NON-PROPRIETARY VERSION OF

TECHNICAL EVALUATION REPORT

TER-C5506-648

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FRANKLIN RESEARCH CENTER

DIVISION OF ARVIN/CALSPAN

MASONRY WALL DESIGN

PACIFIC GAS AND ELECTRIC COMPANY
DIABLO CANYON UNITS 1 AND 2

TER-C5506-648

TECHNICAL REPORT

20TH & RACE STREETS PHILADELPHIA, PA 19103 TWX 710-670-1889 TEL. (215) 448-1000

TECHNICAL EVALUATION REPORT

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MASONRY WALL DESIGN

PACIFIC GAS AND ELECTRIC COMPANY
DIABLO CANYON UNITS 1 AND 2

TER-C5506-648

Prepared for

Nuclear Regulatory Commission
Washington, D.C. 20555

FRC Group Leader: V. Con
NRC Lead Engineer: N. Chokshi

July 24, 1986

Prepared by:	Reviewed by:	Approved by:
Vu Ngoc Con	Stephen Trifo for A. Okaily	R P Carfagno
Principal Author		Department Director
Date: 7-24-86	Date: 7/24/86	Date: 7-24-86

FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN/CALSPAN
20th & RACE STREETS, PHILADELPHIA PA 19103

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FOREWORD

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

1. INTRODUCTION

In an effort to respond to the IE Bulletin 80-11 and as a part of the license conditions, Pacific Gas and Electric Company (PG&E) submitted its seismic evaluation of the reinforced masonry walls to the U.S. Nuclear Regulatory Commission (NRC) for review and evaluation. Bechtel Power Corporation (BPC), San Francisco was the Architect/Engineer and consultants for PG&E. Franklin Research Center (FRC) was retained by the NRC to review and assess the Licensee's submittals. Dr. A. H. Hamid of Drexel University was retained by FRC to evaluate the energy balance technique (EBT) used in qualifying masonry walls in the plant.

This report represents FRC's evaluation and assessments based on review of the Licensee's submittals, other published literature, and test data relating to this subject. The report also reflects the results of two meetings with PG&E regarding safety issues of masonry walls in the plant.

The main body of the report consists of the following sections.

- Plant-specific background
- Evaluation criteria
- Licensee criteria
- Energy balance technique
- Correlation study
- Applicability of energy balance technique to the Diablo Canyon masonry walls

The following appendices are also included with the report:

APPENDIX A - Evaluation of the Licensee's Responses to Action Items Resulting from the October 1984 Meeting

APPENDIX B - Evaluation of the Licensee's Responses to Action Items Resulting from the November 1985 Meeting

APPENDIX C - "Evaluation of the Applicability of the Energy Balance Technique to Masonry Walls at Diablo Canyon Power Plant," Technical Report Prepared by Dr. A. Hamid

APPENDIX D - Samples of Wall Modifications

PG&E relied on the results of a test program conducted by Southern California Edison Company for San Onofre Nuclear Generating Station Unit 1 (SONGS-1) to validate the energy balance technique. Results of the test program are considered proprietary information. As such, Sections 6 through 9 and Appendices A, B, and C of this report are proprietary information.

2. PLANT-SPECIFIC BACKGROUND

Facility Operating Licenses DPR-80 and DPR-82 for Diablo Canyon Units 1 and 2 have a license condition regarding the structural integrity of masonry walls, which requires satisfactory resolution prior to start-up following the first refueling outage. In the evaluation of masonry walls at Diablo Canyon Units 1 and 2, PG&E employed the so-called energy balance technique (EBT). This technique was used when seismic loads caused flexural stresses in excess of working stress allowables specified by the NRC criteria [1].

This technique was presented in a submittal dated September 26, 1984 [2] and also discussed in an audit meeting in October 1984. In this meeting, PG&E presented some preliminary results of a correlation study in which results generated by the EBT were compared with those obtained from a test program conducted by Southern California Edison Company for SONGS-1. As a result of the audit meeting, PG&E was requested to provide additional information to substantiate the adequacy of the EBT, including three specific items to be investigated. It is worth noting that the NRC staff and its consultants have conducted an exhaustive review of this subject based on submittals provided by the Licensee and 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 could explain why the applicability of the EBT to masonry walls in nuclear power plants is questionable [3]. In a subsequent meeting on January 20, 1983, consultants of utility companies presented their rebuttals [4] and requested that they be treated on a plant-by-plant basis.

In accordance with the above request, NRC staff and its consultants visited several nuclear power plants to examine the field conditions of masonry walls in the plants and to gain first-hand knowledge of how the EBT is applied to actual walls.

Subsequent to the October 1984 meeting, PG&E engaged in a investigation using the results of masonry wall panel tests conducted for SONGS-1 to correlate with those obtained by the EBT. Another meeting was held with the

NRC staff and its consultants in November 1985 to discuss the results of this correlation study. Although the NRC staff found the PG&E approach to be promising, PG&E was requested to provide additional information on ten items. Evaluation of these items is provided in Appendix B of this report.

A final report documenting the correlation study was submitted in March 1986 [5]. This report also contains responses to action items resulting from the October 1984 and November 1985 meetings.

The function of safety-related masonry walls at the Diablo Canyon plant is to act as non-bearing partitions or fire walls; they are not relied upon to resist tornado, missile, or building seismic loads. Safety-related systems attached to masonry walls are generally electric raceways, instrumentation, and fire protection piping.

All walls at the plant are single wythe, either 8 or 12 inches thick and are reinforced in both directions. All cells are fully grouted. Horizontally reinforced bond beams are generally used.

Construction materials are as follows:

- Vertical Reinforcing:
  - #4 at 16-inch spacing for 8-inch wall
  - #5 at 16-inch spacing for 12-inch wall
- Horizontal Reinforcing:
  - Two #4 at 32-inch spacing for 8-inch wall
  - Two #5 at 32-inch spacing for 12-inch wall
- Masonry Units
  - Open-ended units conforming to ASTM C-90, Grade A. The average compressive strength of tested blocks is 3830 psi on net cross-sectional area.
- Grout
  - The grout has a minimum specified compressive strength of 2000 psi. The average tested compressive strength is 3285 psi.
- Mortar
  - Mortar type S conforms to ASTM-C270.

Where required, horizontal restraint is provided at the top and/or sides of the walls. At the base of the walls, restraint is provided by cast-in rebar dowels or rebar dowels threaded into expansion anchors. Compressible joint filler is provided at the top and side of the walls where they abut reinforced concrete or structural steel.

A number of walls required modifications so that they could satisfy the working stress method or the EBT. The modifications consist of steel angles at the edges and/or vertical or horizontal steel stiffeners. Typical modifications are provided in Reference 4 and reproduced in Appendix D of this report.

3. 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 [1], the Uniform Building Code [6], and ACI 531-79 [7].

The materials, testing, analysis, design, construction, and inspection of safety-related concrete masonry structures should conform to the SGEB criteria. For operating plants, the loads and load combinations for qualifying the masonry walls should conform to the appropriate specifications in the Final Safety Analysis Report (FSAR) for the plant. Allowable stresses are specified in Reference 7, and the appropriate increase factors for abnormal and extreme environmental loads are given in the SGEB criteria.

4. LICENSEE'S CRITERIA

The Licensee evaluated the masonry walls using the following criteria:

- Design allowables are based on ACI 531-79 and the UBC 1979 Edition for inspected masonry.
- Damping values are as follows:
  - 5% for uncracked section
  - 7% for cracked reinforced section.
- Both one-way action and two-way action are used in the analysis.
- Interstory drift effects are derived from the dynamic analysis of the building wherein the walls are located.
- Cracking moment was based on the transformed area of masonry and cell grout. Masonry and mortar in tension were neglected.
- Block pullouts were considered in the analysis.
- Both the working stress design method and the EBT were employed in the evaluation.
- The criteria of the EBT are as follows:
  - If the predicted displacement exceeds three times the yield displacement, a factor of 2 is multiplied to the predicted displacement and a check is conducted to determine if the displacement may adversely affect the intended function of safety-related items.
  - The midspan deflection is limited to five times the yield displacement.
  - The masonry compressive stresses are limited to 0.85 f'm based on a rectangular stress distribution.
- The analytical approach is outlined in the following steps:
  - The wall is evaluated for the applicable load combinations using the working stress design method.
  - Calculated stresses are compared against those specified in ACI 531-79.
  - If calculated stresses exceed the allowable stresses, the energy balance technique is used to qualify the wall.

5. ENERGY BALANCE TECHNIQUE

The EBT was used to predict the inelastic responses of reinforced walls which are well anchored and supported such that the brittle mode of failure is precluded. The method seeks to approximate the out-of-plane inelastic response of a single-wythe reinforced masonry wall. This technique assumes an elasto-plastic behavior system in which the maximum energy attained beyond the elastic range is equal to the maximum elastic energy attained (as if the system was perfectly elastic).

The EBT has been successfully applied to reinforced concrete that possesses elasto-plastic load-deflection characteristics.

The analytical procedures follow the key steps outlined below:

- Determine the load-deflection relationship of the wall.
- Calculate the maximum out-of-plane inelastic displacement ductility of the wall.
- Convert the maximum displacement ductility of the wall to the maximum inelastic strain ductility of the reinforcing bars.
- Check the compressive stress of the wall.

6. CORRELATION STUDY

In an effort to validate the EBT and to determine its applicability to the Diablo Canyon walls, PG&E used the results obtained from a test program conducted by Southern California Edison Company for SONGS-1 to correlate with predicted responses obtained by the EBT.

6.1 SONGS-1 TEST PANELS

To better understand the correlation study carried out by PG&E, the SONGS-1 test panels are briefly described. Three types of panels were selected for the test program and they represented walls located in various buildings:

<u>Wall Type 1</u>

- o Three specimens were tested: 1A, 1B, and 1C
- o Test panel was 24 ft high
- o No. 7 rebars at 32-in intervals
- o Horizontal rebar #5 at 48-in intervals

<u>Wall Type 2</u>

- o One specimen was tested: 2A
- o Test panel was 16 ft, 8 in high
- o Vertical rebar #4 at 32-in invertals
- o Horizontal rebar #5 at 48-in intervals

<u>Wall Type 3</u>

- o Two specimens were tested: 3A and 3B
- o Test panel was 21 ft, 4 in high
- o Vertical rebar #5 at 32-in intervals
- o Horizontal rebar #5 at 48-in intervals.

The correlation study considered five test panels: 1A, 1B, 1C, 2A, and 3B. It is noted that test panel 3A was unsuccessful because of an actuator malfunction during the test and therefore was not included in the PG&E study.

Further information regarding the SONGS-1 test program is provided in Reference 8.

6.2 COMPARISON OF RESULTS

Results of the five test panels were compared with those obtained based on the EBT. Material properties used in the analysis were based on the measured actual material properties of the test program. The accelerations were based on the average of the top and bottom test input accelerations. As shown in Table 6-1, the following parameters are being compared:

- maximum displacement
- maximum rebar strain ductility.

Table 6-1 shows the analytical prediction for both pin-pin and pin-fixed conditions.

6.3 EVALUATION OF THE CORRELATION STUDY

As discussed above, the test results are in close agreement with the predicted displacements, and the EBT resulted in a conservative estimate for the predicted rebar ductibilities.

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Table 6-1.

SUMMARY OF COMPARISON OF ANALYTICAL RESULTS[a]
WITH TEST RESULTS USING THE INITIAL CRACKING MOMENT CAPACITY
BASED ON TRANSFORMED UNCRACKED SECTION WITH TENSION SIDE OF THE BLOCK EXCLUDED

			Maximum Deflection Δ_{max}(in.)			Rebar Ductility, $\mu = \varepsilon/\varepsilon_y$		
			Measured From Panel Test (d)	Calculated by E. B.		Determined From Test Results (d)(e)	Estimated from E. B. Results	
Panel Type	Vertical Span/ Rebar	Test Panel		Pin-pin (b)	Pin-fixed (c)		Pin-pin (b)	Pin-fixed (c)
1	24 ft, 0 in./ #7 @ 32 in.	1A		9.7	10.3		11.5	12.2
		1B		11.5	10.9		13.0	12.3
		1C		10.8	12.3		12.1	13.8
2	17 ft, 0 in./ #4 @ 32 in.	2A (f)		—	0.3		—	1.1
3	21 ft, 0 in./ #5 @ 32 in.	3B (g)		4.4	1.9		9.0	3.9

(a) The analytical values were based on actual measured material properties and the maximum grout tension stress at cracking is $f_r = 6\sqrt{f'_c}$ psi

(b) Assuming pin-pin condition on the top and bottom boundaries.

(c) Assuming pin condition on the top and fixed condition on the bottom boundary.

(d) See references 2, 3, and 4 for test panel types 1, 2, and 3 respectively.

(e) Rebar ductility calculated from $\mu = \varepsilon/\varepsilon_y$, where ε = measured rebar strain, and ε_y = yielded rebar strain from actual sample test.

(f)

(g)

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Regarding the cracking moment capacity based on an assumed transformed grout section on the tension side, PG&E provided the results (maximum displacements and rebar strain ductibility) using the cracking moment capacity of the gross section (including grout and block shell on the tension side) and the results show no significant difference between the two approaches. Further information on this subject is provided in Appendix A.

It is concluded that the correlation study demonstrates the adequacy of the EBT. The applicability of the EBT to the Diablo Canyon walls is discussed in the next section.

7. APPLICABILITY OF THE ENERGY BALANCE TECHNIQUE TO THE DIABLO CANYON MASONRY WALLS

The EBT has been employed to qualify the masonry walls in both Units 1 and 2 of the Diablo Canyon plant. The analytical procedures and the criteria are outlined in Sections 4 and 5.

An examination of the SONGS-1 and the Diablo Canyon walls shows that they have similarities in wall thickness (8 inches), running bond, same masonry block unit, same reinforcement pattern, same mortar type, masonry compressive strength, grout compressive strength, moment of inertia for cracked section, and cracking moment capacity. In addition, the Diablo Canyon walls have a few features that are better than those of the SONGS-1 walls: fully grouted vs partially grouted, more favorable rebar distribution (16-in vs 32-in spacing), and closer bond beam spacing.

In addition, the midspan displacement is limited to five times the yield displacment; if the predicted displacement exceeds three times the yield displacement, a factor of 2 is mulitiplied to the predicted displacement and a check is performed to determine if the displacement may adversely affect the intended function of safety-related items.

PG&E indicated that the maximum displacements are small (in the order of 1 inch) and verified that there is no adverse affect on a safety function of safety-related items.

It is judged that the Diablo Canyon walls have construction and structural characteristics similar to SONGS-1 walls and that the correlation study discussed in the previous section has demonstrated acceptable results predicted by the EBT. It is concluded that the EBT is applicable to the Diablo Canyon walls.

8. CONCLUSIONS

A detailed review was performed to provide a technical evaluation of the masonry walls at the Diablo Canyon plant. Review of the Licensee's criteria and particularly the energy balance technique led to the following conclusions:

- The Licensee's criteria have been evaluated and judged to be adequate.

- With respect to the energy balance technique, the correlation study using the SONGS-1 test data has produced satisfactory results.

- The Diablo Canyon walls and SONGS-1 walls have similar wall construction details and engineering properties. As discussed in Section 7, the Diablo Canyon walls have a few features that are better than those of SONGS-1 walls: fully grouted, more favorable rebar, and bond beam spacing. In addition, the Diablo Canyon walls are well anchored and supported such that the brittle mode of failure is precluded. The maximum calculated displacement is small, on the order of 1 inch. The energy balance technique is judged to the applicable to the Diablo Canyon walls.

- The Licensee's approach to wall modification consist of steel angles at the edges and/or vertical or horizontal steel stiffeners. The modifications have been reviewed and found acceptable.

9. REFERENCES

1. U.S. Nuclear Regulatory Commission, Standard Review Plant, Appendix A of Section 3.8.4, NUREG-0800
   July 1981

2. J. O. Schuyler (PG&E)
   Letter with Attachments to G. W. Knighton (NRC)
   Subject: Evaluation of Masonry Walls in Accordance with IE Bulletin 80-11 Criteria
   September 26, 1984

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

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

5. J. D. Shiffer (PG&E)
   Letter with Attachments to S. A. Varga (NRC)
   Subject: Masonry Walls License Conditions - Final Report
   March 27, 1986

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

7. Building Code Requirements of Concrete Masonry Structures, American Concrete Institute, 1979, ACI 531-79 and ACI 531-R-79

8. Technical Evaluation Report of Masonry Wall Design, Southern California Edison Company, San Onofre Unit 1, Franklin Research Center, TER-C5506-405
   August 20, 1985

APPENDIX A

EVALUATION OF THE LICENSEE'S RESPONSES
TO ACTION ITEMS RESULTING FROM THE
OCTOBER 1984 MEETING

During the design audits conducted in October 1984, the following concerns were raised by the NRC staff and its consultants regarding the correlation study using SONGS-1 test data to validate the energy balance technique. These concerns are:

1. The difference in the rebar yield length between the test data and the assumption used in the analysis and how this difference affects the ductility prediction.

2. Validity of the elasto-plastic behavior stipulated by the energy balance technique in light of the SONGS-1 test results.

3. Sensitivity of the energy balance technique with respect to the assumption of the initial cracking moment of walls.

PG&E provided information relating to the above concerns and they are summarized below:

1. <u>Rebar Yield Length and Ductility</u>

The Licensee assumed the yield length of the rebar
As shown in Table 6-1 of Section 6, this assumption resulted in calculated rebar strain ductility ratios that are about twice the measured data. If the yield length of the rebar is higher than the rebar strain ductility ratios will be closer to those obtained from the tests. Therefore, the assumption of yield length is conservative in terms of rebar strain ductility calculation.

2. <u>Inelastic Hysteretic Behavior of the Tested Walls</u>

PG&E generated a moment-curvature response hysteresis of test panel 1A for one cycle of response based on the test measurements of rebar strains and deformations (gap measurements). This loop is shown in Figure A-1.

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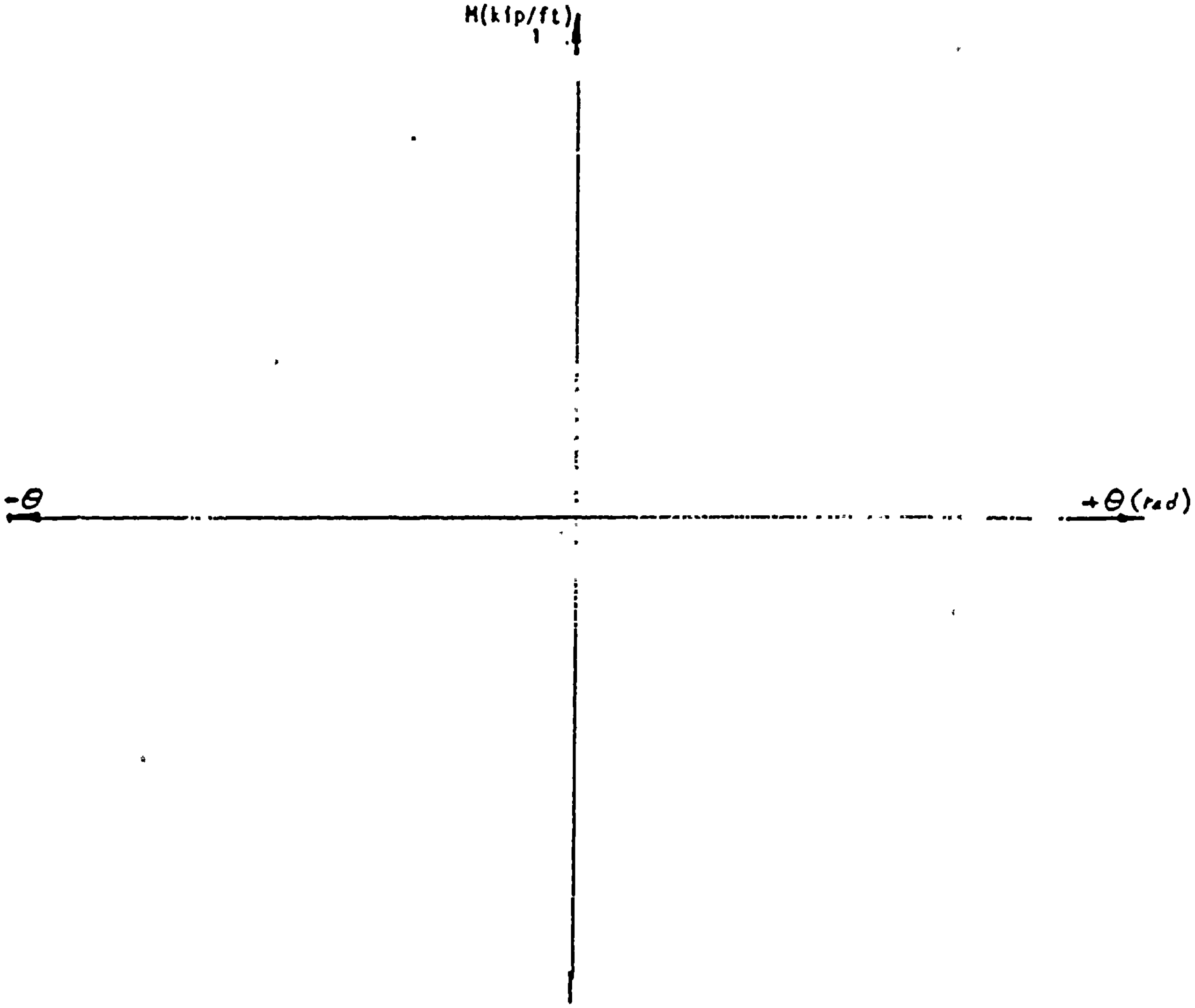

Figure A-1. Moment-Curvature Relationship for Test Panel 1A

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, the proposed method resulted in a reasonable agreement with the test results and, therefore, the Licensee's response is considered to be adequate.

3. Assumption of Initial Cracking Moment

PG&E provided predicted results (maximum displacements and rebar strain ductility) using the cracking moment capacity of the gross section (including block shell and/or mortar bed joint on the tension side). The results show that they are not significantly different from PG&E's analysis in which the cracking moment capacity on the tension side was based on the transformed grout section only.

The Licensee's response has resolved this concern satisfactorily.

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APPENDIX B

EVALUATION OF THE LICENSEE'S RESPONSES TO ACTION ITEMS RESULTING FROM THE NOVEMBER 1985 MEETING

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The evaluation presented in this Appendix is based on PG&E's response to a list of action items resulting from a meeting with the NRC staff and its consultants on November 5, 1985.

Item 1:

Provide additional data for hysteresis loops (i.e., a few more "snapshots" of hysteresis loop for the pin-pin condition).

Response 1

PG&E provided five additional hysteresis loops obtained based on panel 1A test data. Figures B-1 through B-5 show these loops, and Figure B-6 presents the superimposed plots of all loops generated. Figure B-6 indicates a stable behavior of the wall.

PG&E's response is adequate and satisfactory.

Item 2:

Discuss the correlation and conservatism in the energy balance approach in the light of differences between the assumed hysteresis loop in the analytical approach and the test data.

Response 2

PG&E referred to the discussion given in its submittal dated March 27, 1986, which has been covered in Sections 6 and 7 of this report.

Item 3:

Consider bottom hinge effects in the correlation study by calculating the maximum rebar ductility for the bottom hinge.

Response 3

The results

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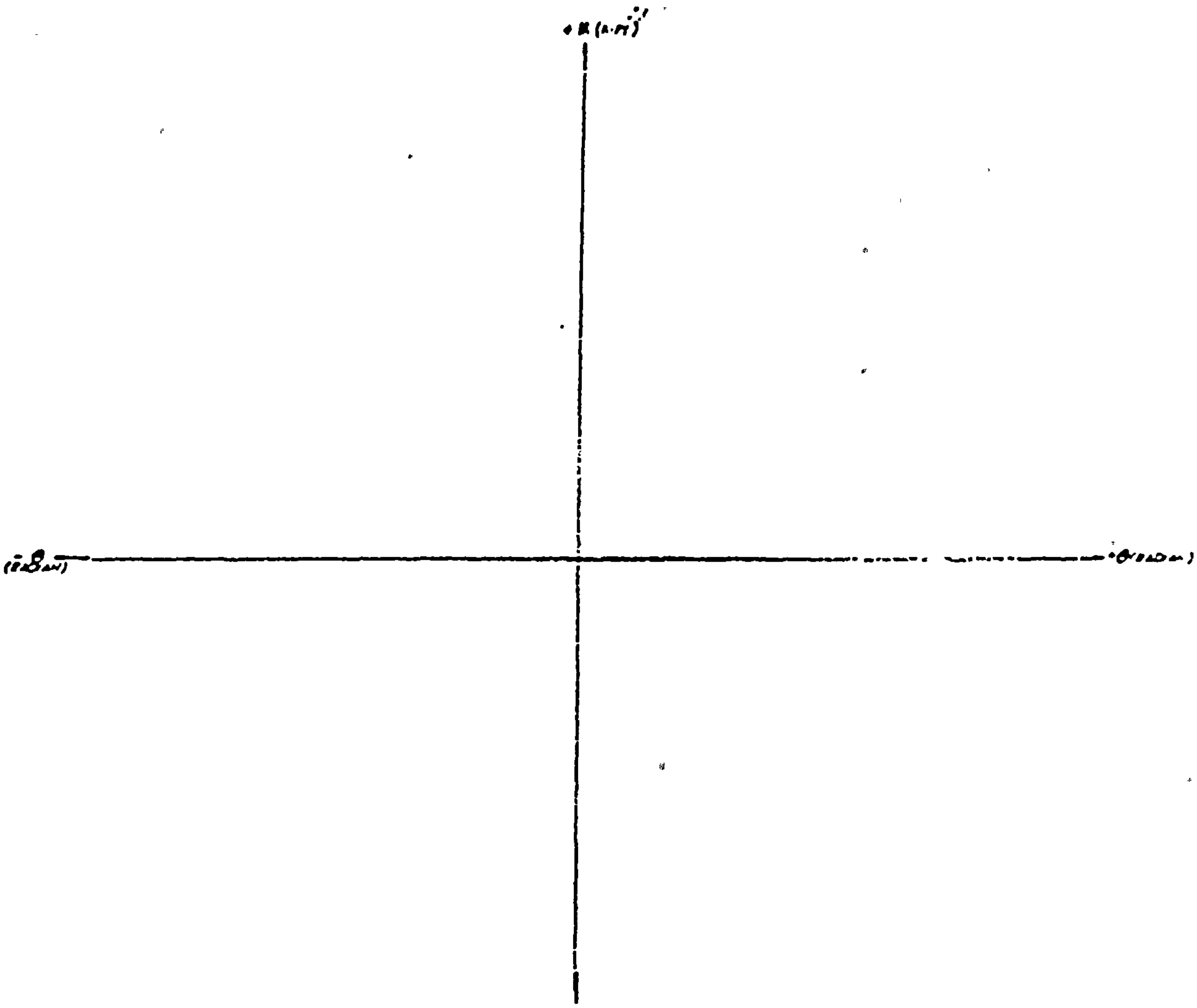

Figure B-1. Moment-Curvature Relationship (Loop No. 1)

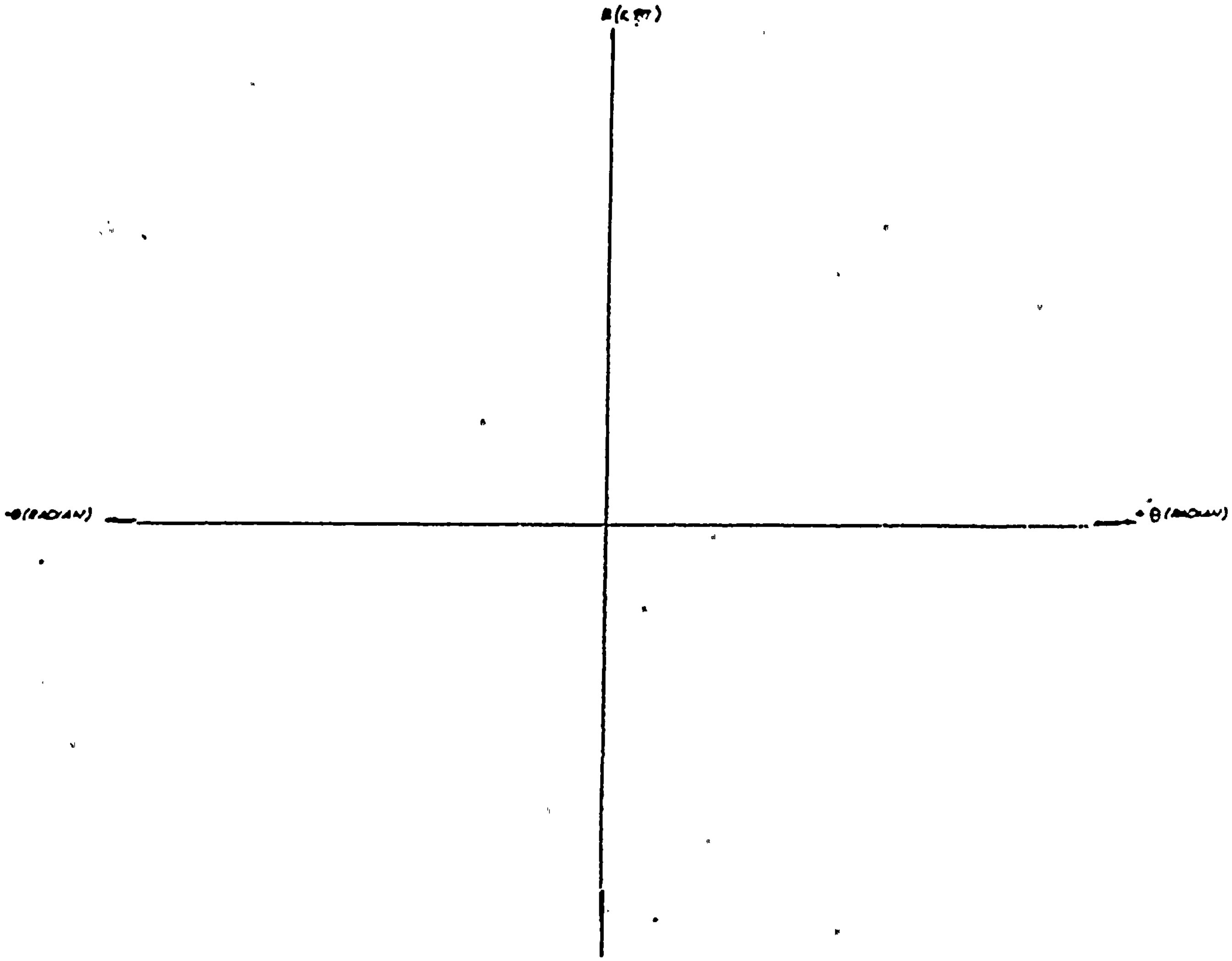

Figure B-2. Moment-Curvature Relationship (Loop No. 2)

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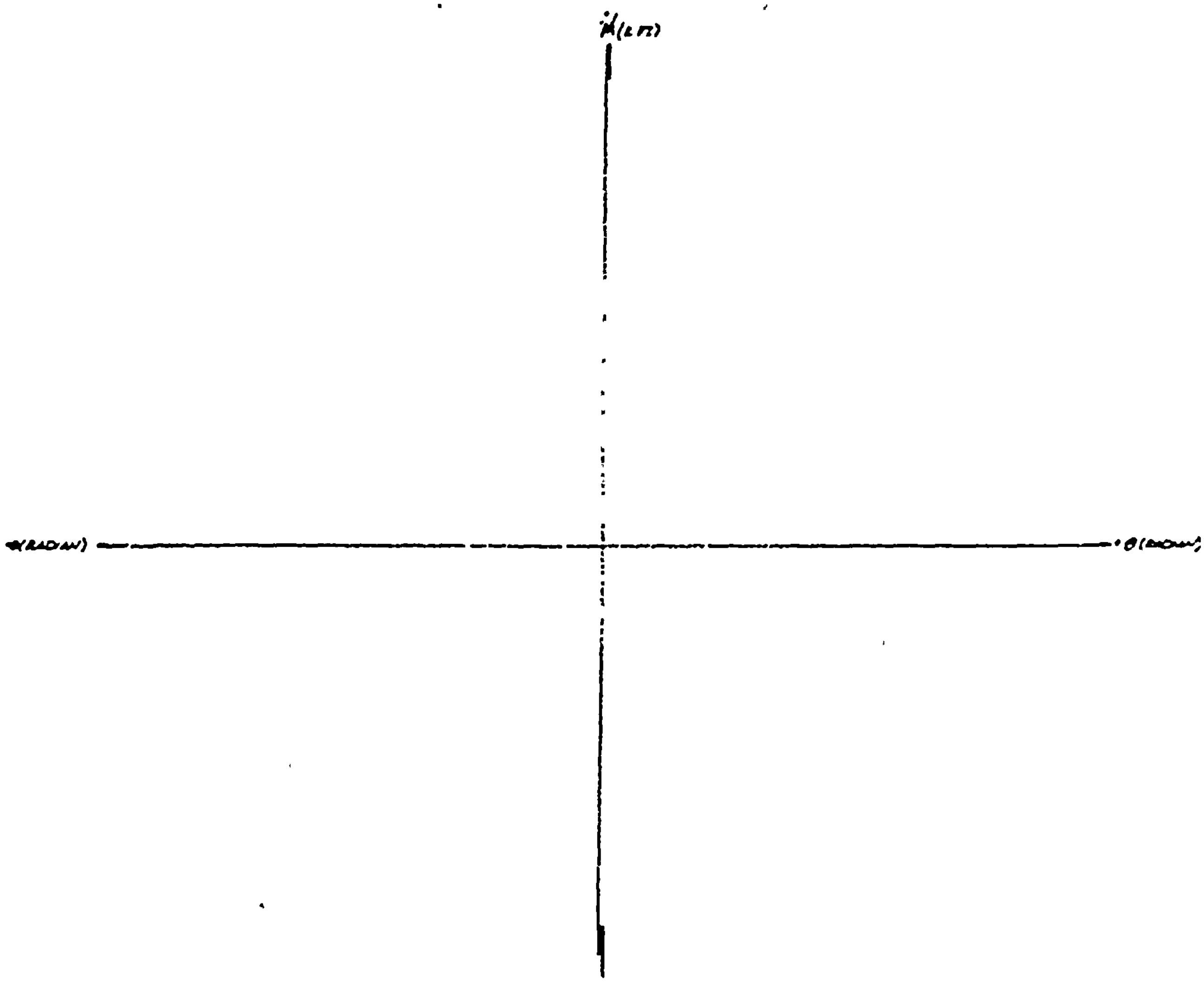

Figure B-3. Moment-Curvature Relationship (Loop No. 3)

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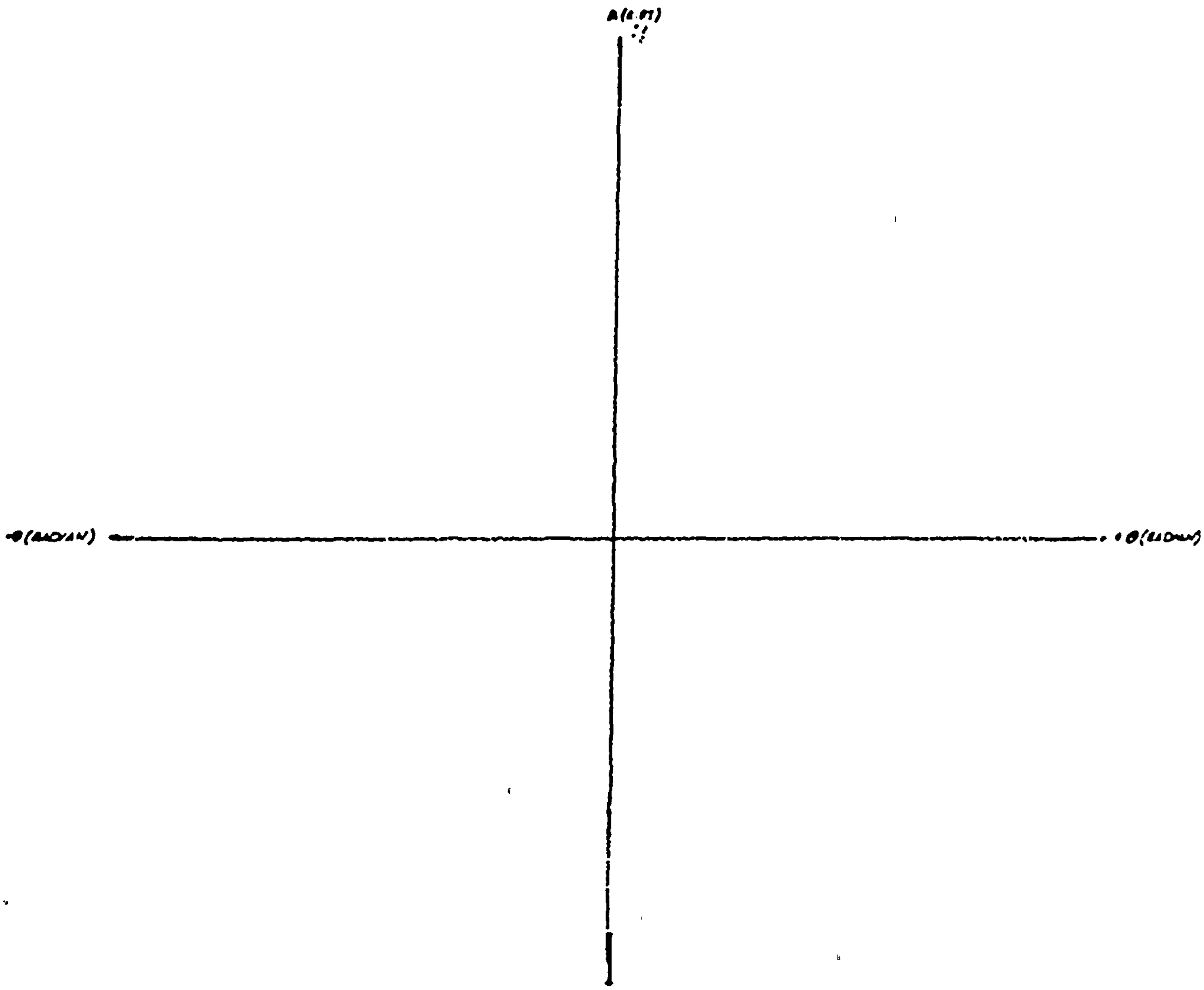

Figure B-4. Moment-Curvature Relationship (Loop No. 4)

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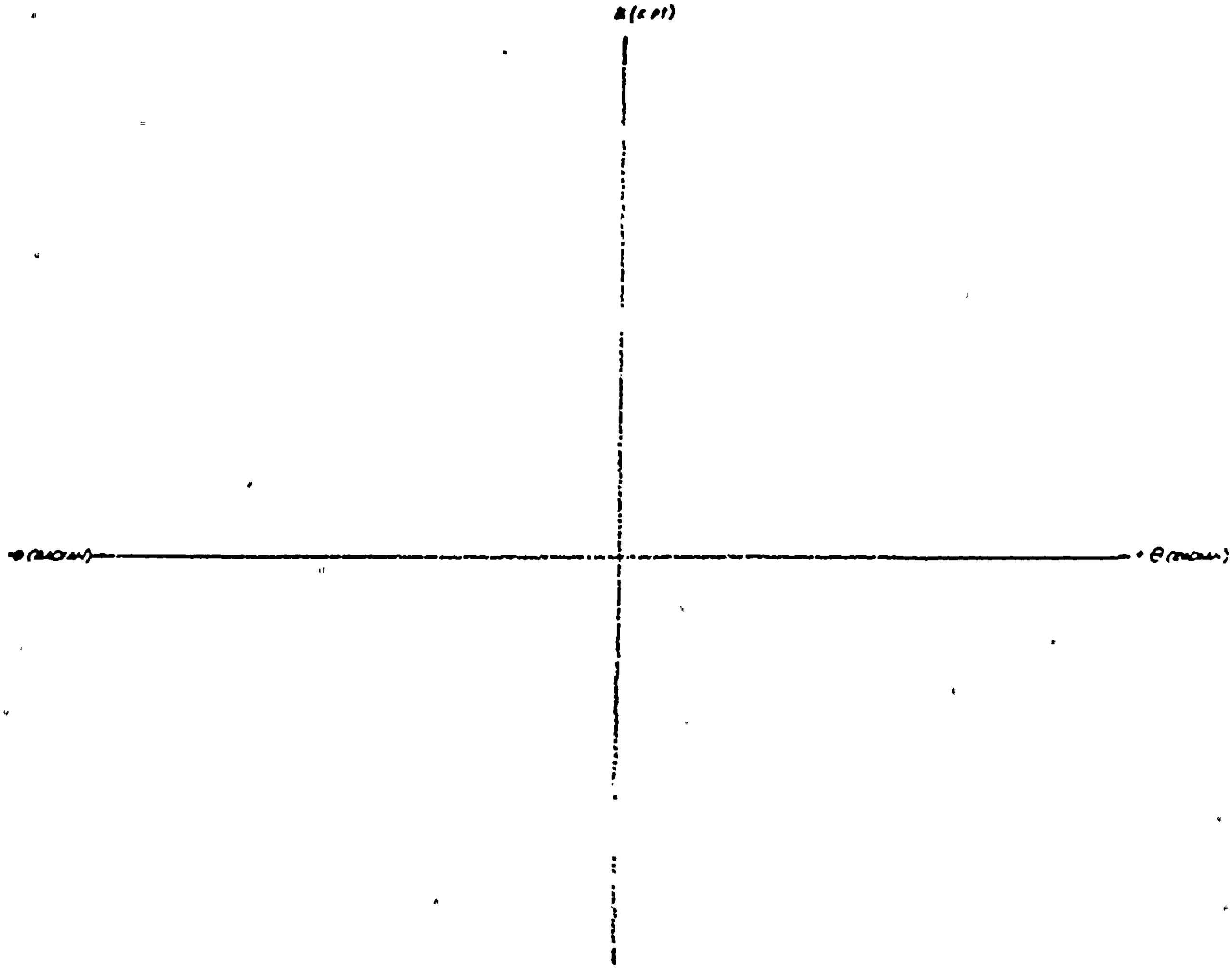

Figure B-5. Moment-Curvature Relationship (Loop No. 5)

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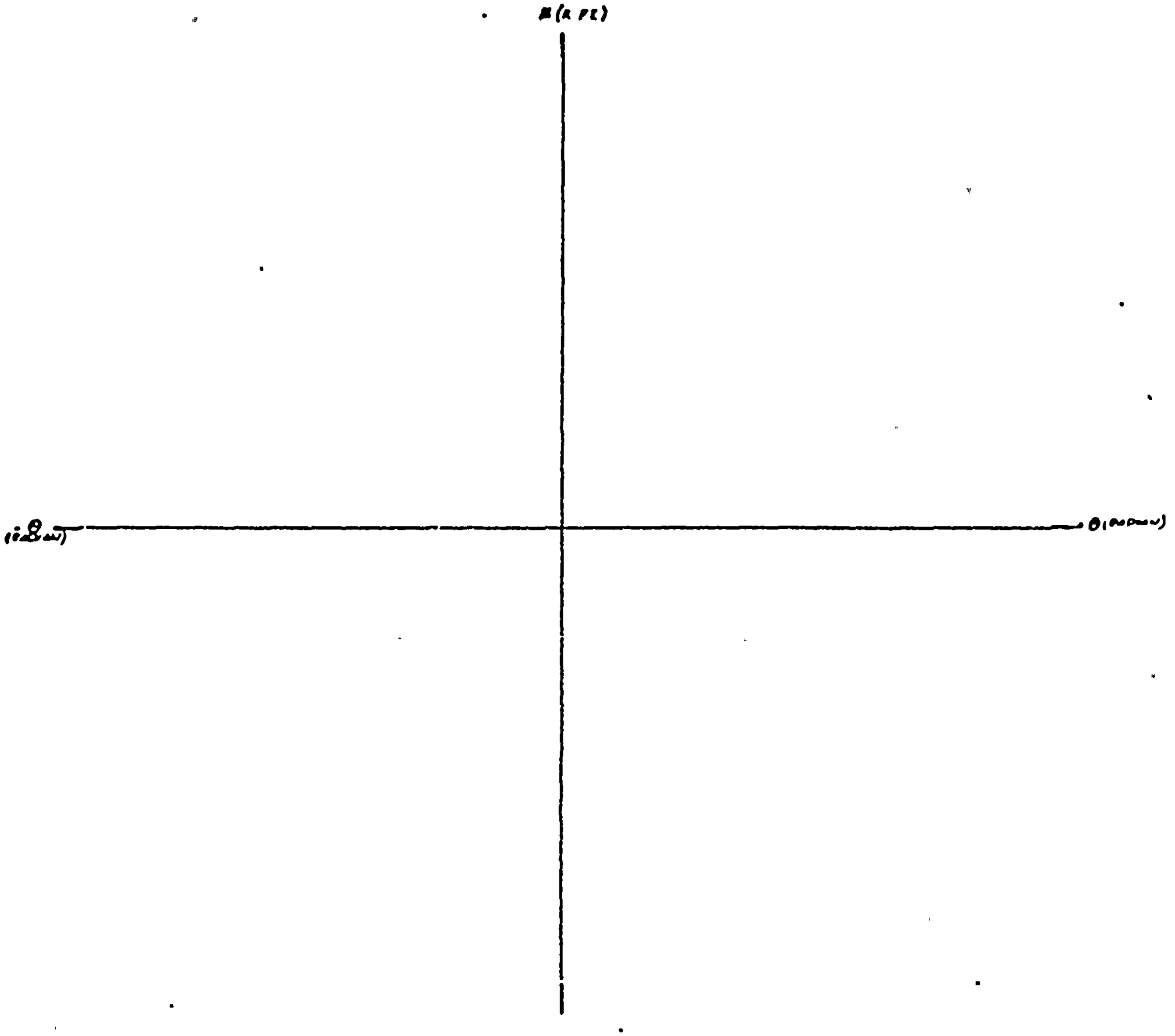

Figure B-6. Moment-Curvature Relationship (Loop No. 6)

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Table B-1

MAXIMUM REBAR DUCTILITY AT BOTTOM HINGE

Test Panel	From Panel Test Data	Calculated by Energy Balance with Assumed Plastic Hinge Length L		
		L = 4D	L = 6D	L = 8D
1-A		23.7	16.1	
1-B		24.3	16.5	12.6
1-C		26.0	17.7	13.5
3-B		7.7	5.5	4.4

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indicate a conservative estimate of the rebar ductility ratios. PG&E's response is adequate and acceptable.

Item 4:

> Provide quantitative arguments to substantiate the similarity between SONGS-1 and Diablo Canyon walls.

Response 4

In this response, PG&E provided information regarding wall construction (i.e., dimension, reinforcement, supporting boundaries), material properties, and engineering properties of both the SONGS-1 and DCPP plants. This information is shown in Table B-2. As can be seen, similarities exist between SONGS-1 and the Diablo Canyon plant. It is noted that the Diablo Canyon walls are fully grouted and have shorter vertical spans and closer bond beam spacing.

It is judged that the Diablo Canyon walls are similar to the SONGS-1 walls and, hence, the Licensee's response is acceptable.

Item 5:

> Discuss the applicability of the plate action in the energy balance technique.

Response 5

PG&E confirmed that plate action was not used in the energy balance technique.

Item 6:

> Provide clarification for five walls where $E_m = 1000\ f'_c$ was used (higher modulus based on the grout strength).

Response 6

PG&E performed a sensitivity study using the modulus of elasticity of 1000 f'm for five walls (T2-85-5, T2-85-6, T2-85-7, T2-85-8, and T2-107-1). The results show insignificant changes in the displacement ductilities of the walls compared with those based on the value of 1000 f'_c (f'_c is the grout strength); hence, this concern has been resolved.

Table B-2.

COMPARISON OF SONGS-1 AND DCPP MASONRY WALLS

	San Onofre Nuclear Generating Station (SONGS-1) Tests	Diablo Canyon Power Plant (DCPP)
Wall Construction		
Thickness	8 in. (nominal = 7.625 in.)	8 in. (nominal = 7.625 in.)
Single or multiple wythe	Single wythe	Single wythe
Bonding	Running bond	Running bond
Grouted cells	Partially grouted (only bond beams and vertical cells with rebars are grouted)	Fully grouted
Bond beam spacing	@ 48 in.	@ 32 in.
Span length and direction	Vertical spans of 17, 21, and 24 ft (panel types 3, 2, and 1)	Vertical spans of 11 to 17 ft
Vertical reinforcing bars	#5 @ 32 in. Panel type 3 #4 @ 32 in. Panel type 2 #7 @ 32 in. Panel type 1	#4 @ 16 in. (typical all walls)
Horizontal reinforcing bars	#5 @ 48 in. Panel types 1, 2 and 3	2 #4 @32 in. (typical all walls)
Supporting boundaries		
Top	Pin	Pin
Bottom	Fixed	Pin

Table B-2. (Cont)

COMPARISON OF SONGS-1 AND DCPP MASONRY WALLS

	San Onofre Nuclear Generating Station (SONGS-1) Test	Diablo Canyon Power Plant (DCPP)
Wall Material Properties		
Block unit weight	Light weight; conforms to ATSM C90 Grade A	Light weight; conforms to ATSM C90 Grade A
Masonry compression strength, f'_m	1,710 to 2030 psi	1,950 psi
Grout compression strength, f'_c	3,540 to 7,350 psi	3,288 psi
Mortar compression strength, M_o	Conforms with ASTM C270	Conforms with ASTM C270
Reinforcing bar yield strength, f_y	54,500 to 62,900 psi	51,400 psi
Modulus of elasticity of masonry, E_m	1.71×10^6 to 2.03×10^6 psi	1.95×10^6 psi
Modulus of elasticity of grout, E_c	3.39×10^6 to 4.89×10^6 psi	3.27×10^6 psi
Modulus of elasticity of steel, E_s	27.1×10^6 to 29×10^6 psi	29×10^6 psi
Wall Engineering Properties		
Moment of inertia for uncracked section (based on transformed masonry section)		
Including block in tension (I_t)	392 to 408 in^4/ft	502 in^4/ft
Ignoring block in tension (I'_t)	146 to 178 in^4/ft	348 in^4/ft

Table B-2. (Cont)

COMPARISON OF SONGS-1 AND DCPP MASONRY WALLS

	San Onofre Nuclear Generating Station (SONGS-1) Test	Diablo Canyon Power Plant (DCPP)
Moment of inertia for cracked section, I_{cr}	13.7 to 30.0 in^4/ft	13.0 in^4/ft
Cracking moment capacity		
For section with block in tension ignored, M_{cr}	1.16 to 2.10 kip-ft/ft	2.0 kip-ft/ft
Yield moment capacity, M_y	1.2 to 4.0 kip-ft/ft	2.2 kip-ft/ft

Item 7:

Discuss the shear transfer capacity for the walls where clip angles do not extend to the block but may extend to the drypack.

Response 7

The Licensee stated that the drypack material has a minimum specified compressive strength of 4,000 psi, whereas the masonry compressive strength is 1950 psi, which was used for the drypack evaluation. The calculated shear stress for walls with drypack was compared with the ACI-531-79 code allowables and resulted in three groups with different safety of factors as described below:

Group I - all walls with a minimum safety of factor of 3.0 except 30 walls given in Groups II and III below

Group II - 16 walls with a safety of factor between 2.0 and 3.0

Group III - 14 walls with a safety of factor between 1.4 and 2.0.

PG&E strengthened Group III walls with vertical steel beams supported by the floor slab at the top and bottom of the beam. A typical detail of drypack connection is provided in Figure B-7.

It is judged that the top connections of these walls have adequate shear transfer capacity.

Item 8:

Provide qualitative discussion on margins of the masonry walls.

Response 8

PG&E provided the following information:

- The maximum allowable displacement of the walls is limited to 5 times the yield displacement.
- If the predicted displacement exceeds 3 times the yield displacement, the resulting displacement is multiplied by a factor of 2 and adverse impact due to this displacement is investigated.

PG&E indicated that the maximum calculated displacement is on the order of 1 inch.

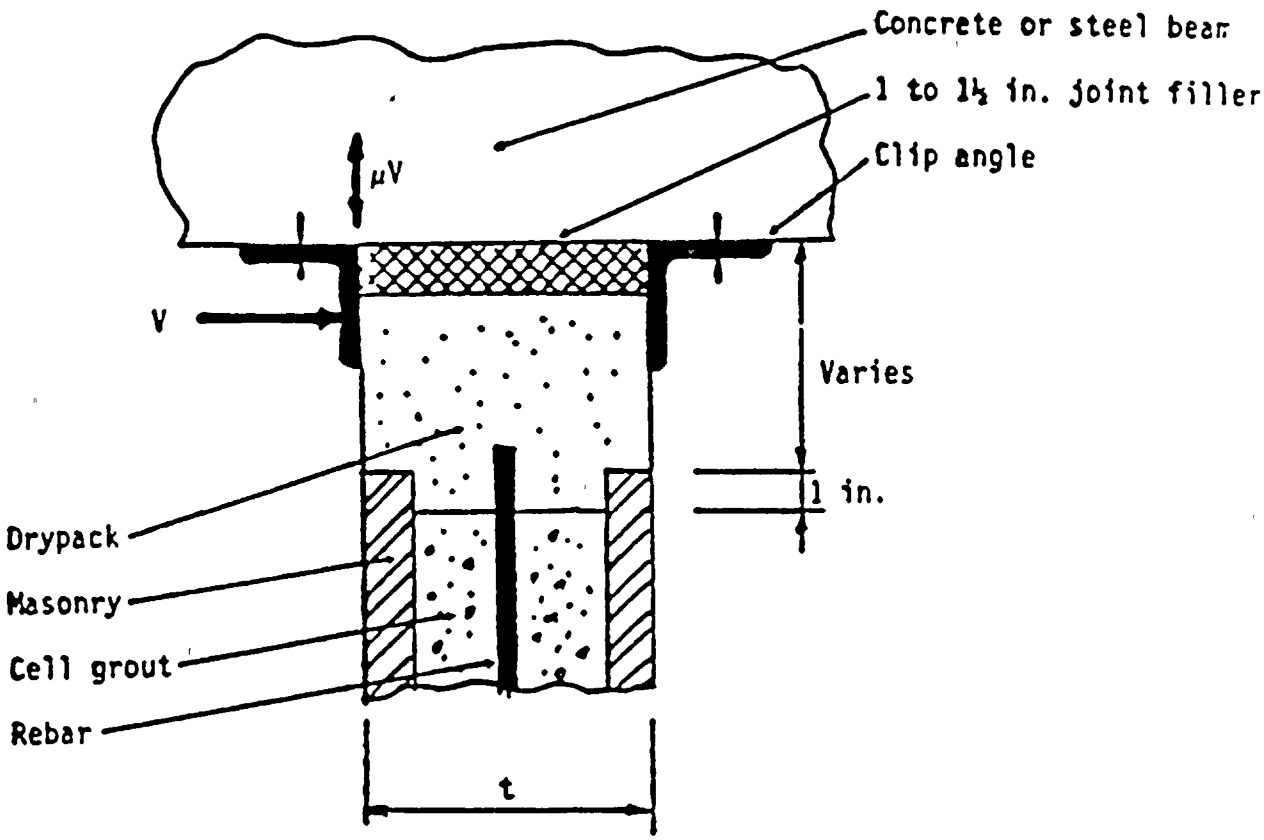

Figure B-7. Typical Details of Drypack Connection

Based on the above information, it is concluded that the Diablo Canyon walls have adequate structural margin to perform their intended functions.

Item 9:

Calculate the yield displacement from the SONGS tests and correlate against energy balance technique prediction.

Response 9

PG&E provided the yield displacements for test panels 1A, 1B, and 1C. The measured data and the predicted values using the energy balance technique are given in Table B-3.

The results show close agreement and, therefore, the Licensee's response is acceptable.

Item 10:

Provide a list of the displacement ductilities for the Diablo Canyon walls to demonstrate that they are less than 3.0.

Response 10

Displacement ductility factors for walls in Units 1 and 2 are shown in Tables B-4 and B-5, respectively.

The Licensee reiterated that the maximum displacements are small (on the order of 1 inch).

The response is considered adequate.

 Proprietary Information Deleted

Table B-3. Yield Displacement Comparison

Test Panel	Yield Displacement (in.) SONGS-1 Tests	Yield Displacement (in.) Energy Balance Technique	Comparison E.B.T/SONGS-1 Tests

 Proprietary Information Deleted

Table B-4.

DISPLACEMENT DUCTILITY FACTORS
FOR UNIT 1 MASONRY WALLS

Ductility Factor Less than 3.0

Wall Number	Maximum Displacement (in.)
A-3a	0.4
A-3b	0.4
A-4a	0.3
A-4b	0.3
A-4c	0.2
T-8b	0.1
T-8c	0.1
T-9b	0.1
T-9c	0.1
T-10a	0.1
T-10b	0.1
T-10c	0.1
T-12a	0.2
T-12b	0.2
T-12c	0.2
T-23c	0.3
T-23e	0.3
T-23d	0.2

Ductility Factor of 3.0 to 5.0

Wall Number	Maximum Displacement (in.)
A-4d	0.5
A-5a	0.3
A-5b	0.3
A-6a	0.4
A-6b	0.4
A-7a	0.5
A-7b	0.5
T-2a	0.7
T-2b	1.1
T-13a	0.4
T-13b	0.4
T-13c	0.4
T-14a	0.4
T-14c	0.4
T-14d	0.5
T-14e	0.5
T-14f	0.4
T-14g	0.4
T-14h	0.5
T-14i	0.5
T-14j	0.4
T-16a	0.6
T-17a	0.4
T-17b	0.4

Table B-5.

DISPLACEMENT DUCTILITY FACTORS
FOR UNIT 2 MASONRY WALLS

Ductility Factor Less than 3.0

Wall Number	Maximum Displacement (in.)
A2-100-1	0.2
A2-100-2	0.2
A2-100-4	0.3
A2-100-7	0.3
T2-85-17	0.2
T2-107-7	0.2
T2-119-1	0.2
T2-119-9	0.4
T2-119-26	0.1
T2-140-1	0.2
T2-140-8	0.3
T2-140-11	0.2

Ductility Factor of 3.0 to 5.0

Wall Number	Maximum Displacement (in.)
A2-100-3	0.5
A2-100-5	0.5
A2-100-6	0.5
A2-115-1	0.4
A2-115-2	0.4
A2-115-3	0.4
T2-85-5	1.2
T2-85-6	0.9
T2-85-7	0.9
T2-107-1	0.6
T2-107-28	0.5
T2-107-29	0.4
T2-107-32	0.5
T2-107-33	0.4
T2-107-34	0.5
T2-107-39	0.5
T2-119-2	0.5
T2-119-3	0.4
T2-119-4	0.4
T2-119-6	0.4
T2-119-7	0.4
T2-119-8	0.4

APPENDIX C

"EVALUATION OF THE APPLICABILITY OF ENERGY BALANCE TECHNIQUE TO MASONRY WALLS OF DIABLO CANYON POWER PLANT"
BY A. HAMID, DREXEL UNIVERSITY

Technical Report

on

EVALUATION OF THE APPLICABILITY OF ENERGY BALANCE TECHNIQUE TO MASONRY WALLS OF DIABLO CANYON POWER PLANT

Submitted

to

Dr. Vu Con
Engineering Dept.
Franklin Research Center
Philadelphia, PA 19103

by

Dr. A. Hamid, Ph.D., P.E.
Associate Professor of Civil Engineering
Drexel University
Philadelphia, PA

June 1986

1. INTRODUCTION

PGandE used the energy balance technique as an alternative evaluation methodology for qualification of Diablo Canyon reinforced block masonry walls for out-of-plane seismic loading. The method was used when the flexural stresses in masonry and in steel rebars exceed IE Bulletin 80-11 working stress allowables.

The NRC and FRC Staff and consultants discussed the proposed methodology with PGandE Staff in a meeting held in Bechtel office in San Francisco on November 1984. The Staff requested that PGandE provide further documentations to substantiate the adequacy of the energy balance technique used to qualify masonry walls at Diablo Canyon (1).

In an attempt to confirm the adequacy of the energy balance technique, PGandE used the dynamic test results of masonry walls performed by Southern California Edison Company for San Onofre Nuclear Generating Station Unit 1. The correlation study between the results obtained from the energy balance technique and the test results were discussed in a meeting at the NRC office in Bethesda on November 1985. Additional information on certain items was requested.

It is the objective of this report to evaluate the correlation study conducted by PGandE and the applicability of the methodology to Diablo Canyon masonry walls as presented in Ref. 2.

2. CORRELATION STUDY WITH SONGS-1 DATA

2.1 Scope

Six wall tests were completed in SONGS-1 masonry wall test program; three type 1 panel, (walls 1A, 1B and 1C) one type 2 panel (wall 2A) and two type 3 panels (walls 3A and 3B). Wall 3A test was unsuccessful because of actuator malfunction. Therefore, the remaining five tests were selected for correlation study. Walls 2A and 3B did not exhibit an inelastic response during the test and therefore do not give good data for correlation study with the energy balance technique which is an inelastic analysis. Therefore, walls 1A, 1B and 1C are considered here for the evaluation of the correlation between test resuts and the results obtained from the energy balance technique. These tests had different input motions and the four walls exhibited inelastic response which provide adequate data base for the correlation study.

2.2 Comparison of Analytical and Test Results

The comparison of the SONGS-1 test results for walls 1A, 1B and 1C with the analytical results obtained from the energy balance technique is presented in Table 4.1 of Ref.2. The comparison includes maximum wall displacements and maximum rebar strain ductilities at midspan of wall panels inferred from the tests. As shown, the maximum displacement predictions are in good agreement with the test results. Rebar ductility

predictions are much higher than test values. This can be attributed to the highly nonlinear strain distribution in the rebar between bed joints and the sensitivity of test results to location of strain gages. The predictions, however, are conservative and well below the allowable.

It is interesting to notice the close agreement between analytical and test results of wall displacements despite of the fact that the energy balance technique is based on elastic-perfectly plastic response which is not the case for reinforced masonry walls (3). The peculiar pinched hysteretic behavior of reinforced masonry walls (3), which have been confirmed by PGandE analysis of SONGS-1 test results, suggests lower predicted maximum wall displacement for the same energy demand.

2.3 Conclusion

The correlation study shows that the energy balance technique was able to predict with reasonable accuracy maximum wall displacements in the inelastic range under out-of-plane loading.

3. APPLICABILITY TO DIABLO CANYON WALLS

3.1 Construction Details

The methodology has been evaluated using SONGS-1 test panels. A comparison between these panels and Diablo Canyon walls is presented in

Table 6.2 of Ref. 2. The comparison shows similarities in wall thickness, number of wythes, cracking and yielding moment capacities and reinforcement patterns. It is to be noted that Diablo Canyon walls have a few structural features that are better than those of the SONGS-1 walls, mainly ; fully grouted cells and closer bond beam spacing. Therfore, it is reasonable to conclude that Diablo Canyon walls will have the same or better energy absorption capability than SONGS-1 walls.

3.2 Material Properties

PGandE conducted a parameteric study of the effect of the EI value on wall response as requested by NRC and FRC staff and Consultants. The results show the insensitivity of the wall response to different assumptions used in the calculation of wall rigidity, EI.

3.3 Stability of Hysteresis Loops

Six hysteresis loops were developed from SONGS-1 test panel 1A. The superimposed plots of all the loops are shown in Fig. 6-6 of Ref. 2. It is shown that the hysteresis loops are stable and there is no strength nor stiffness degredation of the walls having 3-5 displacement ductilty factors.

3.4 Wall Displacements and ductilities

Maximum wall displacements and ductility factors are listed in Table 6-3 of Ref. 2. Maximum deflections ranging from 0.2 in. to 1.2 in. are anticipated which are very small compared to wall height. Maximum lateral displacement to wall height ratio of 0.0056 is expected which is within the UBC allowable of 0.006 for slender loadbearing masonry walls (4). These displacements are not expected to have any detrimental effect on the operation of the safety-related equipment attached to Diablo Canyon walls. Because of the small maximum displacements and the low rebar ductilities, displacement ductility up to 5 is acceptable. In case of ductilities between 3 and 5 the resulting displacement was conservatively multiplied by 2 to evaluate the effect on the support and/or adjacent safety-related components or systems.

3.5 Shear Capacity at the Supports

The top connection is the critical element for shear transfer to the floor slabs. The clip angles provided at the top ensure positive shear transfer mechanism. In case the clip angles do not extend to the masonry blocks the shear capacity of the connection was calculated based on four potential critical section. A minimum safety factor of 2.0 was obtained which is compatible with other margins of safety in masonry wall evaluation. For walls having factor of safety between 1.4 and 2.0 adequate steel beam connections are provided which ensure a reserve shear capacity

3.6 Safety Margins

Adequate margin of safety is ensured for Diablo Canyon walls. This is based on the following design provisions:

1- Displacement ductilities are limited to 3 which is conservative for adequately reinforced fully grouted masonry wall.

2- If the predicted displacement exceeds 3 times the yield displacement, the resulting displacement is multiplied by a factor of 2 and a determination is made to check the function of the safety related equipment.

3- The maximum rebar ductility is 6 which is well below the maximum allowable of 40.

4- The maximum displacement to height ratio is 0.0056 which is well below UBC code limit.

4. CONCLUSION

It has been shown that the energy balance technique provides adequate and conservative estimate of Diablo Canyon wall response to out-of-plane lateral loading. Based on PGandE analysis it is concluded that the safety-related masonry walls at Diablo Canyon units 1 and 2 will perform satisfactorily under earthquake loads, thus assuring the integrity of supported or proximate safety-related equipment or systems.

[illegible]

5. REFERENCES

1. Hamid, A., "Review of Masonry Wall Design-Diablo Canyon Nuclear Power Plant," Technical report, Franklin Research Center, Philadelphia, November 1984.

2. "Verification of Diablo Canyon Energy Balance Technique Using SONGS-1 Masonry Wall Tests." Pacific Gas and Electric Company, San Francisco, March 1986.

3. Harris, G., Hamid, A. and Con, V., " Evaluation of the Applicability of Nonlinear Analysis Techniques to Reinforced Masonry Walls in Nuclear Power Plants", Franklin Research Center, April 1984

4. "Uniform Building Code", Chapter 24, International Conference of Building Officials, Whitter, CA, 1985

APPENDIX D

TYPICAL WALL MODIDICATIONS

FRANKLIN RESEARCH CENTER
DIVISION OF ARVIN·CALSPAN
20th & RACE STREETS, PHILADELPHIA, PA 19103

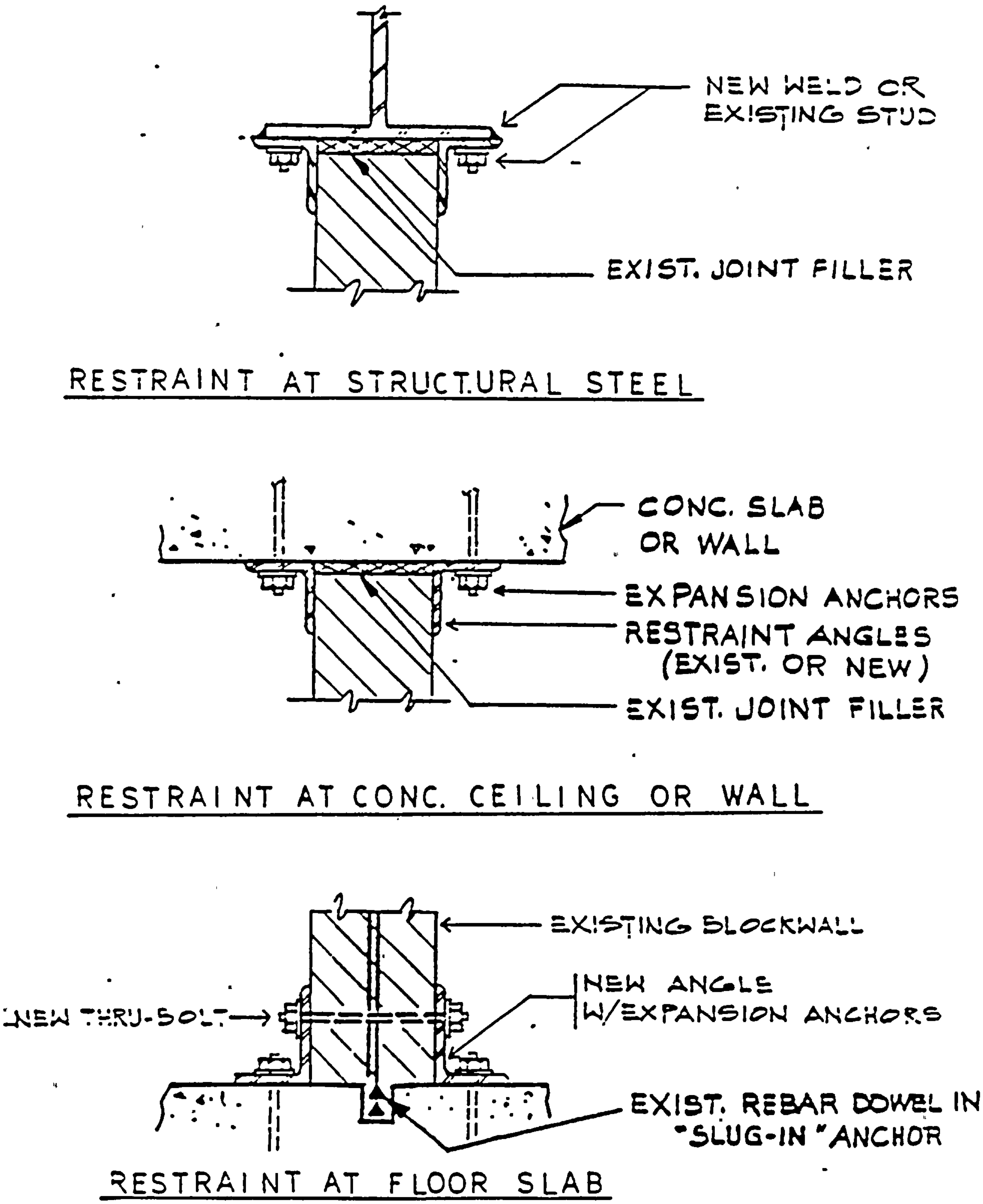

Figure D-1. Masonry Wall Edge Restraints

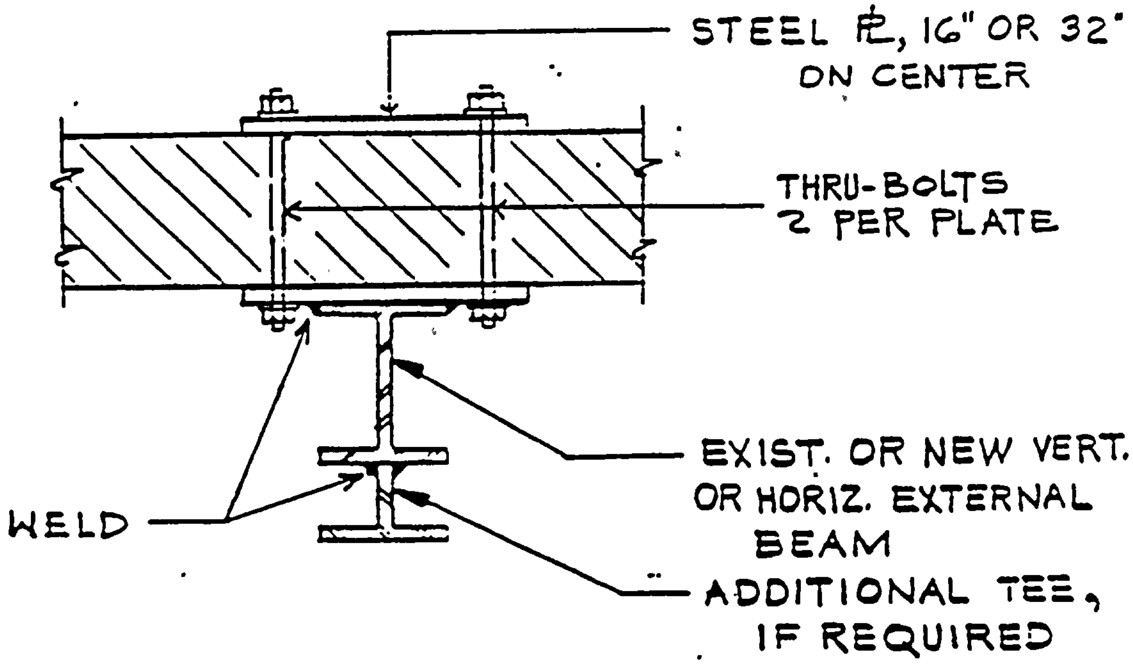

Figure D-2. Vertical or Horizontal Steel Stiffener.