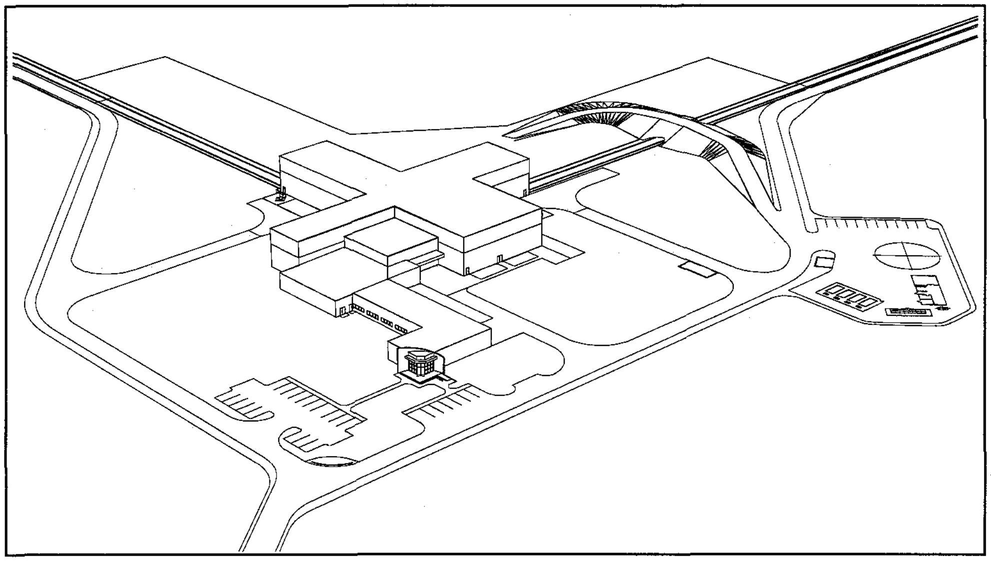


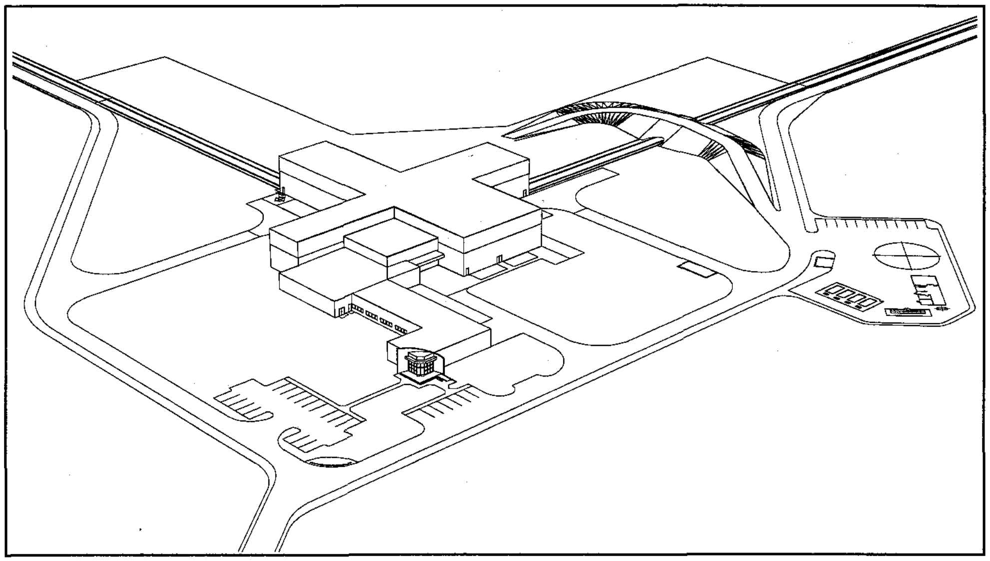
Preliminary Design Report

Presentation

November 9, 1995

LIGO
Laser Interferometer Gravitational-Wave Observatory
California Institute of Technology
The Ralph M. Parsons Company
Contract Number: PP150969

LIGO Document	C951726-00-□
CDRL Number	**22**
DRD Number	**09**



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LIGO Document ______

CDRL Number 22

DRD Number 09

LIGO Facilities

Mel Weingart

Preliminary Design Review Presentation

Purpose and Objective

- Purpose -- Present LIGO Design Team's evaluation of the project and the 30% design that has developed to meet project requirements.
- Objective -- Reach a consensus baseline facility design that will develop into the final design and construction bid packages.

Design Timeline

- Project Start: January, 1995
- 30% Concept Review: February, 1995
  - Presented 6 Interferometer Arrangements
- 60% Concept Review: March, 1995

Parsons Timeline (Continued)

- 90% Concept Review: April, 1995
  - Presented Construction Cost Estimate
  - Estimate for 6 Interferometers Exceeded Budget Constraint
- Project Directed Trade Studies: May, 1995
  - Design Team Directed to Proceed with Final Concept (3 Interferometers)

Parsons Timeline (Continued)

- Descoping Exercise, July, 1995
- Preliminary Design Review: Nov. 9, 1995
- Authorization to proceed: Nov. 15, 1995

Agenda

Topic	Presenter	Time
Introduction	M. Weingart	9:00 am - 9:10 am
Requirements	J. Hermann	9:10 am - 9:25 am
Design		
- Overview	T. Melott	9:25 am - 10:00 am
- 3D Model	R. Carbone	
- Civil	J. Blasius	10:00 am - 10:25 am
- Architecture	S. Ford	10:25 am - 10:50 am
Break		10:50 am - 11:00am

Agenda (con't)

Structural	F. Dickens	10:45 am - 11:15 am
Material Handling	T. Melott	11:15am - 11:30 am
Mechanical	A. Atia	11:30 am - 12:00 am
Lunch		12:00pm -12:30 pm
Electrical	K. Ramsing	12:30 am -1:00 pm
Technology Studies		
- Acoustics	M. Long	1:00 pm - 1:20 pm
- Vibrations	P. MacCalden	1:20 pm - 2:00 pm

Agenda (con't)

Construction Cost Estimate - Basis of Estimate - Hanford Summary - Livingston Summary	W. Messzik	2:00 pm - 2:30 pm
Review Committee Mtg.	M Coles	2:30 pm - Closing

Technical Presentation Format

- Each technical discipline will present the following information:
  - Requirements
  - Proposed Approach
  - Outstanding Issues and Resolutions

Design Review Approach

- Each discipline will make a presentation
- Questions will be entertained at any time during the presentation
- For any comments or issue arises that need dispensation, fill out a comment form and pass it to the Review Board Secretary

Design Review Approach (Continued)

- At the conclusion of the presentations, the comment forms will be screened.
- Comments which require resolution will be read, and individuals responsible for action identified.
- All resolutions will be agreed to by the commentor and the respondent.

Design Requirements

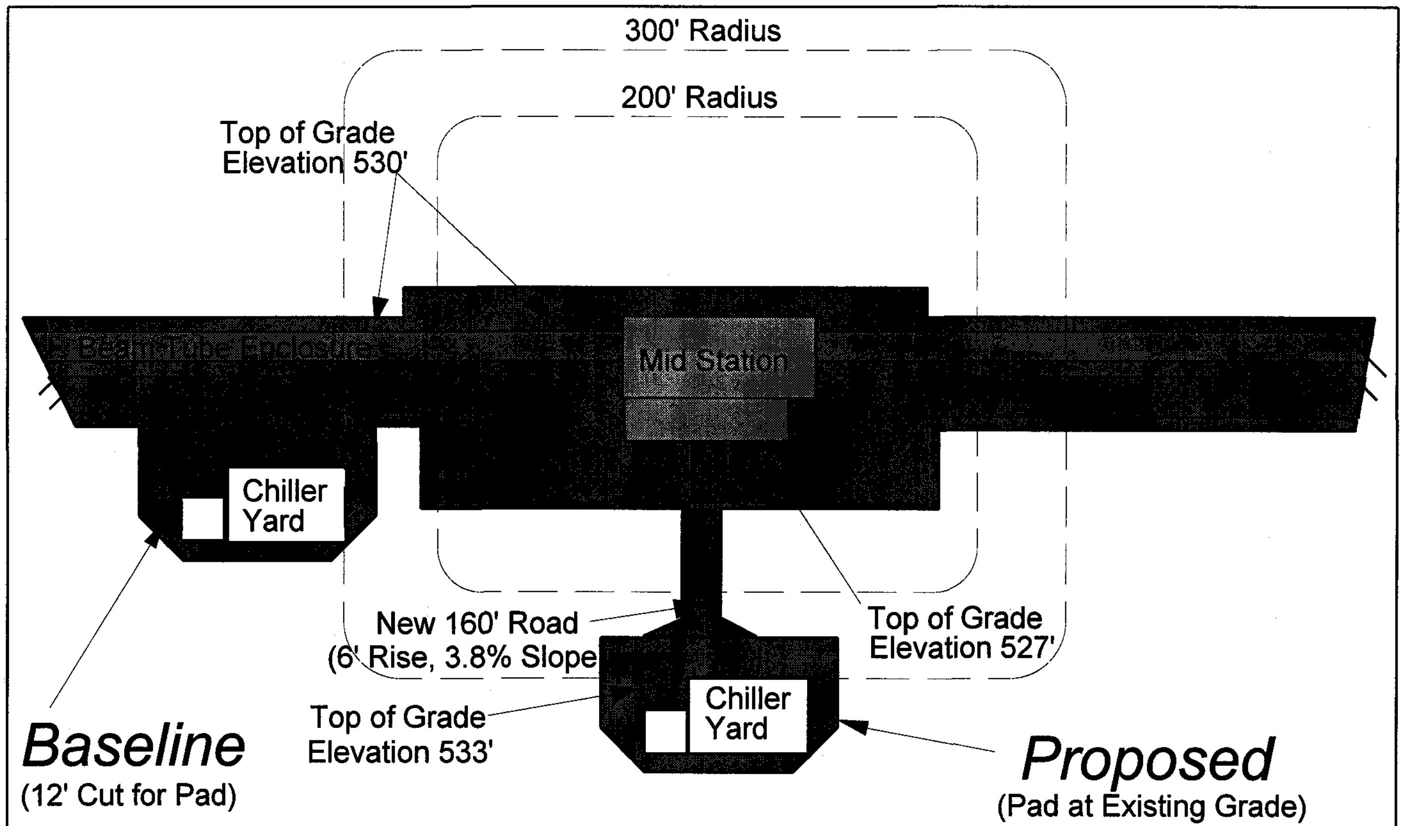
Jeff Hermann

Major DCCD Updates

- Two Interferometers
- Revised Vibration Control Criteria
  - Less Than 4 Times the LIGO Standard PSD
  - Peak Amplitudes Defined
- Removed Cleanrooms
- Change in Lasers: Argon-Ion to Nd:YAG

Major TDMs Received

➢ Relocation of Chiller Plants



Preliminary ICD Information -- Received

- Preliminary Information on LVEA Layout
- Telephone Requirements
- Preliminary Clean Work Benches
- BTE/Facility Interfacing Dimensions
- Plumbing in LVEA and VEAs
- Layout of LVEA Power Distribution

Preliminary ICD Information -- Received (Continued)

- Cooling Water Systems for the LVEA
- Fume Hood in the Optics Lab

Preliminary ICD Information -- Upcoming

- OSB Room Layouts
- Grounding and Shielding Requirements in LVEA/VEAs
- Cryogenic Piping and Storage Dewars

Design Overview
3D CAD Model

Tim Melott and
Randy Carbone

Design Considerations

- Meeting the Technical and Operational Criteria
- Design to Cost
- Expandability

Major Design Features -- General

- Hanford Facility will Accommodate One Full Length and One Half Length Interferometer Housed within a Corner Station with Mid and End Stations Along Each Arm
- Livingston Facility will Accommodate Two Full Length Interferometers Housed within a Corner Station and End Stations Along Each Arm

Major Design Features -- LVEA/VEAs

- Houses the Lasers and Vacuum Equipment
- 68-inch Technical Foundation Separated from the Superstructure Foundation with a 2-Inch Air Gap
- Finishes Consistent with Cleanrooms
- HEPA Filtered Air Supply
- Mechanical Room adjacent to the LVEA
- 5-Ton Crane System

Major Design Features -- OSB

- Houses Control/Computer Rooms, Labs, Shipping/Receiving/Inspection, Change Room, Cleaning Area, Offices, Kitchen, Restrooms, and Visitor Support Functions
- Has a Multi-Use Space for Visitor Displays and for Conferences with up to 50 People

Major Design Features -- Maintenance Building Area

- Support Services Set 300 Feet from the Corner Station
- Maintenance Building Housing Support Shop Functions, Fire Pumps, and Electrical Systems for the Chillers
- Chiller Yard
- Fire Water Storage Tank
- Potable Water System

Major Design Features -- Mid and End Stations

- In addition to a VEA, the Station Houses a Mechanical Room, Shipping/Receiving/Inspection Areas, Change Room, Air Lock, Lab Space, and Restroom Facility

Items not Included in PDR Design Package

- Chiller Plant Relocation at Mid/End Stations
- Grading around Mid/End Stations
- Site Power Distribution
- OSB Detailed Arrangement
- Power Interfaces in the LVEA

Civil Review

John Blasius

Civil Site Work

- Grading
- Drainage
- Roads / Paving
- Parking
- Access
- Layout Features
- Landscaping
- Solid Waste
- Potable Water
- Firewater Distribution
- Chilled Water Alignment
- Sewage System
- Irrigation

Sitework Requirements

- Minimize settlement
- Laser level site along beam arms
- 200 foot traffic exclusion
- 300 foot vibration exclusion
- Interferometer alignment/mount
- Bridge to "backside" for fire protection
- Minimize cost, stay functional

Corner Station - Hanford Approach

- Civil Sitework Description
- Grading/Drainage (Rough & Final)
  - Overexcavation & Compaction
- Exclusion Zones
- Roads / Parking / Paving
- Bridge Over Beam Tube
- Utilities

Mid and End Stations - Hanford Approach

- Civil Sitework Description
- At Lower Grade Than Beam Tube
- Chiller Move to 300 Feet Away
- Access to Nitrogen Tank(s)
- Utilities
  - Potable Water
  - Sewage
  - Chilled Water Alignment

Livingston Sitework Approch

- Generally the same look as Hanford
- Rough Grading & Drainage
  - 500 Year Flood / Freeboard
  - Proper Compaction to Minimize Settlement
  - Minimize Fill
  - Laser Level Site
  - Property Boundaries
- Sewage Treatment
- Water

LIGO Architecture

Sandra L. Ford

LVEA -- Requirements

- Design to Cost Goal
- Interior Clean Environment
- Minimum Disturbance from Acoustical Noise, Ground Vibrations, and Electromagnetic Interference
- Low Risk, Ease of Maintenance, and Operability
- Building Code Requirements

LVEA -- Proposed Approach

- Architectural Philosophy
- Exterior Building Facade
- Roof System
- Interior Clean Environment Materials and Finishes
- Building Code Interpretation
- Expediency of Construction

OSB -- Requirements

- Design to Cost Goal
- Low Risk, Ease of Maintenance, and Operability
- Quality Environment for Personnel
- Facility Monitoring and Control
- Accessibility to the Disabled
- Building Code Requirements

OSB -- Proposed Approach

- Architectural Philosophy
- Exterior Building Facade
- Roof System
- Entry Facade
- Multi-Use Visitors Center
- Comfortable & Quality Work Environment
- Building Code Interpretation
- Expediency of Construction

Mid and End Stations -- Requirements

- Design to Cost Goal
- Interior Clean Environment
- Minimum Disturbance from Acoustical Noise, Ground Vibrations, and Electromagnetic Interference
- Low Risk and, Ease of Maintenance and Operability
- Building Code Requirements

Mid and End Stations -- Proposed Approach

- Architectural Philosophy
- Exterior Building Facade
- Interior Clean Environment Materials & Finishes
- Building Code Interpretation
- Expediency of Construction

Issues and Resolutions

- LVEA
  - Detailed Information for the Final Design
- OSB
  - Detailed Information for Final Design
  - Functional Requirements for Office Floor Plan
  - Computer Locations
  - Facility Control Room Requirements
  - Computer Users Requirements

Issues and Resolutions

- Mid and End Stations
  - Detailed Information for Final Design
  - Computer Locations
  - Work Stations

Structural Review

Freddy Dickens

Corner, Mid and End Stations -- Design Requirements

- Structural Design Meets UBC/SBC
- Isolate Building Foundation From LVEA and VEA Foundations
- 5-Ton Under-Hung Cranes

Corner, Mid and End Stations -- Proposed Design Approach

- Metal Decking Welded to Roof Beams
- Horizontal Roof Bracing Transfers Lateral Loads to Vertical Bracing
- Vertical Wall Bracing Transfers Lateral Load to Foundations
- Isolated and Combined Footings for Superstructure

Corner, Mid and End Stations -- Proposed Design Approach

- Standard Framed Connections
- OSB Main Entrance and Multi-Use Area Roof is Made of Open Web Steel Joists

Issues/Resolutions

- LVEA and VEA Air Gap Location Between Technical and Superstructure Foundations
- LVEA and VEA Technical Foundation Thickness

Material Handling Review

Tim Melott

Requirements

- ➢ 5 Ton Capacity System (Large Item)
- ➢ 26 Foot 6 Inch Hook Height for Cranes
- ➢ Allow Crane Coverage over LVEA and VEA Areas
- ➢ Semi-Clean System
- ➢ Variable Speed Drive
- ➢ Small Item Handling System (1 Metric Ton)

Proposed Approach

- Multi-Bridge System with Laydown Areas Required in the LVEA and VEAs
- Monorail Crane within the Large Item Access Airlock
- Ground Transfer System (by Others) for transfer between the LVEA and the Large Item Access Airlock and for Small Items to and from the OSB

Proposed Approach

- Possible future addition of up to a 5-ton monorail system within the Shipping/ Receiving/Inspection and Cleaning Areas of the OSB and Mid/End Stations

Mechanical Systems Review

Atia Y. Atia, P.E.

HVAC Systems -- Requirements

- Energy Efficient Systems and Equipment
- Stable Space Temperature (72 +/- 3.5 °F)
- Facility Monitoring and Control
- Humidity Control
- Meet UMC and State Energy Code for Washington Site
- Meet Standard Mechanical Code for Louisiana Site

HVAC Systems -- Requirements

- Vibration Mitigation to LVEA and VEA
- Noise Mitigation to LVEA and VEA
- High System Reliability (24 Hr. Operation)
- Low Capital Cost
- Clean Environment

Outdoor and Indoor Conditions

Condition	Washington	Louisiana
Outdoor DB (Summer)	99 F	95 F
Outdoor WB (Summer)	68 F	77 F
Outdoor DB (Winter)	5 F	25 F
Indoor DB	72 +/- 3.5 F	72 +/- 3.5 F
Indoor RH	30% Min. 70% Max.	30% Min. 70% Max.

Vibration Mitigation -- Proposed Approaches

- Eliminate Return Fans
- Vane Axial Fans
- Rotating Equipment, No Reciprocating
- High Deflection Spring Vibration Isolators
- Locate Chillers & Pumps 300' from Bldgs.
- All Rotating Equipment will Run at 20 Hz or Higher
- Synchronizing Fans at Corner Station

Noise Mitigation -- Proposed Approach

- Double Wall Perforated Ducts for LVEA and VEA
- Low Air Duct Velocity
- Sound Attenuators on Supply and Return Air
- Vibration Isolators On Ducts and Pipes

System Reliability Proposed Approaches

- Standby Chillers and Pumps for All Buildings
- Standby Fans for Mid and End Stations
- Multiple Fans for LVEA
- Multiple Fans for OSB (Technical Area)

System Reliability Proposed Approaches (Cont'd)

- Industrial Grade Equipment
- Continuous Monitoring
- Scheduled Preventive Maintenance
- Eliminate Return Air Fans

Stable Space Temperature -- Proposed Approaches

- Return Plenum In Walls and Ceilings
- Individually Controlled Thermal Zones
- Thermal Insulation On Walls and Roofs
- Isolated Foundation Perimeter

Humidity Control -- Proposed Approach

- Washington
  - Dehumidifying by Chilled Water Coil
  - Steam Humidifiers (Electric), On Site Potable Water for Corner Station Facilities
  - Steam Humidifiers (Electric), Off-Site Reverse Osmosis Water for Mid and End Stations

Humidity Control -- Proposed Approach

- Louisiana
  - Dehumidifying by Chilled Water Coil
  - Steam Humidifiers (Electric), On-Site Potable Water for Corner Station Facilities
  - Steam Humidifiers (Electric), Off Site Reverse Osmosis Water for End Stations
  - 25% Min. Air Flow Through Cooling Coil For Humidity Control During Moderate Ambient

Air Handling System -- Proposed Approaches

- Concrete AHUs Enclosure for LVEA, OSB, Mid and End Stations
- Vane Axial Fans (Two Stage)
- Supply Fans Only (No Return Air Fans)
- Direct Drive Fans
- Ducted Supply and Plenum Return

Clean Environment -- Proposed Approaches

- HEPA Filters at Supply Air Outlets for LVEA, OSB, Mid and End Stations
- 90% Efficiency In AHUs
- Return Air Registers Located Near Floor
- Air Locks
- Pressurized Building

HVAC System Application -- Proposed Approaches

- Constant Volume, (Face and Bypass) for LVEA with Duct Heaters
- Constant Volume, (Face and Bypass) for Mid and End Station with Duct Heaters
- Constant Volume, (Double Duct) for OSB
- VAV with Terminal Heating for Offices
- Electric Heating

Energy Conservation -- Proposed Approaches

- Energy Efficient HVAC Systems (CVVT) for LVEA, MID and End Stations
- Minimizing Outside Air
- No Reheat Except For Humidity Control
- High Efficiency Motors and Chillers
- Insulated Ducts and Pipes
- Insulated Walls and Roof
- Air Tight Construction

Facility Monitoring & Control -- Proposed Approaches

- Direct Digital Controls (DDC) for Controls, Monitoring, Diagnostics, and Scheduled Maintenance
- DDC for Security Systems, Fire Alarm, and Enunciation
- Pneumatic Drives for High Reliability

Issues

- Expensive DDC Control and Monitoring
  - $600,000 for DDC Control and Monitoring
  - $400,000 for DDC Control Only
  - $300,000 for Pneumatic Control Only

Water Supply and Sewage -- Requirements

- No Potable Water at Mid and End Stations
- No Sewage Drain at Mid and End Stations
- Meet Uniform Plumbing Code for Washington Site
- Meet Standard Plumbing Code for Louisiana Site

Water Supply and Sewage -- Proposed Approaches

- Potable Water Supply for Corner Station
- Waste Drainage System for Corner Station
- Pressurized Storage Water Tanks for Mid and End Stations
- Holding Tanks at Mid & End Stations
- Point of Use Electric Water Heaters

Fire Protection -- Requirements

- Meet Uniform Fire Code and NFPA Standards for Washington Site
- Meet Standard Fire Prevention Code and NFPA Standards for Louisiana Site

Fire Protection -- Proposed Approaches

- No Sprinkler System
- On-Site Water Storage, Corner Station
- Two Electric Fire Pumps 1,000 GPM Each for Corner Station Fire-Hydrant Loop
- One 1,000-GPM Trailerable Propane-Powered Fire Pump Provided (by Others) to Local Fire Department

Fire Protection -- Proposed Approaches (Cont'd)

- Fire Hose Cabinet for OSB
- Clean Agent (FM 2000) Gas for Critical Rooms of OSB
- Portable Fire Extinguishers for All Facilities

Electrical Systems Overview

Kai Ramsing, P.E.

Electrical Requirements

- Mitigate Vibration
- Electromagnetic Coupling, Noise and Grounding
- System Reliability
- Energy Conservation
- Site Vector Inputs

Mitigate Vibration -- Proposed Approach

- Minimize Vibrating Equipment (i.e., Switchgear, Transformers, etc.) within Exclusion Zones
- Flexible Couplings between Superstructure and Technical Foundation
- Locate all High-Bay Ballasts in the Mechanical Equipment Room

Mitigate Electromagnetic Coupling -- Proposed Approach

- Highest Possible Distribution Voltage
- Separate Grounding for Utility and Facility
  4-Wire Wye Isolation
- Triplex Direct Burial Cable Geometry
- Distance Sources from Victim Systems
- Routing of Electrical Circuits
- Ferrous Conduit to Provide Shielding

Electromagnetic Coupling, Noise and Grounding (Continued)

- Technical Power Isolation Transformers
- Tree Topology Grounding
- Single-Point Ground for Technical Systems
- Grounding Counterpoise for Buildings
- Equipotential Screen Under Computer Rooms (Signal Reference Grid)
- Delta-Wye Transformations to Mitigate Power Frequency Harmonic Conduction

Electromagnetic Coupling, Noise and Grounding (Continued)

- Specify Low Harmonic Distortion Equip.
- Tuned Circuits at the Motor Terminal Boxes Control Voltage Spikes
- RFI Lenses on Fluorescent and Metal-Halide Fixtures
- Transient Voltage Surge Supressors

System Reliability -- Proposed Approach

- Single Utility Company Owns and Operates the Distribution System
- Medium Voltage, Simple Radial System Architecture
- Similar and Simplified Systems for Each Building
- Conventional Manufacturing and Limited Custom Components

Energy Conservation -- Proposed Approach

- Energy Efficient Motors
- Energy Efficient Lighting
- Electronic Ballasts
- Occupancy Sensor Switches
- Phase-controlled Electric Heating
- Facilities Monitoring and Control System

Site Vector Inputs -- Proposed Approach

- Current Sensors in Electrical Equipment
- CDS Collects Sensor Data
- CDS Processes and Interprets the Data
- CDS Real-Time Clock Synchronized

Issues

- Facilities Monitoring and Control System
- Telecommunications
- Laser Equipment Power
- Beam Tube Lightning Protection
- Cost/Benefit of Variable-Speed State-Vector Controlled Motor-Drives

Acoustics Review

Marshall Long

LVEA/VEA Acoustics -- Requirements

- Sound Pressure Level

Frequency	SPL
f > 63 Hz	PNC-50
f = 63 Hz	66 dB
f = 31.5 Hz	64 dB
f = 16 Hz	61 dB
f = 8 Hz	57 dB
f = 4 Hz	55 dB

LVEA/VEA Acoustics -- Considerations

- HVAC Systems
  - Duct-Borne Noise
  - Flow Velocities
  - Duct Rumble
- Exterior Noise
  - Exterior Source -- Trucks
  - Rain and Wind

LVEA/VEA Acoustics -- Projected Results

- HVAC
- Reverberation Time
- Exterior to Interior

LVEA/VEA Acoustics -- Proposed Approach

- HVAC
  - Vane Axial Fans -- High Frequency Noise Components
  - Synchronous Motors with Phase Control
  - Duct Silencers
  - Concrete Block Wall Enclosures to Reduce Well Vibrations

LVEA/VEA Acoustics -- Proposed Approach (Cont'd)

- HVAC
  - Round Duct to Reduce Tin-Canning and Increase Transmission Loss
  - Double Walled Lined Duct
  - Low Flow Velocities
  - Vibration Isolation

LVEA/VEA Acoustics -- Proposed Approach

- Interior Acoustics
  - Acoustical Tile on Ceiling NRC = 0.6
  - Additional Wall Panels
- Exterior to Interior Acoustics
  - Double Wall Construction with Absorption Between
  - High Transmission Loss Acoustical Tile
  - Large Air Space Between Interior and Exterior Walls

LVEA/VEA Acoustics -- Issues and Resolutions

- Low Frequency Data -- HVAC
  Very Little Information Below 63 Hz
- Modeling at Low Frequency Limited
- Rain and Wind Noise not Controlled
  Depending on 5% Criteria

Vibration Review

Paul MacCalden

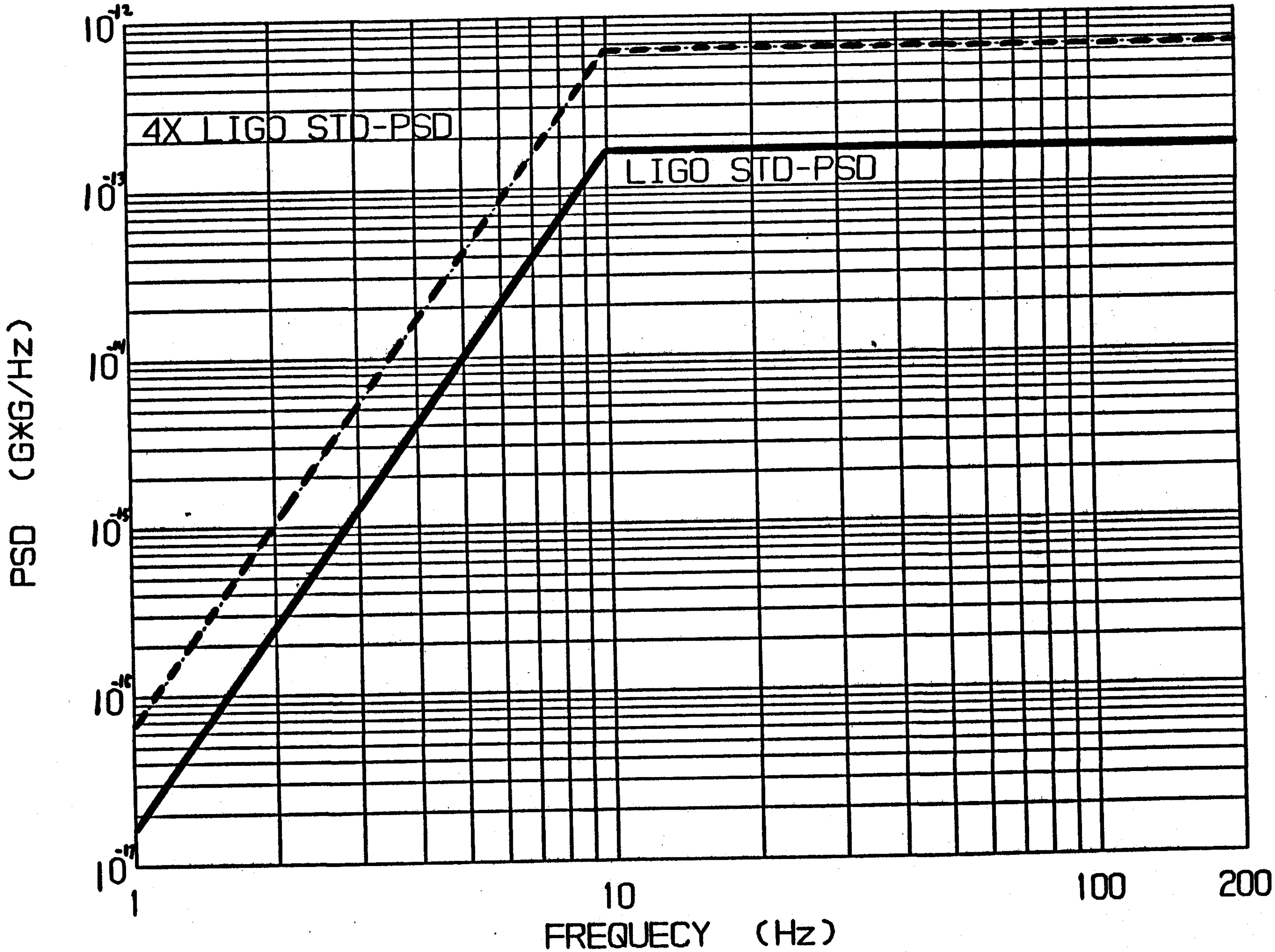
Foundation Analyses

- Vibration Criteria
- Foundation Configurations
- Acoustically Induced Vibrations
- Thermally Induced Distortions
- Ambient PSD Induced Vibrations
- HVAC Equipment Vibrations
- Chiller Equipment Vibrations
- Wind Induced Vibrations
- Foundation Thickness Trade Study

Vibration Criteria

- Broad-Band Vibrations
- LIGO Standard Power Spectral Density (LSPSD)
  - Acoustic Induced Vibrations Less Than the LSPSD
  - Ambient Ground Excited Vibrations Less Than Four Times the LSPSD

LIGO ACCELERATION PSD CRITERIA



Vibration Criteria - 2 nd

➤ Narrow-Band Vibration Requirements

Narrow-Band Vibration Range	RSS of Three Axes Shall Be Less Than
From 0.1 Hz to 1.0 Hz	**2.4×10^{-7} m/sec^2**
From 1.0 Hz to 50 Hz	**5.0×10^{-4} m/sec^2**
Above 50Hz	**3.0×10^{-25} {F/1 Hz}^{9} m**

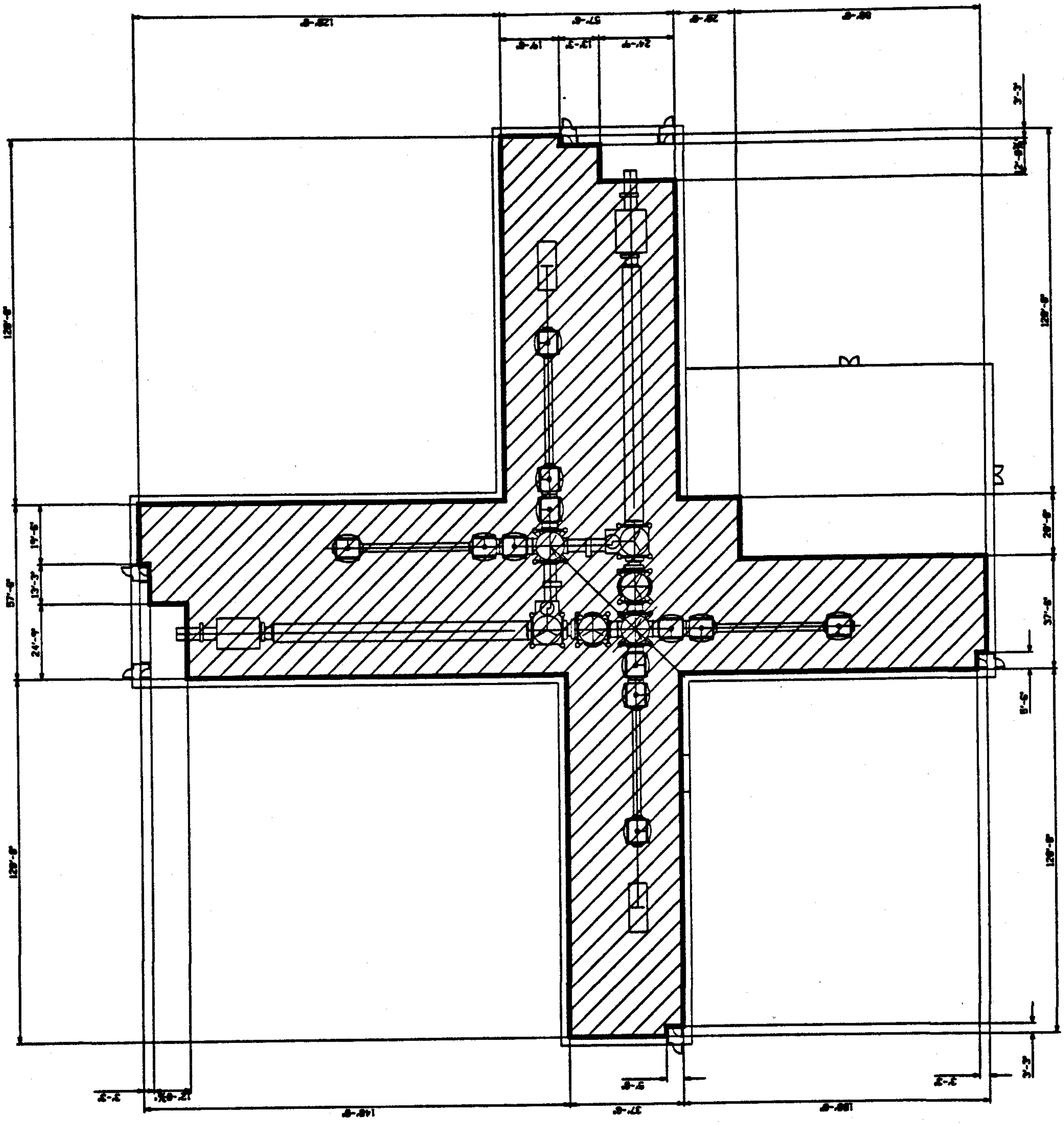
Vibration Criteria - 3 rd

- Acoustic Requirements - SPL
  - Marshall Long's Presentation Slides
- Environmental Effects
  - Acoustic and Vibration Levels Must Not Be Exceeded More Than 5% of the Time
  - Includes Wind, Rain, and Other Local Environmental Effects

Foundation Configuration

- LVEA Foundation
  - 68 Inch Thick -- Solid Reinforced Concrete
- Plan View X-Shaped
  - 277 Feet By 300 Feet -- Overall Plan Dimension
  - 37.5 Feet and 57.5 Feet -- Typical Floor Widths
  - 2 Inch Air Gap Around Perimeter of Floor

8/29/95



Foundation Configuration -- 2nd

- Mid-Station -- VEA
  - 68 Inch Thick -- Solid Reinforced Concrete
  - Plan View Rectangular
  - 35 Feet By 77 Feet
  - 2 Inch Air Gap Around Perimeter of Floor

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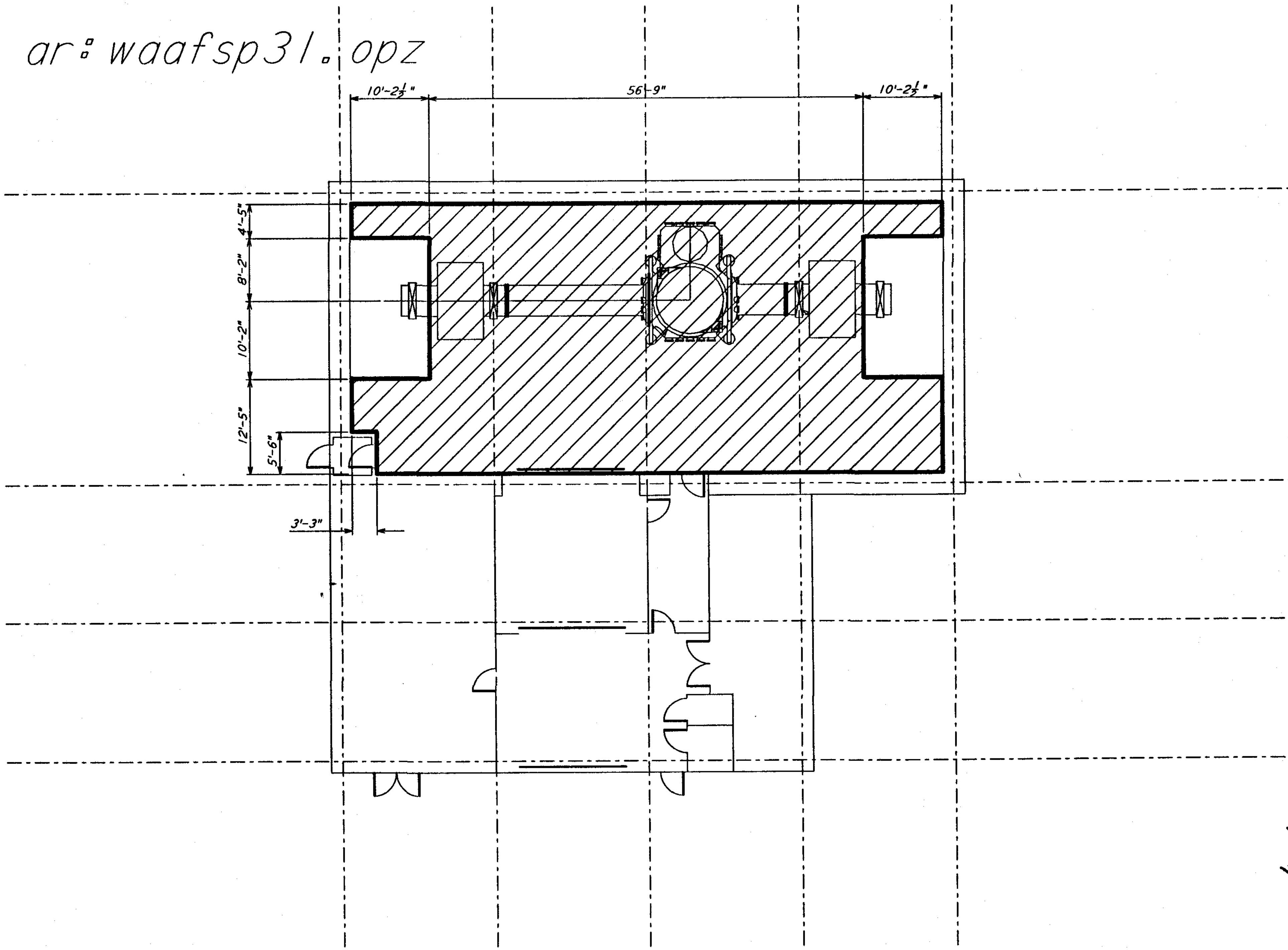

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Foundation Configuration -- 3rd

- End-Station - -VEA
  - 68 Inch Thick - Solid Reinforced Concrete
  - Plan View -- Rectangular
  - 35 Feet By 57 Feet
  - 2 Inch Air Gap Around Perimeter of Floor

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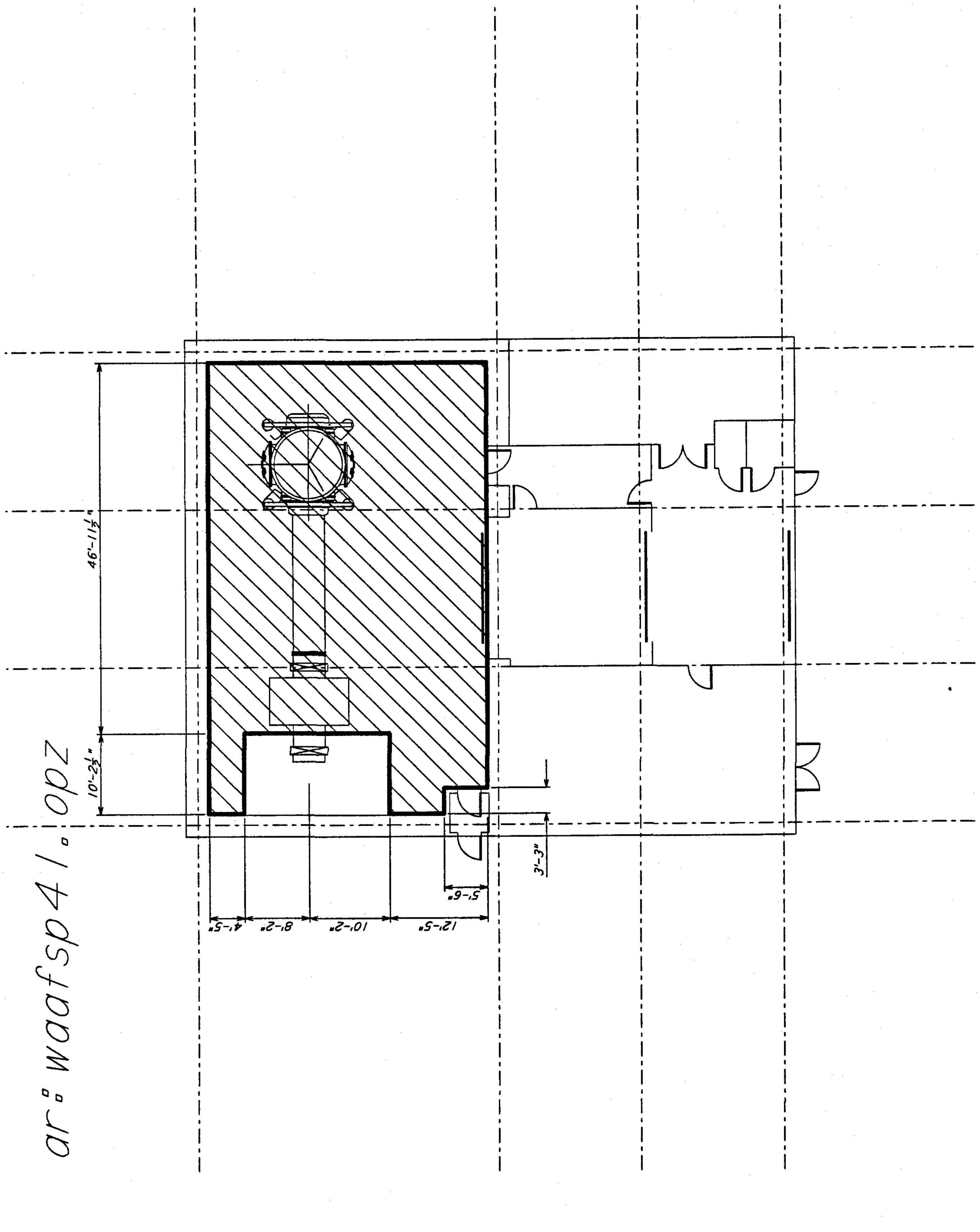
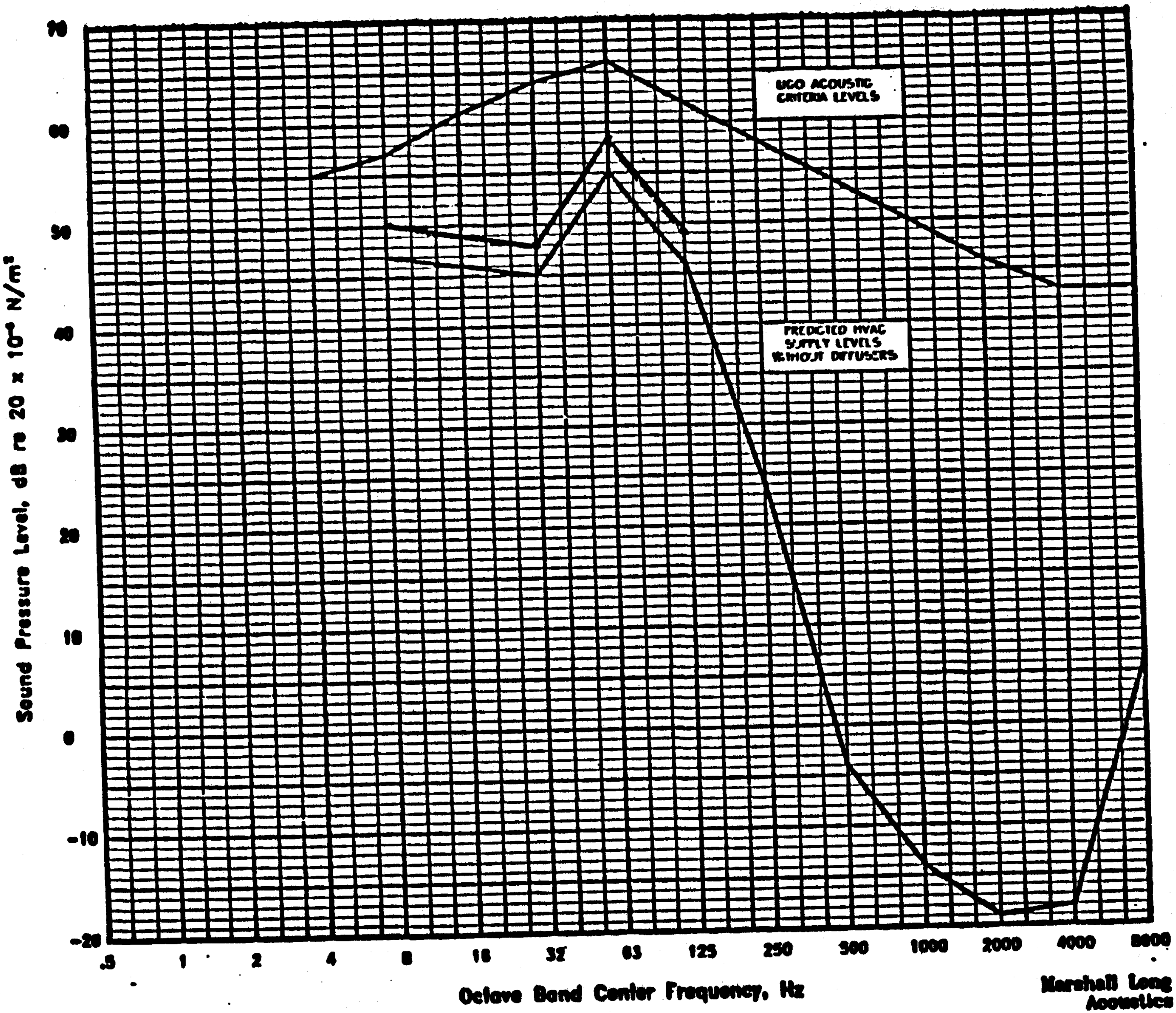


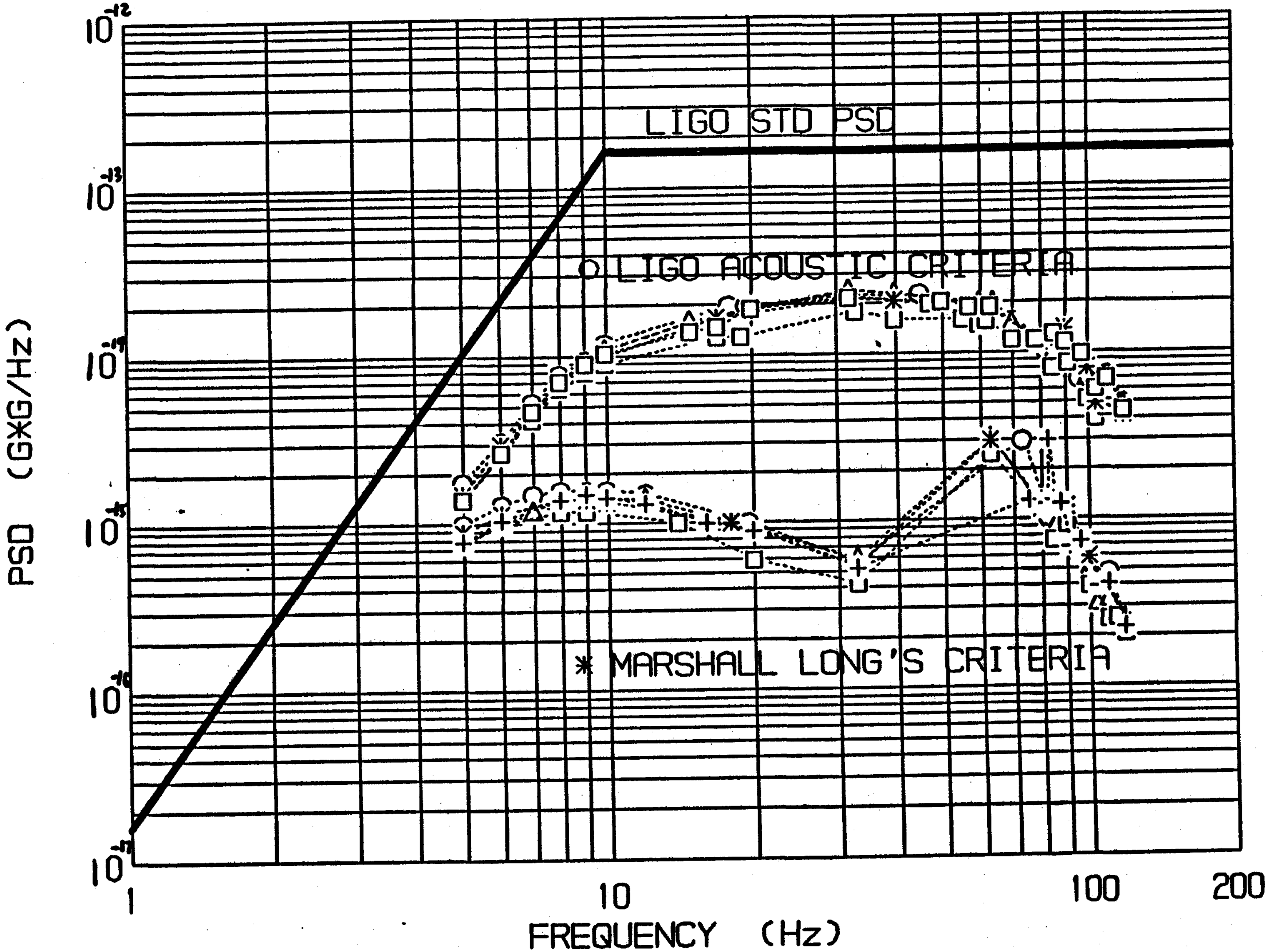
Acoustically Induced Vibrations

- Inputs
  - LIGO Acoustic Criteria = L-SPL
  - Marshall Long's Predicted SPL = ML-SPL
- LVEA Responses
  - 1/7 th of Criteria at L-SPL
  - 1/50 th of Criteria at ML-SPL
- Mid-Station Responses
  - 1/5 th of Criteria at L-SPL
  - 1/50 th of Criteria at ML-SPL

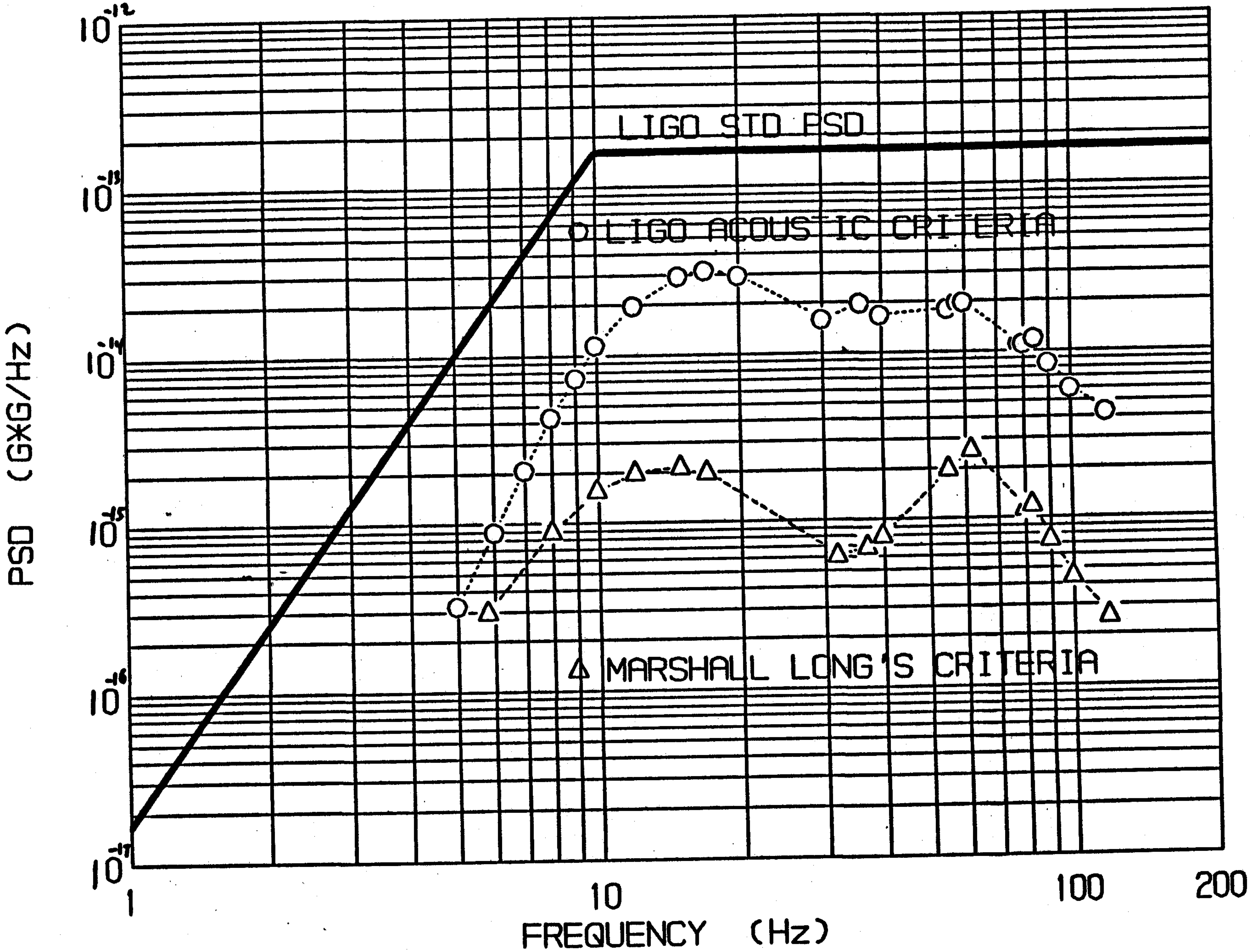


Marshall Long Acoustics

68" LVEA FOUNDATION - ACOUSTIC PSD

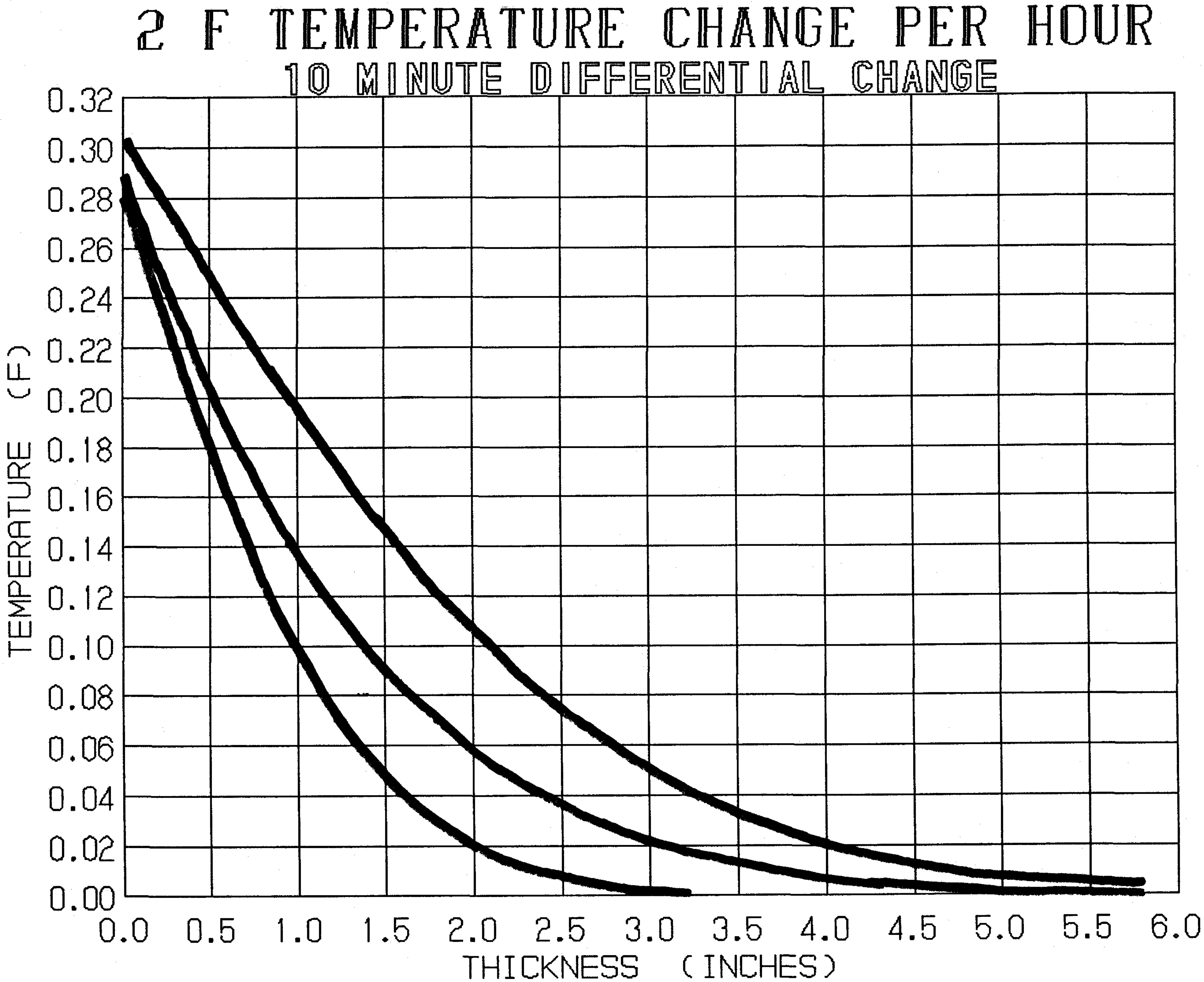


68" MID-STATION FOUNDATION - ACOUSTIC PSD

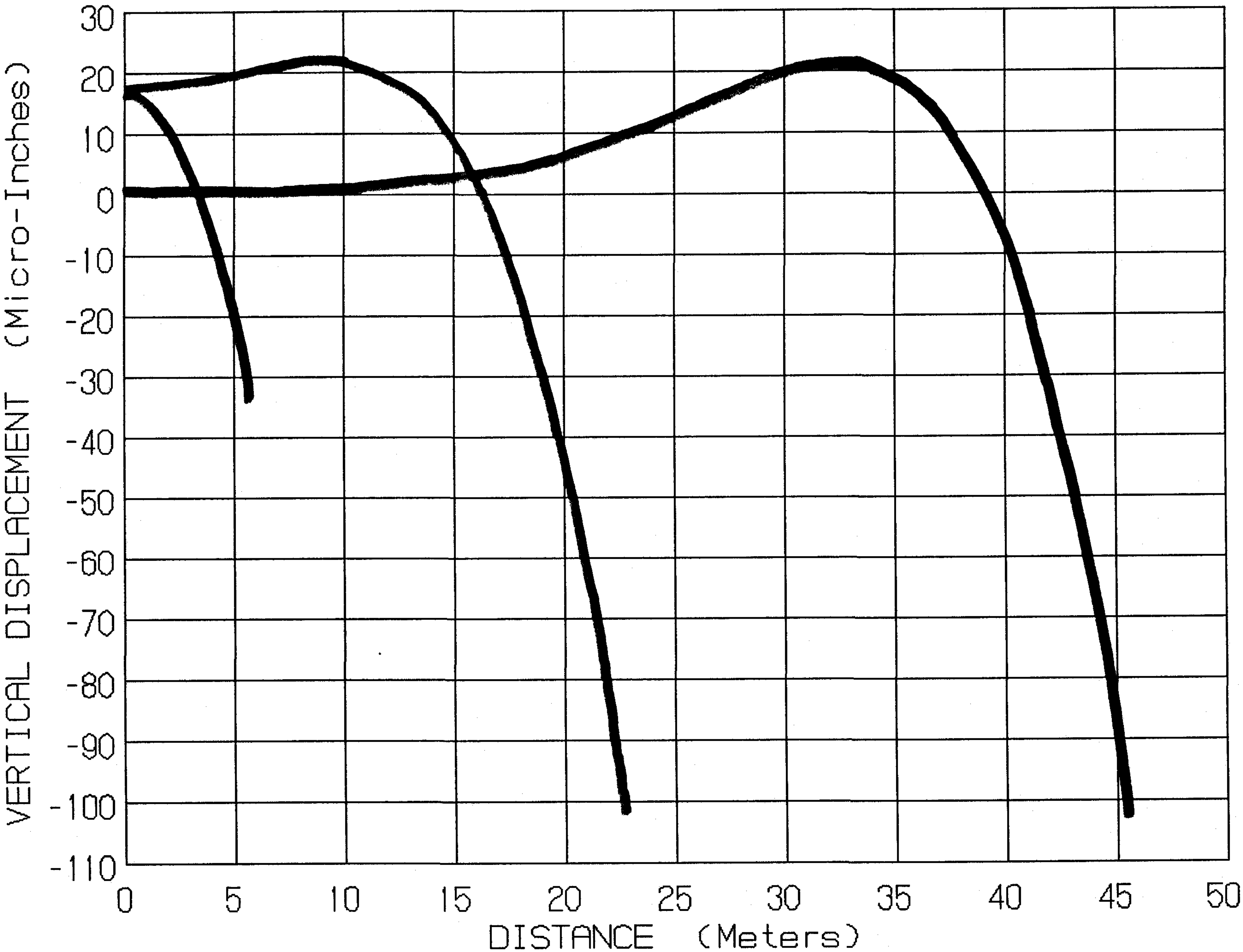


Thermally Induced Distortions

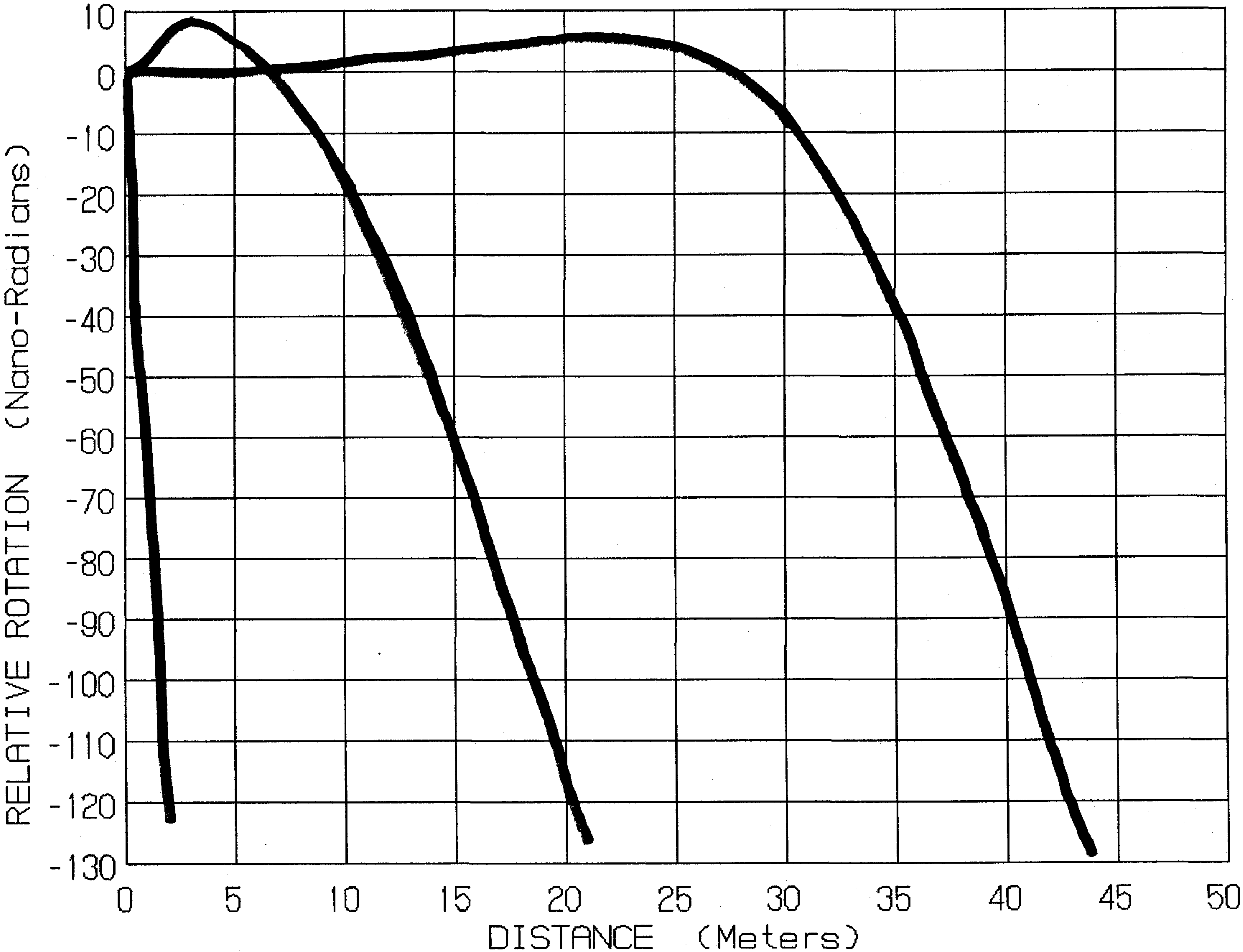
- Input: 2 ^{O}F Air Temperature Change in 1 Hour
- Thermal Response of Floor in 10 Minutes
  - 0.28 ^{O}F at Surface, 0.00 ^{O}F at 3 inch Depth
  - Goal = 50 Nano-Radians Over 2 Meters


2 F TEMPERATURE CHANGE PER HOUR
10 MINUTE DIFFERENTIAL CHANGE
TEMPERATURE (F)
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
THICKNESS (INCHES)

10 MINUTE THERMAL FOUNDATION DEFORMATIONS



10 MINUTE THERMAL FOUNDATION ROTATIONS



Thermal Distortions - 2 nd Response Over 2 Meter Distance

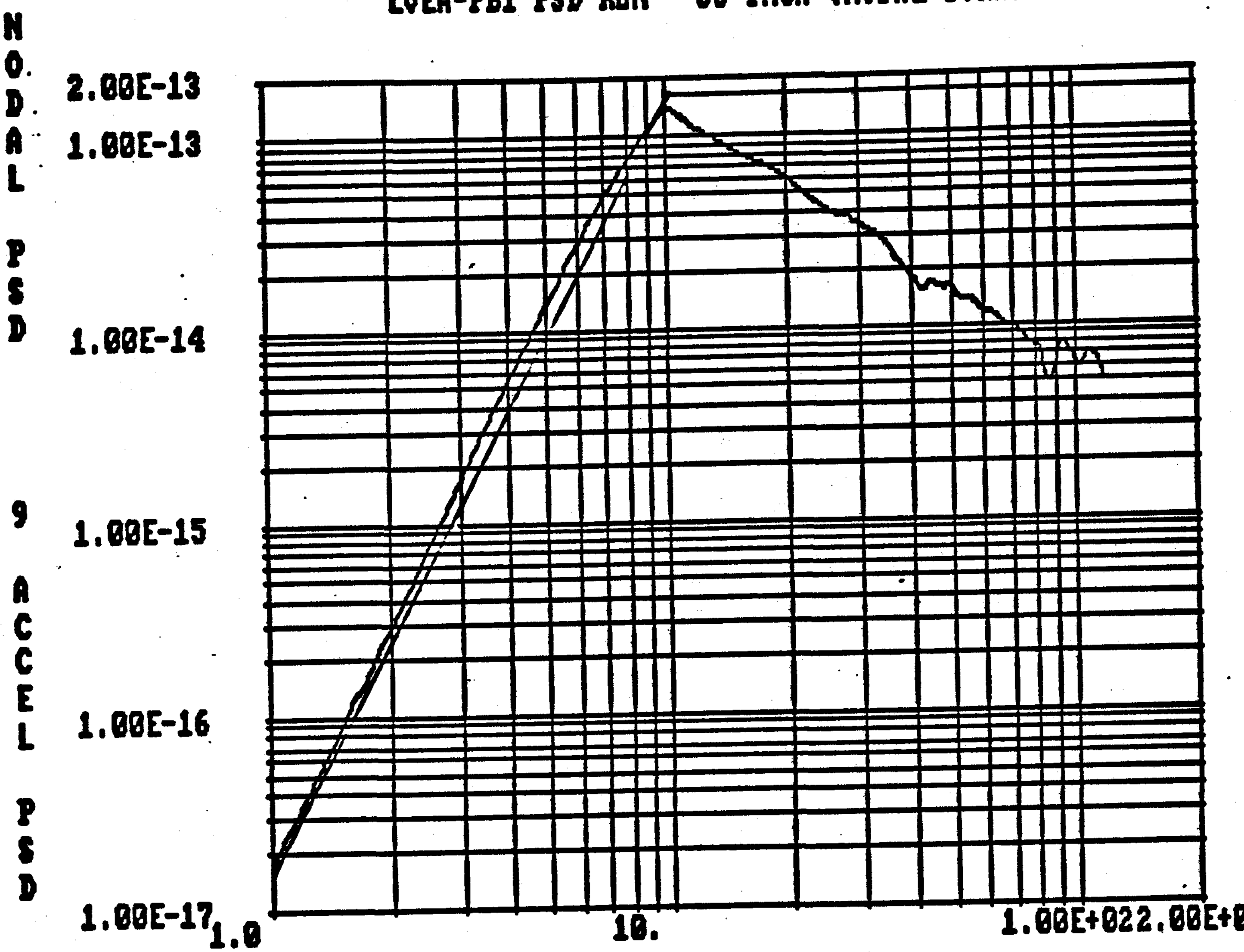
- 12 Meter Floor Span
  - Exceeds Goal at 1 Meter From Center
- 45 Meter Floor Span
  - Exceeds Goal at 14 Meters From Center
- 95 Meter Floor Span
  - Exceeds Goal at 37 Meters From Center

Ambient PSD Induced Vibrations

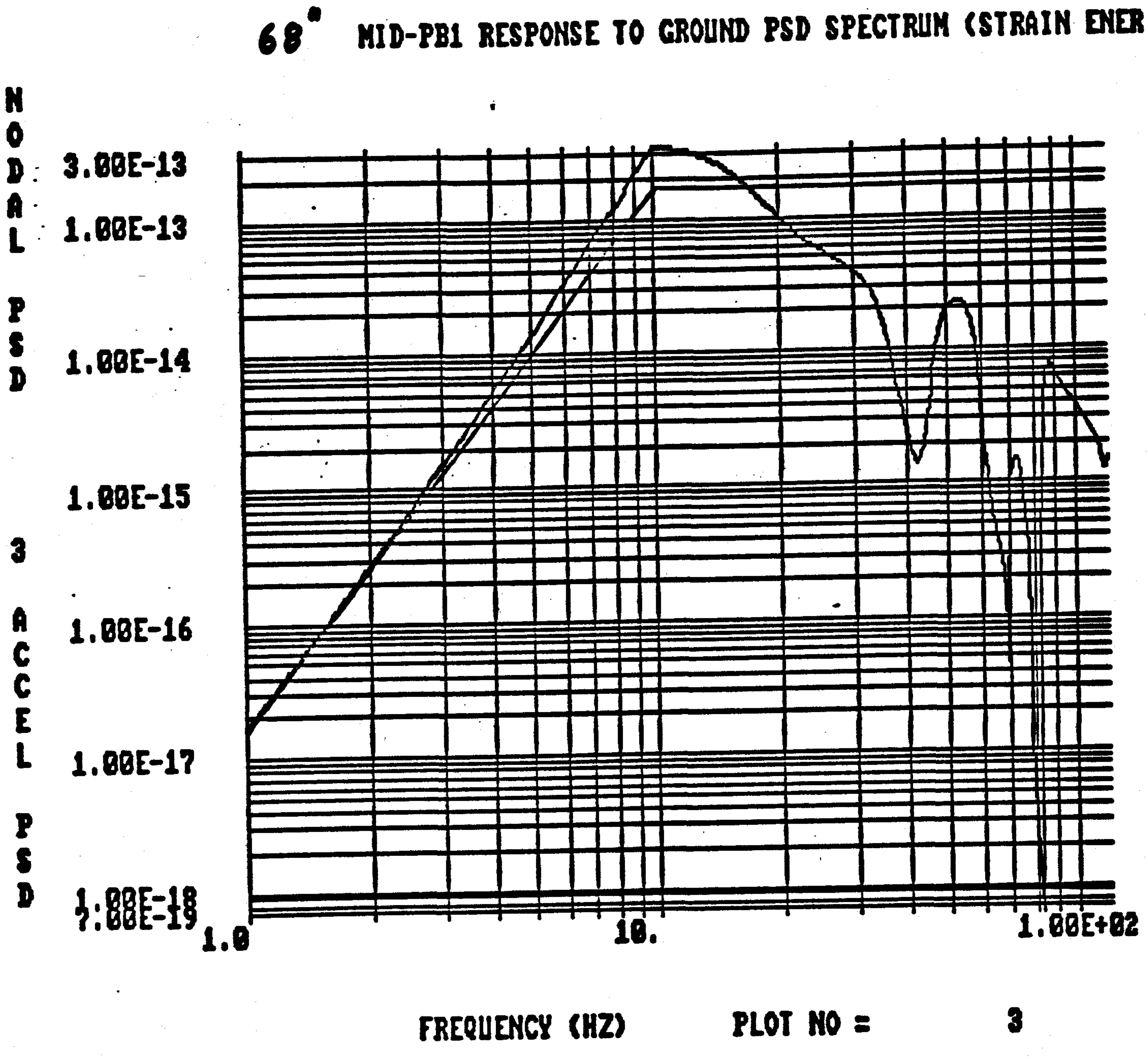
- Criteria = 4 x LIGO Standard PSD
- LVEA, Mid and End Station
- All Foundations Satisfy Criteria
- Significant High Frequency Reductions

Node 792 X3

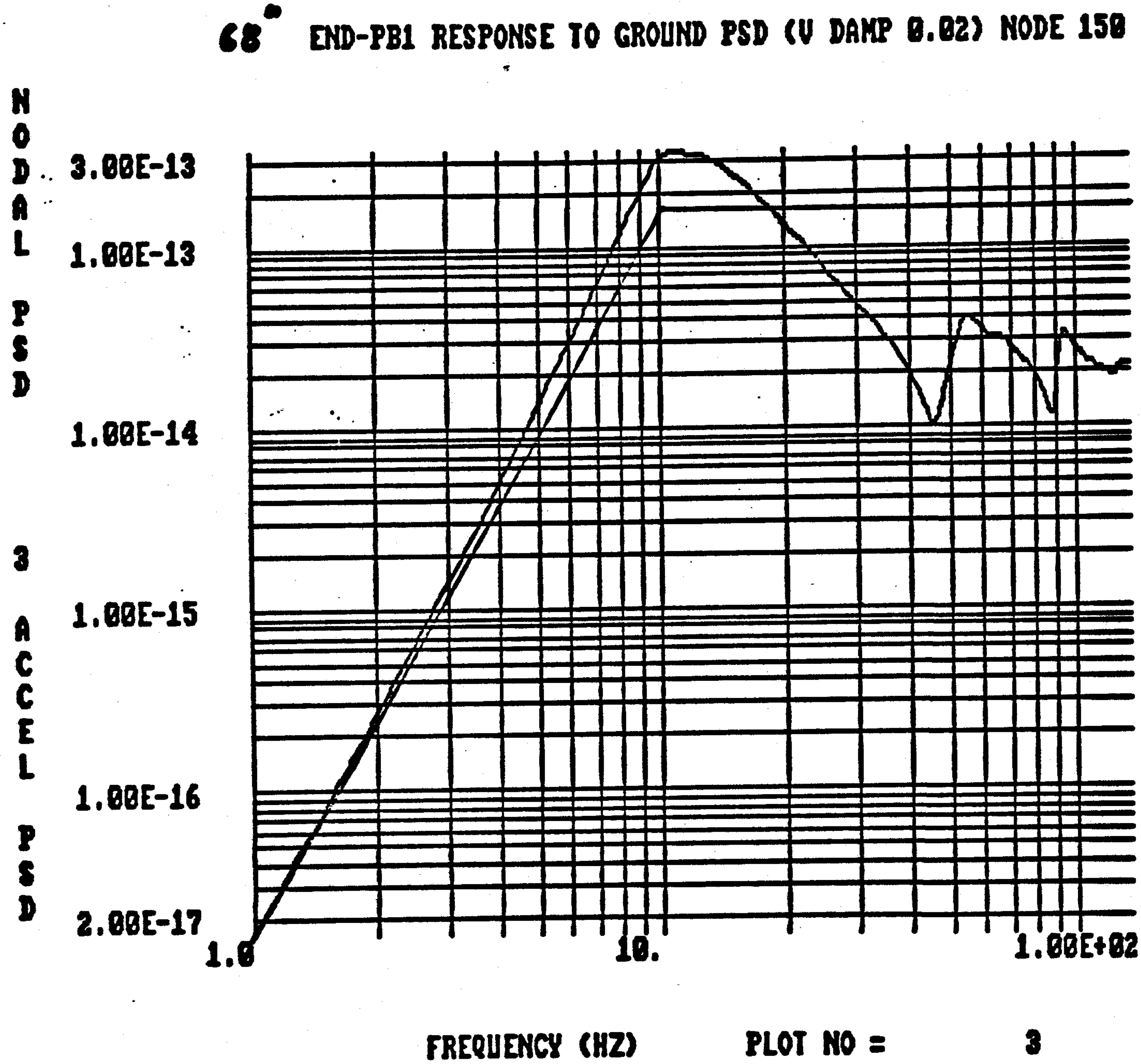
LVEA-PB1 PSD RUN - 68 INCH (MODAL STRAIN ENERGY DAMP



FREQUENCY (HZ) PLOT NO = 9


68°
MID-PB1 RESPONSE TO GROUND PSD SPECTRUM (STRAIN ENER
NODAL PSD 3 ACCEL PSD
3.00E-13
1.00E-13
1.00E-14
1.00E-15
1.00E-16
1.00E-17
1.00E-18
7.00E-19
1.0
10.
1.00E+02
FREQUENCY (HZ)
PLOT NO = 3

68


END-PB1 RESPONSE TO GROUND PSD (V DAMP 0.02) NODE 150
NODAL PSD 3 ACCEL PSD
3.00E-13
1.00E-13
1.00E-14
1.00E-15
1.00E-16
2.00E-17
1.0
10.
1.00E+02
FREQUENCY (HZ)
PLOT NO = 3

HVAC Equipment Vibrations

- Isolated Concrete Fan Room
- Minimum 5 Hz Fan Isolation Skids
- LVEA = Six Fans Operating Continuously
- Mid and End Stations = One Fan Operates
- 0.1g Unbalanced Fan Vibration Source
- 1800 rpm Fan Speed

HVAC Equipment Vibrations -- 2 nd

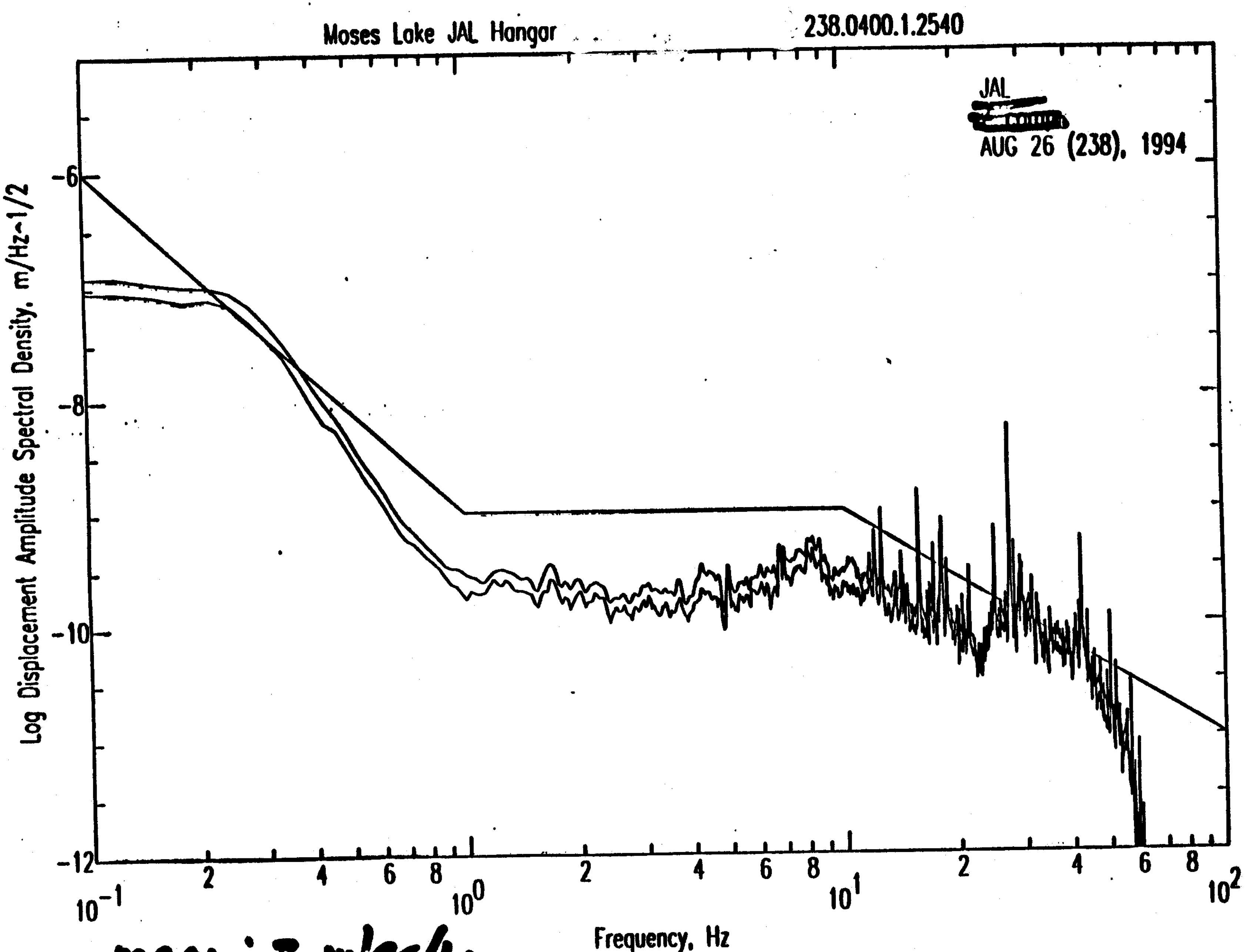
- Proposed Spike Criteria = 1.4×10^{-8} m at 30 Hz
- LVEA Expected Displacement
  - 2.5×10^{-8} m
- Mid & End Station Expected Displacement
  - 5.7×10^{-8} m

Chiller Equipment Vibrations

- Chillers at 300 Feet From LVEA/VEA
- Minimum 5 Hz Rotating Equipment Skid
- 0.1g Unbalanced Vibration Source
- 3600 rpm Rotational Speed
- Proposed Spike Criteria at 60 Hz
  - 3.0×10^{-9} m
- Expected Displacement {LVEA and VEA}
  - 5.6×10^{-9} m

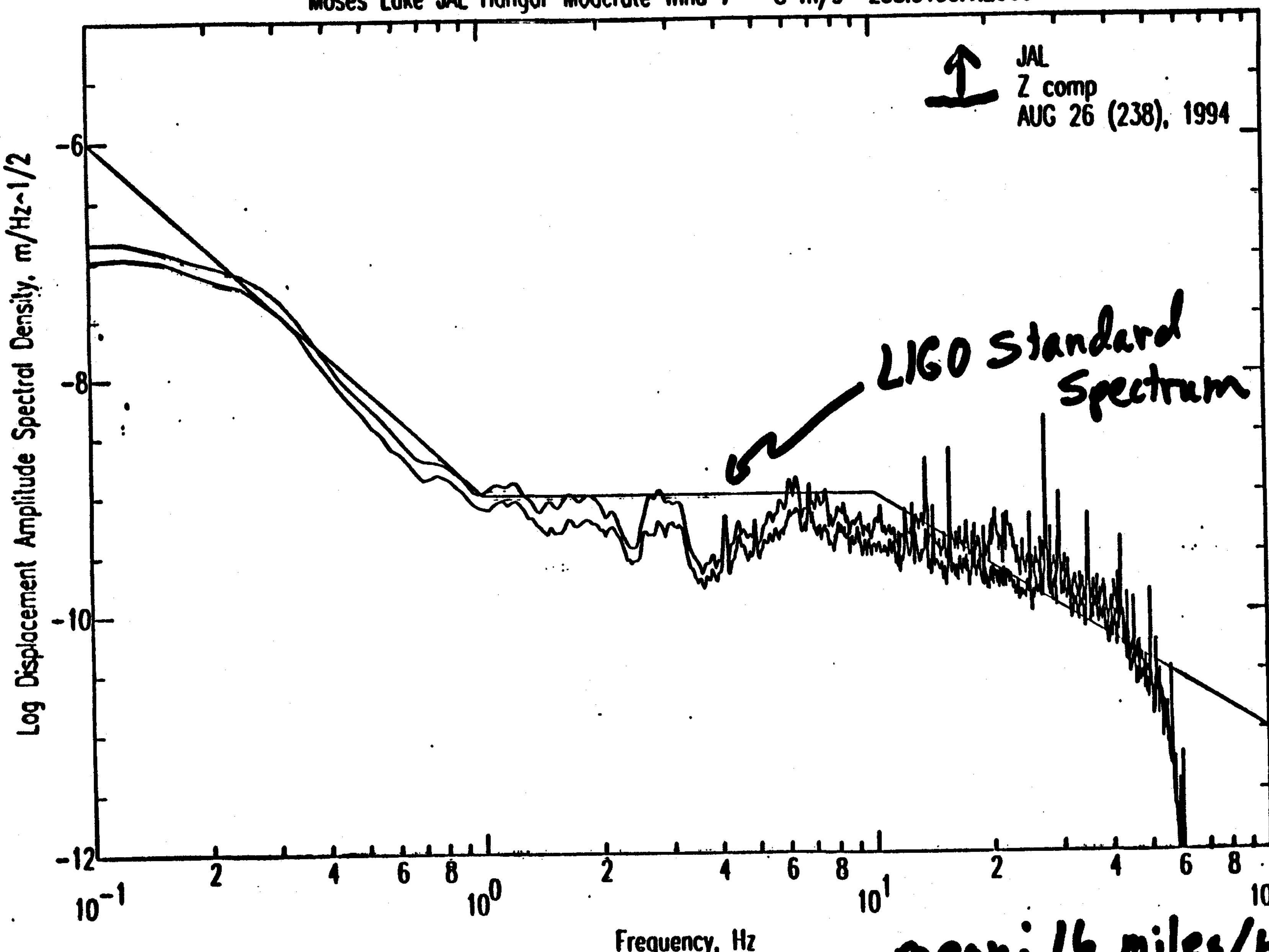
Wind Induced Vibrations

- Wind Exceeds 20 mph less than 5% of Time
- Side-Sway Building Frequency 2.54 Hz
- Side-Sway Vibration at Roof = 0.003 Inches at 20 mph
- LVEA Foundation Vibration = 2.3×10^{-6} m
- Spike Amplitude Criteria = 2.0×10^{-6} m
- Moses Lake Wind Measurements
- Internal Pressure Fluctuations - TBD



mean: 3 miles/hr
peak: 3 miles/hr

Moses Lake JAL Hangar Moderate Wind 7 – 8 m/s 238.0100.1.2000

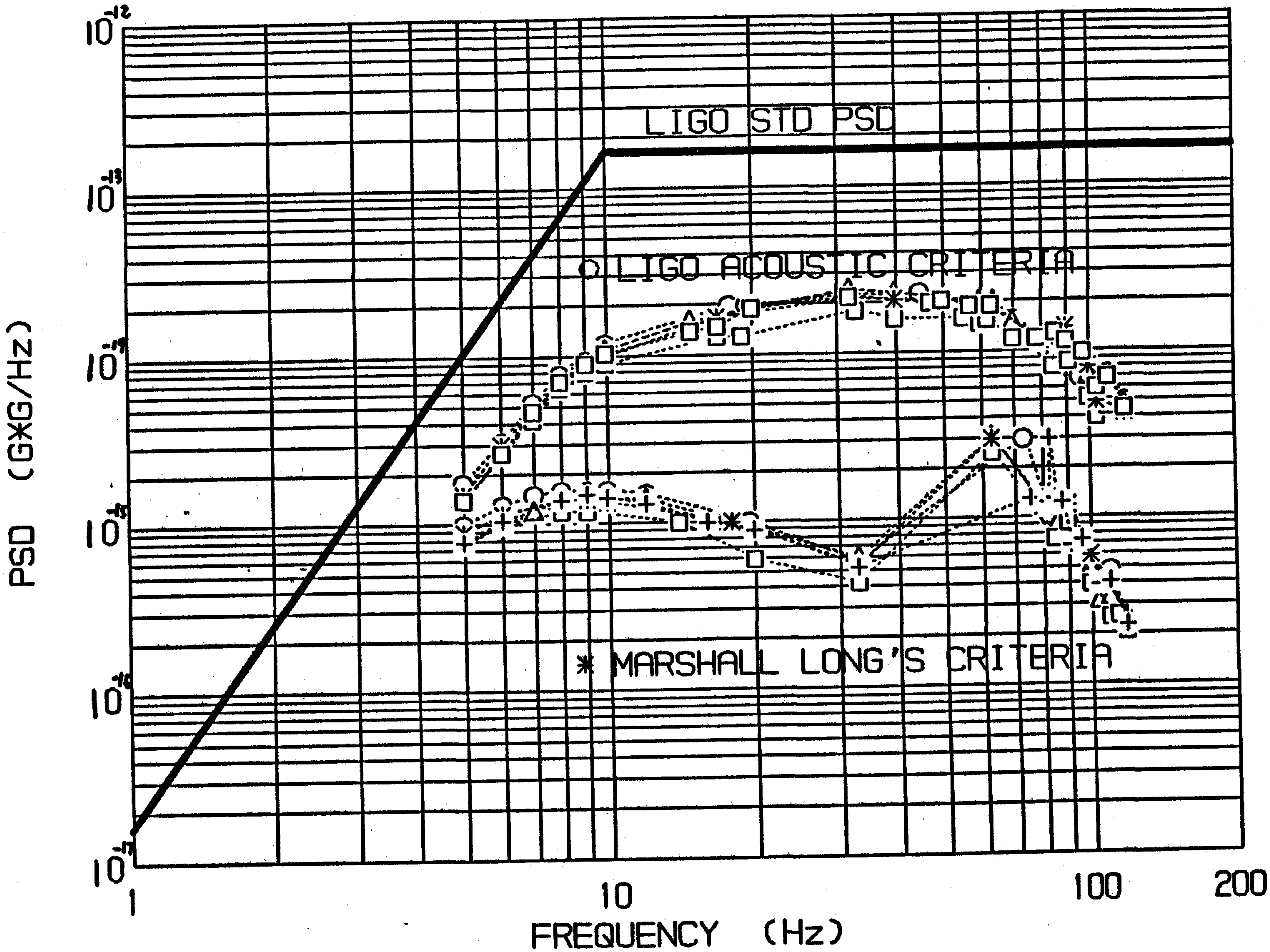


mean: 16 miles/hr
peak: 22 miles/hr

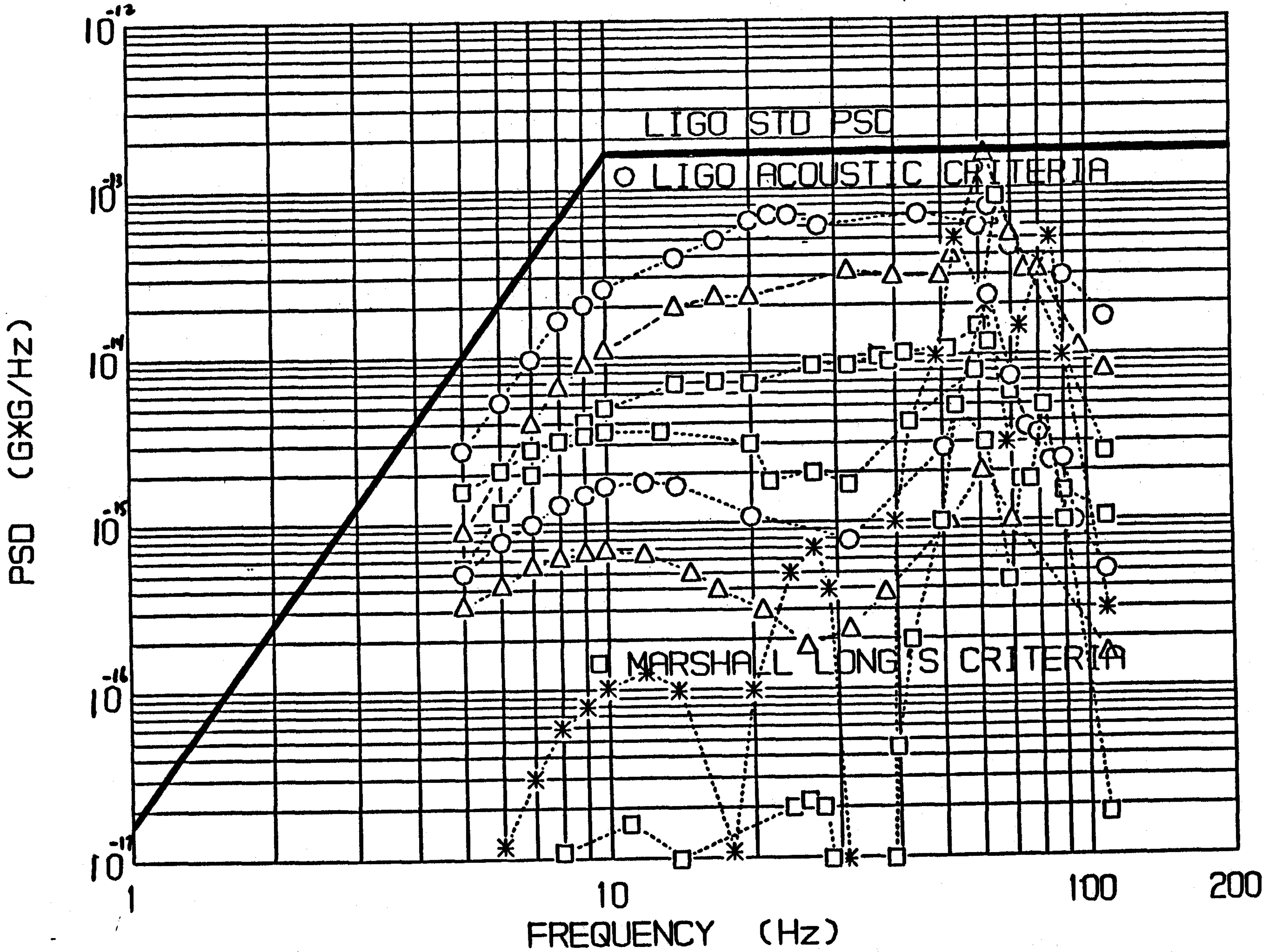
Foundation Thickness Study

- 68 Inch Thick Foundation Meets Criteria
  - With a Substantial Factor of Safety
- 36 Inch Thick Foundation Meets Criteria
  - With No Factor of Safety
- 18 Inch Thick Foundation Exceeds Criteria

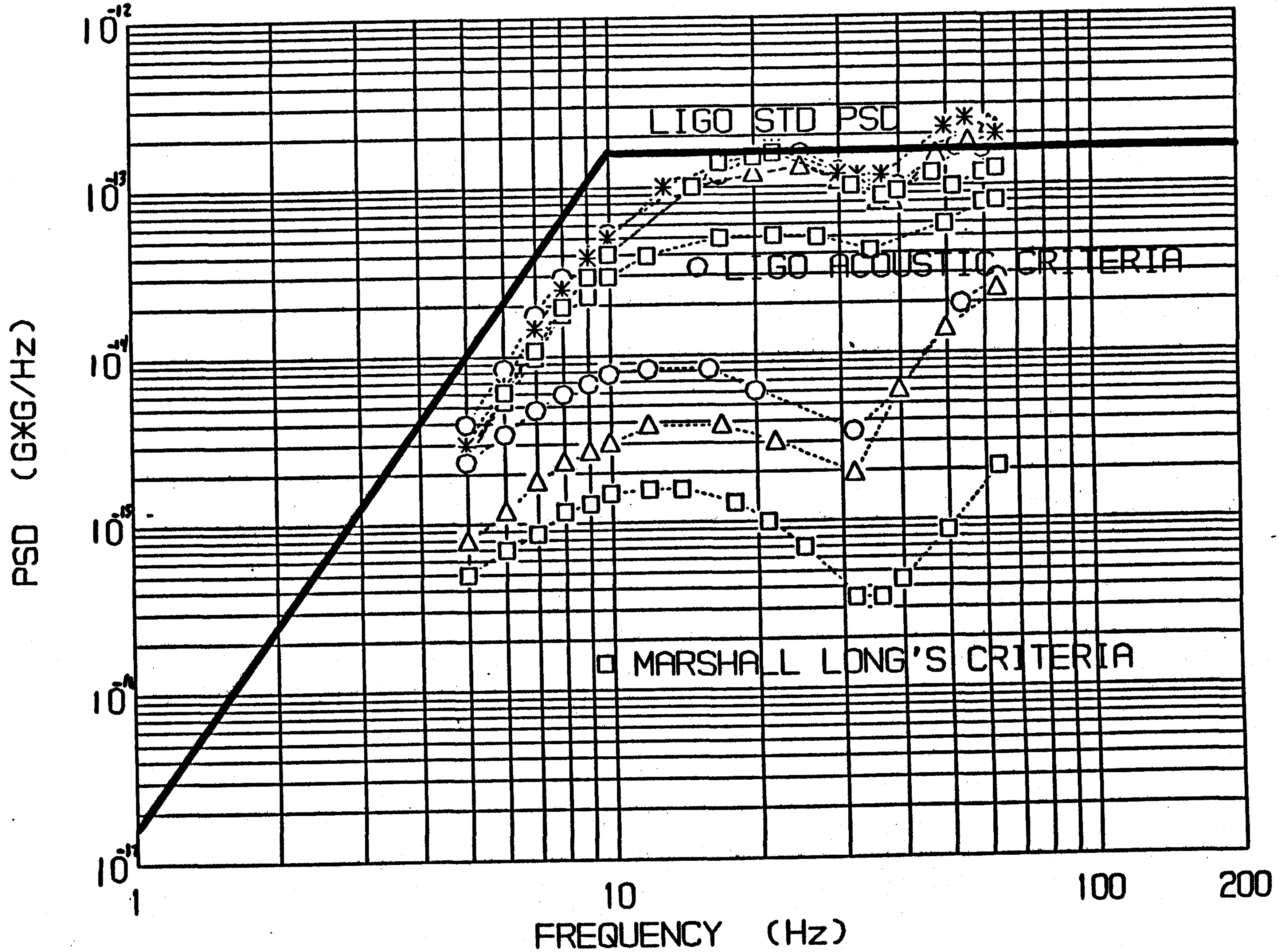
68" LVEA FOUNDATION - ACOUSTIC PSD



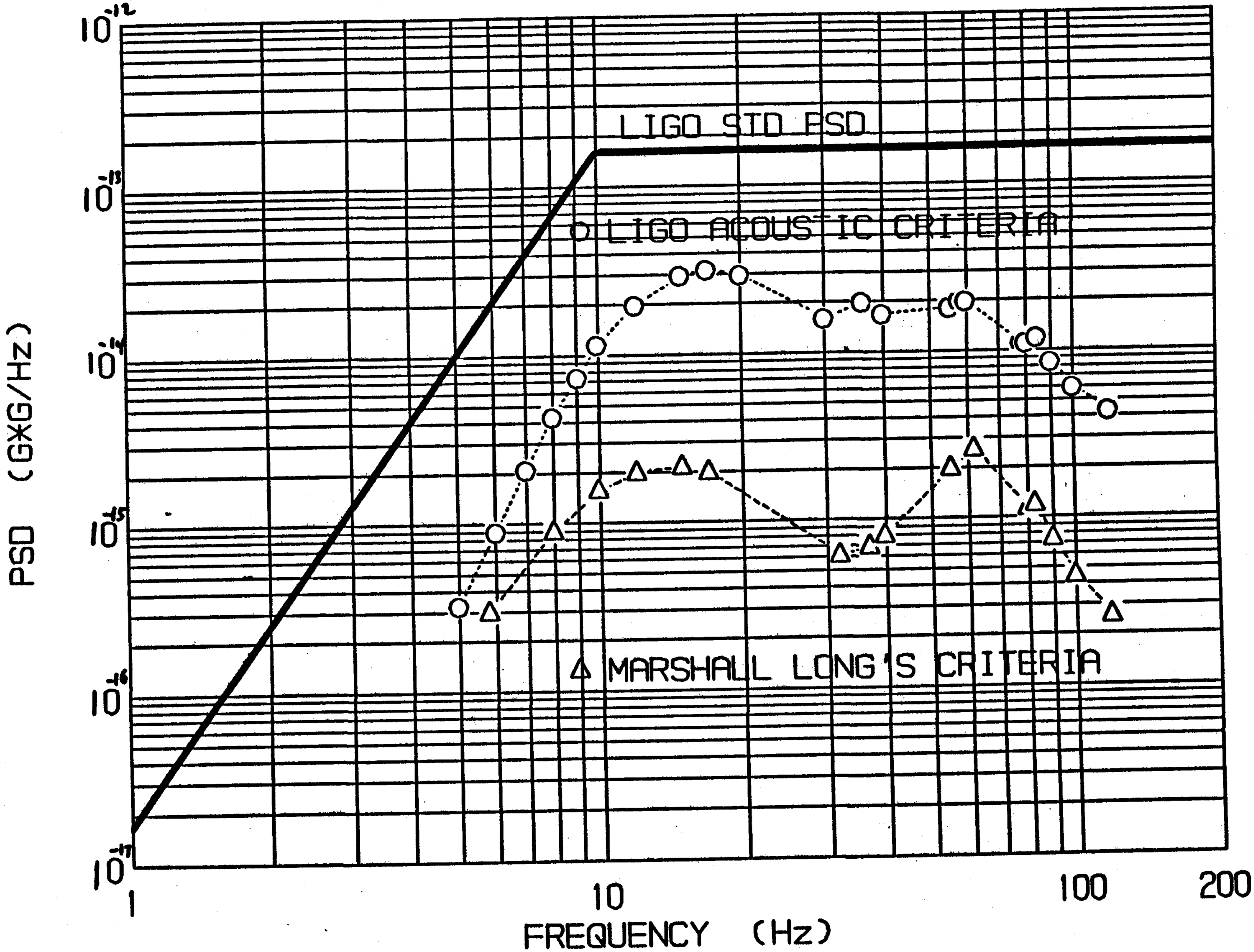
36" LVEA FOUNDATION - ACOUSTIC PSD



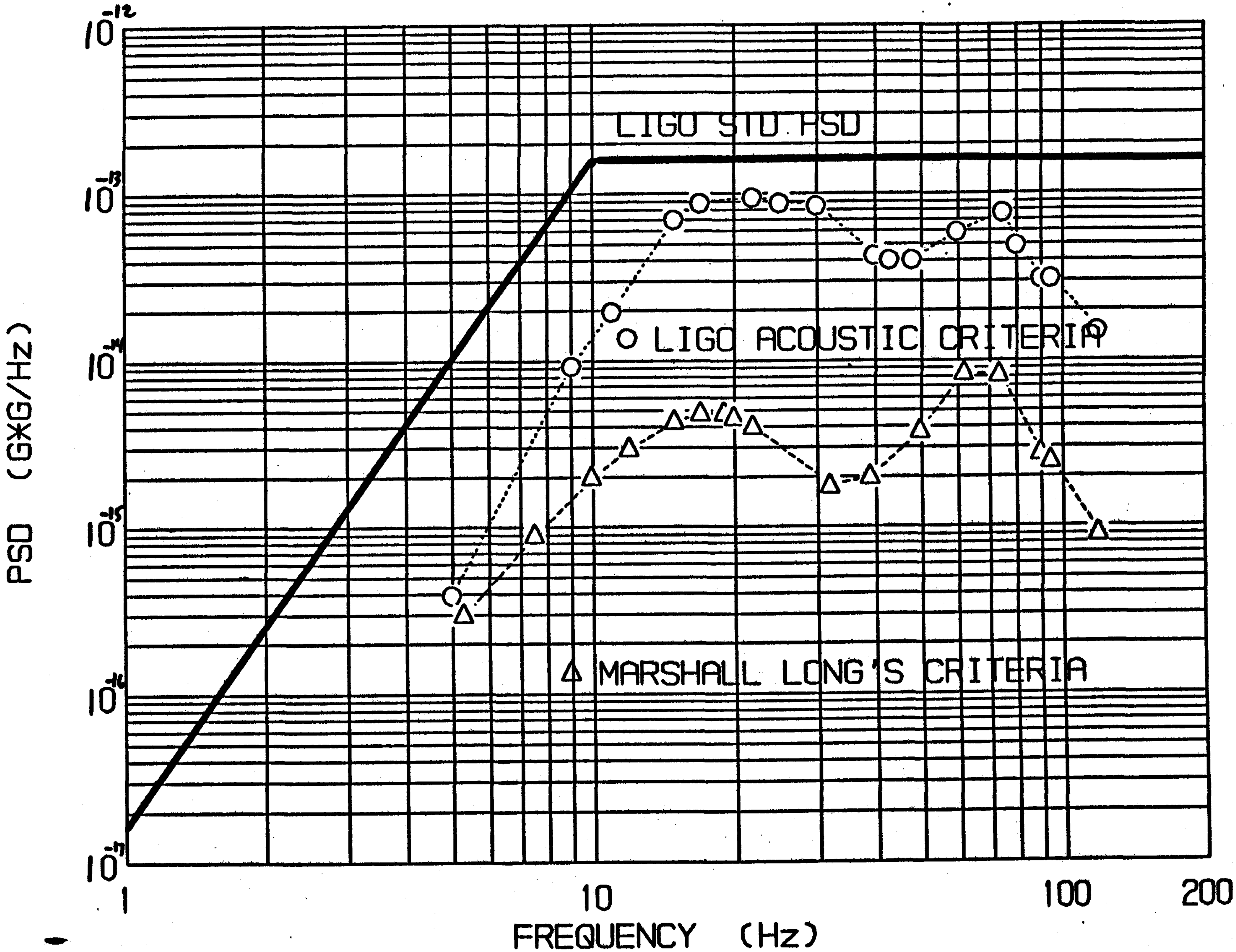
18" LVEA FOUNDATION - ACOUSTIC PSD



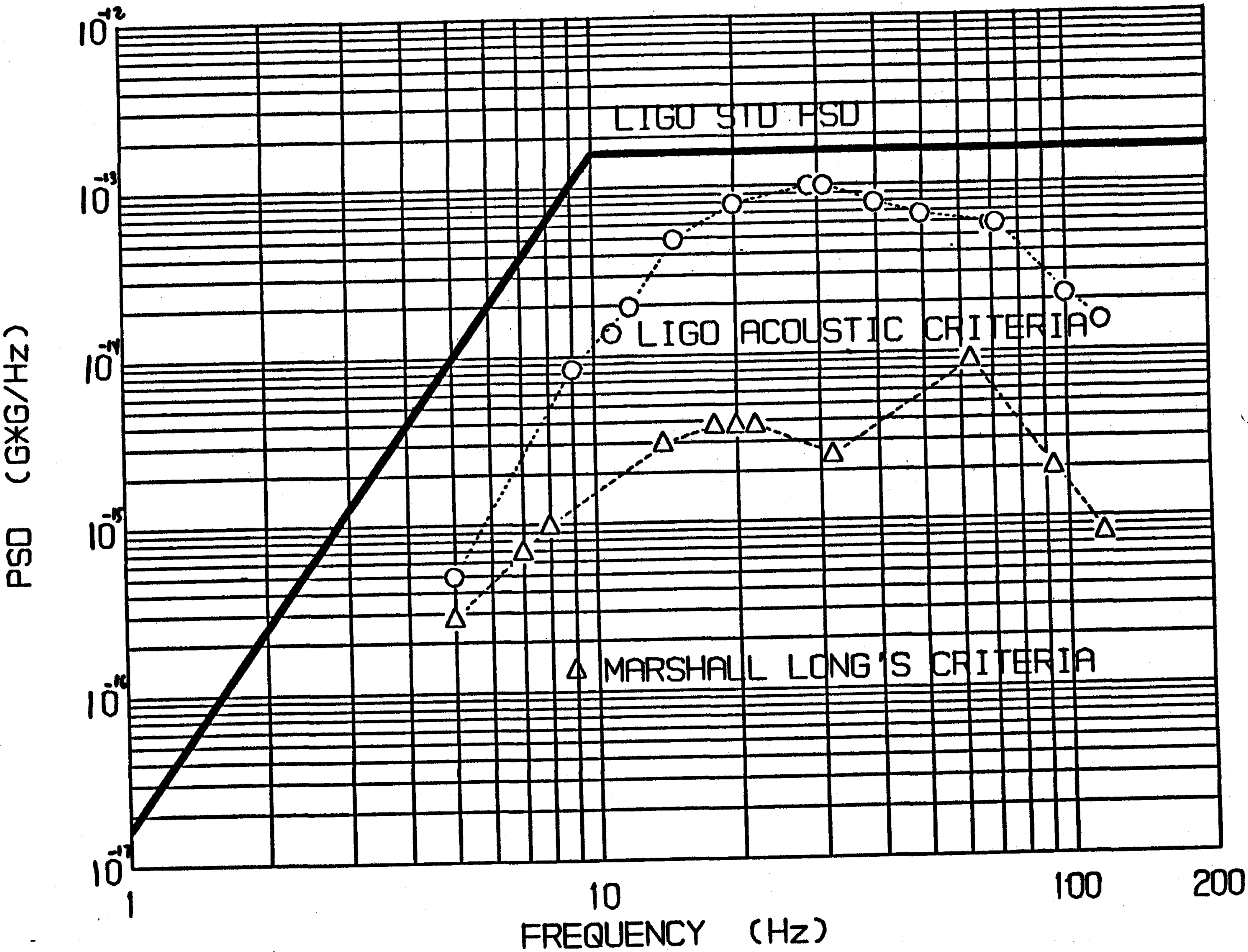
68" MID-STATION FOUNDATION - ACOUSTIC PSD



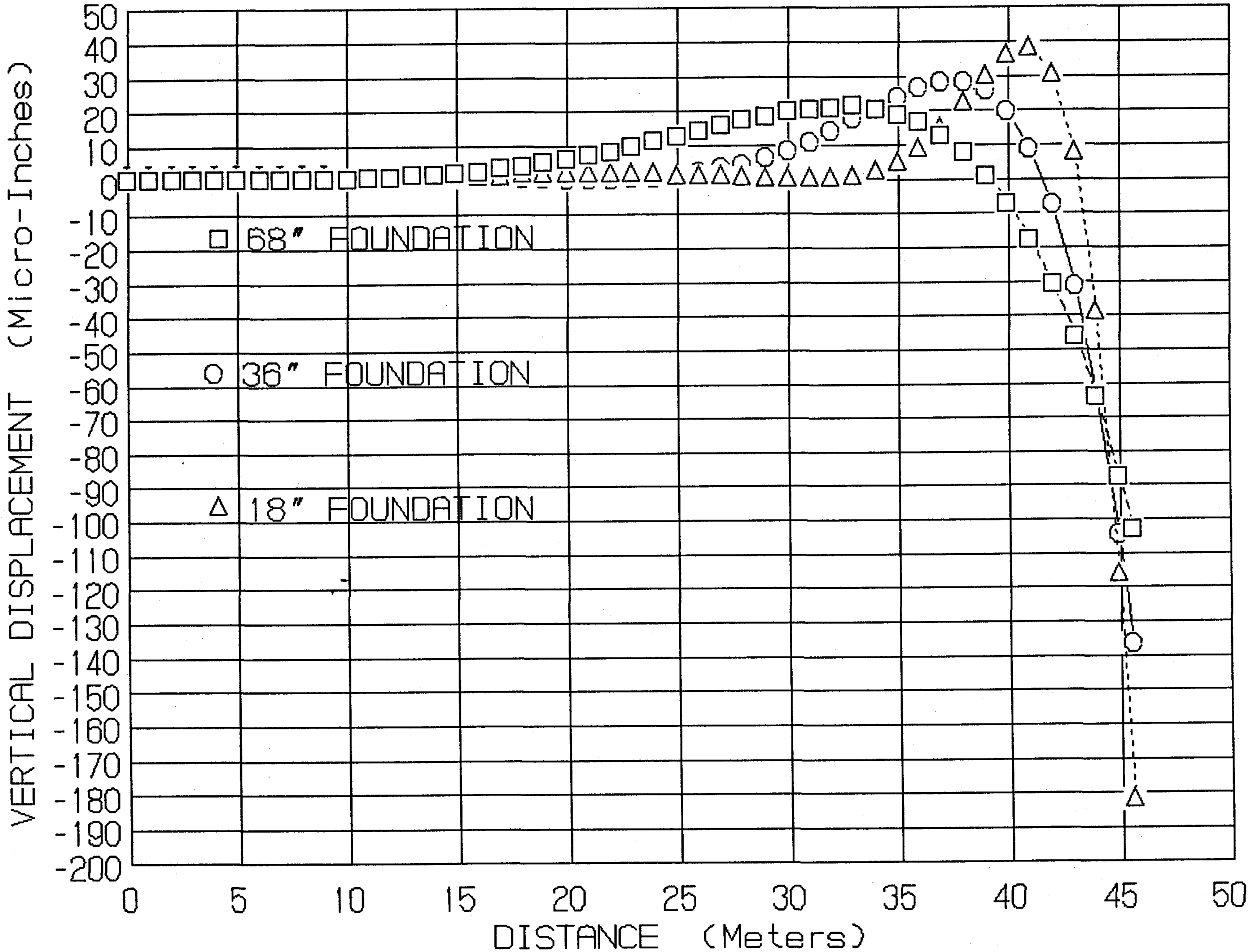
36" MID-STATION FOUNDATION - ACOUSTIC PSD



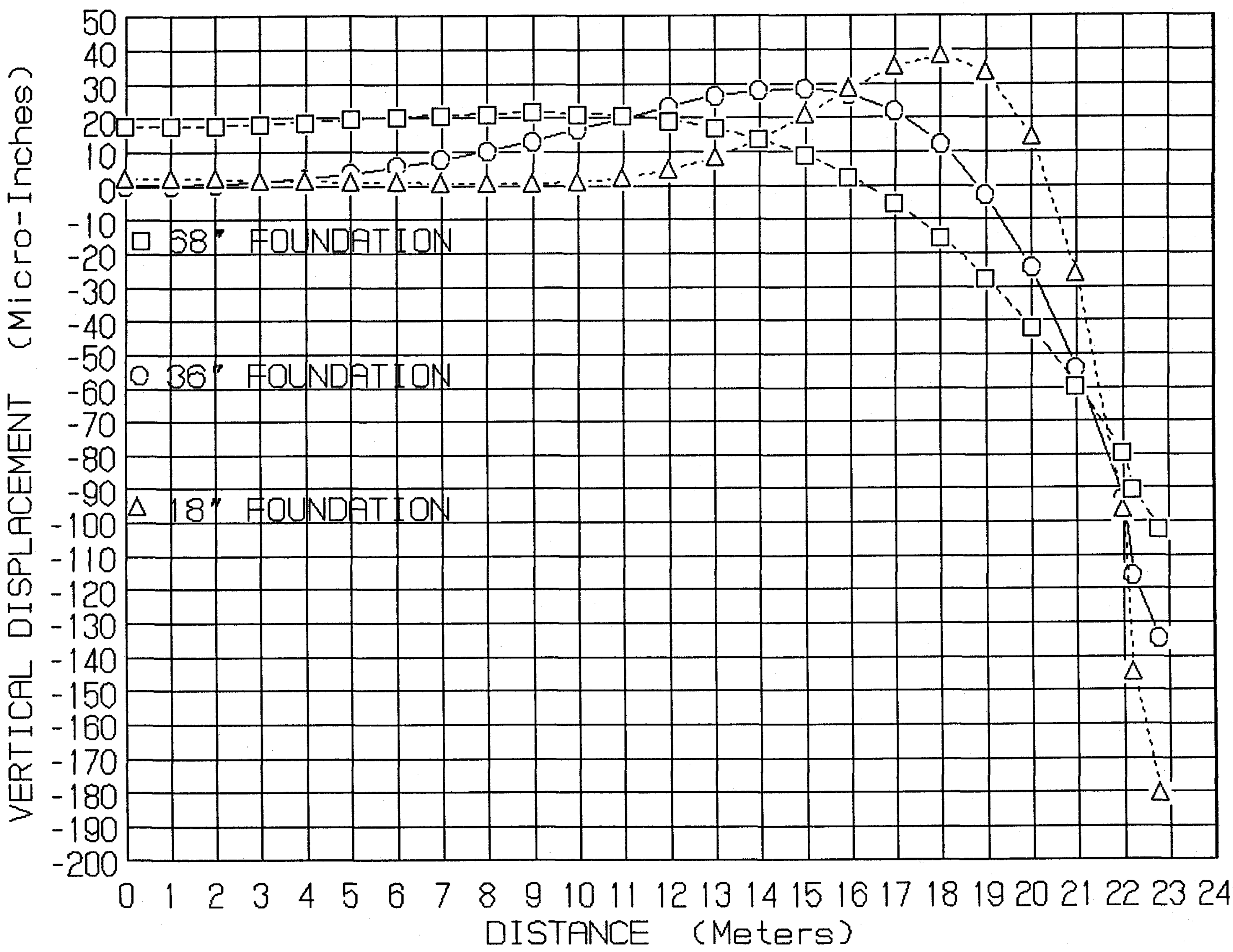
18" MID-STATION FOUNDATION - ACOUSTIC PSD



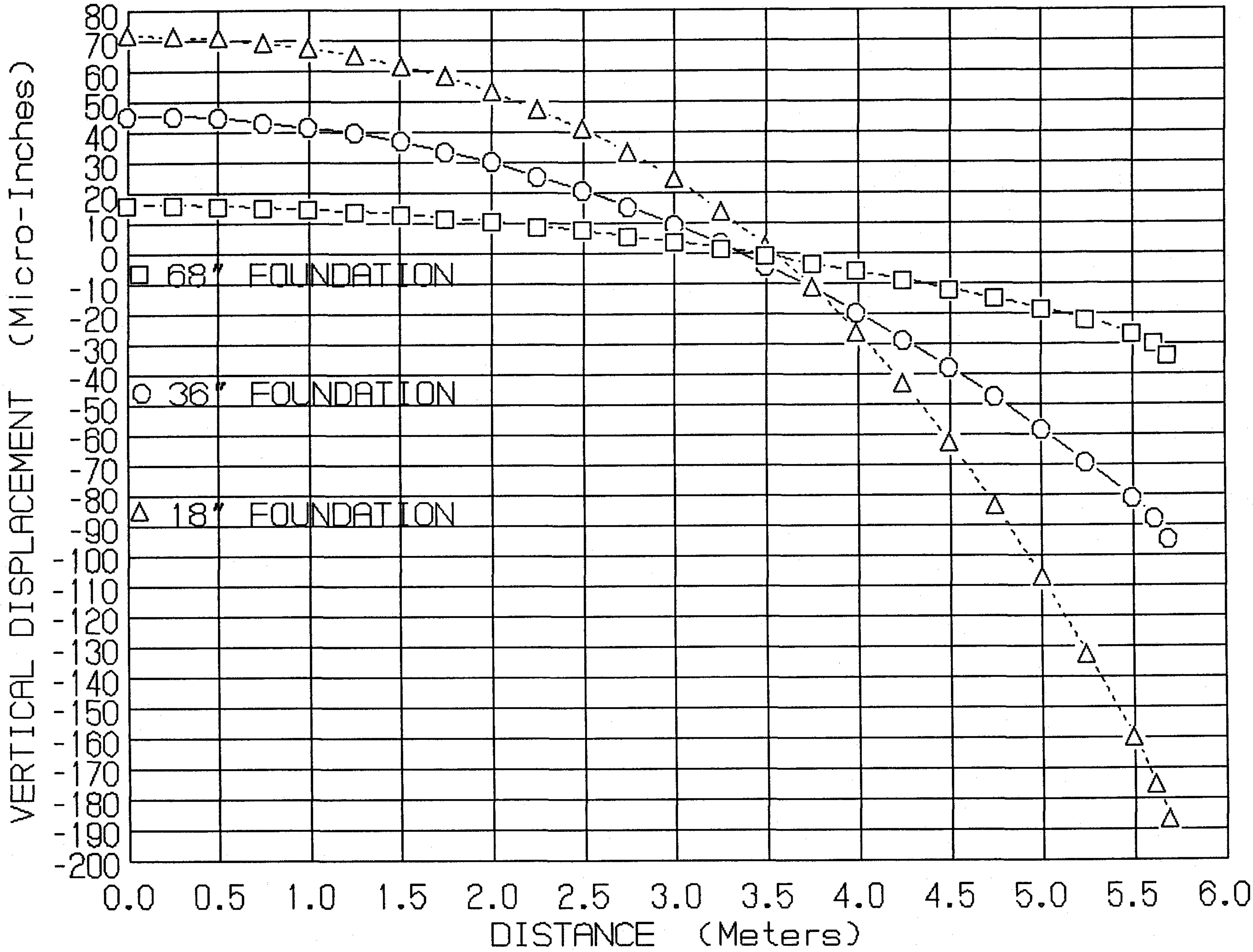
10 MINUTE THERMAL FOUNDATION DEFORMATIONS

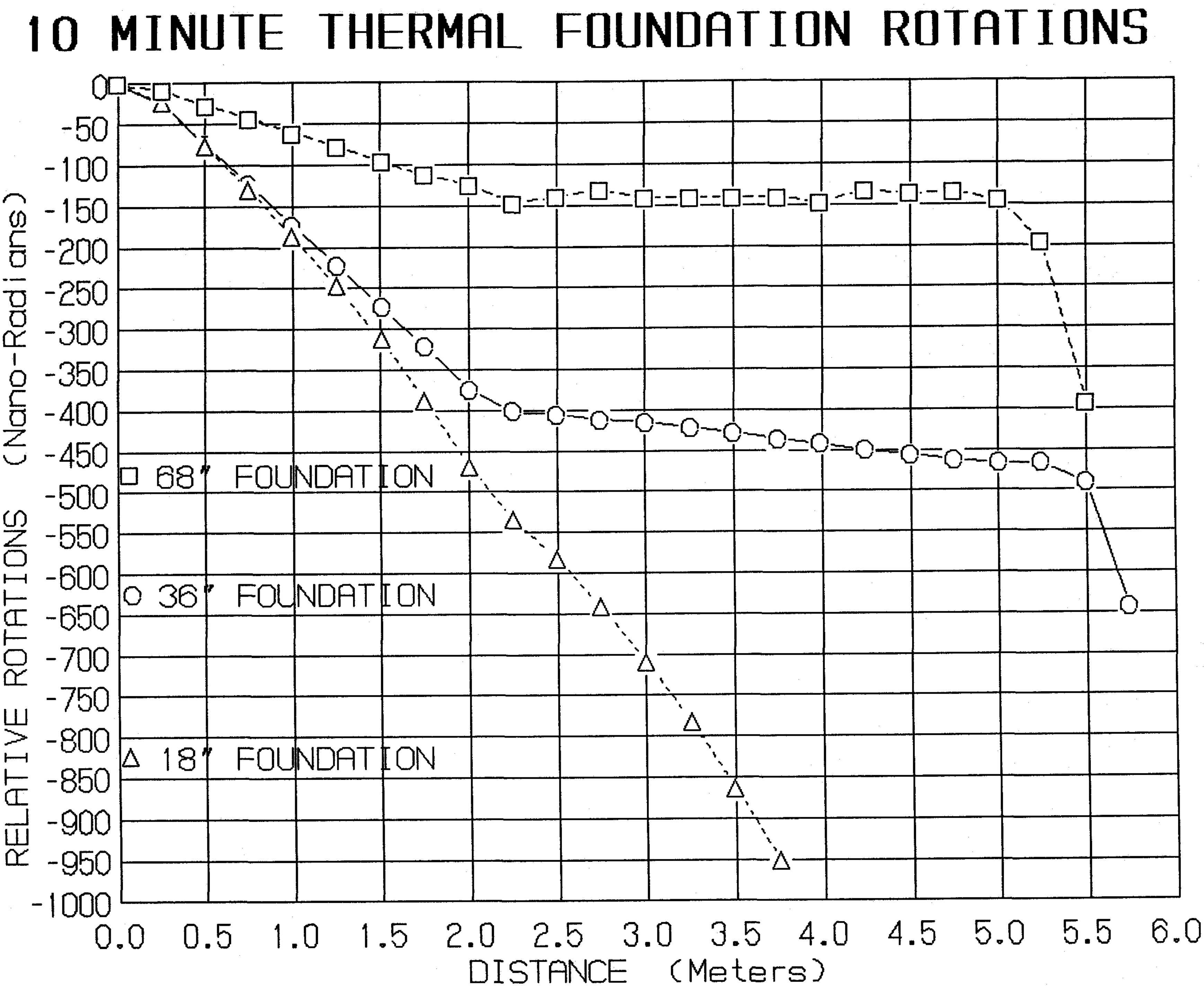


10 MINUTE THERMAL FOUNDATION DEFORMATIONS

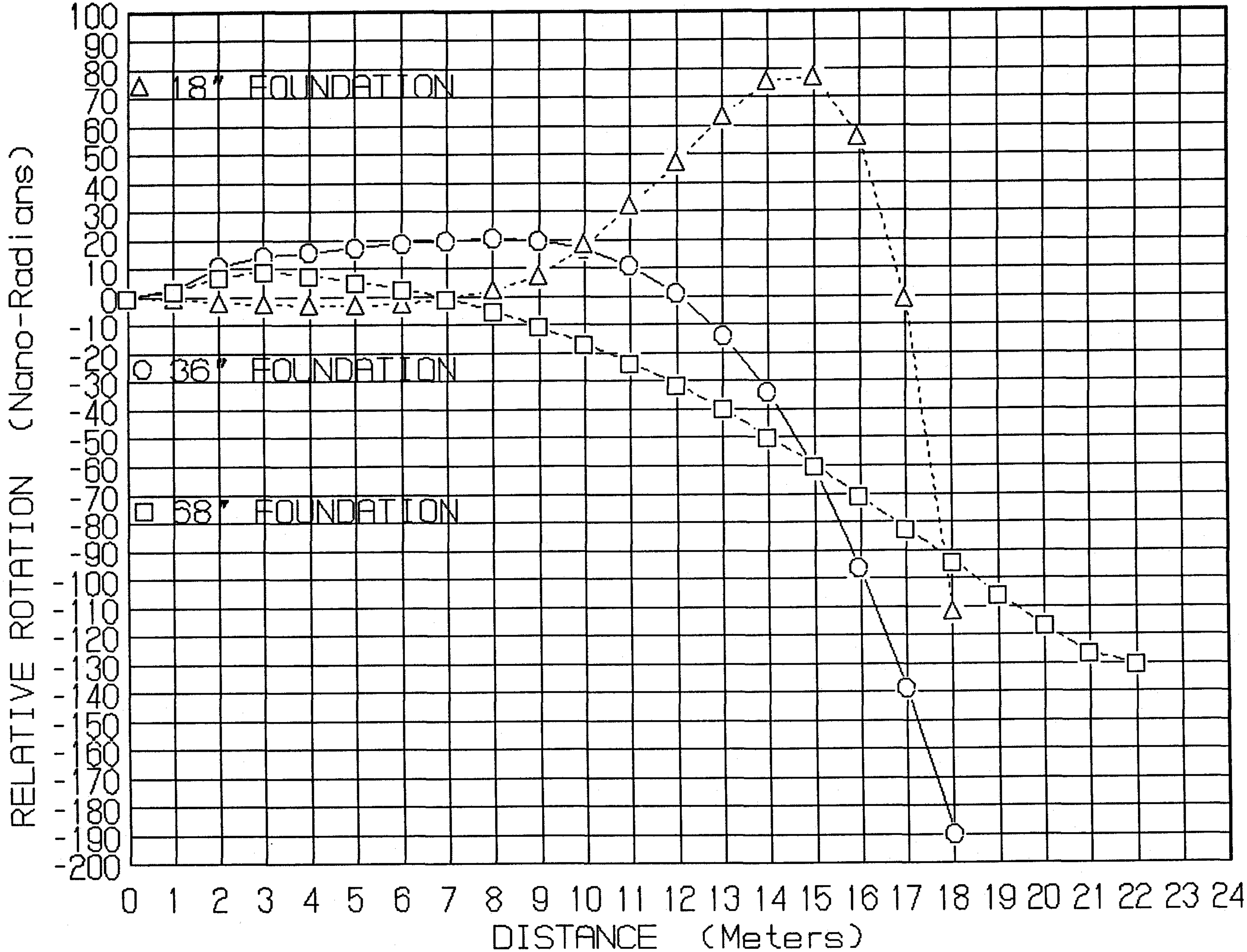


10 MINUTE THERMAL FOUNDATION DEFORMATIONS




10 MINUTE THERMAL FOUNDATION ROTATIONS
RELATIVE ROTATIONS (Nano-Radians)
DISTANCE (Meters)
0
-50
-100
-150
-200
-250
-300
-350
-400
-450
-500
-550
-600
-650
-700
-750
-800
-850
-900
-950
-1000
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
68" FOUNDATION
36" FOUNDATION
18" FOUNDATION

10 MINUTE THERMAL FOUNDATION ROTATIONS



10 MINUTE THERMAL FOUNDATION ROTATIONS