180-DAY REPORT

IN RESPONSE TO IE BULLETIN 80-11

FOR

DRESDEN NUCLEAR POWER STATION

UNITS 2 AND 3

COMMONWEALTH EDISON COMPANY

DOCKET NUMBERS 50-237 AND 50-249

PREPARED BY: Bechtel Power Corporation

Report Date: September 14, 1984
Revision 4

0050c

TABLE OF CONTENTS

APPENDIXES

TABLES

1.0 INTRODUCTION

This 180-day report is being issued in response to NRC IE Bulletin 80-11, dated May 8, 1980 (Reference 6.2). This report has been prepared by Bechtel Power Corporation, Ann Arbor, Michigan, for Commonwealth Edison Company's Dresden Nuclear Power Station, Units 2 and 3. Revision 4 of this report incorporates the status change of two masonry walls which were previously identified in Revision 3 as meeting the acceptance criteria. 4

2.0 SCOPE

The 180-day report furnishes information requested in Item 2b of NRC IE Bulletin 80-11. It deals solely with masonry walls identified in this report as safety-related. Any masonry wall is considered safety-related when it is in proximity to or has attachments from safety-related piping or equipment such that wall failure could damage a safety-related system.

The analyses are based on as-built conditions identified during site surveys of June and July 1980 and July 1981.

3.0 DESCRIPTION OF MASONRY WALLS

3.1 LOCATION

The figures in Appendix A show the location of all safety-related masonry walls.

3.2 FUNCTION

The function of each masonry wall is identified in Table 1 according to one of the following categories.

3.2.1 Fire Wall

These walls were constructed to prevent the spread of fire from one side of the wall to the other according to the appropriate fire rating associated with the wall's thickness.

3.2.2 Partition Wall

The partition walls are interior dividing walls whose sole purpose is to separate a portion of a room from the remainder.

3.2.3 Shielding Wall

The masonry shielding walls, typically made of solid units which are required to restrict radiation exposures.

3.2.4 Blockout

A blockout, made of masonry, seals an opening in a larger concrete wall. These openings are left in the concrete walls to provide for equipment installation or pipe penetrations before the opening is sealed with the masonry.

3.2.5 Exterior Wall

Exterior walls have at least a part of one face exposed to the outside, or are a part of the boundary of the Units 2 and 3 reactor turbine building complex. Only exterior walls are subject to wind or tornado loads.

3.3 WALL CONFIGURATION

Wall dimensions and boundary conditions for each wall are indicated in Table 1. Each boundary is categorized as either a fixed support capable of providing both moment and shear resistance, a simple support resisting only shear forces, or a free edge through which no forces can be transferred.

3.4 CONSTRUCTION MATERIALS

3.4.1 Hollow Masonry

The hollow masonry units, which are identified on the design drawings, were specified as three-core blocks conforming to ASTM C 90, Grade N-I, Lightweight Aggregate. Masonry walls, which are not shown on the design drawings, were assumed to consist of hollow units of the same type specified above. This assumption and the material properties of the hollow block were verified by plant-specific tests (see Section 4.7). Site surveys have found that the hollow masonry walls consist of both two-core and three-core units.

3.4.2 Solid Masonry

Two types of solid blocks (normal weight and magnetite) were used in the solid masonry construction. Plant-specific tests determined the material properties of both types of block (see Section 4.7).

3.4.3 Mortar

The mortar used in the construction of the hollow masonry walls was specified as ASTM C 270, Type N, with a 28-day compressive strength of 750 psi. Tests on the mortar used in the solid masonry found that it was, as a minimum, comparable to that specified for hollow masonry (see Section 4.7).

3.4.4 Reinforcing Steel

According to the design drawings and specifications, the masonry walls are reinforced in the bed joint of every other course. This joint reinforcement consists of heavy-duty, continuous, rectangular, ladder type steel reinforcement, whose minimum yield strength is 65 ksi. Deformed bar steel, where shown on the drawings, has a minimum yield strength of 40 ksi.

3.4.5 Anchors

Masonry anchors have been used in certain locations to tie the masonry wall to an adjacent structural element. These anchors consist of two types: corrugated metal ties (dovetail anchors) which are used for connections to concrete walls or columns and 3/16-inch diameter adjustable bar ties welded to the supporting structural steel.

3.5 CONSTRUCTION PRACTICES

The masonry walls at the station were constructed in accordance with the applicable job and standard specifications for masonry work and have a high quality of masonry workmanship. Conformance to applicable ASTM specifications was required for concrete blocks, mortar, reinforcing ties, and anchors. Storage and protection of blocks and walls, as well as cold weather protection, were specified. The mortar joints of solid masonry walls were required to be constructed with full mortar coverage on all vertical and horizontal faces. The vertical joints were to be shoved tight. A full mortar bedding was specified for webs and face shells of the hollow masonry walls. Face shells were required to be fully buttered and pressed into place to ensure full, well-compacted horizontal and vertical mortar joints.

3.6 RECONCILIATION WITH 180-DAY REPORT, REVISION 3

This latest revision of the 180-day report incorporates the following information:

3.6.1 The inclusion of walls 37 and 103 to the list of walls which do not meet the acceptance criteria. These walls were previously identified as meeting the acceptance criteria. 4

With the incorporation of the above, a total of 64 masonry walls now meet the acceptance criteria. This represents a decrease of two walls over the total shown in Revision 3 of this report.

4.0 REEVALUATION OF MASONRY WALLS

4.1 POSTULATED LOADS

The loads which were considered in the evaluation of each wall are identified in Table 3.

4.1.1 Dead Load (D)

This load includes the dead weight of the wall and all permanently attached equipment, piping, conduit, and cable trays. The construction sequences have allowed the permanent dead load deflection to occur prior to the erection of the masonry walls. Therefore, the dead loads from the floor above are not transferred to the masonry walls.

4.1.2 Live Load (L)

This load includes applicable live loads which can be transferred to the masonry wall through the floor framing. The live loads are not considered in those load combinations when they would relieve wall stresses.

4.1.3 Attachment Loads (R_o and R_a)

The attachment loads are localized loads which are a result of the reactions from the supports of piping, cable trays, conduits, HVAC ducts, and other systems. The reactions are determined for the normal operating or shutdown condition (R_o) and for the accident condition (R_a) which results from the thermal conditions generated by the postulated pipe break and includes R_o.

4.1.4 Wind Load (W)

Exterior walls are subject to a uniform pressure load corresponding to the design wind speed. The design wind speed for Dresden Units 2 and 3 is 110 miles per hour.

4.1.5 Tornado Load (W_t)

Exterior walls are subject to velocity pressures, differential pressures, and tornado missiles of the design tornado identified in the plant FSAR.

The maximum tornado wind speed is 300 miles per hour. The maximum differential pressure is 170 psf.

The following missiles are generated by the design tornado:

a. A telephone pole 35'-0" long, with a butt diameter of 13 inches, a unit weight of 50 pcf, and total weight of 1,200 pounds, and having a velocity of 150 miles per hour

b. A 1-ton mass with a velocity of 100 miles per hour and a contact area of 25 square feet

A probabilistic risk assessment for tornado missiles impacting walls D2-529-43C-74 and D2-517-31G-105 was performed by others. The results of this analysis show the probability of a tornado missile striking either of these two walls to be approximately 10^{-7} per year. Therefore, the evaluation includes only the effects of wind pressure and depressurization.

The original design considered the buildings housing safety-related piping, conduit, cable trays, and equipment as sealed; therefore, tornado loadings do not affect interior walls.

4.1.6 Operating Basis Earthquake (E_o)

This load represents the seismic load generated by the operating basis earthquake (OBE). The design ground accelerations are as follows:

a. Horizontal = 0.1 g

b. Vertical = 0.067 g

4.1.7 Safe Shutdown Earthquake (E_s)

This load represents the seismic load generated by the safe shutdown earthquake (SSE). The design ground accelerations are twice those shown for the OBE.

4.1.8 Thermal Loads (T_o and T_a)

Thermal loads account for the effects of thermal gradients under normal operating (T_o) and accident (T_a) conditions. The operating loads represent the most critical steady-state condition, while the accident condition is a short-term thermal transient resulting from the postulated pipe leak, including T_o.

4.1.9 High-Energy Pipe Break

The high-energy piping systems outside of the primary containment were investigated and their proximity to the safety-related masonry walls was established. It was found that only a break in the RWCS would impact the masonry walls. However, a break in this system is precluded by means of leak detection and administrative action. Room temperature monitors are capable of responding to small RWCS leaks by providing indication and alarm to the control room. At this time, the operators shall take the appropriate action to isolate the RWCS, thereby preventing a full pipe rupture.

The analysis of the masonry walls in proximity to the RWCS addresses the effects of the postulated pipe leak by considering the thermal transient discussed in Subsection 4.1.8 and differential pressure (Pa). This load is represented by an equivalent static pressure across a wall.

4.2 ALLOWABLE STRESSES

The allowable masonry stresses, excluding collar joint stresses, under normal load combinations are in accordance with those given by the Building Code Requirements for Concrete Masonry Structures (ACI 531-79)(Reference 6.1). Allowable stresses for extreme environmental and abnormal load combinations are increased by a factor of 1.67 over the above ACI code allowable stresses.

For the mortar collar joints, the allowable shear and tension stresses are 10 psi for normal load combinations and 14 psi for extreme environmental and abnormal load combinations.

Allowable stresses applicable to the different types of masonry are given in Table 2.

4.3 JUSTIFICATION OF THE REEVALUATION CRITERIA

Except as noted, allowable stresses of masonry units and mortar are based on the code values as published in ACI 531-79. These values are considered reasonable and conservative. References to tests and other codes are provided in the commentary to ACI 531-79. It is noted that the allowable stresses are used for the evaluation of existing masonry walls and not for the design of new walls.

Because building codes do not address abnormal and extreme environmental conditions, a factor of 1.67 was used to provide allowable stresses under these loading combinations. Based on available margins of safety, this factor is considered to be reasonable.

Published data on tension and shear strength of collar joints are almost nonexistent. The ultimate collar joint stresses were therefore determined by plant-specific in situ tests. The allowable stress, as given in Section 4.2, was obtained by applying a safety margin of three to the minimum test result (see Section 4.7).

Additional justification of the reevaluation criteria is provided in Appendix B.

4.4 SEQUENCE OF ANALYSIS

Each wall is initially analyzed considering only dead and seismic loads or dead and tornado loads, whichever appears most critical. For all walls which are found to be acceptable, the following applicable loadings are considered: live load, attachment loads, pipe leak loads, and interstory drift.

4.5 METHOD OF ANALYSIS AND ACCEPTANCE CRITERIA

4.5.1 Stress Analysis

Based on the walls' boundary conditions, each wall is idealized as either a cantilever, one-way strip, or two-way plate which is supported along at least two adjacent edges. The wall is then considered acceptable if all wall stresses under all load combinations are less than or equal to the established allowable stresses.

4.5.2 Stability and Sliding Analysis

Cantilever walls which do not meet the acceptance criteria for allowable stresses are analyzed with regard to overturning stability and sliding movement. A factor of safety against overturning is determined for both OBE and SSE loads. The minimum acceptable factors of safety are 2.0 for OBE and 1.5 for SSE conditions. Before the wall is considered acceptable, the total wall movement, including rocking and sliding, must not adversely affect any safety-related items.

4.5.3 Analysis of Arching Effects

Masonry walls with mortared joints at both the top and bottom boundaries that do not meet the acceptance criteria for allowable stresses are investigated for arching effects. The wall's capability of resisting horizontal loads, after ultimate tension stresses are exceeded, is developed when the wall jams at the top and bottom against the supporting structural members. The center of the wall cracks due to tension stresses, and a three-hinged arch is formed to resist the loads through compression stresses only.

Design seismic loads generated by the safe shutdown earthquake are based on the peak acceleration of the applicable response criteria and a damping factor of 10% of critical.

The stiffnesses of the supporting structural elements are accounted for in the analysis. Also, the deflection at the center hinge must be less than or equal to one third of the wall thickness. If an arching wall meets the above requirement, it is considered acceptable when the compression stress developed in the arch is less than or equal to the allowable flexural compression stress shown in Table 2.

4.5.4 Interstory Drift Under Seismic Loads

The effects of interstory drift are considered by determining the in-plane shear strain in the wall due to the relative displacement between the top and bottom of the wall. The allowable in-plane strains are 0.0001 for unconfined walls and 0.001 for confined walls. An unconfined wall is defined as a wall supported only on two adjacent sides. A confined wall is supported on any three sides or at the top and bottom of the wall (References 6.5, 6.6, and 6.7).

These acceptance criteria are considered to be justified because none of the masonry walls carry a significant part of the buildings' story shear or moment. Also, test data indicate that the gross shear strain of walls is a more reliable indicator for predicting the onset of cracking than loads or stresses.

The out-of-plane relative displacement creates a bending moment in the wall only in the case where the top and bottom boundaries are supported, and at least one represents a fixed condition. None of the masonry walls at the Dresden station are effectively fixed at either the top or the bottom boundary; therefore, the out-of-plane interstory drift is not considered.

4.6 ASSUMPTIONS AND ANALYSIS CONSTRAINTS

The following assumptions and constraints were employed in the reevaluation of the masonry walls.

4.6.1 Nonsafety-related walls, anchor bolts, and embedments were not within the scope of the reevaluation.

4.6.2 All loads and load combinations outlined in the plant FSAR are considered in the reevaluation.

4.6.3 The seismic loads on masonry walls are dependent on the damping characteristics of the material, which are expressed in percentage of critical damping as follows (References 6.3 and 6.4):

a. Uncracked Masonry Wall, Out-of-Plane Acceleration

1) OBE: 2%
2) SSE: 2%

b. Vital Piping Systems, Horizontal and Vertical Accelerations

1) OBE: 0.5%
2) SSE: 2%

The plant FSAR specifies damping of 0.5% under OBE conditions for vital piping systems. For the purpose of this evaluation, vital piping are defined as all safety-related piping.

c. Other Attached Systems, Horizontal and Vertical Accelerations

1) OBE: 1%
2) SSE: 2%

This category includes nonsafety-related piping and safety-related and nonsafety-related conduit, cable trays, and HVAC ductwork.

4.6.4 A masonry wall is considered an isotropic, elastic material. Its natural frequency is calculated using standard plate formulas. For a wall with an opening, the calculated frequency is reduced by 9% if the size of the opening equals or is greater than 15% of the wall area. The reduction is proportionally less for a smaller opening. For multiple openings, the largest one is considered. To account for variation in stiffness and mass of the wall, the above frequency is varied by ± 10% and the maximum response is used in the analysis.

4.6.5 In accordance with the plant FSAR, the effects of the seismic loads of one horizontal and the vertical direction are added arithmetically.

4.6.6 Dead loads from the floor above are not considered being transferred to the masonry walls. A part of the live load from these floors is transferred to the walls; however, it is not considered if it will relieve wall stresses.

4.6.7 Shear and tensile stresses are not transferred across the continuous vertical mortar joints of walls laid in stack bond or the vertical mortar joints of a wall boundary adjacent to a concrete structural member.

4.6.8 Standard, prefabricated sections of the horizontal joint reinforcing steel are provided at all corners of masonry walls. However, their contribution to the strength capacity of this intersection is not considered.

4.7 MASONRY WALL TESTING PROGRAM

A sampling and testing program was performed at the station. This program provided the material properties necessary to determine the allowable stresses applicable for the masonry wall evaluations. The testing was also considered to fulfill the special inspection requirements of Reference 6.1; thus allowing the use of inspected allowable stresses. The findings of the program are as follows.

4.7.1 The hollow masonry block has an average compressive strength of 2,100 psi on the net area.

4.7.2 The solid masonry block has an average compressive strength of 3,400 psi.

4.7.3 The mortar used in both the hollow and solid masonry construction is, as a minimum, comparable to ASTM C 270, Type N.

4.7.4 The average unit weight of the hollow masonry is 110 pcf and the average unit weight for the solid masonry is 132 pcf.

4.7.5 In situ tests were performed on two walls to determine the strength of the mortared collar joint. The resulting failure stresses were 37.6 and 32.7 psi.

4.7.6 One wall (D2-534-33G-21) was found to consist of magnetite aggregate. Tests indicate the block of this wall to have a compressive strength of 6,000 psi and a unit weight of 235 pcf. The mortar was found to be comparable to ASTM C 270, Type M.

5.0 RESULTS OF MASONRY WALL EVALUATION

Table 3 lists the results of the masonry wall reevaluation. The criteria used to justify the wall's acceptance or mode in which it does not meet the criteria are identified.

5.1 SUMMARY

The following summarizes the results of the reevaluation of 96 safety-related masonry walls:

5.1.1 Total number of walls meeting the acceptance criteria: 64

5.1.2 Total number of walls which do not meet the acceptance criteria: 32

6.0 REFERENCES

6.1 Building Code Requirements for Concrete Masonry Structures, ACI 531-79, American Concrete Institute, Detroit, Michigan, 1979

6.2 USNRC IE Bulletin 80-11, dated May 8, 1980

6.3 Final Safety Analysis Report (FSAR) for the Dresden Nuclear Power Station Units 2 and 3

6.4 Damping Values for Seismic Design of Nuclear Power Plants, U.S. Nuclear Regulatory Commission Regulatory Guide 1.61, October 1973

6.5 Becica, I.J. and H.G. Harris, Evaluation of Techniques in the Direct Modeling of Concrete Masonry Structures, Drexel University Structural Models Laboratory Report M77-1, June 1977

6.6 Fishburn, C.C., Effect of Mortar Properties on Strength of Masonry, National Bureau of Standards Monograph 36 U.S. Government Printing Office, November 1961

6.7 Mayes, R.L.; Clough, R.W.; et al, Cyclic Loading Tests of Masonry Piers, 3 Volumes, EERC 76/8, 78/28, 79/12 Earthquake Engineering Research Center, College of Engineering University of California, Berkeley, California

6.8 60-Day Report in response to IE Bulletin 80-11 for Dresden Nuclear Power Station Units 2 and 3, Commonwealth Edison Company, Docket Numbers 50-237 and 50-249 dated July 3, 1980

TABLE 1

MASONRY WALLS - FUNCTION AND PHYSICAL PROPERTIES

Wall	Function	Thick-ness	Type	Wythes	Bond	Size (height x width)	Boundary Support	Shown on Design Drawings	Remarks
D2-570-40M-1	Partition	12"	Hollow	1	Running	14'-9"x22'-0"		Yes	
D2-570-39M-2	Shielding	12"	Hollow	1	Running	16'-3"x21'-7"		Yes	
D2-570-43K-3	Shielding	12"	Solid	2	Running	7'-1"x8'-8"		Yes	
D2-570-42J-4	Shielding	18"	Solid	3	Running	7'-1"x18'-0		Yes	
D3-570-45K-7	Shielding	12"	Solid	2	Running	7'-0"x9'-6"		Yes	
D3-570-45K-8	Shielding	18"	Solid	3	Running	7'-1"x17'-1"		Yes	
D2-570-38M-11	Shielding	12"	Hollow	1	Running	16'-3"x21'-7"		Yes	
D2-561-44D-12	Partition	6"	Hollow	1	Running	5'-5"x22'-11"		Yes	
D3-561-45D-13	Partition	6"	Hollow	1	Running	5'-5"x23'-11"		Yes	
D3-545-44D-14	Partition	12"	Hollow	1	Running	9'-9"x9'-7"		Yes	
D2-570-43K-15	Blockout	24"	Hollow*	2*	Running	1'-6"x2'-0"		No	*-Assumed
D3-570-45K-16	Blockout	24"	Hollow*	2*	Running	1'-4"x1'-11"		No	*-Assumed

BOUNDARY SUPPORTS

Free edge

Simple support

Fixed support

TABLE 1

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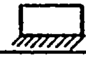
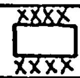
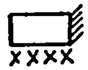
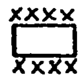
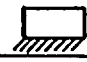
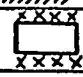
Wall	Function	Thick-ness	Type	Wythes	Bond	Size (height x width)	Boundary Support	Shown on Design Drawings	Remarks
D2-534-33E-20	Partition	12"	Hollow	1	Running	26'-10"x9'-1"		Yes	
D2-534-33G-21	Blockout	18"	Solid	3	Stack	9'-9"x16'-4"		Yes	
D2-534-33H-22	Blockout	8"	Hollow	1	Running	14'-6"x6'-8"		Yes	
D2-545-38H-23	Firewall	12"	Hollow	1	Running	24'-0"x8'-6"		Yes	
D2-545-39J-24	Shielding	24"	Solid	4	Running	12'-3"x14'-2"		Yes	
D2-545-39J-25	Shielding	24"	Solid	4	Running	8'-1"x6'-7"		Yes	
D2-545-41H-26	Shielding	16"	Solid	2	Stack	8'-0"x17'-2"		Yes	
D2-545-44J-31	Shielding	18"	Solid	3	Running	8'-0"x6'-0"		Yes	
D2-545-43L-32	Shielding	48"	Solid	8	Running	10'-10"x11'-4"		Yes	
D2-545-43M-33	Shielding	56"	Solid	8	Running	10'-0"x4'-8"		Yes	
D3-545-44J-34	Shielding	18"	Solid	3	Running	8'-1"x6'-0"		Yes	
D3-545-45L-38	Shielding	48"	Solid	8	Running	10'-8"x11'-6"		Yes	
D3-545-48N-40	Firewall	12"	Hollow	1	Running	12'-8"x14'-10"		Yes	
D2-545-40N-41	Firewall	12"	Hollow	1	Running	12'-8"x14'-10"		Yes	

<u>TABLE 1</u>

MASONRY WALLS - FUNCTION AND PHYSICAL PROPERTIES

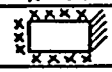
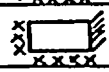
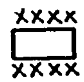
Wall	Function	Thick-ness	Type	Wythes	Bond	Size (height x width)	Boundary Support	Shown on Design Drawings	Remarks
D3-545-49H-42	Shielding	24"	Solid	4	Running	13'-5"x12'-0"		Yes	
D3-545-50H-44	Partition	12"	Hollow	1	Running	24'-6"x8'-8"		Yes	
D2-549-32F-45	Firewall	8"	Hollow	1	Running	9'-0"x10'-4"		Yes	
D2-549-31F-46	Firewall	8"	Hollow	1	Running	10'-6"x22'-4"		Yes	
D2-549-32F-47	Firewall	8"	Hollow	1	Running	10'-6"x21'-8"		Yes	
D2-549-32F-48	Firewall	8"	Hollow	1	Running	10'-6"x9'-8"		Yes	
D2-549-32G-49	Firewall	8"	Hollow	1	Running	10'-6"x20'-9"		Yes	
D2-549-32G-50	Firewall	8"	Hollow	1	Running	10'-6"x17'-2"		Yes	
D2-549-31G-51	Firewall	8"	Hollow	1	Running	10'-6"x21'-5"		Yes	
D2-549-32G-52	Firewall	8"	Hollow	1	Running	8'-11"x17'-3"		Yes	
D2-549-33G-53	Blockout	8"	Hollow	1	Running	12'-0"x6'-0"		Yes	
D2-549-33H-54	Blockout	8"	Hollow	1	Running	12'-0"x14'-8"		Yes	
D2-534-33G-55	Blockout	20"	Hollow	2	Running	14'-6"x4'-8"		Yes	
D2-534-33G-56	Blockout	8"	Hollow	1	Running	14'-6"x6'-9"		Yes	
D2-545-39J-66	Shielding	24"	Solid	4	Running	8'-1"x4'-3"		Yes	
D3-545-47M-67	Blockout	24"	Hollow	2	Running	3'-6"x7'-5"		No	Type of block and number of wythes assumed
D3-545-47M-68	Blockout	24"	Hollow	2	Running	3'-6"x7'-5"		No	Type of block and number of wythes assumed

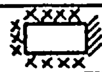
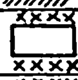
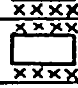
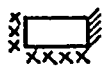
TABLE 1

MASONRY WALLS - FUNCTION AND PHYSICAL PROPERTIES

Wall	Function	Thick-ness	Type	Wythes	Bond	Size (height x width)	Boundary Support	Shown on Design Drawings	Remarks
D2-534-43H-70	Partition	12"	Hollow	1	Running	3'-5"x26'-0"		Yes	
D3-534-45D-71	Partition	12"	Hollow	1	Running	13'-5"x9'-6"		Yes	
D3-534-44D-72	Partition	12"	Hollow	1	Running	13'-5"x14'-7"		Yes	
D3-534-44D-73	Partition	12"	Hollow	1	Running	13'-5"x9'-7"		Yes	
D2-529-43C-74	Partition	12"	Hollow	1	Running	11'-4"x39'-4"		Yes	
D2-545-41J-76	Shielding	24"	Solid	4	Running	8'-1"x4'-0"		Yes	
D3-545-46H-77	Shielding	24"	Solid	4	Running	8'-2"x4'-1"		Yes	
D2-517-33E-80	Partition	12	Hollow	1	Running	15'-11"x9'-3"		Yes	
D2-503-35E-81	Shielding	36"	Solid	6	Running	29'-11"x31'-10"		Yes	
D2-517-31F-82	Firewall	12"	Hollow	1	Running	16'-0"x23'-0"		Yes	
D2-517-32F-83	Firewall	12"	Hollow	1	Running	16'-0"x39'-0"		Yes	
D2-517-32G-84	Firewall	12"	Hollow	1	Running	16'-0"x23'-0"		Yes	
D2-517-33H-85	Shielding	12"	Hollow	1	Running	13'-0"x20'-8"		Yes	
D2-517-33H-86	Firewall	12"	Hollow	1	Running	14'-3"x18'-0"		Yes	
D2-517-38H-87	Firewall	12"	Hollow	1	Running	27'-7"x8'-8"		Yes	
D2-517-39H-88	Blockout	24"	Solid	4	Running	7'-0"x14'-5"		Yes	
D2-517-39K-89	Shielding	24"	Solid	4	Running	8'-2"x9'-10"		Yes	

TABLE 1

MASONRY WALLS - FUNCTION AND PHYSICAL PROPERTIES

Wall	Function	Thick-ness	Type	Wythes	Bond	Size (height x width)	Boundary Support	Shown on Design Drawings	Remarks
D2-517-426-90	Blockout	12"	Hollow	1	Running	8'-6"x17'-6"		Yes	
D3-517-49H-92	Partition	12"	Hollow	1	Running	27'-5"x8'-8"		Yes	
D3-517-49J-93	Shielding	24"	Solid	4	Running	8'-2"x9'-10"		Yes	
D2-517-34E-94	Partition	12"	Hollow	1	Running	31'-0"x29'-0"		Yes	
D2-517-33G-95	Partition	12"	Hollow	1	Running	15'-11"x5'-9"		Yes	
D2-517-43H-96	Shielding	18"	Solid	3	Running	9'-8"x8'-0"		Yes	
D3-517-45H-97	Shielding	18"	Solid	3	Running	9'-8"x8'-0"		Yes	
D3-517-46N-98	Firewall	12"	Hollow	1	Running	7'-0"x11'-5"		Yes	
D3-517-46N-99	Firewall	12"	Hollow	1	Running	7'-0"x11'-5"		Yes	
D3-517-46N-100	Firewall	12"	Hollow	1	Running	7'-0"x16'-8"		Yes	
D2-517-38H-101	Partition	12"	Hollow	1	Running	27'-0"x10'-6"		Yes	
D3-517-50H-102	Partition	12"	Hollow	1	Running	30'-0"x10'-5"		Yes	
D3-507-44C-103	Shielding	12"	Solid	2	Running	10'-1"x5'-3"		Yes	4
D3-517-46G-104	Partition	8"	Hollow	1	Running	12'-6"x17'-6"		No	
D2-517-31G-105	Blockout	12"	Hollow	1	Running	7'-11"x6'-4"		No	
D2-517-33E-106	Partition	12"	Hollow	1	Running	15'-11"x3'-1"		Yes	

<u>TABLE 1</u>

MASONRY WALLS - FUNCTION AND PHYSICAL PROPERTIES

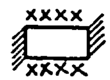
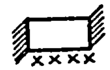
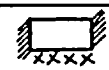
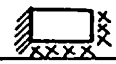
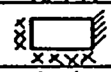
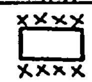
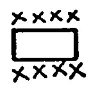
Wall	Function	Thick-ness	Type	Wythes	Bond	Size (height x width)	Boundary Support	Shown on Design Drawings	Remarks
D3-517-45D-107	Blockout	12"	Hollow	1	Running	14'-10"x14'-7"		Yes	
D2-517-44D-108	Shielding	12"	Hollow	1	Running	7'-5"x6'-0"		Yes	Cells filled with sand
D2-517-44E-109	Partition	12"	Hollow	1	Running	9'-10"x13'-2"		Yes	
D2-517-43E-110	Partition	12"	Hollow	1	Running	9'-10"x9'-6"		Yes	
D2-517-39H-111	Blockout	24"	Hollow*	4*	Running	6'-5"x2'-5"		No	*-Assumed
D2-528-35H-112	Firewall	12"	Hollow	1	Running	5'-1"x13'-3"		Yes	
D2-528-34H-113	Firewall	12"	Hollow	1	Running	7'-8"x6'-10"		Yes	
D3-528-54H-114	Firewall	12"	Hollow	1	Running	8'-1"x14'-0"		Yes	
D3-528-54H-115	Firewall	12"	Hollow	1	Running	8'-1"x8'-6"		Yes	
D2-517-43H-116	Blockout	12"	Hollow	1	Running	9'-4"x25'-11"		Yes	
D3-517-49H-117	Shielding	24"	Hollow*	2*	Running	6'-4"x2'-4"		No	* Assumed
D2-507-45C-118	Shielding	8"	Solid	1	Stack	6'-3"x2'-3"		Yes	
D2-517-5A-120	Exterior	12"	Hollow	1	Running	20'-2"x14'-11"		Yes	
D2-517-3A-121	Exterior	12"	Hollow	1	Running	20'-2"x14'-11"		Yes	

TABLE 1

MASONRY WALLS - FUNCTION AND PHYSICAL PROPERTIES

Wall	Function	Thick-ness	Type	Wythes	Bond	Size (height x width)	Boundary Support	Shown on Design Drawings	Remarks
D3-476-45H-122	Blockout	36"	Hollow	3	Running	4'-5"x9'-4"		No	Type of block and number of wythes assumed
D3-476-43H-123	Blockout	36"	Hollow	3	Running	4'-8"x9'-4"		No	Type of block and number of wythes assumed
D2-558-43K-35	Shielding	30"	Solid	5	Running	5'-2" x 13'-3"		Yes	
D2-558-43K-36	Shielding	36"	Solid	6	Running	8'-5" x 12'-0"		Yes	
D2-558-42K-37	Shielding	12"	Solid	2	Running	5'-4" x 3'-4"		Yes	Base not mortared
D3-558-45K-39	Shielding	36"	Solid	6	Running	8'-5" x 12'-0"		No	

TABLE 2

ALLOWABLE STRESSES IN CONCRETE MASONRY WALLS

Type of Stress (psi)			Type 1 Wall Loading Condition: Normal	Type 1 Wall Loading Condition: Abnormal and Extreme Environmental	Type 2 Wall Loading Condition: Normal	Type 2 Wall Loading Condition: Abnormal and Extreme Environmental
Flexural compression, F_m			340	560	390	650
Transverse and punching shear, V_m			35	59	38	63
Shear in mortar collar joint, V_{mcj}			10	14	10	14
Direct or flexural tension	Hollow	Normal to bed joints, F_{thn}	14	23	--	--
	Hollow	Parallel to bed joints, F_{thp}	27	46	--	--
	Solid	Normal to bed joints, F_{tsn}	--	--	27	46
	Solid	Parallel to bed joints, F_{tsp}	--	--	40	68
	Mortar collar joints, F_{tcj}		10	14	10	14

Axial compression allowable (F_a) is dependent upon the height and thickness of the wall

$$F_a = 0.225 f'_m \left[1 - \left(\frac{h}{40t}\right)^3\right]$$

Type 1 Wall	Type 2 Wall
Hollow-unit wall	Solid-unit wall
f'_m = 1,020 psi	f'_m = 1,190 psi
m_o = 750 psi	m_o = 750 psi

1. For walls laid in stack bond, shear and tensile stresses shall not be transferred across the continuous vertical joints.
2. Material properties and the shear capacity of mortared collar joints have been verified by field tests.

TAB

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-570-40M-1	√			√	√			√	√					Exceeds overturning criteria	
D2-570-39M-2	√			√	√			√	√					Exceeds overturning criteria	
D2-570-43K-3	√			√	√	√		√	√				Meets over-turning criteria		
D2-570-42J-4	√			√	√	√		√	√				Meets over-turning criteria		
D3-570-45K-7	√			√		√		√	√				Meets over-turning criteria		
D3-570-45K-8	√			√	√	√		√	√				Meets over-turning criteria		
D2-570-38M-11	√			√	√			√	√					Exceeds overturning criteria	
D2-561-44D-12	√			√				√						Exceeds overturning criteria	

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APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D3-561-45D-13	√			√				√						Exceeds overturning criteria	
D3-545-44D-14	√			√				√					Meets allowable stresses		
D2-570-43K-15	√			√	√	√		√	√				Meets allowable stresses		
D3-570-45K-16	√			√	√	√		√	√				Meets allowable stresses		
D2-534-33E-20	√			√	√			√	√					Exceeds allowable tension	
D2-534-33G-21	√			√	√	√		√	√				Meets allowable stresses		
D2-534-33H-22	√			√	√			√	√					Exceeds overturning criteria	
D2-545-38H-23	√	√		√	√	√		√	√				Meets allowable stresses		

TABL

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-545-39J-24	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D2-545-39J-25	✓			✓	✓			✓	✓				Meets allowable stresses		
D2-545-41H-26	✓			✓	✓	✓		✓	✓				Meets over-turning criteria		
D2-545-44J-31	✓			✓	✓	✓		✓	✓	✓				Exceeds allowable strain for interstory drift	
D2-545-43L-32	✓			✓	✓	✓		✓	✓	✓	✓		Meets allowable stresses		
D2-545-43M-33	✓			✓	✓	✓		✓	✓	✓			Meets allowable stresses		
D3-545-44J-34	✓			✓	✓	✓		✓	✓	✓				Exceeds allowable strain for interstory drift	
D3-545-45L-38	✓			✓	✓	✓		✓	✓	✓	✓		Meets allowable stresses		

TABL

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D3-545-48N-40	√			√	√			√	√					Exceeds allowable stresses	
D2-545-40N-41	√			√	√			√	√					Exceeds allowable stresses	
D3-545-49H-42	√	√		√		√		√					Meets allowable stresses		
D3-545-50H-44	√	√		√	√	√		√	√				Meets allowable stresses		
D2-549-32F-45	√			√	√	√		√	√				Meets allowable stresses		
D2-549-31F-46	√			√	√	√		√	√				Meets allowable stresses		
D2-549-32F-47	√			√	√	√		√	√				Meets allowable stresses		
D2-549-32F-48	√			√	√	√		√	√				Meets allowable stresses		

TAB

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-549-32G-49	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D2-549-32G-50	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D2-549-31G-51	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D2-549-32G-52	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D2-549-33G-53	✓			✓	✓			✓	✓					Exceeds allowable tension	
D2-549-33H-54	✓			✓	✓			✓	✓					Exceeds allowable tension	
D2-534-33G-55	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D2-534-33G-56	✓			✓	✓	✓		✓	✓				Meets allowable stresses		

TAB

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-545-39J-66	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D3-545-47M-67	✓			✓	✓	✓		✓	✓				Meets allowable stresses		
D3-545-47M-68	✓			✓		✓		✓					Meets allowable stresses		
D2-534-43H-70	✓			✓	✓			✓	✓				Meets allowable stresses		
D3-534-45D-71	✓	✓		✓	✓	✓		✓	✓				Meets allowable stresses		
D3-534-44D-72	✓	✓		✓	✓			✓	✓				Meets allowable stresses		
D3-534-44D-73	✓			✓				✓					Meets allowable stresses		
D2-529-43C-74	✓	✓	✓	✓	✓		✓	✓	✓					Exceeds allowable tension	

TABL

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads: Normal: D	L	W	E_o	R_o	Abnormal: Dr	W_t	E_s	R_a	T_a	P_a	Y_p	Evaluation Results: Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	Remarks
D2-545-41J-76	√			√		√		√						Exceeds allowable strain for interstory drift	
D3-545-46H-77	√			√	√	√		√	√					Exceeds allowable strain for interstory drift	
D2-517-33E-80	√			√	√			√	√					Exceeds allowable tension	
D2-503-35E-81	√	√		√	√			√	√					Exceeds arching criteria	
D2-517-31F-82	√			√	√			√	√					Exceeds allowable tension	
D2-517-32F-83	√			√	√			√	√					Exceeds overturning criteria	
D2-517-32G-84	√			√	√			√	√					Exceeds allowable tension	
D2-517-33H-85	√			√	√			√	√					Exceeds allowable tension	

TABL

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-517-33H-86	√			√	√			√	√					Exceeds allowable stresses	
D2-517-38H-87	√	√		√	√	√		√	√				Meets allowable stresses		
D2-517-39H-88	√			√	√	√		√	√				Meets allowable stresses		
D2-517-39K-89	√			√	√	√		√	√				Meets allowable stresses		
D2-517-42G-90	√			√	√			√	√				Meets over-turning criteria		
D3-517-49H-92	√	√		√	√	√		√	√				Meets allowable stresses		
D3-517-49J-93	√			√	√	√		√	√				Meets allowable stresses		
D2-517-34E-94	√			√	√			√	√					Exceeds overturning criteria	

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APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-517-33G-95	✓			✓	✓			✓	✓					Exceeds allowable tension	
D2-517-43H-96	✓			✓				✓						Exceeds overturning criteria	
D3-517-45H-97	✓			✓		✓		✓					Meets over-turning criteria		
D3-517-46N-98	✓			✓	✓			✓	✓				Meets allowable stresses		
D3-517-46N-99	✓			✓	✓			✓	✓				Meets allowable stresses		
D3-517-46N-100	✓			✓	✓			✓	✓					Exceeds allowable tension	
D2-517-38H-101	✓	✓		✓	✓			✓	✓				Meets allowable stresses		
D3-517-50H-102	✓	✓		✓	✓			✓	✓				Meets allowable stresses		

TABL

APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	D_r	W_t	E_s	R_a	T_a	P_a	Y_p			
D3-507-44C-103	✓			✓				✓						Exceeds overturning criteria	4
D3-517-46G-104	✓			✓	✓	✓		✓	✓				Meets arching criteria		
D2-517-31G-105	✓		✓	✓			✓	✓					Meets arching criteria		
D2-517-33E-106	✓			✓	✓			✓	✓				Meets allowable stresses		
D3-517-45D-107	✓	✓		✓	✓	✓		✓	✓				Meets allowable stresses		
D2-517-44D-108	✓			✓				✓					Meets overturning criteria		
D2-517-44E-109	✓			✓	✓			✓	✓				Meets allowable stresses		
D2-517-43E-110	✓			✓	✓			✓	✓				Meets allowable stresses		

TABLE

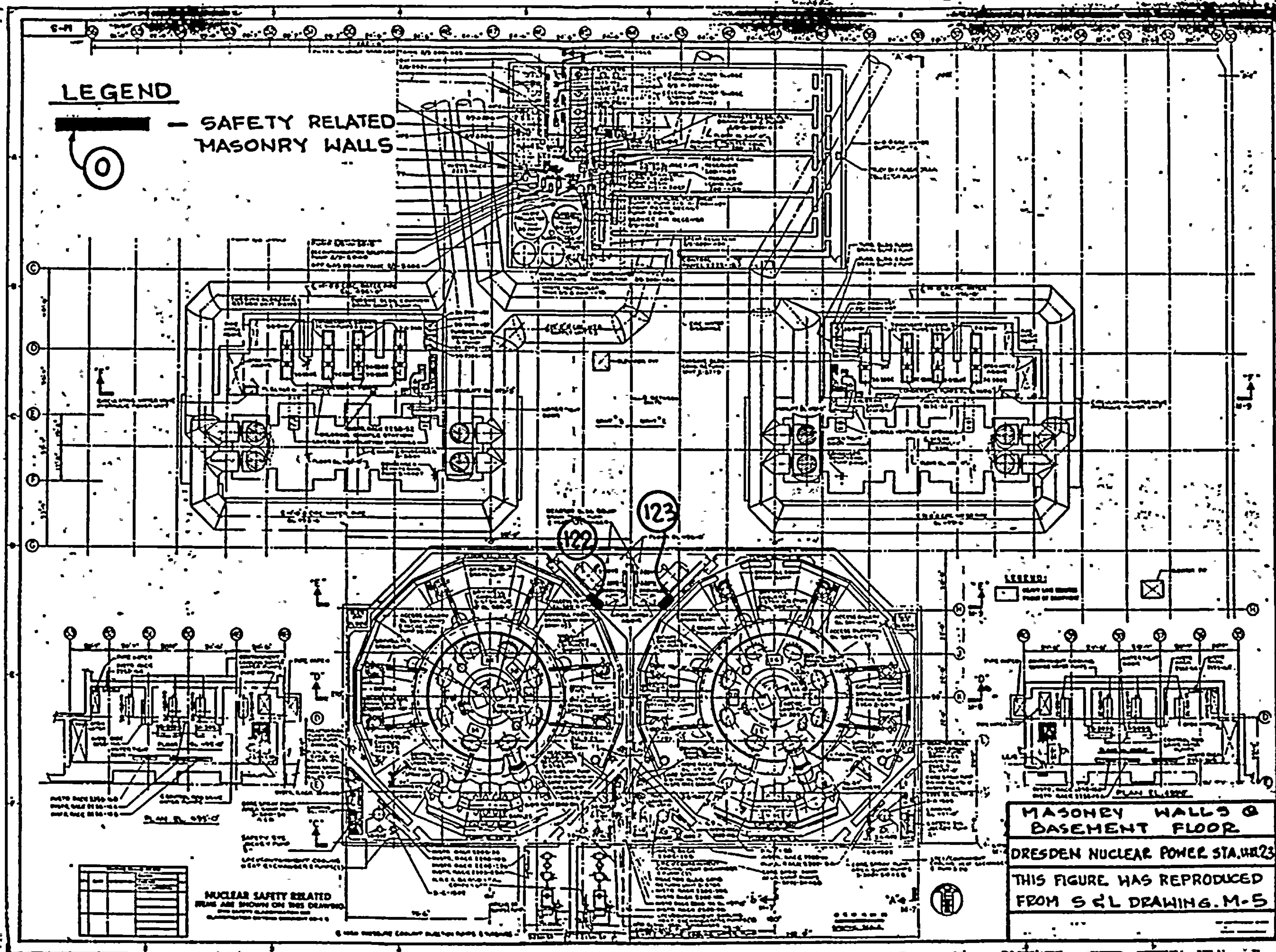
APPLIED LOADS AND EVALUATION RESULTS

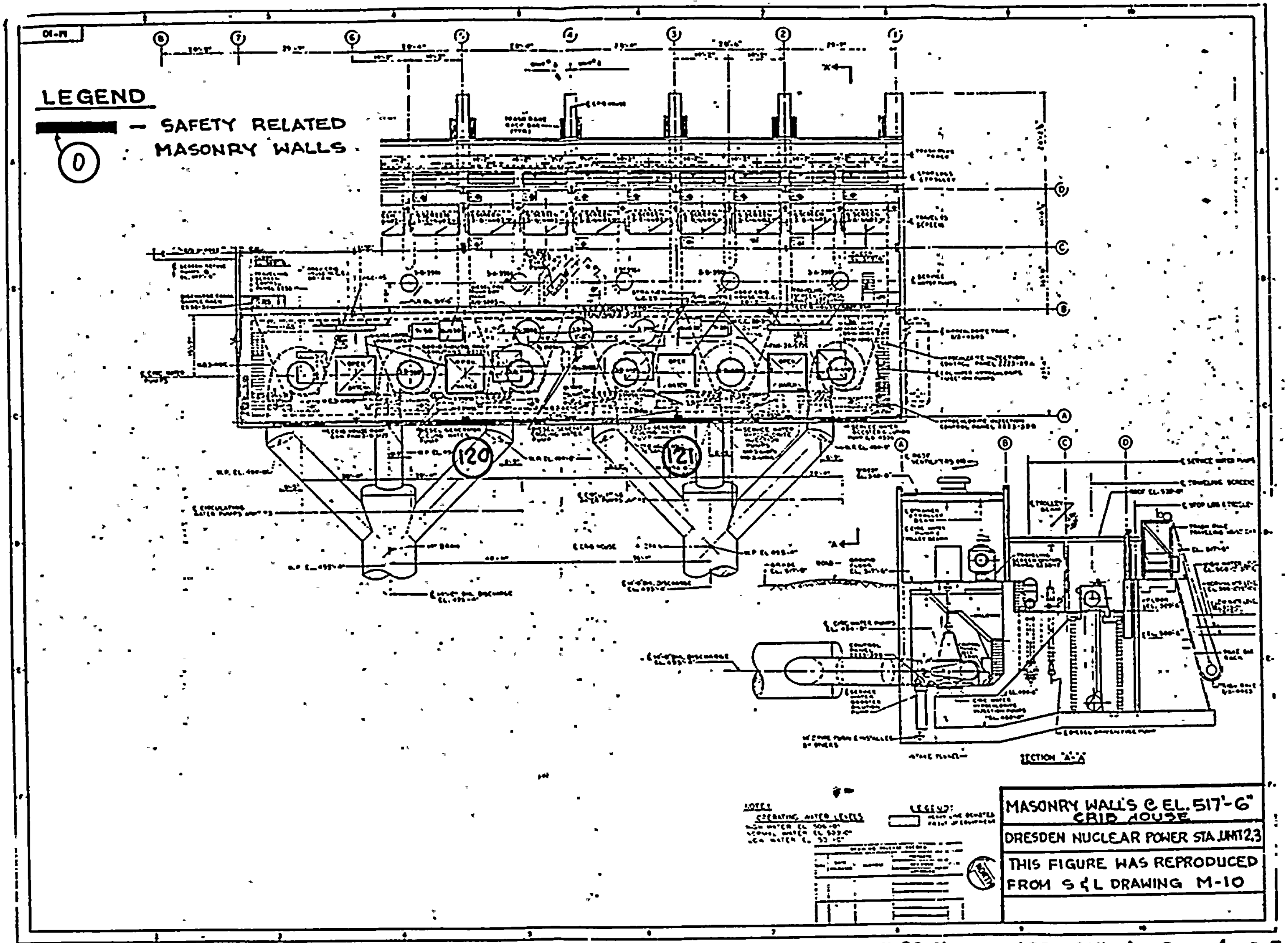
Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-517-39H-111	√			√		√		√					Meets allowable stresses		
D2-528-35H-112	√	√		√	√	√		√	√	√		√	Meets allowable stresses		
D2-528-33H-113	√	√		√	√	√		√	√	√		√	Meets allowable stresses		
D3-528-54H-114	√			√	√			√	√				Meets allowable stresses		
D3-528-54H-115	√			√	√			√	√				Meets allowable stresses		
D2-517-43H-116	√			√	√	√		√	√				Meets allowable stresses		
D3-517-49H-117	√			√		√		√					Meets allowable stresses		
D2-507-45C-118	√			√				√						Exceeds overturning criteria	

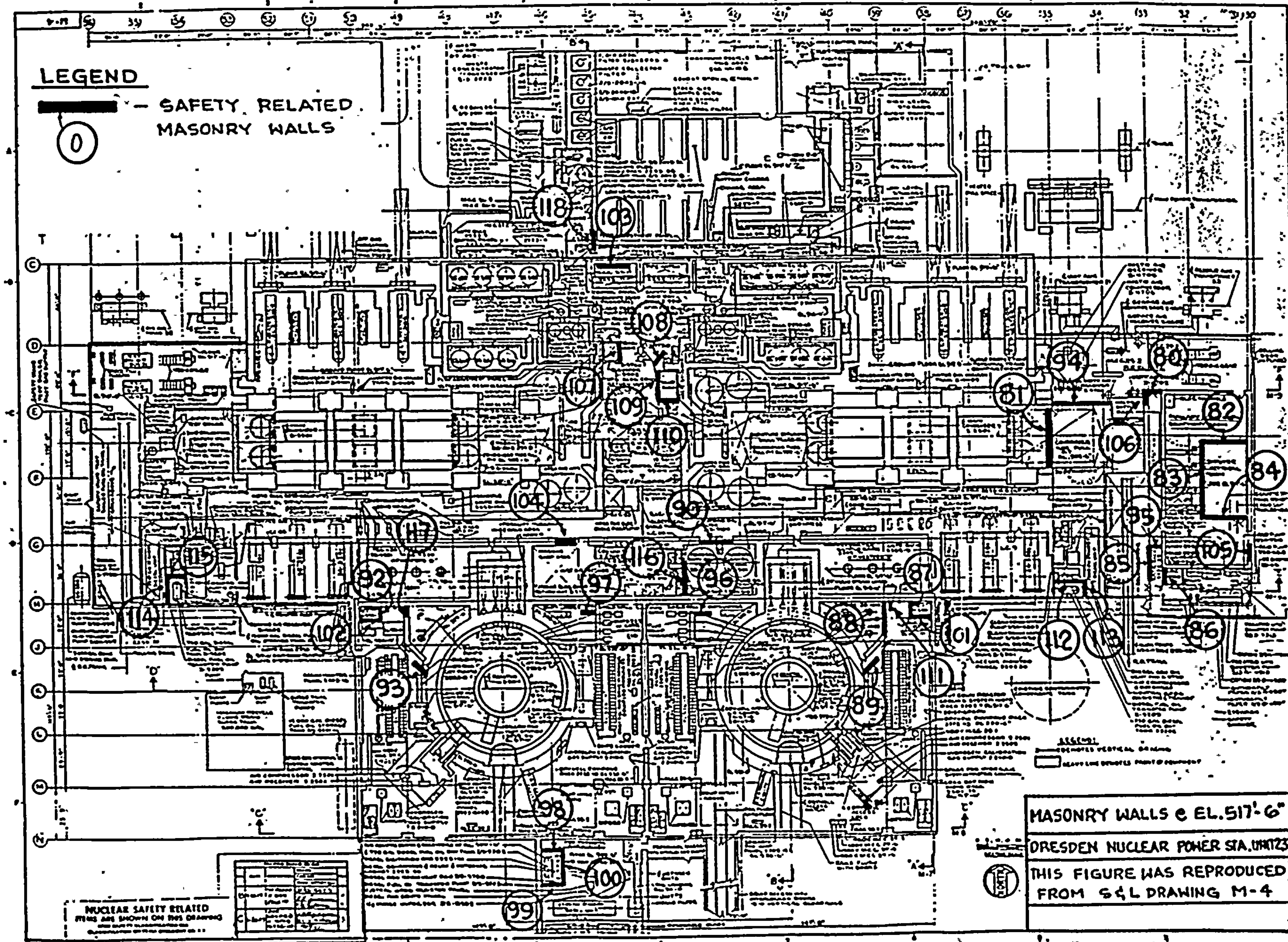
TAB

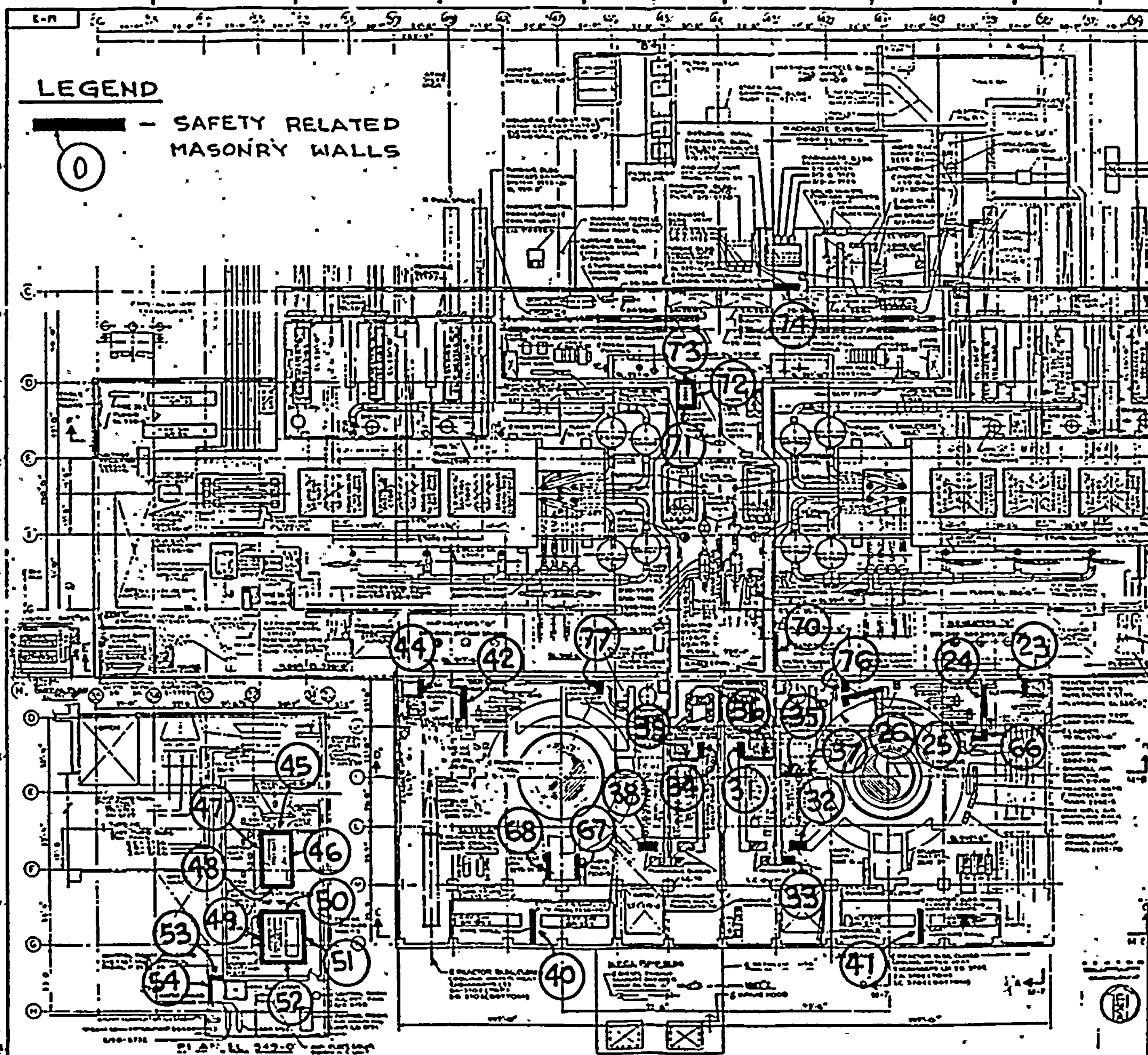
APPLIED LOADS AND EVALUATION RESULTS

Wall	Applied Loads												Evaluation Results		Remarks
	Normal					Abnormal							Meets Acceptance Criteria	Does Not Meet Acceptance Criteria	
	D	L	W	E_o	R_o	Dr	W_t	E_s	R_a	T_a	P_a	Y_p			
D2-517-5A-120	✓		✓	✓	✓		✓	✓	✓					Exceeds allowable stresses	
D2-517-3A-121	✓		✓	✓	✓		✓	✓	✓					Exceeds allowable stresses	
D3-476-45H-122	✓			✓		✓		✓					Meets allowable stresses		
D3-476-43H-123	✓			✓		✓		✓					Meets allowable stresses		
D2-558-43K-35	✓			✓		✓		✓		✓	✓		Meets allowable stresses		
D2-558-43K-36	✓			✓		✓		✓		✓	✓		Meets allowable stresses		
D2-558-42K-37	✓			✓				✓		✓	✓			Exceeds allowable stresses in support bracket.	4
D2-558-45K-39	✓			✓		✓		✓		✓	✓		Meets allowable stresses		**LEGEND** Dr = Interstory drift


LEGEND
— SAFETY RELATED MASONRY WALLS
0
122
123
NUCLEAR SAFETY RELATED
MASONRY WALLS @ BASEMENT FLOOR
DRESDEN NUCLEAR POWER STA. UNIT 2/3
THIS FIGURE HAS REPRODUCED FROM S&L DRAWING. M-5


LEGEND
— SAFETY RELATED MASONRY WALLS
0
120
121
SECTION "A-A"
MASONRY WALLS @ EL. 517'-6"
CRIB HOUSE
DRESDEN NUCLEAR POWER STA. UNIT 2,3
THIS FIGURE WAS REPRODUCED FROM S&L DRAWING M-10

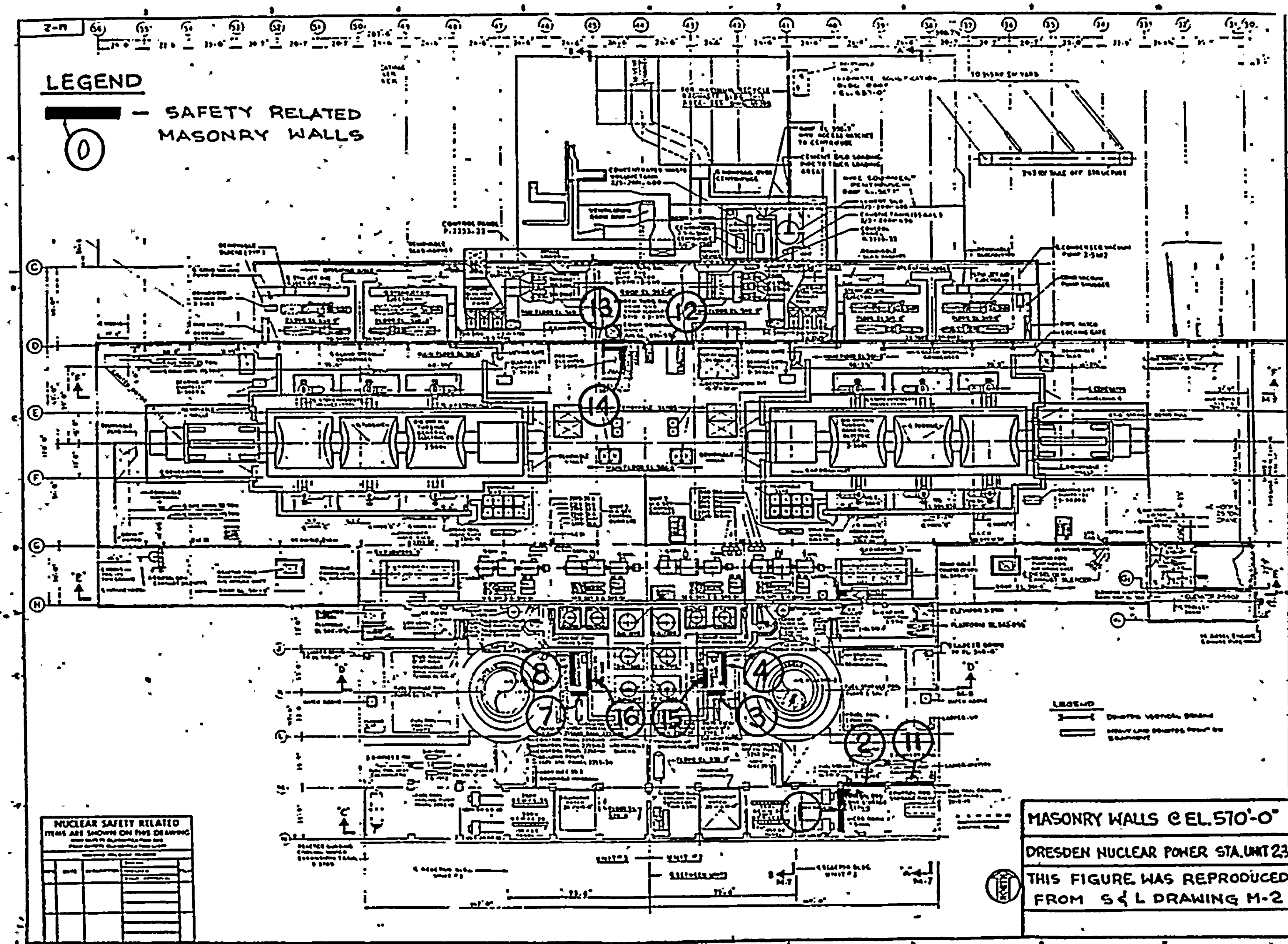

LEGEND
— SAFETY RELATED MASONRY WALLS
0
MASONRY WALLS @ EL. 517'-6"
DRESDEN NUCLEAR POWER STA. UNIT 2/3
THIS FIGURE WAS REPRODUCED FROM S&L DRAWING M-4
NUCLEAR SAFETY RELATED



MASONRY WALLS @ EL. 545'-6"

DRESDEN NUCLEAR POWER STA. UNIT 2&3

THIS FIGURE WAS REPRODUCED FROM S&L DRAWING M-3



LEGEND
— SAFETY RELATED MASONRY WALLS
MASONRY WALLS @ EL. 570'-0"
DRESDEN NUCLEAR POWER STA. UNIT 2/3
THIS FIGURE WAS REPRODUCED FROM S&L DRAWING M-2
NUCLEAR SAFETY RELATED ITEMS ARE SHOWN ON THIS DRAWING

APPENDIX B

ADDITIONAL JUSTIFICATION

OF THE

REEVALUATION CRITERIA

0052C

TABLE OF CONTENTS

TABLES

1.0 INTRODUCTION

The following discussions and test results are intended to provide additional justification of the reevaluation criteria for the safety-related masonry walls. This information has been extracted from the references identified in Section 6.0.

2.0 ABBREVIATIONS

Abbreviation	Title
ACI	American Concrete Institute
ASCE	American Society of Civil Engineers
ATC	Applied Technology Council
EERC	Earthquake Engineering Research Center
NBS	National Bureau of Standards
NCMA	National Concrete Masonry Association

3.0 ALLOWABLE STRESSES

3.1 AXIAL COMPRESSION

The objective was to develop reasonable and safe engineering design criteria for nonreinforced concrete masonry based on all existing data. A review in 1967 of the compilation of all available test data on compressive strength of concrete masonry walls did not, according to some, provide a suitable relationship between wall strength and slenderness ratio. From a more recent analysis, it was noted in many of the 418 individual pieces of data that either the masonry units or mortar, or in some cases, both units and mortar, did not comply with the minimum strength requirements established for the materials permitted for use in "engineered concrete masonry" construction. Accordingly, it was decided to reexamine the data, discarding all tests which included materials that did not comply with the following minimum requirements:

Material	Compressive Strength (psi)
Solid units	1,000
Hollow units	600 (gross)
Mortar	700

Also eliminated from the new correlation were walls with a slenderness ratio of less than 6; walls with an h/t ratio of less than 6 were considered to be in the category of "prisms". For evaluation of slenderness reduction criteria, only axially loaded walls were used. The data that were available consisted of tests on 159 axially loaded walls with the h/t ratio ranging between 6 and 18. With this as a starting point, the data were analyzed assuming that the parabolic slenderness reduction function $[1 - (h/40t)^3]$ is valid.

The basic equation used to evaluate the test data was:

$$\frac{f_{test}}{S.F.} = C_o\, f'_m \left[1 - \left(\frac{h}{40t}\right)^3\right] \qquad (1)$$

$$\frac{f_{test}}{f'_m \left[1 - \left(\frac{h}{40t}\right)^3\right]} = C_o \times S.F. \qquad (2)$$

$$C_o \times S.F. = K \qquad (3)$$

where

f'_m = Assumed masonry strength, net area, based on strength of units

f_{test} = Net area compressive strength of panel

S.F. = Safety Factor

C_o = Strength reduction coefficient

h = Height of specimen, inches

t = Thickness of specimen, inches

The net area used in the above formulae is the net area of the masonry, and does not distinguish between type of mortar bedding. In the evaluation, mortar strength was assumed to be constant and was not considered a significant influence on wall strength.

It was determined that the objective of reasonable and safe criteria would be met if 90% of the K values were greater than the K value selected and gave a minimum safety factor of 3. Accordingly, the K values were listed in ascending order and the value satisfying the above conditions was K = 0.610 for the 159 tests as seen from Table B-2. Therefore, from Equation (3):

$$C_o \times S.F. = K$$

$$C_o \times 3 = 0.610$$

$$C_o = \frac{0.610}{3} = 0.205$$

This value (0.205) agrees very closely with the coefficient 0.20 which had been used for a number of years with reinforced masonry design. An analysis of the safety factors present with the formula:

$$f_m' = 0.205\, f_m' \left[1 - \left(\frac{h}{40t}\right)^3\right]$$

indicates the following:

A safety factor greater than 3 is available in 93% of the tests, greater than 4 in 51% of the tests, greater than 5 in 15% of the tests, and greater than 6 in 5% of the tests.

In ACI 531, the factor of 0.20 was increased to 0.225. The recommended value of 0.22 for unfactored loads has factors of safety comparable to those given above.

3.2 FLEXURAL COMPRESSION

It is assumed that masonry can develop 85% of its specified compressive strength at any section. The recommended procedure for calculating the flexural strength of a section is the working stress procedure, which assumes a triangular distribution of strain.

For normal loads, an allowable stress of 0.33 f_m has a factor of safety of 2.6 for the peak stress, which only exists at the extreme fiber of the unit and has been used in practice for many years. The recommended value for factored loads also only exists at the extreme fiber and is the value recommended in the ATC-3-06 provisions.

3.3 BEARING

These values for normal loads are taken directly from the ACI 531-79 code.

3.4 SHEAR

The most extensive review on shear strength literature appears to have been done by Mayes, et al (Reference 6.1), and published in Earthquake Engineering Research Center Report EERC 75-15 which was performed for both brick and masonry block.

This report attempts to summarize some of the findings that appear to be pertinent towards defining permissible shear stress values that can be used for reevaluation of the nonreinforced concrete masonry.

A number of tests have been identified as being the primary basis for permissible shear stress values in both NCMA Specifications for the Design and Construction of Load-Bearing Concrete Masonry (References 6.4 and 6.5) and the ACI Standard Building Code Requirements for Concrete Masonry Structures, ACI 531-79 (References 6.2 and 6.3).

Out-of-plane flexural shear is defined by the code (References 6.2 and 6.3) as equaling $1.1\sqrt{f_m}$. The derivation of this value is analogous to the permissible shear value of concrete, disregarding any reinforcement, of $1.1\sqrt{f_c}$ (Reference 6.30). Although this is somewhat different (there is no tension steel by which to determine the appropriate j distance), the actual value is a mute point because tension will be the critical value for determining out-of-plane acceptability of a flexural member.

Because of the nature of the stresses, however, and the various concerns with regard to the correctness of interpretation of the effects on boundary conditions, as well as such conditions as actual mortar properties, absorptivity of the mortar, confinement or lack of it on the test specimen during test, and arrangement and effect of actual load, it does not seem warranted to increase these stresses beyond a factor of 1.67 under abnormal and extreme environmental loads.

3.5 TENSION

3.5.1 Normal to the Bed Joint

A summary of the static monotonic tests performed to determine code allowable stress for tension normal to the bed joint was given in the NCMA specifications.

Stresses for tension in flexure are related to the type of mortar and the type of unit (hollow or solid). Research used to arrive at allowable stresses for tension in flexure in the vertical span (i.e., tension perpendicular to the bed joints) consisted of 27 flexural tests of uniformly loaded single-wythe walls of hollow units. These monotonic tests were made in accordance with ASTM E 72. Table B-2 summarizes the test results.

From Table B-2, the average modulus of rupture for walls built with Types M and S mortar is 93 psi on net area. For Type N mortar, the value is 64 psi. Applying a safety factor of 4 to these values results in allowable stresses for hollow units as follows:

Mortar Type	Allowable Tension in Flexure (psi)
M&S	23
N	16

These values are consistent with those published in the 1970 ACI Committee 531 report, which have been only slightly altered in the ACI 531-79 code.

Based upon these tests, the minimum factors of safety for each mortar type are:

Mortar Type	Factor of Safety
M	3.87
S	2.60
N	2.81

To establish allowable tensile stresses for walls of solid units, the 8-inch composite walls in Table B-3 were used. These walls, composed of 4-inch concrete brick and 4-inch hollow block, were greater than 75% solid, and thus, were evaluated as solid masonry construction. The modulus of rupture (gross area) for these walls averaged 157 psi, giving an allowable stress of 39 psi when a safety factor of 4 is applied. The composite wall tests in Table B-3 used Type S mortar. To establish allowable stresses for solid units with Type N mortar, the mortar influence established previously for hollow units was used.

$$\frac{23}{16} = \frac{39}{f} \;;\; f = 27 \text{ psi}$$

The minimum factor of safety for these tests for Type S mortar was 2.33.

Recent dynamic tests have been performed at Berkeley and the values of tension obtained at cracking at the mid-height of the walls are as follows: 13 psi, 20 psi, 23 psi, and 27 psi.

The recommended values have a factor of safety of 2.8 with respect to the lower bound of the static tests for the unfactored loads and are towards the lower limit of the initiation of cracking for the dynamic tests. An increase of 1.67 appeared reasonable for factored loads based on the static tests.

3.5.2 Tension Parallel to Bed Joints

Values for allowable tension in flexure for walls supported in the horizontal span are established by doubling the allowable stresses in the vertical span. While it is recognized that flexural tensile strength of walls spanning horizontally is more a function of unit strength than mortar, it is conservative to use double the vertical span values. Table B-4 lists a summary of all published tests and indicates an average safety factor of 5.3 for the 43 walls containing no joint reinforcement and 5.6 for the 15 walls containing joint reinforcement.

It is important to note that the factor of safety for those walls loaded at the quarter points (Reference 6.6) have an average factor of safety of 2.02 with a minimum value of 1.22, while those loaded at the center had an average factor of safety of 6.08 with a minimum value of 3.59. However, it should be noted that the values tested at the quarter points were also tested at 15 days.

The results associated with the early date of testing and the use of quarter-point loading are difficult to explain other than to state they are at variance with all other test results.

An increase in the allowable stresses by a factor of 1.67 is recommended for abnormal and extreme environmental loads. The recommended values could be increased because of the larger factors of safety in the test results; however, the value of 1.67 was chosen to be compatible with the increase in other stresses for unreinforced masonry.

3.6 SHEAR AND TENSILE BOND STRENGTH OF MASONRY COLLAR JOINT

The collar joint shear and tensile bond strength is a major factor in the behavior of multi-wythe masonry construction, particularly with respect to weak axis bending. A widely stated position is that for composite construction, the collar joint must be completely filled with mortar. However, even if this joint is filled, there must be a transfer of shearing stress across this joint without significant slip in order for full composite interaction of the multiple wythes to be realized. Because the cracking strength, moment of inertia, and ultimate flexural strength of the wall cross-section are significantly influenced by the interaction of multiple wythes, it is crucial to establish the collar joint shear bond strength.

The only applicable published data on the shear bond strength of collar joints is that determined by Bechtel on the Trojan Nuclear Power Plant (Reference 6.29). Therefore, to correlate the shear bond strength of mortared collar joints, plant-specific in situ tests were performed in August 1982. The results of these tests showed the ultimate failure stresses to be 37.6 and 32.7 psi. A factor of safety of three was used in

determining the allowable stress for normal load combinations. For abnormal and extreme environmental combinations, the allowable stress is increased by a factor of 1.33.

There are conflicting data available on the relationship between the shear and tensile bond strengths. In most tests performed on mortar bed joints (couplet tests), the shear bond strength was approximately twice the tensile bond strength. In a more recent method of evaluation by means of centrifugal force, the shear bond strength was found to be 60% of the tensile bond strength (Reference 6.16). The authors of the report consider the test procedure to be an improvement over present methods because joint precompression is essentially eliminated as a result of the testing procedure.

Because of the conflict in the test data, it is recommended that the values for tensile bond strength be the same as for shear bond.

Unless metal ties are used at closely spaced intervals (less than 16 inches on center), it is recommended that their contribution to shear and tensile bond strength be neglected.

4.0 <u>IN-PLANE EVALUATION CRITERIA</u>

4.1 INTRODUCTION

Much of the effort to define a permissible in-plane shear stress may be somewhat academic in that the normal case for unreinforced walls being used in nuclear plant structures, the nature of the shear, is one of being forced on the structural panel as a result of being confined by the building frame and not one of depending on the panel to transmit building shear forces. This forced drift or displacement results in shear stresses and strains, but because of the complex interaction between the panel and the confining structural elements, strain or displacement is a more meaningful index for qualifying the in-plane performance of the panel.

In-plane effects may be imposed on masonry walls by the relative displacement between floors during seismic events. However, the walls do not carry a significant part of the associated story shear, and their stiffness is extremely difficult to define. In addition, because the experimental evidence to date demonstrates that the apparent in-plane strength of masonry walls depends heavily upon the in-plane boundary conditions, load or stress on the walls is not a reasonable basis for evaluation criteria.

However, examination of the test data provided by the list of references of Section 4.2 indicates that the gross shear strain of walls is a reliable indicator for predicting the onset of significant cracking. A significant crack is considered here to

be a crack in the central portion of the wall extending at least 10% of a wall's width or height. Cracking along the interface between a block wall and steel or concrete members does not limit the integrity of the wall.

4.2 TEST RESULTS

Test results indicate that to predict the initiation of significant cracking, masonry walls must be divided into two categories:

4.2.1 Unconfined Walls: Not bounded by adjacent steel or concrete primary structure. Significant "confining" stresses cannot be expected.

4.2.2 Confined Walls: At a minimum, bounded top and bottom or bounded on three sides.

For unconfined concrete block masonry walls, the works of Fishburn (Reference 6.18) and Becica (Reference 6.17), yield an allowable shear strain of 0.0001. It should be noted that Fishburn's test specimens were an average of 15 days old.

For confined walls, the most reliable data appears to be that of Mayes et al (Reference 6.20). In static and dynamic tests of masonry piers (confined top and bottom) varying block properties, mortar properties, reinforcement, vertical load, and grout conditions, significant cracking was initiated at strains exceeding approximately 0.001. It should be noted here that reinforcement can have no significant effect on the behavior prior to cracking. Similarly, the presence of cell grout should have no effect on stress or cracking in the mortar joints at a given strain. Both predictions are confirmed by the data in Reference 6.20. In addition, the data shows that the onset of cracking is not sensitive to the magnitude of initial applied vertical load.

Klingner and Bertero (Reference 6.19) performed a series of cyclic tests to failure and found excellent correspondence with a nonlinear analysis in which the behavior of an infilled frame prior to cracking is determined by an equivalent diagonal strut. While the equivalent strut technique has been used by many investigators to study the stiffness and load-carrying mechanisms of infilled frames, Klingner and Bertero found that the quasicompressive failure of the strut could be used to predict the onset of significant cracking.

5.0 ALTERNATIVE EVALUATION CRITERIA

5.1 ARCHING

An extensive test program performed by Gabrielson (Reference 6.21) on blast loading of masonry walls provides validation of the concept of arching action of masonry walls

subjected to loads that exceed those that cause flexural cracking of an unreinforced masonry wall. An analytical procedure was developed to predict with reasonable accuracy the ultimate capacity of the unreinforced walls tested.

5.2 ROCKING

Freestanding block walls may rock or slide as rigid bodies during an earthquake. Such rocking and sliding of walls in nuclear plants is permissible as long as it is within certain tolerance limits. Only when the rocking of a wall increases to a critical value does the wall become unstable and overturn.

A freestanding wall starts to rock about an edge when the supporting floor moves horizontally with an acceleration greater than (t/h)g, where t = thickness of wall, h = height of wall, and g = acceleration due to gravity. If the coefficient of friction between the wall and floor is less than (t/h), the wall will not rock, but will slide instead.

The rocking behavior of cantilever structures has been studied and reported in References 6.23, 6.24, and 6.25. In References 6.24 and 6.25, a nonlinear differential equation for the rocking motion is formulated and solved numerically for different support excitations. Some test results on the rocking of block specimens are reported in Reference 6.24. The method used to predict the rocking of block walls is similar to the one in References 6.22 and 6.23 for cantilever structures. Application of the method to seismic rocking of structures has been justified in Reference 6.26 based on the numerical results using ANSYS program.

A rocking wall switches from one edge to another and a considerable amount of energy is dissipated whenever the wall impacts the floor. Thus, the seismic rocking behavior of a wall is nonlinear and the frequency of rocking varies as a function of the maximum rocking angle in a cycle (Reference 6.23).

5.3 SLIDING

Sliding is the horizontal movement of a wall as a rigid body with respect to the supporting floor. In general, a wall will either rock or slide during an earthquake. It appears that a rocking wall will not slide and vice versa. Sliding resistance and sliding displacement of a wall depend on the coefficient of friction between the two contact surfaces. Based on the discussion in Reference 6.31, the following are reasonable friction values for concrete depending on the surface roughnesses:

μ = 0.33 -between smooth surfaces

μ = 0.67 -between smooth and rough surfaces

μ = 1.0 -between rough surfaces

Seismic sliding of cantilever structures is studied in Reference 6.28 by nonlinear seismic analyses using ANSYS program. This study substantiates the simple energy balance method given in References 6.22 and 6.27 to predict sliding.

A wall begins to have sliding oscillations whenever the horizontal seismic floor acceleration in g-units exceeds the friction coefficient.

6.0 REFERENCES

6.1 Mayes and Clough, "Literature Survey - Compressive, Tensile, Bond, and Shear Strength of Masonry," Earthquake Engineering Research Center, University of California, 1975

6.2 ACI Standard, "Building Code Requirements for Concrete Masonry Structures" (ACI 531-79)

6.3 Commentary on "Building Code Requirements for Concrete Masonry Structures" (ACI 531-79)

6.4 "Specification for the Design and Construction of Load-Bearing Concrete Masonry," NCMA, 1979

6.5 Research Data and Discussion Relating to "Specification for the Design and Construction of Load-Bearing Concrete Masonry," NCMA, 1970

6.6 Fishburn, "Effect of Mortar Strength and Strength of Unit on the Strength of Concrete Masonry Walls," Monograph 36, NBS, 1961

6.7 Copeland, R.E. and Saxer, E.L., "Tests of Structural Bond of Masonry Mortars to Concrete Block," Proceedings, American Concrete Institute, Volume 61, Number 11, November 1964

6.8 Richart, Frank E., Moorman, Robert B.B., and Woodworth, Paul M., "Strength and Stability of Concrete Masonry Walls," Bulletin 251, Engineering Experiment Station, University of Illinois, 1932

6.9 Hedstrom, R.O., "Load Tests of Patterned Concrete Masonry Walls," Proceedings, American Concrete Institute, Volume 57, p 1265, 1961

6.10 Menzel, Carl A., "Tests of the Fire Resistance and Strength of Walls of Concrete Masonry Units," Portland Cement Association, 1934

6.11 Nylander, H., "Investigation of the Strength of Concrete Block Walls," Swedish Cement Association, Technical Communications and Reports of Investigations, 1944, Number 6 (October)

6.12 Copeland, R.E. and Timms, A.G., "Effect of Mortar Strength and Strength of Unit on the Strength of Concrete Masonry Walls," Proceedings, American Concrete Institute, Volume 28, p 551, 1932

6.13 Beyer, A.H. and Krefeld, W.J., "Comparative Tests of Clay, Sand-Lime, and Concrete Brick Masonry," Columbia University, Department of Civil Engineering, April 1923

6.14 Livingston, A.R., Mangotich, E., and Dikkers, R., "Flexural Strength of Hollow Unit Concrete Masonry Walls in the Horizontal Span," Technical Report 62, NCMA, 1958

6.15 Cox, F.W. and Ennenga, J.L., "Transverse Strength of Concrete Block Walls," Proceedings, ACI, Volume 54, p 951, 1958

6.16 Hatzinkolas, M., Longworth, J., and Wararuk, J., "Evaluation of Tensile Bond and Shear Bond of Masonry by Means of Centrifugal Force," Alberta Masonry Institute, Edmonton, Alberta

6.17 Becica, I.J. and Harris, H.G., "Evaluation of Techniques in the Direct Modeling of Concrete Masonry Structures," Drexel University Structural Models Laboratory Report M77-1, June 1977

6.18 Fishburn, C.C., "Effect of Mortar Properties on Strength of Masonry," National Bureau of Standards Monograph 36, U.S. Government Printing Office, November 1961

6.19 Klingner, R.E. and Bertero, V.V., "Earthquake Resistance of Infilled Frames," Journal of the Structural Division, ASCE, June 1978

6.20 Mayes, R.L., Clough, R.W., et al, "Cyclic Loading Tests of Masonry Piers," 3 volumes, EERC 76/8, 78/28, 79/12, Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, California

6.21 Gabrielson, G., Wilton, C., and Kaplan, K., "Response of Arching Walls and Debris from Interior Walls Caused by Blast Loading," URS Report 2030-23, URS Research Company, 1975

6.22 Topical Report, "Seismic Analyses of Structures and Equipment for Nuclear Power Plants," BC-TOP-4, Revision 4, Bechtel Power Corporation, 1980

6.23 Housner, G.W., "The Behavior of Inverted Pendulum Structures During Earthquakes," Bulletin of the Seismological Society of America, Volume 53, Number 2, February 1963

6.24 Aslam, M., et al, "Earthquake Rocking Response of Rigid Bodies," ASCE, Journal of the Structural Division, ST2, February 1980

6.25 Yim, C-S., et al, "Rocking Response of Rigid Blocks to Earthquakes," Report UCB/EERC-80/02, University of California, Berkeley, January 1980

6.26 "Seismic Loading Criteria for Base Mat Design," Bechtel Power Corporation, San Francisco, Internal Report, Revision 2, November 1976

6.27 Newmark, N.M., "Effects of Earthquakes on Dams and Embankments," Geotechnique, Volume XV, Number 2, pp 139-159, June 1965

6.28 Kausel, E.A., et al, "Seismically Induced Sliding of Massive Structures," ASCE, Journal of the Geotechnical Engineering Division, GT12, December 1979

6.29 Report on Tests of Shear Strength of Collar Joint Mortar in Double Wythe Masonry Walls, Trojan Nuclear Power Plant, Portland General Electric Company, April 14, 1980

6.30 ACI Standard, "Building Code Requirements for Structural Plain Concrete" (ACI 322-72)

6.31 PCI Design Handbook, "Precast Prestressed Concrete," Prestressed Concrete Institute, Second Edition, 1978

TABLE B-1

COMPRESSIVE STRENGTH OF AXIALLY LOADED CONCRETE MASONRY WALLS

Ref.	Concrete Masonry Units			Mortar		Walls				
	Percent Solid	Strength, psi, net area	f'_m, psi	Str., psi	Bedding	h/t	Strength, psi, net f_{test}	f'_m C	K	S.F.
6.8	63	1160	980	1180	Full	6.0	750	978	.798	3.83
	63	1160	980	1180	Full	6.0	685	978	.701	3.49
	63	1160	980	1160	FS	6.0	670	978	.686	3.42
	63	1160	980	900	FS	6.0	555	978	.568	2.83
	63	1200	1000	1230	Full	6.0	860	995	.863	4.30
	63	1200	1000	730	Full	6.0	625	995	.627	3.12
	63	1200	1000	960	FS	6.0	580	995	.582	2.89
	63	1200	1000	780	FS	6.0	650	995	.652	3.25
	63	1320	1060	880	Full	6.0	1110	1055	1.050	5.25
	63	1320	1060	810	Full	6.0	970	1055	.918	4.58
	63	1320	1060	810	FS	6.0	780	1055	.738	3.69
	63	1160	980	1080	Full	6.0	800	978	.818	4.08
	63	1160	980	1080	Full	6.0	670	978	.686	3.42
	63	1810	1275	1270	Full	6.0	940	1270	.739	3.67
	63	1810	1275	1270	Full	6.0	940	1270	.739	3.67
	63	1505	1150	1670	Full	6.0	825	1145	.719	3.60
	63	1505	1150	1670	Full	6.0	820	1145	.715	3.57
	63	1240	1020	980	Full	6.0	1010	1015	.993	4.95
	63	1240	1020	980	Full	6.0	870	1015	.856	4.26
	63	1720	1230	880	Full	6.0	1035	1225	.844	4.21
	63	1720	1230	880	Full	6.0	940	1225	.766	3.81
	63	1380	1090	1730	Full	6.0	1000	1085	.920	4.58
	63	1380	1090	1730	Full	6.0	1010	1085	.930	4.63
	63	1780	1262	1870	Full	6.0	1450	1257	1.152	5.75
	63	1780	1262	1870	Full	6.0	1570	1257	1.248	6.22
	43	3300	1790	1230	Full	6.0	1560	1782	.874	4.36
	43	3300	1790	1230	Full	6.0	1730	1782	.969	4.84
	70	1645	1208	1140	Full	6.0	1000	1200	.830	4.15
	70	1645	1208	1140	Full	6.0	1220	1200	1.013	5.06
6.12	63	509	458	3140	Full	6.0	303	455	.664	3.30
	63	509	458	1610	Full	6.0	295	455	.646	3.21
	63	509	458	1060	Full	6.0	295	455	.646	3.21
	63	840	756	3140	Full	6.0	532	753	.706	3.52
	63	840	756	1610	Full	6.0	540	753	.716	3.58
	63	840	756	1060	Full	6.0	505	753	.670	3.35
	63	875	788	3140	Full	6.0	438	785	.558	2.79

Table B-1 (continued)

Ref.	Concrete Masonry Units: Percent Solid	Strength, psi, net area	f'_m, psi	Mortar: Str., psi	Bedding	Walls: h/t	Strength, psi, net f_{test}	f'_m C	K	S.F.
6.12	63	875	788	1610	Full	6.0	430	785	.547	2.74
	63	875	788	1060	Full	6.0	500	785	.637	3.17
	63	1080	940	3140	Full	6.0	605	936	.646	3.22
	63	1080	940	1610	Full	6.0	715	936	.763	3.81
	63	1080	940	1060	Full	6.0	765	936	.817	4.07
	63	1230	1015	3140	Full	6.0	1160	1010	1.146	5.70
	63	1230	1015	1610	Full	6.0	1000	1010	.988	4.92
	63	1230	1015	1060	Full	6.0	1110	1010	1.097	5.46
	63	1410	1105	3140	Full	6.0	1140	1100	1.030	5.16
	63	1410	1105	1610	Full	6.0	985	1100	.893	4.45
	63	1410	1105	1060	Full	6.0	1030	1100	.935	4.66
	63	1520	1157	3140	Full	6.0	660	1152	.572	2.85
	63	1520	1157	1610	Full	6.0	740	1152	.642	3.20
	63	1520	1157	4780	Full	6.0	830	1152	.719	3.58
	63	1860	1295	3140	Full	6.0	1476	1290	1.143	5.70
	63	1860	1295	1610	Full	6.0	1539	1290	1.192	5.94
	63	1860	1295	1060	Full	6.0	1365	1290	1.058	5.27
	63	2510	1554	3140	Full	6.0	1698	1550	1.096	5.47
	63	2510	1554	1610	Full	6.0	1365	1550	.881	4.39
	63	2510	1554	1060	Full	6.0	1325	1550	.856	4.27
	63	3030	1710	3140	Full	6.0	2222	1705	1.304	6.50
	63	3030	1710	1610	Full	6.0	2222	1705	1.304	6.50
	63	3030	1710	1060	Full	6.0	1984	1705	1.164	5.80
	63	3740	1923	3140	Full	6.0	1857	1918	.969	4.82
	63	3740	1923	1610	Full	6.0	2523	1918	1.316	6.56
	63	3740	1923	4780	Full	6.0	2317	1918	1.209	6.03
	63	6640	2400	3140	Full	6.0	3587	2392	1.499	7.48
	63	6640	2400	1610	Full	6.0	3856	2392	1.612	8.04
	63	6640	2400	4780	Full	6.0	5031	2392	2.102	10.49
** 6.13	100	1383	1257	2562	Full	7.0	1140	1254	.910	4.13
	100	1388	1640	3017	Full	7.0	1358	1635	.830	4.57
	100	1892	1853	2317	Full	7.0	1469	1846	.795	4.52
	100	1923	1630	2153	Full	7.0	1394	1625	.858	4.29
	100	2508	2390	2427	Full	7.0	1947	2380	.817	4.56
	100	2529	2630	2347	Full	7.0	2151	2620	.820	4.68
	100	2545	2130	2143	Full	7.0	1930	2120	.909	4.17
	100	2610	2220	3195	Full	7.0	2078	2210	.939	4.71
	100	2678	2030	2322	Full	7.0	1832	2020	.905	3.99
	100	4474	2210	2792	Full	7.0	1810	2200	.821	4.10
	100	4474	2540	2154	Full	7.0	2157	2530	.937	4.09

** f'_m values from this reference were determined from prism tests instead of assumed values. Test results multiplied by factor of 1.2.

Table B-1 (continued)

Ref.	Concrete Masonry Units: Percent Solid	Strength, psi, net area	f'_m, psi	Mortar: Str., psi	Bedding	Walls: h/t	Strength, psi, net f_{test}	f'_m C.	K	S.F.
6.10	62	2547	1556	1400	FS	9.0	1241	1540	.807	4.05
	62	1886	1305	1400	FS	9.0	1153	1290	.894	4.50
	62	1999	1350	1400	FS	9.0	967	1335	.724	3.63
	62	1499	1150	1400	FS	9.0	685	1135	.603	3.02
	62	1934	1325	1400	Full	9.0	1354	1310	1.033	5.19
	62	2305	1473	1400	FS	9.0	1096	1455	.752	3.78
	62	2136	1405	1400	FS	9.0	1128	1390	.812	4.07
	62	1773	1260	1400	FS	9.0	1088	1245	.873	4.38
	62	1298	1049	1400	FS	9.0	854	1037	.823	4.14
	62	1241	1031	1400	FS	9.0	685	1010	.678	3.41
	62	1612	1196	1400	FS	9.0	991	1180	.838	4.20
	62	1805	1273	1400	FS	9.0	1088	1260	.864	4.33
	62	1491	1146	1400	FS	9.0	854	1133	.754	3.78
	62	1088	944	1400	FS	9.0	629	933	.673	3.38
	62	1918	1318	1400	FS	9.0	1072	1302	.822	4.12
	62	1169	985	1400	FS	9.0	605	975	.621	3.12
	45	2655	1598	1400	FS	9.0	989	1578	.626	3.15
	62	1088	944	1400	FS	9.0	564	933	.604	3.03
	62	1290	1045	1400	FS	9.0	701	1032	.678	3.41
	62	1999	1350	1400	FS	9.0	1104	1335	.826	4.16
	62	1862	1296	1400	Full	9.0	1378+	1280	1.075	5.44+
	62	967	870	1400	Full	9.0	758	860	.881	4.42
	62	1967	1338	1400	Full	9.0	1241	1320	.938	4.72
6.10	57	2280	1463	1400	FS	9.3	1228	1450	.849	4.27
	67	1917	1318	1400	FS	9.3	836	1302	.642	3.23
	67	1380	1090	1400	FS	9.3	724	1078	.672	3.37
	67	1902	1312	1400	FS	9.3	1223	1300	.943	4.74
	67	1246	1023	1400	FS	9.3	739	1010	.731	3.67
	57	2087	1386	1400	FS	9.3	1193	1370	.871	4.38
	57	2087	1386	830	FS	9.3	1298	1370	.948	4.76
	57	2385	1505	1400	FS	9.3	719	1485	.484	2.44
	57	2385	1505	1400	FS	9.3	789	1485	.530	2.67
	57	2385	1505	1400	FS	9.3	1105	1485	.743	3.74
	57	2385	1505	1400	FS	9.3	1140	1485	.766	3.85
6.8	39	1590	1187	1130	Full	9.5	885	1170	.756	3.79
	39	1590	1187	1010	Full	9.5	1000	1170	.853	4.28
	39	1718	1238	1070	Full	9.5	949	1220	.777	3.89
	39	1718	1238	840	Full	9.5	910	1220	.745	3.73

Table B-1 (continued)

	Concrete Masonry Units			Mortar		Walls				
Ref.	Percent Solid	Strength, psi, net area	f'_m, psi	Str., psi	Bedding	h/t	Strength, psi, net f_{test}	f'_m C	K	S.F.
6.8	63	1159	985	1180	Full	14.3	683	940	.726	3.62
	63	1159	985	1440	Full	14.3	690	940	.734	3.66
	63	1159	985	1440	Full	14.3	738	940	.784	3.91
	63	1159	985	1060	FS	14.3	532	940	.565	2.82
	63	1159	985	900	FS	14.3	563	940	.599	2.98
	63	1159	985	1920	FS	14.3	563	940	.599	2.98
	63	1206	1020	1230	Full	14.3	738	974	.758	3.80
	63	1206	1020	730	Full	14.3	683	974	.702	3.51
	63	1206	1020	1130	Full	14.3	746	974	.765	3.83
	63	1206	1020	960	FS	14.3	571	974	.586	2.94
	63	1206	1020	780	FS	14.3	603	974	.619	3.10
	63	1206	1020	1250	FS	14.3	595	974	.610	3.05
	63	1317	1080	880	Full	14.3	905	1030	.877	4.38
	63	1317	1080	750	Full	14.3	1063	1030	1.030	5.14
	63	1317	1080	810	Full	14.3	929	1030	.901	4.49
	63	1317	1080	1020	FS	14.3	714	1030	.692	3.45
	63	1317	1080	1020	FS	14.3	667	1030	.647	3.23
	63	1159	985	1120	Full	14.3	579	940	.616	3.07
	63	1159	985	1150	Full	14.3	635	940	.675	3.37
	63	1159	985	1080	Full	14.3	635	940	.675	3.37
	63	1810	1274	1270	Full	14.3	873	1218	.717	3.54
	63	1810	1274	940	Full	14.3	881	1218	.725	3.58
	63	1810	1274	1120	Full	14.3	817	1218	.671	3.32
	63	1508	1153	1380	Full	14.3	706	1100	.641	3.17
	63	1508	1153	1380	Full	14.3	746	1100	.677	3.34
	63	1508	1153	1670	Full	14.3	643	1100	.584	2.88
	63	1238	1025	1920	Full	14.3	833	978	.851	4.24
	63	1238	1025	980	Full	14.3	802	978	.819	4.09
	63	1238	1025	1280	Full	14.3	817	978	.835	4.16
	63	1714	1230	800	Full	14.3	1111	1172	.946	4.73
	63	1714	1230	800	Full	14.3	1127	1172	.959	4.79
	63	1714	1230	750	Full	14.3	1079	1172	.918	4.59
	63	1381	1090	1730	Full	14.3	968	1040	.930	4.64
	63	1381	1090	2200	Full	14.3	960	1040	.923	4.61
	63	1774	1245	2100	Full	14.3	1240	1190	1.043	5.21
	63	2253	1450	1230	Full	14.3	936	1385	.675	3.42
	63	2253	1450	1270	Full	14.3	920	1385	.664	3.37
	70	1643	1206	1180	Full	14.3	807	1150	.701	3.55
	70	1643	1206	1300	Full	14.3	986	1150	.857	4.33
	55	1273	1040	1220	Full	14.3	727	993	.732	3.66
	55	1273	1040	1220	Full	14.3	764	993	.770	3.84
6.11	100	2900	1665	1475	Full	15.0	1250	1565	.801	3.93
6.10	65	1746	1250	1400	Full	18.0	1108	1135	.975	4.87
	65	1246	1015	1400	Full	18.0	785	925	.850	4.25
	65	1562	1175	1400	Full	18.0	1203	1065	1.131	5.66

TABLE B-2

FLEXURAL STRENGTH--SINGLE WYTHE WALLS OF HOLLOW UNITS--
UNIFORM LOAD--VERTICAL SPAN

Mortar Type Proportion ASTM C 270	Modulus of Rupture psi, Net Area	Reference
M	110	6.7
M	108	NCMA
M	102	6.7
M	97	6.7
M	95	NCMA
S	94	NCMA
M	91	NCMA
M	89	NCMA
N	88	6.9
S	84	6.7
S	83	NCMA
S	81	6.7
S	75	NCMA
S	69	NCMA
N	67	6.9
N	62	6.9
S	60	6.7
N	58	6.9
N	45	6.9
O	60	6.7
O	41	6.9
O	36	6.9
O	36	6.9
O	33	6.9
O	32	6.9
O	30	6.7
O	27	6.9

TABLE 5-3

FLEXURAL STRENGTH, VERTICAL SPAN CONCRETE MASONRY WALLS
FROM TESTS AT NCMA LABORATORY

ASTM Mortar Type*	Wall				
	Nominal Thickness in.	Max. Uniform Load psf.	Net Section Modulus in 3/ft	Modulus of Rupture	
				Gross Area, psi	Net Mortar Bedded Area, psi
Monowythe Walls of Hollow Units					
M	8	85.15	80.97	61.74	88.73
M	8	87.10	80.97	63.15	90.76
M	8	91.00	80.97	65.97	94.82
M	8	103.35	80.97	74.93	107.69
S	8	62.40	80.97	45.24	69.47
S	8	72.15	80.97	52.31	75.18
S	12	183.3	164.64	57.11	93.94
S	12	161.2	164.64	50.22	82.62
Composite Walls of Concrete Brick & Hollow CMU					
S	8	222.3	103.82	161.16	180.67
S	8	219.7	103.82	159.29	178.55
S	8	187.2	78.16	135.72	202.09
S	8	228.8	103.82	165.88	185.95
S	8	218.4	78.16	158.34	235.77
S	8	223.6	78.16	162.11	241.38
S	12	171.6	139.83	53.46	103.55
S	12	150.8	139.83	46.98	91.00
S	12	156.0	139.83	48.60	94.14
S	12	213.2	139.83	66.42	128.66
Cavity Walls					
S	10	98.8	50.36	158.62	165.55
S	10	156.0	50.36	250.44	261.38
S	10	88.4	48.16	141.91	154.88
S	10	119.6	50.36	192.01	200.40
S	10	114.4	50.36	183.66	191.68
S	10	109.2	48.16	175.30	191.32
S	12(4-4-4)	145.6	50.36	233.73	243.94
S	12(4-4-4)	145.6	50.36	233.73	243.94
S	12(6-2-4)	135.2	77.80	127.38	146.63
S	12(6-2-4)	119.6	77.80	112.68	129.70

* Mortar type by proportion requirements

TABLE B-4

FLEXURAL STRENGTH, HORIZONTAL SPAN, NONREINFORCED CONCRETE MASONRY WALLS

Construction	Mortar Type	Loading Type	Loading psf	Modulus of Rupture Net Area; psi	S.F. Act./Allow	Ref.
Monowythe 8"	N	Uniform	127	132	4.13	6.9
Hollow, 3-Core	N	"	136	141	4.41	6.9
	N	"	127	132	4.13	6.9
	N	"	169	176	5.50	6.9
	N	"	173	180	5.63	6.9
	O	"	123	128	4.00	6.9
	O	"	158	164	5.13	6.9
Monowythe 8"	N	"	149	155	4.84	6.9
Hollow, Joint	N	"	160	166	5.19	6.9
Reinf. @ 16 in.cc	N	"	193	201	6.28	6.9
	O	"	150	156	4.88	6.9
	O	"	186	193	6.03	6.9
Monowythe 8"	N	"	203	211	6.59	6.9
Hollow Joint	N	"	196	204	6.38	6.9
Reinf. @ 8 in.cc	O	"	202	210	6.56	6.9
	O	"	195	203	6.34	6.9
Monowythe 8"	N	1/4 pt	56	58	1.81	6.6
Hollow	N	"	38	39	1.22	6.6
	N	"	61	63	1.97	6.6
	N	"	60	62	1.94	6.6
	N	"	69	71	2.22	6.6
	N	"	93	96	3.00	6.6
8" Monowythe	M	Center	199	217	4.72	6.15
Hollow, 2-Core	M	"	176	192	4.17	6.15
	M	"	151	165	3.59	6.15
4-2-4 Cavity	M	"	111	210	4.57	6.15
Wall, Hollow	M	"	135	255	5.54	6.15
Units	M	"	95	180	3.91	6.15
8" Monowythe	M	"	159	173	3.76	6.15
Hollow 2-Core	M	"	159	173	3.76	6.15
Joint Re. @ 8"oc	M	"	191	208	4.52	6.15
4-2-4 Cavity of	M	"	159	300	6.52	6.15
Hollow Units Tied	M	"	159	300	6.52	6.15
w/Joint Re. @ 8"oc	M	"	159	300	6.52	6.15

Table B-4 (continued)

Construction	Mortar Type	Loading Type	Loading psf	Modulus of Rupture Net Area;psi	S.F. Act/Allow	Ref
4" Hollow Monowythe	N	Center	138	365	11.41	6.14
	N	"	157	415	12.97	6.14
	N	"	101	268	8.38	6.14
8" Hollow Monowythe	M	"	268	202	4.39	6.14
	M	"	314	237	5.15	6.14
	M	"	314	237	5.15	6.14
8" Hollow Monowythe	N	"	277	210	6.56	6.14
	N	"	314	237	7.41	6.14
	N	"	314	237	7.41	6.14
8" Hollow Monowythe	O	"	259	195	6.09	6.14
	O	"	277	210	6.56	6.14
	O	"	277	210	6.56	6.14
8" Hollow Monowythe	M	"	268	202	4.39	6.14
	M	"	297	224	4.87	6.14
	M	"	277	210	4.56	6.14
8" Hollow Monowythe	N	"	277	210	6.56	6.14
	N	"	259	195	6.09	6.14
	N	"	297	224	7.00	6.14
8" Hollow Monowythe	O	"	360	271	8.45	6.14
	O	"	297	224	7.00	6.14
	O	"	268	202	6.31	6.14
12" Hollow Monowythe	N	"	352	142	4.44	6.14
	N	"	314	127	3.97	6.14
	N	"	333	134	4.19	6.14

[illegible]
[illegible]