TECHNICAL EVALUATION REPORT

MASONRY WALL DESIGN

BALTIMORE GAS AND ELECTRIC COMPANY

CALVERT CLIFFS NUCLEAR POWER PLANT UNITS 1 AND 2

NRC DOCKET NO. 50-317, 50-318

NRC TAC NO. —

NRC CONTRACT NO. NRC-03-81-130

FRC PROJECT C5506

FRC ASSIGNMENT 6

FRC TASK 249

Prepared by

Franklin Research Center
20th and Race Street
Philadelphia, PA 19103

Author: S. Triolo

FRC Group Leader: V. N. Con

Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

Lead NRC Engineer: N. C. Chokshi

September 12, 1984

Franklin Research Center

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

TECHNICAL EVALUATION REPORT

MASONRY WALL DESIGN

BALTIMORE GAS AND ELECTRIC COMPANY

CALVERT CLIFFS NUCLEAR POWER PLANT UNITS 1 AND 2

NRC DOCKET NO. 50-317, 50-318

NRC TAC NO. —

NRC CONTRACT NO. NRC-03-81-130

FRC PROJECT C5506

FRC ASSIGNMENT 6

FRC TASK 249

Prepared by

Franklin Research Center
20th and Race Street
Philadelphia, PA 19103

Author: S. Triolo

FRC Group Leader: V. N. Con

Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

Lead NRC Engineer: N. C. Chokshi

September 12, 1984

Prepared by:	Reviewed by:	Approved by:
Stephen Triolo	V. Ngoc Con	O P Carfagno
Principal Author:	Group Leader	Department Director
Date: 9-12-84	Date: 9-12-84	Date: 9-12-84

Franklin Research Center

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

CONTENTS

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 technical evaluations of licensee responses to IE Bulletin 80-11 [1]* with respect to compliance with the Nuclear Regulatory Commission (NRC) masonry wall criteria. In addition, if a licensee has planned repair work on masonry walls, the planned methods and procedures are to be reviewed for acceptability.

1.2 GENERIC ISSUE BACKGROUND

In the course of conducting inspections at the Trojan Nuclear Plant, Portland General Electric Company determined that some concrete masonry walls did not have adequate structural strength. Further investigation indicated that the problem resulted from errors in engineering judgment, a lack of established procedures and procedural details, and inadequate design criteria. Because of the implication of similar deficiencies at other operating plants, the NRC issued IE Bulletin 80-11 on May 8, 1980.

IE Bulletin 80-11 required licensees to identify plant masonry walls and their intended functions. Licensees were also required to present reevaluation criteria for the masonry walls with the analyses to justify those criteria. If modifications were proposed, licensees were to state the methods and schedules for the modifications.

1.3 PLANT-SPECIFIC BACKGROUND

In response to IE Bulletin 80-11, Baltimore Gas and Electric Company provided the NRC with documents [2] describing the status of masonry walls at Calvert Cliffs Nuclear Power Plant. The information in these documents was reviewed, and a request for additional information was sent to the Licensee [3] to which the Licensee responded [4]. Additional questions [5] were sent to the Licensee, to which it has also responded [6].

---

* Numbers in brackets indicate references, which are cited in Section 5.

A total of 147 safety-related walls were identified. All walls subject to reevaluation under Bulletin 80-11 are found in the auxiliary building.

The masonry construction at Calvert Cliffs Units 1 and 2 consists of single- and double-wythe walls of the running bond type. Their functions include partition, shielding, blockout, bearing, and filler. Vertical reinforcement is provided by grouting reinforcing bars in vertical cells. "Dur-o-Wal" was used for horizontal reinforcement. Both reinforced and unreinforced walls were built in the plant. The construction materials used are as follows:

Mortar - ASTM C-270, Type S
Grout - ASTM C-476
Concrete - Blocks specified to meet both ASTM C-90 and C-129, Grade N-1
Reinforcing steel - ASTM A-615, Grade 40.

Arching action was used to qualify one wall; however, this wall was scheduled for modifications by October 1, 1984 that will bring the wall within SGEB elastic requirements. The Licensee has concluded that all other walls satisfy the reevaluation criteria and has proposed no other modifications.

The Licensee has relied upon the energy balance technique to qualify some masonry walls. NRC, FRC, and FRC's consultants (Drs. H. Harris, and A. Hamid of Drexel University) have conducted an exhaustive review of this subject based on submittals provided by the Licensee and on published literature and have concluded that the available data in the literature do not give enough insight for understanding the mechanics and performance of reinforced masonry walls under cyclic, fully reversed dynamic loading. As a result, a meeting with representatives of the affected plants was held at the NRC on November 3, 1982 so that the NRC and FRC's staff and consultants could explain why the applicability of the energy balance technique to masonry walls in nuclear power plants is questionable [7]. In a subsequent meeting on January 20, 1983, consultants of utility companies presented their rebuttals [8] and requested that they be treated on a plant-by-plant basis. In accordance with the above request, NRC, FRC, and consultants visited several nuclear power plants to examine the field conditions of masonry walls in the plant and to gain first-hand knowledge of how the energy balance technique is applied to actual walls. Further discussion on this subject is provided in Section 3.1.

2. EVALUATION 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 (attached as Appendix A to this report), the Uniform Building Code [9], and ACI 531-79 [10].

The materials, testing, analysis, design, construction, and inspection of safety-related concrete masonry structure 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 Final Safety Analysis Report (FSAR) for the plant. Allowable stresses are specified in Reference 10 and the appropriate increase factors for abnormal and extreme environmental loads are given in the SGEB criteria (Appendix A).

3. TECHNICAL EVALUATION

This technical evaluation is based on the Licensee's earlier submittals [2] and subsequent responses [4, 6] to the NRC requests for additional information [3, 5]. The Licensee's criteria were evaluated with regard to design and analysis methods, loads and load combinations, allowable stresses, construction specifications, materials, and any relevant test data.

3.1 EVALUATION OF LICENSEE'S CRITERIA

The Licensee has evaluated the masonry walls using the following criteria:

- o The design allowables are based on ACI 531-79 [10].
- o The working stress design method and the energy balance technique were used in the analysis. Out of 147 safety-related walls, 22 were qualified by the energy balance technique.
- o Loads and load combinations are consistent with Final Safety Analysis Report specifications.
- o Critical damping values of 4% for operating basis earthquake (OBE) and 7% for safe shutdown earthquake (SSE) were used for vertically reinforced walls which were assumed to crack under seismic conditions. A damping value of 2% was used for uncracked walls.
- o The typical analytical procedure is summarized below:
  - Determine wall boundary conditions
  - Using a one-way beam model and the floor response spectrum, determine the responses of the first three modes and combine them by the square root of the sum of the square method.
  - Compare computed stresses with the allowable values in ACI 531-79.

Other than those areas identified in Section 4, the Licensee's criteria have been reviewed and found to be technically adequate and in compliance with the SGEB criteria. The review of the Licensee's responses [4, 6] to the requests for additional information [3, 5] follows.

Question 1

With reference to multiple wythes, clarify whether the collar joint strength was used in the analysis. If so, justify by any existing test data the values for allowable shear and tension of collar joints. Also, provide sample calculations illustrating how stresses were calculated for a multi-wythe wall.

Response 1 [Reference 4]

In this response, the Licensee confirmed that collar joint strength in multiple-wythe walls was assumed to be zero and, in all cases, wythes were treated independently of each other. This approach is satisfactory with respect to the SGEB criteria.

Question 2

Indicate whether the allowable masonry stresses were taken from the ACI 531-79 special inspection category. Explain and justify the use of this category if construction practices do not conform with the provisions specified for the special inspection category in ACI 531-79.

Response 2 [Reference 4]

In this response, the Licensee indicated that the allowable stresses of the ACI 531-79 special inspection category were used in the analysis of masonry walls and were appropriate for the following reasons:

a. Masonry walls were constructed from project drawings and specifications, which delineated requirements to ensure proper workmanship and materials and to prevent voids and other weaknesses.

b. Field engineers were on site during the construction of masonry wall to report any errors or inadequacies in materials or worksmanship.

c. The masonry wall walkdown reported the existence of cracks and the general condition of the walls. The walls were in good condition.

The Licensee's response is considered to be satisfactory.

Question 3

With respect to Section 5.2.1, Attachment D, Reference 2, the Licensee uses an increase factor of 1.67 for allowable masonry stresses in tension and shear, whereas the SEB Criteria allow only 1.3 for shear and tension normal to the bed joint and only 1.5 for tension parallel on the bed joint. The Licensee justifies the factor of 1.67 by claiming that it provides a factor of safety of 1.8 = (3 divided by 1.67). Substantiate this justification by any existing test data. The applicability of the tests should be discussed for the following areas:

- o Nature of loads
- o Boundary conditions
- o Sizes of test walls
- o Type of masonry construction (block type, mortar type, grouted, or ungrouted).

In addition, the Licensee is requested to indicate if the SEB Criteria were used, how many walls cannot be qualified, and to identify these walls.

Response 3 [Reference 4]

In this response, the Licensee stated that, because all elastically qualified walls were analyzed as vertically spanning beam strips, the factor of 1.67 was used only for tension perpendicular to the bed joint. A list of eight walls was provided which would not qualify if the SEB criteria were to be used for tension normal to the bed joint. Also, the Licensee showed that actual shear stress values would fall within allowable limits even if the SEB factor of 1.3 were used instead of 1.6.

A table was provided listing the actual increase factors required to bring the walls within allowable limits and the percentage by which these factors exceeded the SGEB factor. The highest percentage of exceedance was 26% and the lowest was 11.5%. However, this increase could be compensated for by various conservative measures such as the conservative analytical assumptions of one-way vertical spans and a 2% damping value for these uncracked walls, in which masonry tension normal to the bed joint is used. In addition, whenever the natural frequency of the wall falls in the lower side of the peak response spectra, this peak value was used to obtain a conservative seismic loading as shown in Figure 1.

Question 4

In Reference 2, the Licensee indicated that "inelastic design," and "arching theory," have been used to qualify some of the masonry walls. The NRC, at present, does not accept the application of these methods to masonry walls in nuclear power plants in the absence of conclusive evidence to justify this application. The Licensee is requested to provide sample calculations to illustrate the analysis by each method.

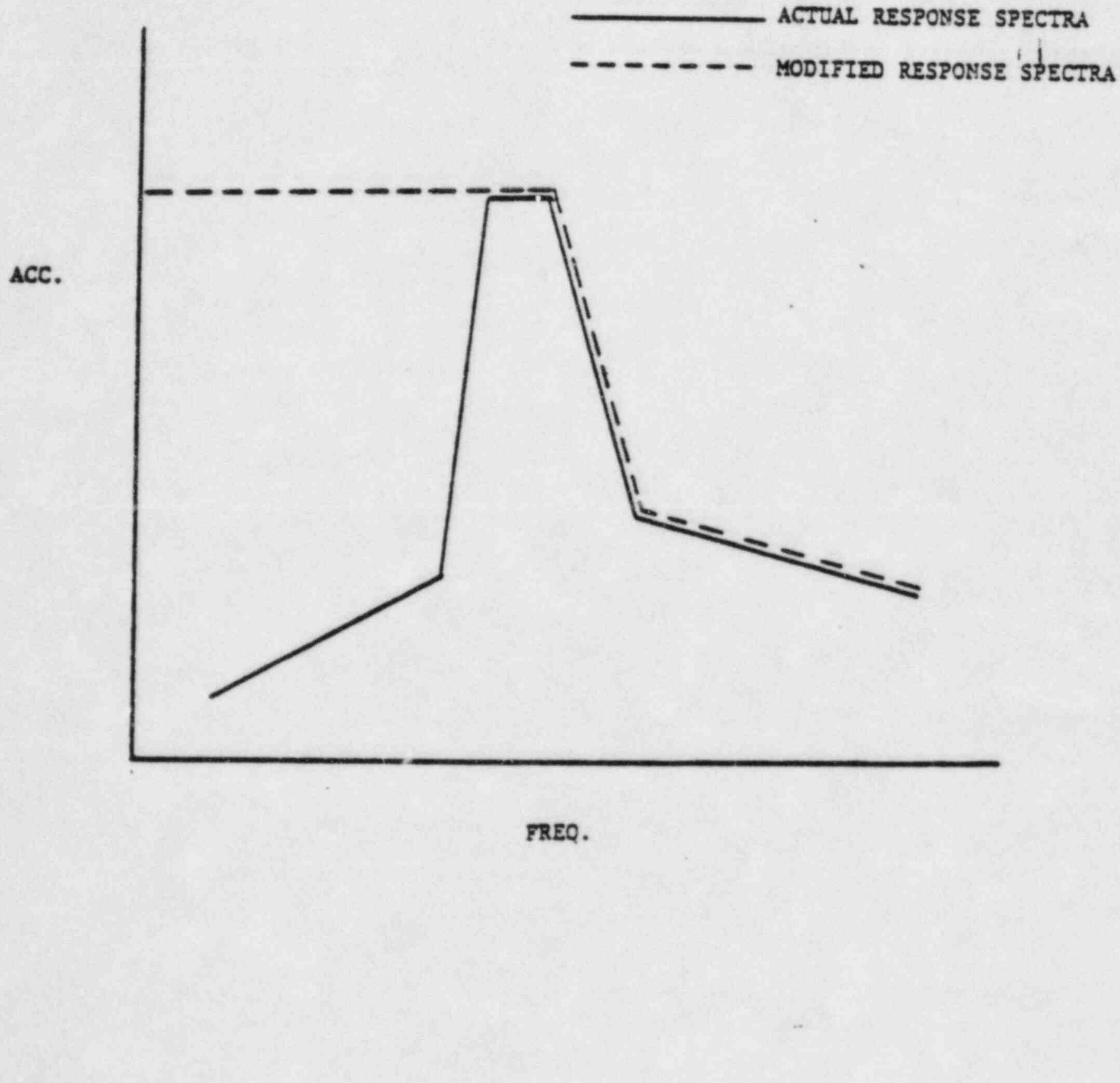

Figure 1. Response Spectrum Modification

In addition, the following areas need technical verification before any conclusion can be made about these techniques.

4.1 Inelastic design/energy balance technique

- o For the walls which are analyzed by using the energy balance technique, provide technical basis to ensure that the ductile mode of failure will take place (if they fail).
- o Provide justification and test data (if available) to validate the applicability of the energy balance technique to the masonry structures at Calvert Cliffs Units 1 and 2 with particular emphasis on the following areas:

  a. Nature of the load
  b. Boundary condition
  c. Material strengths
  d. Size of test walls

4.2 Arching Theory

- o Explain how the arching theory handles cyclic loading, especially when the load is reversed.
- o Provide justification and test data (if available) to validate the applicability of the arching theroy to the masonry strutures at Calvert Cliffs Units 1 and 2 with particular emphasis on the following areas:

  a. Nature of the load
  b. Boundary condition
  c. Material strengths
  d. Size of test walls

- o If hinges are formed in the walls, the capability of the structures to resist in-plane shear force would be diminished, and shear failure might take place. This in-plane shear force would also reduce the out-of-plane stiffness. Explain how the effect of this phenomenon can be accurately determined.

Response 4 [Reference 4]

The Licensee stated that one wall (wall ZZ) was qualified by the arching theory. However, this wall has been scheduled for modifications by October 1, 1984 to bring the wall within SGEB elastic requirements.

In this response, the Licensee provided justification for its use of the energy balance technique. NRC staff, FRC, and FRC's consultants have conducted an exhaustive review of available information on this subject and of licensees' responses to determine the technical adequacy of the methodology. FRC and its consultants have issued their evaluation and assessment of the use energy balance technique in masonry walls [7, 11]. The Structural and Geotechnical Engineering Branch (SGEB) has issued a position statement regarding this subject which will be addressed in its Safety Evaluation Report.

Question 5

> Section 3.7.2 of the Standard Review Plan requires that unless a dynamic analysis is performed, the effect of higher modes of vibration shall be accounted for by multiplying the peak acceleraton of the floor respose spectrum by a factor of 1.5. The Licensee is requested to explain how higher modes of vibration were accounted for in the analysis.

Response 5 [Reference 4]

The Licensee explained that a modal analysis technique was used in conjunction with the response spectrum method to determine the seismic response of masonry walls. Typically, a computer program was used to calculate the first three modes of vibration for the wall; then their respective responses, from the floor response spectrum, were combined by the SRSS method to gain the total wall response. The results of the analysis were verified against a nine mode solution.

Since it has been observed in other plants that the first mode usually contributes 95% or more to the total response of a wall, for all practical purposes, the Licensee's approach is acceptable under the SGEB criteria.

Question 6

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

Response 6 [Reference 4]

In this response, the Licensee indicated that the seismic forces in the vertical and two horizontal directions were considered to act simultaneously. The critical walls for each of the following in-plane load cases were considered:

1. vertical seismic
2. horizontal seismic in unreinforced unconfined wall
3. horizontal seismic in reinforced unconfined wall.

Stresses due to in-plane loads were generally insignificant.

This response is satisfactory with respect to the SGEB criteria.

Question 7

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 7 [Reference 4]

The Licensee indicated that the damping values used for reinforced walls which were expected to crack were 4% for OBE and 7% for SSE, and the value for uncracked walls was 2% for OBE and SSE. Since these values are consistent with Regulatory Guide 1.61, the Licensee's response is adequate and in compliance with the SGEB criteria.

Question 8

Indicate if block pullout was considered in the evaluation. If yes, provide sample calculations of block pullout analysis.

Response 8 [Reference 4]

The Licensee provided calculatins for block pullout, which determined the minimum allowable pullout force, based on an allowable shear value at the four sides of the block mortared to other blocks, of $1.1\sqrt{f'_m}$ or 38.8 psi in accordance with ACI 531-79. The wall analyses were reviewed for concentrated loads of the critical magnitude, and all were considerably less than the allowable pullout force.

This response satisfies the SGEB criteria.

Question 9

Specify the number of masonry walls analyzed for impact and suddenly applied loads. Provide the results (stresses, displacements) of these analyses. In addition, provide a sample calculation illustrating the analysis for impactive and suddenly applied loads.

Response 9 [Reference 4]

This response stated that none of the masonry walls at Calvert Cliffs were subject to impact or suddenly applied loads.

Question 10

The following drawings in Reference 2 are illegible: A.21 of Appendix F "Typical Joint Details" and C.1 of Attachment C "Masonry Details." Provide legible copies of these drawings.

Response 10 [Reference 4]

Legible copies of drawings A.21 and C.1 were provided.

3.2 EVALUATION OF LICENSEE'S APPROACH TO WALL MODIFICATIONS

The Licensee has concluded that all safety-related masonry walls at Calvert Cliffs Nuclear Power Plant satisfy the reevaluation criteria. Therefore, no wall modifications have been proposed, except for wall ZZ at 69'-0", which was qualified by arching action and will be modified by October 1, 1984 to conform to SGEB elastic criteria. (See Response 4 for further details.)

4. CONCLUSIONS

A detailed study was performed to provide a technical evaluation of the masonry walls at the Calvert Cliffs Nuclear Power Plant Units 1 and 2. With respect to the SGEB criteria, the Licensee's submittals and additional information provided by the Licensee have been reviewed and the following conclusions have been reached.

- o Higher allowable stress increase factors were used for tension normal to the bed joint (1.67 as opposed to 1.3 by the SGEB criteria) to qualify eight masonry walls. As indicated in Response 3 of Section 3, the actual increase factors exceed the SGEB allowables by 11.5% to 26%. However, various conservative measures have been used in the analysis. A one-way vertical span (instead of two-way action) and 2% critical damping (as opposed to 7% as specified in the SGEB criteria) for uncracked walls were used in the analysis and should result in a conservative stress calculation. In addition, whenever the natural frequency of the wall falls within the lower side of the peak response spectra, this peak value was used to obtain a conservative seismic loads as shown in Figure 1. Therefore, it can be concluded that the Licensee's increase factors are technically adequate and meet the intent of the SGEB criteria.

- o With regard to the energy balance technique, the following walls are affected:

Auxiliary Building	El. 27'-0"	Walls A and R
	El. 14'-0"	Walls F, T, V, W, CC, DD, EE, FF, QQ, RR, SS, TT, UU, VV, A24
Auxiliary Building	El. 69'-0"	Walls B, D, X, Z, VV

  As stated in Response 4, FRC and its consultants have issued their evaluation of the energy balance technique [7], and the SGEB has issued a position statement on this subject which will be addressed in its Safety Evaluation Report.

- o With regard to the arching theory, the Licensee stated that one wall was originally qualified by this method. However, this wall will be modified by October 1, 1984 to satisfy the SGEB criteria.

5. REFERENCES

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

2. A. E. Lundvall, Jr.
   Letter to B. H. Grier, NRC, Subject: Calvert Cliffs Nuclear Power Plant Units 1 and 2 - IE Bulletin 80-11
   Baltimore Gas & Electric Co., 30-Mar-81

3. R. A. Clark, NRC
   Letter to A. E. Lundvall, Jr.
   Subject: Request for Additional Information Calvert Cliffs Units 1 and 2; IE Bulletin No. 80-11
   14-Sept-82

4. A. E. Lundvall, Jr.
   Letter to R. A. Clark, NRC
   Subject: Calvert Cliffs Nuclear Power Plant Units 1 and 2 - IE Bulletin 80-11
   Baltimore Gas & Electric Co., 13-Dec-82

5. NRC (SGEB)
   Request for Additional Information: Masonry Wall Design, IE Bulletin 80-11, Calvert Cliffs Nuclear Power Plant Units 1 and 2
   24-Feb-84

6. A. E. Lundvall, Jr.
   Letter to F. R. Miller, NRC
   Subject: Calvert Cliffs Nuclear Power Plant Units 1 and 2, IE Bulletin No. 80-11, "Masonry Wall Design"
   Baltimore Gas & Electric Co., 23-April-84

7. H. G. Harris and A. A. Hamid, "Applicability of Energy Balance Technique to Reinforced Masonry Walls"
   Department of Civil Engineerng, Drexel University
   August 1982

8. Computech Engineering Services, Inc.,
   URS/Blume and Associates, and Bechtel Power Corporation
   "Rebuttal to 'Applicability of Energy Balance Technique to Reinforced Masonry Walls' by Hamid and Harris"
   February 1983

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

10. Building Code Requirements for Concrete Masonry Structures
Detroit: American Concrete Institute, 1979
ACI 531-79 and ACI 531-R-79

11. H. G. Harris and A. A. Hamid, "Applicability of Arching Theory to Unreinforced Block Masonry Walls Under Earthquake Loading," Department of Civil Engineering, Drexel University
August 1982

APPENDIX A

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

Franklin Research Center
A Division of The Franklin Institute
The Benjamin Franklin Parkway, Phila., Pa. 19103 (215) 448-1000

CONTENTS

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.

SGEB STAFF POSITON ON USE OF ENERGY
BALANCE TECHNIQUE TO QUALIFY REINFORCED
MASONRY WALLS IN NUCLEAR POWER PLANTS

INTRODUCTION

Under seismic loads, strain energy transfer through elastic response is very small compared to the inelastic response for energy dissipation. Therefore, inelastic non-linear analysis of reinforced masonry walls is an attractive approach. Some of the licensees have relied on a non-linear analysis approach known as "energy-balance technique" to qualify some of the reinforced masonry walls in their plants.

The staff and their consultants have reviewed the basis provided by licensees to justify the use of energy-balance technique to qualify the reinforcd masonry walls. The staff met with a group of licesees representing approximately ten utilities on November 3, 1982 and January 20, 1983 to discuss this issue. Further, site visits and detailed review of design calculations were conducted by the staff and their consultants to gain first-hand knowledge of field conditions and the application of energy-balance technique 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 energy-balance technique to qualify reinforced 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 energy-balance technique or any other non-linear analysis approach is not acceptable to the staff without further confirmation by an adequate test program. Therefore, the staff position consists of the following three options. Adoption of any one of the option and successful implementation will constitute a resolution of the issue regarding the qualification of reinforced masonry walls by energy balance technique or other non-linear techniques.

1. Reanalyse walls qualified by the energy-balance technique by linear elastic working stress approach as recommended in the staff acceptance criteria (SRP Section 3.8.4, Appendix A) and implement modifications to walls as needed.

2. Develop rigorous non-linear time-history analysis techniques capable of capturing the mechanism of the walls under cyclic loads. Different stages of behavior should be accurately modeled; elastic uncracked, elastic cracked and inelastic cracked with yielding of the central rebars. Then, a limited number of dynamic tests (realistic design earthquake motion inputs at top and bottom of the wall) should be conducted to demonstate the overall conservatism of the analysis results. In this case, "as built" walls should be constructed to duplicate the construction details of a specific plant.

3. For walls qualified by energy-balance technique, conduct a comprehensive test program to establish the basic non-linear behavioral characteristics of masonry walls (i.e. load-deflection hysteretic behavior, ductility ratios, energy absorption and post yield envelopes) for material properties and construction details pertaining to masonry walls in question. The

behavior revealed from tests should then be compared with that of elastic-perfectly-plastic materials for which the energy balance technique was originally developed. If there are significant differences, then the energy balance technique should be modified to reflect the actual wall behavior.

EVALUATION OF THE APPLICABILITY OF NONLINEAR ANALYSIS TECHNIQUES TO REINFORCED MASONRY WALLS IN NUCLEAR POWER PLANTS

Prepared by

Harry G. Harris (1)
Ahmad A. Hamid (1)
Vu Con (2)

August 1984

---

(1) Department of Civil Engineering, Drexel University, Philadelphia, Pennsylvania
(2) Nuclear Engineering Department, Franklin Research Center, Philadelphia, Pennsylvania

~~8410120139~~ 12pp.

INTRODUCTION

In response to IE Bulletin 80-11, a total of 10 nuclear power plants have indicated that the energy balance technique has been employed to qualify some reinforced masonry walls in out-of-plane bending. Based on the review of submittals provided by the licensees and all available literature, the Franklin Research Center (FRC) staff and FRC consultants have concluded that the available data in the literature is not sufficient to warrant the use of nonlinear analysis techniques to predict the response of masonry walls under cyclic, fully reversed dynamic loading. As a result, a meeting with representatives of the affected plants was held at the NRC on November 3, 1982 so that the NRC, FRC staff and FRC consultants could explain their concern regarding the applicability of the energy balance technique to masonry walls in nuclear power plants [1]. In a subsequent meeting on January 20, 1983, consultants of utility companies presented their rebuttals [2] and requested that they should be treated on a plant-by-plant basis. In accordance with their requests, the NRC staff started the process of evaluating each plant on an individual basis. In this process, the NRC, FRC staff and consultants visited a few nuclear power plants to examine the field conditions of reinforced masonry walls in the plants and to gain first-hand knowledge of how the energy balance technique is applied to actual walls. Key calculations were reviewed with regard to the energy balance technique.

EVALUATION OF ENERGY BALANCE TECHNIQUE

Based on a review of the submittals provided by the licensees, specific plant visits, evaluation of typical design computations and review of all available literature, it is concluded that the concerns raised by the Franklin Research Center (FRC) staff and consultants pertaining to the use of energy balance technique have not been resolved. A summary of these concerns are listed below:

1. Only a few isolated tests have been reported on the lateral resistance of reinforced concrete block and brick masonry walls in out-of-plane bending. These tests can be summarized as follows:

   (i) Tests have been conducted on 20' high reinforced concrete block walls 8" thick in running bond and stack bond configurations by Dickey and Mackintosh [3]. These tests, although limited, revealed that, under monotonically increasing load, some of the panels failed in a brittle mode prior to reaching yield and that the stack bond was less effective than the running bond.

   (ii) More recent tests conducted by the ACI-SEASC Task Committee on Slender Walls [4] on face loaded 24' high reinforced masonry walls under monotonically increasing load showed relatively low ductility ratios in the 3 panels that attained failure. Two 6" nominal fully grouted concrete masonry walls attained ductility ratios of approximately 2 when they failed inadvertently in compression. One 6" hollow brick wall tested to failure also attained a ductility ratio of approximately 2. It has been noted that walls tested were fully grouted and have high steel percentages (0.22% to 0.37%).

   (iii) Tests conducted by Scrivener [5,6] on face loaded reinforced masonry walls made of 4 1/4" reinforcing brick revealed high ductilities. The one cyclicallly loaded panel whose load-deflection results are reported [5] revealed very peculiar hysteretic behavior unlike the required elasto-plastic behavior needed for application of the energy balance technique.

   (iv) Tests on small masonry structures resulting from an assembly of various components to form single story masonry homes have been carried out at the UC, Berkeley earthquake simulator [7]-[9]. The main objective was to provide design recommendations on the minimum reinforcement required for masonry housing in seismic zone 2. These are the only tests of reinforced masonry walls under realisitc earthquake loads. The reinforced walls tested under out-of-plane bending in this program did not yield under the applied loads. In addition, these walls did not have the boundary conditions of typical applications of masonry walls in nuclear power plants.

(v) Dynamic tests on slender reinforced block masonry walls have been conducted at the EERC, University of California, Berkeley for Bechtel Power Corporation. The program has been conducted to demonstrate the conservatism of the nonlinear dynamic analysis performed by Computech Engineering Services for the masonry walls in the San Onofre Nuclear Generating Station, Unit 1 (SONGS-1). The FRC staff and consultants witnessed one of the tests. It was shown that the wall was capable of resisting significant inelastic deformations when subjected to earthquake input motion. It has to be mentioned, however, that the few tests performed were plant specific and aimed at verifying the conservatism of the nonlinear dynamic analysis technique developed by Computech Engineering Services. Consequently, the parameters included in the program were limited to "as built" condition of the walls in SONGS-1. The program objective was not to verify the use of the energy balance technique.

The above tests that have been conducted on reinforced masonry walls and which are relevant to the evaluation of concrete masonry walls in nuclear power plants do not form a sufficient data base to warrant the use of the energy balance technique.

2. A Technical Coordinating Committee for Masonry Research (TCCMAR) has been formed under the auspises of the US-Japan Cooperative Research Program. It is a recognition of the urgent need for research in the area of seismic resistance of masonry. The committee met in Pasadena in February 1984 to assess the current state of knowledge and to outline an experimental program to provide the necessary data. It has been concluded that the current state-of-the-art of masonry has not progressed enough to

warrant inelastic analysis methodology of masonry structures [11]. A comprehensive test program was recommended. This significant undertaking is a clear indication of the lack of test data available for masonry. (Note: Dr. Hamid serves as a member of TCCMAR.)

3. A large number of variables exist in the construction of concrete block walls used in nuclear power plants. For example, the walls can be fully grouted, partially grouted, stack bond, running bond, single and multiple wythes with different block sizes ranging from 4" to 12" in width. No adequate test data exist in the literature to enable a clear understanding of the effects of these variables on the dynamic fully reversed cyclic behavior of masonry walls.

4. Effects of cut-outs and eccentric loads due to attachments on reinforced concrete masonry walls of the type used in nuclear power plants have not been evaluated experimentally. This type of information, when available, will help to substantiate the various assumptions made in the analysis of such safety related walls.

5. The limited tests that have been conducted and summarized in item 1 above have pointed out to the inability to preclude brittle type failures with low ductility ratios on face loaded panels under monotonically increasing load. A lack of knowledge exists on the maximum attainable compressive strains in the face shell of reinforced concrete masonry walls under out-of-plane bending. This is particularly true under cyclic dynamic loading.

6. In examining the available test data, it is also obvious that there is a significant lack of information about the post-yield envelope and established cyclic load characteristics for reinforced concrete masonry walls under out-of-plane bending which is essential to demonstrate the stable ductile behavior required for the applicability of the energy balance technique. This is attributed to the fact that most tests were not conducted to ultimate failure which is essential for the determination of the post-yield envelope. This deficiency exists for all of the types of masonry construction used in nuclear power plants [10].

7. Some walls are qualified based on one-way bending in the horizontal direction or two-way plate action. These walls are horizontally reinforced with joint reinforcement embedded in the mortar joints every course or every other course. This type of steel is a high tensile steel with a yield stress as high as 100,000 psi indicating a very limited ductility. Masonry codes are not specific about the usefullness of joint reinforcement, particularly in seismic areas [12,13]. If joint reinforcement is to be used to resist tensile stresses, the WSD method should be employed with an allowable steel stress limited to 30,000 psi. The only code [14] that addresses the use of joint reinforcement in seismic areas for categoriees C and D structures was developed by the Applied Technology Council. This code does not allow the use of joint reinforcement as a load carrying element for these two categories.. Safety-related masonry walls in nuclear power plants would fit into these categories. Information about the

cyclic behavior of joint reinforced masonry walls is not available in the masonry literature at the present time [12,13].

8. The energy balance technique has been originally developed as an approximate design tool to check the resistance of ductile concrete and steel frame buildings subjected to seismic loads. With the fast development in computers in recent years, more rigorous nonlinear dynamic analyses of ductile structures have also been made possible.

NONLINEAR ANALYSIS OF MASONRY WALLS

Under seismic loads, strain energy transfer through elastic reponse is very small compared to the inelastic response for energy dissipation. With regard to inelastic behavior, two methods have been used to investigate the dynamic response of concrete and steel structures to a strong motion earthquake. One of the methods requires the formulation of an inelastic model of the structure utilizing the finite element technique. The model is then subjected to time-history ground motion and the dynamic response is determined. The results of this approach, which is time consuming and costly, depends on how accurately the structure is represented by the inelasctic model and how well the material properties are defined. Therefore, a limited confirmatory dynamic test program should be conducted to check the conservatism of the assumptions used.

The other method, which is easier to apply in a design office, separates the properties of the structure from those of the earthquake. The earthquake is represented by a response spectrum which is then modified to accomodate the inelastic or ductile response of the wall [15]. This method which relies on the energy balance technique requires information about ductility and energy absorbtion capability of masonry walls which, as discussed previously, have not been demonstrated experimantally for general applications. A ductility factor of 1 or 1.5 is suggested [16] for damage-level earthquake intensities where as ductilities of 2 to 3 is recommended [16] for use with collapse-level response spectra. Because the energy balance technique is an approximate simplified method, an adequate and more comprehensive data base should be generated to check this design methodology.

TEST PROGRAM RELATED TO ENERGY BALANCE TECHNIQUE

If a confirmatory test program is elected to justify the use of the energy balance technique, it is expected that the test panels should represent the actual configuration, construction details and boundary conditions of masonry walls in nuclear power plants.

The test program should cover the different parameters that would affect wall performance such as steel percentage, bond type, partial grouting and block size.

The test objectives should be centered upon the following:

1. To demonstrate that the masonry walls would maintain their structural and functional integrity when subjected to SSE and other applied loads.
2. To demonstrate that a stable ductile behavior characterized by steel yielding is guaranteed and that any

brittle failure (e.g. crushing) is precluded.

3. To develop necessary information to verify the energy balance technique as a methodology for the qualification of reinforced masonry walls in nuclear power plants.

4. To demonstrate that adequate margins of safety exist for walls subjected to design lateral loads.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A review and evaluation of the available information on the nonlinear behavior of block masonry walls under out-of-plane loading has been presented. It is concluded that test data are needed to substantiate the use of nonlinear analysis techniques to qualify reinforced block walls in nuclear power plants.

To qualify masonry walls based on nonlinear analysis, two alternatives are recommended:

1- Develop rigorous nonlinear time-history analysis techniques capable of capturing the mechanism of the walls under cyclic loads. Different stages of behavior should be accurately modeled: elastic uncracked, elastic cracked and inelastic cracked with yielding of the central rebars. Then, a limited number of dynamic tests (realistic design earthquake motion inputs at top and bottom of the wall) should be conducted to demonstrate the overall conservatism of the analysis results. In this case, "as built" walls should be constructed to duplicate the construction details of a specific plant.

2- Conduct a comprehensive test program to establish the basic nonlinear behavioral characteristics of masonry walls (ie. load-deflection hysteretic behavior, ductility ratios, energy absorbtion and post-yield envelopes) for material properties and construction details pertaining to masonry walls in question. The behavior revealed from the tests should then be compared with that of elastic-perfectly-plastic materials for which the energy balance technique was originally developed. If there are significant differences, then the energy balance technique should be modified to reflect the actual wall behavior.

REFERENCES

1. Hamid, A.A. and Harris, H.G., "Applicability of Energy Balance Technique to Reinforced Masonry Walls," Franklin Research Center, Philadelphia, PA, June 1982.

2. "Rebuttal to Applicability of Energy Balance Technique to Reinforced Masonry Walls," URS/John A. Blume Associates and Bechtel Power Corporation, January 1983.

3. Dickey, W.L. and Mackintosh, A., "Results of Variation of "b" or Effective Width in Flexeral Concrete Block Panels," Masonry Institute of America, LA, 1971.

4. Annonymous, "Test Report on Slender Walls," Report of the Task Committee on Slender Walls, Edited by J.W. Athey, ACI, Southern California Chapter, and the Structural Engineers Association of Southern California, Feb. 1980-Sept. 1982, Los Angeles, CA.

5. Scrivener, J., "Reinforced Masonry - Seismic Behavior and Design," Bulletin of New Zealand Society for Earthquake Engineering, Vol. 5, No. 5, Dec. 1972.

6. Scrivener, J., "Face Load Tests on Reinforced Hollow Brick Non-Load-Bearing Walls," New Zealand Engineering Journal, July 1969.

7. Clough, R., Mayes, R. and Gulkan, P., "Shaking Table Study of Single Story Masonry Houses, Volume 3: Summary, Conclusions and Recommendations," Earthquake Engineering Research Center, Report No. UCB/EERC-79/23, College of Engineering, University of California, Berkeley, CA, September 1979.

8. Gulkan, P., Mayes, R. and Clough, R. "Shaking Table Study of Single Story Masonry Houses, Vol. 2: Test Structures 3 and 4," Earthquake Engineering Research Center, Report No. UCB/EERC-79/24, College of Engineering, University of California, Berkeley, CA, September, 1979.

9. Manos, G., Clough, R. and Mayes, R., "Shaking Table Study of Single Story Masonry Houses- Dynamic Performance under Three Component Seismic Input and Recommendations," Report No. UCEERC-83/11, Univ. of Calif., Berkeley, July 1983.

10. Hamid, A.A., Harris, H.G., Con, V.N. and Chokshi, N.C., "Performance of Block Masonry Walls in Nuclear Power Plants," Proceedings of the Third Canadian Masonry Symposium, Alberta, Canada, June 1983, pp. 12-1 to 12-9.

11. Hamid, A.A. and Harris, H.G., "State-of-the-Art Report: Nonlinear Behavior of Reinforced Masonry Walls under Out-of-Plane Lateral Loading," Proceedings of the International Symposium on Reinforced and Prestressed Masonry, Edinburgh, Scotland, August 1984.

12. Hamid, A. A., Harris, H. G., and Becica, I. J., "The Use of Joint Reinforcment In Block Masonry Walls," Franklin Research Center, Philadelphia, March 1983.

13. Harris, H.G., Hamid, A.A., Becica, I.J., Con, V.N., and Chokshi, N.C., "The Use of Joint Reinforcement in Qualifying Masonry Walls in Nuclear Power Plants," Presented at the ASCE Specialty Conference on Structural Engineering in Nuclear Facilities, Sept. 10-12, 1984, NC State University, Raleigh, North Carolina.

14. Applied Technology Council, "Tentative Provisions for a Development of Seismic Regulations for Buildings," ATC 3-06, (NSF Publication 78-8, NBS Special Publication 510), U.S. Government Printing Office, June 1978.

15. Englekirk, R.E., Hart, G.C. and the CMA of California and Nevada, Earthquake Design of Concrete Masonry Buildings, Vol. 1 Response Spectra Analysis and General Earthquake Modeling Considerations, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1982.

16. Englekirk, R.E., Hart, G.C. and the CMA of California and Nevada, Earthquake Design of Concrete Masonry Buildings, Vol. 2 Strength Design of One-to-Four-Story Buildings, Prentice-Hall, Inc., Englewood Cliffs, N.J., 1984.