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HORIZONTAL REINFORCEMENT ELONGATION IN MASONRY MORTAR JOINTS

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ABSTRACT

Horizontal joint reinforcement in masonry walls has been used successfully for a long time. Recently, questions have arisen as to the amount of elongation that can take place of the joint reinforcement wire which is embedded in masonry mortar joints. This amount of elongation is important for shear walls being subjected to large forces during earthquakes.

This study investigated the amount of gage length and elongation that is possible for various amounts and kinds of joint reinforcement embedded in mortar for masonry wall units. Epoxy joint reinforcement was considered as well as the ordinary galvanized joint reinforcement. An amount of strain elongation to allow deformation of the wire across a small crack is found to be beneficial for the joint reinforcement provided that the wire itself has the capable strain elongation. This paper and presentation will present the results of a test to determine the gage elongation lengths due to different amounts of surcharge for wires embedded in mortar joints.

INTRODUCTION

Since as early as 1939 the use of steel placed in horizontal mortar joints has been the principle means through which tension cracks have been controlled. Bartlett (1965) A few studies have been conducted which subjected masonry shear walls reinforced with wire joint reinforcement to reversed cyclic in-plane loads. Shing, Schuller, et al. (1990); Shing, Noland, et al. (1989); Tomazevic & Zarnic (1985); Shing & Noland (1992) The basic response from these studies was that not enough wire joint reinforcement was provided to allow a ductile response of a masonry shear wall upon cracking. Several of the researchers added that a large part of the brittle response was due to the low strain capacity of the wire joint reinforcement. Due to these investigations, the use of wire joint reinforcement as part or all of the structural horizontal steel in shear-critical masonry walls vulnerable to seismic loading has been questioned.

To answer some of the questions about the behavior of wire joint reinforcement in mortar, a research investigation was conducted at Iowa State University. Part of the research program was aimed at determining the strain energy that could be absorbed by different wire joint reinforcement configurations (different coatings and diameters under different surcharges) to address the criticisms of the previous research projects on the ability of wire joint reinforcement to satisfy horizontal reinforcement requirements. The portion of the research program presented in this paper is to evaluate the commercially available wire joint reinforcement specimens embedded in masonry mortar joints as applied to shear walls with different surcharge loads.

The scope of a part of the project was to:

- test specimens using four types of wire to conventional "in-air" tension tests and determine their mechanical stress-strain properties.
- Develop a masonry specimen and corresponding frame which would allow a wire specimen to be pulled out by a tensile load (pullout specimen).
- Subject pullout specimens to tension and measure endslip, front slip, and load.
- Compare average unit bond stress results to those from previous research investigations on wire and other reinforcement.
- determine the effects of surcharge on bond stress by utilizing the "effective gage length" results (for application with an equation developed by Arthur Schultz. Schultz (1996)

MATERIALS AND SPECIMENS

Four types of joint reinforcement were investigated, and all were the ladder type with the following designations:

1. 9 gage (W1.7)[1], galvanized

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[1] W1.7 and W2.8 refer to ASTM A82 specification size numbers. ASTM (1996)

2. 9 gage (W2.8), epoxy-coated
3. 6 gage (W2.8), galvanized
4. 6 gage (W2.8), epoxy-coated

The galvanized specimens were coated with zinc according to ASTM A 82 and comprised either one or two longitudinal wires separated with 9 gage cross-wires spaced at a nominal 15 inches on-center. ASTM (1996) The center-to-center width of the longitudinal wires was approximately 6 inches.

The mortar properties that were considered in this investigation were compressive strength and sand gradation. Both properties were varied from specimen to specimen in order to ascertain their relative effect on the bond characteristics of the joint reinforcement. Three mortar mixes were used in the test program: Quikrete® (Types S and N) and Gilmore City (Type S). Quikrete® is a proprietary pre-blended dry mix commonly used by masons in the Central Iowa area. The Gilmore City mix is a mortar that is named for the manufactured sand labeled "Gilmore City Man. Sand" by Martin Marietta of Ames, Iowa. The purpose of using the Gilmore City mix was to follow ASTM C 270 by the proportion method and ASTM C 144 for acceptable sand gradation. ASTM (1996)

The pullout test mechanism and procedure that was finally used by ISU researchers to calculate average unit bond stress and effective gage length was the product of an evolution of test methods and approaches. Since the goal of the ISU researchers was to reach, as close as possible, the tensile strength of each wire configuration in the masonry pullout tests, an embedment length of 14 inches was used. The extra length was the most realistic maximum length that could be achieved without including a cross-wire and keep the specimen to only one block length. A total of 80 tests were conducted on 48 specimens with variables including surcharge amount, wire coating, wire gage, and mortar type. An important component of the masonry pullout testing was the application of surcharge. The surcharge amounts were: 0, 20, and 50 psi.

RESULTS

The final mechanical values, presented in Table 1, are used as the benchmarks upon which the full masonry assemblages are compared in the remainder of the paper. A series of symbols are defined in Table 2. For this reason, each individual symbol will not be completely defined in the paper text. The two most important symbols defined in Table 2 are f_b (average unit bond stress), and l_{ge} (effective gage length), because they are the numerical objectives of the research program. To further define these two important items, a series of equations were developed based on geometry of the joint reinforcement and statics. The applied load (P) is resisted entirely by the average unit bond stress (f_b) over a given embedment length (l_b). To convert f_b into a force, the surface area of the portion of the wire was calculated based on l_b and the outside diameter of the coated steel wire ($d_{s,b}$). Utilizing statics, the summation of the applied load (P) and the resisting bond load must equal zero. Subsequently, the average unit bond stress (f_b) is seen to equal the applied load (P) divided by the total surface area of the bonded portion of the wire in Equation 1.

$$f_b = \frac{P}{\pi d_{s,b} l_b} \qquad (1)$$

To determine an expression for the effective gage length (l_{ge}) of the joint reinforcement, the ultimate average unit bond stress ($f_{b,ult}$) is defined as the level of f_b at which the wire has reached its TS. As seen in Equation 2, at $f_{b,ult}$ the applied load (P) must equal the tensile strength (TS) of the wire times its uncoated cross-sectional area of steel (A_s). Substituting P from Equation 2 into Equation 1 results in an expression for $f_{b,ult}$ in Equation 3 which relates the ultimate average unit bond stress ($f_{b,ult}$) to effective gage length (l_{ge}) in terms of mechanical and geometrical properties of the joint reinforcement. Finally, Equation 3 is rearranged to result in an expression for l_{ge} in Equation 4.

$$@\, f_{b,ult}: P = TS(A_s) = \frac{TS(\pi d_s^2}{4} \qquad (2)$$

$$f_{b,ult} = \frac{TS(\pi d_s^2}{4\pi d_{s,b} l_{ge}} = \frac{TS}{4 l_{ge}}\left(\frac{d_s^2}{d_{s,b}}\right) \qquad (3)$$

$$l_{ge} = \frac{TS}{4 f_{b,ult}}\left(\frac{d_s^2}{d_{s,b}}\right) \qquad (4)$$

Pullout testing comprised the benchmark tests upon which the behavior of wire embedded in mortar was evaluated. The average unit bond stress (f_b) results of the pullout testing is presented and empirical relationships are developed for f_b as a function of surcharge (σ). Empirical equations are developed to express effective gage length (l_{ge}) as a function of surcharge.

Specimens were split into eight separate groups so each of the variables could be properly compared. These eight groups are organized following a pattern of wire gage, wire coating, and mortar type. For instance, the first group includes 9 gage galvanized specimens embedded in Type S mortar. The second group consists of 9 gage galvanized specimens embedded in Type N mortar. All of the variables, including wire gage (6 or 9), wire coating (galvanized or epoxy-coated), and mortar type (S or N) are presented following this pattern. The specific surcharge amounts of 0, 20, and 50 psi, are presented in each group, respectively, in Tables 3-6 for Type S mortar (Type N yielded similar results).

The equations were empirically determined as relationships between average unit bond stress (in psi) and surcharge (in psi) for the 9 and 6 gage wall specimens, respectively.

As a means of graphically comparing the equations, Figure 1 presents each equation. By far, the 9 gage galvanized specimens are the most dependent on surcharge where the f_b values increase by nearly four times the amount of surcharge applied. The 6 gage galvanized specimens are only about half as dependent on surcharge as their 9 gage counterparts. Both epoxy-coated specimens appear to have very similar slopes with magnitudes approximately 1/4 as large as the 9 gage galvanized wire and ½ as large as the 6 gage galvanized wire. This behavior is expected since the epoxy-coating probably has a smaller coefficient of friction than zinc and the notch depths are smaller in the epoxy-coated specimens. Therefore, dependence on surcharge was expected to be less in the epoxy-coated specimens.

Equation 4 expressed l_{ge} as a function of wire diameter (d_s and $d_{s,b}$), ultimate average unit bond stress ($f_{b,ult}$), and tensile strength (TS) of the material. Utilizing the criterion of $\Delta_E = 0.001"$ as the point of endslip for specifying average unit bond stress, the expressions for f_b were substituted for $f_{b,ult}$ in Equation 4 to arrive at the effective gage length for each wire type. Substituting Equations 5 and 6 into Equation 4 results in the equations which, after simplification, express effective gage length (in inches) as a function of surcharge (in psi), are shown in Figure 2. (As with the average unit bond stress expressions, no distinction is made between mortar Types N and S). The abscissa is extrapolated out to a surcharge of 300 psi to provide a broader range of predicted effective gage lengths. As expected, the 9 gage galvanized specimens exhibit by far the smallest effective gage lengths of the four wire types. This observation is due to a combination of high average unit bond stresses and small cross-sectional area (requiring lower loads to reach TS of the material). The 6 gage galvanized specimens exhibit significantly larger effective gage lengths than the 9 gage specimens, especially at higher levels of surcharge. Both epoxy-coated specimens exhibit very large effective gage lengths. This behavior is primarily due to their relatively low average unit bond stresses and relatively high tensile strengths. The significant increase in effective gage length for the 6 gage epoxy-coated wire is due to the large outside area ($A_{s,b}$), low bond strength, and high tensile strength.

The inclusion of cross-wires in ladder type wire reinforcement is assumed to effectively anchor the joint reinforcement at their respective positions. Therefore, the effective gage lengths plotted in Figure 2 will have an upper limit equal to the spacing of these cross-wires. The spacing of the cross-wires in the specimens used in this test program was approximately 15 inches on center. This spacing signifies the upper limit on effective gage length and is indicated as such in Figure 2. Also indicated are the amounts of surcharge required to result in effective gage lengths less than 15 inches. As seen, only a 16 psi surcharge is required to result in failure of a 9 gage galvanized specimen with an embedment of 15 inches. On the other extreme, 137 psi is required for the 6 gage epoxy-coated specimens to reach the fracture load of the material.

CONCLUSIONS

- Surcharge application appears to have a significant effect on the average unit bond stress for each wire specimen. The largest effect is with the 9 galvanized specimens where surcharge adds 3.7 times its own magnitude to the average unit bond stress. For the 6 gage galvanized wire, surcharge adds approximately double its magnitude to bond stresses. Both the 9 gage and 6 gage epoxy-coated specimens were less effected by surcharge as it added only 1.2-1.3 times its magnitude to bond stresses.

- The overall bond stresses associated with epoxy-coated specimens appear to be 1/4-1/2 as large as the bond stresses associated with the galvanized specimens. ISU researchers hypothesize that these smaller values are the result of a lower coefficient of friction and smaller notch depths of the epoxy-coated specimens.
- The effective gage lengths of the epoxy-coated specimens are significantly larger than the galvanized specimens due to the lower bond stresses and higher strengths.
- The 9 gage galvanized specimens exhibited the lowest effective gage length of all four specimen types.

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Table 1. Recommended Mechanical Properties of Joint Reinforcement

Specimen Type	E^1 (ksi)	PL^1 (psi)	YP^1 0.2% Offset (psi)	YS 0.2% Offset (in./in.)	TS^1 (psi)	FS (in./in.)
9 gage, galvanized	28,900	80,600	95,700	0.00548	98,800	0.0515
6 gage, galvanized	30,400	76,300	90,900	0.00503	93,200	0.0439
9 gage, epoxy-coated	28,800	85,000	110,800	0.00570	115,300	0.0130
6 gage, epoxy-coated	28,800	72,500	103,200	0.00567	106,100	0.0124

[1] All stresses are based on A_s from from uncoated steel.

Table 2. Pullout Testing Symbol Definitions

Symbol	Name	Definition	Units
A_s	Area of Uncoated Steel	Cross-sectional area of the uncoated wire available to resist tensile forces. See Table 1.	in.^{2}
$A_{s,b}$		Effective cross-sectional area of the steel wire with the zinc or epoxy-coating, used for bond stress calculations of the steel wire.	
d_s	Diameter of Uncoated Steel	See Table 1.	in.
$d_{s,b}$	Diameter of Coated Steel	See Table 1.	in.
f_b	Average Unit Bond Stress	An assumed uniform bond stress that exists between the mortar and the wire coating specified at either an endslip value or applied load value.	psi
$f_{b,ult}$	Ultimate Average Unit Bond Stress	The value of f_b at which the wire has reached its TS.	psi
l_b	Embedment Length	Length of wire that is bonded to the mortar prior to application of the load.	in.
l_{ge}	Effective Gage Length	Length of wire embedded in (bonded to) mortar over which some finite amount of stress and strain exists when the wire reaches its tensile strength (TS).	in.
l_d	Development Length	Length of wire embedded in (bonded to) mortar required to reach the yield point (YP) of the wire.	
l_L	Unbonded Loaded Length	Length of wire that is loaded and unbonded to the mortar but is included in the front deflection measurements.	in.
P	Applied Load	Force applied to the wire at any point throughout the load cycle specified at an endslip value.	lbs

Symbol.	Name	Definition	Units
σ	Surcharge	Amount of dead load applied to the specimen divided by the net area of the mortar bed joint.	psi
TS	Tensile Strength	See Table 2.	psi

Table 3. Average Unit Bond Stress Results, 9 Gage Galvanized Type S

Specimen Label (surcharge %)	$\pi d_{a,b} l_b$ (in.^{2})	Δ_ε=0.001" Criterion		$P = P_{max}$		Criterion Difference %	Failure Mode
		P (lbs)	f_b (psi)	P (lbs)	f_b (psi)		
Average (0)	6.421	1198	187	1198	187	0.0	—
Average (20)	6.421	1616	252	1616	252	0.0	—
Average (50)	6.421	1558	242	1558	242	0.0	---

Table 4. Average Unit Bond Stress Results, 9 Gage Epoxy-Coated Type S

Specimen Label (surcharge psi)	$\pi d_{a,b} l_b$ (in.^{2})	Δ_ε=0.001" Criterion		$P = P_{max}$		Criterion Difference %	Failure Mode
		P (lbs)	f_b (psi)	P (lbs)	f_b (psi)		
Average (0)	7.433	1150	155	1162	156	1.1	—
Average (20)	7.433	1248	168	1454	196	15.7	—
Average (50)	7.433	1660	223	1877	253	12.6	---

Table 5. Average Unit Bond Stress Results, 6 Gage Galvanized Type S

Specimen Label (surcharge psi)	$\pi d_{a,b} l_b$ (in.^{2})	Δ_ε=0.001" Criterion		P = P_{max}		Criterion Difference %	Failure Mode
		P (lbs)	f_b (psi)	P (lbs)	f_b (psi)		
Average (0)	8.181	1119	137	1119	137	0.0	—
Average (20)	8.181	2073	253	2073	253	0.0	—
Average (50)	8.181	2359	288	2365	289	0.3	---

Table 6. Average Unit Bond Stress Results, 6 Gage Epoxy-Coated Type S

Specimen Label (surcharge psi)	$\pi d_{a,b} l_b$ (in.^{2})	Δ_ε=0.001" Criterion		P = P_{max}		Criterion Difference %	Failure Mode
		P (lbs)	f_b (psi)	P (lbs)	f_b (psi)		
Average (0)	8.972	1108	123	1108	123	0.0	—
Average (20)	8.972	1192	133	1355	151	12.6	—
Average (50)	8.972	1574	181	2073	238	24.6	---

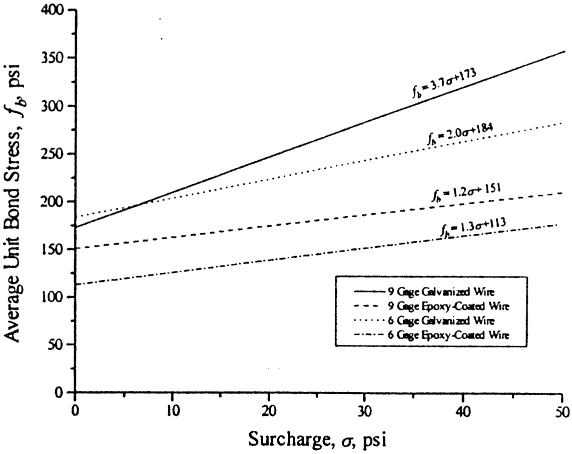

Fig. 1. Pullout 4 Bond Stress vs. Surcharge, All Wire Types

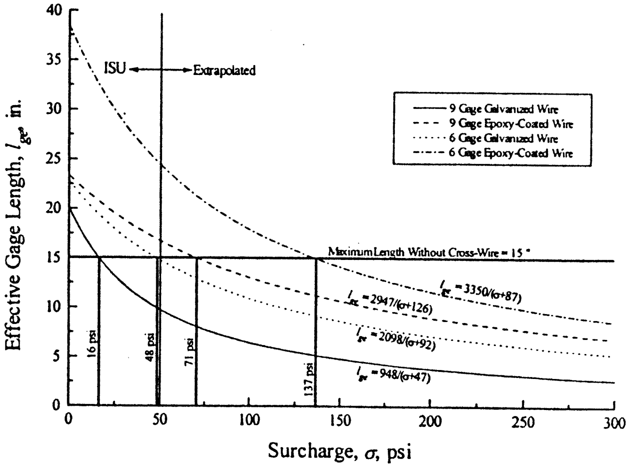

Figure 2. Effective Gage Length vs. Surcharge, All Wire Types