TECHNICAL REPORT

ON

THE USE OF JOINT REINFORCEMENT

IN BLOCK MASONRY WALLS

SUBMITTED

TO

FRANKLIN RESEARCH CENTER

PHILADELPHIA, PENNSYLVANIA

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1. PROBLEM STATEMENT

Joint reinforcement has been used as a structural element to qualify unreinforced block masonry walls in nuclear power plants. Joint reinforcement is commonly used for crack control and to provide continuity for multiple wythe walls [10, 14].

The structural significance (resisting of tensile stresses) of joint reinforcement in masonry walls is not well established. This is particularly true for unreinforced hollow block masonry walls under cyclic dynamic loading. The following two sections summarize test data and building code requirements for joint reinforcement in an attempt to evaluate its structural significance.

2. EVALUATION OF TEST DATA

There are few test programs documented in the literature addressing the function of joint reinforcement embedded in the mortar joints of masonry walls. Table 1 summarizes the different test data of joint reinforced walls having material properties and construction details similar to block walls in nuclear power plants. The available data are limited to static, normal loads applied to horizontally spanning wall segments. Analysis of the test data presented in the table revealed the following conclusions:

1. Joint reinforcement did not affect the cracking load. Uncracked wall stiffness of unreinforced walls was similar to that of walls with joint reinforcement.

2. The contribution of joint reinforcement in the load carrying capacity ranges from -10% to 300% indicating the sensitivity to variation in material properties and construction details.

3. The single test data [2] available under cyclic loads showed a 33% strength reduction on the first half cycle. This indicates the possible strength degradation under earthquake loads.

4. The deflection at ultimate loads of reinforced walls was, in some cases, much higher than that for unreinforced walls which exhibited a brittle cleavage failure.

5. The statistical significance of the few samples tested is questionable and does not provide confidence in the available test results.

Table 1. Summary of Test Results

Program	Specimen	Joint Reinforcement	No. of Test Repetitions	Failure Mode	% Increase in Cracking Load	% Increase in Ultimate Load	Deflection	Findings	Remarks
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	-	-	[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
		[illegible]	[illegible]			[illegible]			
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-		
		[illegible]	[illegible]			[illegible]			
[illegible]	[illegible]	[illegible]	[illegible]	Ductile failure	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	-	-	-	[illegible]	-		
		[illegible]	-	-	-	[illegible]	-	[illegible]	
	[illegible]	[illegible]	-	-	-	[illegible]	-		
		[illegible]	-	-	-	[illegible]	-		
[illegible]	[illegible]	[illegible]	[illegible]		-	-	-	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]		-	[illegible]	-	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	-	[illegible]	-		
		[illegible]	[illegible]		-	[illegible]	-		
		[illegible]	[illegible]		-	[illegible]	-		

[illegible]

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3. REVIEW OF CODE PROVISIONS

Table 2 presents the different code design provisions concerning the role of joint reinforcement in masonry walls. As can be noted from Table 2, these codes are rarely specific about the usefulness of joint reinforcement and its function as a structural element to carry lateral loads. The codes, however, allow the use of joint reinforcement as part of the required minimum reinforcement in reinforced masonry construction. This implies that the main structural function of joint reinforcement is to distribute the load to the main vertical steel. It must be noted, however, that the codes, if they allow wire reinforcement to be used as principal reinforcing steel, specify that the working stress design (WSD) approach should be followed. The WSD approach assumes linear elastic material properties and limits the allowable steel stress to 30,000 psi.

The new edition (1982) of the Uniform Building Code (UBC) allows the use of joint reinforcement as principal horizontal steel to carry design stresses [13]. This is, however, limited to reinforced masonry walls designed using the WSD method.

The design provisions of most codes apply to masonry buildings under static loads. ATC-3 [3] is the only code that specifies the structural use of joint reinforcement under earthquake loads in seismic areas. It does permit the use of joint reinforcement to resist tensile stresses for seismic Category A and B structures, but states that it cannot be used as the principal reinforcement for Categories C and D structures, except as part of the minimum reinforcing requirements.

4. DESIGN OF MASONRY WALLS WITH JOINT REINFORCEMENT

North American codes for reinforced masonry design assign allowable flexural compressive stresses for masonry and tensile stresses for reinforcing steel. Table 3 presents calculated allowable moments/ft of typical 8-in hollow block walls which span horizontally based on the working stress design. It is assumed that the wall is cracked and that steel carries all the tension. The allowable moment (M_{AU}) the unreinforced wall carries horizontally is calculated based on an allowable flexural stress of $1.0\sqrt{f'_m}$ [1].

Table 2. Code Design Provisions for Joint Reinforcement

Code		Design Provisions
ACI [1]	Section 6.7	"Horizontal joint reinforcement may be used in the wall to increase the tensile resistance and as a means to resist design tensile stresses."
	Section 8.2	"The function of joint reinforcement is to prevent the formation of excessively large, unacceptable shrinkage cracks in masonry walls."
UBC [12]	Section 2418	"The minimum diameter of reinforcement shall be 3/8 inch except that joint reinforcement may be considered as part of the required minimum reinforcement."
NCMA [15]	Section 3.10	"Approved wire reinforcement, placed in horizontal mortar joint, may be used as part of the required reinforcement."
ATC [3]	Section 12.5.1	"JOINT REINFORCEMENT: Longitudinal masonry joint reinforcement may be used in reinforced grouted masonry and reinforced hollow unit masonry only to fulfill minimum reinforcement ratios but shall not be considered in the determination of the strength of the member."
CSA [6]	Section 4.6.8.1	"Wire reinforcement in the mortar joints may be considered as required horizontal reinforcement."

Note: No provisions are given in BS 5628 [4] or TMS [16] concerning the use of joint reinforcement.

Table 3. Allowable Moments

Joint Reinforcement		Calculated Allowable Moment, M_{AR}, lb-in/ft [10]	$\frac{M_{AR}}{M_{AU}}$*
9 gage	8 in o.c.	4880	1.42
	16 in o.c.	2440	0.71
8 gage	8 in o.c.	5820	1.69
	16 in o.c.	2910	0.85
3/16"	8 in o.c.	7430	2.16
	16 in o.c.	3720	1.08

f'_m = 2000 psi, f_m = 0.33 f'_m, f_s = 30,000 psi, type S-mortar,
*ratio of calculated moment of reinforced wall to unreinforced wall (M_{AU} = 3436 lb-in/ft).

The results presented in Table 3 show that the allowable moments for masonry walls spanning horizontally depend primarily on the steel ratio. It is interesting to note that joint reinforcement at lower percentages does not increase the wall resistance.

The contribution of joint reinforcement in the ultimate (failure) lateral load resistance of masonry walls was calculated by Cajdert [5]. He assumed a linear bending strain with a triangular stress distribution in the compression zone. The ultimate strength is assumed to be reached when, after yielding of the tensile reinforcement, the ultimate masonry strength, f'_m, is reached. It must be noted that the joint reinforcement is high tensile steel with a yield stress as high as 100,000 psi. No published data are available on its stress-strain behavior which is needed in the ultimate load analysis. Cajdert's [5] approach of ultimate stress design necessitates precluding any bond failure to develop yielding of the joint reinforcement.

5. CONCLUSIONS AND RECOMMENDATIONS

The structural performance of joint reinforcement is not well established. The qualification of masonry walls in nuclear power plants which takes into account tensile stength due to joint reinforcement is questionable. This is based on the following arguments:

1. The available test data are scarce. Conflicting values have been obtained concerning the contribution of joint reinforcement. Also, the statistical significance of so few samples of such a variable material is questionable.

2. All the tests were performed under static loading which cannot be extrapolated to predict the performance under earthquake loads, which are dynamic and cyclic, fully reversed in nature. The only test data for cyclic static loading showed a dramatic decrease in strength of 33% in half a cycle. This indicates the possibility of severe strength deterioration under multiple reversed cyclic dynamic loading.

3. Masonry codes are not specific about the usefulness of joint reinforcement. Its use is allowed to satisfy the minimum steel requirements for reinforced masonry. If it is to be used to resist tensile stresses, the WSD method should be employed with an allowable steel stress limited to 30,000 psi. This approach limits the contribution of joint reinforcement in increasing the allowable moment over that of unreinforced walls with running bond. It must be noted that codes allow the use of joint reinforcement as a structural steel <u>only</u> in reinforced walls which satisfy the minimum steel requirements in both vertical and horizontal directions. This may not be the case for the masonry walls in nuclear power plants.

4. The only code [3] that addresses the use of joint reinforcement in seismic areas does <u>not</u> allow its use as principal steel for Categories C and D structures. Safety-related masonry walls in nuclear power plants would fit into these categories.

5. For hollow block walls with joint reinforcement, cracking extends to the compression face shell causing a dramatic reduction in wall stiffness and consequently excessive deflection, particularly under cyclic loading.

   A serviceability limit state should be applied to assure proper performance of wall attachments (pipes). This limit state may restrict the performance of joint reinforcement to the linearly elastic stage.

6. Unreinforced walls in nuclear power plants that are joint reinforced to span horizontally should have base boundary conditions which are free to allow both translation and rotation in the out-of-plane direction. This boundary condition, if it exists, forces the wall to transfer its self weight by beam action to the vertical support. Therefore, the wall is under in-plane and out-of-plane forces. The effect of possible interaction on the wall performance, particularly under cyclic dynamic loads, is not known.

In conclusion, the state-of-the art does not give enough insight to understand the performance of joint reinforcement under seismic loads. Therefore, it is the FRC consultants' opinion that <u>no</u> credit should be given

to joint reinforcement to resist tensile stresses due to earthquake loads. A confirmatory test program is therefore recommended to provide data about the structural performance of joint reinforcement in block masonry walls under cyclic dynamic loading.

6. REFERENCES

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ATTACHMENT

SGEB Staff Position on Use of Arching Action Theory to Qualify Unreinforced Masonry Walls in Nuclear Power Plants

INTRODUCTION

Unreinforced hollow block masonry walls have a very limited capacity under the action of out-of-plane loads. Higher resistance could be developed by creating large in-plane clamping forces, thereby forming a three hinged arch mechanism after mid-span and support flexural cracking has occurred. The most important conditions for the arching mechanism to develop are the existence of rotational restraint at the boundaries and the prevention of gross sliding of the wall at support sections. Some of the licensees have relied on the development of this arching mechanism (referred to herein as 'arching action theory') to qualify unreinforced masonry walls in their plants.

The staff and their consultants have reviewed the basis provided by licensees to justify the use of arching action theory to qualify the unreinforced masonry walls. The staff met with a group of licensees representing approximately eleven utilities and twenty two units on November 3, 1982 and January 20, 1983 to discuss this issue. Further, a

site visit and detailed review of design calculations were conducted by the staff and consultants to gain first-hand knowledge of field conditions and the application of arching action theory in qualifying in-place masonry walls. Based on the information gained through the above activities, the staff has formulated the following position on the acceptability of the use of arching action theory to qualify unreinforced masonry walls in operating nuclear power plants. The staff's technical basis for the position is discussed in the attached report.

POSITION

The use of arching action theory to qualify unreinforced masonry block walls is not acceptable. Therefore, the licensee shall fix the walls currently qualified by the use of arching action theory such that they meet the staff acceptance criteria based on the working stress approach.

ENCLOSURE TO ATTACHMENT