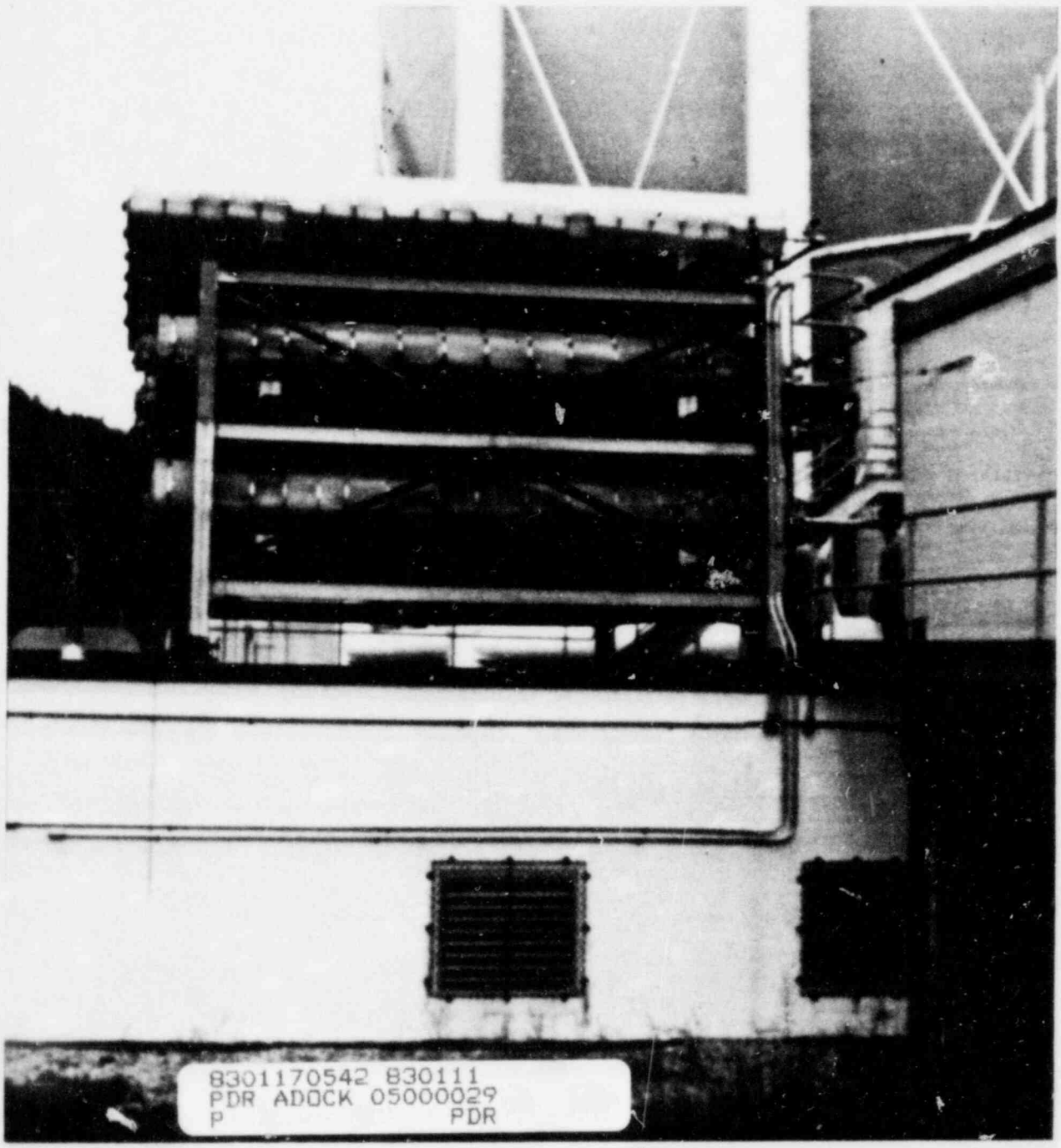
# Diesel Generator Building & Annex

## Yankee Nuclear Power Station

## Structural Analysis Report

**For: Yankee Atomic Electric Company**

**By: Cygna Energy Services**





January 6, 1983 Rev. 2

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January, 1983
Rev. 2

# Diesel Generator Building and Annex

# Yankee Nuclear Power Station

# Rowe, Massachusetts

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CYGNA

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# I. EXECUTIVE SUMMARY

## I.1 Purpose

The purpose of this report is to summarize the results of the structural analyses performed by Cygna Energy Services (Cygna) for Yankee Atomic Electric Company (YAEC). The results described in this report pertain to the Diesel Generator Building (DGB) and the newly-built and attached Annex at the Yankee Nuclear Power Station (YNPS) at Rowe, Massachusetts.

## I.2 Scope

As requested by YAEC, Cygna has performed detailed structural analysis of the existing DGB and Annex with minor modification. These analyses were based on the following input data for YNPS:

- Structural drawings of existing DGB (See Appendix A)
- Structural drawings of new Annex
- Design Criteria (See Section III)
- Seismic ground motion (See Appendix C)

## I.3 Conclusion

After attaching the new Annex to the DGB, the DGB will be able to withstand Dead Load and Live Load (DL+LL) plus the Yankee Composite Spectrum (YCS) or the Nuclear Regulatory Commission (NRC) spectrum loads with minor modifications for load paths and member strengthening.

## II. DESCRIPTION OF STRUCTURE

### II.1 Diesel Generator Building

The DGB was originally constructed of braced steel frames and it is structurally connected to the north-west corner of the Primary Auxiliary Building as shown in Figs. A.1 through A.11. Outside the steel frames, the building is enclosed by unreinforced concrete block walls. The building consists of three parts: the Main Structure, the Accumulator Tank Room and the Nitrogen Storage Tank Supporting Frame. The weight of the entire building excluding the Annex is 388 kips.

The original Main Structure is "L" shaped and has one level. The dimensions of the Main Structure are 36'-2" x 24'-0" between Column Lines 102 and 104 and 32'-0" x 60'-0" between Columns Lines 104 and 105. The height of the structure is 14'-3".

The Accumulator Tank Room is located between Column Lines 101 and 102. It has three levels with heights from top to bottom equal to 9'-1 1/2", 10'-0" and 14'-3", respectively. The dimensions of this room are 10'-4" x 14'-6".

The Nitrogen Storage Tank Supporting Frame is connected to the roof of the Main Structure and its top extends 12'-2" above the roof of the Main Structure. It has dimensions of 17'-0" x 13'-10".

As indicated in Figs. A.4 and A.5, the column-to-foundation connections and the beam-to-column connections cannot resist moment. Therefore, the lateral stiffness of the main structure is provided mainly by the recently added Annex as shown in Fig. A.9. The lateral stiffness of the Accumulator Tank Room and the Nitrogen Storage Tank Supporting Frame is provided by "X" and single diagonal braces.

## II.2 Annex

In 1982 the Annex, measuring 36'-0" x 17"-0", was added to the northern side of the DGB between column lines 103, 104, X and W. The annex is composed of a reinforced concrete slab roof supported on reinforced blockwalls as shown in Fig 9. The foundation is primarily a reinforced concrete grade beam. The annex is structurally connected to the DGB along the roof slab. Thus the walls of the Annex will resist lateral forces developed in the DGB.

## III. PERFORMANCE CRITERIA

### III.1 Materials

(a) Steel Frames

Except for the diagonal braces, the stress developed in structural steel members is limited by the allowable stresses specified in the Part 1 of the AISC Specifications [2]. The 1/3 increase in the allowable stressses when the seismic loading is combined with other loads (Section 1.5.6 of the AISC Specification) was also employed.

(b) Diagonal and K-Braces

The diagonal braces are made of slender members. This reduces significantly the capacity of these braces to resist compression. For a pair of X-braces, it was assumed that only the tension member is effective in resisting the loads. More specifically, the combined tension and compression stresses in a pair of X-braces shall not exceed 1.33 x 0.6 fy = 26.4 ksi. For a single diagonal brace or a K-brace, the maximum stress shall be limited by the allowable compression stress as discussed in Item (a).

(c) Shear Walls in Annex

The 12" reinforced blockwalls of the Annex are assumed to act as shearwalls in resisting most of the lateral forces developed in the DGB. The allowable stresses conform to the requirement of UBC (1979) Reinforced Masonry Design provisions for walls where special inspection is required [2].

## III.2 Earthquake Loadings

The DGB and Annex were analyzed for the Yankee Composite Spectrum (YCS) and NRC Spectrum with 7% critical damping ratio (Fig. C.1). Each spectrum was applied in two horizontal directions and it was scaled down to two-thirds of the original magnitude when applied in the vertical direction. The stresses introduced by the spectrum applied in two horizontal directions are combined by the SRSS method and those introduced by the vertical spectrum are added to the horizontal results by the absolute sum method.

## IV. ANALYSIS PROCEDURES

### IV.1 General

The DGB and interconnected Annex were analyzed without considering the stiffness of the unreinforced concrete block walls. The DGB building and the Annex were modeled together since structurally they form one unit. The modeled structure was then analyzed using the YCS and NRC response spectra.

The Accumulator Tank, which is structurally independent of the building, was analyzed separately.

### IV.2 Computer Programs

Two computer programs were used to perform the analyses. BATS [3] and SAP IV [5] computer programs were used to run the response spectra analyses.

### IV.3 Assumptions

1. The dynamic analysis of the model was carried out assuming that the DGB and the Annex form one unit structurally. This was achieved by connecting the Annex to the DGB in the X and Y directions.

2. The concrete blockwalls (reinforced) were assumed to be acting as shear walls to carry most of the lateral forces generated in the DGB.

3. In order for the Annex to act efficiently in resisting lateral forces generated in the DGB, the DGB roof will have to act as a rigid diaphragm. This is possible only if horizontal X-braces are introduced in the roof as modifications; this was assumed in the model. Also, since the Annex is weaker in the X-direction due to large unavoidable opening, and in order to avoid larger drift, more braces have to be

introduced in the Nitrogen and Accumulator towers. These are assumed in the model.

4. As shown in Detail B of Fig. A.4, the 1-1/2" hole along X-direction was provided for the 3/4" diameter bolts which connect the steel beam to the reinforced concrete wall of the Primary Auxiliary Building. Therefore, it was assumed that the reinforced concrete wall of the Primary Auxiliary Building provides only the vertical but not lateral support to the steel beam of the DGB. For this reason, the seismic analyses of the DGB and Annex was made independently of the Primary Auxiliary Building.

## IV.4 Mathematical Models

### IV.4.1 Horizontal Models

The horizontal model of the DGB and interconnected Annex is shown in Figs. B.1 to B.6. This model was used to study the responses of the building to the horizontal earthquake loads.

The horizontal model of the Accumulator Tank is shown in Fig. B.7. It is a simple stick model with only one column line and three levels.

### IV.4.2 Vertical Models

The vertical model of the DGB is shown in Fig. B.8. This model was used to study the responses of the building to the vertical earthquake loads.

BATS computer program cannot handle the motion in the vertical direction. Therefore, the vertical model was turned in the horizontal direction as shown in Fig. B.8. As shown in this figure, Springs K1 through K4 represent the axial stiffness of the columns located in the corre-

sponding column lines. The dummy column indicated has zero stiffness.

The vertical model for the Nitrogen Storage Tank Supporting Frame is shown in Fig. B.9. Similarly, this model was turned in the horizontal direction. The dummy columns indicated have also zero stiffness.

The vertical model for the Accumulator Tank is similar to the horizontal model shown in Fig. B.7 except it was turned in the horizontal direction. The column elements used in the horizontal model were replaced by the spring elements in the vertical model.

## V. STRUCTURAL CHARACTERISTICS AND ANALYTICAL RESULTS

### V.1 Structural Characteristics

The first twenty modes of the DGB and interconnected Annex were included in the dynamic analysis. Table D.1 shows the frequencies and mode shapes of these twenty modes. From Table D.1, the fundamental frequency of the structure is equal to 3.5 Hz. This frequency is an improvement over the frequency of the DGB without the Annex connected to it, since it was estimated to be very low. The cumulative percent mass of the first twenty modes is almost equal to 100% in the X and Y directions. Therefore, it can be concluded that the first twenty modes are sufficient to accurately study the dynamic responses of the structure.

The horizontal model of the Accumulator Tank has three degrees of freedom. The characteristics of the first three modes of the tank are shown in Table D.3.

Table D.4 shows the dynamic characteristics of the vertical models. For all the structures analyzed, 100% of the cumulative percent mass has been accounted for.

### V.2 Analytical Results for NRC Spectrum

The results of the dynamic analysis of the DGB and interconnected Annex under dead load, live load and NRC spectrum loads are shown in Tables E.1 through E.3. Under this loading condition, and with the Annex and minor modifications, stresses in all members of the existing building are within the allowables.

The maximum displacements at selected points of the structure under the NRC spectrum loads are shown in Table E.3. The maximum X-displacement at Column

Lines X and 105 of Level 1 due to translational and torsional movement is 0.27" and the corresponding story drift index is 0.016. The maximum Y-displacement is also 0.28" at Lines Z and 105 and corresponds to the same drift which is less than the maximum allowable index of 0.005 h as specified in Section 2312(h) of the 1979 UBC [2].

## VI. SUMMARY OF REVIEW

1. The fundamental frequency of the DGB with the Annex is 3.5 Hz. The displacements are within acceptable magnitudes and the stresses within specified allowable.

2. Under dead load, live load, YCS or NRC spectrum loads, stresses in members of the existing building and drift are within acceptable limits with minor modifications. Minor modifications required are as follows:

   a. Horizontal X-braces to achieve rigid diaphragm action of the roof of the DGB.

   b. Vertical bracing in the Nitrogen Tower and Accumulator Building.

3. Existing connections can withstand the forces developed under DL, LL, and YCS or NRC spectrum loads.

4. As far as the Foundations are concerned, the bearing pressure is found to be within the allowables for YCS or NRC spectrum loading.

# APPENDIX A

BUILDING PLANS

| Figure No. | Contract Drawing No. |
|---|---|
| Fig. A.1 | S&W DWG 9699-FA-19A |
| A.2 | -20A |
| A.3 | -21A |
| A.4 | FS-25A |
| A.5 | FS-25B |
| A.6 | FC-63A |
| A.7 | FC-63B |
| A.8 | FC-63C |
| A.9 | SPD 81061-U1 |
| A.10 | SPD 81061-S1 |
| A.11 | SPD 81061-A1 |

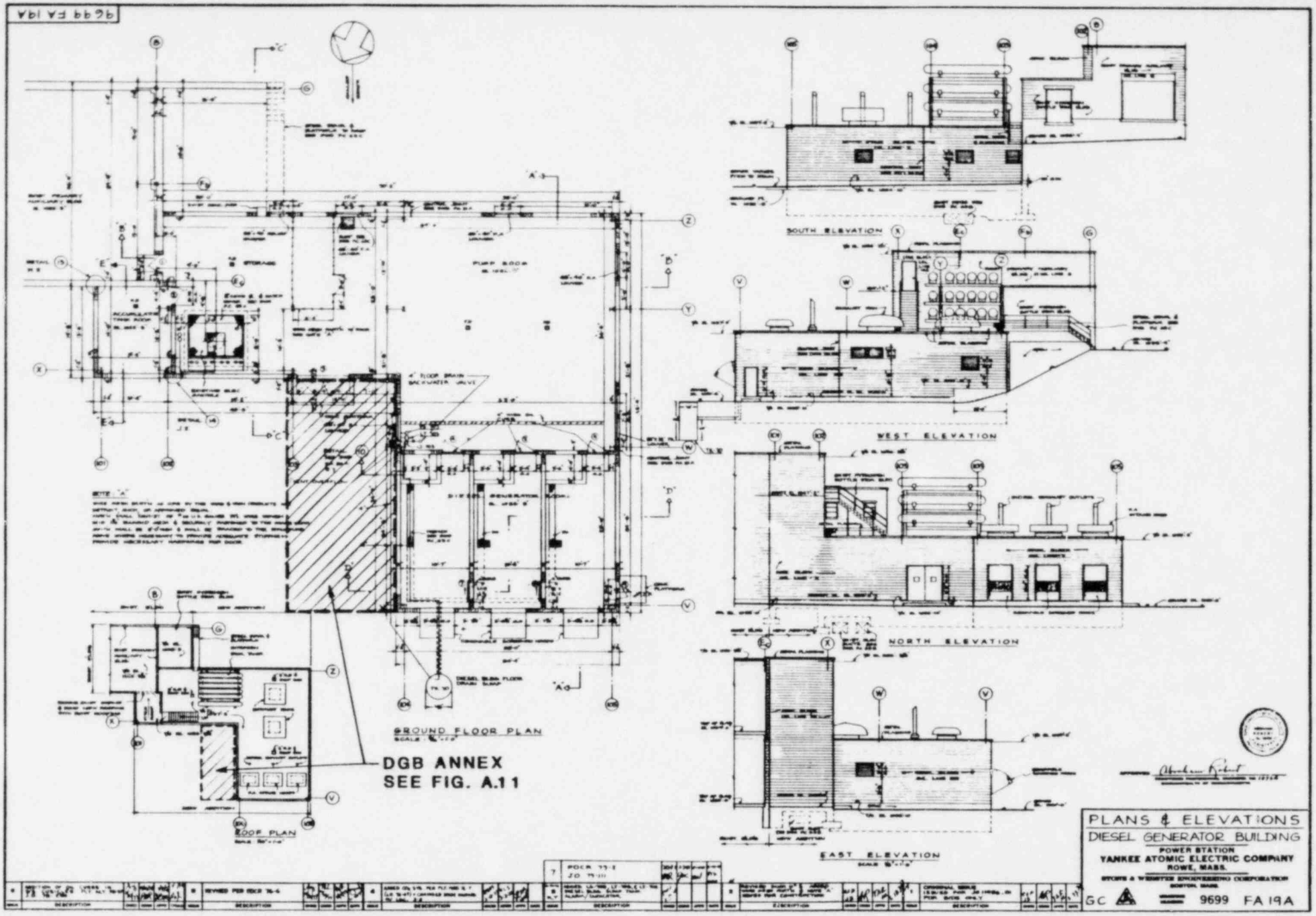


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FIG. A.1

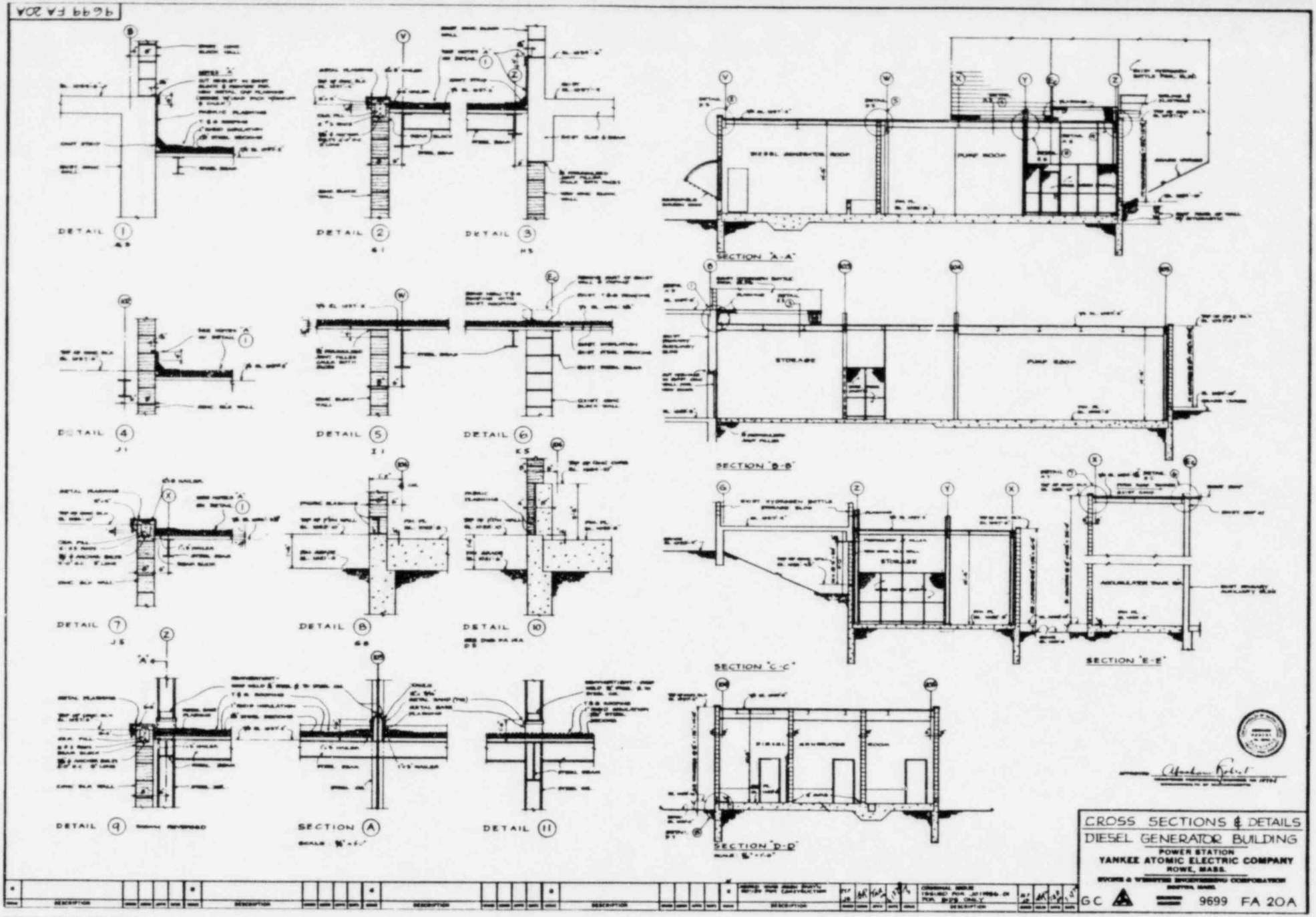


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FIG. A.2

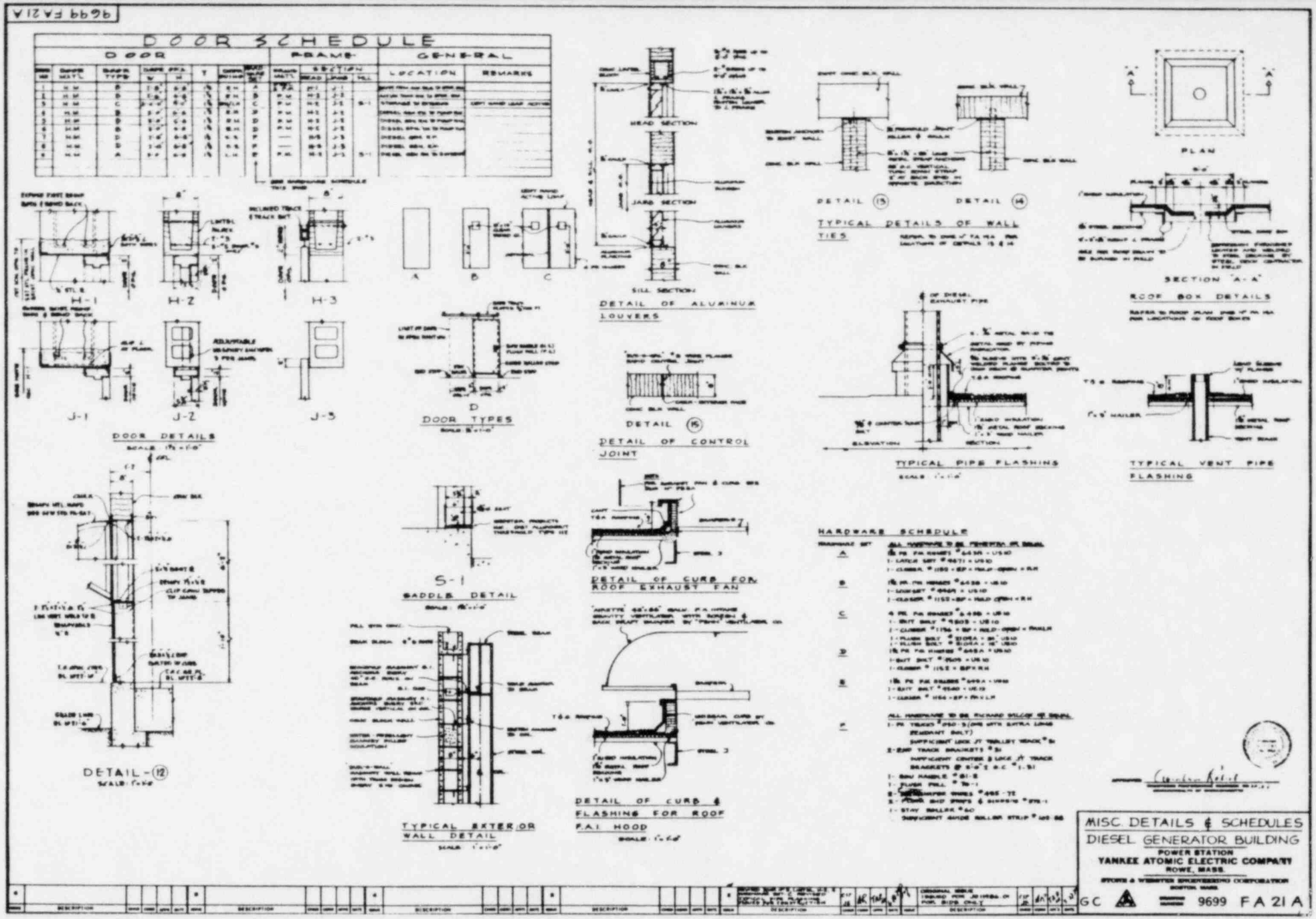


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FIG. A.3

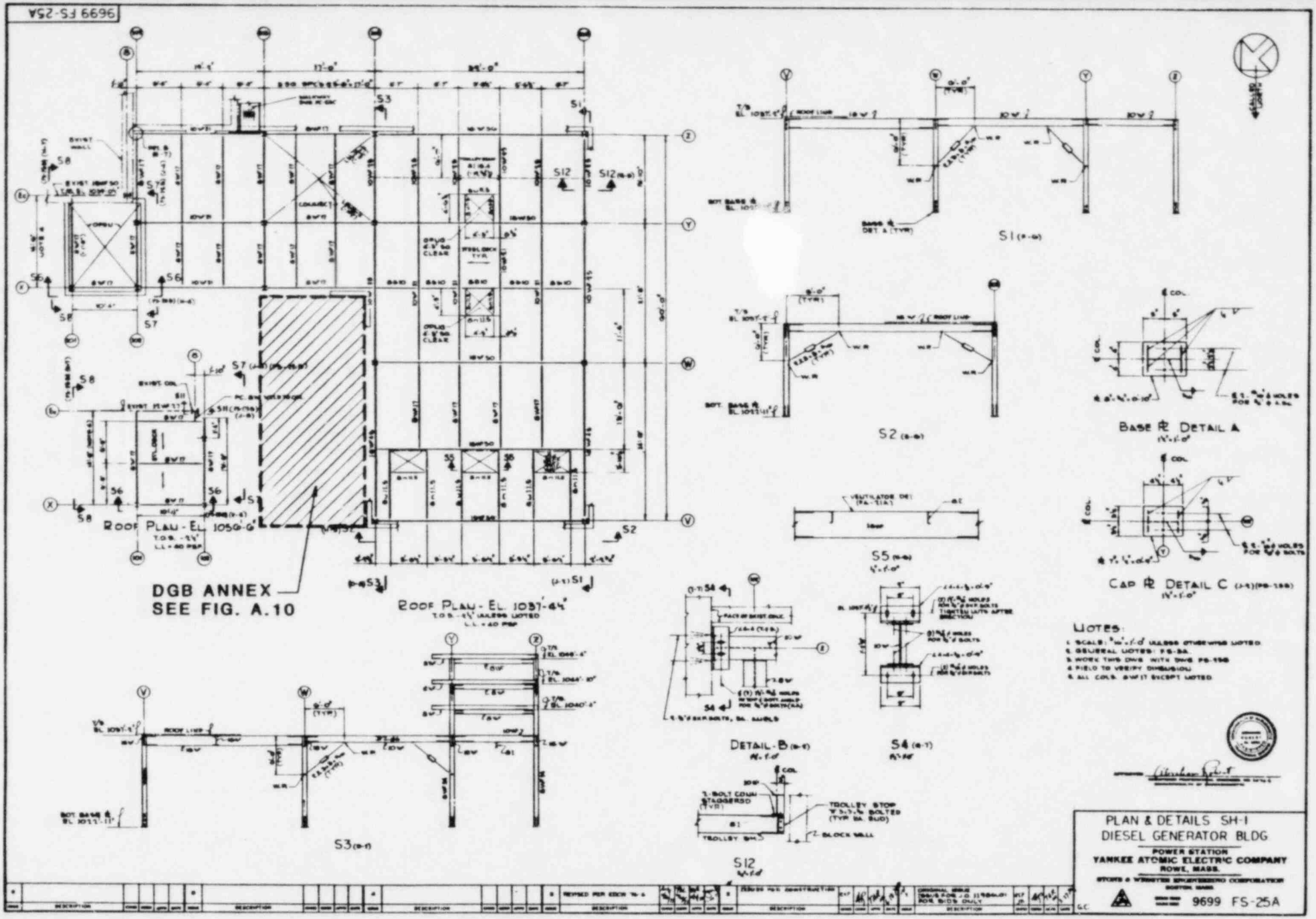


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FIG. A.4

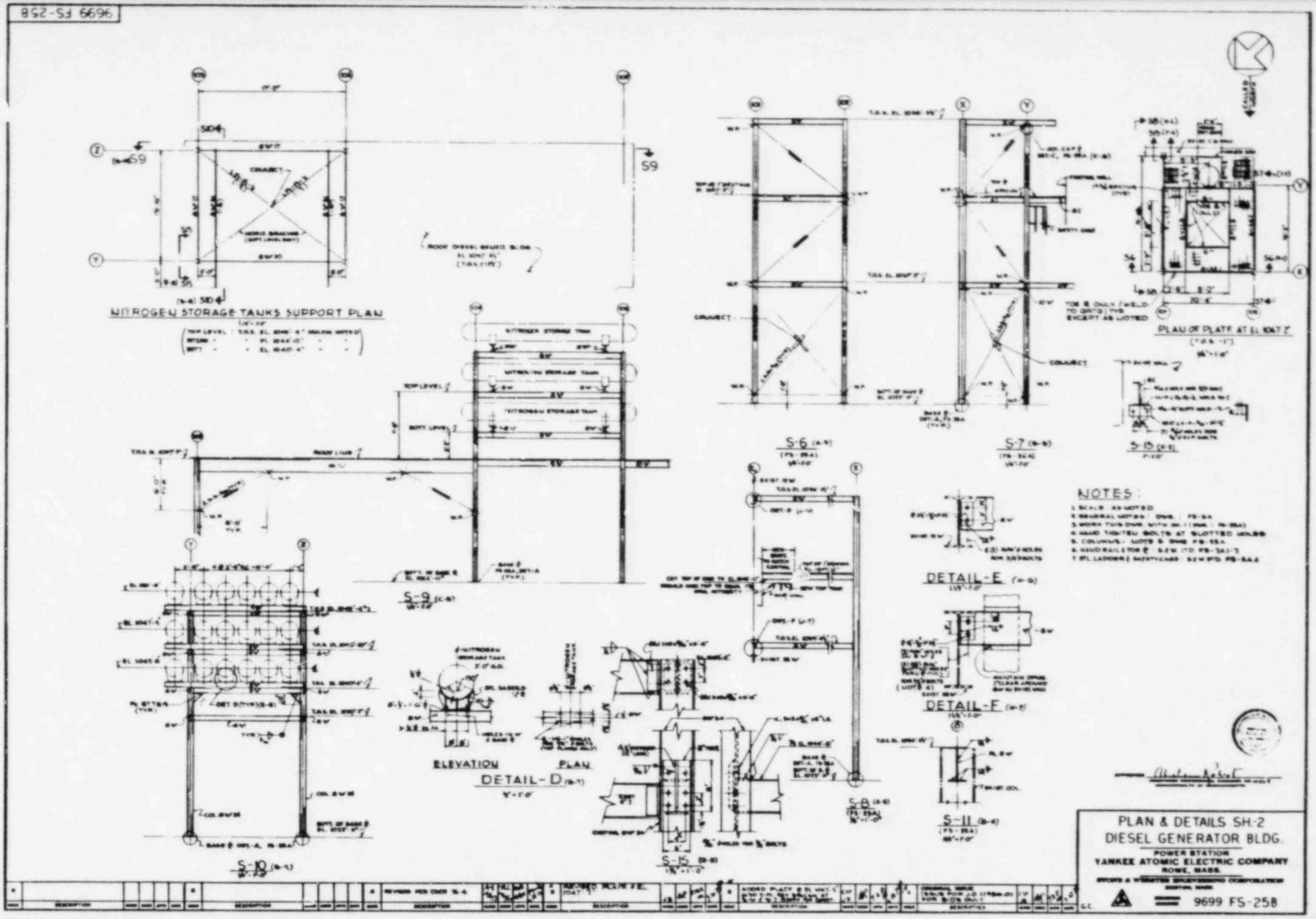


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FIG. A.5

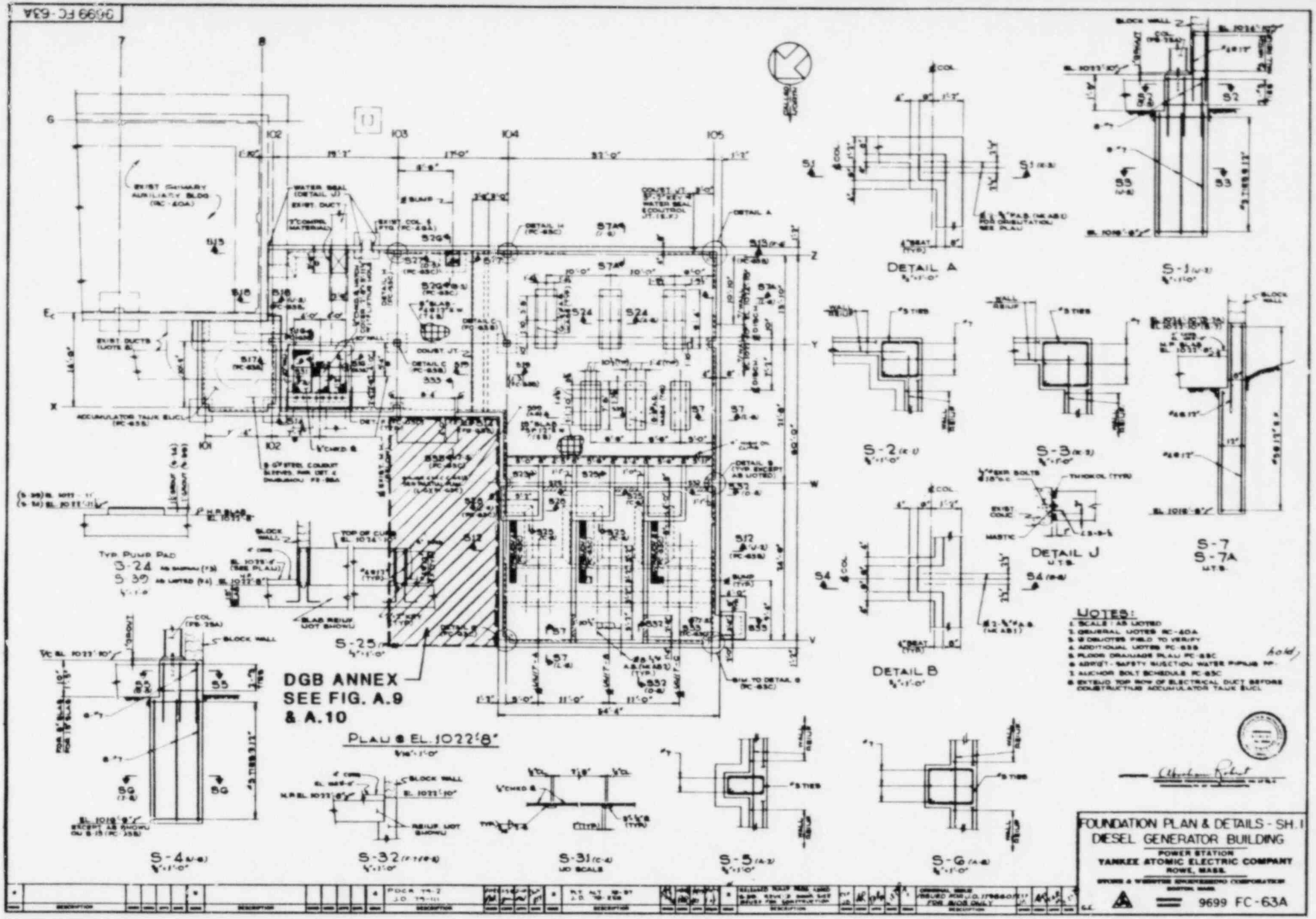


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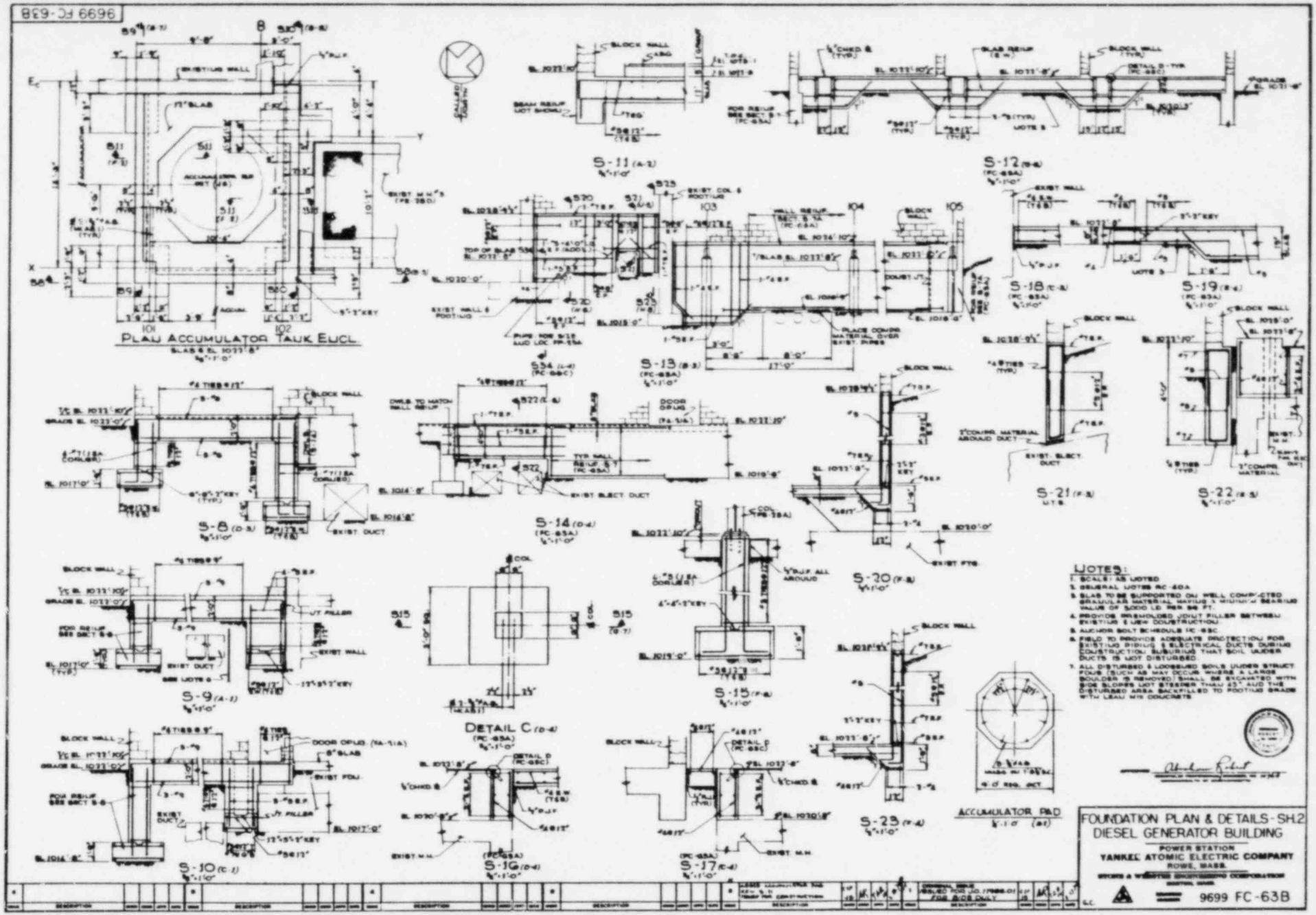
FIG. A.6




Yankee Atomic Electric Company FIG. A.7
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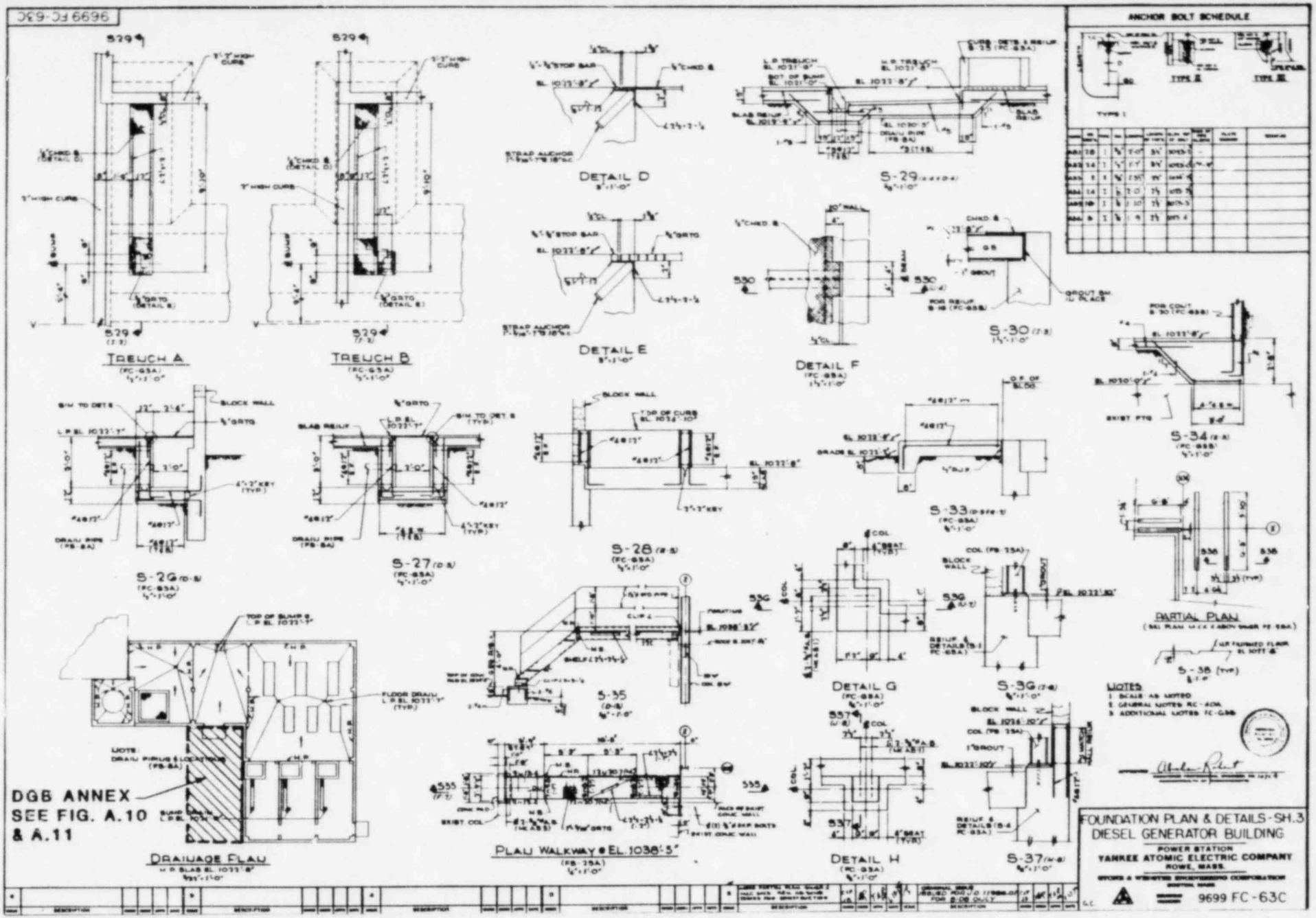


Yankee Atomic Electric Company FIG. A.8
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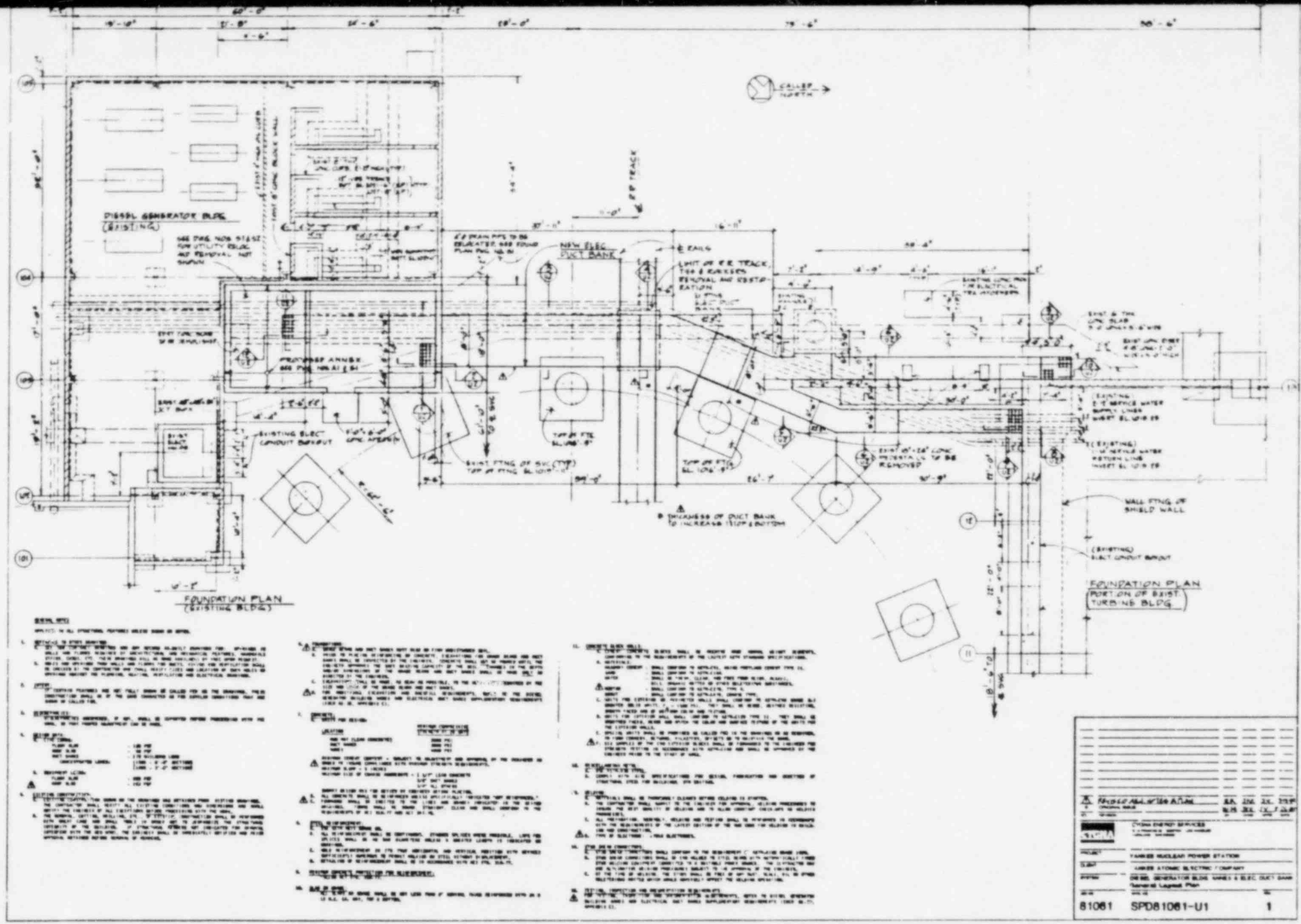


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FIG. A.9

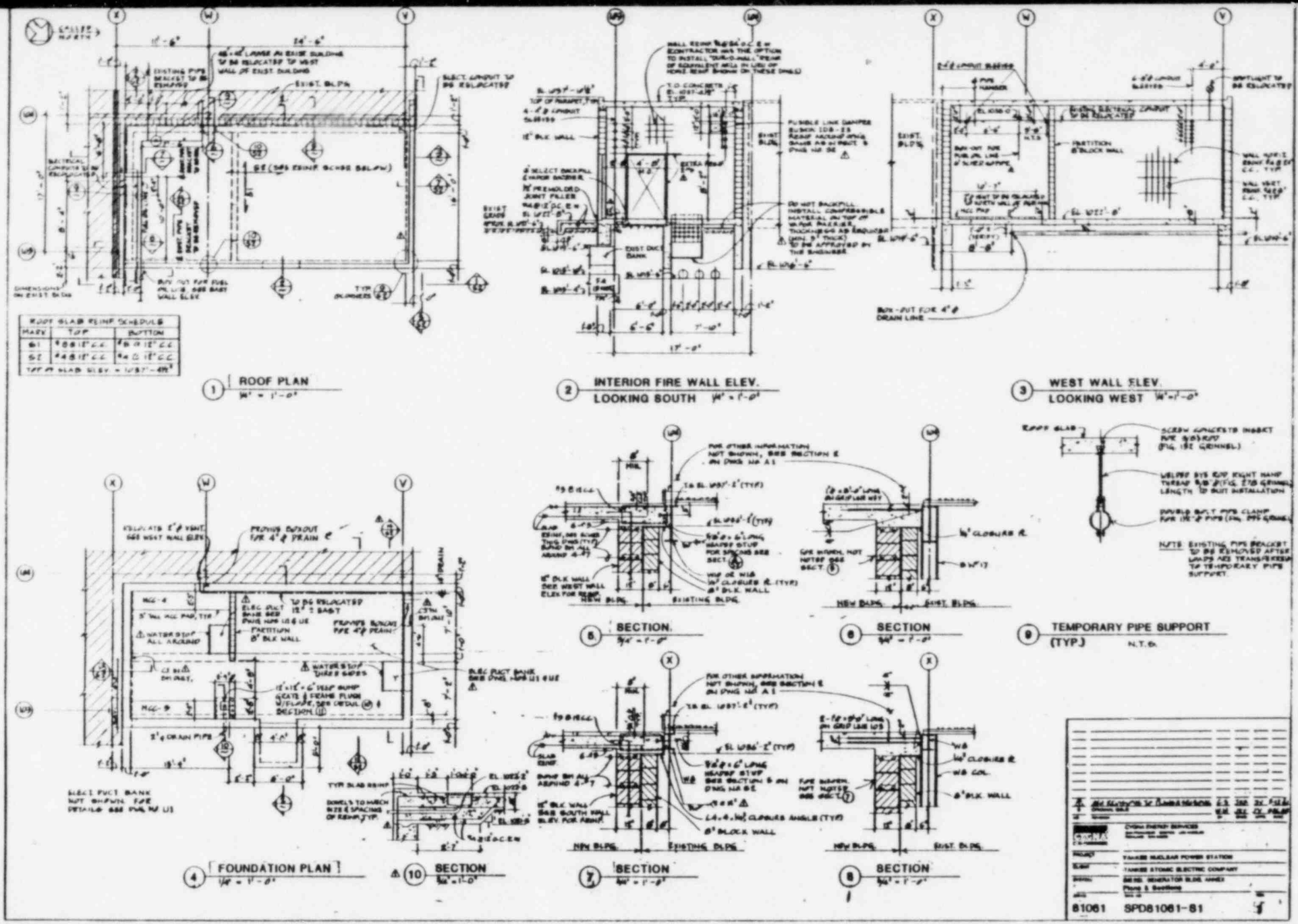


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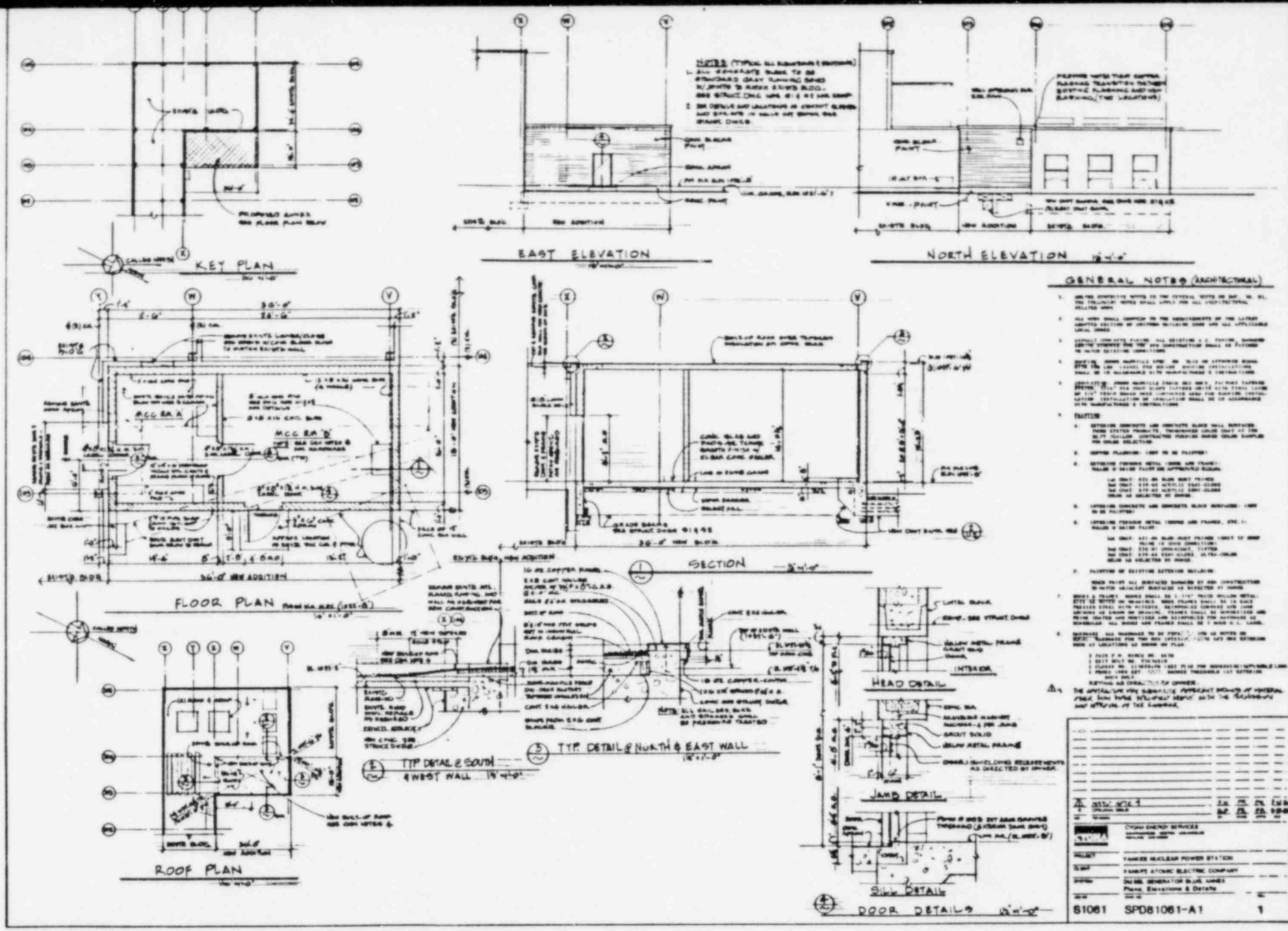
FIG. A.10




Yankee Atomic Electric Company FIG. A.11
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# APPENDIX B

# COMPUTER MODELS

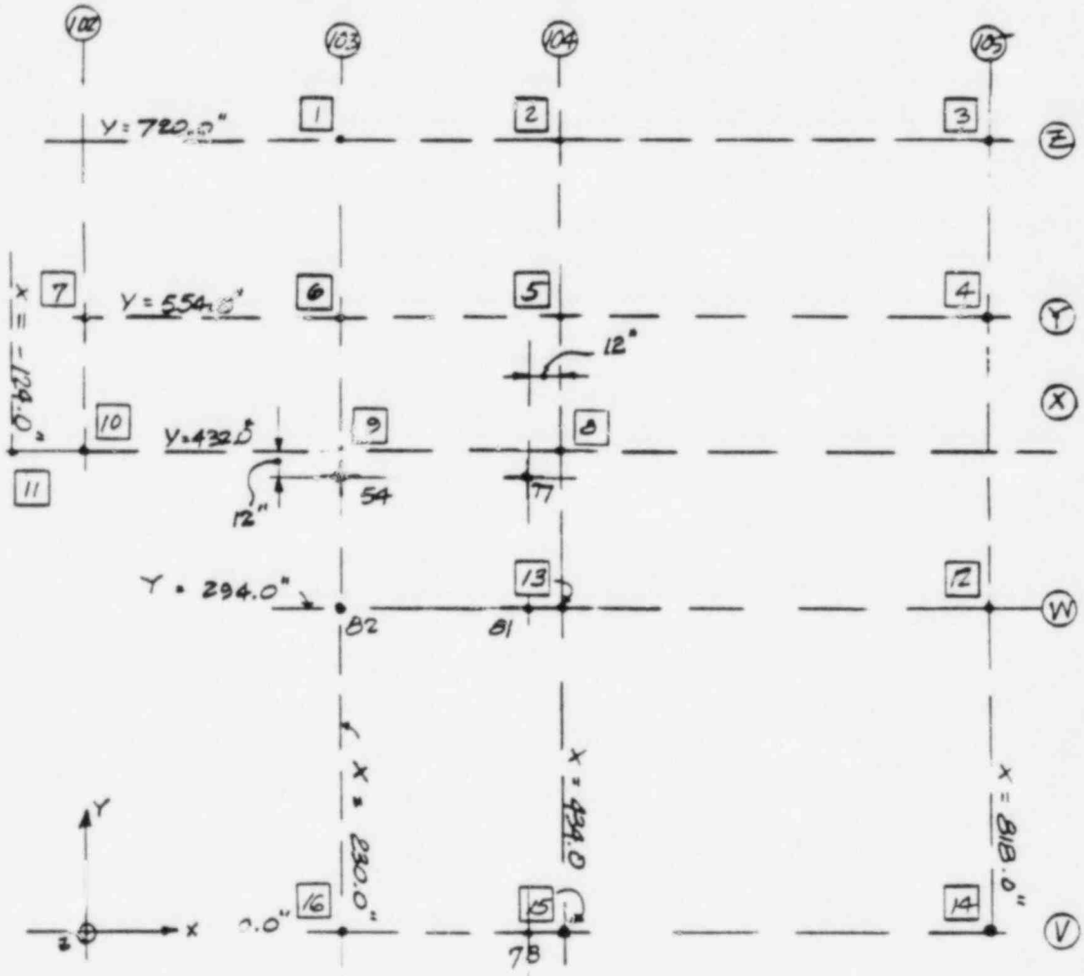



FIGURE B-1

MODEL NODAL POINTS GROUND LEVEL ELEV. 1022'11"

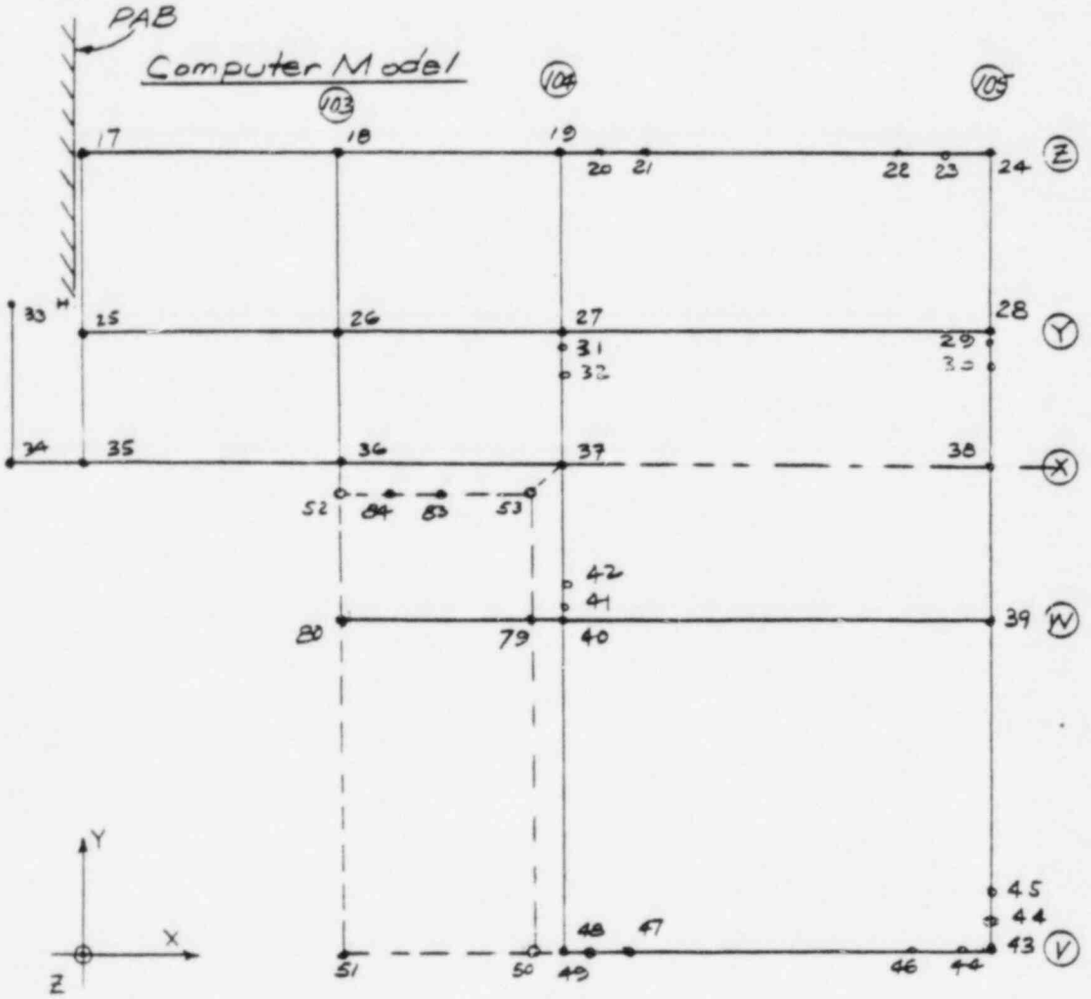



FIGURE B-2

MODEL NODAL POINTS LEVEL @ ELEV. 1037'4½" (ROOF)

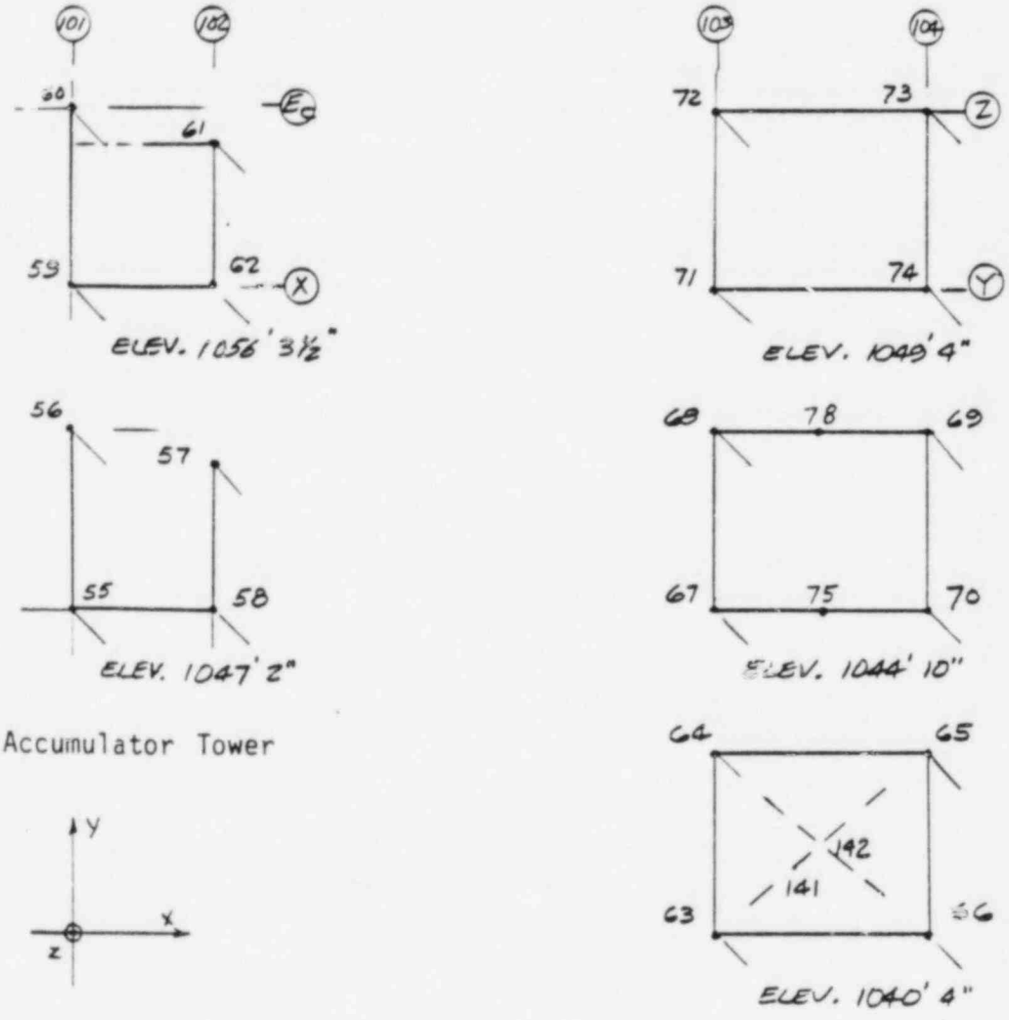



FIGURE B-3

MODEL NODAL POINTS FOR ACCUMULATOR & NITROGEN TOWERS

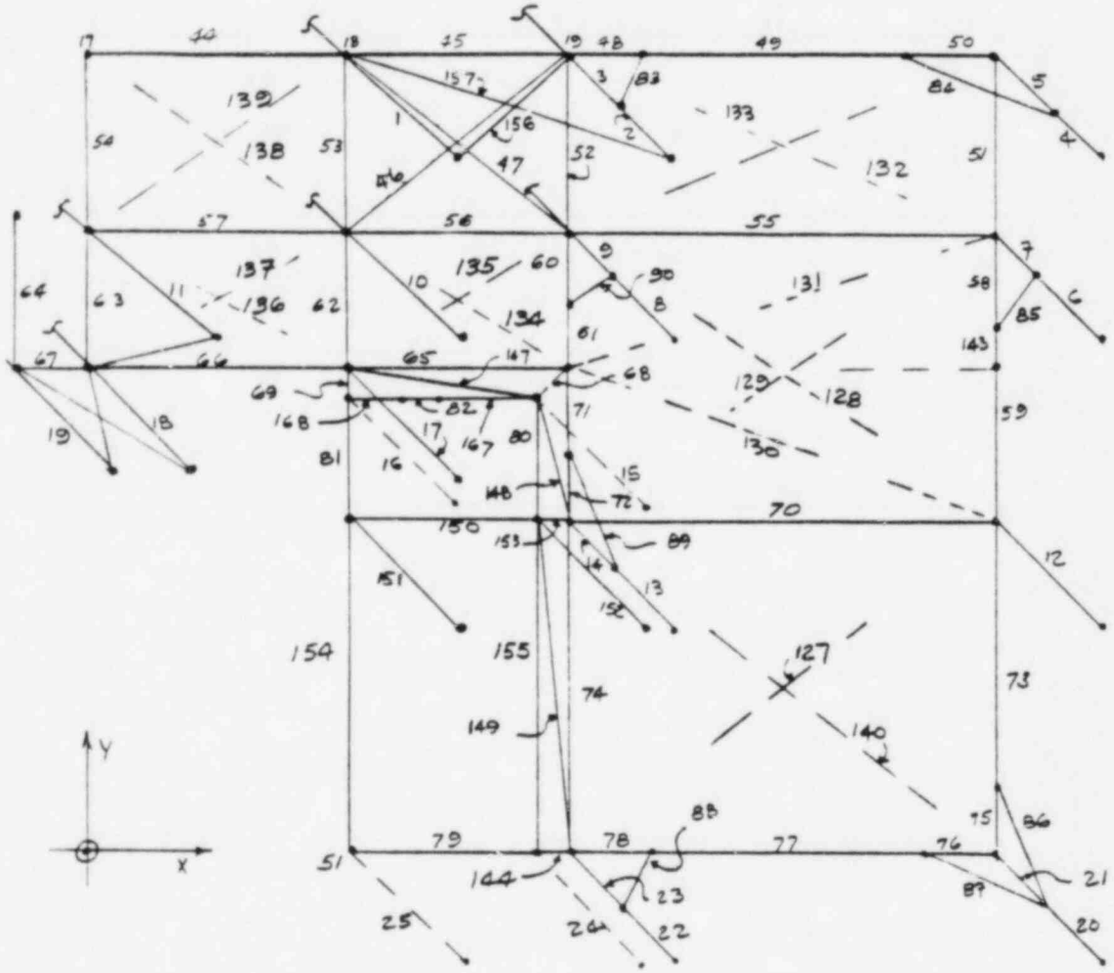
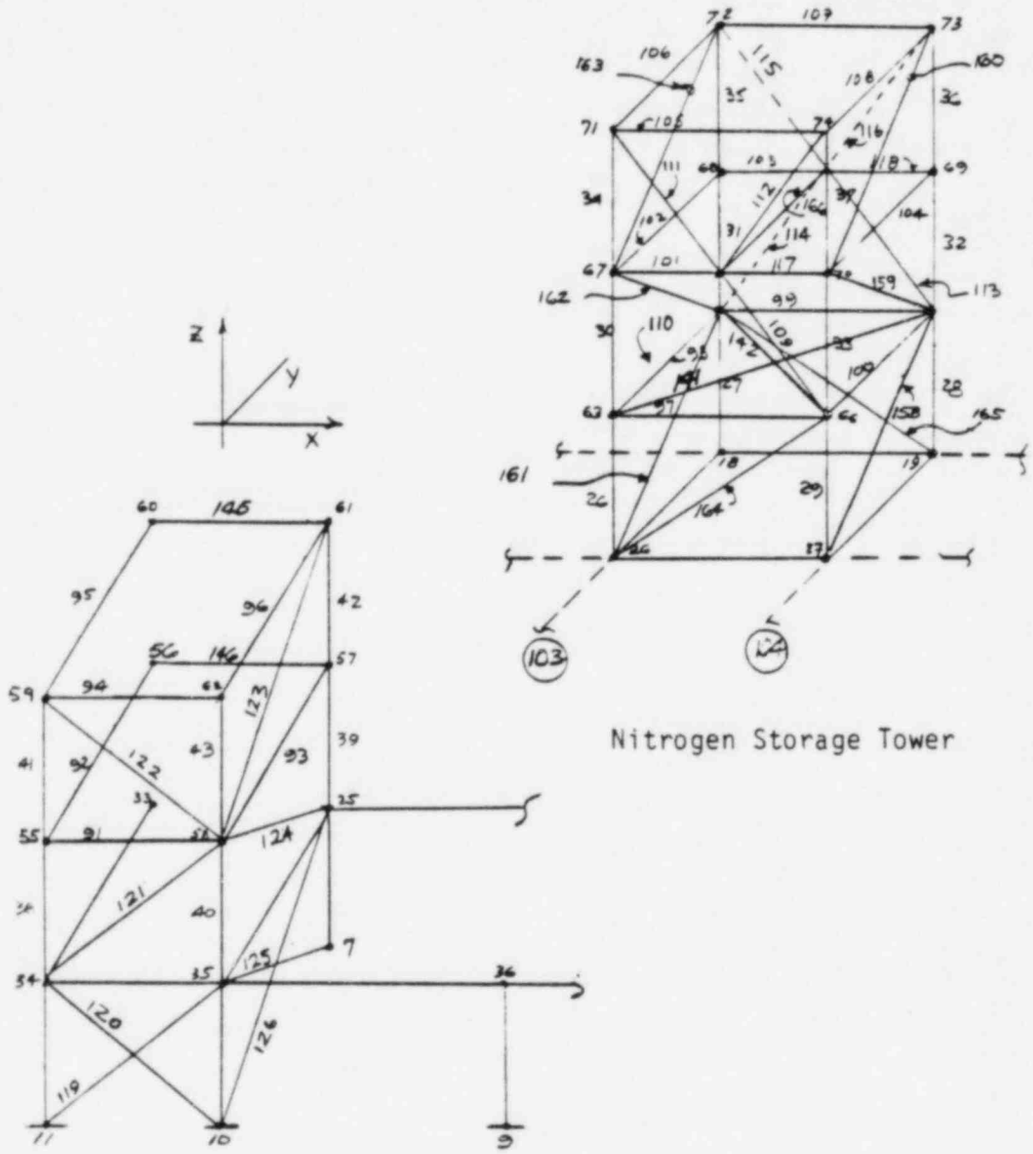



FIGURE B-4

MODEL MEMBERS BELOW EL. 1037'4½" (ROOF)




Nitrogen Storage Tower

Accumulator Tower

FIGURE B-5

MODEL MEMBERS OF NITROGEN TOWER AND ACCUMULATOR TOWER

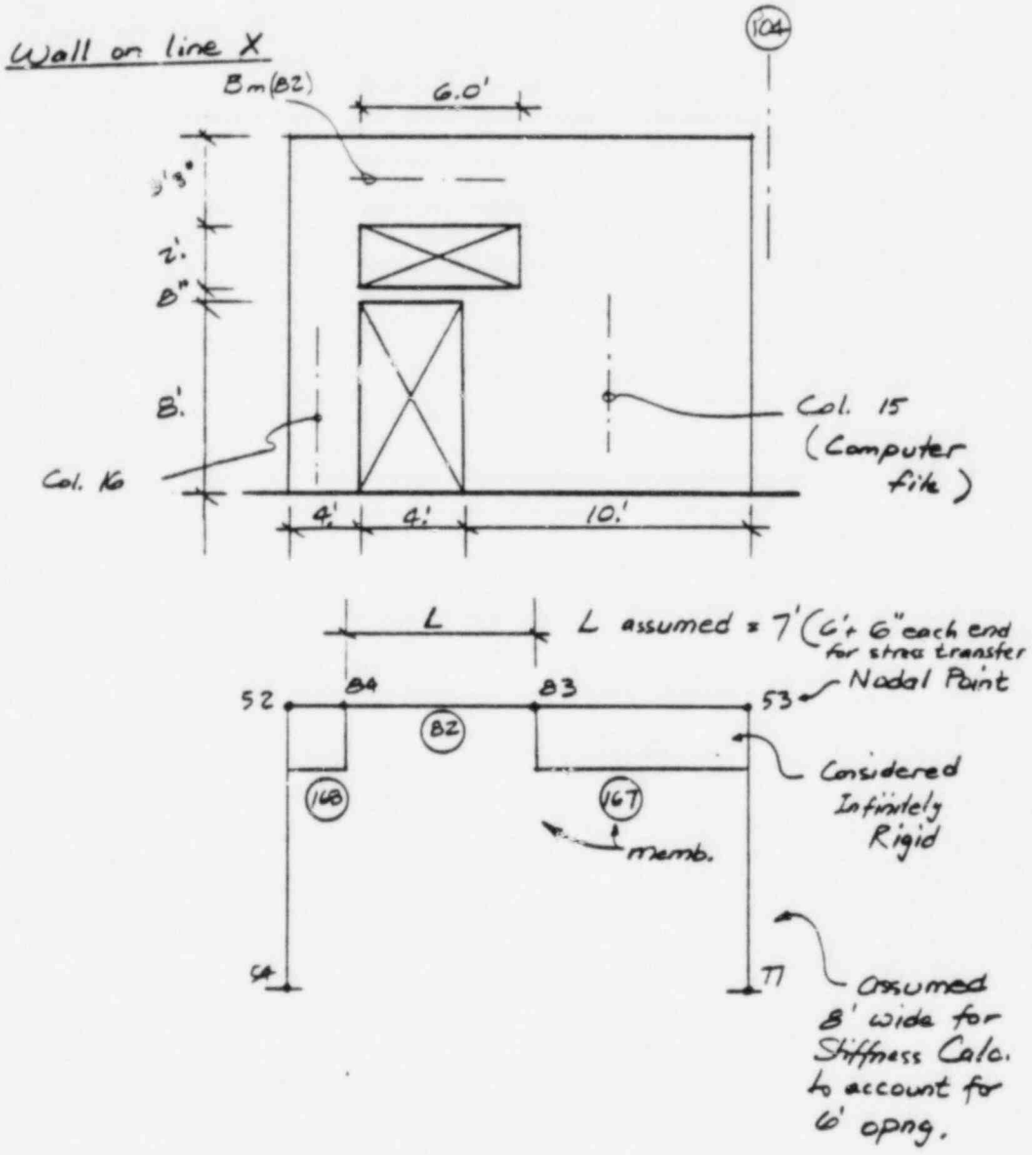



FIGURE B-6

REVISED NODEL OF WALL ON LINE X

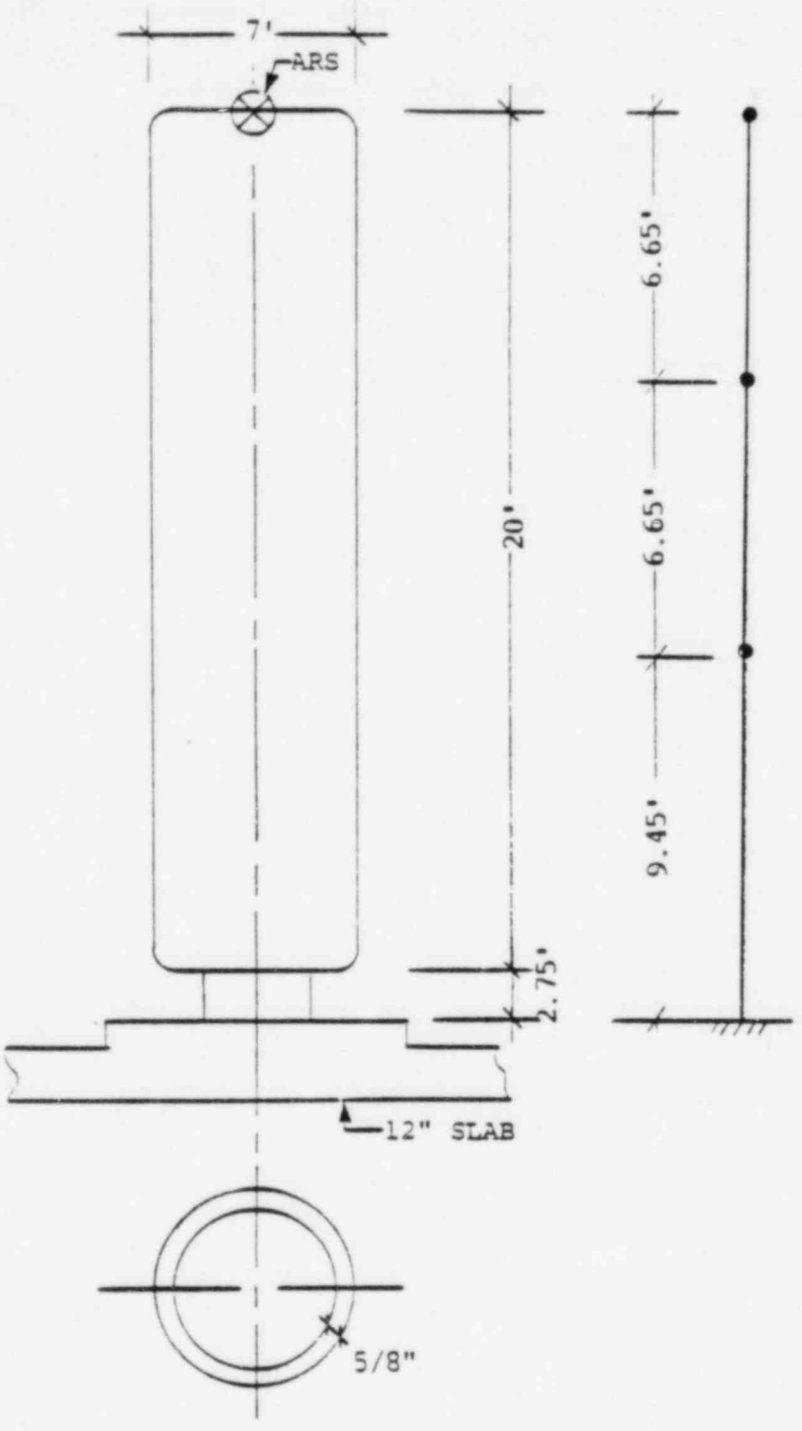
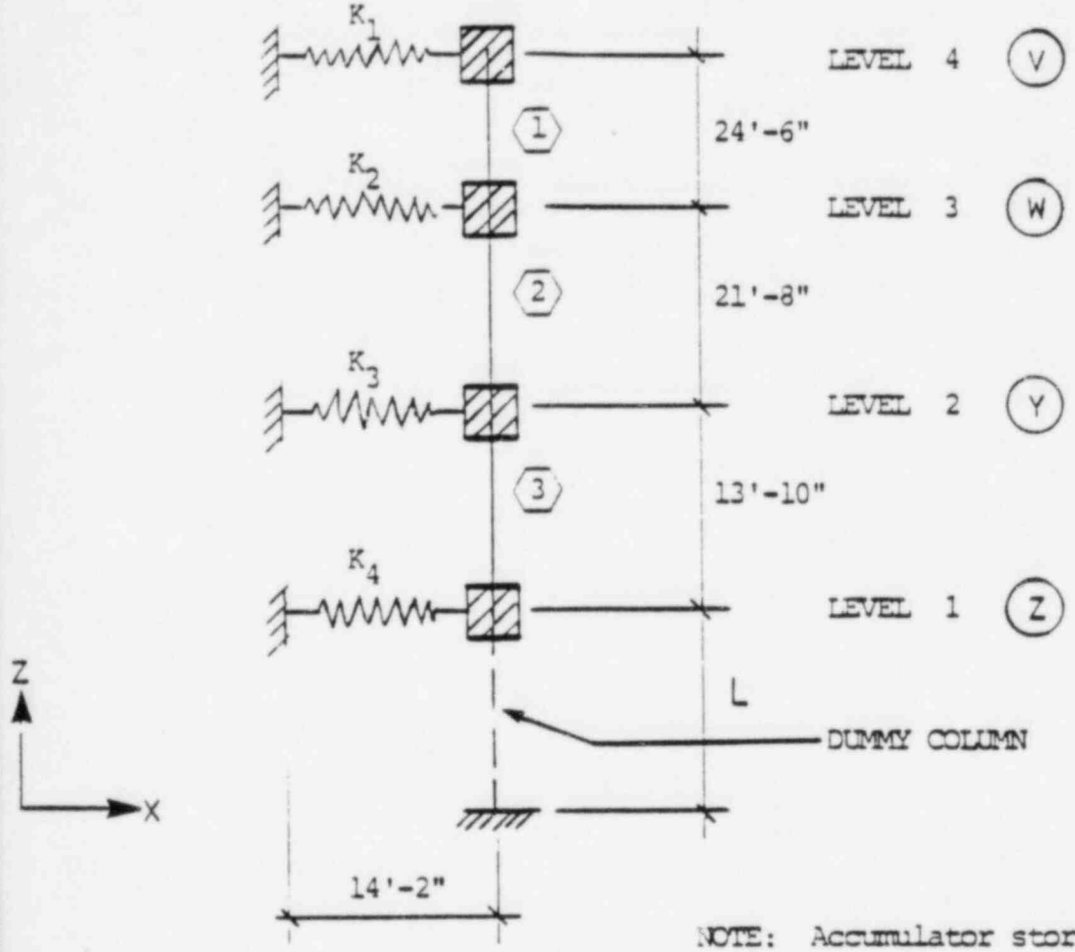



FIG. B.7 HORIZONTAL AND VERTICAL MODEL OF ACCUMULATOR TANK




NOTE: Accumulator storage tank is not included.

LEGEND: (TYPICAL)

COLUMN LINE NO.

BEAM NO.

FIG. B.8 VERTICAL MODEL OF DIESEL GENERATOR BUILDING

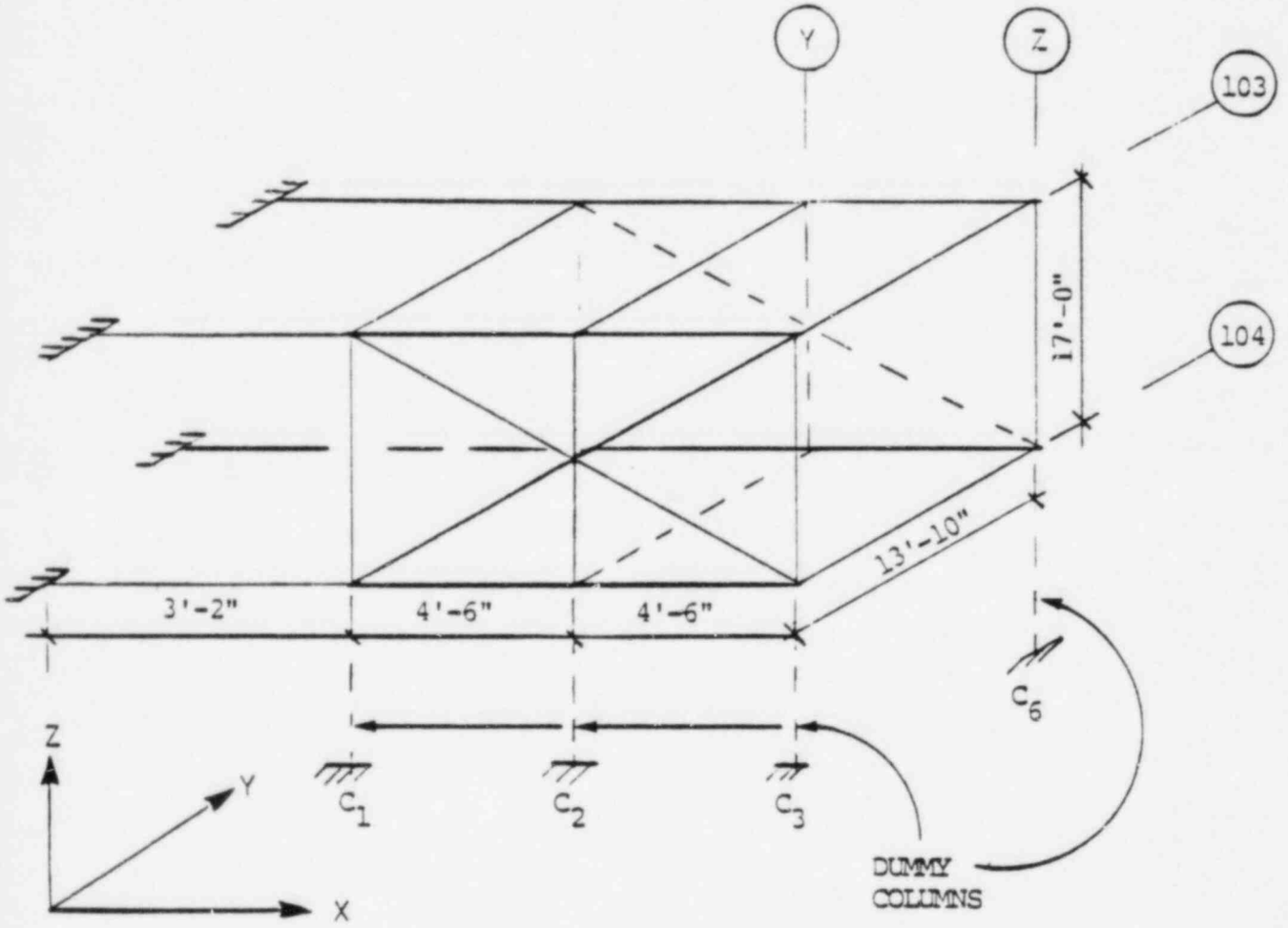



FIG. B.9 VERTICAL MODEL OF NITROGEN STORAGE TANK SUPPORTING FRAME

# APPENDIX C

# EARTHQUAKE SPECTRUM

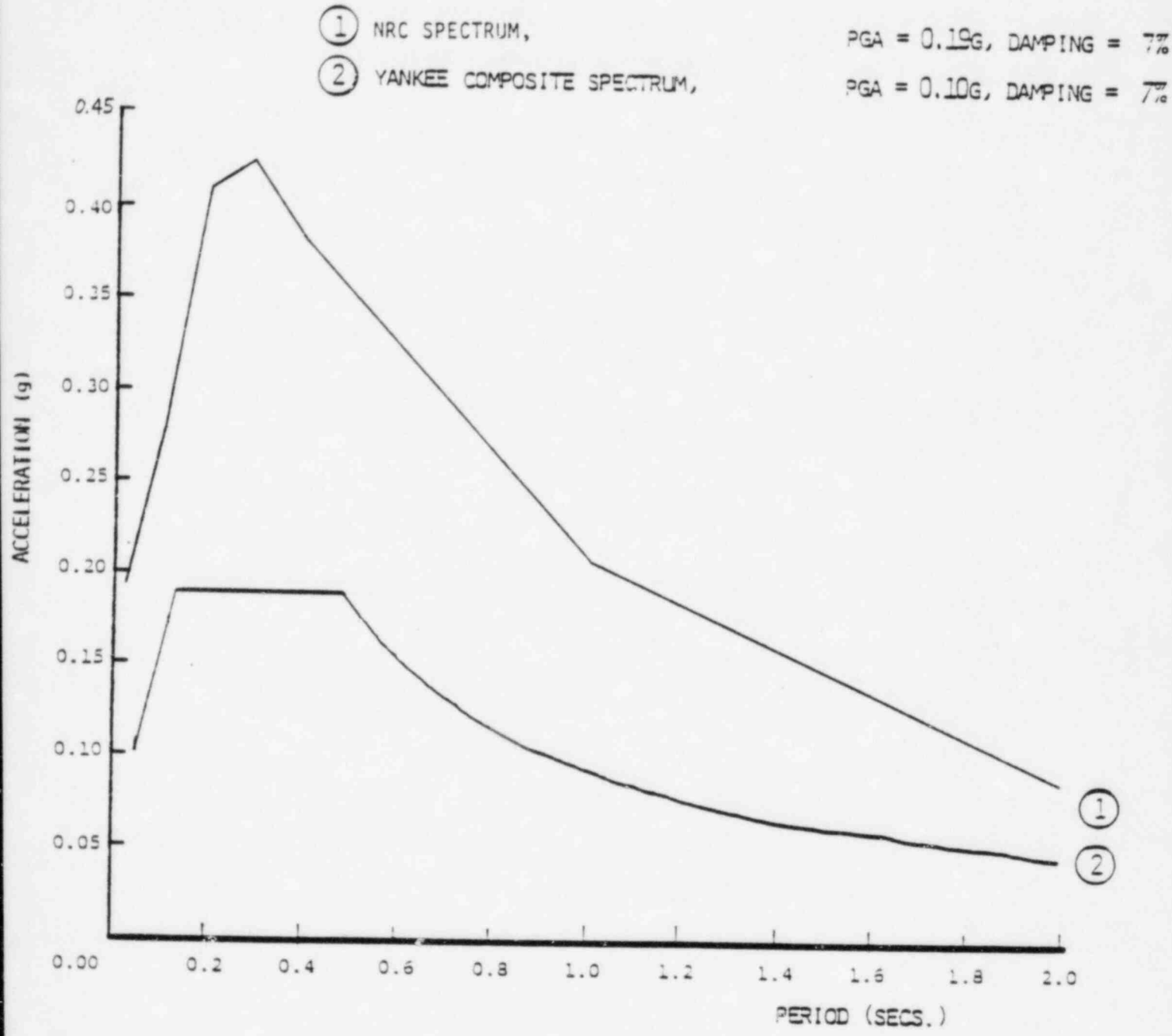



FIG. C.1 EARTHQUAKE SPECTRA

# APPENDIX D

## TABLE OF FREQUENCIES, MODE SHAPE AND PARTICIPATION FACTORS

**TABLE D.1**

FREQUENCIES OF DGB & ANNEX

| MODE NUMBER | FREQUENCY (CYCLES/SEC) | PERIOD (SEC) |
|---|---|---|
| 1 | 0.3499E 01 | 0.2858E 00 |
| 2 | 0.3515E 01 | 0.2845E 00 |
| 3 | 0.4561E 01 | 0.2193E 00 |
| 4 | 0.5082E 01 | 0.1968E 00 |
| 5 | 0.5130E 01 | 0.1949E 00 |
| 6 | 0.5205E 01 | 0.1921E 00 |
| 7 | 0.6126E 01 | 0.1632E 00 |
| 8 | 0.6582E 01 | 0.1519E 00 |
| 9 | 0.6897E 01 | 0.1450E 00 |
| 10 | 0.7699E 01 | 0.1299E 00 |
| 11 | 0.7902E 01 | 0.1266E 00 |
| 12 | 0.8423E 01 | 0.1187E 00 |
| 13 | 0.8754E 01 | 0.1142E 00 |
| 14 | 0.9937E 01 | 0.1006E 00 |
| 15 | 0.9966E 01 | 0.1003E 00 |
| 16 | 0.1101E 02 | 0.9079E-01 |
| 17 | 0.1103E 02 | 0.9066E-01 |
| 18 | 0.1218E 02 | 0.8208E-01 |
| 19 | 0.1233E 02 | 0.8107E-01 |
| 20 | 0.1338E 02 | 0.7476E-01 |

TABLE D-3

DYNAMIC CHARACTERISTICS OF HORIZONTAL MODEL OF ACCUMULATOR TANK

| Mode No. | Frequency (Hz) | Modal Mass ($lb\text{-}sec^2/in$) | Percent Mass (%) | Cumulative Percent Mass (%) |
|---|---|---|---|---|
| 1 | 15.7 | 1.543 | 81.1 | 81.1 |
| 2 | 56.8 | 0.352 | 18.5 | 99.6 |
| 3 | 115.5 | 0.007 | 0.4 | 100.0 |

**TABLE D-2**

MODAL PARTICIPATION FACTORS

| MODE | X-DIRECTION | Y-DIRECTION | Z-DIRECTION |
|---|---|---|---|
| 1 | -0.4028E-01 | 0.1076E 00 | 0.2317E-03 |
| 2 | -0.2918E-03 | 0.4215E-02 | -0.4250E-05 |
| 3 | 0.7175E 00 | -0.1888E 00 | -0.8835E-02 |
| 4 | -0.2214E 00 | 0.1202E 00 | 0.3062E-02 |
| 5 | 0.3006E-01 | 0.2300E-01 | 0.9736E-03 |
| 6 | 0.6482E-01 | 0.6180E-01 | 0.1779E 00 |
| 7 | 0.3135E-01 | 0.1190E-01 | -0.3912E-03 |
| 8 | -0.3323E 00 | -0.6898E 00 | -0.3530E-02 |
| 9 | 0.4364E 00 | 0.1927E 00 | -0.2079E-01 |
| 10 | -0.2412E 00 | 0.2636E 00 | -0.3955E-01 |
| 11 | -0.6544E-01 | 0.1231E 00 | -0.1524E-01 |
| 12 | 0.5582E 00 | -0.8534E-01 | 0.2237E-01 |
| 13 | -0.6129E 00 | -0.3693E-02 | -0.2576E-01 |
| 14 | -0.4746E-02 | 0.4751E-02 | -0.7767E-03 |
| 15 | -0.1662E-01 | -0.3623E-01 | -0.1954E-02 |
| 16 | -0.1720E-03 | 0.3073E-01 | 0.1242E-03 |
| 17 | -0.1533E-01 | 0.1106E-02 | -0.9279E-03 |
| 18 | -0.4618E-01 | -0.2835E 00 | 0.5103E-01 |
| 19 | 0.2169E-01 | 0.1577E-01 | -0.5070E-02 |
| 20 | 0.5373E 00 | -0.2333E 00 | -0.1854E-01 |

TABLE D-4

DYNAMIC CHARACTERISTICS OF VERTICAL MODELS

| Structure | Mode No. | Freq. (Hz) | Modal Mass ($lb\text{-}sec^2/in$) | Percent Mass (%) | Cumulative Percent Mass (%) |
|---|---|---|---|---|---|
| DGB Main Structure | 1 | 13.89 | 237.3 | 27.8 | 27.8 |
| | 2 | 17.43 | 353.4 | 41.3 | 69.1 |
| | 3 | 19.33 | 121.1 | 14.2 | 83.3 |
| | 4 | 27.45 | 143.1 | 16.7 | 100.0 |
| Nitrogen Storage Tank Supporting Frame | 1 | 33.44 | 162.1 | 64.5 | 64.5 |
| | 2 | 33.44 | 57.3 | 22.8 | 87.3 |
| | 3 | 91.57 | 22.8 | 9.1 | 96.4 |
| | 4 | 91.6 | 2.4 | 1.0 | 97.4 |
| | 5 | 127.2 | 6.4 | 2.5 | 99.9 |
| | 6 | 127.2 | 0.3 | 0.1 | 100.0 |
| Accumulator Tank | 1 | 73.67 | 1.83 | 96.39 | 96.39 |
| | 2 | 198.9 | 0.07 | 3.56 | 99.95 |
| | 3 | 319.0 | 0.001 | 0.05 | 100.0 |

# APPENDIX E

## SUMMARY OF STRESSES AND DISPLACEMENTS

**TABLE E-1**

STRESSES DEVELOPED IN COLUMNS DUE TO DL + LL + NRC

| LEVEL | INTERSECTION OF COLUMN LINES | STRESSES (KSI) DUE TO | | | TOTAL STRESS $F_T$ (KSI) | ALLOWABLE STRESS $F_a$ (KSI) | STRESS RATIO $F_T/F_a$ |
|---|---|---|---|---|---|---|---|
| | | DEAD LOAD | LIVE LOAD | EQ | | | |
| 1 | X & 102 | .16 | .22 | 4.72 | 5.10 | 9.14 | 0.56 |
| 1 | Y & 103 | 3.30 | .30 | 3.05 | 6.65 | 9.14 | 0.73 |
| 1 | Y & 104 | 3.41 | .30 | 3.41 | 7.12 | 15.60 | 0.46 |
| 1 | Z & 104 | 3.17 | .16 | 12.09 | 15.42 | 21.44 | 0.72 |
| 2 | Z & 103 | 2.69 | .30 | 11.5 | 14.54 | 24.97 | 0.58 |
| 2 | Y & 104 | 2.69 | .30 | 14.58 | 17.57 | 24.97 | 0.70 |

## TABLE E-2

FORCES DEVELOPED IN DIAGONAL BRACE UNDER NRC

| BRACE ELEMENT MODEL NO. | LOCATION | | AREA ($IN^2$) | AXIAL FORCE (KIPS) | AXIAL STRESS (KSI) | ALLOWABLE TENSILE STRESS $F_T$ (KSI) | STRESS RATIO $\frac{\text{AXIAL STRESS}}{F_T}$ |
|---|---|---|---|---|---|---|---|
| | LEVER NO. | COLUMN LINE | | | | | |
| 114* | 3 | 2-103 | 1.88 | 12.43 | 6.61 | 31.35 | 0.21 |
| 121* | 2 | X-101 | 1.78 | 23.9 | 13.43 | 31.35 | 0.43 |
| 121A** | 2 | X-102 | 1.78 | 23.9 | 13.43 | 31.35 | 0.43 |
| 124* | 2 | 102-Y | 1.78 | 18.3 | 10.28 | 31.35 | .33 |
| 124A** | 2 | 102-X | 1.78 | 18.3 | 10.28 | 31.35 | .33 |

* EXISTING DIAGONAL BRACE

** PROPOSED DIAGONAL BRACE REQUIRED TO FORM X-PAIR

**TABLE E-3**

MAXIMUM DISPLACEMENT OF CERTAIN
MODEL NODES UNDER NRC

| STRUCTURE | NODE NO. | MAXIMUM X-DISPLACEMENT (IN) | MAXIMUM Y-DISPLACEMENT (IN) |
|---|---|---|---|
| MAIN STRUCTURE | 17 | 0.18 | 0.12 |
| | 18 | 0.18 | 0.00 |
| | 24 | 0.20 | 0.28 |
| | 38 | 0.27 | 0.27 |
| | 43 | 0.03 | 0.26 |
| NITROGEN TOWER | 72 | 0.36 | 0.11 |
| | 73 | 0.36 | 0.15 |
| ACCUMULATOR TANK | 62 | 0.36 | 0.36 |

# APPENDIX F

# REFERENCES

## APPENDIX G

REFERENCES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