(3)

SUMMARY OF

ORIGINAL STRUCTURAL INVESTIGATIONS

General Electric Test Reactor

presentation to

Advisory Committee on Reactor Safeguards

Subcommittee Meeting

June 16 & 17, 1980

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ENGINEERING DECISION ANALYSIS COMPANY, INC.

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SUMMARY OF STRUCTURAL INVESTIGATIONS

ORIGINAL INVESTIGATIONS

- VIBRATORY GROUND MOTION
- SURFACE RUPTURE OFFSET
- POST-OFFSET VIBRATORY MOTION
- PIPING AND EQUIPMENT

RECENT INVESTIGATIONS

- COMBINED VIBRATORY MOTIONS AND SURFACE RUPTURE OFFSET
- VIBRATORY MOTIONS ON CALAVERAS FAULT
- PIPING AND EQUIPMENT
- CONSERVATISMS IN EVALUATIONS OF REACTOR BUILDING

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STRUCTURAL INVESTIGATIONS

REACTOR BUILDING

- LINEAR AND NONLINEAR DYNAMIC ANALYSES
- STATIC SURFACE RUPTURE OFFSET ANALYSES

REACTOR BUILDING PIPING SYSTEMS AND COMPONENTS

- LINEAR DYNAMIC ANALYSES FOR:

  PRIMARY PIPING
  OTHER SAFETY-RELATED PIPING
  REACTOR PRESSURE VESSEL
  HEAT EXCHANGERS
  FUEL STORAGE TANKS
  THIRD FLOOR MISSILE IMPACT SYSTEM
  MISCELLANEOUS COMPONENTS

- TESTING AND DYNAMIC ANALYSES FOR VALVES

FUEL FLOODING SYSTEM

- STATIC SURFACE RUPTURE OFFSET AND DYNAMIC ANALYSES, AND COMPONENT TESTING FOR:
  STORAGE TANKS
  SUPPLY LINES

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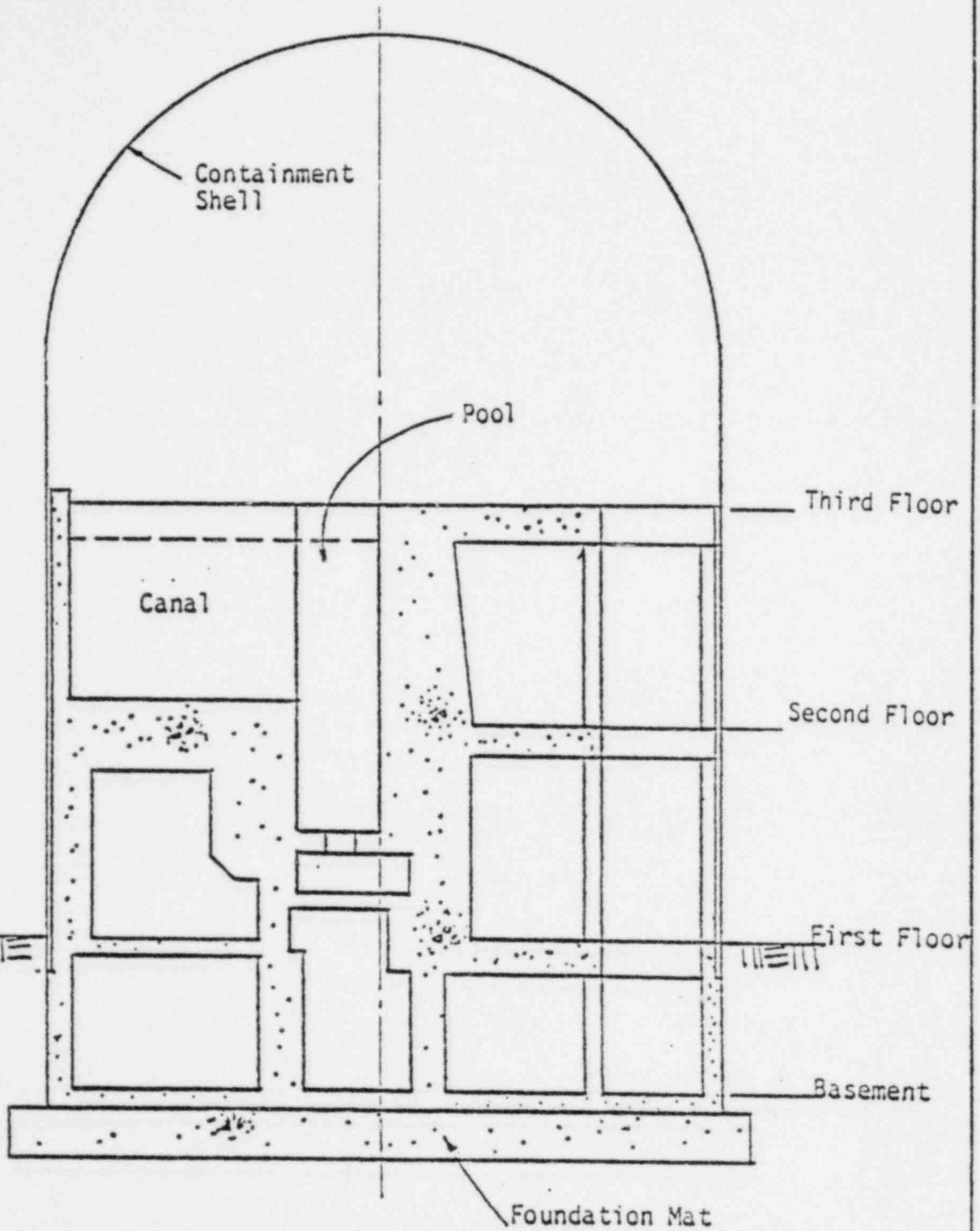

FIGURE 3-5 REACTOR BUILDING VERTICAL SECTION

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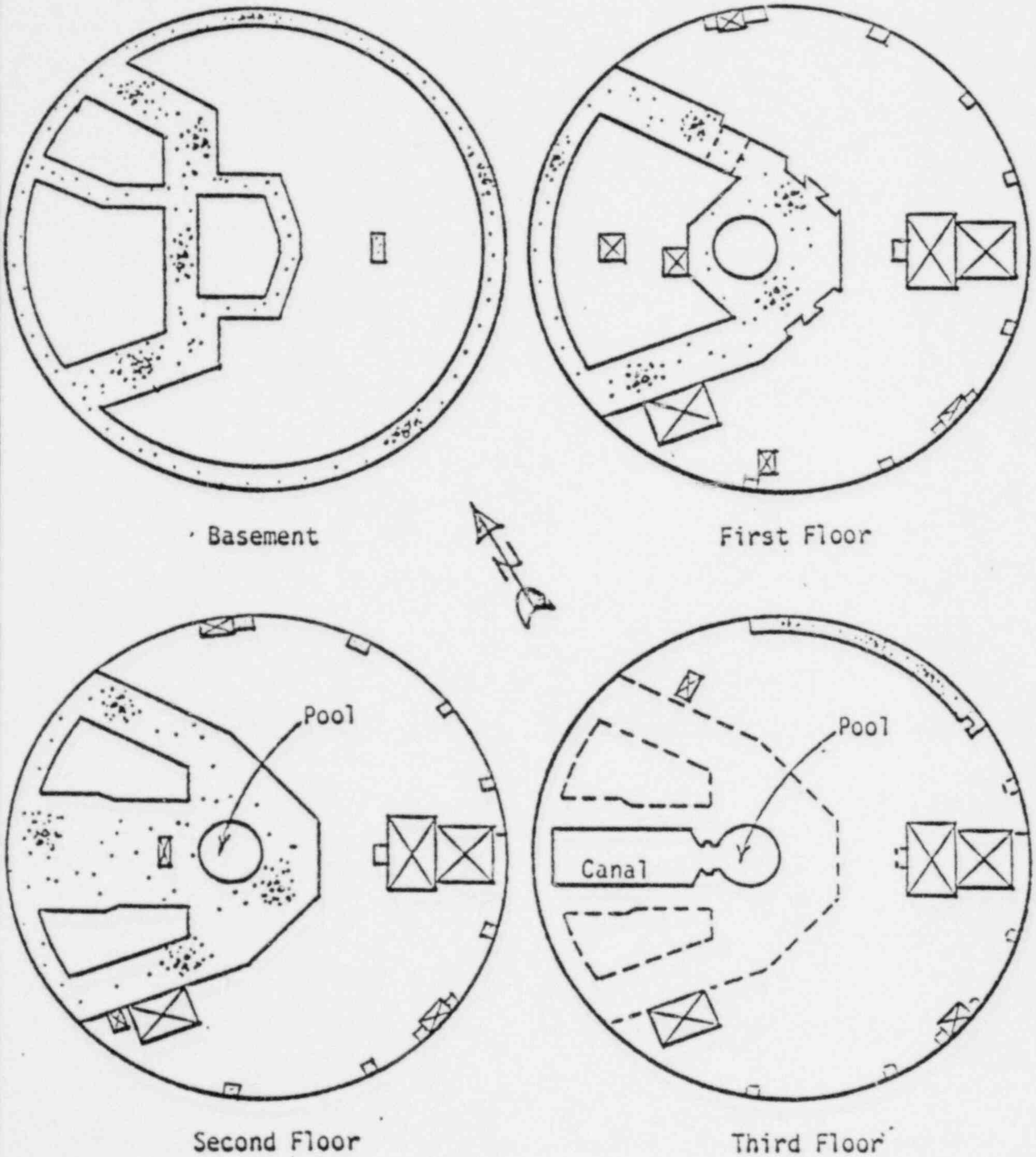

FIGURE 3-6 REACTOR BUILDING FLOOR PLANS

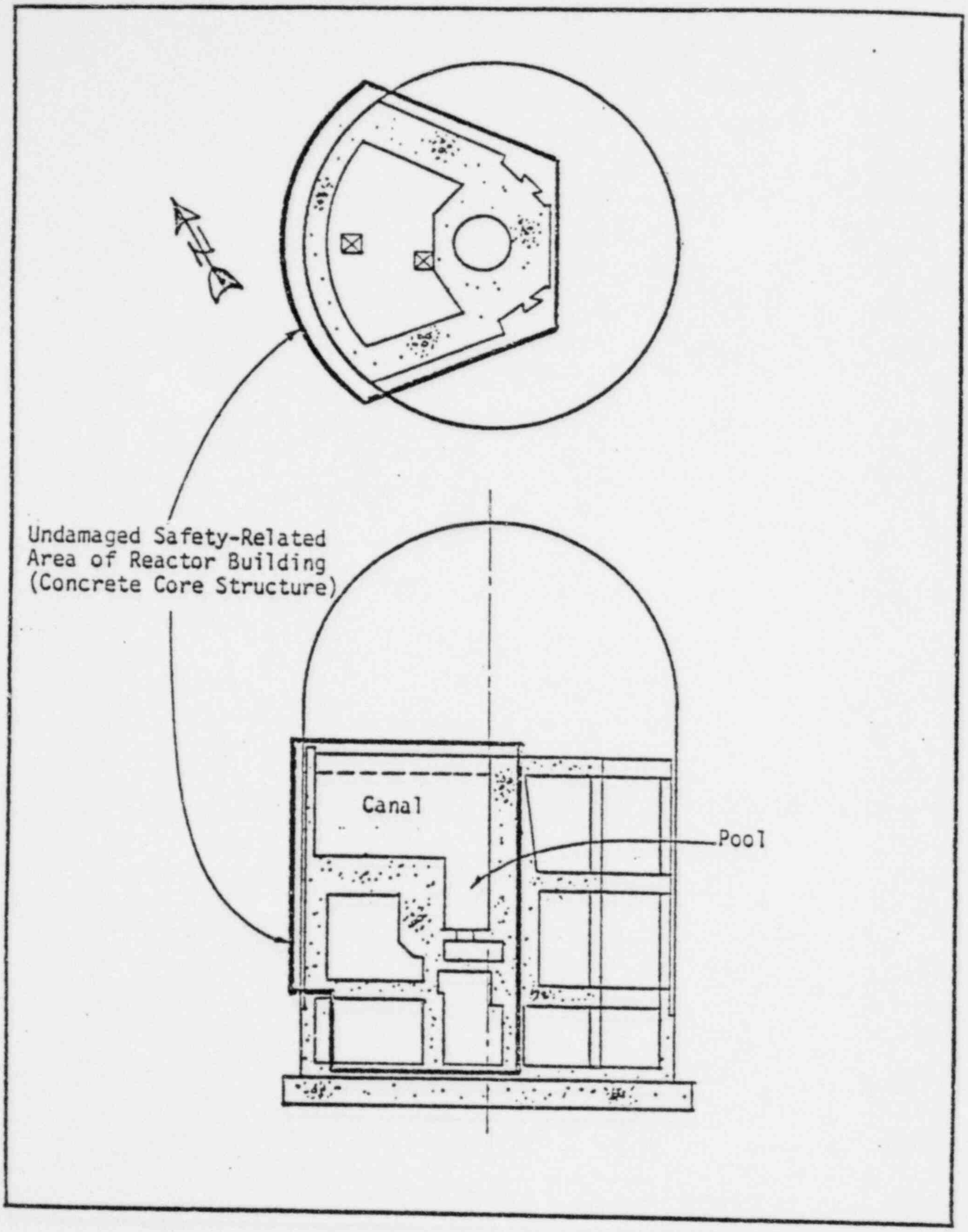

FIGURE 3-7 REACTOR BUILDING SAFETY-RELATED AREA

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BASES FOR STRUCTURAL INVESTIGATIONS

- 0.8g EFFECTIVE GROUND ACCELERATION AND RG 1.60 RESPONSE SPECTRUM SHAPE
- 1 METER SURFACE RUPTURE OFFSET
- 1 METER OFFSET FOLLOWED BY 0.8g SEISMIC EVENT

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VIBRATORY GROUND MOTION ANALYSES

LINEAR ELASTIC ANALYSES

- LUMPED MASS MODEL
- DYNAMIC RESPONSE
- PARAMETRIC ANALYSES
- FLOOR RESPONSE SPECTRA
- STRESSES IN CONCRETE
- CONCLUSION: Structure Is Adequate

NONLINEAR ANALYSES

- SLIDING
- UPLIFT
- CONCRETE DUCTILITY
- STABILITY
- CONCLUSION: Linear Elastic Analyses Are Conservative

PIPING AND EQUIPMENT

- LINEAR DYNAMIC ANALYSES
- CONSERVATIVE STATIC ANALYSES
- MODIFICATIONS WHEN REQUIRED

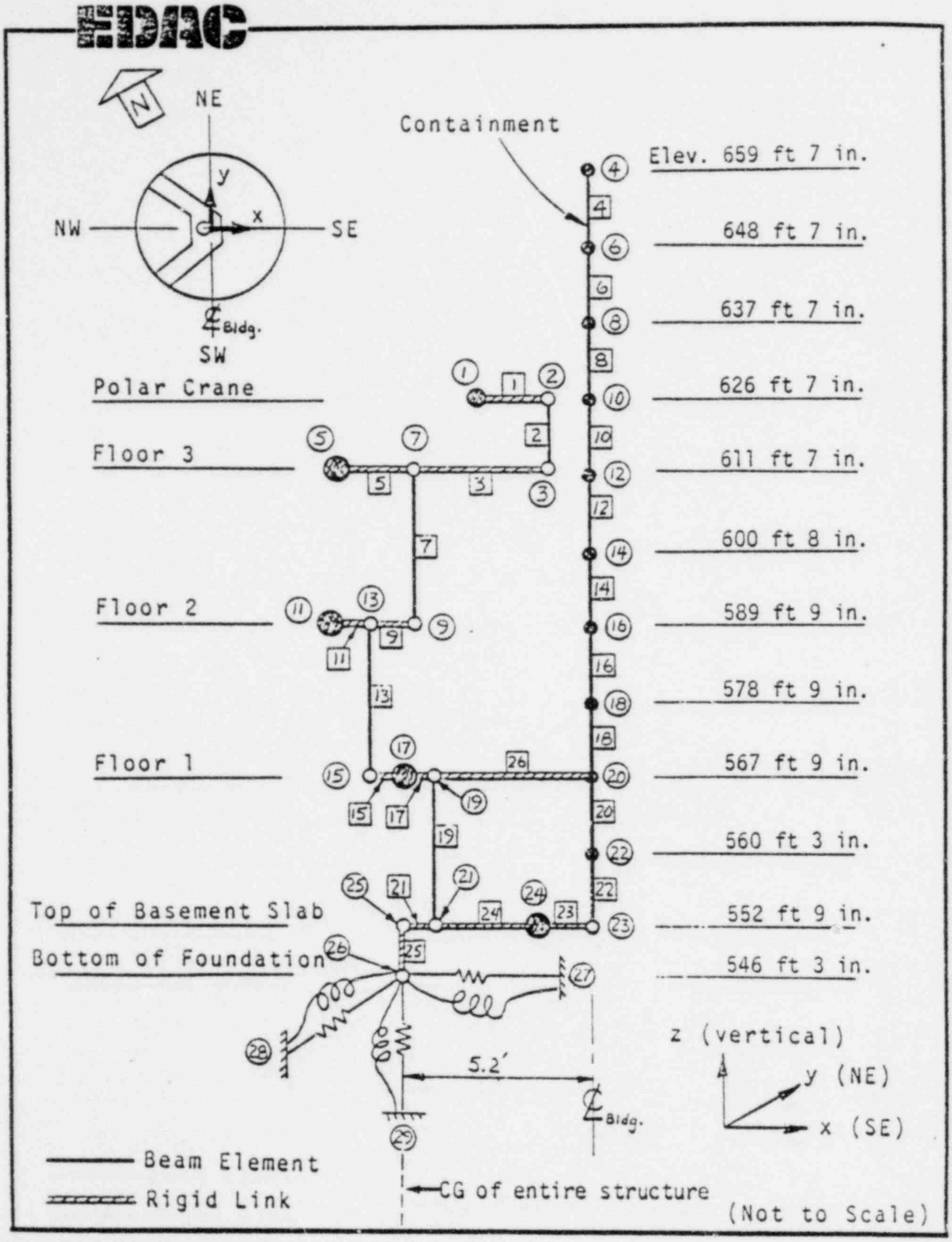

FIGURE 2-5 MATHEMATICAL MODEL FOR THE LINEAR ELASTIC DYNAMIC ANALYSES

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SURFACE RUPTURE OFFSET ANALYSES

- PHYSICAL CASES
- SELECTED CASE FOR ANALYSIS (Extreme Bound)
- CONCLUSION: Structure, Related Piping and Equipment are Adequate

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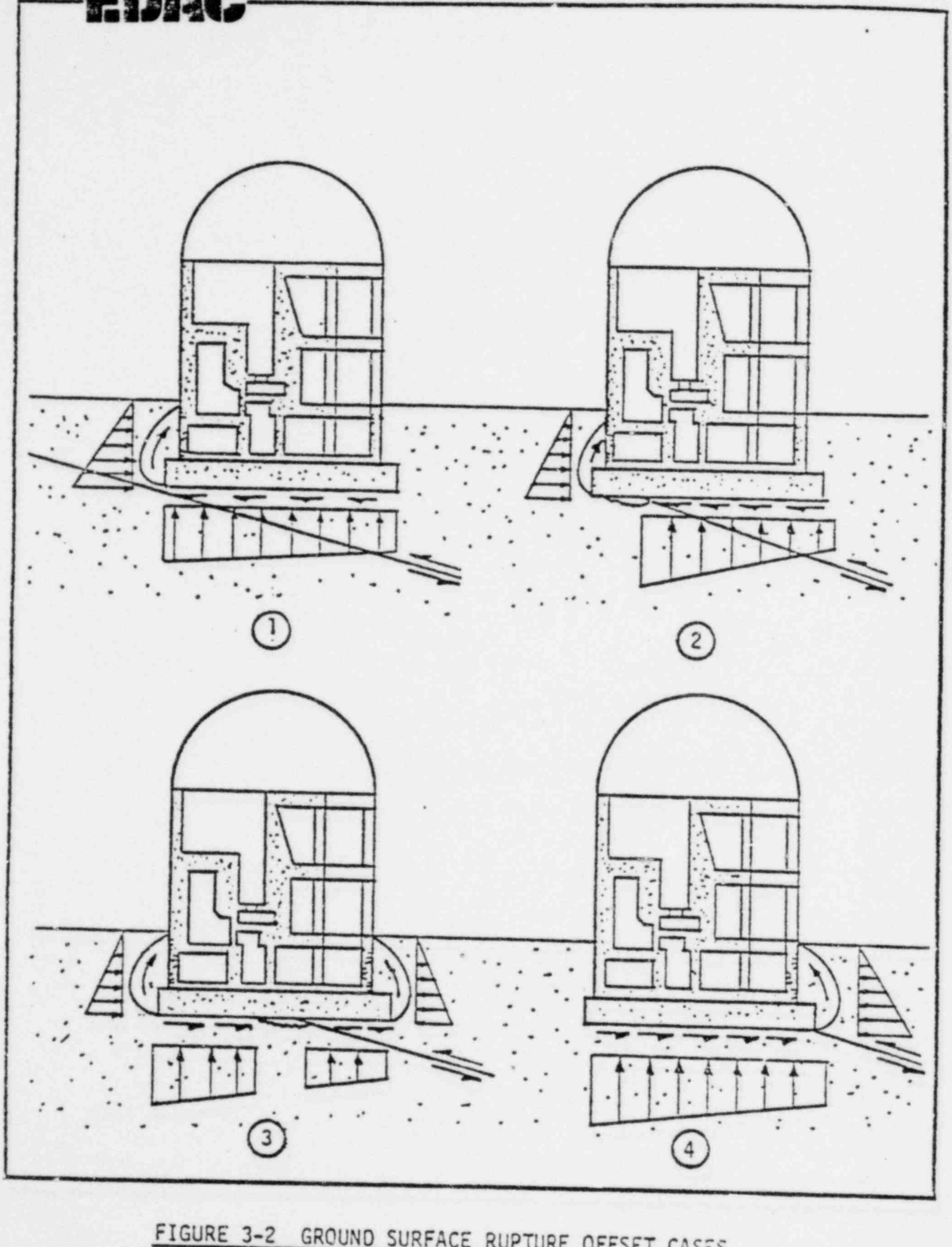

FIGURE 3-2 GROUND SURFACE RUPTURE OFFSET CASES

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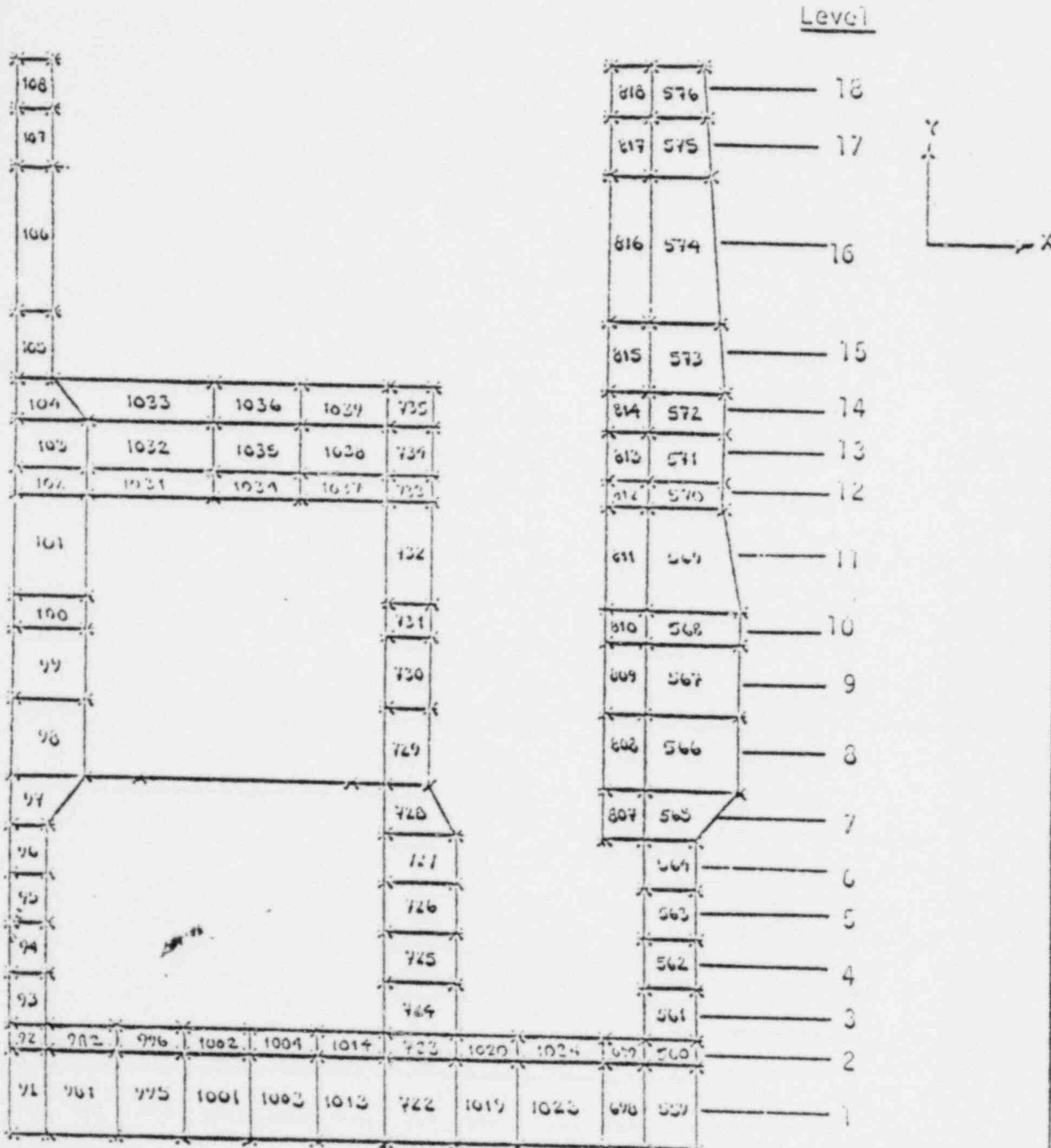

FIGURE A-1 VERTICAL SECTION OF REACTOR BUILDING CORE MODEL

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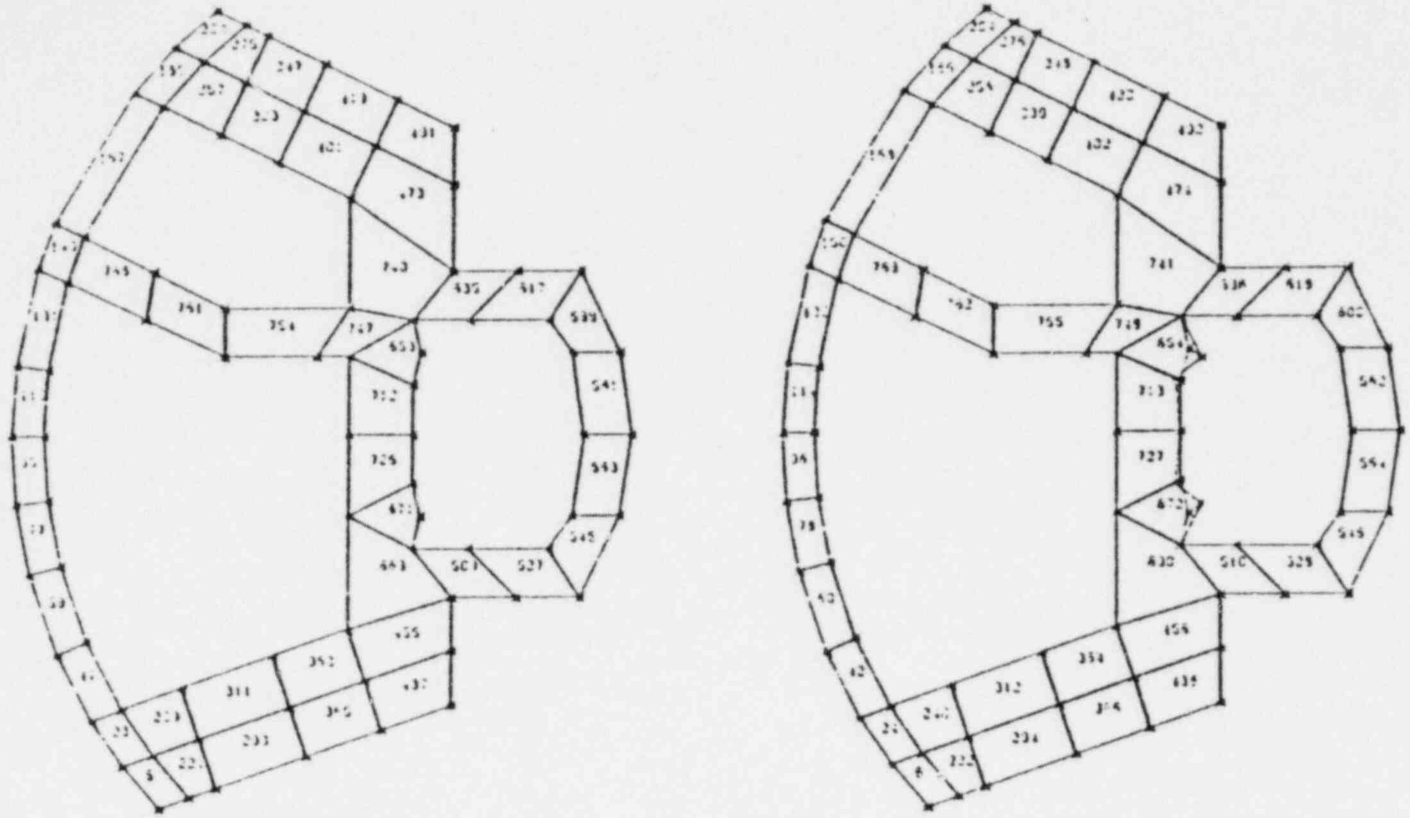

Level 5

Level 6

See Figure A-1 for location of element levels

FIGURE A-4 MODEL ELEMENTS LEVELS 5 AND 6

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FINDINGS OF STRUCTURAL INVESTIGATIONS

REACTOR BUILDING

- SAFETY-RELATED CONCRETE CORE STRUCTURE WILL REMAIN INTACT

REACTOR BUILDING SAFETY-RELATED PIPING SYSTEMS AND COMPONENTS

- RESTRAINTS ADDED TO PIPING SYSTEM
- RPV LATERAL SUPPORT STRENGTHENED
- RESTRAINTS ADDED TO HEAT EXCHANGERS
- FUEL STORAGE TANKS REPLACED
- MISSILE IMPACT SYSTEM INSTALLED
- OTHER COMPONENTS WILL RESIST SEISMIC FORCES

FUEL FLOODING SYSTEM

- COMPONENTS WILL RESIST SEISMIC FORCES

SUMMARY OF

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PRESENTATION OUTLINE

RECENT STRUCTURAL INVESTIGATIONS

Part 1. Earthquake on Postulated Verona Fault

Part 2. Earthquake on Calaveras Fault

Part 3. Piping and Equipment

Part 4. Conservatisms in the Seismic Evaluations

Part 5. Summary of Conclusions

<u>Focus</u>: Concrete core structure and related piping and equipment

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PRESENTATION

PART 1

ADDITIONAL INVESTIGATIONS TO DETERMINE THE EFFECTS OF COMBINED VIBRATORY MOTIONS AND SURFACE RUPTURE OFFSET DUE TO AN EARTHQUAKE ON THE POSTULATED VERONA FAULT

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PRESENTATION OUTLINE

- PRELIMINARY COMMENTS
- GROUND MOTION CRITERIA
- HYPOTHETICAL SURFACE RUPTURE OFFSET CRITERIA
- LOAD COMBINATION CASES
- COMPONENTS OF EARTHQUAKE VIBRATORY MOTIONS
- ANALYTICAL MODEL
- STRESS ANALYSES AND CHECK AGAINST CAPACITIES
- CONCLUSIONS

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PRELIMINARY COMMENTS

- Probability of occurrence of surface rupture offset (SRO) is so low that it should not be included in design bases.

- Evaluations for combined load case of SRO and vibratory motions have been performed in response to USNRC requests.

- Assumed that postulated SRO will tend to "lift" (as well as shake) the structure.

- Focus of the evaluations was on concrete core structure of Reactor Building.

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LOAD COMBINATION CASES

- Two Main Parameters of Interest
  - Vibratory Ground Motion
  - Unsupported Length
- Load Combinations Based on Probabilistic Considerations
- Load Combinations Based on Physical Argument (Soil Pressure Analyses)

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GROUND MOTION CRITERIA

- Effective Horizontal Ground Acceleration: 0.40g
- Effective Vertical Ground Acceleration: 0.27g

- Response spectrum shape: Regulatory Guide 1.60

HYPOTHETICAL SURFACE RUPTURE OFFSET CRITERIA

- SRO = 1.0m

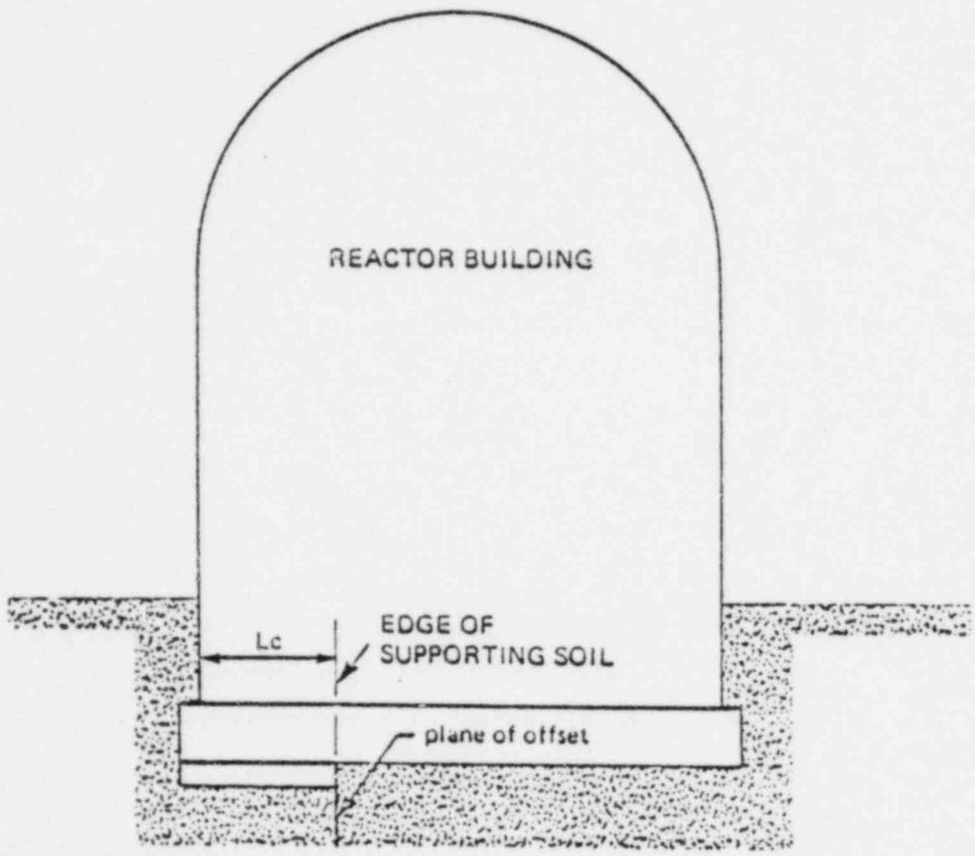

FIGURE 1 HYPOTHETICAL "UNSUPPORTED LENGTH," Lc

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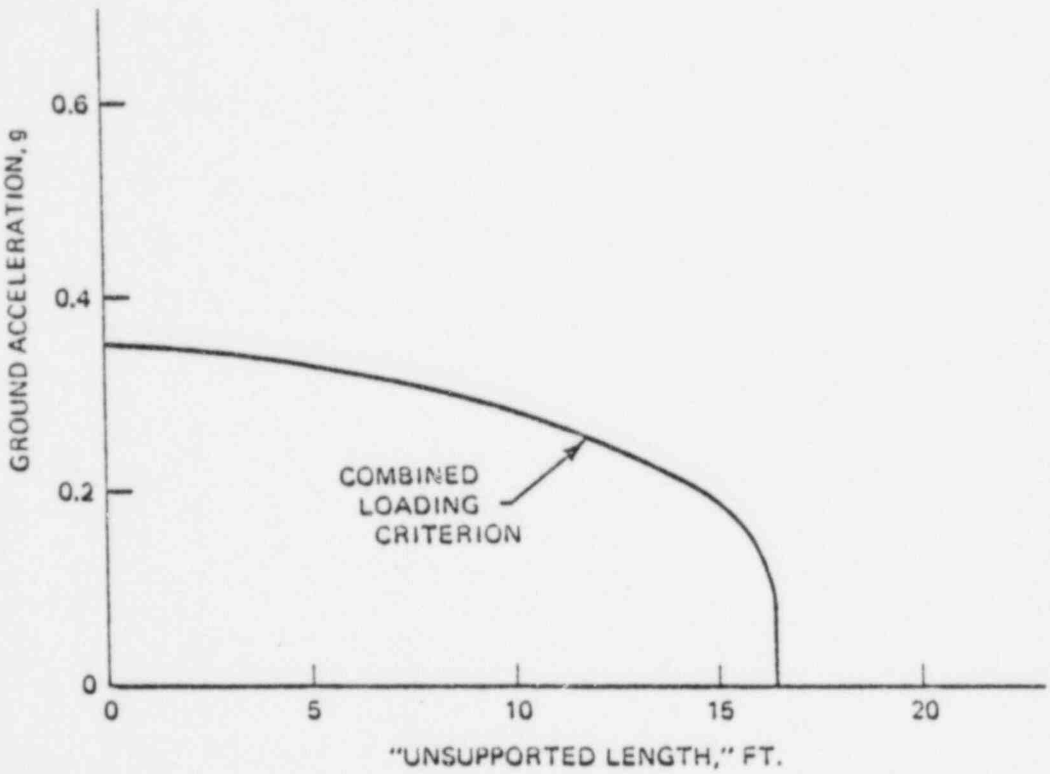

FIGURE 2 COMBINATION OF LOADINGS BASED ON PROBABILISTIC CONSIDERATIONS (AFTER REF. 3)

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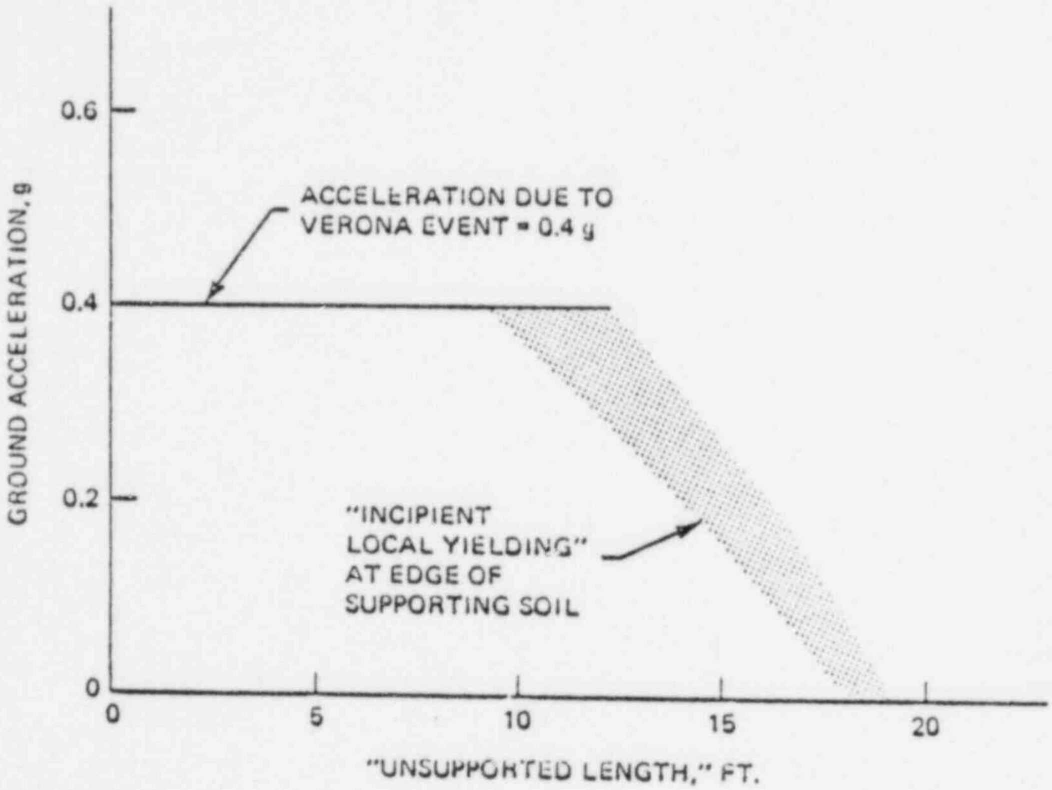

FIGURE 3 RESULTS OF SOIL PRESSURE ANALYSES

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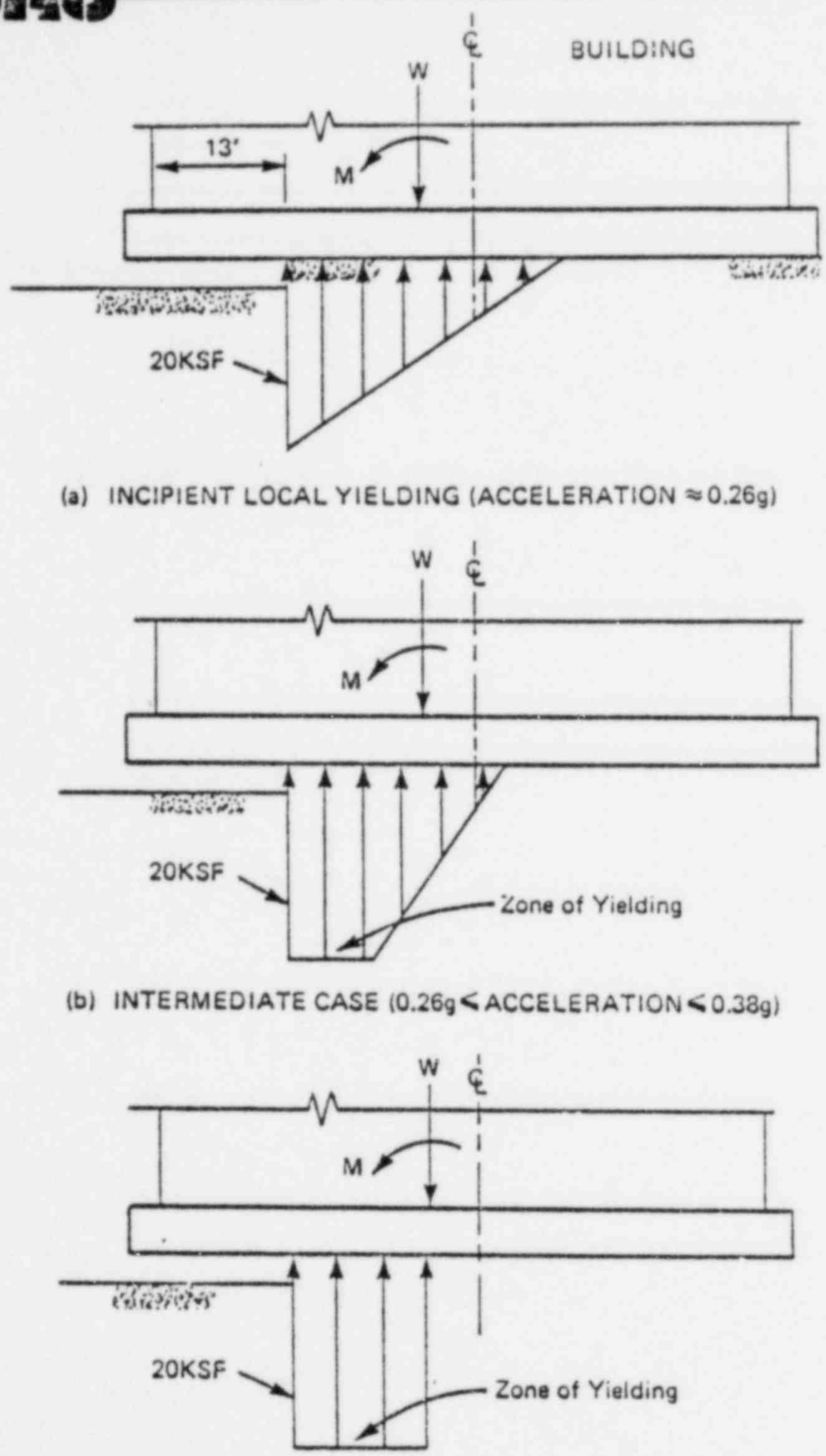

(a) INCIPIENT LOCAL YIELDING (ACCELERATION ≈ 0.26g)

(b) INTERMEDIATE CASE (0.26g < ACCELERATION < 0.38g)

(c) UPPER LIMIT ON LOCAL YIELDING (ACCELERATION ≈ 0.38g)

FIGURE 2. SOIL PRESSURE DISTRIBUTIONS (For Example Case of 13 ft Unsupported Length)

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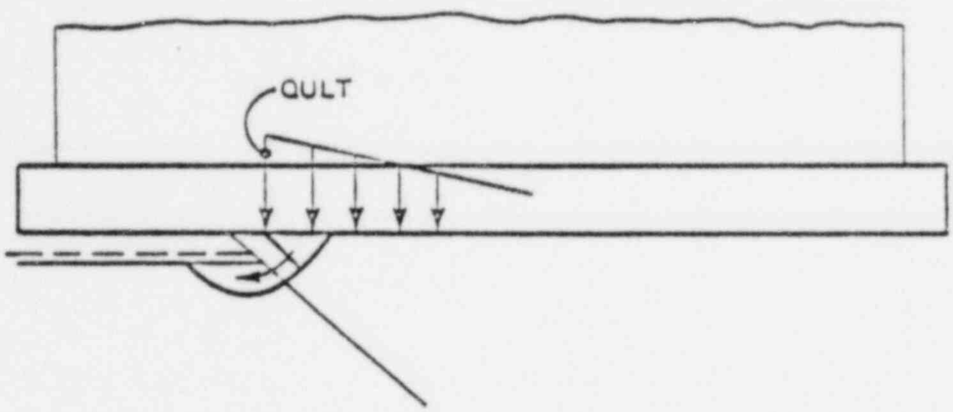

RAPID LOADING AT Q < 20 ksf CAUSES LOCAL YIELDING
OF FOUNDATION SOILS

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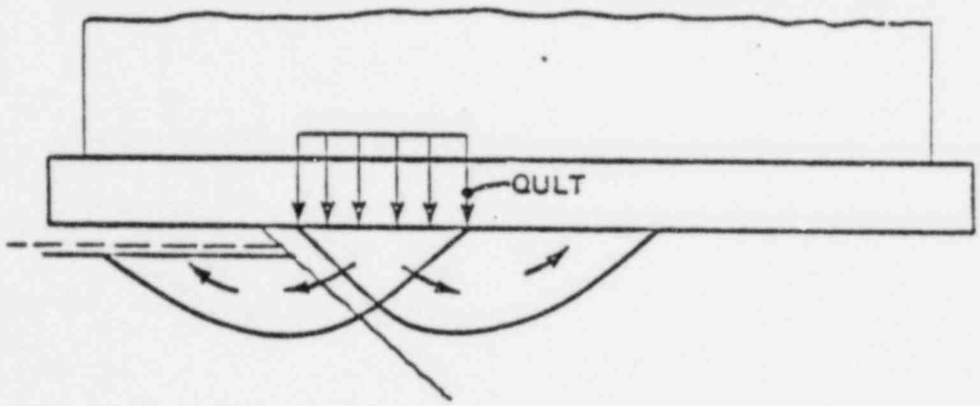

RAPID LOADING AT QULT ≈ 20 ksf CAUSES LOCAL FAILURE
OF FOUNDATION SOILS

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PARAMETERS FOR

SELECTED ANALYSIS CASE

- Ground Acceleration = 0.30g
- Unsupported Length = 17 ft.
- Conservative from Two Points of View
  - Probabilistic
  - Physical (Soil Deformations)

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COMPONENTS OF EARTHQUAKE

VIBRATORY MOTIONS

Case	H1 (0.3g)	H2 (0.3g)	Vertical (0.2g)
1	± 100%	± 40%	± 40%
2	± 40%	± 100%	± 40%
3	± 40%	± 40%	± 100%

Example:

Case 1.1 HI=+0.3g H2=+0.12g V=+0.08g

ANALYTICAL MODEL

- 3-D Finite Element
- Used Previously in Phase 2 Analyses
- Modified to Represent 17 ft. Unsupported Length
- Inertia forces are conservative

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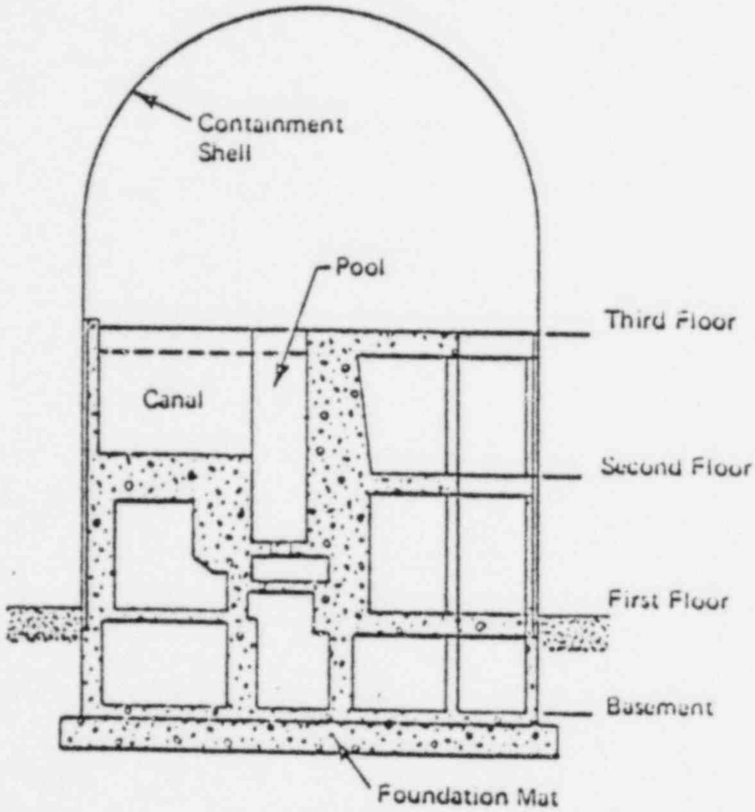

(Reprinted from Figure 3-5 of Reference 1)

FIGURE 4 REACTOR BUILDING VERTICAL CROSS-SECTION

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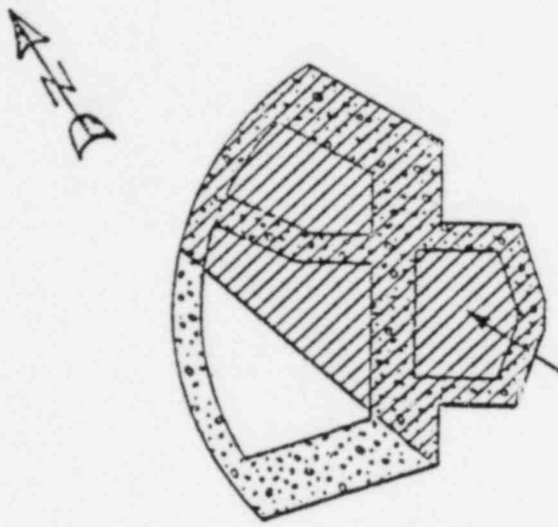

FIGURE 5 REGION OF SUPPORT IN ANALYTICAL MODEL

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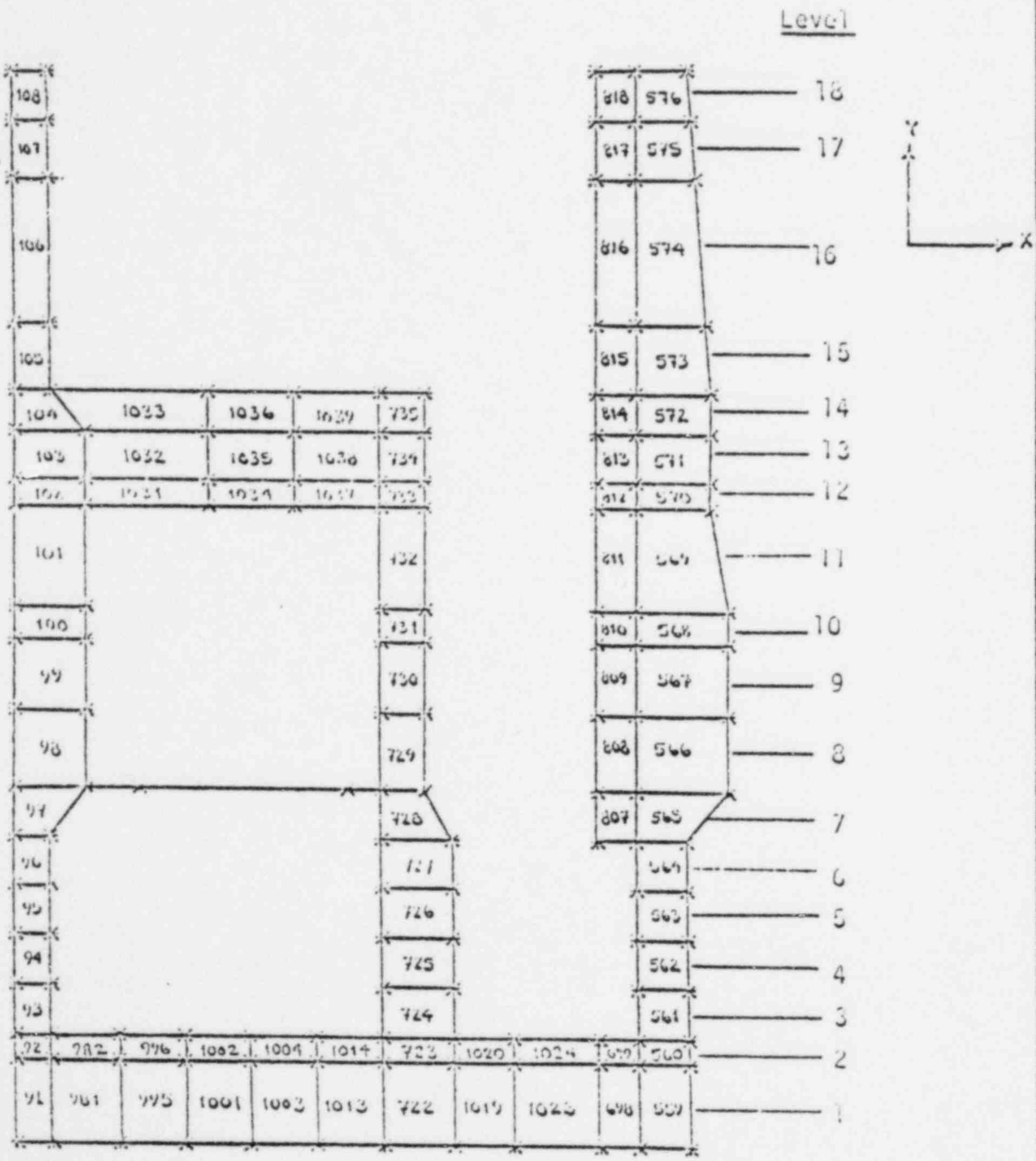

FIGURE A-1 VERTICAL SECTION OF REACTOR BUILDING CORE MODEL

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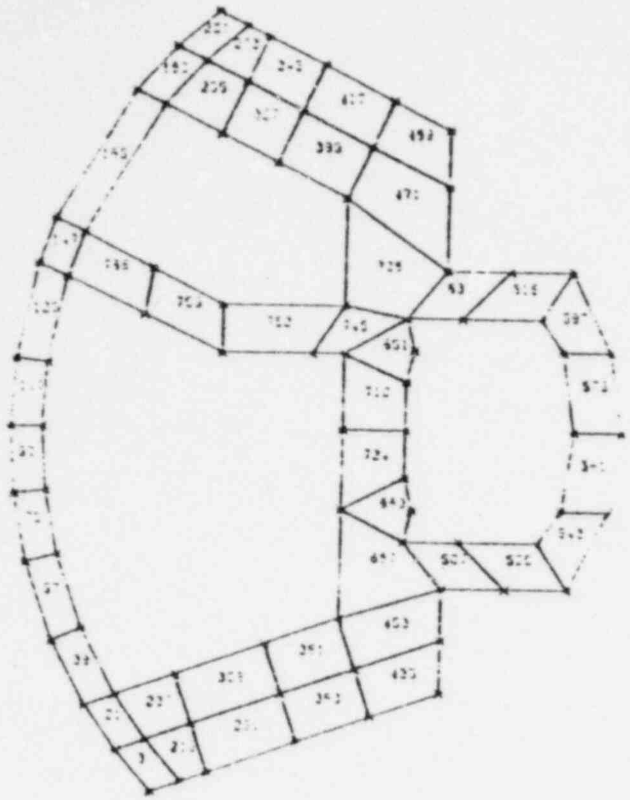
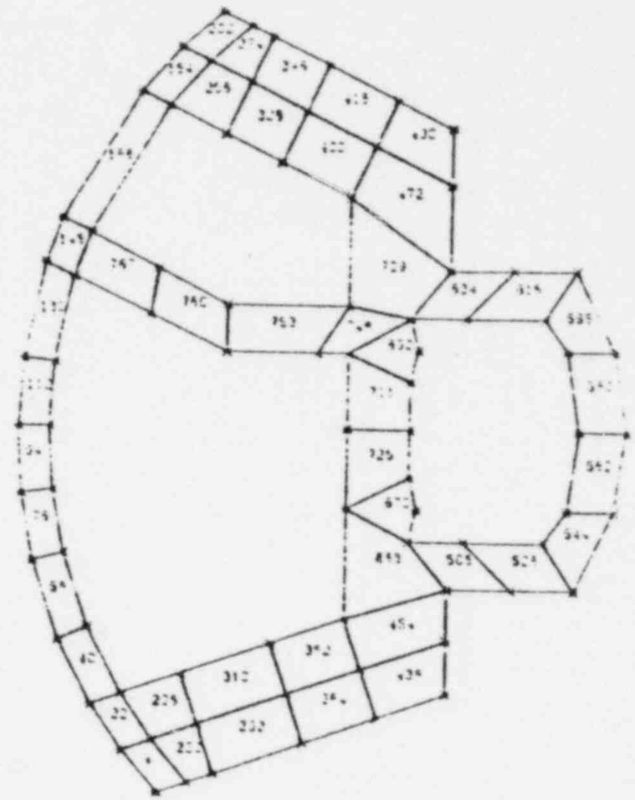


Level 3



Level 4

See Figure A-1 for location of element levels

FIGURE A-3 MODEL ELEMENTS LEVELS 3 AND 4

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STRESS ANALYSES

AND CHECK AGAINST CAPACITIES

- Capacity (initiation of cracking) = $6\sqrt{f_c'}$

- Only 2 elements with stress ratios over 0.83 (which corresponds to $5\sqrt{f_c'}$)

- No elements above first floor with stress ratios above $2.9\sqrt{f_c'}$

- Highest stressed element above first floor (Element 735, Level 14, Figure 6)

  - Stress ratio based on capacity of $6\sqrt{f_c'}$ = 0.49 (tensile stress).

  - Maximum stress = $2.9\sqrt{f_c'}$.

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STRESS ANALYSES AND CHECK AGAINST CAPACITIES

-continued-

- Highest stressed element between basement and first floors (Element 749, Level 7, Figure 7)
  - Stress ratio based on capacity of $6\sqrt{f'_c}$ = 0.99 (tensile stress)
  - Stress ratio based on capacity of $6\sqrt{f'_c}$ = 0.85 (shear stress).

- Average stress ratio in elements surrounding highest stressed element $\approx 2\sqrt{f'_c}$

- Estimated average shear stress between basement and first floors:
  - Stress ratio based on capacity of $6\sqrt{f'_c} \approx 0.05$.
  - Maximum stress $\approx 0.3\sqrt{f'_c}$.

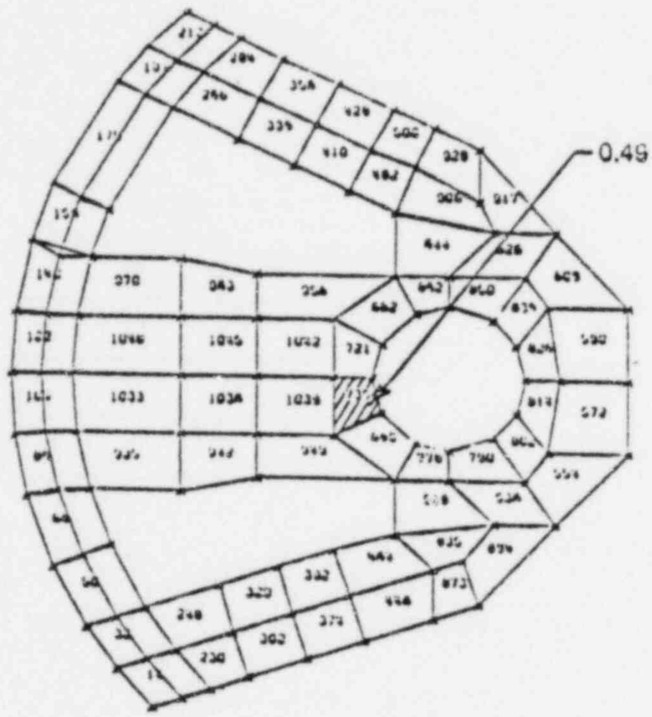

FIGURE 6 PLAN – LEVEL 14

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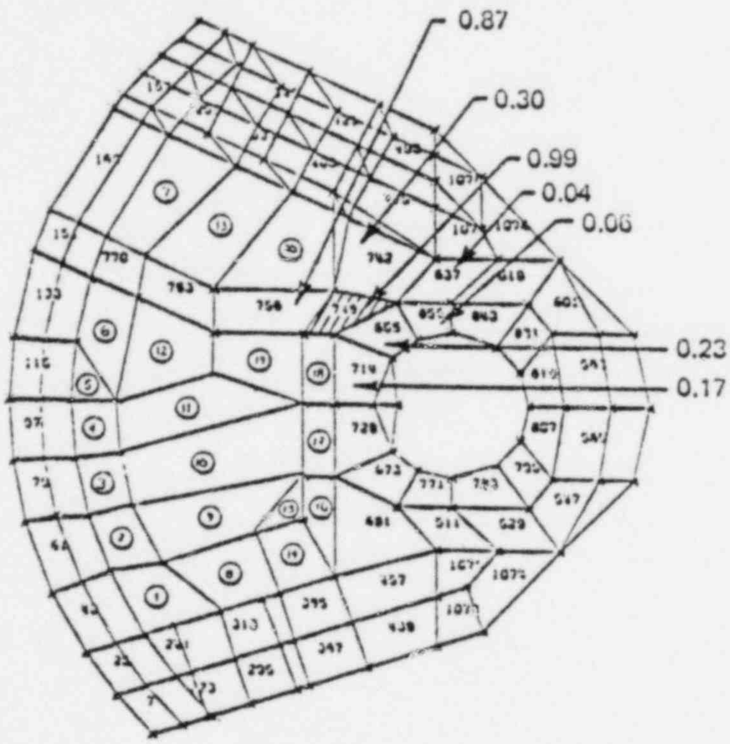

FIGURE 7 PLAN – LEVEL 7

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CONCLUSIONS

- Recent analyses demonstrated that structure can withstand:
  - 17 ft/0.30g load case

- Previous Phase 2 analyses demonstrated that structure can withstand:
  - 20 ft/0.0g load case
  - 0 ft/0.80g load case

- Capacity curve demonstrates that concrete core structure can withstand all reasonable load combinations.

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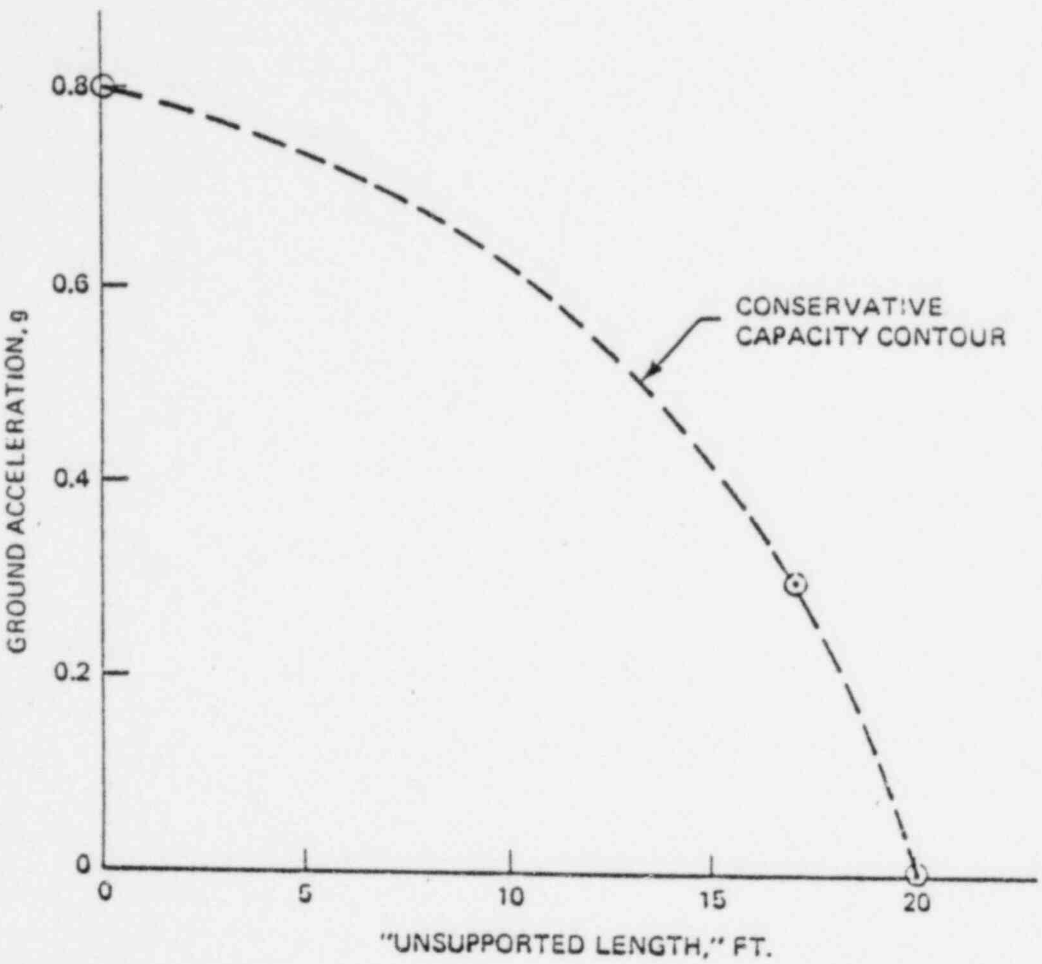

FIGURE 11 CAPACITY CONTOUR FOR COMBINED LOADING

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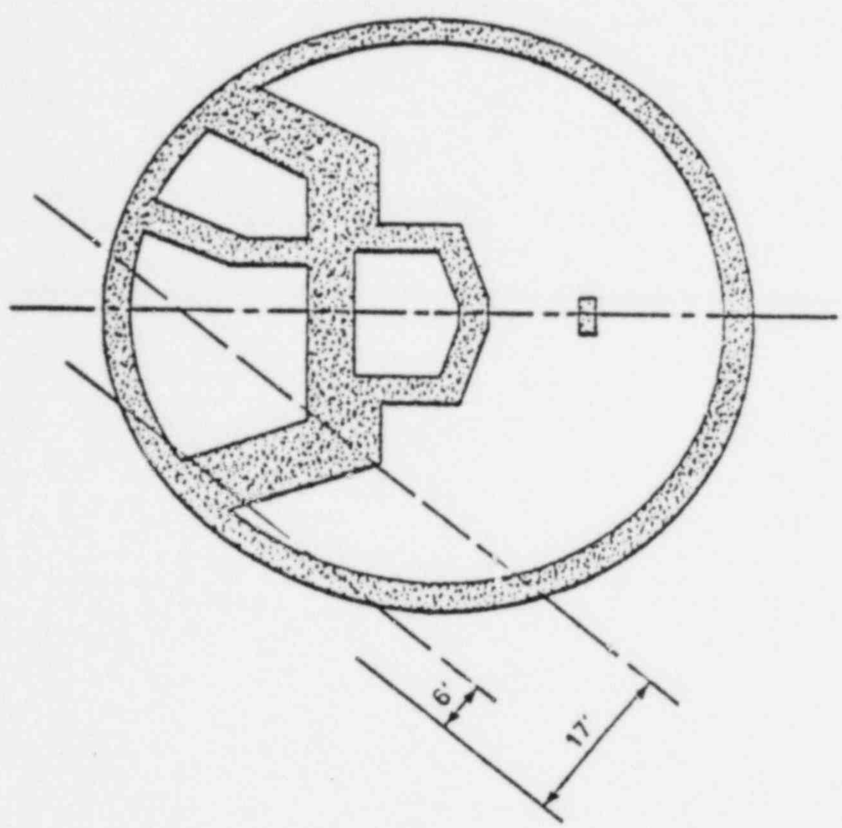

PLAN VIEW – SHORT "UNSUPPORTED LENGTH" (~6')

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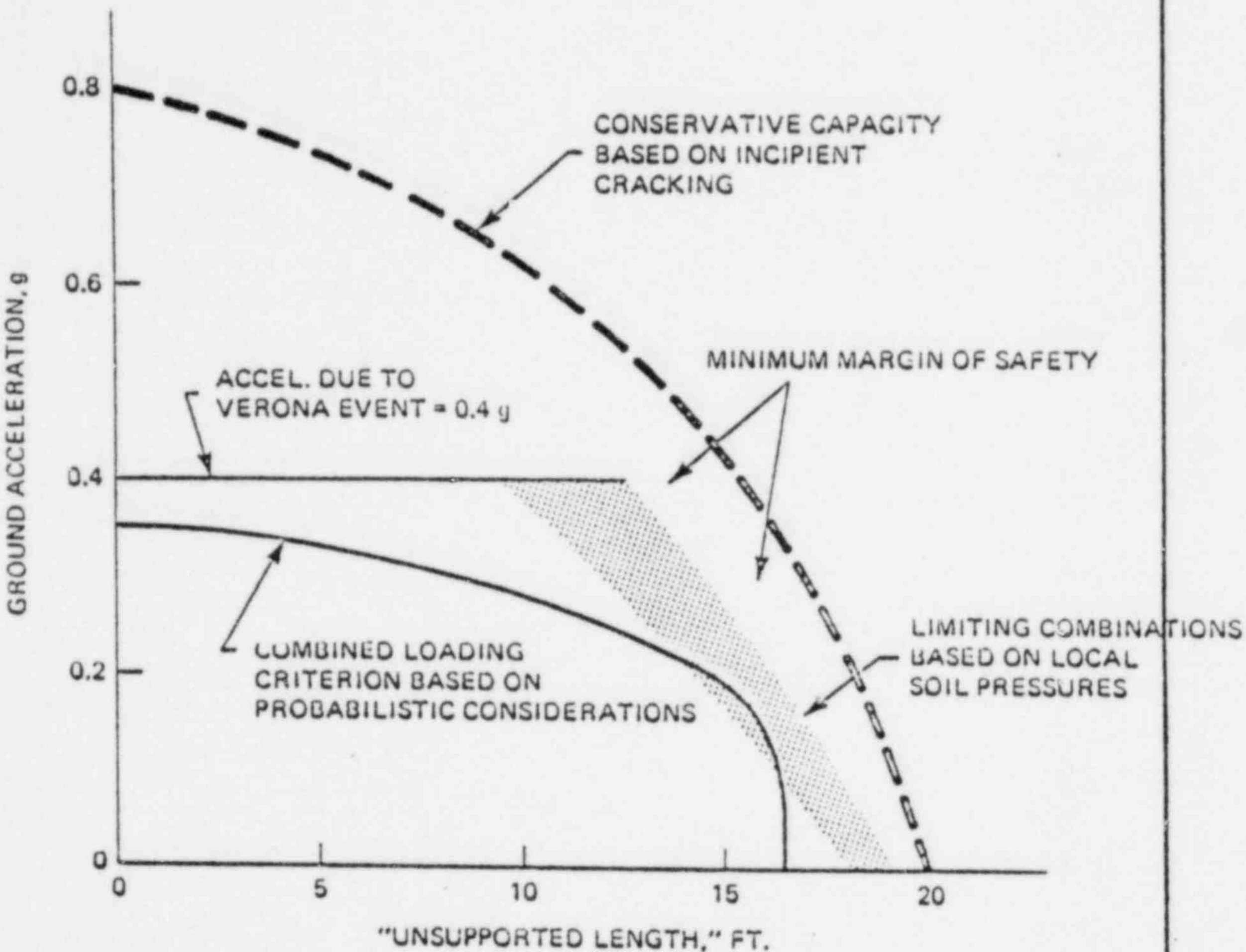

FIGURE 12 LOADING VS CAPACITY

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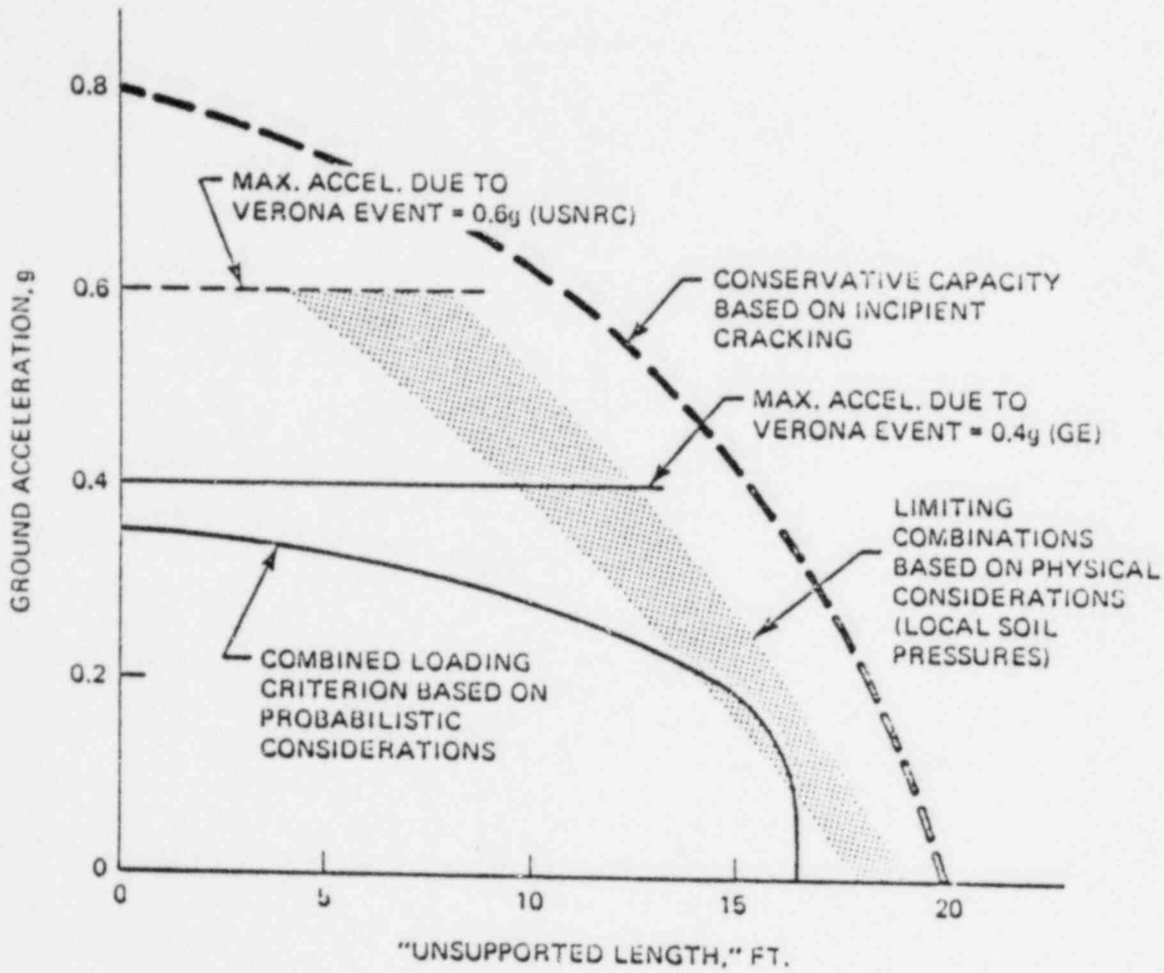

LOADING VS CAPACITY

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PRESENTATION

PART 2

ADDITIONAL INVESTIGATIONS TO DETERMINE EFFECTS OF
VIBRATORY MOTIONS DUE TO AN EARTHQUAKE
ON THE CALAVERAS FAULT

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PRESENTATION OUTLINE

- GROUND MOTION CRITERIA
- COMPONENTS OF EARTHQUAKE VIBRATORY MOTIONS
- EVALUATIONS OF BUILDING

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GROUND MOTION CRITERIA

- Effective horizontal ground acceleration: 0.60g
- Effective vertical ground acceleration: 0.40g
- Response spectrum shape: Regulatory Guide 1.60

COMPONENTS OF EARTHQUAKE VIBRATORY MOTIONS

Case	H1 (0.6g)	H2 (0.6g)	Vertical (0.4g)
1	±100%	± 40%	± 40%
2	± 40%	±100%	± 40%
3	± 40%	± 40%	±100%

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EVALUATIONS OF BUILDING

- PHASE 2 LINEAR ELASTIC DYNAMIC ANALYSIS WAS PERFORMED FOR 0.8g HORIZONTAL GROUND ACCELERATION.
- CONSERVATIVE INERTIA FORCES WERE OBTAINED.
- SEVERE MODEL WAS USED.
- STRESS ANALYSES SHOWED THAT THE CONCRETE STRUCTURE IS ADEQUATE.

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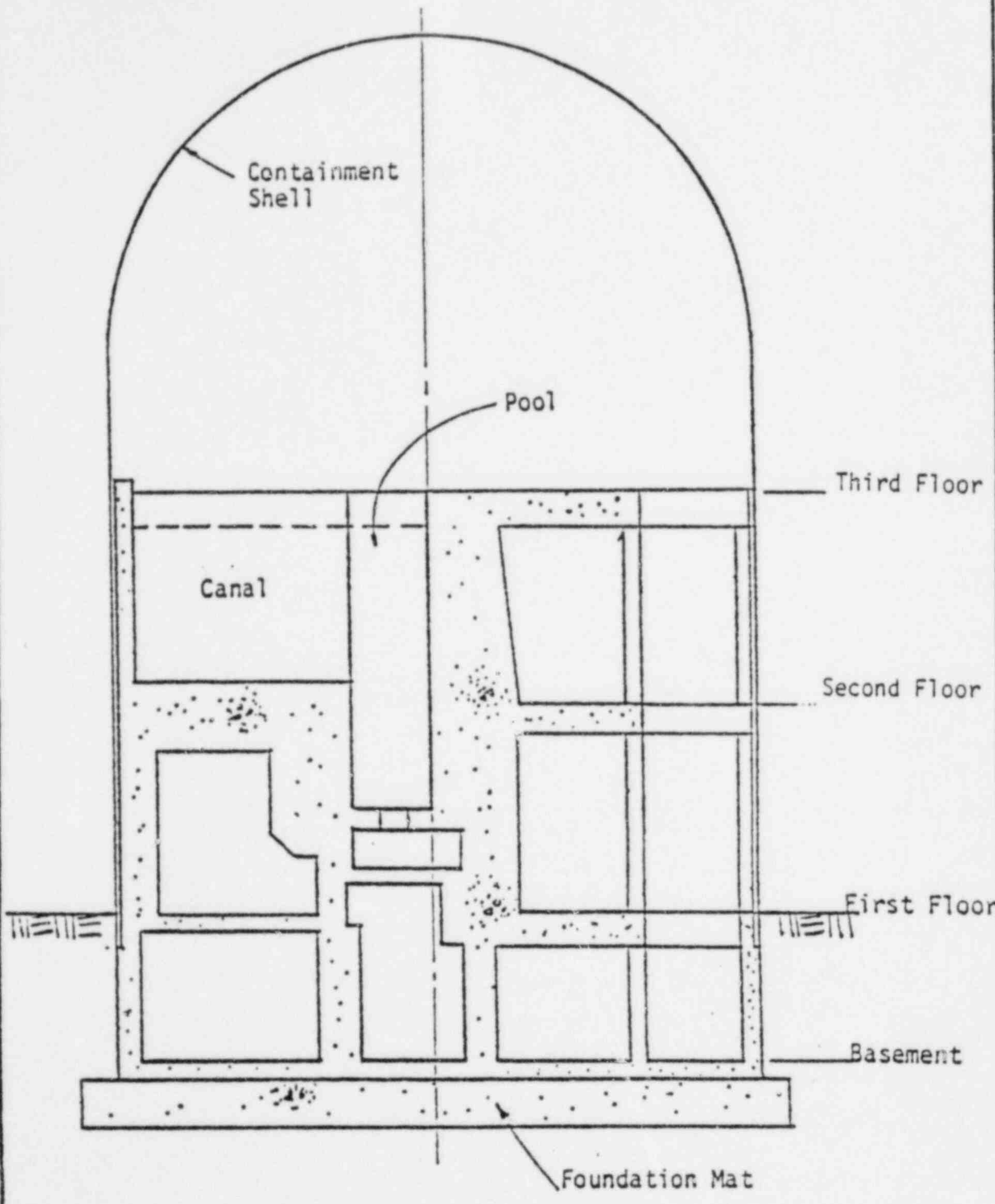

FIGURE 3-5 REACTOR BUILDING VERTICAL SECTION

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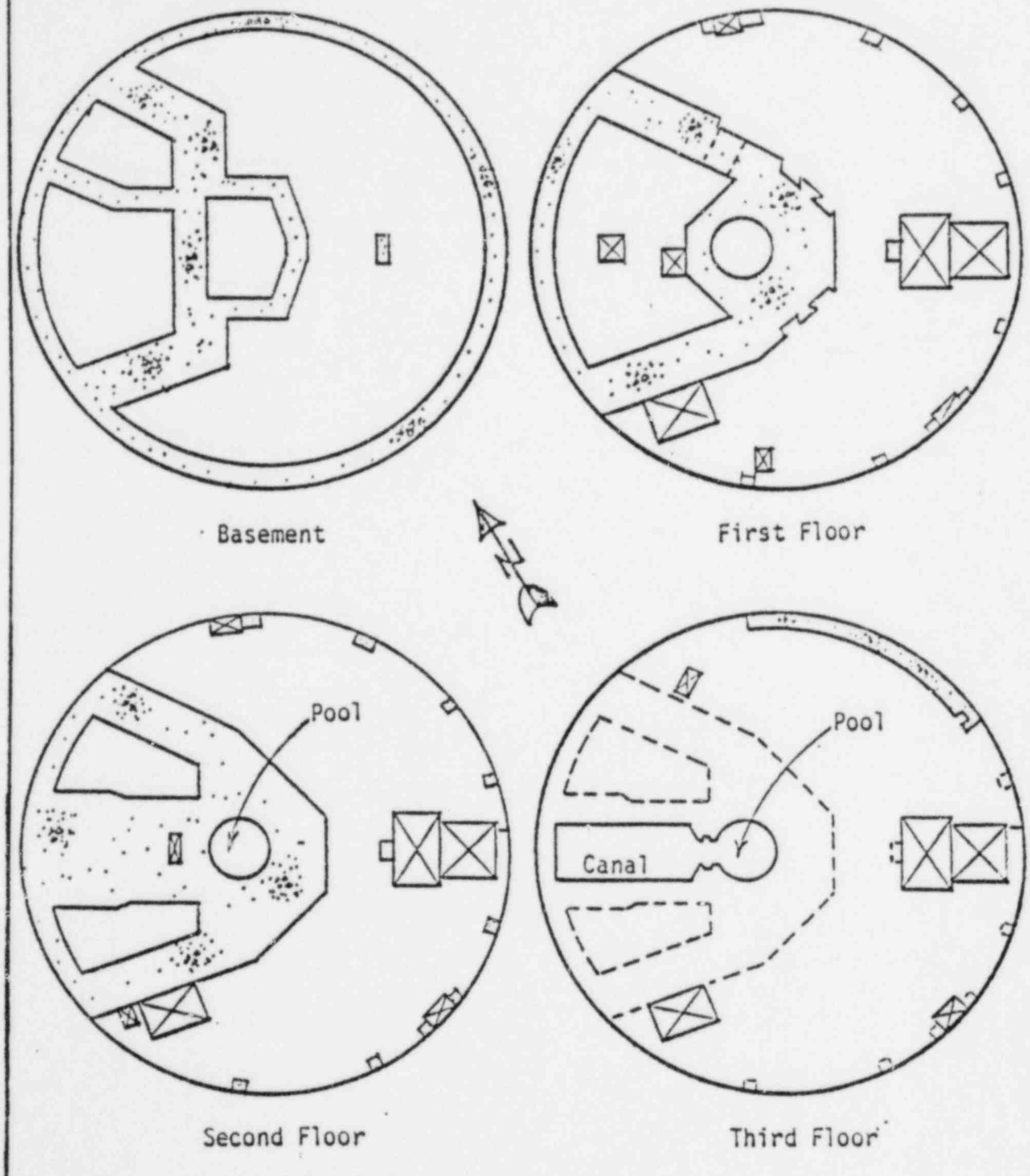

FIGURE 3-6 REACTOR BUILDING FLOOR PLANS

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PRESENTATION

PART 3

ADDITIONAL INVESTIGATIONS TO DETERMINE EFFECTS OF VIBRATORY MOTIONS DUE TO AN EARTHQUAKE ON PIPING AND EQUIPMENT

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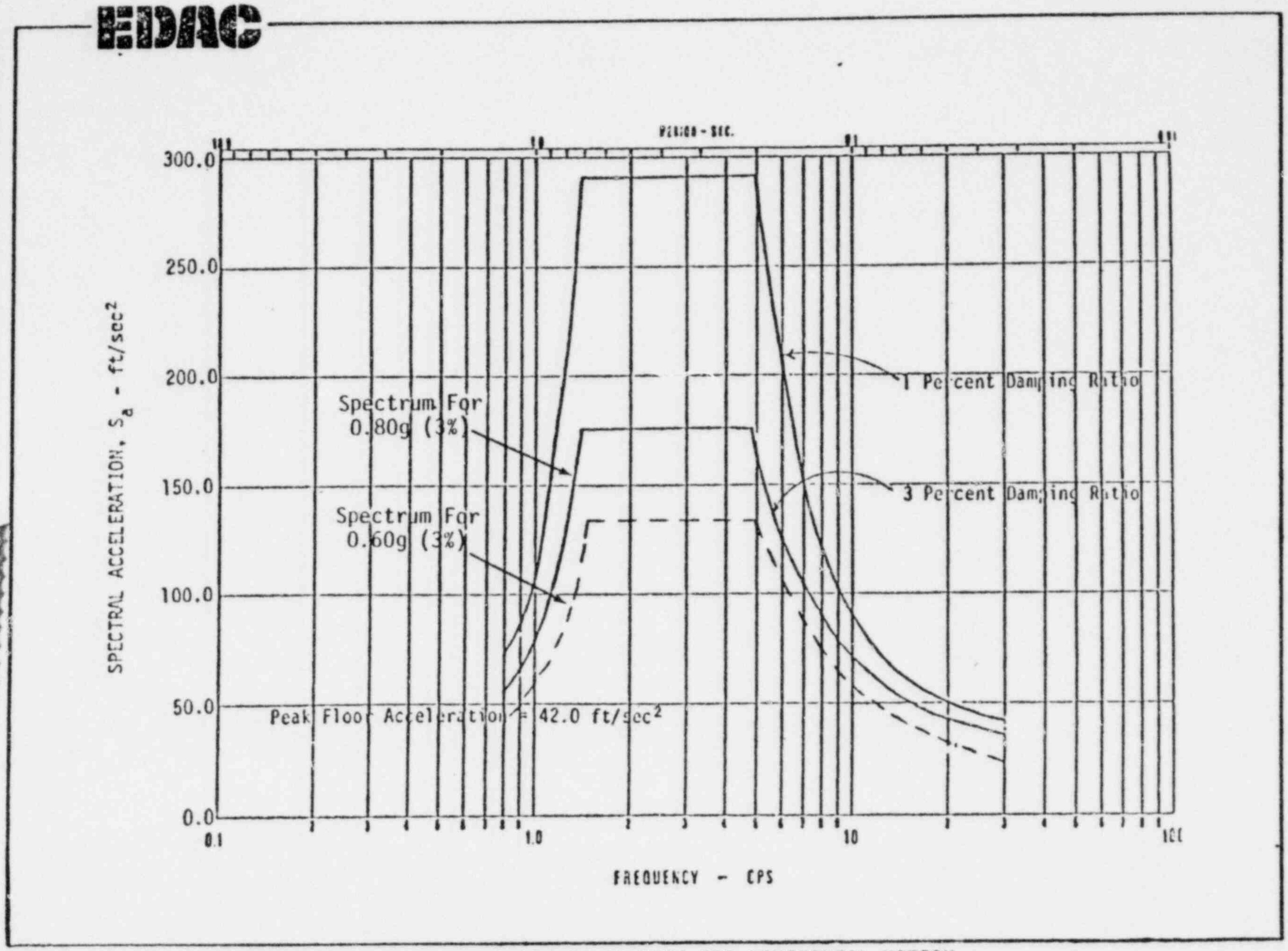
FLOOR RESPONSE SPECTRA

- Originally obtained from lumped mass linear elastic dynamic analysis (0.8g)
- Amplitudes and widths of peaks are conservative
- Calculated H1, H2, V spectra (building global axes) were enveloped and broadened to produce H and V spectra.
- Equipment analyses were performed for h1, h2, and v directions (equipment global axes) and responses were combined by SRSS
- Spectra for 0.6g case are enveloped by 0.8g design case (see figure)
  - Primary cooling system run 1, f_1 = 7.4Hz
  - Primary cooling system run 2, f_1 = 11.4 Hz
  - HE101, f_1 = 19.1Hz
  - Control rod drive assembly, $f_1 \geq$ 33Hz, f_1' > 13Hz
  - Incore shuttle drive assembly, f_1 > 33Hz



ENVELOPE FLOOR RESPONSE SPECTRA FOR HORIZONTAL MOTION

AT ELEVATION 611.0 FT 7.0 IN.

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PRESENTATION

PART 4

CONSERVATISMS IN THE SEISMIC EVALUATIONS

OF THE GETR REACTOR BUILDING

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CONSERVATISMS IN THE SEISMIC EVALUATIONS OF THE GETR REACTOR BUILDING

- Many conservatisms exist in the seismic evaluations of the GETR Reactor Building.
- Conservatisms are inherent in
  - Selection of seismic criteria which quantify postulated seismic events,
  - Analytical procedures used to determine the response of the structure to the postulated events,
  - The acceptance criteria for the structure.
- Conservatisms tend to over-estimate response and under-estimate capacities.

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CONSERVATISMS IN THE SEISMIC EVALUATIONS OF THE GETR REACTOR BUILDING

(Continued)

- Actual overall safety margin is substantial.

- Objective is to point out the conservatisms which exist, and illustrate the likely influence of these conservatisms on the total safety margin.

- Permits, as a minimum, the qualitative conclusion that the total safety margin is substantially above the values determined by the conservative seismic evaluations of the GETR Reactor Building.

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TABLE 1

SUMMARY LIST OF AREAS OF CONSERVATISM

CHARACTERIZATION OF EARTHQUAKES

1. Selection of a Low Probability Extreme Event
2. Use of Wide-Band Ground Response Spectra
3. Conservative Amplification Factors in Response Spectra
4. Duration of Time History of Input Motions
5. Decrease of Ground Motions With Depth
6. Propagation of Seismic Waves Beneath the Base of a Building of Finite Width ("Tau Effect")

POSTULATED VERONA FAULT

7. Postulated Surface Rupture Offset
8. "Unsupported Length" in Surface Rupture Offset Case

ANALYTICAL MODELS

9. Modeling Assumptions -- Response Models
10. Modeling Assumptions -- Stress Analysis Model
11. Embedment Effects
12. Additional Nonlinear Effects

STRENGTH AND CAPACITY

13. Static Versus Dynamic Strength
14. Concrete Strength
15. Energy Dissipation Capacity

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CONCLUSIONS

- There are numerous conservatisms in the procedures used to evaluate the adequacy of the GETR Reactor Building.
- Conservatisms are cumulative.
- Illustration of influence of conservatisms on total safety margin
  - Assume Loads (L) = Capacities (C) = 1.0 as calculated by conventional procedures.
  - Assume actual Loads, L' = 0.7L = 0.7
  - Assume actual Capacities, C' = 1.3C = 1.3
  - Actual safety margin = (1.3)/(0.7) = 1.9

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CONCLUSIONS

-continued-

- If all individual margins were quantified, the result would be a total margin of safety significantly above (and likely on the order of at least two times) that conservatively determined by the seismic evaluations of the GETR Reactor Building.

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PRESENTATION

PART 5

SUMMARY OF CONCLUSIONS

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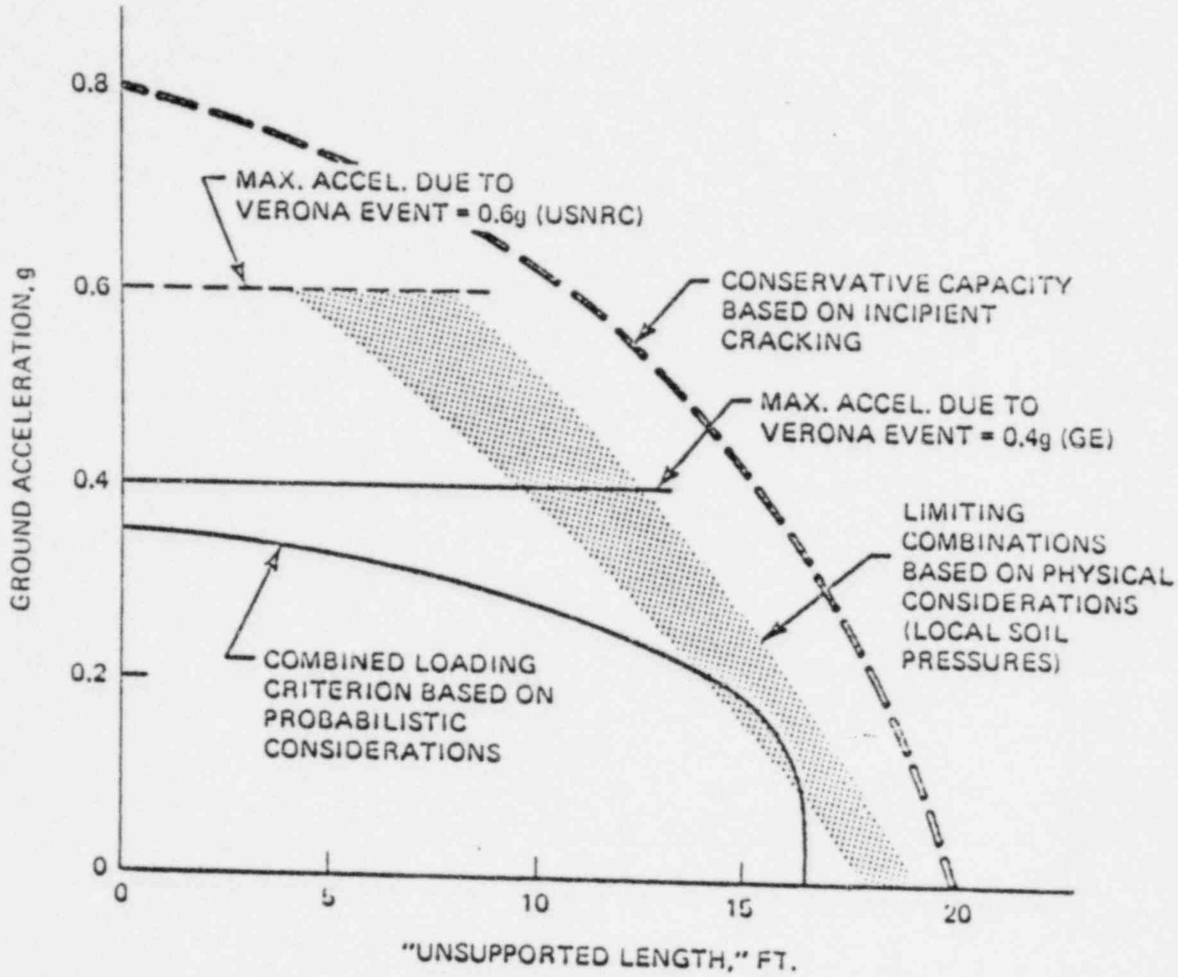

LOADING VS CAPACITY

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GETR LANDSLIDE INVESTIGATIONS

o Geologic investigations, assessment of surficial and large-scale landsliding	Phase I report	February, 1978
o Relative stability analysis, simplified slip-circle analyses	Report	July, 1978
o Review of relative stability analysis in light of Phase II investigations	Phase II report	February, 1979
o CDMG simplified slip-circle analyses	Special Publication 56	August, 1979
o Parametric stability analyses	Meeting with NRC	January, 1980
o Proposed program of field and laboratory investigations and analyses	Submittal	March, 1980
o Slope monitoring program		May, 1980

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PROPOSED FIELD AND LABORATORY INVESTIGATIONS AND ANALYSES

Field Investigation

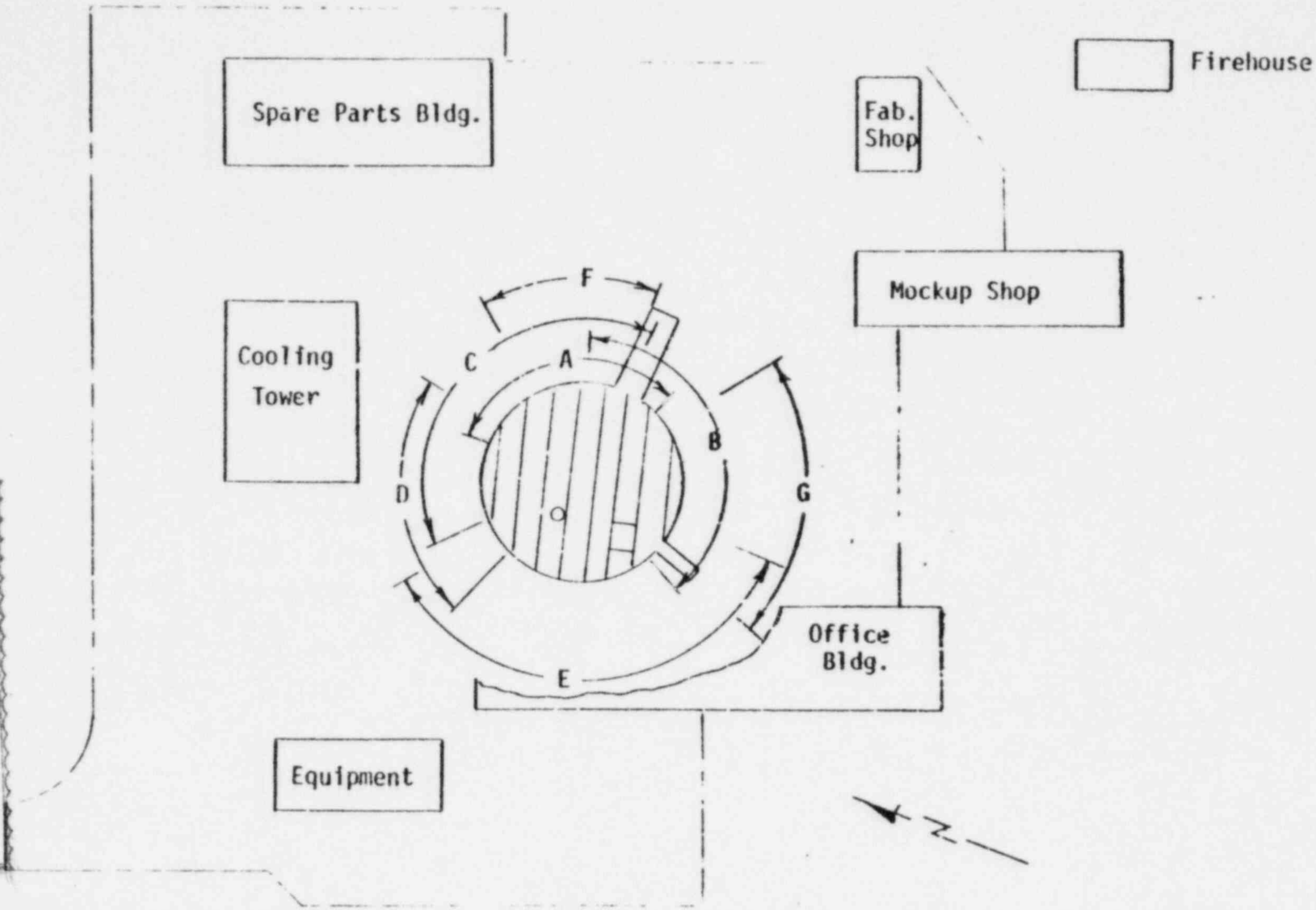
- borings
- e-logging
- piezometer installation
- test pits (contingency)

Laboratory Investigations

- index properties
- static triaxial testing
- direct shear testing (possible option)
- cyclic triaxial and post-cyclic static triaxial testing (possible option)

Analyses

- static analysis using STABL2
- pseudo-static analysis using STABL2
- simplified deformation analysis after Makdisi and Seed, 1978



GETR PLOT PLAN

RANGE OF VIEW OF EXCAVATION PHOTOGRAPHS

SOIL STRATIGRAPHY AND AGE DATING

- Age of buried paleosols
- Age of sediments under GETR
- Age of modern solum

SUMMARY OF SOIL-STRATIGRAPHY

- Upper buried paleosol developed during isotope stage 5-70,000 to 125,000 years B.P.
- Underlying sediments are of stage 6 age; deposited about 125,000 to 200,000 years B P.
- Sediments in the GETR foundation are at least 125,000, and more likely 350,000 years old.
- The modern solum is developing on sediments laid down in latest Pleistocene time.
- The albic horizon (Ae) may occur at any position within the profile.
- Radiocarbon ages must be corrected for (1) mean residences time, and (2) modern organic matter contamination.
- Last displacement on the B-1/B-3 and B-2 shears took place before about 8,000 years B.P.

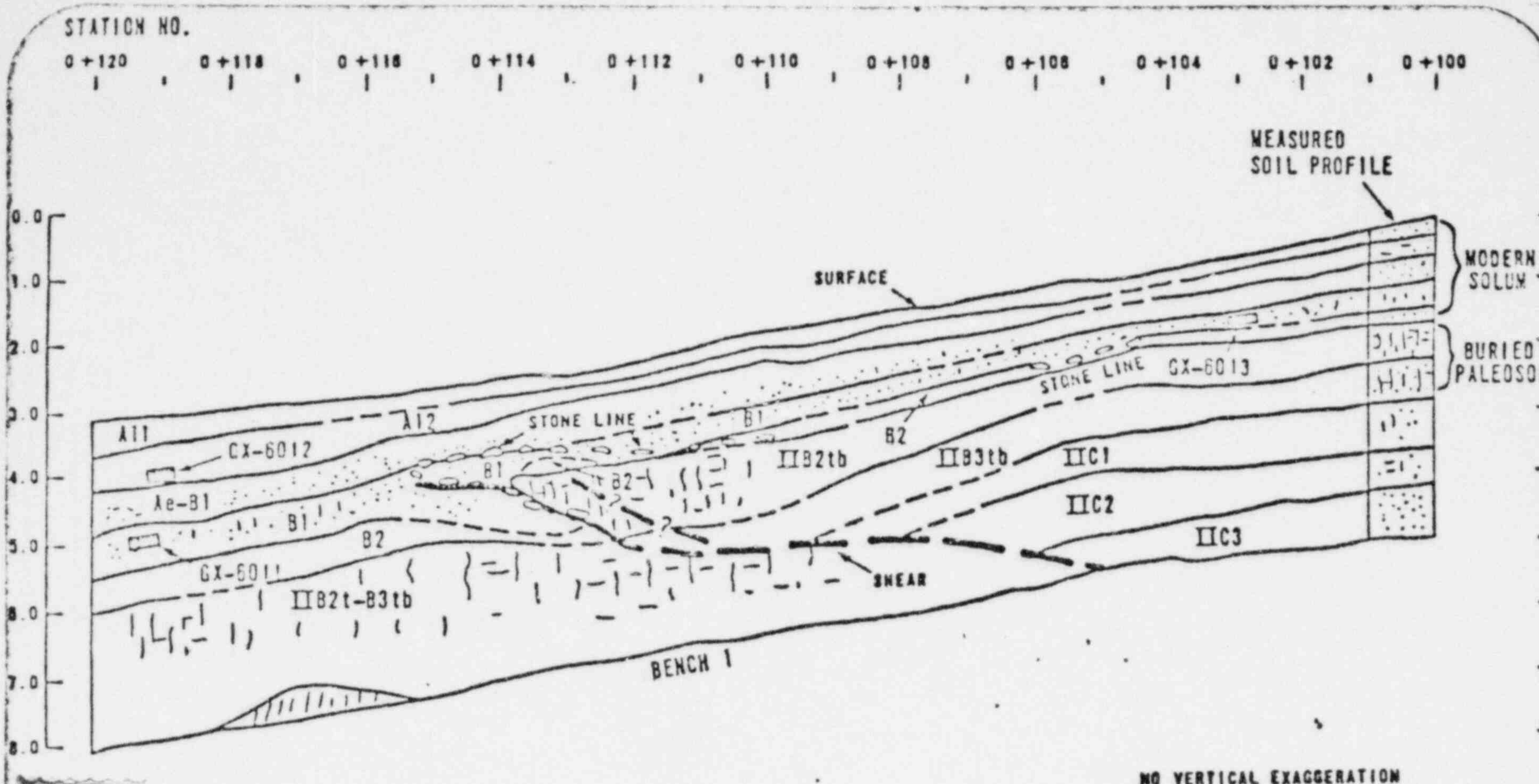


Figure A-9: Soil-stratigraphy, west wall, Trench B-2; ESA stations 1+00–1+20. Repr sentative soil profile measured at station 1+00 (Table 3). Albic horizon (Ae) extends into low r B_1 of modern solum below shear (station 1+14). Radiocarbon sample localities indicated by laboratory number (e.g., GX-6011; see Table 1).

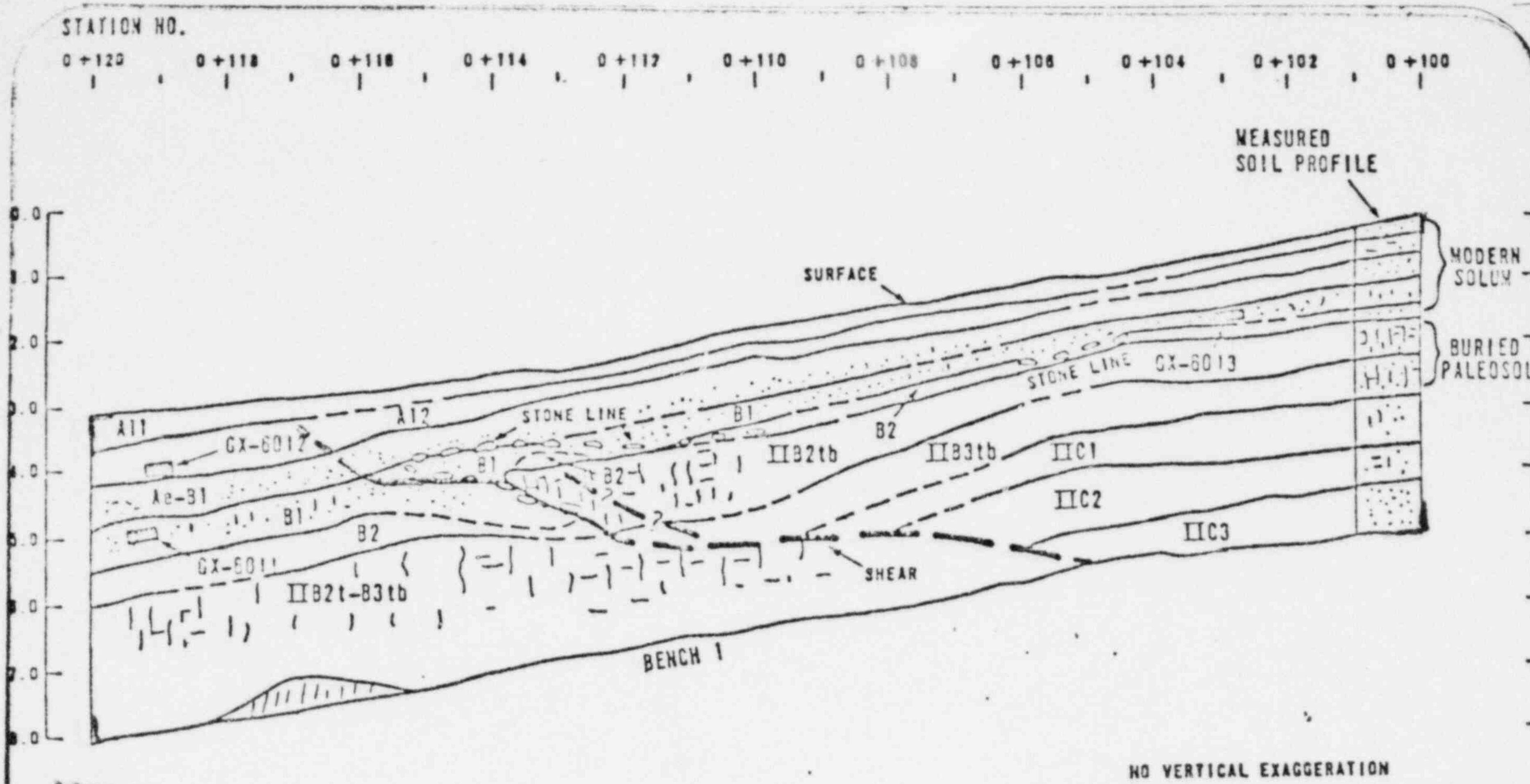


Figure A-9: Soil-stratigraphy, west wall, Trench B-2; ESA stations 1+00–1+20. Representative soil profile measured at station 1+00 (Table 3). Albic horizon (Ae) extends into lower B_1 of modern solum below shear (station 1+14). Radiocarbon sample localities indicated by laboratory number (e.g., GX-6011; see Table 1).

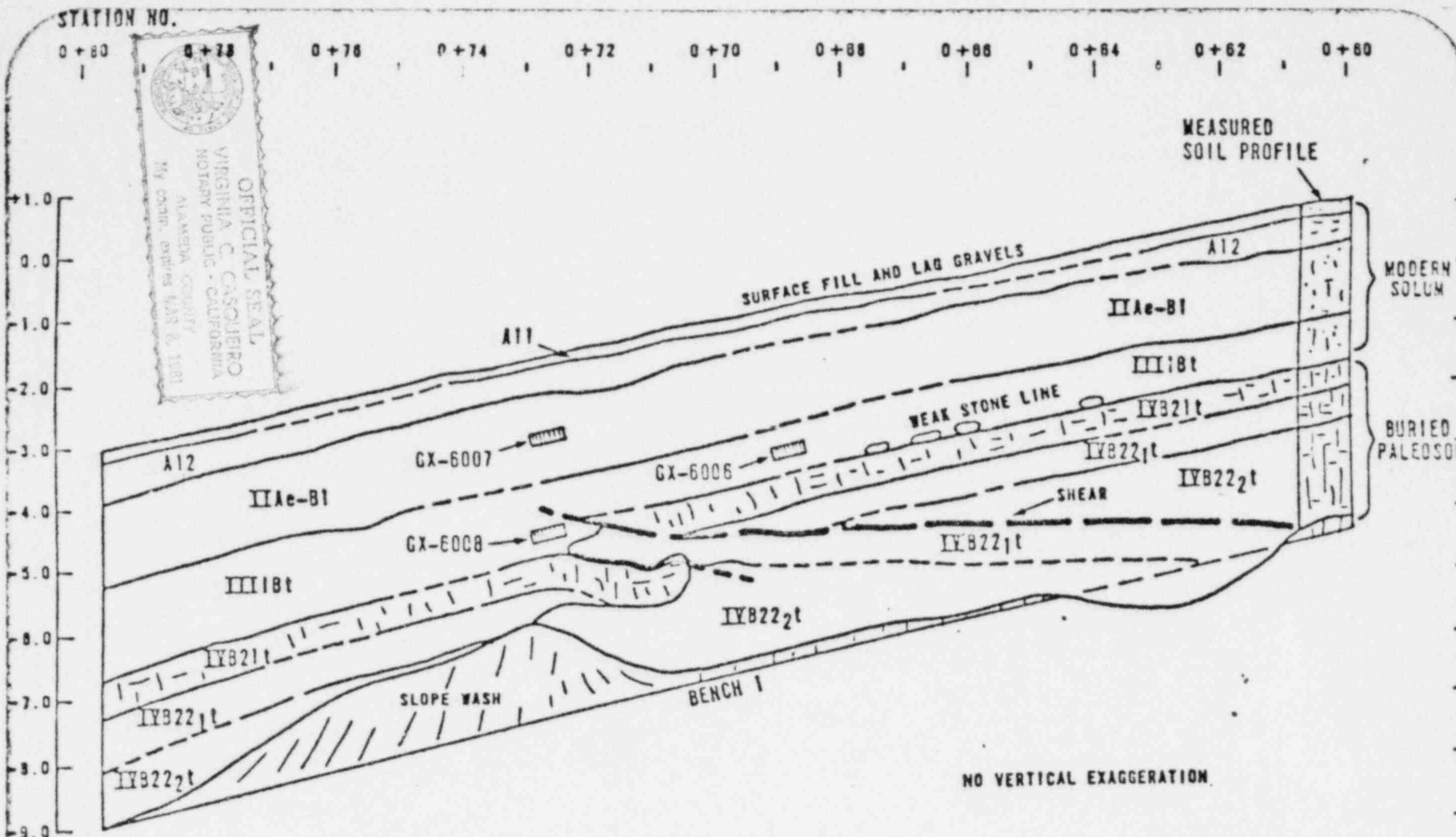


Figure A-8: Soil-stratigraphy, west wall, Trench B-1; ESA stations 0+60–0+80. Representative soil profile measured at station 0+60 (Table 2). Dominant shear extends into $IIIB_t$ horizon of modern solum. Radiocarbon sample localities indicated by laboratory number (e.g., GX-6008; see Table 1).

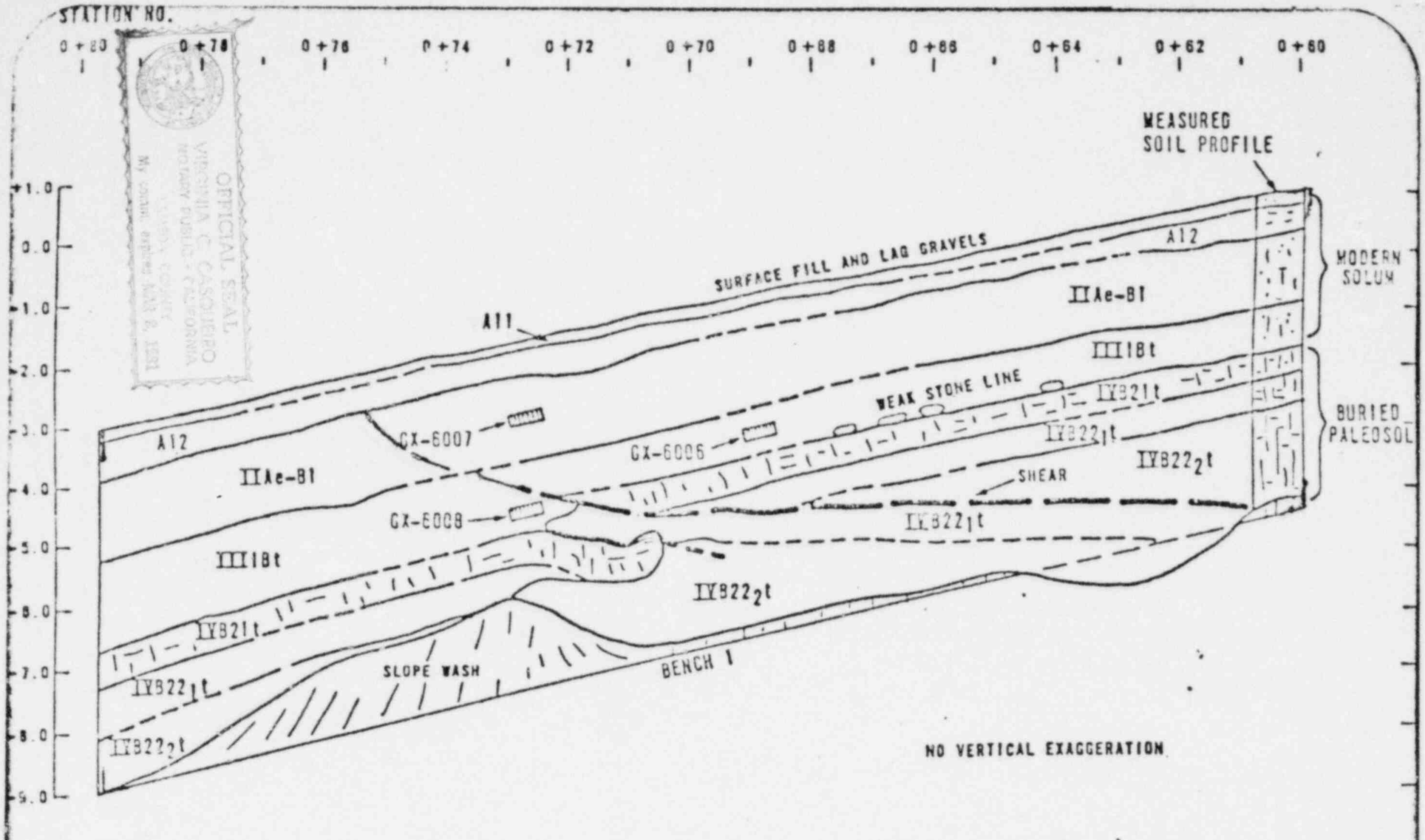


Figure A-8: Soil-stratigraphy, west wall, Trench B-1; ESA stations 0+60–0+80. Representative soil profile measured at station 0+60 (Table 2). Dominant shear extends into $IIIB_t$ horizon of modern solum. Radiocarbon sample localities indicated by laboratory number (e.g., GX-6008; see Table 1).

SUMMARY

- o THE GEOLOGIC INVESTIGATION WAS THOROUGH AND RESPONSIVE TO SUGGESTIONS FROM THE NRC STAFF AND USGS
- o THE SEISMIC DESIGN BASIS SPECIFIED BY NRC STAFF IS VERY CONSERVATIVE
- o ANALYSES SHOW THE GETR CONCRETE STRUCTURE AND SAFETY RELATED EQUIPMENT WILL PERFORM THEIR REQUIRED FUNCTIONS DURING AND AFTER THE POSTULATED EVENT AND THE FUEL WILL REMAIN COVERED WITH WATER
- o THE PROPOSED LANDSLIDE STABILITY ANALYSIS WILL BE COMPLETED AND IT IS CONTEMPLATED THAT IT WILL RECEIVE APPROVAL BY THE NRC STAFF
- o REQUEST A REVIEW BEFORE THE FULL ACRS COMMITTEE AT THE EARLIEST POSSIBLE OPPORTUNITY

RWD:6/13/80