Masonry Bed Joint Reinforcement

By

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Discussion of a test program conducted to determine capacity of bed joint reinforcing in solid units and in hollow unit masonry. Also made to verify capacities of various types of splices for use in solid and in face shells of hollow unit masonry, for resistance to lateral forces perpendicular to wall face.

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INTRODUCTION

A recent test program was conducted to clarify Uniform Building Code provisions for use of wire bed joint reinforcement, for resistance to shrinkage and temperature as well as for resistance to wind and seismic stress design. Although this item had been included in the Uniform Building Code the limitations were not clear, so a study and extensive test program was necessary.

This discussion is to clarify some of the historical use and to present the details of the test program to provide assurance of the validity of design use including critical splices in the thin face shells of hollow masonry units.

HISTORICAL

Bed joint reinforcement has been used in masonry for many years to prevent cracks such as due to restraint of volume change, i.e., shrinkage or temperature. Also, it has been used to a limited degree to resist tensile bending stress as in glass block, grills, screens, prefabrication etc.

However, there had not been full acceptance and confidence in calculated stress resistance to transverse wind or seismic loads or even for loads such as in basement walls.

Early test programs had been made on joint reinforcement as in Reference (1) and in Reference (2). National Concrete Masonry Association Technical Bulletin No. 99, Reference (3) had summarized much of the data for use. Tests as shown in Reference (4) have shown the excellent development of bond of small reinforcement in mortar joints which was probably due to the good bond surface to cross section area ratio and to the good bond due to deformations and also due to the good effect of welded spacer cross wires acting as "Special Anchorage."

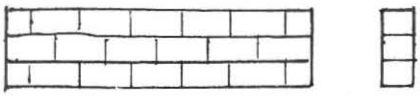
Dur-O-waL and other manufacturers of wire joint reinforcement compiled technical and performance data and installation information into brochures.

TEST PROCEDURE

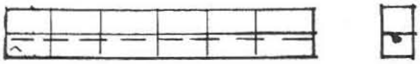
This test program was set up to assure the satisfactory use and to establish safe limits. The test panels were purposefully directed to specific parameters of resistance to lateral load perpendicular to the wall face. They were to be built in normal position and then rotated to provide the loading perpendicular to the face. These panels are shown schematically in the following summary with description of those parameters.

CONTROL PANELS

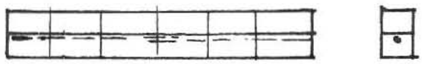
These were to establish a base for comparison with other variables. In general the test specimens were in stack bond in order to better note the tensile action of the joint reinforcing.



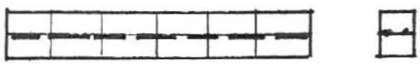
RBN,A & B, Running Bond No reinforcing To demonstrate capacity of a conventional running bond block wall with no reinforcing.



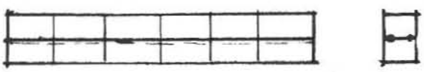
GBB,A & B, Grouted Bond Beam.
This contained one #3 rebar in grout bond beam similar to conventional grouted reinforced masonry construction.



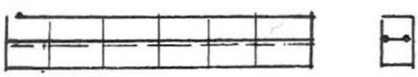
GBBS, A & B, Grouted Bond Beam, Spliced bar.
This contained a conventionally spliced #3 bar in grout to compare capacity of a conventional grouted bar splice.



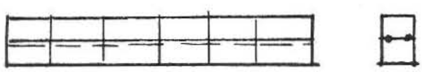
9JG, A & B, 9ga in Joint, Grouted.
This contained solid grout in order to determine if such solid grouting would increase capacity, because some engineers demanded such grout. The cross wires between the longitudinal wires were 15" on center.



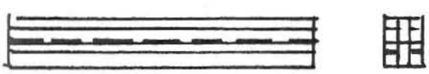
9JG, A & B, 9ga in Joint Grouted.
This was grouted as above but the spacer wires were at 16" on center instead of 15" on center.



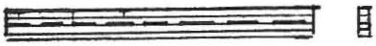
9J, A,B,C, 9ga in Joint.
Three specimens to determine the capacity of 9ga wire bed joint reinforcement in hollow units.



6J, A,B,C, 6ga in Joint.
Three specimens to determine the capacity of the 6 gauge wires in the bed joint of hollow units.



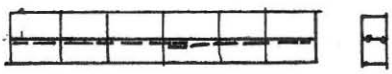
6RGB, A,B, 6ga Reinforced Grouted Brick.
To compare the performance of 6 gauge wire in conventional reinforced grouted brick walls, i.e., 2 wythes of clay brick with grout collar joint.



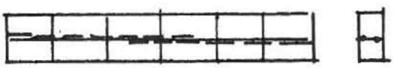
94B, A,B, 9ga, 4" clay Brick.
To compare the value of 9ga reinforcing in the solid bed joints of 4" clay brick.

COMPARISON OF REINFORCING SPLICE TYPES

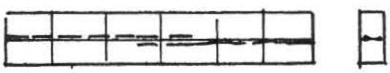
This was considered one of the most important questions, especially as to splices of joint reinforcing in the thin face shells of hollow units such as concrete block or hollow clay tile. In general the concrete block were laid with the bottom, or narrow, faces together for the bed joint in order to simulate minimum field placement.



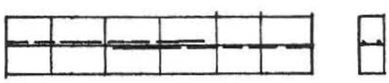
9SJ8, A,B,C, 9ja Splice in Joint 8".
This splice was Type A, that is, simple lap of wires, of approximately 8", in the face shells of hollow units.



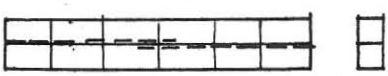
9SJ16, A,B, 9ga Splice in Joint 16".
This was a simple lap of 16" in the face shells of hollow units.



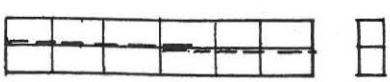
9SJ16T, A,B, 9ga Splice in Joint 16".
These were made with the top, or wide, faces of the block units placed together to contain the lap, with greater bed width



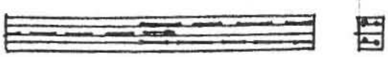
6SJ24, A,B,C, 6ga Splice in Joint 24"
This was a B type of lap splice of the 6 gauge wires, lapped 24" in hollow unit face shell.



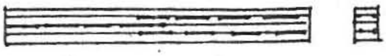
9SJC, A,B, 9ga Splice in Joint of Clay units.
This was to verify the value of the splice in clay units as compared to concrete units



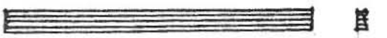
9SC, A,B, 9ga Splice in Cell.
This provided a Type C splice by embedding the wires into the vertical grouted cell, such as occur in conventional earthquake reinforced masonry at not more than 4' intervals.



9SAJ, B,B, 9ga Splice in Alternate (clay) Joints
This provided for lapping of the wires in alternate joints, of clay units, rather than in the same bed joint.



9SAJ, A,B, 9ga Splice in alternate Joints, 4" Hi Block.
This is to provide a comparison of the splice in alternate joints for concrete block, compared to the clay units.



9SJ4, A, B, 9ga Splice in Alternate Joint of 4" clay brick.
This was to compare the effect of splices in alternate joints of solid units.

The panels were constructed in their normal position and were approximately 8' long. The hollow units contained a vertical bar at the ends of the panel in order to resist any distress due to unequal reaction load applications during the test. They were built using conventional commercial type workmanship. The mortar and grout were carefully controlled so there would be no variable introduced and the mortar and grout were tested according to Uniform Building Code standards, which consider the influence of unit absorption upon the mortar and grout strength. They were as shown in the Summary and in the Photographs

The test machine was as shown in the sketch and in photographs.

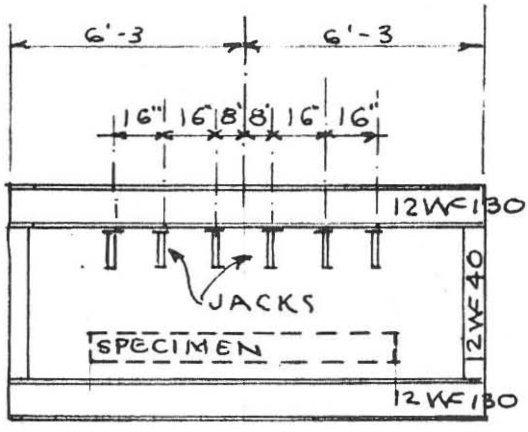
The 6 jacks to apply the load P were calibrated as a unit with the hydraulic pump and gauge in a standard laboratory test machine. The jack load was hence divided into 6 equal loads of P/6.

The bending Moment on the specimen was the sum of the total dead load of the specimen, or WL/8, plus the jack load of P (including 30# for weight of cross bars).

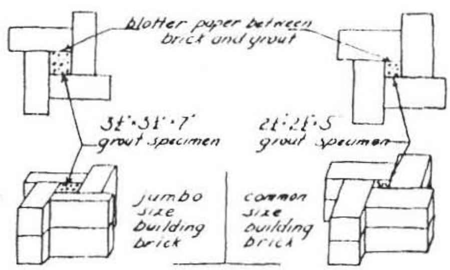
The test panels were checked with a steel straight edge for alignment while in a vertical position, as built. They were then picked up with a fork lift, weighed on a platform scale, rotated, and placed on their sides on the test rig reaction supports. The deflection due to the specimen dead load was checked with the straight edge, recorded, and then the jack load was applied in increments with a record of deflection due to each load application until the panel completely failed.

MATERIALS, TESTING

The materials were tested according to American Society for Testing and Materials standards or, in the case of mortar and grout, according to Uniform Building Code standards and are shown as follows:



TEST FRAME



This is a recommended procedure for grout specimens. The use of blotter paper or other porous material when pouring grout test prisms will prevent the grout from sticking to the brick. This method of grout test yields laboratory strengths which are closer to field conditions than in the case with test cylinders poured in non-absorbent molds.

Wire reinforcing

	Diameter	Area	Yield	Ultimate Tensile
9 gage	.15	.0177"	98,850#	105,775 psi
6 gage	.191	.0287"	91,500#	95,550 psi

15" cross wire spacing, had spacing for longitudinal wires of 5-7/8"
16" cross wire spacing, had spacing for longitudinal wire of 5-3/4" & 2-1/8"

Rebar #3	.375	.11"	60,000# (Grade 60)	93,650

Block (Concrete)

Face shell average	1.276"	
Compression gross area	1863 psi	
" net area	3723 psi	(50% solid)
Modulus of E, elasticity	788,000	(Measured)
Modulus of Rupture	107 psi	(in side bending)

Common Clay Brick

Compression	10,753 psi
Rupture	625 psi

Hollow Clay Brick

Compression	net 3724 psi (55% solid)
Rupture	69 psi

Modular Clay Brick (4 x 12 face)

Compression	11,897 psi
Rupture	713 psi

Mortar, when used on:

Concrete Hollow Block	5540 psi
Clay Hollow	7844 psi
Modular Brick	6093 psi
Common Brick	6597 psi

Grout when used:

in block	4277 "
in Brick	4826 "

These values for mortar and grout emphasize the validity of the Standard which was developed for Uniform Building Code. The method is intended to determine the probable strength of mortar and grout in place in the structures, i.e., as influenced by the water reduction caused by various masonry unit absorption rates, a factor not considered in the ASTM standards. The mortar and grout were carefully proportioned, measured and mixed for constant consistency with minimum variations. However, the effect of masonry unit absorption on strength was quite noticeable. The low absorption rate of the concrete block units did not reduce the water cement ratio of the cement matrix as much as did the more absorbent units. The greater the absorption of the clay units the greater the consequent "in-place" strength of the mortar and grout.

CALCULATIONS

The total moment imposed was the jack load moment plus the uniform specimen dead load moment. The weight of the specimen was corrected by the reduction ratio of the loaded span length divided by the specimen weight, i.e., to include the weight of the span load. However, the negligible effect of the small cantilever moment beyond the span support was neglected.

The resisting section capacity to determine the f_s was based on the simple linear elastic equations as used in Uniform Building Code design.

$$p = As/bd$$

$$k = \sqrt{2np + np^2} - np$$

$$j = 1 - k/3$$

$$f_s = M/Asjd$$

The governing moment was limited by areas of steel, A_s, and the j value was quite high, about 0.95. It was noted that this was confirmed in the test by the extent of the crack at failure. It extended to very near the top face of the specimen while the tension steel continued to elongate.

This introduced a complication in the calculation, that is, the fact the area of the wire that was on the compression side was also put into tension. Furthermore this tension was a greater tension than the simple elastic assumptions would indicate. The reinforcing on the tension side continued to elongate after reaching yield point and the elongation at the crack was an accumulation from an appreciable distance each side of the crack, that is, the angular rotation was much more than the linear elastic assumption indicated. Hence, the moment contributed by the so-called compression steel was at a high level and its moment was much greater than would be contributed by the small tension that was indicated by elastic assumption. It was probably nearly fully developed to yield stress. Consequently, it contributed much more capacity than the calculations would indicate. This must be considered in determination of the steel stress on the tension side of the specimen.

There was another factor that confused the initial stress calculation, this was that the capacity of the masonry section acting as an unreinforced masonry element was appreciable. In running bond masonry the masonry could develop considerable moment before failure before the tension crack occurred and the load subsequently was transferred to the reinforcing. This high capacity was evident also even in some of the clay masonry specimens in stack bond. There was enough tension developed across the mortar head joint in some cases to pull off portions of the brick.

Some spans develop considerably greater capacity uncracked, than when acting as a reinforced, cracked section.

The calculation for capacity according to code, i.e., the Allowable Moment, was based on the allowable values permitted in the UBC based on the linear elastic assumptions. These were used as the basis for comparison and determination of factor of safety, that is, test load/design load.

SPLICES

The splices in flat bed joints were easily developed to fully develop the tension wires in such joints. This confirmed earlier test that had been made by Dur-O-waL that the wire capacity could be developed by 4" long laps.

A lapped splice in the thin face shells of a hollow unit was more subject to workmanship errors than other splices and greater care must be exercised. Also it was noted that when the long 24" splice was used an attempt was made to spread the wires of one to go outside the wires of the other piece. This was not effective. The splices should be made with the wires simply side by side, that is, both the wires of one piece on the same side of the wires of the other piece. Due to the sensitivity of the splices to workmanship it was recommended that the splices in thin face shells be extended to a bar diameter l/d ratio compatible with uninspected bond stresses instead of inspected bond stresses.

The splices that were developed by bending into the vertical grout cells developed good moment capacity even though the effective depth or "d" was reduced at that point. Apparently the bond was so effective that in effect additional reinforcing was functioning for that length.

The effectiveness of the splices in alternate bed joints was rather surprising. There was very positive development of the bars with complete tension failure in the spliced area, that is, the wire was fully developed. It is obviously possible that shorter distances of lap might develop the bars adequately, the installation tested was on the conservative side. There is no great need to develop the theory further because it would merely result in a slightly shorter length of wire, with a probably negligible cost influence.

The UBC allowable design tension stress for wire reinforcing is 30,000 psi and the allowable bond stresses are 140 psi for inspected masonry, 100 for uninspected. Calculations for length required to develop an equality of those factors, or an l/d would be:

$$l \times \pi d \times 140 = 30{,}000 \times \pi d/4$$

$$\text{or } \frac{l}{d} = 54$$

$$l \times \pi d \times 100 = 30{,}000 \times \pi d/4$$

$$\text{or } \frac{l}{d} = 75$$

This factor was considered in preparing a revision to the Uniform Building Code that was subsequently submitted and approved.

The results of the test loads and the calculations for factors of safety are summarized in the enclosed table.

CONCLUSIONS

There were many items demonstrated by the test program in addition to the simple determination of bed joint reinforcing.

The requirement in the Uniform Building Code, Section 2417 (1) of .017 square inches at 16" on center to replace the running bond lap bond capacity is adequately met by the 9ga reinforcing in 8" concrete block. It provides an equivalent capacity to the running bond capacity.

Wire joint reinforcing can be used as principal reinforcing in masonry following the linear elastic principal stated in UBC, i.e., stress in proportion to strain, plane sections remain plane and reinforcing, only, carries the tensile load. It is to be noted however, that in many cases masonry will be stronger uncracked as unreinforced masonry than as reinforced masonry with cracked section.

Splices are easily made in solid bed joints such as in solid brick bed joints.

Splices in face shells of hollow units are critical but may be made satisfactorily in several manners, i.e.,

A. By bending the wires so they lap in grouted cells 54 bar diameters. This is for consistency with the UBC bond value of 140 psi and tensile value of 30,000 psi.

B. By lapping in alternate adjacent courses, i.e., successive courses by a lap distance of 54 diameters, plus twice the course height.

C. By lapping in face shells a distance of at least 75 wire diameters.

D. By welding the wires to provide continuity.

E. By detailing the splice locations to be in areas of no stress, just as is done with reinforcing bars.

Reinforcing bars may also be spliced satisfactorily in bond beam units of conventional construction.

Wire joint reinforcing provides greater strength than equivalent total areas or weights of reinforcing bars which are placed conventionally at the center of walls in grouted bond beam elements.

Wire joint reinforcing permits continuous vertical cavities in hollow unit walls so that insulating fill may be placed for energy conservation. It also permits elimination of grout, hence greatly reducing dead weight and reducing consequent seismic loads on walls, hence providing more capacity to resist imposed live loads. The reduction of dead weight could reduce some seismic wall loads on structures by one half. It also reduces the gravity loads on beams, columns and foundations comparably.

Joint reinforcing provides a stiffer reinforced wall than grouted reinforcing bars placed at the center of the wall.

The joint reinforcement masonry walls provides greater residual capacity for lateral or seismic load resistance than does the grouted construction because of the

greater dead load and consequent seismic load the grout weight imposes.

Joint reinforcing provides the effect of greater ductility in one respect. After the wires on one face fail the wires on the opposite face continue to function, helping to maintain some structural integrity.

Since joint reinforcing is placed near the faces of the wall with little cover there has been question about Fire Endurance or Fire Rating. However, it was recognized that in standard ASTM fire tests there is no lateral load imposed. Therefore, the effect of heat stress reduction would have no influence on the loadbearing capacity, and the steel upon cooling would be about as effective as before testing. Therefore it was obvious the joint reinforcing would have no effect on the structural performance of the walls in fire resistance testing so would be of no concern.

Reference (1) A Report to DUR-O-WAL Division on "Horizontal Joint Reinforcement in Concrete Masonry Construction" by Edwin L. Saxer, 1956.

Reference (2) "Bond Test Data on Masonry Joint Reinforcement" compiled for DUR-O-WAL NATIONAL, Inc. by R. E. Copeland.

Reference (3) "The Structural Role of Joint Reinforcement in Concrete Masonry." National Concrete Masonry Association Technical Bulletin 99.

Reference (4) Results of 120 pullout tests conducted by Professor Edwin L. Saxer, University of Toledo, Ohio.

JOINT REINFORCING TEST SUMMARY

PANEL	M_1 UBC (in.lbs)	M_2 DL	LL	L&D	f's $\frac{M_2}{A_s jd}$	F.S. $\frac{M_2}{M_1}$	REMARKS
RBN,A - no reinf.	2300	9032	5647	14679	0	6.38	Running bond, no As
RBN,B (do)	2300	9122	5647	14769	0	6.42	Running bond, no As
GBB,A #3 in grouted	10098	8332	31830	40162	99^k	3.97	A_s=.11 vs A=.035 in wall .11/.035=3.1 times
GBB,B (do)	10098	7617	31117	38734	96^k	3.84	
GBBS,A (do)	10098	7741	35370	43111	114	4.27	This confirms that the spliced rebar functions at high value. Panel broke at first joint away from center.
GBBS,B (do)	10098	8287	15559	23846	74	2.36	Bond failure at splices
9JGA (15):9ga wire in	4649	9752	2115	11867	99	2.55	As required by SEAOSC. The extra weight left little capacity for LL
9JGB (do)	4649	10060	2824	12884	108	2.77	
9JG,A (16)i.e.,cross wires	4649	9112	5611	14730	123	3.17	
9JG,B (do)	4649	9112	5611	14736	123	3.17	Wire failed
JOINT REINF.							
9J,A 9ga in joint, of block, no splice	4649	5852	13432	19285	156*	4.15	Wire broke 4" from cross wire
9J,B (do)	4649	5829	6360	12189	104	2.62	Wire broke near weld of cross wire
9J,C (do)	4649	5631	7065	12695	112	2.73	
6J,A 6ga, or 3/16",in block joint	7538	5666	18383	24084	130*	3.19	
6J,B (do)	7538	5924	16796	22900	118	3.04	Clay bond had pulled off surface (adding to capacity
6J,C (do)	7538	5631	19800	25431	137	3.37	
6RGB,A 6ga in 2 wythe	7538	9930	15559	25489	---	3.38	
clay brick	*	9930	8482	18412	104	2.44	Wire failed in tension (see Calc)
6RGB,B (d0)	7538	10153	14850	25003	---	3.32	
94B,A 9ga in 4" brick	2072	3399	4241	7640	1*	3.69	Wire failed in tension
94B,B (do)	2072	3337	1406	4743	*	2.29	Wire failed in tension

JOINT REINFORCING TEST SUMMARY

PANEL	M_1 UBC (Seismic)	DL	M_2 LL	L&D	f's $\frac{M_2}{Asjd}$	F.S. $\frac{M_2}{M_1}$	REMARKS This group compares <u>splices</u>
SPLICES							
9SJ8-A Nominal 8" splice in bed joint	4649	5683	8482	14166	120*	3.05	Splice yielded, bond sliding
9SJ8-B (do)	4649	--	--				Lap pulled out during weighing. Mortar not around wire (was visible)
9SF8-C (do)	4649	5626	7775	13401	112	2.88	Wire failed near cross wire weld
9SJ16-A Nominal 16" splice in bed joint	4649	5567	7065	12632	111	2.72	
9SJ16-B (do)	4649	5758	9900	15658	134*	3.37	
9SF16T,A Normal 16" splice, wide faces together	4649	5573	4950	10523	89	2.26	The tops,or wide edges were placed together. Wire broke at heat affected zone of weld
9SF16T,B (do)	4649	5706	9191	14897	125	3.20	Broke wire
6SJ24,A 6ga,24" splice in bed joint	7538	5660	4241	9901	54	1.31	Panel cracked on weighing, wire was visibly out of mortar bed.
6SJ24,B (do)	7538	5841	9191	15032	78	1.99	
6SJ24,C (do)	7538	5700	3532	9232	52	1.22	Splice not embedded in mortar
9SJC,A 9ga in clay block bed joints	4649	5449	4950	10400	86	2.24	Sudden
9SJC,B (do)	4649	5471	----	-----	---	----	Lap pulled out, not embedded
9SC,A Splice in grouted cell	4649	6083	7774	13857	116	2.98	Bond slippage, slow
9SC,B (do)	4649	5140	3533	8673	74	1.87	
9SAJ,A Splice in Alt joint,4" hi block	4649	5545	10609	16154	135*	3.47	Wire failed & joint yielding
9SAJ,B (do)	4649	5660	9191	14851	124*	3.19	Sudden failure
9SAJ,A Clay block, splice in Alt Jt.	4649	5910	7774	13684	116	2.94	Wire pulled out
9SAJ,B (do)	4649	5926	9191	15117	128	3.26	
9SJ4,A 9ga Splice in bed of 4" brick	2072	3319	2824	6137	122	2.96	Running bond, Bond yielded
9SJ4,B (do)	2245	3451	1406	4857	86	2.16	Broke wire