EARTHQUAKE ANALYSIS OF THE CONTROL BUILDING COOPER NUCLEAR STATION

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To J. Greenberg

EARTHQUAKE ANALYSIS OF THE CONTROL BUILDING COOPER NUCLEAR STATION

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EARTHQUAKE ANALYSIS
OF THE
CONTROL BUILDING
COOPER NUCLEAR GENERATING STATION

FOR

BURNS AND ROE, INC.
Engineers and Contractors

By

EARTH SCIENCES
A Teledyne Company
171 North Santa Anita Avenue
Pasadena, California

23 January 1969

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CONTENTS

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EARTHQUAKE ANALYSIS OF THE CONTROL BUILDING
COOPER NUCLEAR GENERATING STATION

1.0 INTRODUCTION

Cooper Nuclear Station is located in Nemaha County, Nebraska on the west bank of the Missouri River. The owner is Consumers Public Power District of Columbus, Nebraska. This report on the seismic response of the Control Building has been prepared for the Architect-Engineer, Burns and Roe, Inc. of Oradell, New Jersey. Figure 1 shows the location of the Control Building in relation to the remaining structures of the plant complex.

The results of the analysis for the design earthquake forces include displacements, moments, shears and accelerations in the Control Building and the response spectra for each floor.

2.0 DESCRIPTION OF THE BUILDING

The Control Building is an "L" shaped reinforced concrete shear wall building as shown in Figure 2. Resistance to lateral forces is provided by the shear walls which vary in thickness from 1.5 to 3.0 feet. The four story building is founded on an eight foot thick concrete mat, the top of the mat is at elevation 877'-6". The top of the building is at elevation 948-9".

3.0 DEFINITION OF THE EARTHQUAKE

The Preliminary Safety Analysis Report (Reference 1) for Cooper Nuclear Station sets forth the criteria for the "Maximum Probable Design Earthquake" and the "Hypothetical Maximum Design Earthquake". Table 1 summarizes the maximum values of ground acceleration.

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VALUES OF MAXIMUM GROUND ACCELERATION		
	Design Earthquake	
	Maximum Probable	Hypothetical Maximum
Horizontal Component	0.10g	0.20g
Vertical Component	0.05g	0.10g

Table 1

The maximum values of Table 1 are to be used for the ground acceleration at both the rock surface and the base of the structure.

The N69W component of the 21 July 1952 earthquake recorded at Taft, California was specified as an appropriate accelerogram for the Cooper plant site. Since the N69W component had a recorded maximum acceleration of 0.157 gravity the accelerogram amplitude was multiplied respectively by 0.100/0.157 and 0.200/0.157 to represent the horizontal components of the Maximum Probable and Hypothetical Maximum design earthquakes.

Acceleration response spectra are shown in Figures 3 and 4 for each design earthquake. Figure 3 is the response spectrum for the Maximum Probable Design Earthquake, calculated with damping set to 5 percent of critical. This damping value is taken to represent energy losses in the reinforced concrete building and surrounding soil when excited at the Maximum Probable intensity. The smooth response curve of Figure 3 represents the Maximum Probable Design Spectrum. It has been drawn as an approximate average of the peaks and valleys contained within the Taft response spectrum. Similarly, Figure 4 is the response spectrum for the Hypothetical Maximum Design Earthquake. The damping value of 7 percent represents energy losses in the reinforced concrete building and surrounding soil when excited at the Hypothetical Maximum intensity. The

Hypothetical Maximum Design spectrum is represented by the smooth curve of Figure 4.

Figure 5 is an additional plot of the response spectrum for the Maximum Probable Design Earthquake calculated for 5 percent damping. The tripartite log graph permits simultaneous display of acceleration, velocity, and displacement response.

4.0 MATHEMATICAL MODEL

The Control Building is described mathematically by four translational masses lumped at the floor levels and one rotative mass at the foundation level. At each floor level translational and rotational displacements are permitted and rotational displacement is permitted at the base of the structure. The structural properties of the building and the mathematical model are shown in Figure 6. The mass at each floor level includes the weight of the concrete floor and the tributary weight of the walls and equipment between adjoining floors. The stiffness characteristics of the building between the lumped masses were determined from calculations of the cross sectional areas and area moments of inertia of the concrete walls between the floors. The torsional rigidity of the building is large. Therefore, torsional response has been neglected.

The time dependent accelerations of the design earthquakes are assumed to occur at the base of the model (elevation 873'-6"). In responding to horizontal accelerations at the base, the building tends to rock on the foundation. A rotational spring $K_\theta = 0.222 \times 10^{10}$ kip-ft/rad in the East-West direction and $K_\theta = 0.123 \times 10^{10}$ kip-ft/rad in the North-South direction represent rocking interaction between the building and its foundation. The soil spring values and the section properties of the structure were provided by Burns and Roe and checked by Earth Sciences. (Reference 3)

5.0 METHOD OF ANALYSIS

The response of the Control Building to the earthquake accelerograms was calculated on a time-dependent basis using the mode superposition method (References 4, 5, 6, and 7). The characteristic free vibration shapes (modes) were used as principal coordinates permitting the independent evaluation of each coordinate response. All five modes of vibrations were used to obtain the response. In the modal coordinate system, the response of the structure to the applied loads is determined at each interval of time. By transforming back to the structural coordinate system, the displacements and accelerations at each of the nodal points are calculated. Then the shears and overturning moments are calculated by application of the structural stiffness matrix.

A macro flow diagram for the computer program used for this study is shown in Figure 7.

Figure 3 is the response spectrum for the Taft earthquake recorded on 21 July 1952 in the N69W direction, normalized to 0.1 gravity (damping = 5 percent critical). For design purposes the peaks and valleys are smoothed out. This is accomplished by constructing a curve to bound the peaks and a similar curve to bound the valleys. The design spectrum is then considered as a smooth curve drawn midway between the maximum and minimum curves.

For each of the first five periods, participation factors are computed. The participation factor is the ratio of the response value taken from the Taft spectrum to that of the smoothed spectrum. These participation factors are shown in Table 2.

Table 2

Mode	Participation Factors			
	Max. Prob. Earthquake		Hyp. Max. Earthquake	
	E-W	N-S	E-W	N-S
1	.905	1.093	.942	.991
2	1.164	1.168	1.154	1.189
3	1.159	1.169	1.166	1.190
4	1.082	1.092	1.116	1.084
5	1.075	1.074	1.090	1.079

6.0 RESULTS

Analyses were carried out for both the East-West and North-South direction for both the Maximum Probable Earthquake (maximum acceleration of 0.1 gravity), and the Hypothetical Maximum Earthquake (0.2 gravity).

In both the North-South and East-West directions the fundamental mode is dominated by rocking on the soil foundation. The modes of vibration and associated periods for both directions are shown in Figures 8 and 9.

For each of the four analyses the following results were obtained:

1. Maximum relative displacements
2. Maximum total accelerations
3. Maximum moments
4. Maximum shears.

These results were plotted graphically for the floors of the Control Building and are shown in Figures 10 through 17.

From the time histories of accelerations computed at each floor level for both the Maximum Probable Earthquake and the Hypothetical Maximum Earthquake, response spectra were calculated using damping values of 1 percent and 0.5 percent of critical. The plots of the spectra are given in Appendix B.

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LIST OF REFERENCES

1. P.S.A.R., Volume III, Appendix A, Section III, p. 11.

2. N. M. Newmark, "Design Criteria for Nuclear Reactors Subjected to Earthquake Hazards," Urbana, Illinois, 25 May 1967.

3. Transmittal from Burns and Roe, November 1, 1968.

4. R. W. Clough, "Use of Modern Computers in Structural Analysis," Journal of the Structural Division of the ASCE, 1958.

5. R. W. Clough, "Earthquake Analysis by Response Spectrum Superposition," Bulletin of The Seismological Society of America, Vol. 52, No. 3, July 1962.

6. M. Rubenstein. "Matrix Computer Analysis of Structures," Prentice Hall, 1966.

7. G. L. Rogers, "An Introduction to the Dynamics of Fram . Structures," John Wiley, 1959.

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APPENDIX A

FIGURES AND RESULTS

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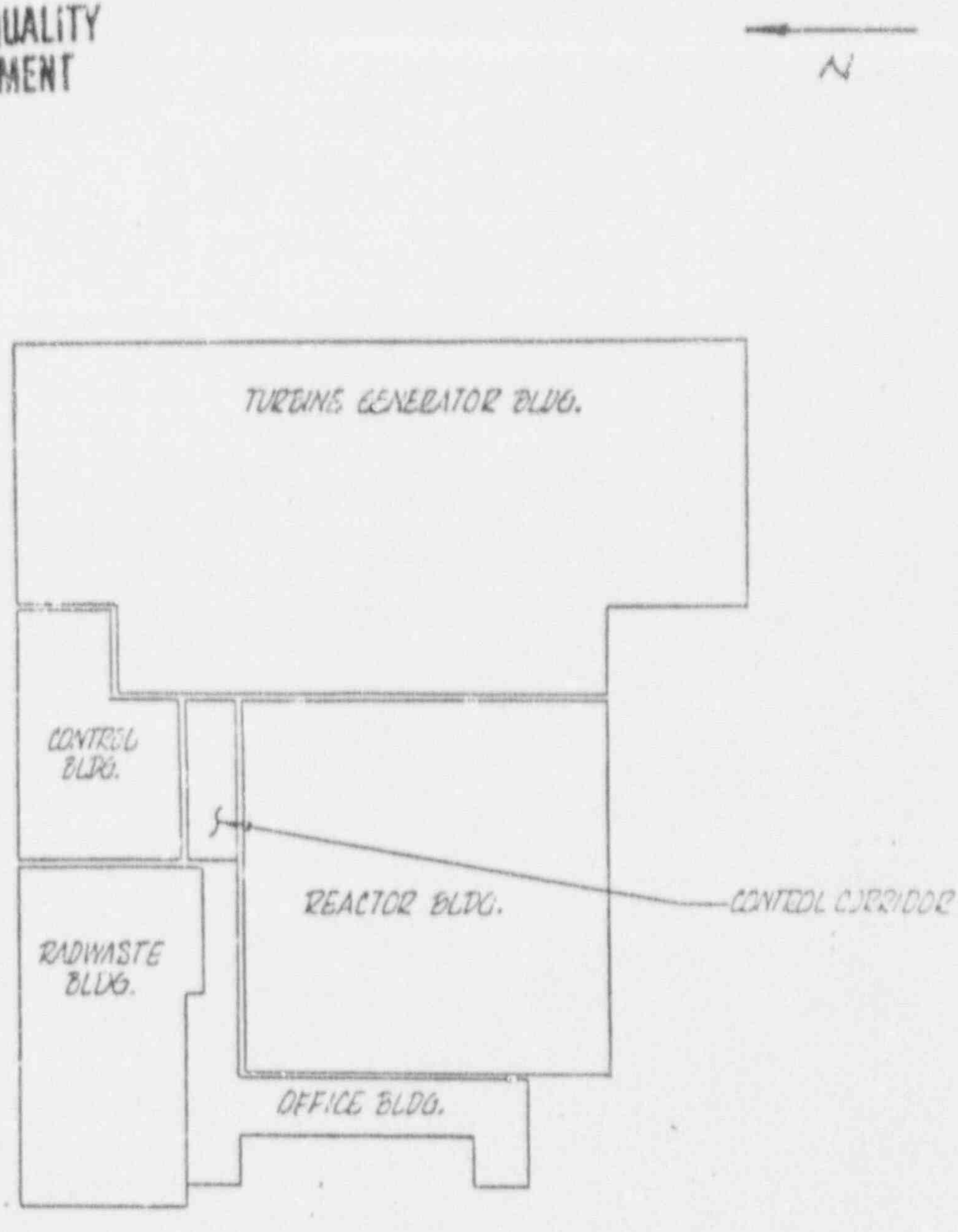

COOPER NUCLEAR STATION
GENERAL PLAN
CLIENT BURNS AND ROE
Job No. 7195 | By E.A. | Date 11-5-76 | Chk. SAS

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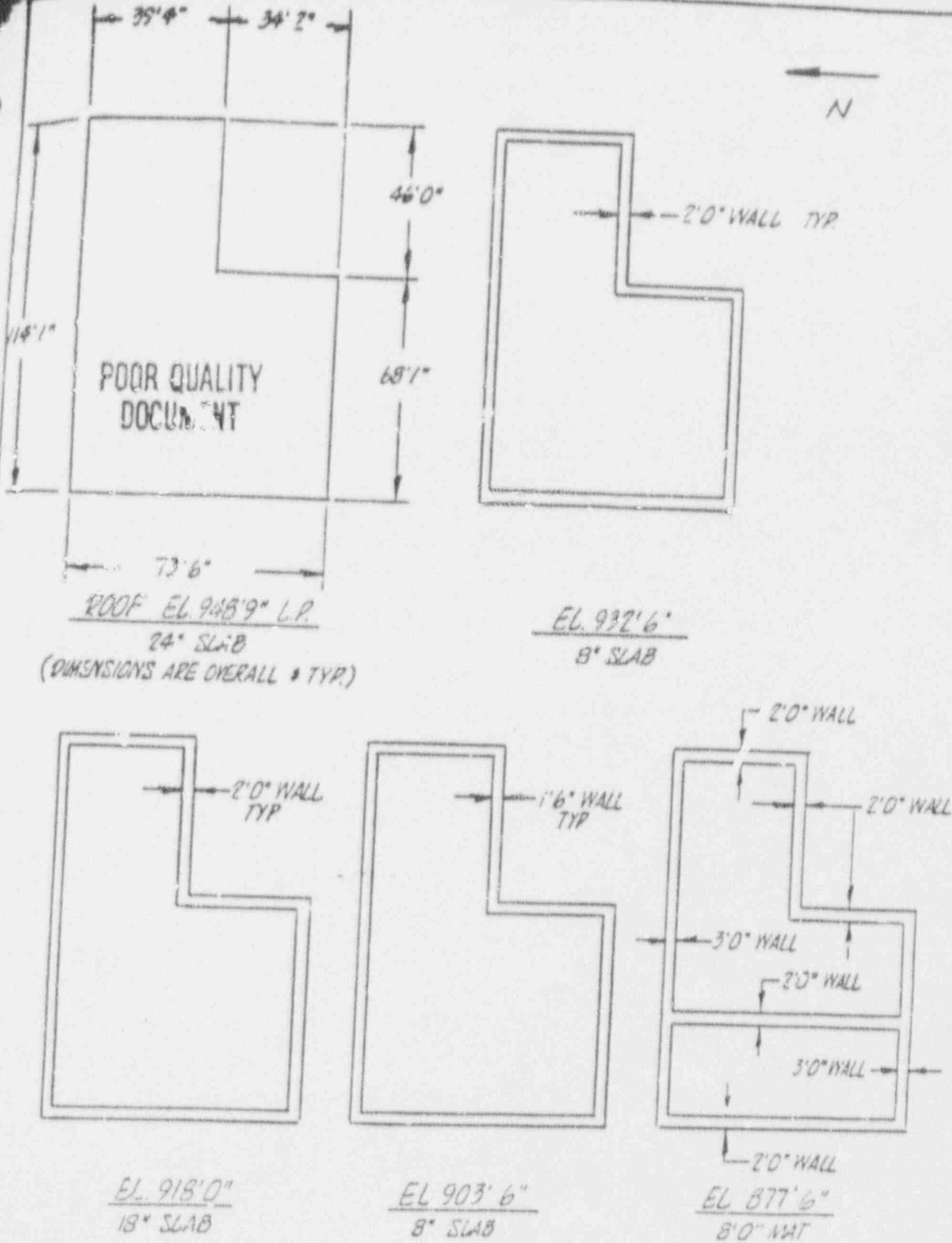
PAGE FIG. 1



JOB COOPER NUCLEAR STATION		EARTH SCIENCES	PAGE
CONTROL BLDG - PLANS		A TELEDYNE COMPANY	FIG 2
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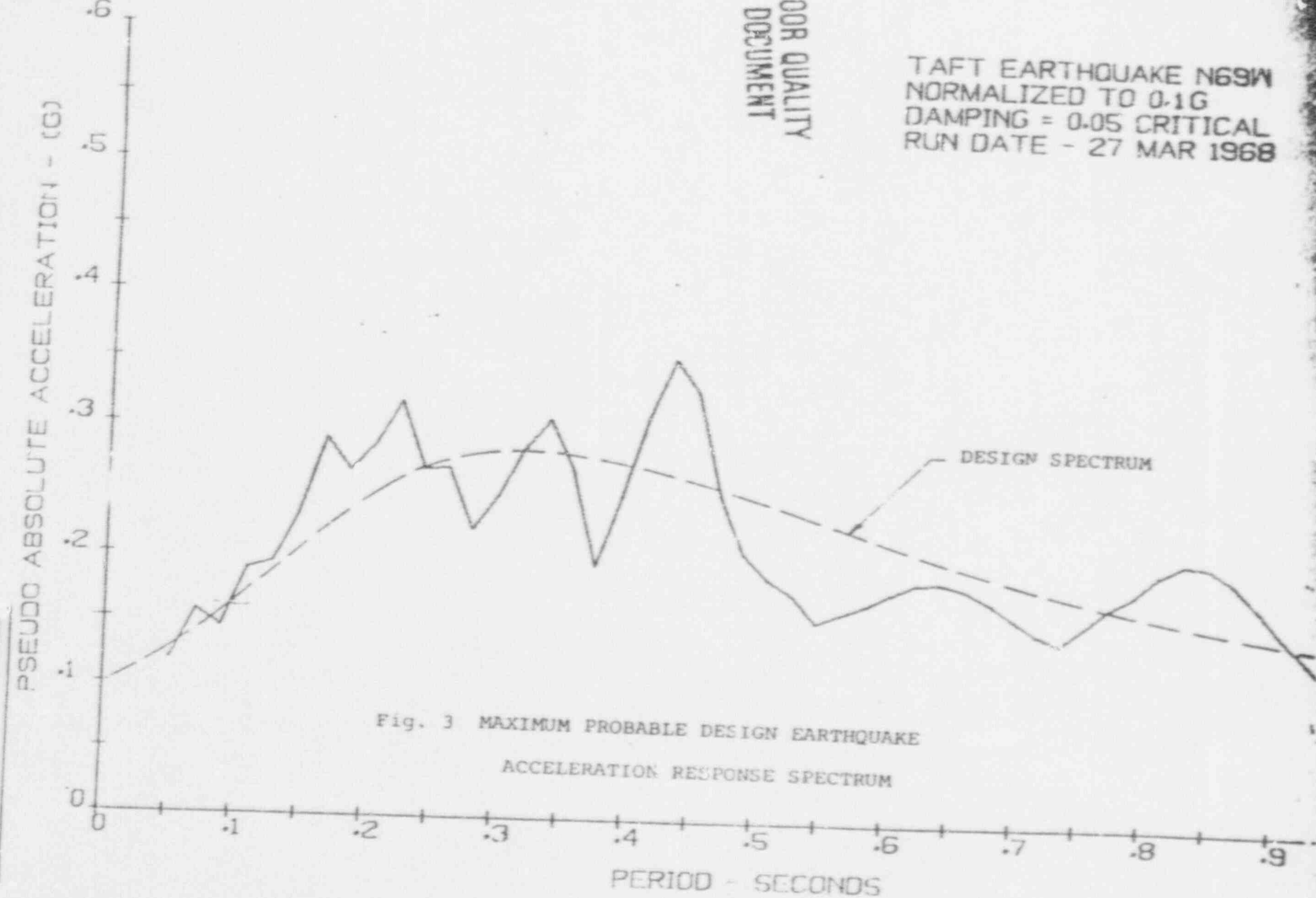

Fig. 3 MAXIMUM PROBABLE DESIGN EARTHQUAKE

ACCELERATION RESPONSE SPECTRUM

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0 0 5 1 0 381

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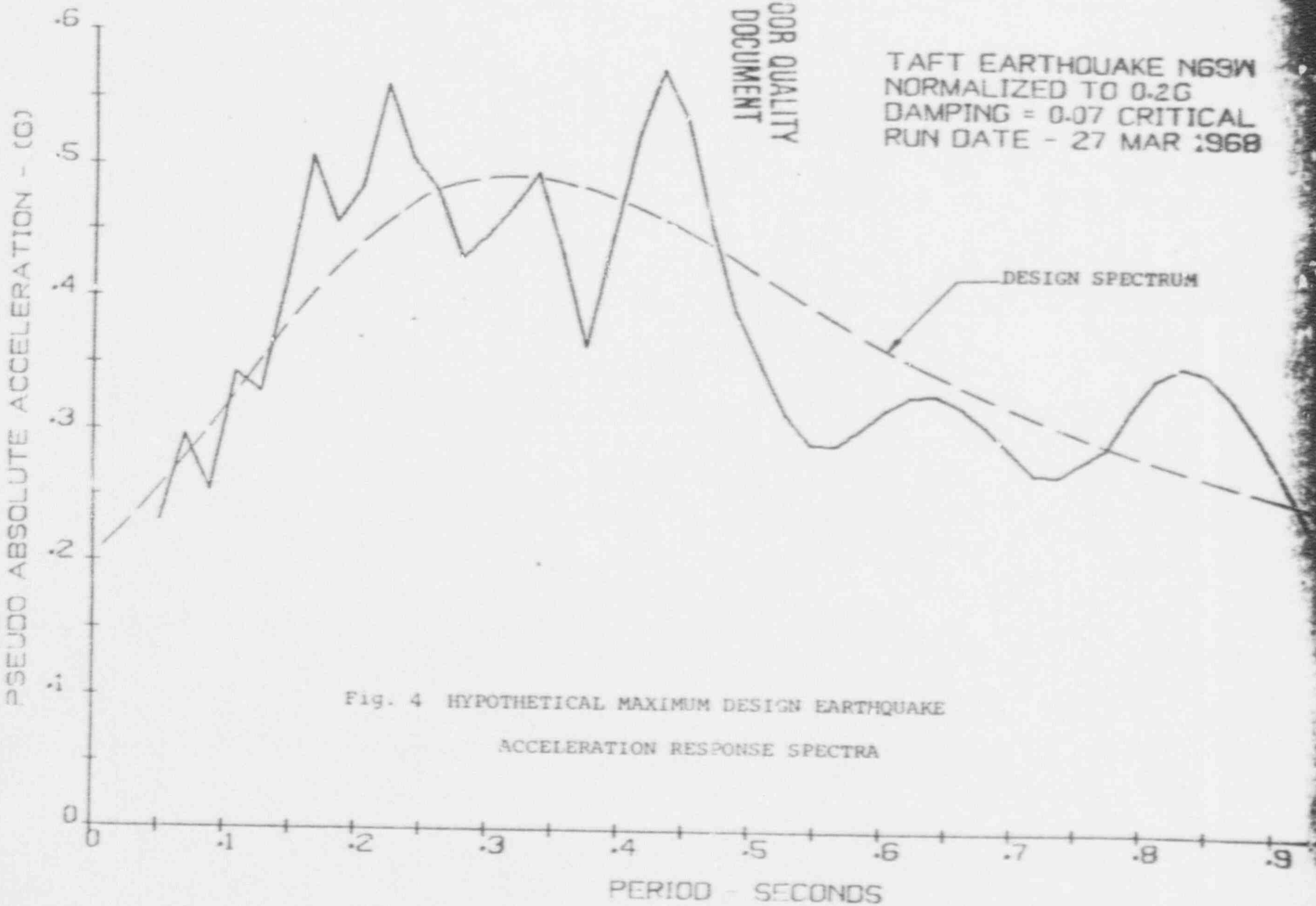

Fig. 4 HYPOTHETICAL MAXIMUM DESIGN EARTHQUAKE

ACCELERATION RESPONSE SPECTRA

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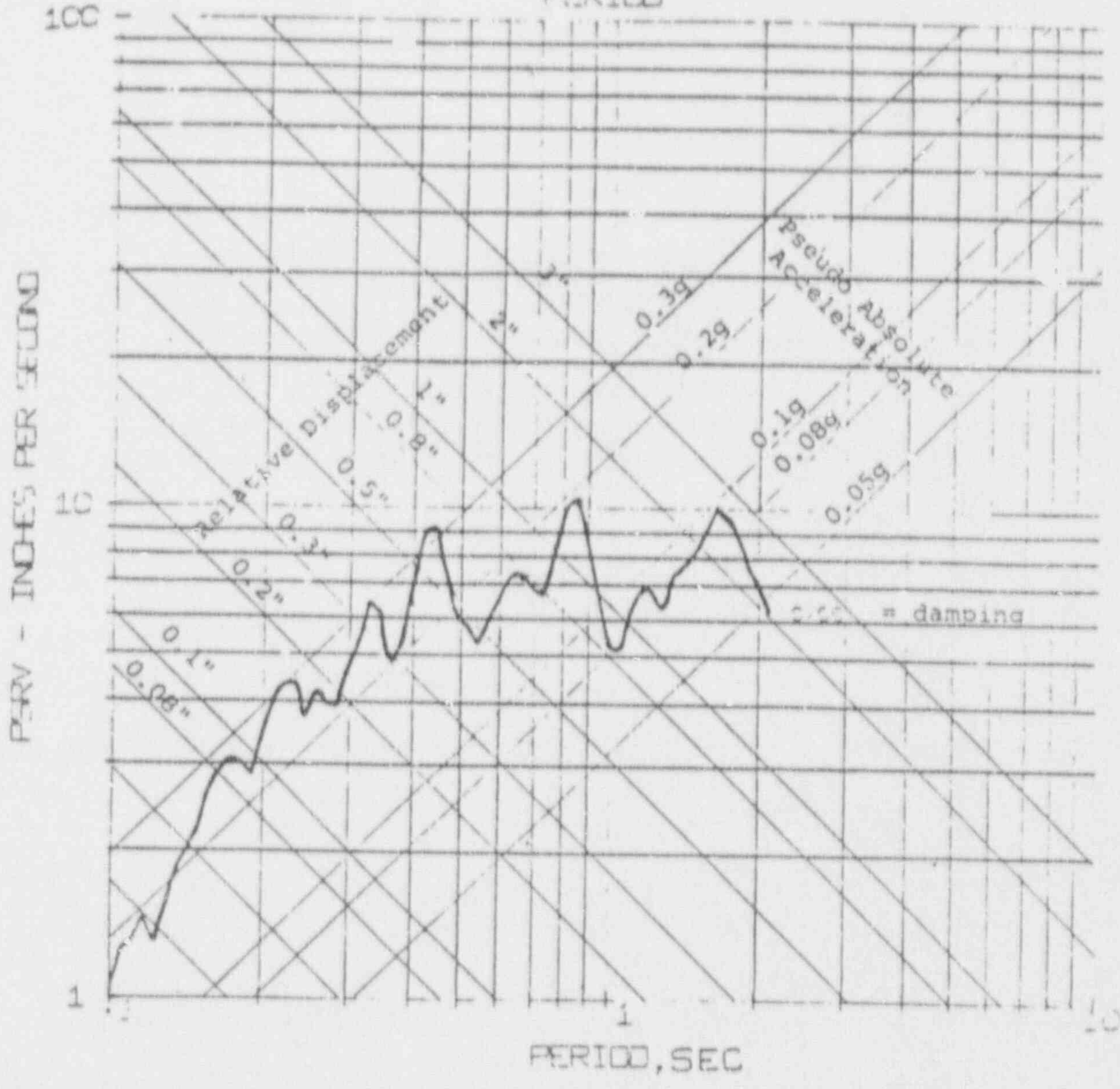
PSEUDO RELATIVE VELOCITY
VS
PERIOD



TAFT N69W
DESIGN EARTHQUAKE
NORMALIZED TO 0.1G

FIG. 5

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DYNAMIC MODEL

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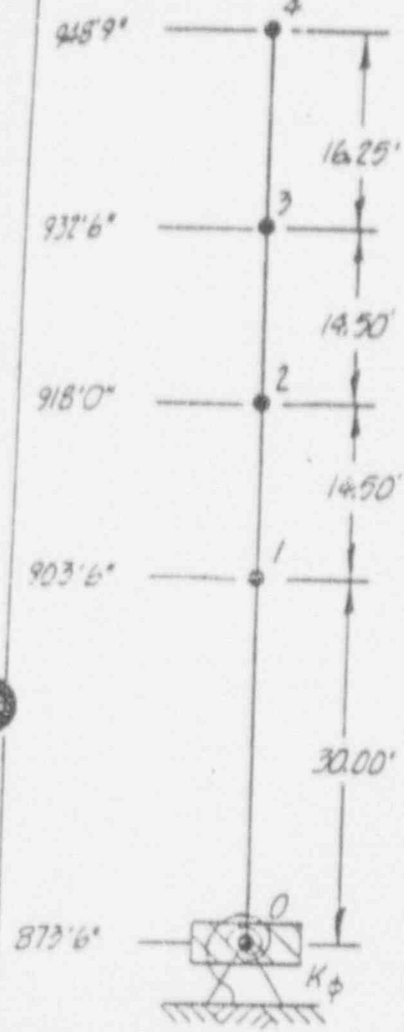

MASS (K-SEC²) FT	EFFECTIVE SHEAR AREA (FT^2) E-W	EFFECTIVE SHEAR AREA (FT^2) N-S	MOMENT OF INERTIA (FT^4) E-W	MOMENT OF INERTIA (FT^4) N-S	MODULUS OF ELASTICITY ($K\text{-}FT^2$)
81.7					
	456.0	294.1	815870.	340674.	454000.
129.5					
	456.0	294.1	815870.	340674	454000.
104.6					
	341.0	220.3	622654.	259572.	454000.
145.5					
	638.0	429.1	999353	520497.	525000.
480.0					

$G = E/2.3$

SOIL SPRING CONSTANTS:

$(K_\phi)_{EW} = 0.222 \times 10^{10}$ K-FT/RAD

$(K_\phi)_{NS} = 0.123 \times 10^{10}$ K-FT/RAD

MASS MOMENT OF INERTIA @ ELEV 873'6"

$(J_0)_{EW} = 441,881$ K-FT-SEC²

$(J_0)_{NS} = 193,552$ K-FT-SEC²

JOB: COOPER NUCLEAR STATION — CONTROL BUILDING STRUCTURAL PROP.	EARTH SCIENCES — A TELEDYNE COMPANY	PAGE: FIG 6
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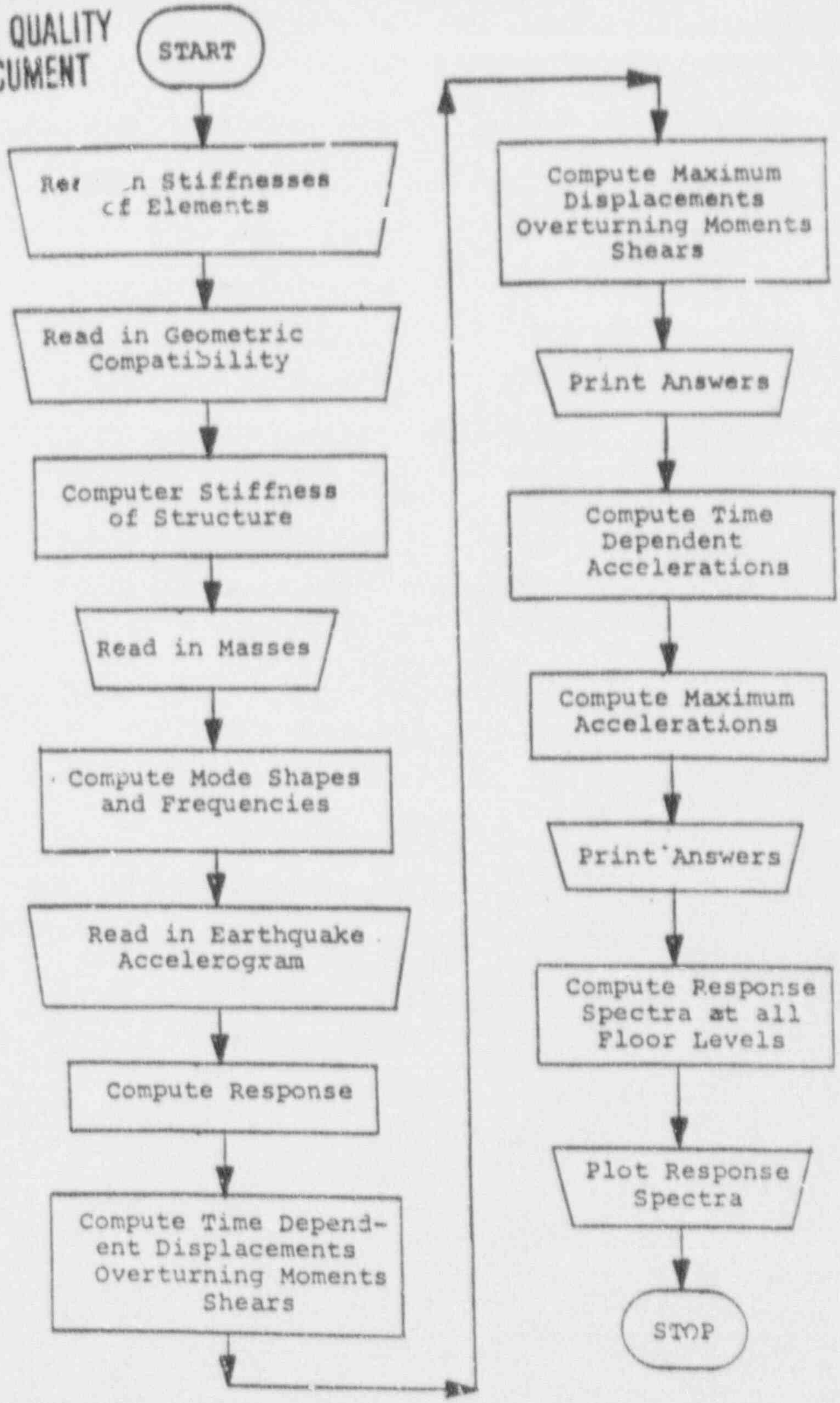

JOB COOPER NUCLEAR STATION			EARTH SCIENCES A TELEDYNE COMPANY 171 N. Santa Anita Ave. • Pasadena, Calif.	PAGE Fig 7
CLIENT BURNS & ROE INC				
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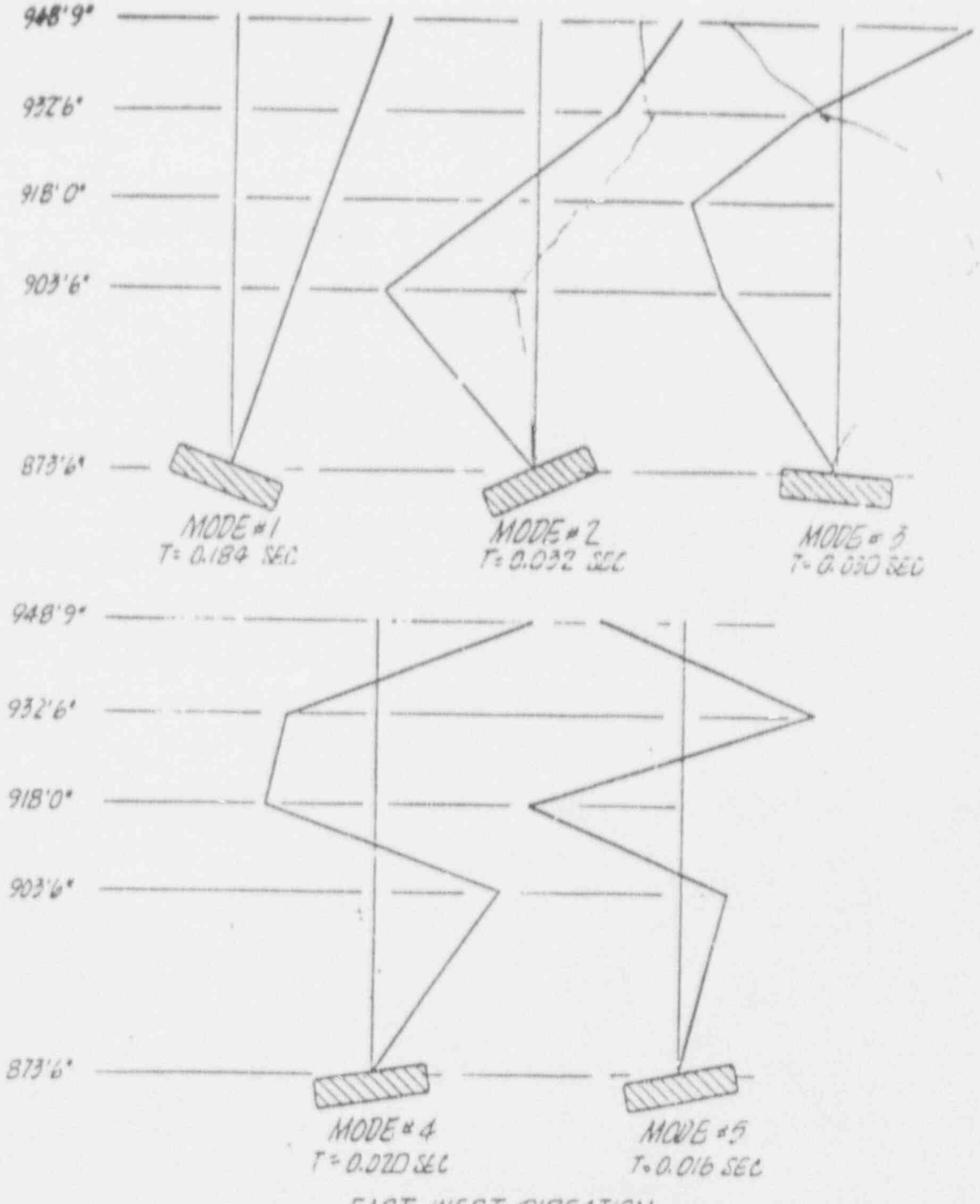

EAST-WEST DIRECTION

JOB COOPER NUCLEAR STATION CONTROL BUILDING MODE SHAPES CLIENT BURNS AND ROE		EARTH SCIENCES A TELEDYNE COMPANY 171 N. Santa Anita Ave. • Pasadena, Calif.	PAGE FIG 3
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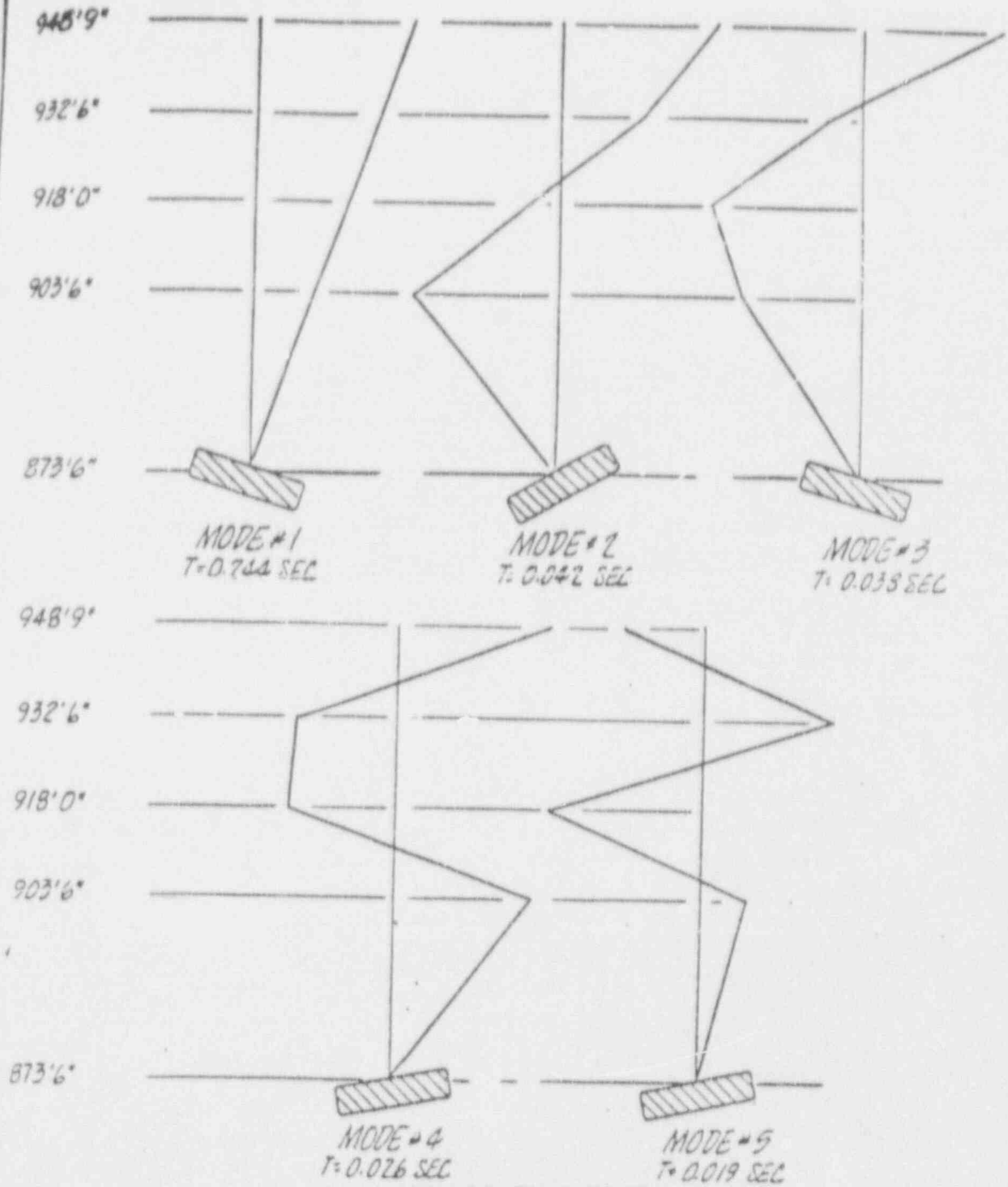

NORTH-SOUTH DIRECTION

JOB COOPER NUCLEAR STATION CONTROL BUILDING MODE SHAPES				EARTH SCIENCES A TELEDYNE COMPANY
CLIENT BURNS AND ROE				171 N. Santa Anita Ave. • Pasadena, Calif.
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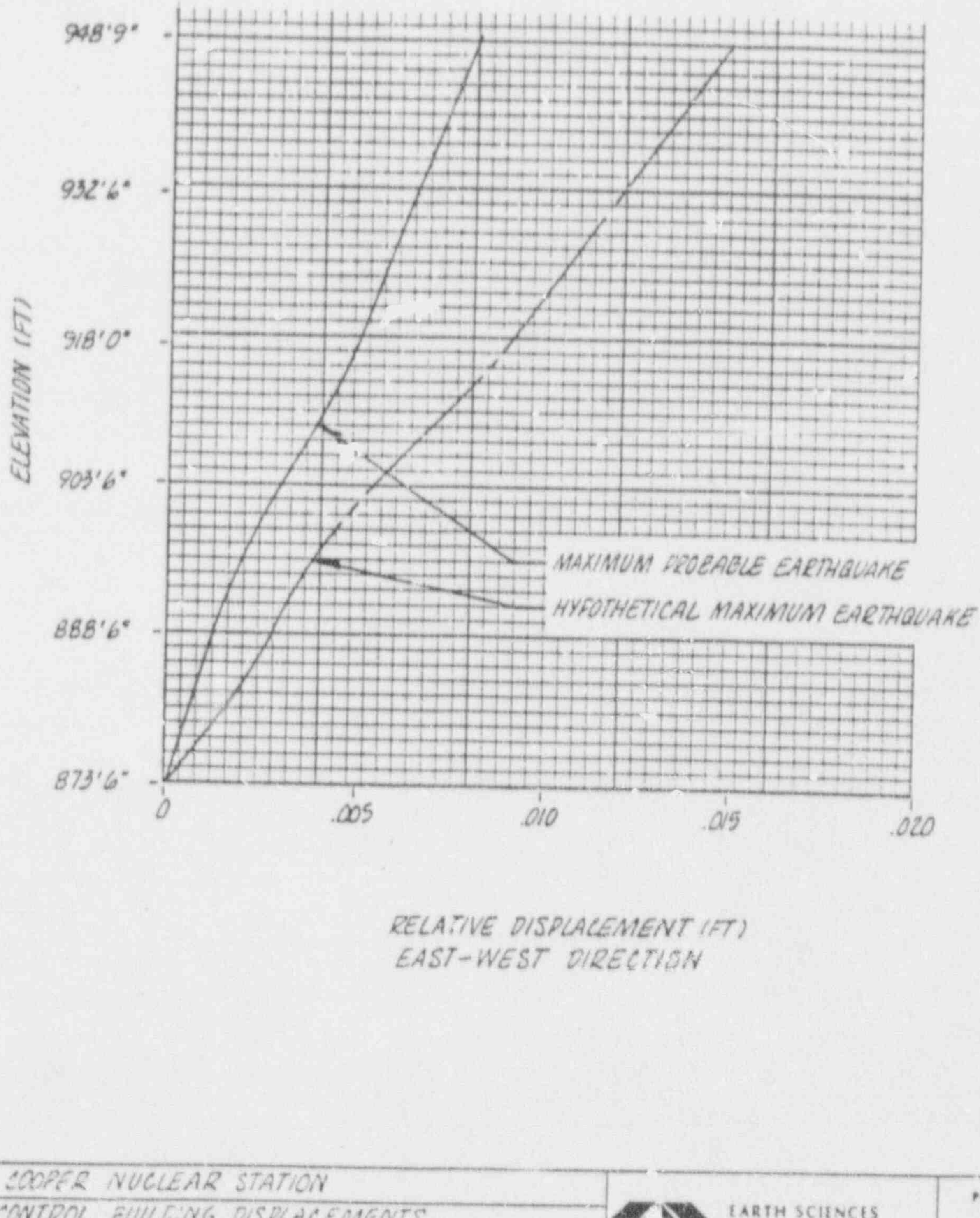

JOB COOPER NUCLEAR STATION CONTROL BUILDING DISPLACEMENTS			
CLIENT BURNS AND ROE			EARTH SCIENCES A TELEDYNE COMPANY	PAGE FIG 10
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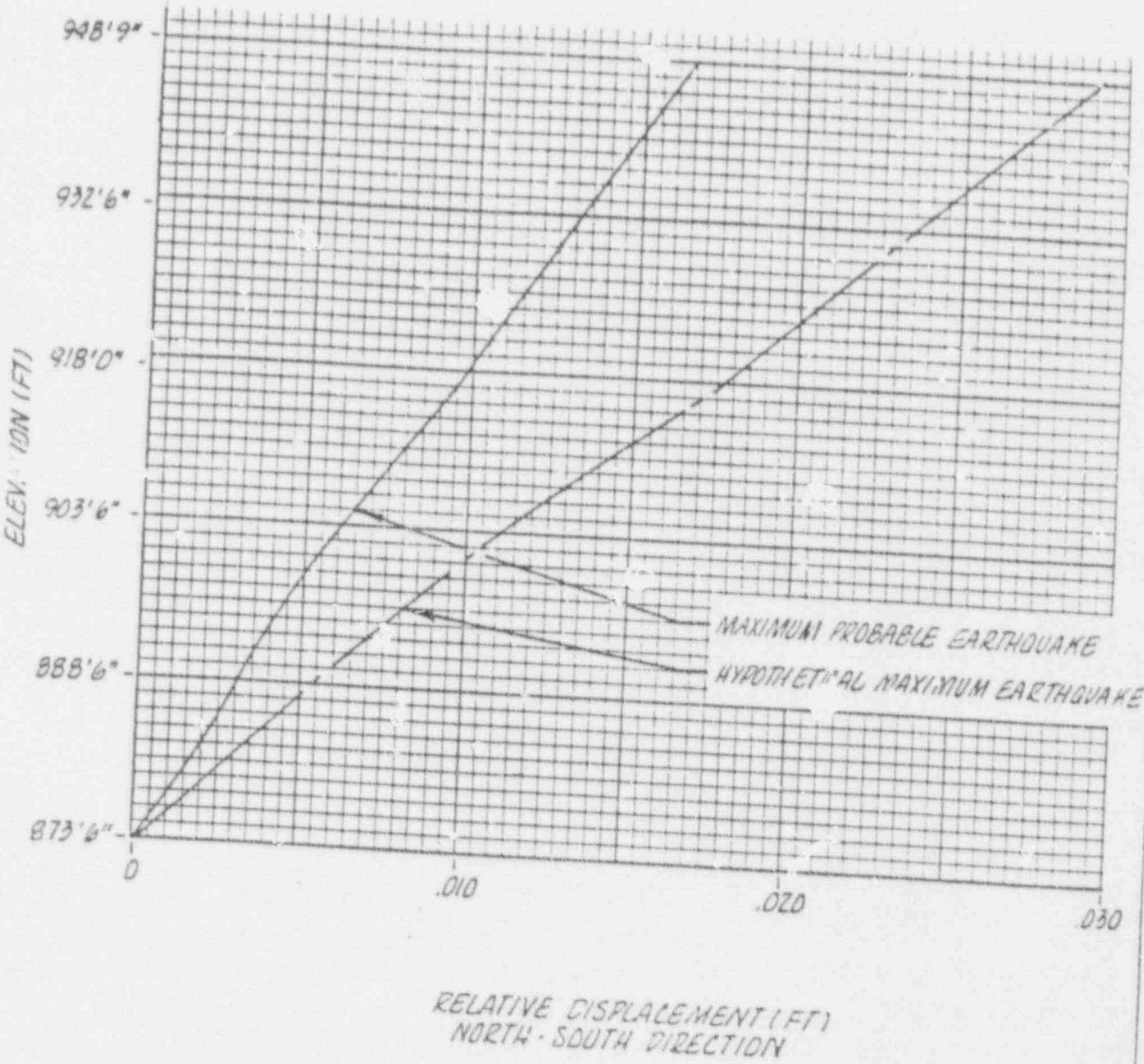

COOPER NUCLEAR STATION CONTROL BUILDING DISPLACEMENTS				EARTH SCIENCES A TELEDYNE COMPANY 171 N. Santa Anita Ave. • Pasadena, Calif.
Client: BURNS AND ROE				
Job No. 7195	By E.A.	Date 1-17-69	Chk. SAS	PAGE FIG 11

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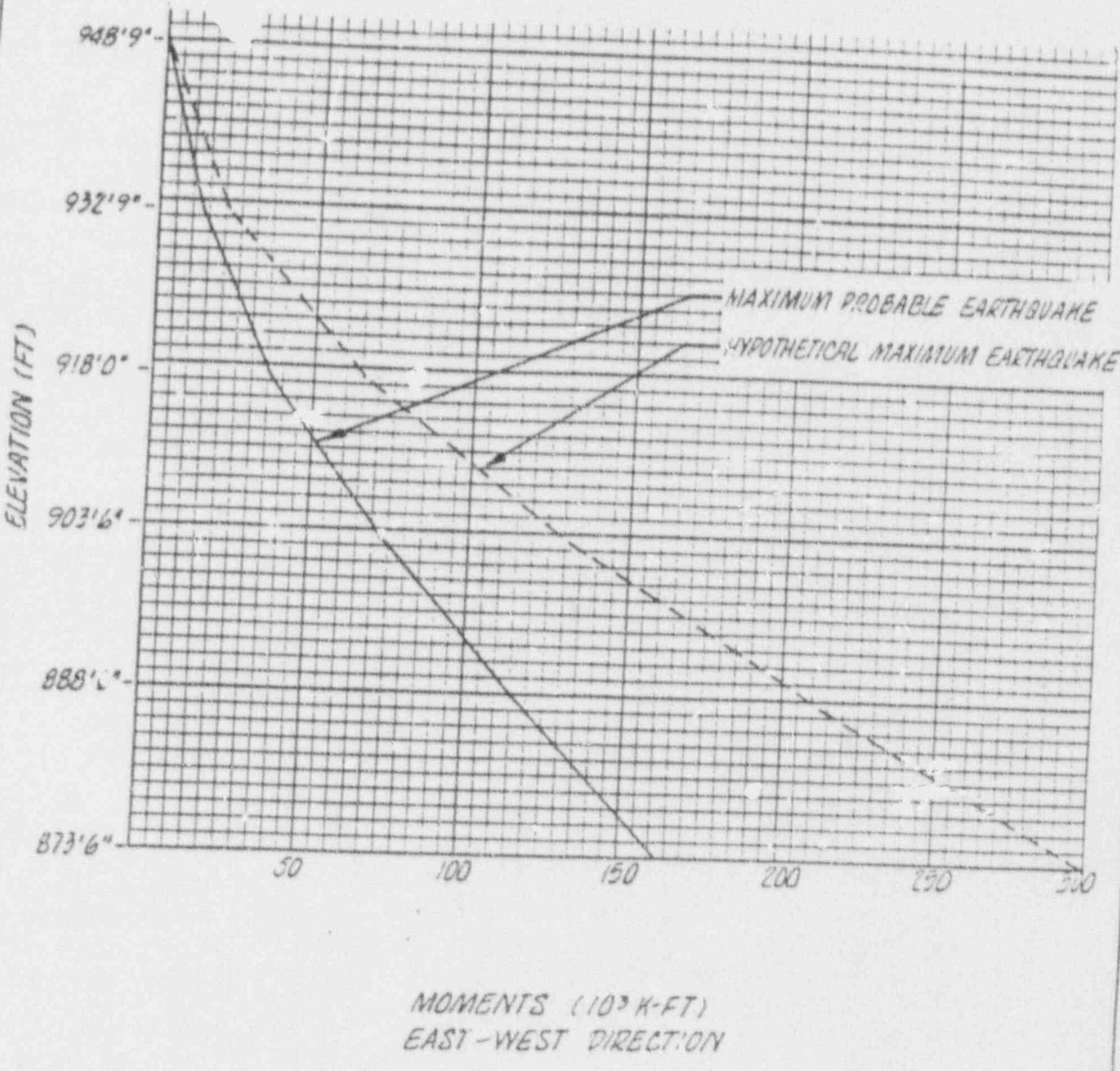

JOB COOPER NUCLEAR STATION CONTROL BUILDING MOMENTS		EARTH SCIENCES A TELEDYNE COMPANY	PAGE
CLIENT BURNS AND ROE			FIG 12
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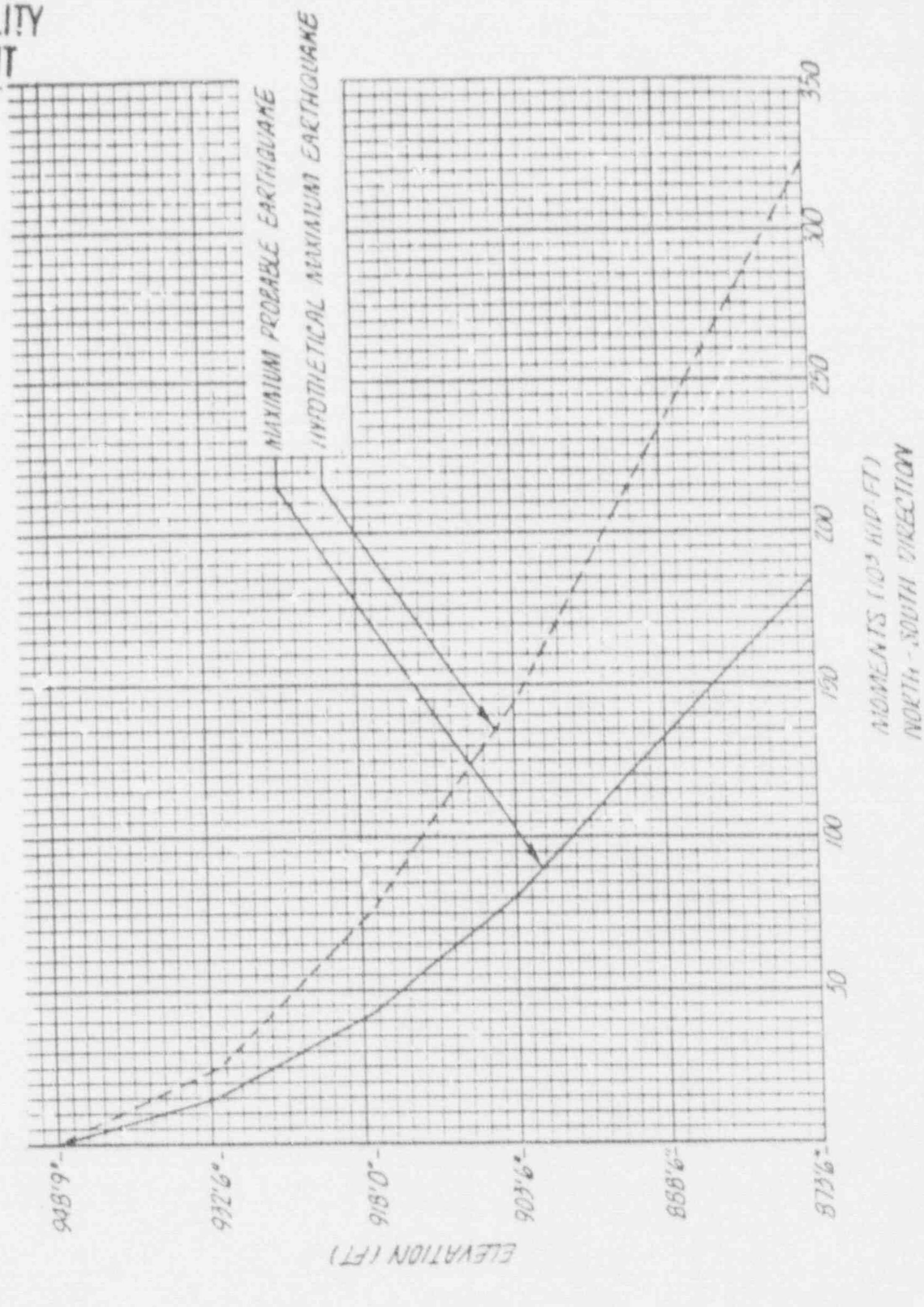

JOB	COOPER NUCLEAR STATION				EARTH SCIENCES A TELEDYNE COMPANY 171 N. Santa Anita Ave. • Pasadena, Calif.	PAGE FIG 13
	CONTROL BUILDING MOMENTS					
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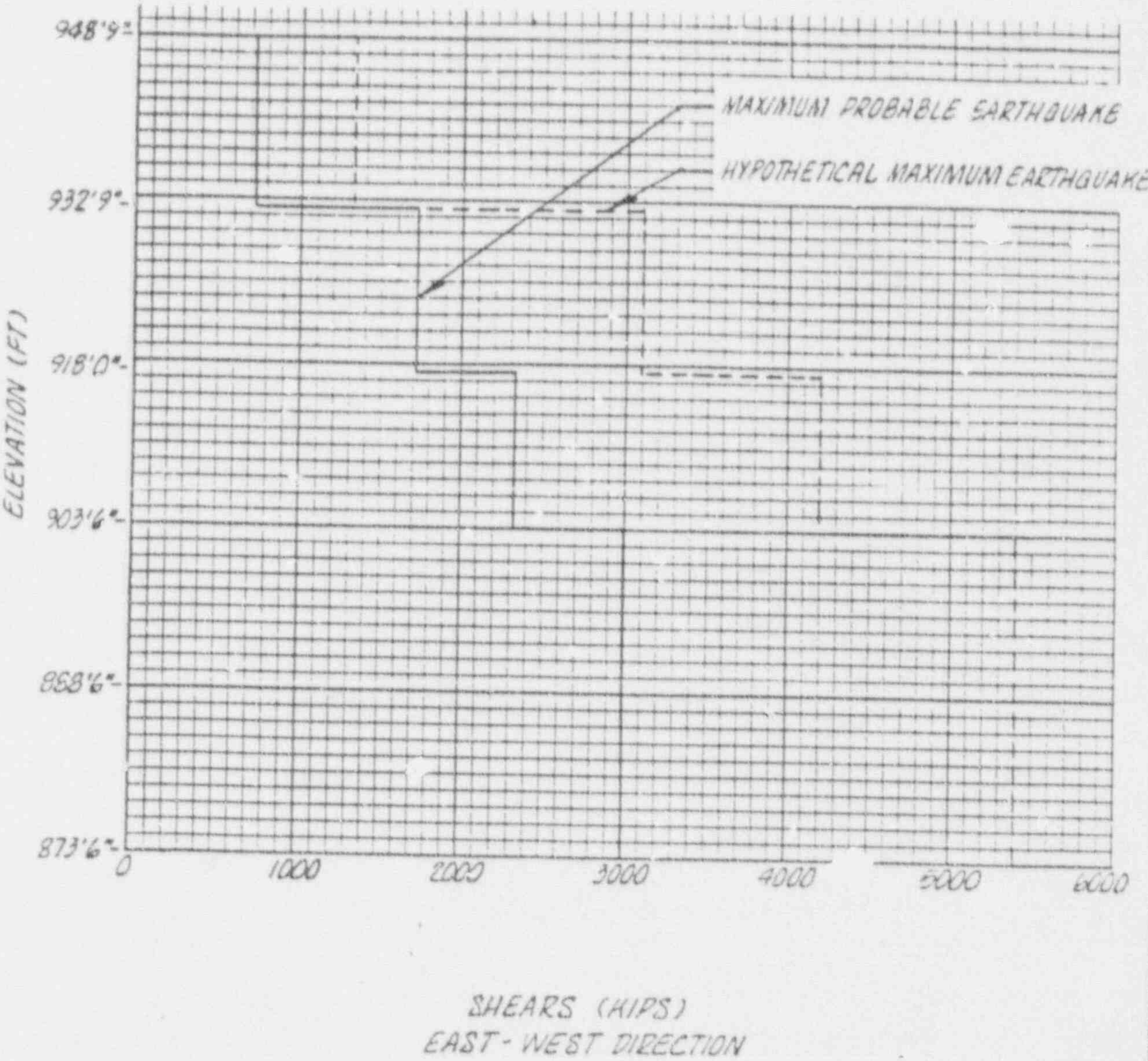

JOB COOPER NUCLEAR STATION CONTROL BUILDING SHEAR		EARTH SCIENCES A TELEDYNE COMPANY	PAGE FIG 14
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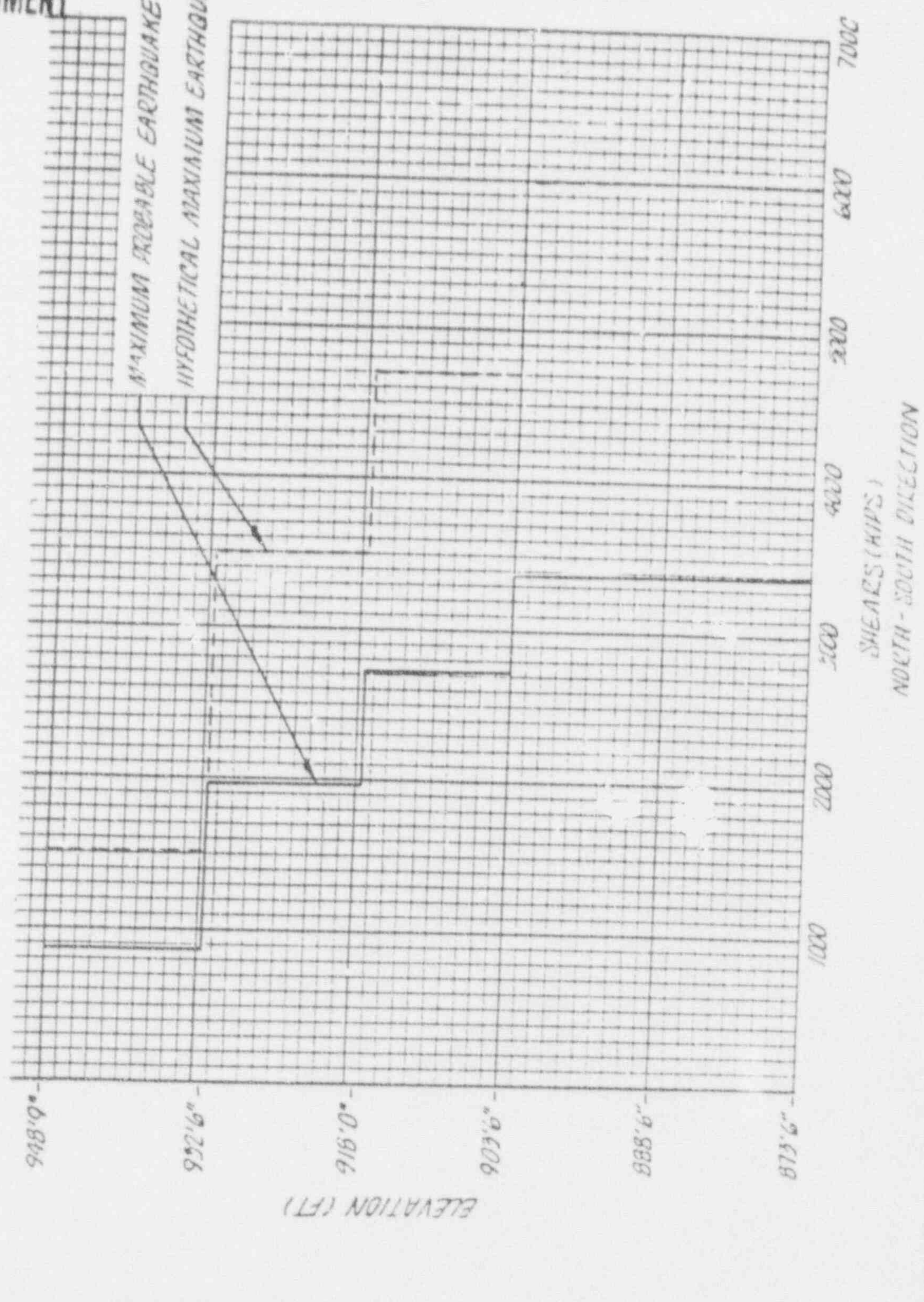

JOB COOPER NUCLEAR STATION CONTROL BUILDING SHEAR				EARTH SCIENCES A TELEDYNE COMPANY
CLIENT BURNS AND ROE				PAGE FIG 19
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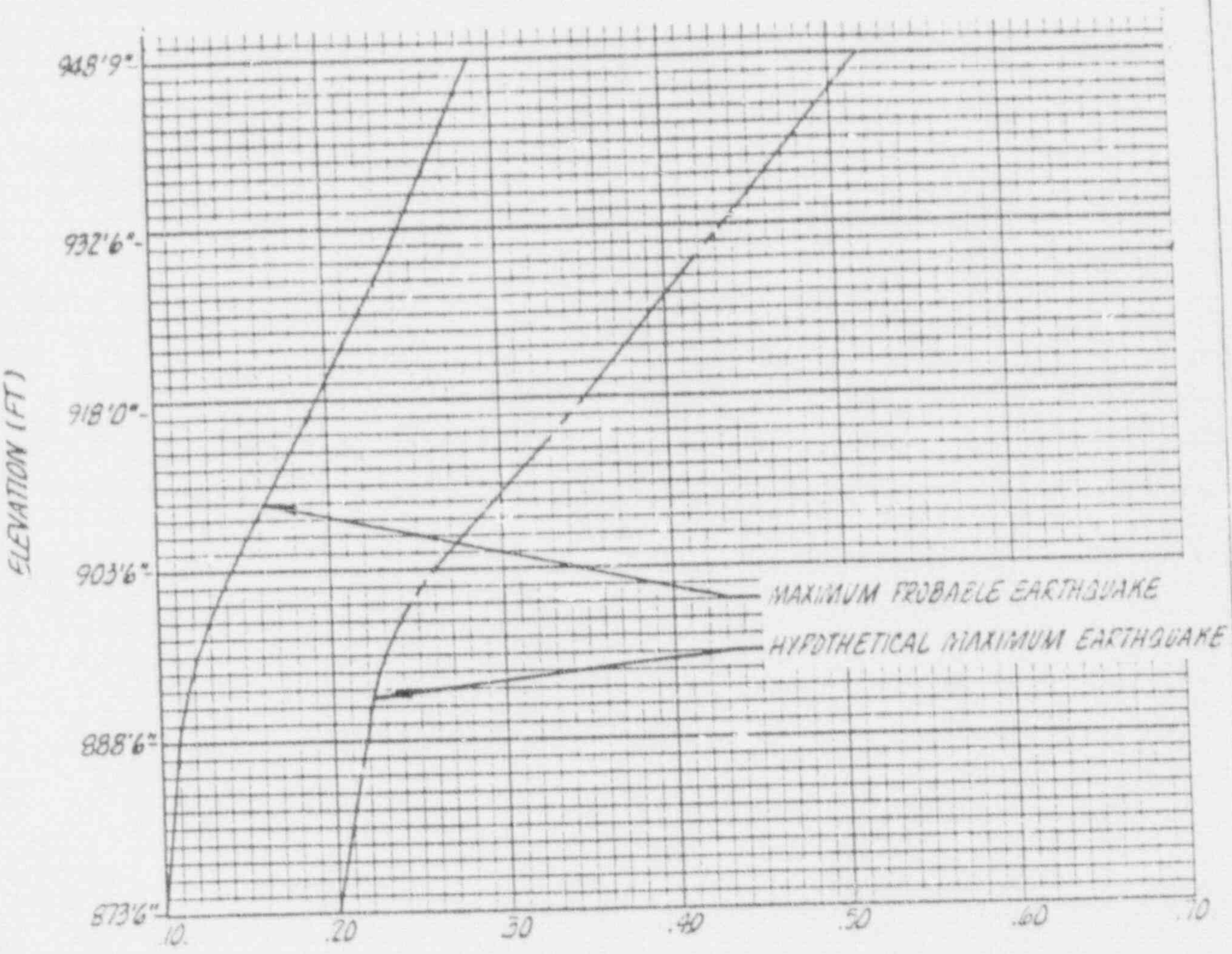

TOTAL ACCELERATION (g)
EAST-WEST DIRECTION

JOB COOPER NUCLEAR STATION				EARTH SCIENCES		PAGE
CONTROL BUILDING ACCELERATION				A TELEDYNE COMPANY		FIG 16
CLIENT BURNS AND ROE						
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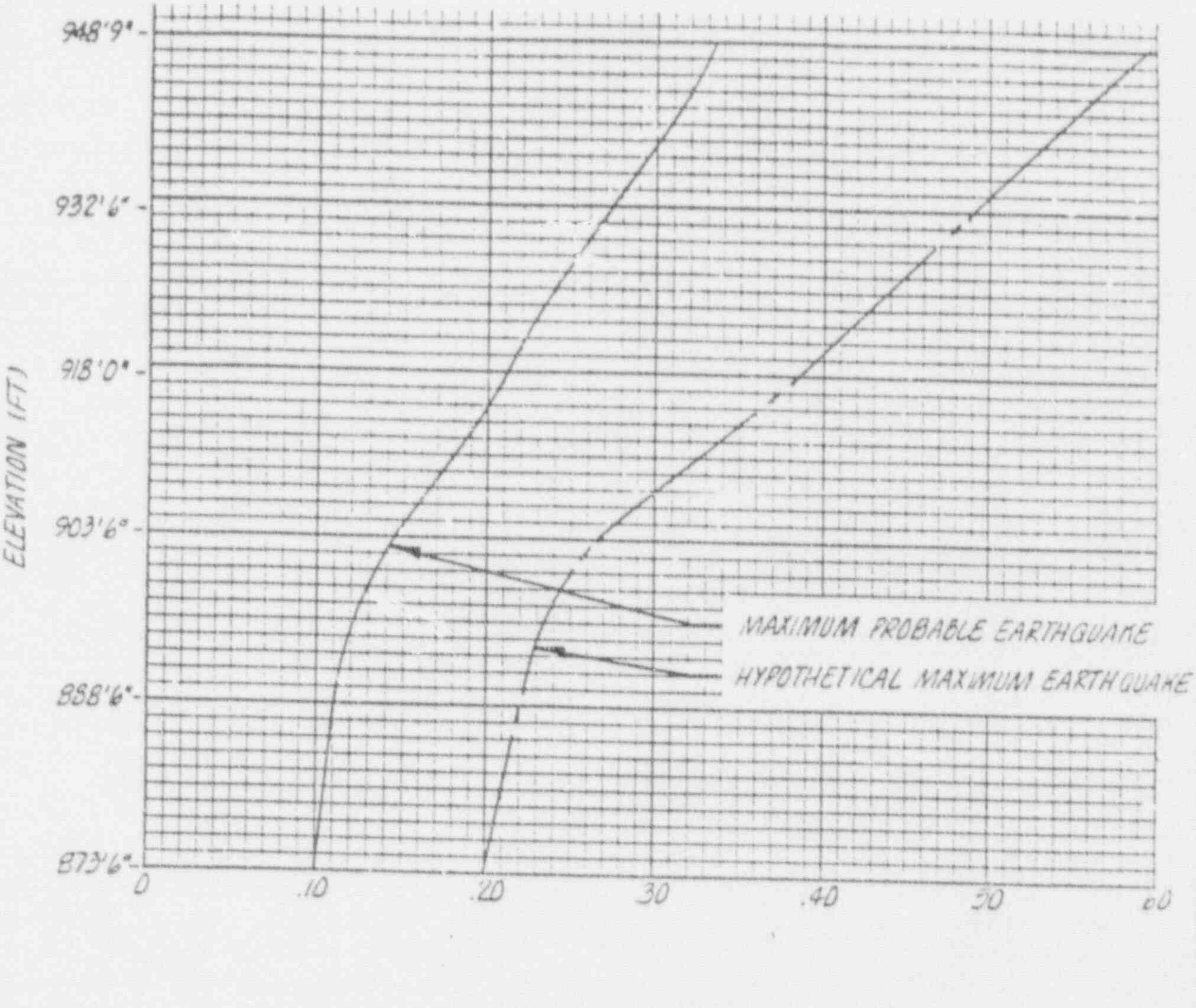

JOB	COOPER NUCLEAR STATION CONTROL BUILDING ACCELERATION					EARTH SCIENCES A TELEDYNE COMPANY 171 N. Santa Anita Ave. • Pasadena, Calif.	PAGE FIG 17
CLIENT	BURNS AND ROE						
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Attachment 2
To NSD921004

EARTHQUAKE ANALYSIS OF THE REACTOR BUILDING
COOPER NUCLEAR STATION