive Method* spanning up to 4 ft. (1.23m). Also, it is possible to span typical openings with lintels formed by the screen-grid ICF system. Additional testing and analytical work are required to develop efficient screen-grid lintel tables in future additions of the *Prescriptive Method*.

Additional testing of ICF lintels spanning larger openings may also lead to the elimination of shear reinforcement in longer spans or an increase in the current spans. Analytical work using finite element modeling should be used to expand the existing tests and any future tests to a greater variety of applications. Finite element modeling should also be used to support the development of design procedures appropriate for future editions of *ACI 318-95*. Again, the results of the screen-grid testing are very promising and additional testing should be conducted in order to develop efficient span tables for this system.

This testing program, along with previous research, reveals that the ACI Equation (11-3) and the minimum shear reinforcement requirements should be examined closer [3][4]. Additional testing should be done to refine ACI Equation (11-3) in order to better estimate the shear capacity of concrete beams, particularly for efficient use of ICF systems in residential construction.

References

[1] *Prescriptive Method for Insulating Concrete Forms in Residential Construction*, Prepared for the U.S. Department of Housing and Urban Development, the Portland Cement Association, and the National Association of Home Builders by the NAHB Research Center, Inc., Upper Marlboro, Maryland, 1998.

[2] *Building Code Requirements for Reinforced Concrete (ACI 318-95)*, American Concrete Institute, Detroit, Michigan, 1995.

[3] Kani, G., *Basic Facts Concerning Shear Failure*, American Concrete Institute, ACI Journal, Volume 63, No. 6, Detroit, Michigan, 1966.

[4] ACI-ASCE Committee 426, *The Shear Strength of Reinforced Concrete Members*, Proceedings, Chapters 1 to 4, Volume 99, Detroit, Michigan, 1973.

[5] ASTM 143-84 *Slump of Portland Cement Concrete*, American Society of Testing Standards (ASTM), West Conshohocken, Pennsylvania, 1996.

[6] ASTM C39-96 *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*, American Society of Testing Standards (ASTM), West Conshohocken, Pennsylvania, 1996.

[7] ASTM C31-96 *Standard Practice for Making and Curing Concrete Test Specimens in the Field*, American Society of Testing Standards (ASTM), West Conshohocken, Pennsylvania, 1996.

[8] ASTM C192-96 *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*, American Society of Testing Standards (ASTM), West Conshohocken, Pennsylvania, 1996.

[9] ASTM C78-96 *Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*, American Society of Testing Standards (ASTM), West Conshohocken, Pennsylvania, 1984.

Appendix A - Concrete Mix Data

Quantity Ordered: 5.00 cy.

Mix Ingredient	Quantity
Cement Type I/II	2,115 lb.
Concrete Sand	6,541 lb.
#67 Washed Gravel	9,000 lb.
Daravair 1000	20 oz.
WRDA with HYCOL	60 oz.
Water	150 gal.

Notes:

1. Daravair 1000 is an air-entraining admixture and is formulated to comply with Specification for Air-Entraining Admixtures for Concrete, ASTM Designation C 260.

2. WRDA with HYCOL is a water reducing admixture and is formulated to comply with Specification for Chemical Admixtures for Concrete, ASTM Designation C 194.

Appendix B - Example Calculations

1. Ultimate shear for the FLAT_4x12 specimen

   $$V_c = 2\sqrt{f_c'}\,bd = 2\sqrt{2{,}795}(4)(10) = 4{,}229.4\,lb$$
   Ultimate Load = (4,229.4)(2) = 8,458*lb*

2. Ultimate shear capacity for the WAFFLE_6x16 specimen

   According to the manufacturer b_w = 2 in.
   $$V_c = 2\sqrt{f_c'}\,bd = 2\sqrt{2{,}795}(2)(14) = 2{,}690.6\,lb$$
   Ultimate Load = (2,114.7)(2) = 5,921*lb*

3. Ultimate shear capacity for SCREEN_6x12

   Since b_w = 0 in. V_c = 0.