TECHNICAL EVALUATION REPORT

MASONRY WALL DESIGN (B-59)

INDIANA AND MICHIGAN ELECTRIC COMPANY

DONALD C. COOK NUCLEAR PLANT UNITS 1 AND 2

NRC DOCKET NO. 50-315, 50-316

NRC TAC NO. 42859, 42860

NRC CONTRACT NO. NRC-03-81-130

FRC PROJECT C5506

FRC ASSIGNMENT 6

FRC TASK 241

Prepared by

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Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

Lead NRC Engineer: N. Chokshi

July 18, 1983
Revised July 27, 1983

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The Benjamin Franklin Parkway, Phila., Pa. 19103 (215) 448-1000

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FOREWORD

This Technical Evaluation Report was prepared by Franklin Research Center under a contract with the U.S. Nuclear Regulatory Commission (Office of Nuclear Reactor Regulation, Division of Operating Reactors) for technical assistance in support of NRC operating reactor licensing actions. The technical evaluation was conducted in accordance with criteria established by the NRC.

1. INTRODUCTION

1.1 PURPOSE OF REVIEW

The purpose of this review is to provide a technical evaluation of the Licensee response to IE Bulletin 80-11 [1] with respect to compliance with the U.S. Nuclear Regulatory Commission (NRC) masonry wall criteria. In addition, if the Licensee plans repair work on masonry walls, the planned methods, procedures, and repair schedules are reviewed for acceptability.

1.2 PLANT-SPECIFIC BACKGROUND

In response to IE Bulletin 80-11, Indiana and Michigan Electric Company provided the NRC with letters and attachments [1-5]. As a results of the review of these references, a request for additional information was sent to the Licensee on July 13, 1982 [6]. The Licensee has responded to this request by providing answers to all questions [7]. With regard to the use of joint reinforcement, a set of questions was sent to the Licensee [8] to which a response was submitted [9].

According to the Licensee's responses to IE Bulletin 80-11, the information regarding the masonry walls in the Donald C. Cook Nuclear Plant Units 1 and 2 is given as follows:

1. There are no masonry walls in the containment building.
2. No safety-related equipment or piping systems are attached to or supported by masonry walls, with the exception of certain junction boxes for some safety-related conduits.
3. According to Reference 5, Attachment A and Reference 7, the following table summarizes the status of masonry walls at the Cook plant:

o Masonry walls in Class I areas	144
o Number of safety-related walls	122
o Number of non-safety-related walls	22
o Number of safety-related walls modified	34

- Walls do not have vertical reinforcement.
- Walls have running bond construction pattern.
- Dur-O-Wal was placed in alternate bed joints. Dur-O-Wal was continually installed around corners and ends were lapped 8 inches.
- Anchors were also provided at every 16 inches along the vertical edges.
- Construction materials are given below:

Compressive strength of masonry	
Hollow masonry units	1000 psi (ASTM-C90)
Solid masonry units	1200 psi (ASTM-C145)
Compressive strength of mortar	
Type N mortar (hollow units)	750 psi
Type M mortar (solid units)	2500 psi
Yield strength of Dur-O-Wal truss reinforcing	70 ksi (ASTM-A82)

2. REVIEW CRITERIA

The basic documents used for guidance in this review were the criteria developed by the Structural and Geotechnical Engineering Branch (SGEB) of the NRC [10] (attached as Appendix A to this report), the Uniform Building Code [11]; and ACI-531-79 [12].

In general, the materials, testing, analysis, design, construction, and inspection of safety-related masonry structures should conform to the SGEB criteria. For operating plants, the loads and load combinations for qualifying the masonry walls should conform to the appropriate specifications in the FSAR for the plant. Allowable stresses are specified in Reference 12 and the appropriate increase factors for abnormal and extreme environmental loads are given in the SGEB criteria (Appendix A).

3. TECHNICAL EVALUATION

This evaluation is based on the Licensee's earlier responses [2-5] and subsequent responses [7, 9] to the requests for additional information [6, 8]. The Licensee's criteria were evaluated with regard to design and analysis methods, loads and load combinations, allowable stresses, construction specifications, and materials. The Licensee's response to the questions contained in the request for additional information was also reviewed.

3.1 EVALUATION OF LICENSEE'S CRITERIA

The Licensee has performed the reevaluation of the masonry walls using the following criteria:

- o Analysis was performed by working stress design method.
- o For allowable stresses, ACI 531-79 [12] was used.
- o Damping values used are specified as follows:
  - 2% damping for operating basis earthquake (OBE)
  - 5% damping for design basis earthquake (DBE).
- o Walls were modeled as horizontal spans
- o Loads and load combinations are the applicable loads from the plant FSAR.
- o Horizontal reinforcement (Dur-O-Wal) has been used to qualify five masonry walls.

The Licensee's responses [7, 9] to the requests for additional information [6, 8] are reviewed below:

Question 1

Describe the assumptions, modeling techniques, and procedures used in the analysis.

Response 1

The Licensee's response indicated that the working stress design method was used in the analysis. The walls were horizontally restrained by intersecting concrete or masonry walls and steel columns, and mortar joint was provided at the bases. At the intersection of two walls, joint reinforcement was continuous around corners, and ends were lapped 8 inches; anchors were also installed along the vertical edges at every 16 inches. The tops of the walls were not restrained. The walls were analyzed as horizontally spanned walls. It is noted that the walls have Dur-O-Wal placed in alternate bed joints and that no vertical reinforcement was installed along the vertical direction.

A review of sample calculations indicated that a beam strip with proper boundary conditions was employed in the analysis. Shear and moment distribution was obtained via the working stress design method. Calculated shear and moment were compared to the allowables specified in the ACI 531-79 codes. The analysis procedures are judged adequate and in compliance with the SGEB criteria.

Question 2

> Specify the number of modes of vibration considered in the seismic analysis, and show how the effect of higher modes of vibration has been considered.

Response 2

The Licensee's response indicated that fundamental frequency was used to determine the acceleration. A peak acceleration of the floor response spectra was used. In addition, the damping values used were also conservative (2% for OBE and 5% for SSE). Based on these conservative measures and for all practical purposes, the fundamental mode should adequately cover the total responses of the walls. It has been found, in many cases at other plants, that the first mode usually contributes 95% or more to the total responses.

Therefore, it can be concluded that the Licensee's approach is satisfactory and in compliance with the SGEB criteria.

Question 3

Indicate how earthquake forces in three directions were considered in the analysis.

Response 3

The Licensee clarified that, for seismic analysis, one horizontal earthquake force and the vertical earthquake force are considered to act simultaneously. This, in fact, is the licensing basis for the D. C. Cook plant. The Licensee's response is adequate and in compliance with the plant's Final Safety Analysis Report (FSAR). Therefore, it meets the requirements of the SGEB criteria.

Question 4

Indicate how the seismic analysis accounted for variations of frequency due to uncertainties in mass, materials, and other parameters used.

Response 4

To account for variations of frequency due to uncertainties in mass, materials, and other parameters, the Licensee indicated that, for a typical wall, a range of fundamental frequencies was estimated based on 10% variation in both material mass and strength. The greatest acceleration was obtained from the floor response spectra and was used to determine the seismic force. The Licensee's response is satisfactory and in compliance with the SGEB criteria.

Question 5

Specify material types used and provide values of allowable stresses for masonry, mortar, grout, and reinforcement.

Response 5

The Licensee provided the following information:

Compressive strength of masonry

Hollow masonry units	1000 psi (ASTM-C90)
Solid masonry units	1200 psi (ASTM-C145)

Compressive strength of mortar

Type N mortar (hollow units)	750 psi
Type M mortar (solid units)	2500 psi

Yield strength of Dur-O-Wal truss reinforcing 70 ksi (ASTM-A82)

Furthermore, the Licensee used the allowable stresses specified in ACI-531-79 [10] for the uninspected construction category. The Licensee indicated that the masonry walls were erected as per Architectural Specification No. DCC-A139-QCS, which did not require written documentation for field inspection during construction. To account for this lack of documentation, reduced allowable stresses were used in the reevaluation.

Based on a review of ASTM standards specified above and due to the fact that reduced allowable stresses were used for the uninspected construction category, the Licensee's response is adequate and satisfies the SGEB criteria.

Question 6

Regulatory Guide 1.61 allows 4% damping for the operating basis earthquake (OBE) and 7% damping for the safe shutdown earthquake (SSE). Provide the damping values used in the analysis and justify them if they are higher than those allowed in Regulatory Guide 1.61.

Response 6

The Licensee has provided for damping values used in the analysis as follows:

- 2% damping for operating basis earthquake
- 5% damping for design basis earthquake.

These values are more conservative than those allowed in Regulatory Guide 1.61 and are therefore satisfactory.

Question 7

Provide any increase factors that may have been used for allowable stresses under abnormal conditions. If they are higher than those factors listed in the SGEB criteria [8], provide justification. The SGEB factors are listed below by types of stress.

Axial or flexural compression	2.5
Bearing	2.5
Reinforcement stress except shear	2.0 but not to exceed 0.9 fy
Shear reinforcement and/or bolts	1.5
Masonry tension parallel to bed joint	1.5
Shear carried by masonry	1.3
Masonry tension perpendicular to bed joint	
reinforced masonry	0
unreinforced masonry	1.3

Response 7

The Licensee's response has provided the stress increase factors used in the abnormal load conditions as follows:

Axial or flexural compression	1.33
Bearing	1.33
Shear carried by masonry	1.33
Masonry tension parallel to bed joint	1.33
Masonry tension perpendicular to bed joint	
reinforced masonry	0
unreinforced masonry	1.33
Shear reinforcement and/or bolts	1.33
The Dur-O-Wal reinforcing was stressed to	0.9 fy

Except for the increase factor for Dur-O-Wal reinforcing (to be discussed later in this section), the increase factors are satisfactory since they are equal to or lower than those allowed by the SGEB criteria.

Question 8

Indicate the boundary conditions used for analyzing the masonry walls and provide justification for those boundary conditions.

Response 8

Regarding the boundary conditions used in the analysis, the Licensee indicated that the walls are restrained at their bases and along the vertical edges. Dur-O-Wal truss reinforcing was installed continuously around corners, and ends were lapped 8 inches. In addition, anchors were provided at every 16 inches along the vertical edge. The analyzed walls were assumed to be simply supported along the vertical edges and free at the top and base.

The Licensee's response is considered adequate and satisfactory.

Question 9

Indicate if the cracking of sections of the walls was given proper consideration in the analysis.

Response 9

The Licensee indicated in Reference 7 that the tensile stresses existing in the masonry walls are lower than the tensile capacity of the mortar in most cases; hence, uncracked section properties were used in these cases. The tensile capacity was exceeded in only five walls, and in these cases, the walls were assumed cracked and the joint reinforcement will carry the tensile stresses. The cracking of sections was considered in these five walls only. The use of joint reinforcement will be discussed later. The Licensee's response has resolved this question satisfactorily.

Question 10

Provide information on loads and load combinations applicable to masonry walls.

Response 10

The Licensee has provided the requested information on load and load combinations. A review of the plant's FSAR indicated that the loads and load combinations used are per plant FSAR and therefore satisfy the SGEB criteria.

Question 11

Describe how interstory drift (both in-plane and out-of-plane) was accounted for.

Response 11

The Licensee's response stated that no contact existed between the top of the masonry wall and the floor above. None of the masonry walls are building structural bearing walls. Load effects due to floor differential displacements are resisted by reinforced concrete structural elements.

The Licensee's response is considered adequate and satisfactory.

Question 12

Provide information on construction practices and the availability of relevant quality assurance/quality control (QA/QC) records to justify the use of allowable stresses applicable to the Special Inspection Category.

Response 12

The Licensee's response supplied information on the criteria used for construction of concrete masonry walls in the plant. However, as indicated in Response No. 5, no written document was available with regard to QA/QC records; therefore, the Licensee assumed that the construction was not inspected and used the allowable stresses specified for uninspected construction.

The Licensee's response meets the requirements of the Uniform Building Code [9] and ACI-531-79 [10] and therefore satisfies the SGEB criteria.

Question 13

Indicate whether the walls are stack bond or running bond. If any stack bond wall exists, provide sample calculations to obtain moment and shear stress of a typical wall.

Response 13

The Licensee stated that all masonry walls of this plant have running bond construction, thus eliminating the concern about stack bond construction.

Question 14

Indicate how wall attachments (equipment, pipes) were considered in the analysis.

Response 14

The Licensee's response indicated that there are no pipe support or equipment reactions applied to any wall. There are some light loads such as fire extinguishers, electrical switch boxes, and conduit supports. The effects of these light loads have been considered in the analysis. The Licensee's response is judged adequate and satisfactory.

Question 15

Provide sample calculations for:

- o Block pullout analysis
- o Missile impact.

Response 15

In this response, the Licensee stated that the concrete masonry walls were not subject to missile impact.

Regarding the block pullout analysis, the Licensee has submitted a sample calculation. A review of the calculation indicated that the pullout forces due to attached equipment have been properly accounted for. The calculated shear stress has been compared to the allowable values given in the ACI 531-79 codes. Therefore, the Licensee's response satisfies the SGEB criteria.

Question 16

With reference to the multiple wythes, clarify whether the collar joint strength was used in the analysis. If so, justify the values used.

Also, on page 2 of Reference 2, the Licensee explained that, when Dur-O-Wal reinforcing has not been used, the wall strength is a multiplication of a single wythe. Explain how shear and tension can be transferred along the collar joint so that the wall strength is a multiplication of single-wythe strength. Also, provide a sample calculation.

Response 16

The Licensee's response indicated that the collar joint was not used in the analysis. A sample calculation illustrating the fact that collar joint strength was not used in qualifying the multi-wythe walls has been provided [7]. In fact, a single wythe was assumed in the analysis.

With regard to the walls without Dur-O-Wal reinforcing, the Licensee indicated that they are knockout panels which have been encapsulated within a structural steel framing.

The Licensee's response is considered adequate and meets the requirements of the SGEB criteria.

Question 17

Indicate if any nonlinear technique was used in the analysis. If so, provide justification for its use. If any existing test data are used to justify the technique, the applicability of the tests should be discussed for the following areas:

Nature of loads
Boundary conditions
Materials used
Wall sizes
Amount and distribution of reinforcement.

Response 17

The Licensee stated that the analysis performed was linear elastic analysis. Nonlinear analysis techniques were not used.

The Licensee's response has eliminated the concern about nonlinear analysis methods.

Question 18

Provide the number of walls which are unreinforced. Also, provide a sample calculation illustrating how tension, shear, and displacement were obtained.

Response 18

The Licensee's response indicated that all masonry walls either have joint reinforcement (Dur-O-Wal) or are encapsulated within structural steel framing, which is a steel grating covering both faces of the wall and connected by tie rods bolted through the walls. Regarding the use of joint reinforcement, the Licensee indicated that all but five walls were qualified relying on the mortar strength. The use of joint reinforcement is further discussed below. The Licensee has provided a sample calculation illustrating how tension, shear, and displacement were evaluated. This calculation has been reviewed and is considered technically adequate since the analysis procedures as well as the allowable stresses were in compliance with the SGEB criteria.

Question 19

Provide detailed drawings of the modifications used. Also, provide a sample calculation to illustrate that the modified wall will be qualified under the working stress design condition.

Response 19

In response to this question, the Licensee has provided detailed drawings of the modifications. In addition, a sample calculation was provided to demonstrate that the modified wall will be qualified under the working stress design method. The modifications and sample calculation have been reviewed and found adequate; they satisfy the SGEB criteria. Further discussion on the modifications will be given in Section 3.2 on the next page.

Additional Responses

With regard to the use of joint reinforcement (Dur-O-Wal) to qualify the masonry walls in the plant, a list of questions was sent to the Licensee [8].

In its response, the Licensee indicated that Dur-O-Wal reinforcing is made of ASTM Standard A82 steel for "Cold Drawn Steel Wire for Concrete Reinforcement." However, all but five walls were qualified relying on the mortar strength. Furthermore, it was noted that if the allowable stresses for the inspected construction category were used, these five walls would be qualified without the use of Dur-O-Wal. The Licensee also indicated that efforts have been initiated to verify the existence of the Dur-O-Wal reinforcing as specified in the design specification through the use of metal detectors. The affected walls are 12-4031-W1, 1-40330-W2 and -W3, and 2-4036-W2 and -W3. NRC staff, FRC, and their consultants have conducted an exhaustive review of available information and licensees' responses to determine the technical adequacy of the use of joint reinforcement to qualify masonry walls in nuclear power plants. The Structural and Geotechnical Engineering Branch (SGEB) of the NRC is developing a position statement regarding this issue which will be available shortly.

3.2 EVALUATION OF LICENSEE'S APPROACH TO WALL MODIFICATIONS

From its evaluation, the Licensee has concluded that 34 walls at the D. C. Cook Nuclear Plant Units 1 and 2 require modification. According to Reference 5, Attachment B, four types of modifications were made at the plant:

1. Beams added to the faces of walls
2. Angles added to the faces of walls
3. Grating added at knock-out areas to encapsulate block walls
4. Beams added at the ends of walls.

All modifications were completed as of October 30, 1981.

With reference to the Response 19 (Section 3.1), the Licensee has provided detailed drawings of the modifications. The Licensee has also provided a sample calculation demonstrating that the modified walls satisfy the SGEB criteria.

4. CONCLUSIONS

A review has been performed to provide a technical evaluation of the masonry walls at D. C. Cook Nuclear Plants Units 1 and 2.

The criteria used for reevaluation of the masonry walls, along with the additional information and clarification provided by the Licensee, indicate that the Licensee's criteria are in compliance with the SGEB criteria except for the issue of joint reinforcement which will be addressed in the NRC staff position. The following walls are affected: 12-4031-W1, 1-40330-W2 and -W3, and 2-4036-W2 and -W3.

With reference to Response 19 (Section 3.1), the Licensee's approach to wall modifications is judged to be adequate, and the modified walls satisfy the SGEB criteria.

5. REFERENCES

1. "Masonry Wall Design"
   NRC, 08-May-81
   IE Bulletin 80-11

2. G. P. Maloney (Indiana & Michigan Electric Company)
   Letter with attachment to J. G. Keppler (NRC)
   Subject: Response to IE Bulletin 80-11, Masonry Wall Design
   July 10, 1980

3. R. S. Hunter (Indiana & Michigan Electic Company)
   Letter to J. G. Keppler (NRC)
   Subject: Interim Supplemental Response to IE Bulletin 80-11
   March 20, 1981

4. R. S. Hunter (Indiana & Michigan Electric Company)
   Letter to J. G. Keppler (NRC)
   Subject: Supplemental Response to IE Bulletin 80-11
   January 14, 1981

5. R. S. Hunter (Indiana & Michigan Electric Company)
   Letter with attachments to James G. Keppler (NRC)
   Subject: Final Report of the Description of Design Modifications and Plant Changes
   October 30, 1981

6. S. A. Varga (NRC)
   Letter to R. S. Hunter (Indiana & Michigan Electric Company)
   Subject: NRC IE Bulletin 80-11 (Masonry Walls). Request for Additional Information
   July 13, 1982

7. R. S. Hunter (Indiana & Michigan Electric Company)
   Letter with attachments to H. R. Denton (NRC)
   Subject: NRC IE Bulletin 80-11 (Masonry Wall). Request for Additional Information
   August 20, 1982

8. S. A. Varga (NRC)
   Letter to R. S. Hunter (Indiana & Michigan Electric Company)
   Subject: NRC IE Bulletin 80-11 (Masonry Walls). Request for Additional Information
   October 4, 1982

9. R. S. Hunter (Indiana & Michigan Electric Company)
Letter with attachments to H. R. Denton (NRC)
Subject: NRC IE Bulletin 80-11 (Masonry Walls). Request for Additional Information
November 19, 1982

10. "Structural and Geotechnical Engineering Branch (SGEB) Criteria for Safety-Related Masonry Wall Evaluation"
NRC, July 1981

11. Uniform Building Code
International Conference of Building Officials, 1979

12. "Building Code Requirements for Concrete Masonry Structures"
American Concrete Institute, 1979
ACI 531-79 and Commentary ACI 531R-79

APPENDIX A

SGEB CRITERIA FOR SAFETY-RELATED MASONRY WALL EVALUATION
(DEVELOPED BY THE STRUCTURAL AND GEOTECHNICAL ENGINEERING BRANCH
[SGEB] OF THE NRC)

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1. General Requirements

The materials, testing, analysis, design, construction, and inspection related to the design and construction of safety-related concrete masonry walls should conform to the applicable requirements contained in Uniform Building Code - 1979, unless specified otherwise, by the provisions in this criteria.

The use of other standards or codes, such as ACI-531, ATC-3, or NCMA, is also acceptable. However, when the provisions of these codes are less conservative than the corresponding provisions of the criteria, their use should be justified on a case-by-case basis.

In new construction, no unreinforced masonry walls will be permitted. For operating plants, existing unreinforced walls will be evaluated by the provisions of these criteria. Plants which are applying for an operating license and which have already built unreinforced masonry walls will be evaluated on a case-by-case basis.

2. Loads and Load Combinations

The loads and load combinations shall include consideration of normal loads, severe environmental loads, extreme environmental loads, and abnormal loads. Specifically, for operating plants, the load combinations provided in the plant's FSAR shall govern. For operating license applications, the following load combinations shall apply (for definition of load terms, see SRP Section 3.8.4II-3).

(a) Service Load Conditions

(1) D + L

(2) D + L + E

(3) D + L + W

If thermal stresses due to T_o and R_o are present, they should be included in the above combinations as follows:

(1a) $D + L + T_o + R_o$

(2a) $D + L + T_o + R_o + E$

(3a) $D + L + T_o + R_o + W$

Check load combination for controlling condition for maximum 'L' and for no 'L'.

(b) Extreme Environmental, Abnormal, Abnormal/Severe Environmental, and Abnormal/Extreme Environmental Conditions

(4) $D + L + T_o + R_o + E$

(5) $D + L + T_o + R_o + W_t$

(6) $D + L + T_a + R_a + 1.5\ P_a$

(7) $D + L + T_a + R_a + 1.25\ P_a + 1.0\ (Y_r + Y_j + Y_m) + 1.25\ E$

(8) $D + L + T_a + R_a + 1.0\ P_a + 1.0\ (Y_r + Y_j + Y_m) + 1.0\ E'$

In combinations (6), (7), and (8) the maximum values of P_a, T_a, R_a, Y_j, Y_r, and Y_m, including an appropriate dynamic load factor, should be used unless a time-history analysis is performed to justify otherwise. Combinations (5), (7), and (8) and the corresponding structural acceptance criteria should be satisfied first without the tornado missile load in (5) and without Y_r, Y_j, and Y_m in (7) and (8). When considereing these loads, local section strength capacities may be exceeded under these concentrated loads, provided there will be no loss of function of any safety-related system.

Both cases of L having its full value or being completely absent should be checked.

3. Allowable Stresses

Allowable stresses provided in ACI-531-79, as supplemented by the following modifications/exceptions, shall apply.

(a) When wind or seismic loads (OBE) are considered in the loading combinations, no increase in the allowable stresses is permitted.

(b) Use of allowable stresses corresponding to special inspection category shall be substantiated by demonstration of compliance with the inspection requirements of the SEB criteria.

(c) When tension perpendicular to bed joints is used in qualifying the unreinforced masonry walls, the allowable value will be justified by test program or other means pertinent to the plant and loading conditions. For reinforced masonry walls, all the tensile stresses will be resisted by reinforcement.

(d) For load conditions which represent extreme environmental, abnormal, abnormal/severe environmental, and abnormal/extreme environmental conditions, the allowable working stress may be multiplied by the factors shown in the following table:

Type of Stress	Factor
Axial or Flexural Compression[1]	2.5
Bearing	2.5
Reinforcement stress except shear	2.0 but not to exceed 0.9 fy
Shear reinforcement and/or bolts	1.5
Masonry tension parallel to bed joint	1.5
Shear carried by masonry	1.3
Masonry tension perpendicular to bed joint	
for reinforced masonry	0
for unreinforced masonry[2]	1.3

Notes

(1) When anchor bolts are used, design should prevent facial spalling of masonry unit.

(2) See 3(c).

4. Design and Analysis Considerations

(a) The analysis should follow established principles of engineering mechanics and take into account sound engineering practices.

(b) Assumptions and modeling techniques used shall give proper considerations to boundary conditions, cracking of sections, if any, and the dynamic behavior of masonry walls.

(c) Damping values to be used for dynamic analysis shall be those for reinforced concrete given in Regulatory Guide 1.61.

(d) In general, for operating plants, the seismic analysis and Category I structural requirements of FSAR shall apply. For other plants, corresponding SRP requirements shall apply. The seismic analysis shall account for the variations and uncertainties in mass, materials, and other pertinent parameters used.

(e) The analysis should consider both in-plane and out-of-plane loads.

(f) Interstory drift effects should be considered.

(g) In new construction, grout in concrete masonry walls, whenever used, shall be compacted by vibration.

(h) For masonry shear walls, the minimum reinforcement requirements of ACI-531 shall apply.

(i) Special constructions (e.g., multiwythe, composite) or other items not covered by the code shall be reviewed on a case-by-case basis for their acceptance.

(j) Licensees or applicants shall submit QA/QC information, if available, for staff's review.

In the event QA/QC information is not available, a field survey and a test program reviewed and approved by the staff shall be implemented to ascertain the conformance of masonry construction to design drawings and specifications (e.g., rebar and grouting).

(k) For masonry walls requiring protection from spalling and scabbing due to accident pipe reaction (Y_r), jet impingement (Y_j), and missile impact (Y_m), the requirements similar to those of SRP 3.5.3 shall apply. However, actual review will be conducted on a case-by-case basis.

5. <u>References</u>

(a) Uniform Building Code - 1979 Edition.

(b) Building Code Requirements for Concrete Masonry Structures ACI-531-79 and Commentary ACI-531R-79.

(c) Tentative Provisions for the Development of Seismic Regulations for Buildings - Applied Technology Council ATC 3-06.

(d) Specification for the Design and Construction of Load-Bearing Concrete Masonry - NCMA August, 1979.

(e) Trojan Nuclear Plant Concrete Masonry Design Criteria Safety Evaluation Report Supplement - November, 1980.

Attachment 2

SGEB Staff Position
on the Use of Joint Reinforcing
in Qualifying Unreinforced Masonry Walls

Introduction

The function of joint reinforcement in masonry walls is to prevent the formation of unacceptable shrinkage cracks. The structural significance (i.e., to provide resistance to tensile stresses) of joint reinforcement in masonry walls is not well established. This is particularly true for unreinforced hollow block masonry walls subject to cyclic dynamic loading. However, some licensees have proposed to use joint reinforcement as a structural element to qualify unreinforced masonry walls in their plants.

The staff and their consultants have reviewed the technical justifications provided by some licensees for using the joint reinforcing (such as 'Dur-O-Wal') as a structural element in qualifying masonry walls which are unreinforced or do not meet the minimum reinforcement requirements of the Uniform Building Code. The staff has further reviewed the test results available in the literature, codes, and other pertinent information. Based on these reviews, the staff has formulated the following position on the use of joint reinforcing as a structural reinforcing element in unreinforced masonry walls. The staff's technical basis for this position is discussed in the attached report.

Position

The use of joint reinforcing as a structural element (to evaluate the capacity of the wall in resisting applied loads) for qualifying masonry walls not meeting the minimum reinforcement requirements with respect to steel ratios, spacing, etc., of the Uniform Building Code-1979 edition is not acceptable*. Therefore, the licensee shall fix the walls currently qualified by the use of joint reinforcing as a structural element such that they meet the staff's acceptance criteria for unreinforced walls (Appendix A of TER, Attachment 1).

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* As noted in the attached report, the use of high allowables in joint reinforcement, say beyond 30,000 psi, even in the case of reinforced walls is questionable and not acceptable. However, this position only addresses the use of joint reinfrocing in unreinforced walls.

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
Dickey [9]	2 courses wide by 6 blocks longs stack bonded hollow blocks	9 gage Dur-O-Wal Ladder Type	3	Wire broke	-*	150	Load-deflection curves were not presented.	Wire reinforcement can be used as principal reinforcing following the linear elastic principle stated in UBC.	Unreinforced specimens laid up in running bond whereas reinforced specimens laid up in stack bond making direct comparison inappropriate.
		6 gage Dur-O-Wal Ladder Type f_y = 95-105 ksi	3	-	-	240			
Hedstrom [11]	3 courses wide by 12 courses high, stack bond, spanned along the shorter direction	9 gage 8" o.c.	2	Mortar bond failure with steel failing in the same location	No increase	380	Large deflection at ultimate compared to deflection before cracking.	Joint reinforcement did not increase load at first cracking but it was effective in increasing the ultimate strength, particularly for stack walls.	
		16" o.c.	2			325			
	3 courses wide by 12 courses high, running bond, spanned along the shorter direction	9 gage 8" o.c.	2	Straight line vertical crack passing through the head joints	No increase	49	-		
		16" o.c.	2			18			
Cox & Ennenga [7]	Panels 3'-4" x 8', hollow blocks spanned along the 8 ft dimension	9 gage in each joint	1	Ductile failure	12	36	Increase 10% of deflection at ultimate compared to unreinforced walls.	Joint reinforcement increased both ultimate load and maximum deflection.	
NCMA [15]	Panels 4' x 8' spanned horizontally, hollow block, running bond	9 gage 8" o.c.	-	-	-	60	-	Joint reinforcement increases a wall's resistance to bending in horizontal direction particularly for stack bond walls.	
		16" o.c.	-	-	-	20	-		
	Panels 4' x 8' spanned horizontally, hollow block, stacked bond	9 gage 8" o.c.	-	-	-	400	-		
		16" o.c.	-	-	-	300	-		
Anderson et al. [2]	8' x 8' walls, running bond, hollow blocks	wires d - 0.15" in each joint f_y = 60 ksi	1		-	-	-	A 33% strength reduction on the reversed half cycle.	No reference wall (unreinforced) was tested; therefore, the contribution of joint reinforcement can not be determined.
Churchward & Mattison [8]	4' x 2' walls running bond, 4" thick solid walls	d = 0.103" f_y = 75 ksi	2	Bond failure between mortar and blocks	-	-10	-	High percentage of steel is required to match the cracking strength of unreinforced walls; normal joint reinforcement patterns do not satisfy these requirements.	They attributed the strength reduction to the breakdown in mortar-block bonding caused by reinforcement splitting the mortar joints into smaller areas.
		d = 0.128" f_y = 68 ksi	2		-	-13	-		
		d = 0.048" f_y = 78 ksi	2		-	-15	-		
		d = 0.048" f_y = 88 ksi	2		-	-18	-		

*Data are not available.

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 $1.0\sqrt{m_o}$ [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.

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