MONTICELLO

APPENDIX A

SEISMIC DESIGN CRITERIA

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SEISMIC DESIGN CRITERIA

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APPENDIX A

SEISMIC DESIGN CRITERIA

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GENERAL ELECTRIC COMPANY
ATOMIC POWER EQUIPMENT DEPARTMENT

MONTICELLO NUCLEAR GENERATION PLANT

RECOMMENDED EARTHQUAKE CRITERIA

JOHN A. BLUME AND ASSOCIATES, ENGINEERS
SAN FRANCISCO

JOHN A. BLUME & ASSOCIATES, ENGINEERS
612 HOWARD STREET • SAN FRANCISCO, CALIFORNIA 94105 • (415) 397-2525

JOHN A. BLUME
J. P. NICOLETTI
H. J. SEXTON
R. L. SHARPE
D. M. TEIXEIRA

July 15, 1966

General Electric Company
175 Curtner Street
San Jose, California

Attention: Mr. R. B. Gile

Subject: Earthquake Design Criteria for the Monticello Nuclear Generation Plant

Gentlemen:

Transmitted herewith is our recommended earthquake design criteria for the subject project.

Since not all field data have yet been made available it will be necessary that we review the findings presented herein. We do not however, expect drastic changes in these criteria.

Very truly yours,

JOHN A. BLUME & ASSOCIATES, ENGINEERS

H. J. Sexton

H. J. Sexton,
Vice President and Chief Engineer

JOHN A. BLUME
J. P. NICOLETTI
H. J. SEXTON
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D. M. TEIXEIRA

JOHN A. BLUME & ASSOCIATES, ENGINEERS
[illegible] HOWARD STREET • SAN FRANCISCO, CALIFORNIA 94105 • (415) 397-2525

February 6, 1967

General Electric Company
Atomic Power Equipment Dept.
175 Curtner Street
San Jose, California 95103

Attention: Mr. R. B. Gile
MC-750

SUBJECT: Monticello Nuclear Plant

Gentlemen:

The following telegram was sent to Northern States Power Company this date:

> MR. A. V. DIENHART
> NORTHERN STATES POWER CO.
> 414 NICOLLET AVENUE
> MINNEAPOLIS, MINNESOTA
>
> SUBJECT: MONTICELLO NUCLEAR PLANT
> REFERENCE OUR LETTER TO GENERAL ELECTRIC DATED SEPTEMBER 30, 1966. WHEN LETTER WAS WRITTEN WE WERE AWARE THAT THE CLAY LAYER WAS TO BE REMOVED AND REPLACED WITH A COMPACTED GRANULAR FILL. IT IS OUR OPINION THAT THE GROUND ACCELERATION AND RESPONSE SPECTRA DATA PRESENTED IN OUR REPORT OF JUly 15, 1966 ARE STILL VALID.

Reference is made to our letter of September 30, 1966. At the time of this letter we were aware that the clay layer assumed to underlie the reactor building foundation was to be removed and replaced with a compacted granular fill. Since this layer is assumed to be only about 15 feet in depth, it is our opinion that changing the clay layer to a granular fill layer will have no effect on the earthquake criteria.

Your attention is invited to the end of the first sentence of the above-referenced letter. The date of the dynamic response report was listed as July 17, 1966. This should be revised to July 7, 1966. For your information we are transmitting herewith two (2) copies of the Dynamic-Response Data Investigation.

Very truly yours,

JOHN A. BLUME & ASSOCIATES, ENGINEERS

E. J. Keith

E. J. Keith
Assistant Vice President

EJK/hp
Enclosures

JOHN A. BLUME & ASSOCIATES, ENGINEERS
612 HOWARD STREET • SAN FRANCISCO, CALIFORNIA 94105 • (415) 397-2525

JOHN A. BLUME
J. P. NICOLETTI
H. J. SEXTON
R. L. SHARPE
D. M. TEIXEIRA

September 30, 1966

General Electric Company
Atomic Power Equipment Department
175 Curtner
San Jose, California

ATTENTION: Mr. R. B. Gile, MC-750

SUBJECT: Earthquake Design Criteria for the Monticello Nuclear Generation Plant

Gentlemen:

We have reviewed the Dames & Moore Report of Foundation Investigation, Proposed Nulcear Power Plant - Unit Number 1 for the Northern States Power Company dated July 27, 1966 and the report on the Dynamic Response Data Investigation, Proposed Nuclear Power Plant, Monticello, Minnesoto for Northern States Power Company dated July 17, 1966. The data provided therein have no effect on the results of the report to you dated July 15, 1966 and the findings therein are sound.

Very truly yours,

JOHN A. BLUME & ASSOCIATES, ENGINEERS

H. J. Sexton

HJS/gr

PRELIMINARY EARTHQUAKE DESIGN CRITERIA

FOR THE

MONTICELLO NUCLEAR GENERATION PLANT

NEAR

MONTICELLO, MINNESOTA

This report is based on preliminary geologic and soil data furnished by Dames and Moore, foundation engineers, and the assumption that the reactor-building is founded in a 15-foot layer of stiff clay immediately above sandstone. When final earth science reports are available this report will be reviewed and revised if necessary.

The proposed site is located near the right bank of the Mississippi River in Wright County, Minnesota at about latitude 45° 20' North and Longitude 93° 50' West, approximately 30 miles northwest of Minneapolis.

GEOLOGY

Regional Geology - The basement rocks of Minnesota, some as old as Precambrian, generally are covered by Pleistocene glacial debris and younger alluvial deposits. Volcanic rocks occur in some areas. Sediments of these types rest on glacially-carved bedrock of sandstone and shale in turn underlain by weathered granite rocks. The bedrock surface slopes east to southeast.

The Minnesota area here discussed is part of a deep, southerly-trending trough in which were deposited sediments and volcanics during later Precambrian and Paleozoic time. Paleozoic rocks are exposed in the southern part of the trough and, in the Minneapolis-St. Paul area, form an artesian basin.

Regional Faulting - The results of regional geophysical surveys indicate that a major fault system of Precambrian age may be present in the region. Displacements of thousands of feet are believed to have occurred on the faults in Precambrian time and displacements of lesser magnitude in Paleozoic time. There is no evidence of faulting in the last few million years.

Two lobes of ice, both of the Wisconsin glacial stage, advanced across the region, the older from the Lake Superior area and the other from the southwest. Both left terminal moraines, the moraines of the older of the lobes being immediately south of the present-day Mississippi River.

The depths of stream channels cut in the area in pre-glaciation time not only may be greater than that of the Mississippi River, but they also bear no directional relationship to present-day channel. The locating of these old channels is hindered by lack of bore-hole information.

Site Geology - Decomposed igneous rocks of Precambrian age lie at a depth of about 70 feet at the site. These rocks are overlain by 10 to 15 feet of sandstone which, although in places weathered and friable, is in general moderately well cemented. The sandstone is in turn overlain by approximately 50 feet of glacial and alluvial debris consisting of sands and gravels. In the reactor-building area, the sandstone is overlain by clay of variable thickness. It is not presently known whether or not the building will be founded in this clay.

Borings and well information in the vicinity of Monticello - about 2-3/4 miles east of the site - indicate that that locality is underlain by 150 to 200 feet of unconsolidated alluvium and glacial drift which in turn

overlie sandstone and shale; granite at that locality lies at a depth greater than 500 feet. The indication is therefore, that the rock and soil units at the site slope eastward toward the sedimentary basin and its artesian ground-water aquifers

SEISMOLOGY

Seismic History - Table A numerically lists the earthquakes in the general region in and around Minnesota. Those more applicable to the site are plotted on Plate I. The earliest earthquake on record occurred in 1860 in central Minnesota, thus the record here is for only some ninety years. During that period the historical earthquakes have had little effect at the proposed site.

Faulting in Area - The nearest known or inferred fault - the Douglas Fault - is 23 miles southeast of the site (Plate 2). According to referenced geological information, there is no indication that faulting has affected the area of the site in the last few million years. The major fault system of Precambrian age, which is associated with the Precambrian structural trough, is also seen on Plate 2. Major movements of thousands of feet along this system appear to have been restricted to Precambrian time, with minor displacements having occurred during the Paleozoic. Faulting within recent geologic time is not in evidence.

Richter's Seismic Regionalization Map (Plate A, Appendix) shows the area of the site in a probable maximum intensity of VIII, Modified Mercalli. This intensity has been based on the area's relationship to the Canadian shield. Stable shields in other continents are usually fringed by belts of moderate seismicity, with occasionally large earthquakes. Historically, this area is too young to prove or disprove such seismic activity.

The Coast and Geodetic Survey's Seismic Probability Map of the United States (Plate B in Appendix) assigns the area to Zone 0 - no damage.

It is our opinion that neither the regionalization nor the probability map is satisfactory in determining a proper seismic factor if considered alone. Each, however, is based on judgment and fact which, when weighed with other data, become more meaningful. In the case at hand, the assignment of an VIII as the largest probable intensity for general area must be tempered by the fact that the intensity at or near the sandstone will be much less than that experienced in areas of less competent material, where invariably the maximum damage is sustained.

Earthquakes can and do occur in this region away from faults, and probably result from residual stresses due to recent glaciers. A quake similar to Nos. 12 and 24 was postulated near the site and using the dynamic response data obtained insitu, the Taft earthquake of July 21, 1952

North 69 West component with an applied factor of 0.33 was selected as best representative for the design earthquake. Plate 3 shows single-mass spectra when averaged. Recommended design criteria follow which utilize this earthquake record.

RECOMMENDED EARTHQUAKE DESIGN PROCEDURES

For purposes of design, structures (buildings or equipment) are divided into two classes:

Type I. Those structures whose failure may damage vital equipment and thus might cause a nuclear incident.

Type II. Those structures whose failure could cause no nuclear incident.

Recommended Procedures for Type I Structures and Equipment

1. For structures or equipment founded directly on soil, a structural design shall first be executed based on estimated seismic shears, moments, and displacements. The structures thus designed shall then be subjected to a dynamic analysis using the spectra on Plate 3 and damping values from Table 1. Sufficient modes shall be included to assure participation of all modes having a period greater than 0.08 second. A vertical ground acceleration of two-thirds the horizontal ground acceleration shall be applied to the structure and resulting stresses due to horizontal and vertical accelerations shall be considered to act simultaneously and shall be added directly. When combined with stresses from operating conditions, the resulting stresses shall comply with applicable codes without the usual fractional increase for short-term loading. The final design shall be reviewed for compliance with local requirements. If computerized methods of dynamic analysis are used, the mathematical model may be subjected to an excursion through the Taft earthquake of July 21, 1952 North 69 West component with an applied factor of 0.33. After this has been satisfied, the structure shall be examined under values of twice those given in Plate 3 or a dynamic excursion through the Taft earthquake of July 21, 1952 North 69 West component, with an applied factor of 0.66. As before, horizontal and vertical seismic components shall be considered with other appropriate loads, but in this case vertical ground accelerations shall be 0.08g. Under this loading condition there shall be no failure that could cause injury or prevent a safe shutdown during or after the earthquake.

2. Structures or equipment supported in or on other structures or equipment are placed into three categories based on their natural frequency and the predominant frequency of the supporting structure:

(1) Rigid category: $\frac{fm}{f} > 2.0$

(2) Resonance category: $0.7 \leq \frac{fm}{f} \leq 2.0$

(3) Flexible category: $\frac{fm}{f} < 0.7$

Where:

fm is the natural frequency of the mechanical structure or equipment, and f is a predominant frequency of supporting structure at the location of installation.

(1) For Rigid Category: Because of the high frequency, the design shall be based on an acceleration corresponding to the maximum acceleration experienced by the supporting structure at the location of equipment support.

(2) For Resonance Category: Elimination of resonance phenomena is one of the principles of the design. In order to eliminate resonance vibration some modification of the natural frequency of the supporting structure may be required. In case the resonance vibration cannot be avoided, prevention of large amplitudes by means of damping devices is required or dynamic design considering resonance vibration is required. In case the mass of the object is such as to produce an "Appendage" condition with large deflections and accelerations, a thorough dynamic study will be performed. Should the restriction of vibration be enough to make the object rigid, examination for rigid category is also required.

(3) For Flexible Category: Those items which are designated as flexible will be designed using induced accelerations corresponding with their frequencies. Careful examinations will be made concerning objects coming into contact because of excessive displacements.

3. For structures and equipment too complex for direct analytical procedures, vibration tests should be performed to establish the earthquake-resistant capabilities.

TABLE 1

RECOMMENDED DAMPING VALUES

Item	Percent Critical Damping
Reactor-building (massive construction with many cross walls and equipment and providing only secondary containment	5.0
Thin-shell and prestressed concrete structures	2.0
Steel structures	2.0
Vital piping systems	0.5
Ground rocking modes of vibration	10.0

Recommended Procedures For Type II Structures and Equipment

It is recommended that Type II structures and equipment be designed on basis of a minimum seismic horizontal coefficient of 0.10 with a one-third allowable increase in basic stress. Allowable increase in soil stresses if any, must be taken from recommendations of the Soils Engineer. All equipment should be so bolted or fastened that its displacement will not occur if friction is non existent.

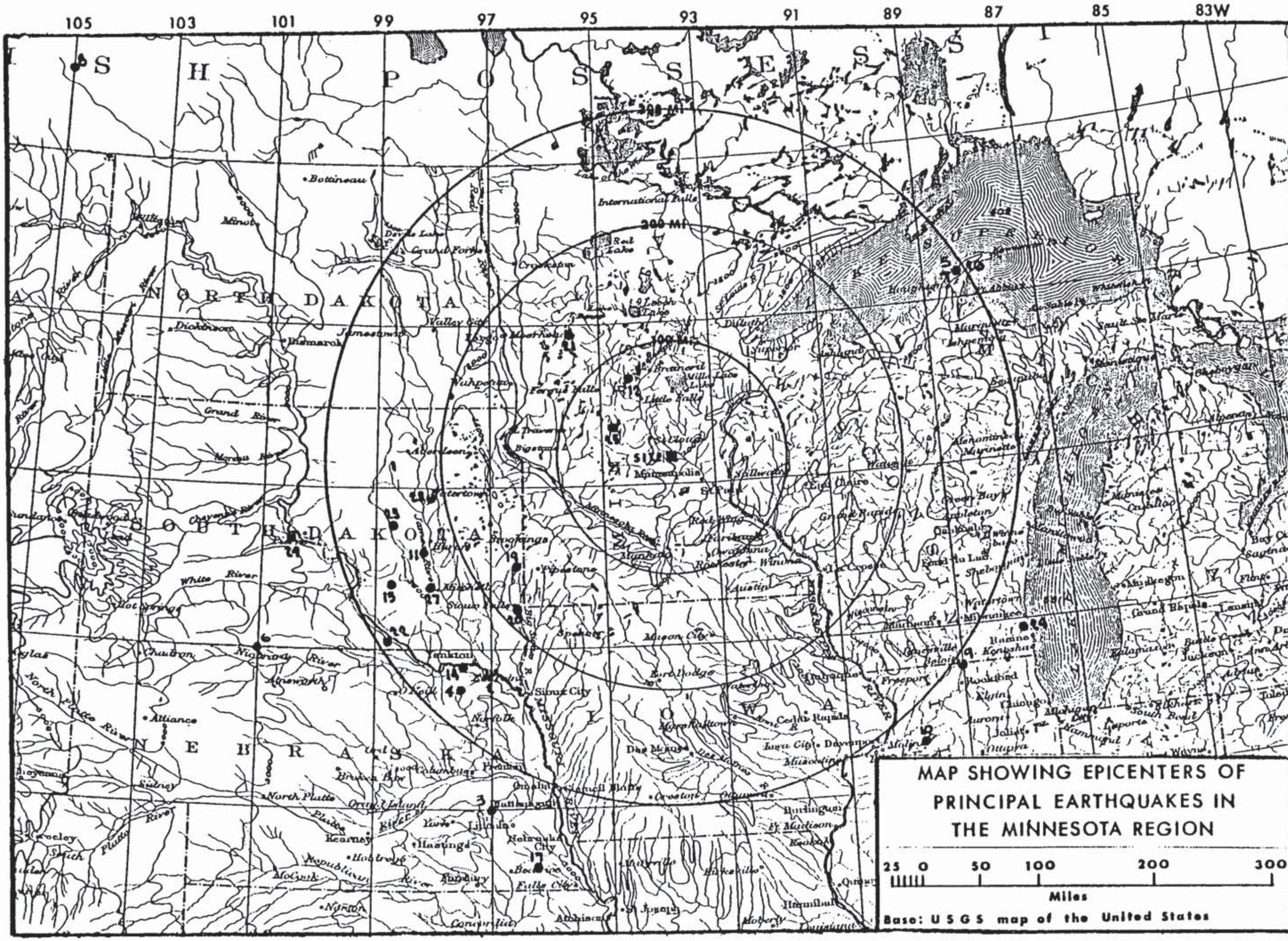
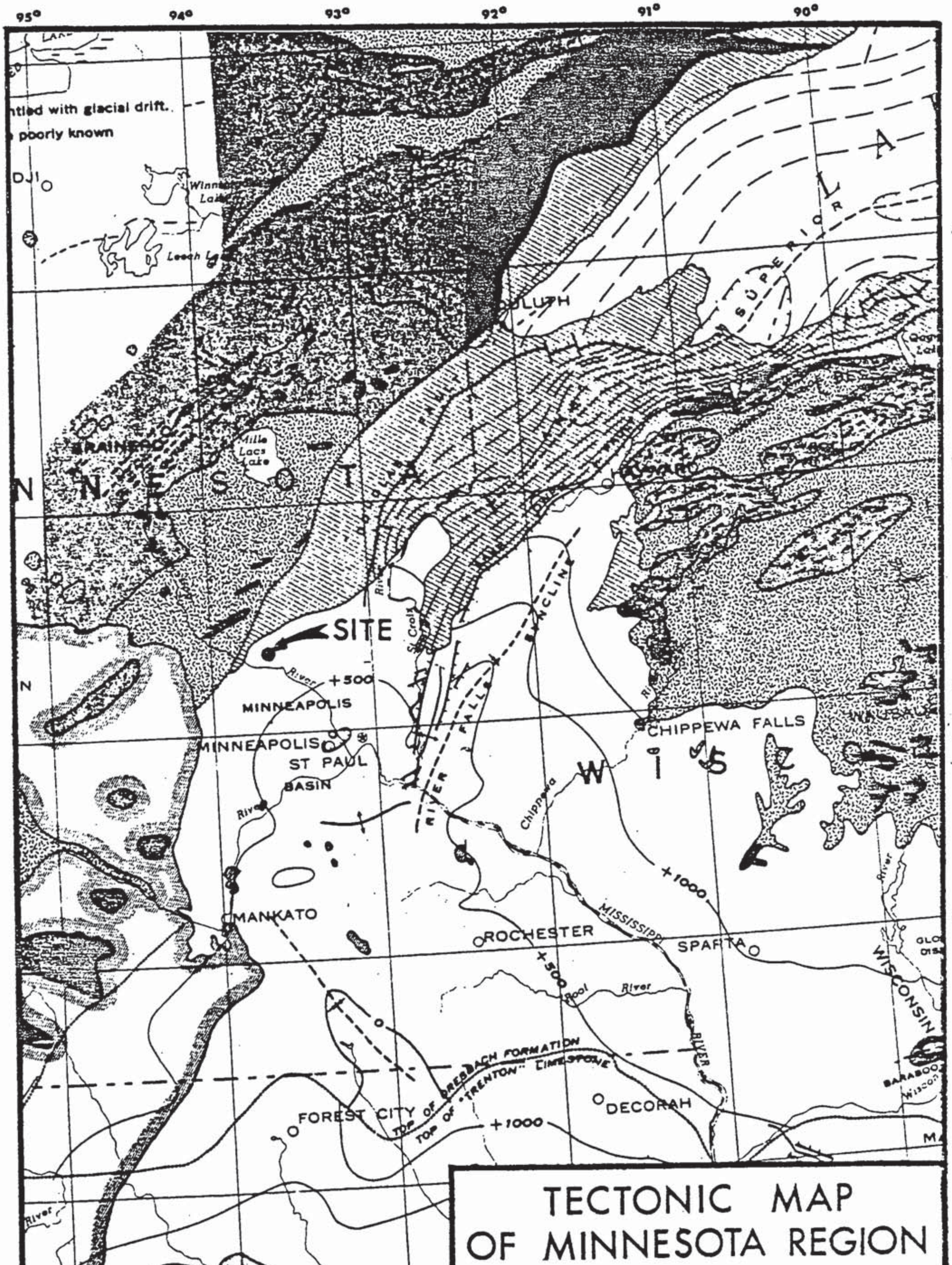

MAP SHOWING EPICENTERS OF
PRINCIPAL EARTHQUAKES IN
THE MINNESOTA REGION
25 0 50 100 200 300
Miles
Base: U S G S map of the United States
105
103
101
99
97
95
93
91
89
87
85
83W
49
47
45
43N
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
IOWA
300 MI
200 MI
100 MI
Minneapolis
St Paul
Duluth
Sioux City
Des Moines
Milwaukee
Chicago
Bismarck
Aberdeen
Yankton
Sioux Falls

PLATE 1



TECTONIC MAP OF MINNESOTA REGION

PLATE 2

Base: USGS and AAPG

JOHN A. BLUME & ASSOCIATES, ENGINEERS

RESPONSE ACCELERATION SPECTRA

FOR THE

MONTICELLO NUCLEAR GENERATION PLANT

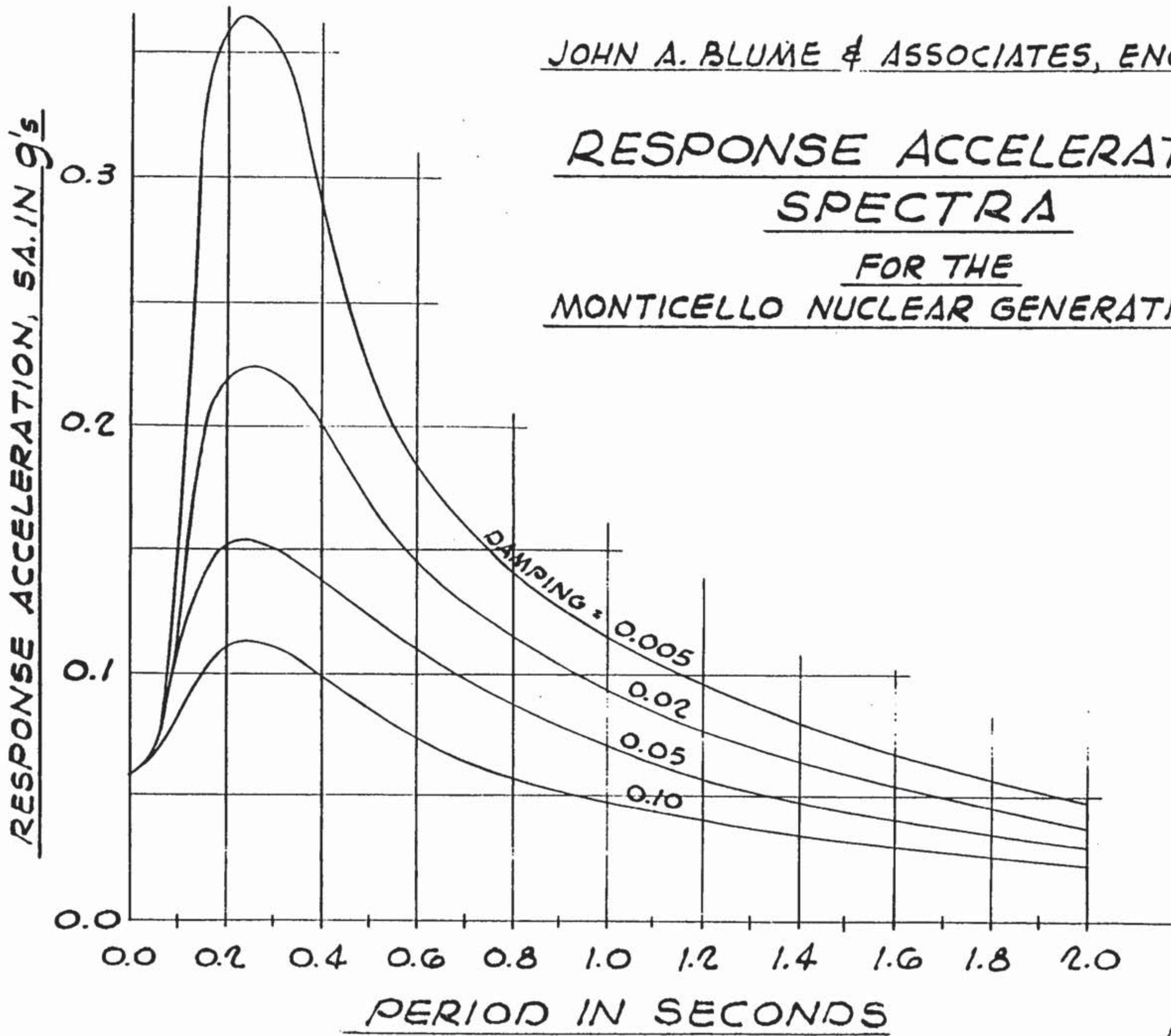


PLATE 3

REFERENCES

1. Dames and Moore, Preliminary Geological Report for the Proposed Nuclear Power Plant near Monticello, Minnesota, June 22, 1966.

2. Dames and Moore, Report - Dynamic Response Data Investigation Monticello, Proposed Nuclear Plant for the Northern States Power Company, July 7, 1966.

3. Monticello Soil Boring Data, Sheets 1, 2 & 3, Northern States Power Company, February 17, 1966.

4. Hough, Jack, L., Geology of the Great Lakes, University of Illinois, 1958.

5. Heck, N.H., Earthquake History of the United States, U.S.Coast and Geodetic Survey, 1956 revised.

6. Richter, C.F., Seismic Regionalization, Bulletin of the Seismological Society of America, Vol. 49, No. 2, April, 1959.

7. Building Design in Canada 1965 associate committee on the National Building Code, National Research Council, Ottawa, Canada

8. Blume, John A., Earthquake Ground Motion and Engineering Procedures for Important Installation Near Active Faults, Third World Conference on Earthquake Engineering, 1965.

9. Wiggins, John H., Jr., Effect of Site Conditions on Earthquake Intensity, ASCE, Vol. 90 No. ST2, Part 1 (1964).

10. Hershberger, John, A Comparison of Earthquake Acceleration with Intensity Ratings, Bulletin of the Seismological Society of America, Vol. 46, 1956.

11. Seed, H.B., Soil Strength During Earthquakes, Second World Earthquake Conference, Tokyo, 1960.

APPENDIX

TABLE A

SEISMIC HISTORY OF THE REGION

No.	Date	Location: Place	Location: N.Lat	Location: W.Long	Intensity (M.M.)	Remarks
						* Indicates epicenter not plotted on map
*1	1860	Central Minn.	-	-	Unknown	
2	10/9/1872	Sioux City, Iowa	42.7	97.0	V	Felt over 3,000 square miles.
3	11/15/1877	East Neb.	41.0	97.0	VII	Felt over 140,000 square miles.
4	7/28/1902	East Neb.	42.5	97.5	V	Felt over 35,000 square miles.
5	7/26/1905	Calumet, Mich.	47.3	88.4	VII	Felt over 16,000 square miles.
6	5/9/1906	Washabaugh County, S. D.	43.0	101.0	VI	Felt over 8,000 square miles.
7	5/26/1906	Keewenaw Peninsula, Michigan	47.3	88.4	VIII	Felt over 1,000 square miles.
8	5/15/1909	Canada, felt to South	50.0	105.00	VIII	Felt over 500,000 square miles.
9	5/26/1909	Dixon, Ill.	42.5	89.0	VII	Felt over 40,000 square miles.
10	10/22/1909	Sterling, Ill.	41.6	89.8	IV-V	
11	6/2/1911	South Dak.	44.2	98.2	V	Felt over 40,000 square miles.
12	9/3/19/7	Minnesota	46.3	94.5	VI	Felt over 10,000 square miles.
*13	2/38/1925	Canada	48.2	70.8	VIII	Felt over 2,000,000 square miles.
14	10/6/1929	Yankton, S.D.	42.8	97.4	V (est.)	
15	1/17/1931	White Lake, S.D.	43.8	98.7	V (est.)	
*16	11/12/1934	Rock Island & Moline, Ill. Davenport, Iowa	41.4	90.5	V	
17	3/1/1935	Eastern Neb.	40.3	96.2	VI	Felt over 50,000 square miles.
*18	11/1/1935	Canada	46.8	79.1	IX & over	Felt over 1,000,000 square miles, felt in Minn.

No.	Date	Location: Place	N.Lat	W.Long	Intensity (M.M.)	Remarks
19	11/1/1935	Egan, S.D.	44.0	96.6	V (est.)	
20	10/1/1938	Siox Falls, S.D.	43.5	96.6	V	Felt over 3,000 square miles.
21	1/28/1939	Detroit Lake, Minn.	46.9	95.5	V (est.)	
22	6/10/1939	Fairfax, S.D.	43.1	98.8	VI (est.)	
23	7/23/1946	Wessington, S.D.	44.5	98.7	VI (est.)	
24	5/6/1947	Milwaukee Area	42.9	87.9	VII	Felt Sheboygon to Kenosha.
25	2/15/1950	Alexandria, Minn.	45.7	94.8	V-VI(est.)	
26	1/6/1955	Hancock, Mich.	47.3	88.4	V	
27	12/3/1957	Mitchell, S.D.	43.8	98.0	V	
28	1/12/1959	Doland, S.D.	44.9	98.0	V	
29	12/31/1961	W.Pierre, S.D.	44.4	100.5	VI	

TABLE 2

MODIFIED MERCALLI INTENSITY SCALE OF 1931

(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV. During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed, walls make creaking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.

V. Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbs persons driving motor cars.

IX. Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

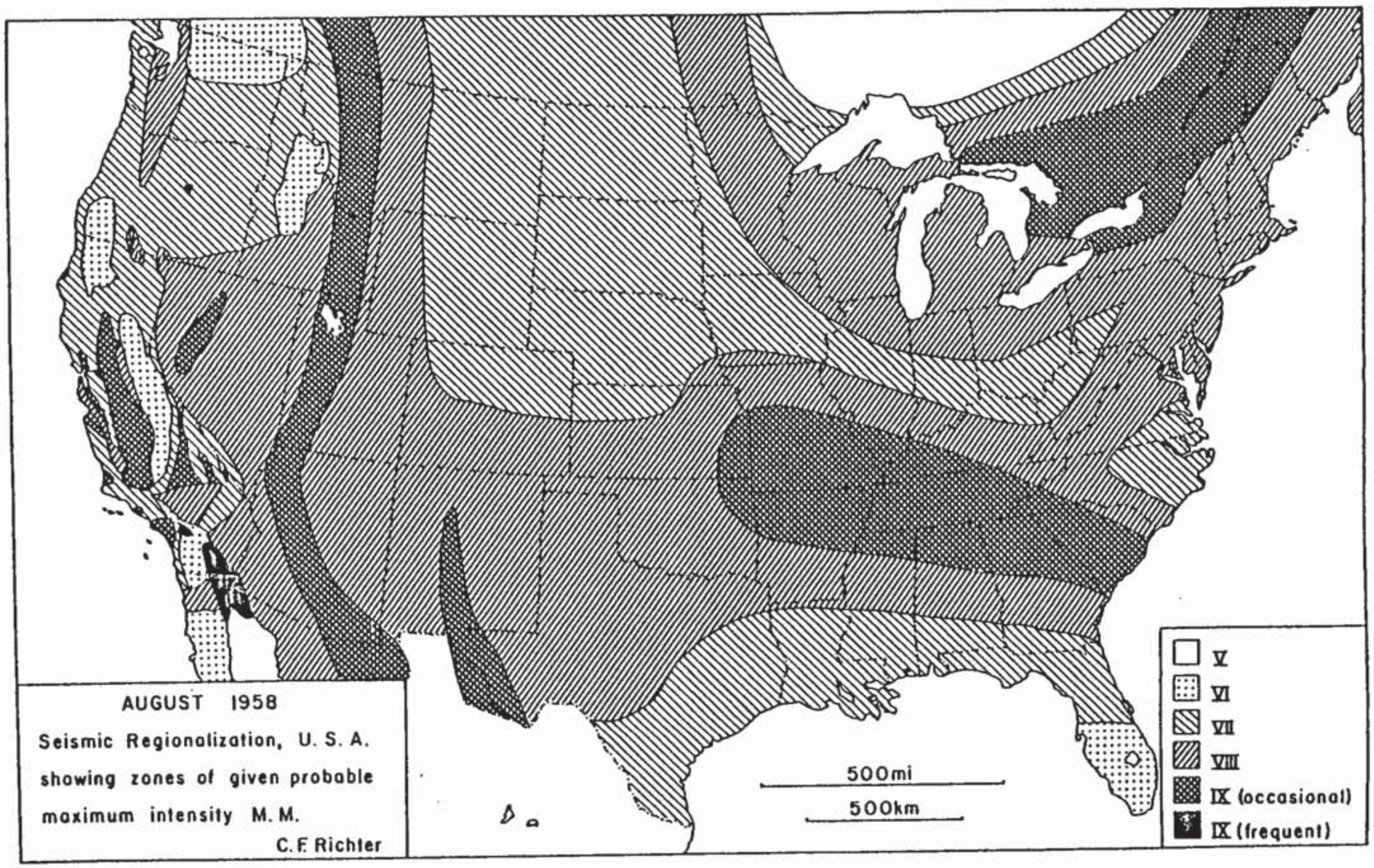
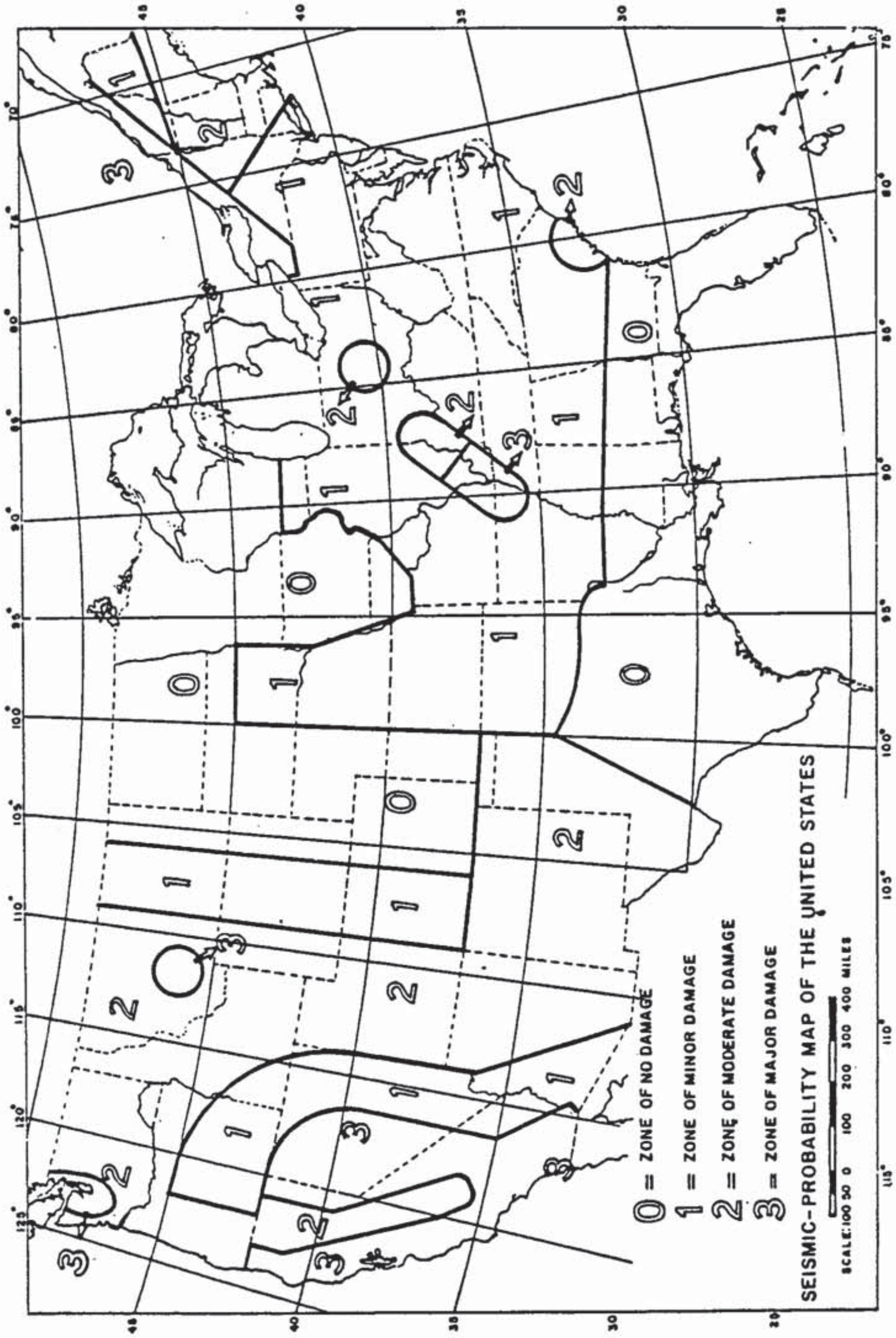

AUGUST 1958
Seismic Regionalization, U. S. A.
showing zones of given probable
maximum intensity M. M.
C. F. Richter
500mi
500km
V
VI
VII
VIII
IX (occasional)
IX (frequent)

PLATE A



From U.S. Coast and Geodetic Survey

PLATE B

GENERAL ELECTRIC COMPANY
ATOMIC POWER EQUIPMENT DEPARTMENT

MONTICELLO NUCLEAR GENERATION PLANT

EARTHQUAKE ANALYSIS: REACTOR BUILDING

JOHN A. BLUME AND ASSOCIATES, ENGINEERS
SAN FRANCISCO

JOHN A. BLUME & ASSOCIATES, ENGINEERS
612 HOWARD STREET • SAN FRANCISCO, CALIFORNIA 94105 • (415) 397-2525

July 18, 1967

General Electric Company
Atomic Power Equipment Department
175 Curtner Street
San Jose, California

ATTENTION: Mr. R. B. Gile

SUBJECT: Monticello Nuclear Generation Plant
Earthquake Analysis of the
Reactor Building

Gentlemen:

Transmitted herein is the subject report based on the information furnished us by General Electric Company, and as listed in the references.

The analysis consists of an investigation of the coupled flexural dynamic response and the rocking dynamic response of the subject building including appendage, the results of which are presented in the report. This analysis is based upon the preliminary building drawings listed in the reference which were furnished to facilitate the preparation of the subject earthquake report. The results presented herein should be used in producing the final building design drawings, and these final drawings should then be reviewed to determine if any changes in the building's structural properties warrant a further earthquake analysis.

Very truly yours,

JOHN A. BLUME & ASSOCIATES, ENGINEERS

E. J. Keith

E. J. Keith
Assistant Vice President

EJK/nb
Enclosure

GENERAL ELECTRIC COMPANY
Atomic Power Equipment Department

MONTICELLO NUCLEAR GENERATION PLANT

Report on the Earthquake Analysis of the Reactor Building

JOHN A. BLUME AND ASSOCIATES, ENGINEERS
SAN FRANCISCO

MONTICELLO NUCLEAR GENERATION PLANT

REACTOR BUILDING

SEISMIC ANALYSIS

Page

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MONTICELLO NUCLEAR GENERATION PLANT

REACTOR BUILDING

SEISMIC ANALYSIS

INTRODUCTION

The purpose of this report is to summarize the results of the seismic investigation of the Monticello Nuclear Generation Plant Reactor Building. Based upon the recommended earthquake design criteria established for the Plant, design envelopes of maximum acceleration, displacement, shear, and overturning moment versus height of the building have been developed for both directions and are herein presented.

DESIGN CRITERIA

Based upon data developed by John A. Blume & Associates, Engineers (Reference 6), the design earthquake established for this analysis is the North 69° West Component of the 1952 Taft earthquake, normalized to a maximum ground acceleration of 0.06 gravity.

BUILDING DESCRIPTION

The reactor building is a reinforced concrete structure from its foundation at elevation 890'-3" to elevation 1027'-8". (See Sheets 10 through 15 & 18). At this level a steel framed top story has been placed.

The arrangement of the framing of this top story is indicated on Sheet SK-C41D of the Bechtel drawings. (See Reference 1 and also Sheets 16 through 18). The lateral bracing elements at the top story are as shown on Sheet 17.

The reactor building is founded on medium sand with some gravel at an elevation of 890'-3". The foundation of this building is of reinforced concrete having plan dimensions of 143'-6" by 140'-6". At elevation 935'-0", the building has plan dimensions of 137'-6" by 137'-6" with an appendage of 57'-0" by 28'-6". This configuration of concrete building is maintained to elevation 1001'-2" where the dimensions of the structure diminish to 137'-6" by 105'-3".

METHOD OF ANALYSIS

For the dynamic response analysis, the equivalent mass system shown on Sheet 1 was selected to approximate the reactor building. Masses were lumped at each floor level except that the top story steel frame was approximated by an equivalent two-mass system.

Each story level mass represents the mass of the concrete and equipment at each floor and the tributary mass of the concrete walls and equipment between adjacent floors. The top story masses are similarly developed but include the tributary mass of the walls, frame, bridge crane, and the mechanical equipment of the top story.

The average area and moment of inertia of the concrete walls between floors was used to determine the stiffness characteristics between masses. The steel framed top story, however, was investigated separately. For this story an equivalent frame stiffness was developed for each direction. A value of 3,000,000 psi was assigned as the Elastic Modulus of the concrete.

The natural frequencies and mode shapes and the dynamic response of the equivalent lumped mass system were determined with the aid of an IBM 7094 digital computer. Three modes were considered with the damping value assigned as 5 percent for all modes.

The ground motion utilized in determining the dynamic response of the reactor building has a maximum base acceleration of 0.06 gravity and corresponds to the response spectrum set forth in Reference 6.

ELASTIC SPRINGS
REPRESENTING SOIL CONDITION

References 2 and 12 present the data associated with the granular material which supports the reactor building. These values are as follows:

E_{dyn} = 78,500 pounds per square inch.

G = 29,500 pounds per square inch.

μ = 0.33 (dimensionless).

ρ = 135 pounds per cubic foot.

Using these given field determined values the rotational and lateral foundation spring supports were determined using the following equations (References 3 and 4):

$$K_s = \frac{E_{dyn}}{m\sqrt{A}\,(1-\mu^2)} = 90.58$$ kips per cubic foot -------- (1)

$$K_{rot} = K_s\, I_B$$ -------- (2)

For earthquake in N-S direction:

K_{rot} = 3,299,934,382 kip - feet per radian.

For earthquake in E-W direction:

K_{rot} = 4,234,677,410 kip - feet per radian.

$$K_G = \frac{mm'G\sqrt{A}}{1-\mu} = 1,581,549$$ kips per foot -------------- (3)

where: A = Area of foundation base = 21,786.25 square feet

m = 0.95

mm' = 0.845 (Table I - 11 of Ref. 4)

ANALYTICAL PROCEDURE

Periods and Mode Shapes

The natural periods of vibration and mode shapes of the mathematical model are given by Equation (4).

$$\left[\underline{K} - W_n^2 \underline{M}\right] \underline{\Phi}_n = \underline{O} \quad \text{------------------ (4)}$$

where:

$\underline{K}$ = Stiffness matrix (see Remarks on the Computer Program)

W_n = Natural circular frequencies for the $n^{\underline{th}}$ mode

$\underline{M}$ = Mass matrix

$\underline{\Phi}_n$ = Mode shape matrix for the $n^{\underline{th}}$ mode

$\underline{O}$ = Zero matrix

By use of a computer program the W_n value and the $\underline{\Phi}_n$ matrix for the $n^{\underline{th}}$ mode are obtained.

Generalized Displacement Response

The generalized displacement response of the structure, once the period and mode shapes have been determined, is given by the following equation:

$$\underline{\ddot{Y}_n}(t) + 2W_n\lambda_n \underline{\dot{Y}_n}(t) + W^2 \underline{Y_n}(t) = \underline{M_n}^{-1} \underline{R_n}(t) \ddot{U}_g(t) \quad \text{----- (5)}$$

where:

$\underline{Y_n}(t)$ = Generalized coordinate matrix

$$= \frac{R_r}{M_n W_n} \int_0^t \ddot{U}_g(\tau)\, e^{-\lambda_n W_n (t-\tau)} \operatorname{Sin}\left[W_n (t-\tau)\right] d\tau \quad \text{---- (6)}$$

$\underline{M_n}$ = Generalized mass matrix

$= \underline{\Phi_n^T} \cdot \underline{M} \cdot \underline{\Phi_n}$

$\underline{M}_n^{-1}$ = Inverse of the Generalized mass matrix

$\ddot{U}_g(t)$ = Earthquake input ground motion

λ_n = Damping for each mode - taken as 5 percent for all modes

$d\tau$ = Integration interval used in the step by step solution of the Duhamel Integral - 0.010 second. (Experience has shown that excellent accuracy is obtained if the integration interval is less than one tenth of the first mode period of vibration of the building).

From the Generalized Coordinate matrix the time history of displacements is found according to Equation (7).

$$\underline{v(t)} = \underline{\Phi}\ \underline{Y(t)} \qquad \text{-------------------- (7)}$$

where:

$$\underline{\Phi} = \begin{bmatrix} \Phi_1 & \Phi_2 & \text{--------} & \Phi_m \end{bmatrix}$$

m = Number of modes considered.

$$\underline{Y(t)} = \begin{bmatrix} Y_1(t) \\ Y_2(t) \\ \text{----} \\ \text{----} \\ \text{----} \\ Y_m(t) \end{bmatrix}$$

$\underline{v(t)}$ = Displacement - time history matrix

Inertia Forces

The time history of the inertia forces is then determined according to Equation (8).

$\underline{Q(t)} = \underline{K} \ \underline{v(t)}$ ------------------ (8)

where:

$\underline{Q(t)}$ = Matrix of inertia forces for each time increment for each mass.

Once displacement and inertia force - time histories have been established, the time histories of shears, moments, and accelerations are determined. These records are then enveloped to determine the maximum values which are then graphically presented in the report and used by the designer.

Remarks on the Computer Program

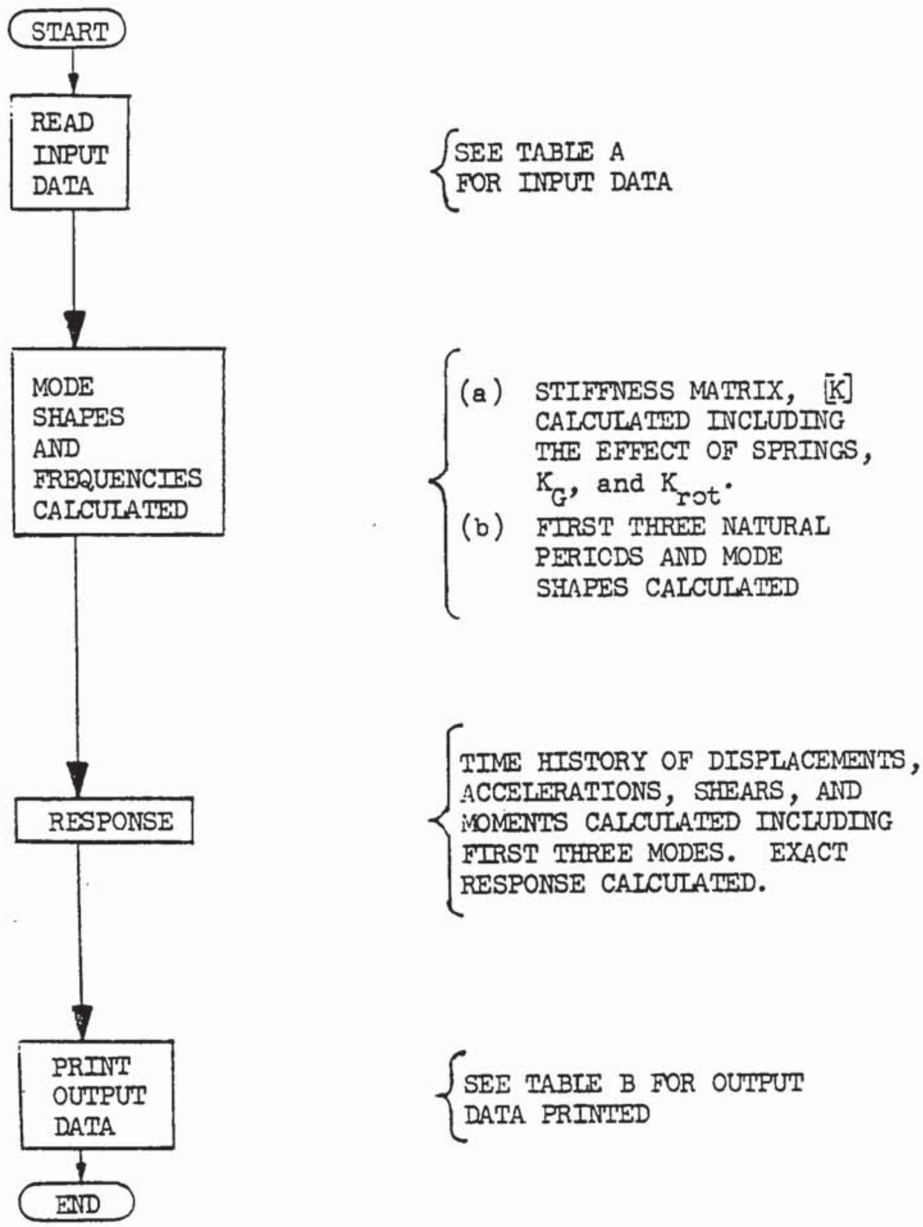
1) The computer program used in this analysis was specially designed to solve the dynamic response of structures subjected to arbitrary ground motions. Since the program was written to cover as many structural configurations as possible, the structural member input data for the program, except for the foundation springs, is in the form of member moments of inertias, areas, and effective shear areas. The effects of axial deformations and shear deformations are included in the calculation of the stiffness matrix.

2) The computer retains the response of each mass for each individual mode at each increment of time, and the total response for each increment of time is obtained by adding together the responses of each mass point for each mode at a particular instant of time. This results in an exact combination of mode participation without the necessity of using approximate methods such as the root-mean-square method.

3) Individual elements in the stiffness matrix are designated K_{ij} and are stored in the computer such that the i value designates the row number and the j value the column number. K_{ij} is determined by applying a unit displacement at the $\underline{j^{th}}$ point while restraining the other points against

displacement, and finding the corresponding reaction at the $\underline{i}^{th}$ point. In this manner the foundation spring constants are included in the stiffness matrix. This procedure couples the foundation springs and elastic springs of the structural system.

4) The general computer techniques used in this analysis are taken from References 7, 8, 9, 10 and 11. A simplified block diagram of the computer program, and the input and output data are shown on Plate A, and Tables A and B respectively.



SIMPLIFIED BLOCK DIAGRAM
OF DYNAMIC COMPUTER PROGRAM

PLATE A

TABLE A

INPUT DATA

1. Geometry of Model
   a) Vertical distances between mass points
   b) Mass point identification

      ie: Mass 1

      Mass 2

      Etc.

2. Cross Section Properties and Foundation Stiffnesses
   a) Moments of inertia of columns
   b) Areas of columns
   c) Shear areas of columns
   d) Foundation spring constants K_G, K_s

3. Weights and Masses
   a) Weight of each mass point
   b) Mass of each mass point

4. Input Earthquake Data
   a) Input earthquake - time in seconds and acceleration in gravity units.
   b) Time length of earthquake record used - 9.6 seconds of earthquake.
   c) Integration interval to be used in step by step solution of Duhamel Integral (0.010 second).

TABLE B

OUTPUT DATA

1. Maximum displacement of each mass point.
2. Maximum absolute accelerations of each mass point.
3. Maximum shears at each mass point.
4. Maximum overturning moments at each mass point.
5. Natural circular frequency of vibration of each mode calculated.

DISCUSSION OF RESULTS

Absolute Accelerations

The curves shown on Sheets 2 and 6 give an envelope of the maximum absolute accelerations with respect to height. These curves can be used for the seismic design of equipment elements rigidly attached to the reactor building, but since the curves given are for absolute accelerations the moment, shear and displacement curves presented should be used in the design of the building. Critical pieces of equipment which cannot be definitely assumed as rigid (period greater than 0.05 second) shall not be designed on the basis of the curves presented, but should be dynamically investigated, individually, to determine the effect of the interaction of the equipment and building.

Shears, Moments and Displacements

The maximum envelopes of building design shears, moments and displacements are presented graphically on Sheets 3, 4, 5, 7, 8 and 9. These curves should be used in the seismic design of the reactor building.

Periods of Vibration

Direction of Earthquake	First Mode (Seconds)	Second Mode (Seconds)	Third Mode (Seconds)
North-South	0.596	0.211	0.183
East-West	0.549	0.221	0.186

Recommendations

It is recommended that the subject structure be designed to resist the seismic shears and moments presented herein without the usual increase in stress for short term loadings. In addition, the structure should be reviewed to assure that it can resist twice the seismic shears and moments presented herein without hindering the ability of the plant to safely shut down. In addition to the horizontal accelerations, a vertical building (and equipment) acceleration of 0.04 gravity, acting simultaneously with the horizontal accelerations is recommended for design.

MONTICELLO NUCLEAR GENERATION PLANT

REACTOR BUILDING

SEISMIC ANALYSIS

REFERENCES

1. Preliminary Design Drawings

   General Electric Drawings:

   5828-SK-C-15D, dated June 7, 1967
   5828-SK-C-41D, dated June 6, 1967
   NF-36166, dated April 3, 1967

2. Report of Foundation Investigation - Proposed Nuclear Power Plant - Unit Number 1, Monticello, Minnesota, by Dames and Moore, dated July 27, 1966 (including Supplements 1 through 5).

3. Theory of Elasticity, by Timoshenko and Goodier, Second Edition, McGraw Hill Company, 1951.

4. Dynamics of Bases and Foundations, by D. D. Barkan, McGraw Hill Company, 1962.

5. Nuclear Geoplosics, Stanford Research Institute, Defense Atomic Support Agency, Part Two, Mechanical Properties of Earth Materials, May 1962.

6. Recommended Earthquake Criteria, by John A. Blume and Associates, July 15, 1966.

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

8. Use of Modern Computers in Structural Analysis, by R. W. Clough, Journal of the Structural Division of the American Society of Civil Engineers, ST 3, May 1958.

9. Structural Analysis of Multistory Buildings, by R. W. Clough, Ian P. King, and Edward L. Wilson, Journal of the Structural Division of the American Society of Civil Engineers, ST 3, June 1964.

REFERENCES (Con't.)

10. Dynamic Effects of Earthquakes, by R. W. Clough, Transactions of the American Society of Civil Engineers, Paper No. 3252.

11. Large Capacity Multistory Frame Analysis Programs, by R. W. Clough, Edward L. Wilson, and Ian P. King, Journal of the American Society of Civil Engineers, ST 4, August 1963.

12. Report - Dynamic Response Data Investigation - Proposed Nuclear Power Plant, Monticello, Minnesota, by Dames and Moore, dated July 7, 1966.

MONTICELLO NUCLEAR GENERATION PLANT

REACTOR BUILDING

SEISMIC ANALYSIS

LIST OF FIGURES

LIST OF PROPERTIES

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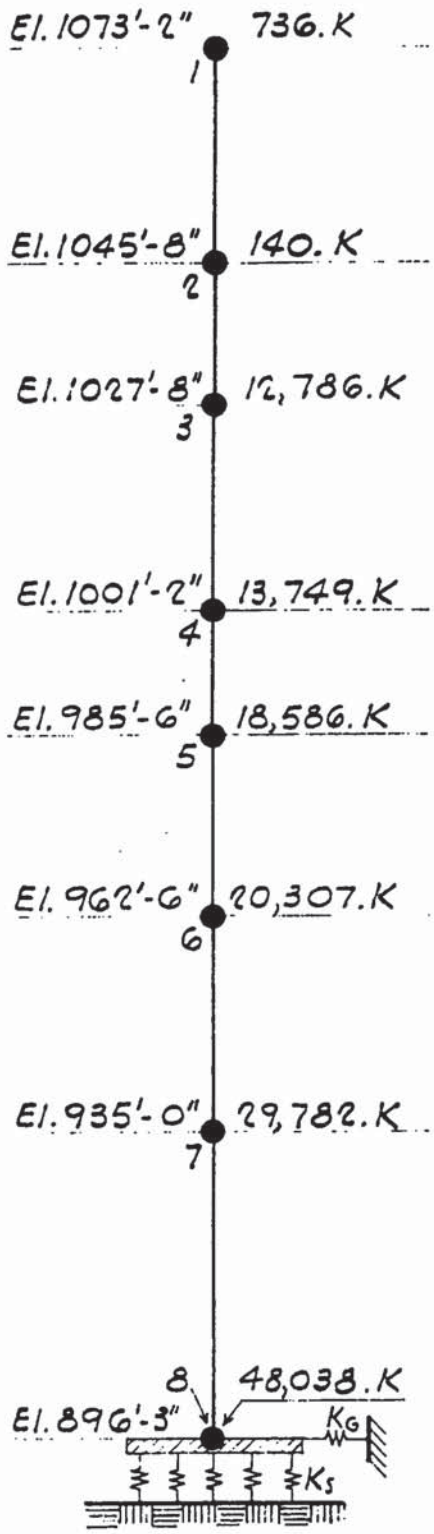
MONTICELLO REACTOR BUILDING
SEISMIC ANALYSIS



I_c (ft^4) N-S AXIS	I_c (ft^4) E-W AXIS	A_c (ft^2)
BRACED AREA		
3,662,210.	1,805,790.	2,256.
5,202,269.	5,140,204.	3,365.
4,481,508.	4,460,485.	2,835.
4,052,402.	5,006,316.	2,784.
11,808,952.	9,693,452.	5,941.
I_{BASE} = 46,750,688.8	I_{BASE} = 36,431,158.9	A_{BASE} = 21,786.25

MATHEMATICAL MODEL

SHEET NO. 1

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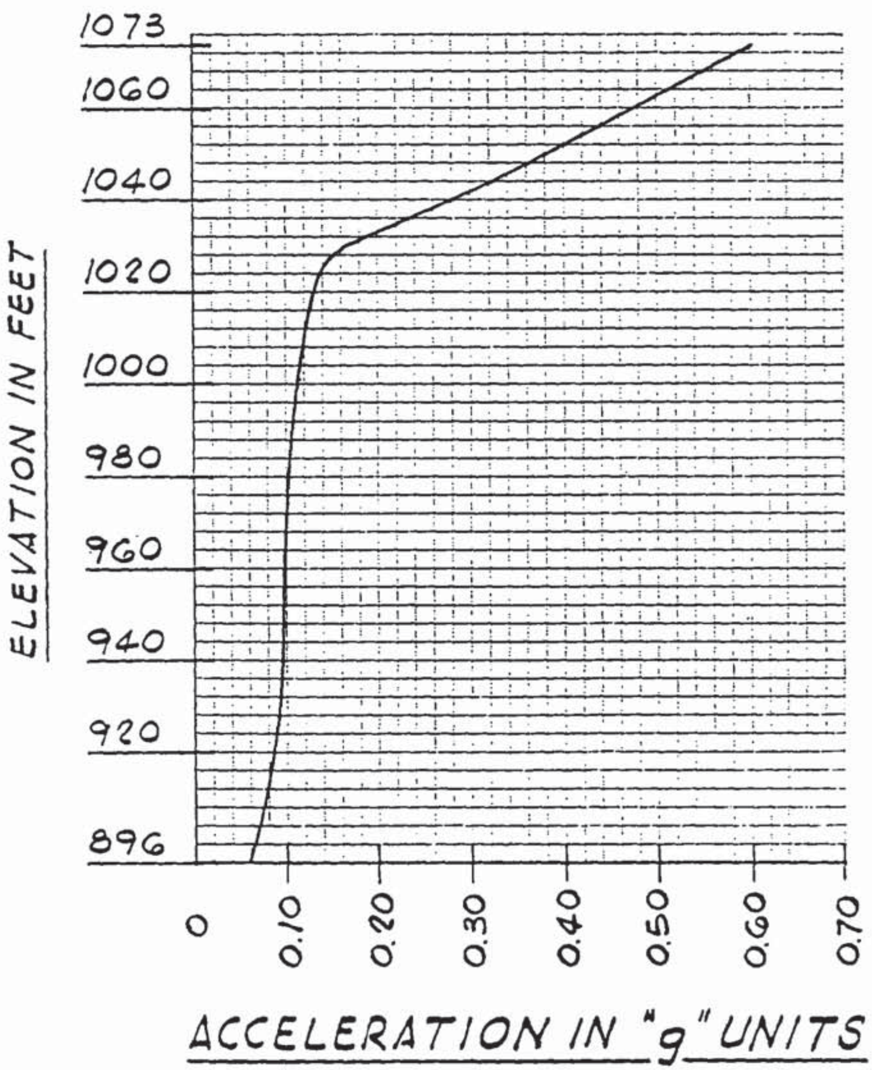
MONTICELLO REACTOR BUILDING
SEISMIC ANALYSIS
ACCELERATION DIAGRAM
UNDER SEISMIC LOADS
N-S DIRECTION



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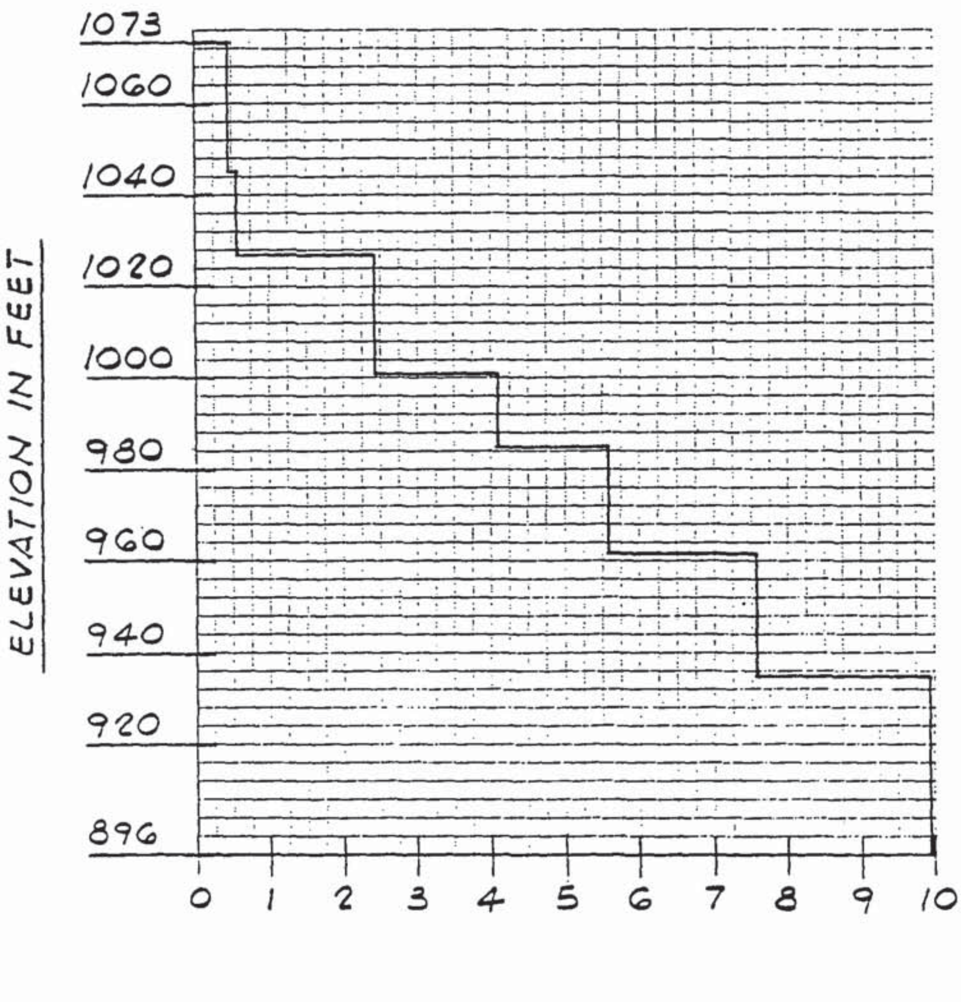
MONTICELLO REACTOR BUILDING

SEISMIC ANALYSIS

SHEAR DIAGRAM

UNDER SEISMIC LOADS

N-S DIRECTION



SHEAR IN KIPS × 10^3

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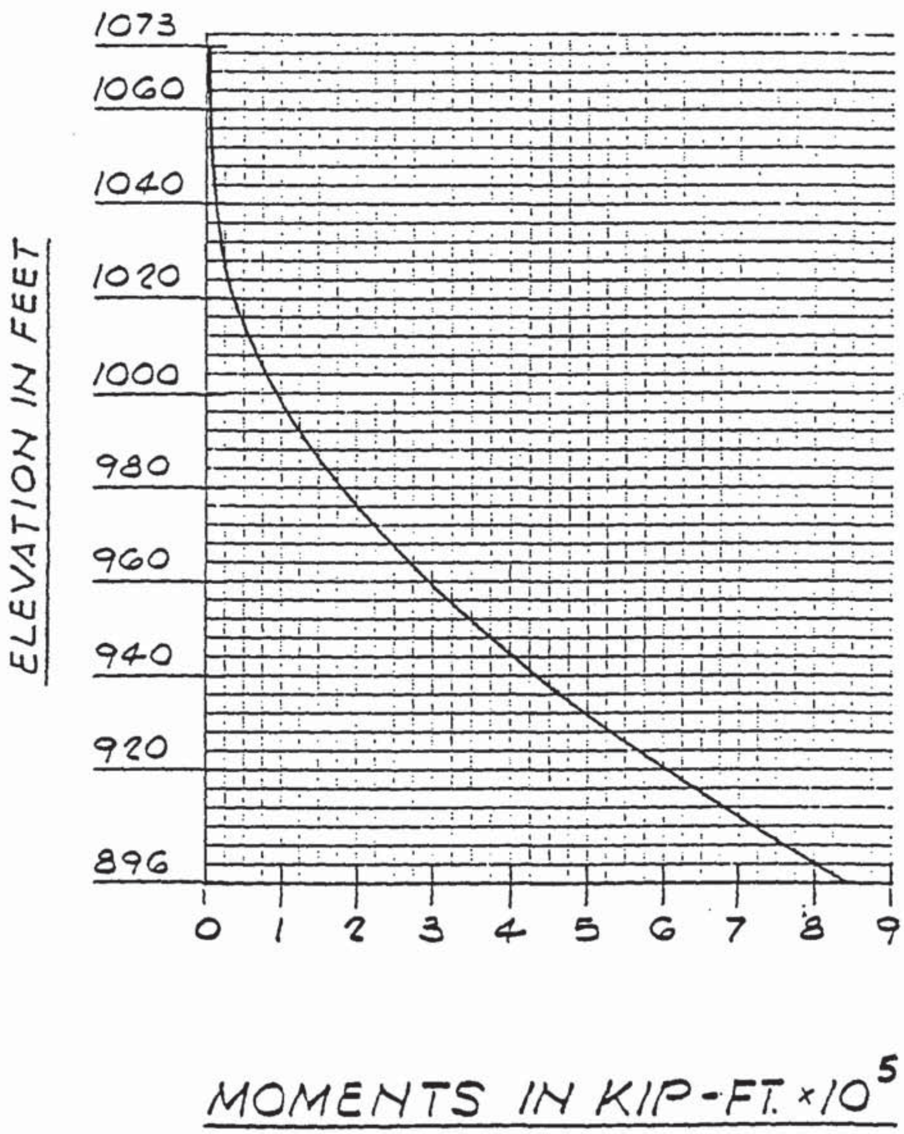
MONTICELLO REACTOR BUILDING
SEISMIC ANALYSIS
MOMENT DIAGRAM
UNDER SEISMIC LOADS
N-S DIRECTION



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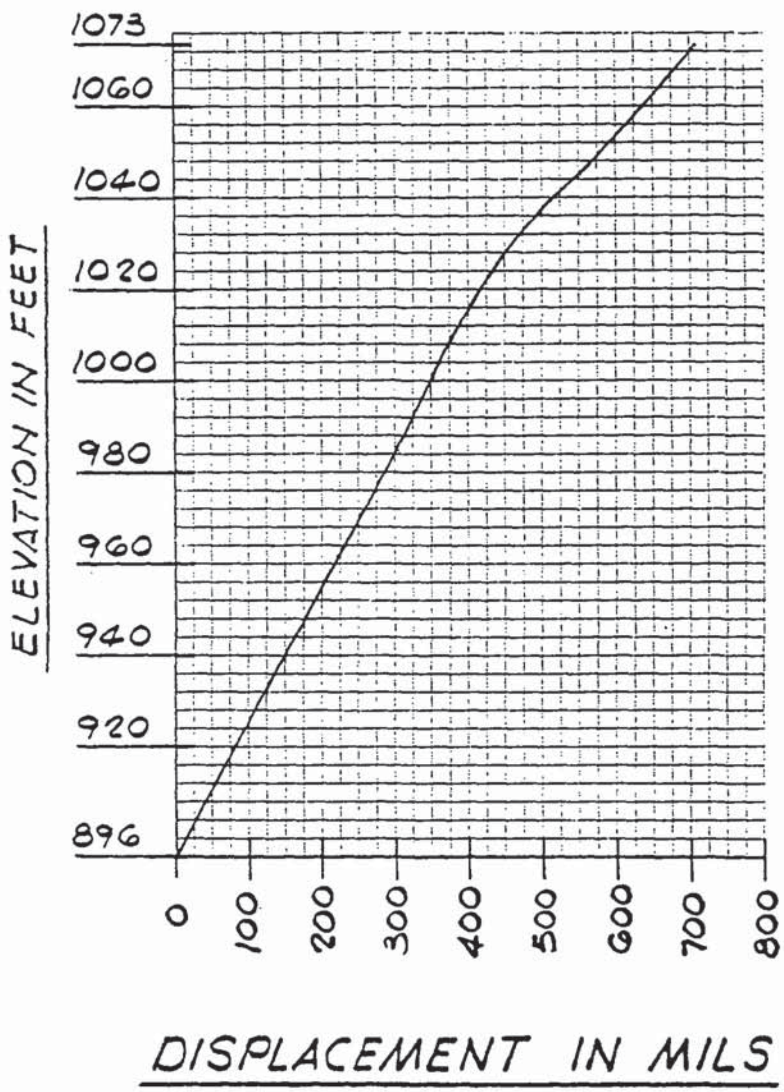
MONTICELLO REACTOR BUILDING
SEISMIC ANALYSIS
DISPLACEMENT DIAGRAM UNDER SEISMIC LOADS N-S DIRECTION



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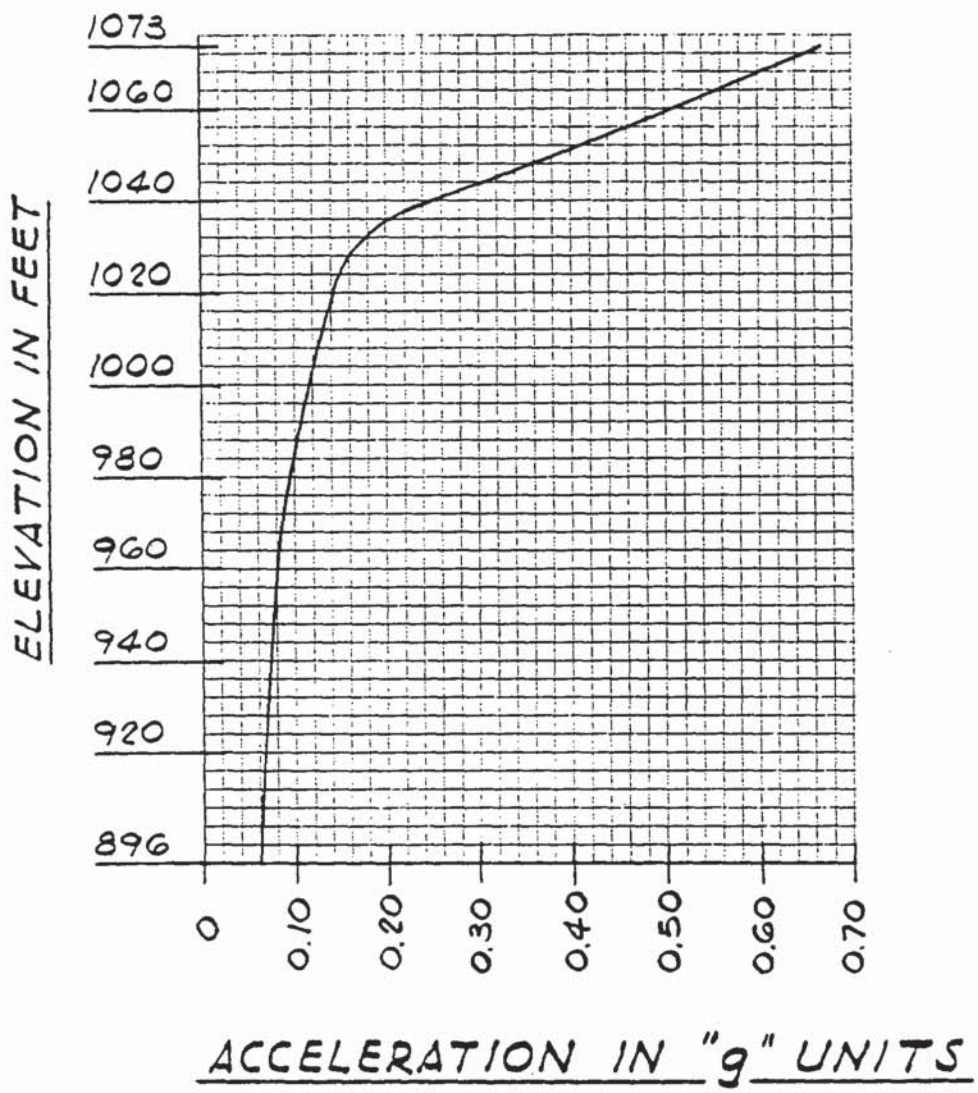
MONTICELLO REACTOR BUILDING
SEISMIC ANALYSIS
ACCELERATION DIAGRAM
UNDER SEISMIC LOADS
E-W DIRECTION



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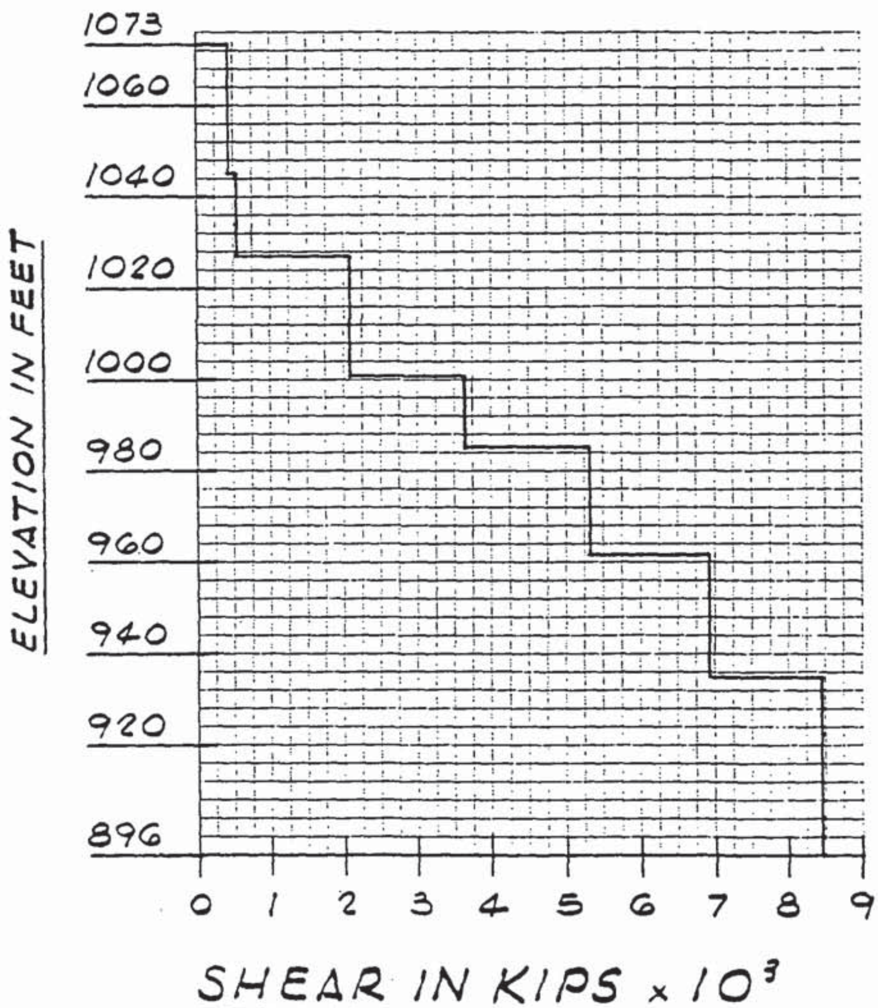
MONTICELLO REACTOR BUILDING
SEISMIC ANALYSIS
SHEAR DIAGRAM
UNDER SEISMIC LOADS
E-W DIRECTION



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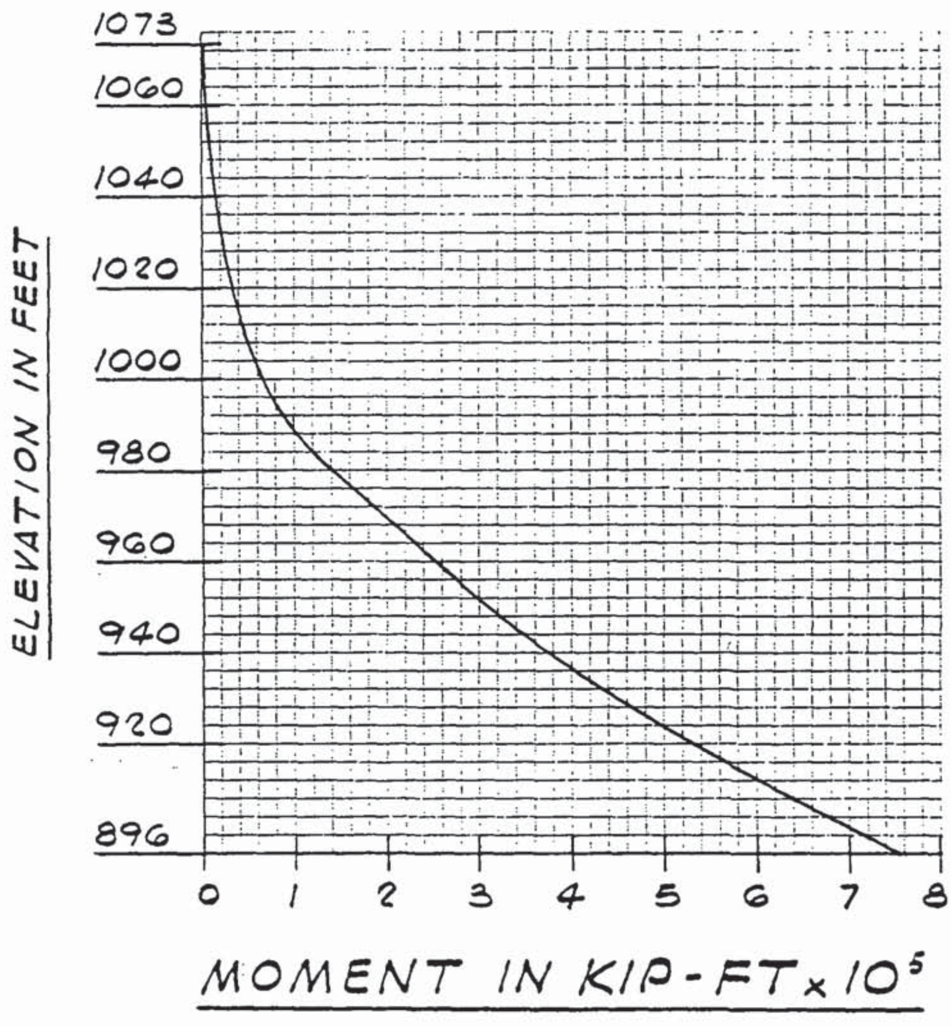
MONTICELLO REACTOR BUILDING
SEISMIC ANALYSIS
MOMENT DIAGRAM
UNDER SEISMIC LOADS
E-W DIRECTION



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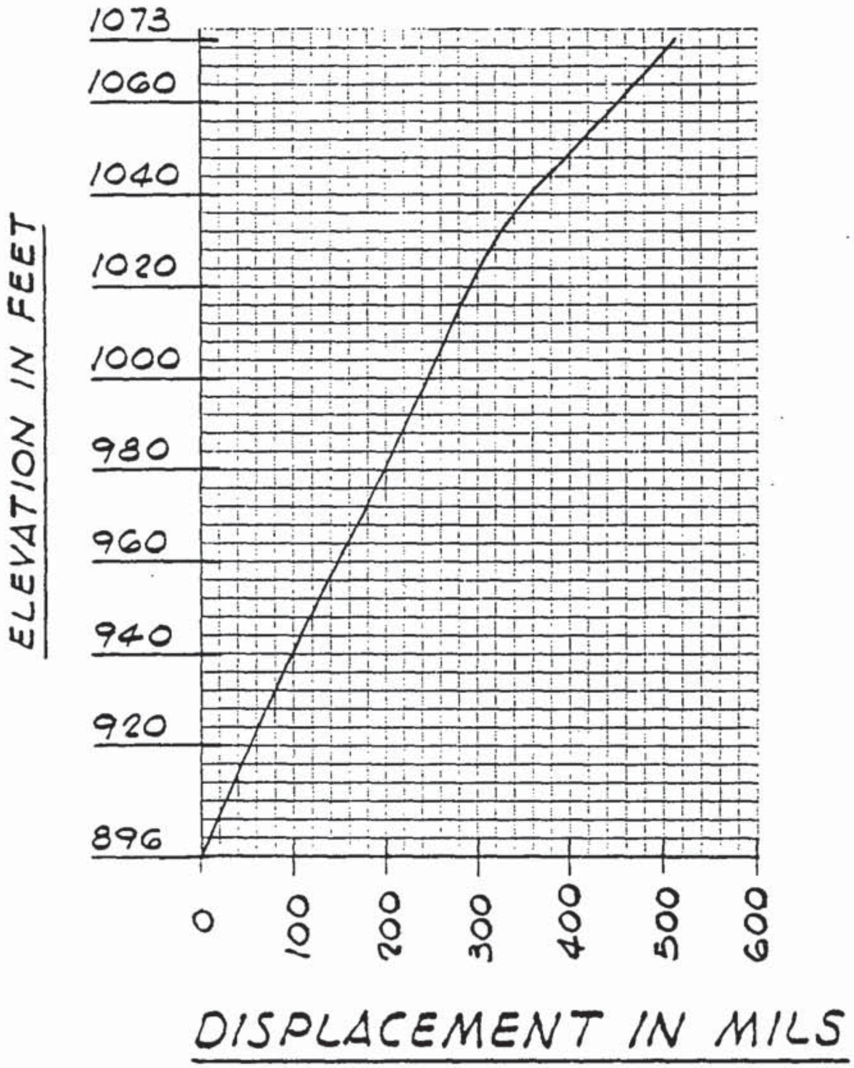
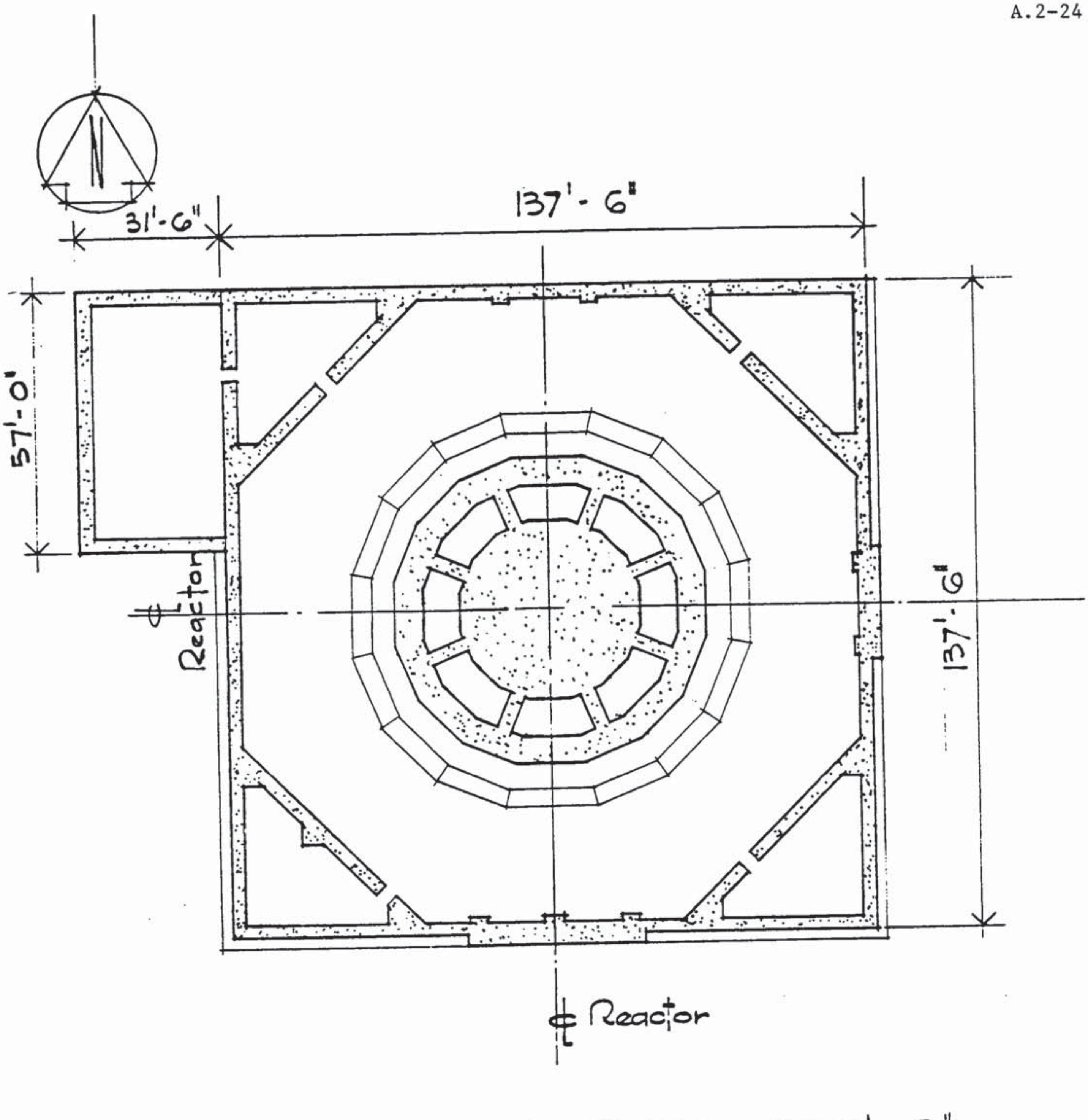
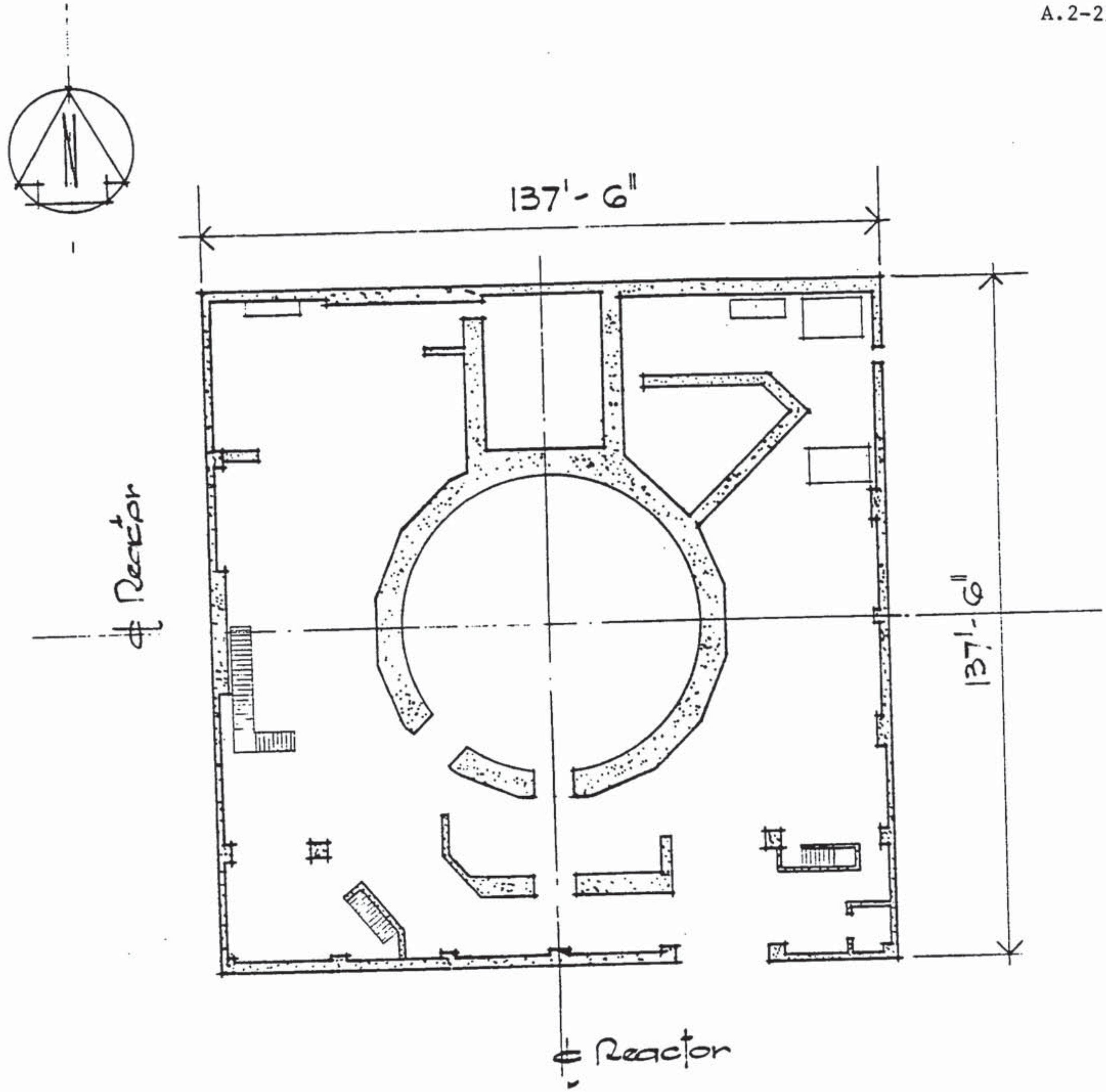
MONTICELLO REACTOR BUILDING SEISMIC ANALYSIS DISPLACEMENT DIAGRAM UNDER SEISMIC LOADS E-W DIRECTION





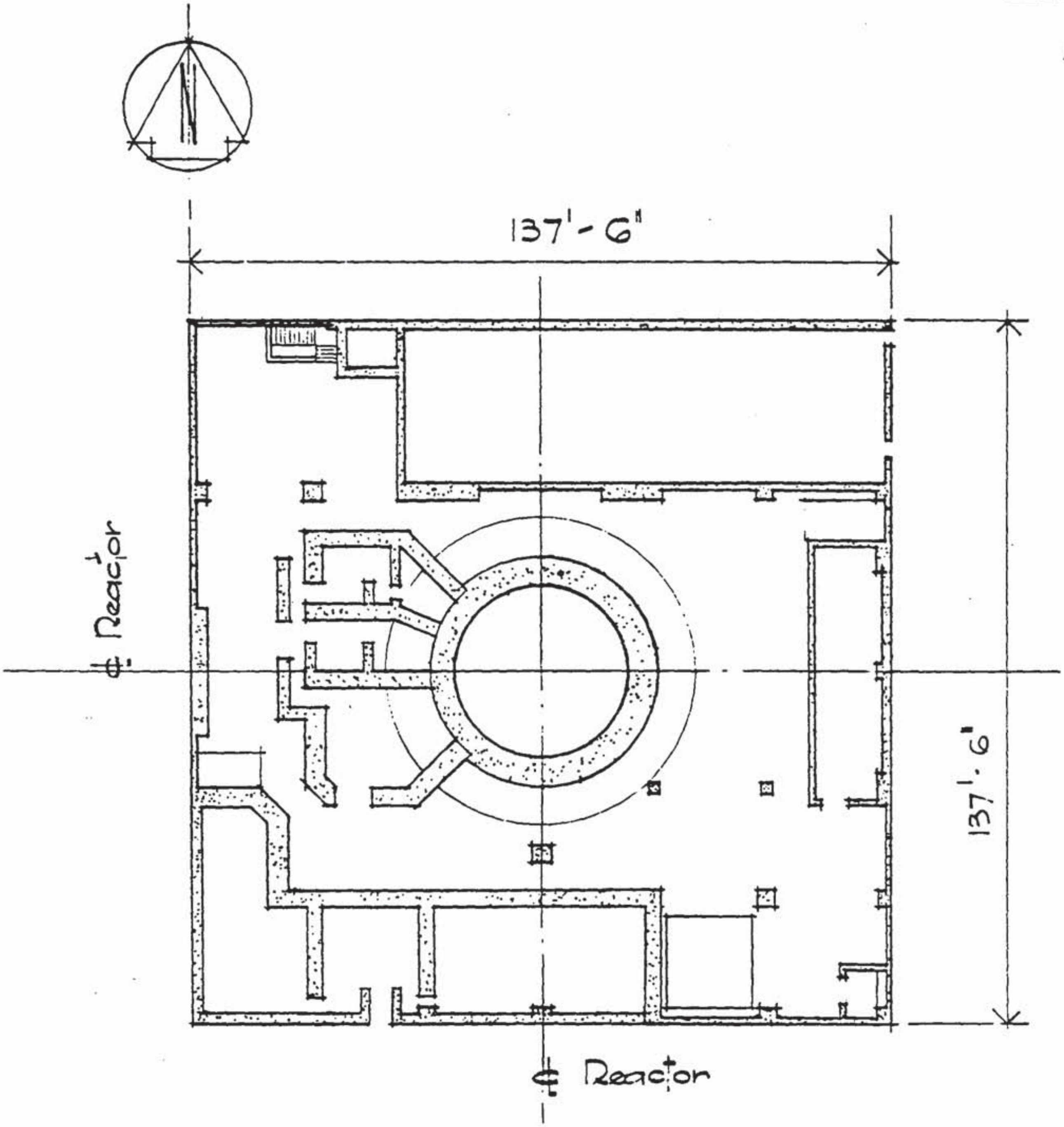
PLAN ABOVE ELEV. 896'-3"

SHEET NO. 1



PLAN AT ELEV. 935'-0'

SHEET NO. 11



PLAN ABOVE ELEV. 962'-6'

SHEET NO.

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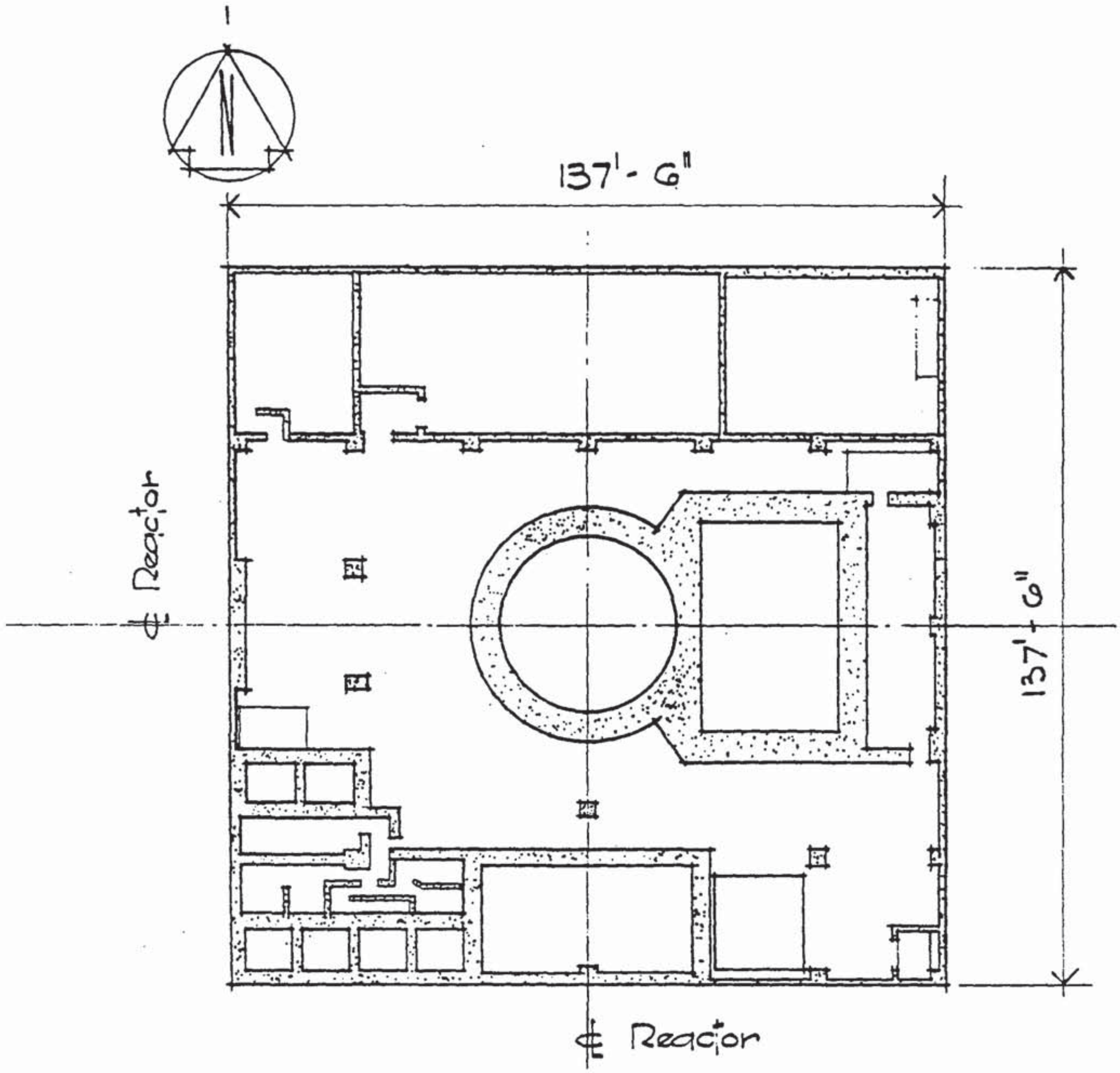

PLAN AT ELEV. 985'-6"

SHEET NO. 13

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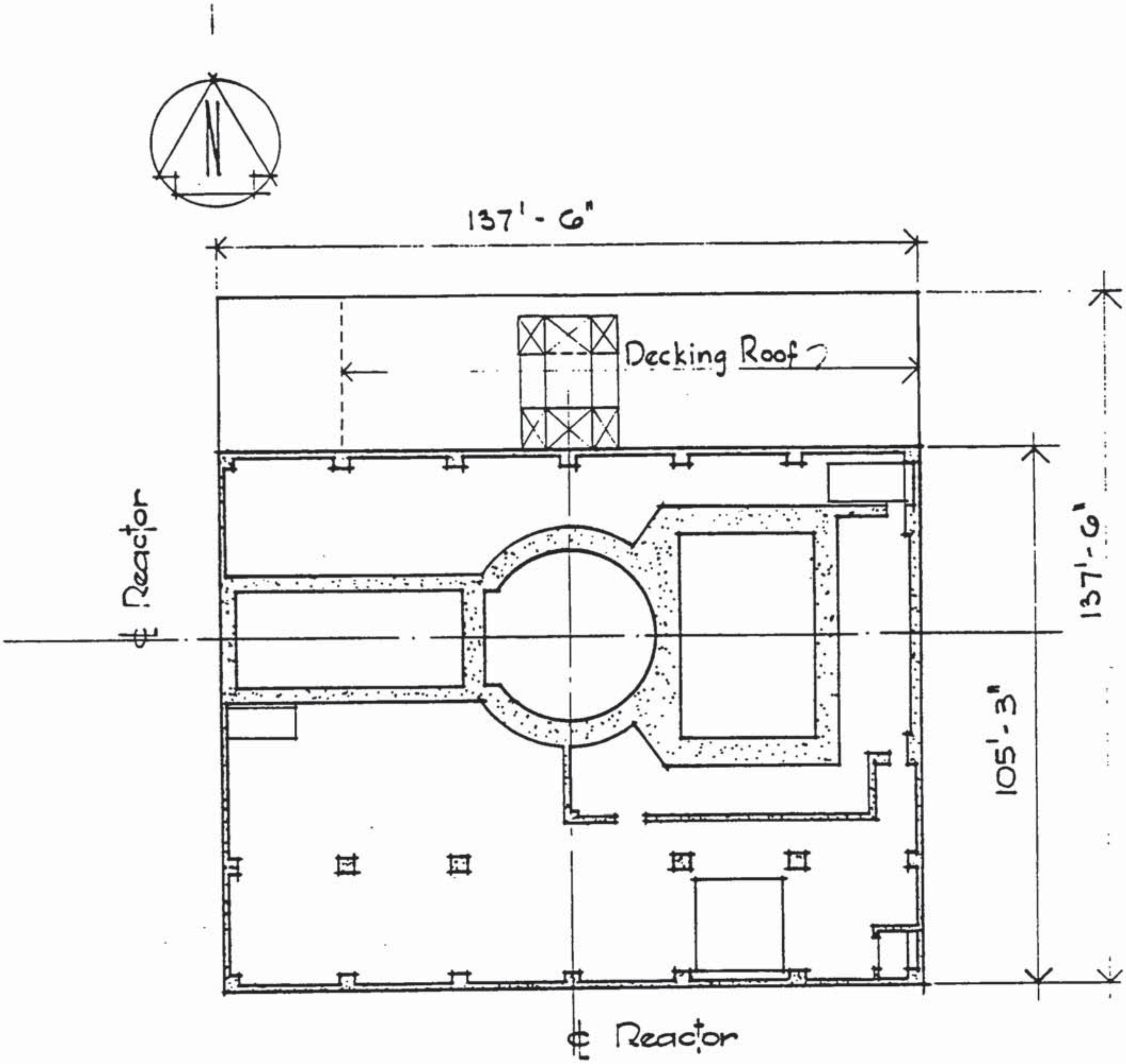

PLAN AT ELEV. 1001'-2"

SHEET 14

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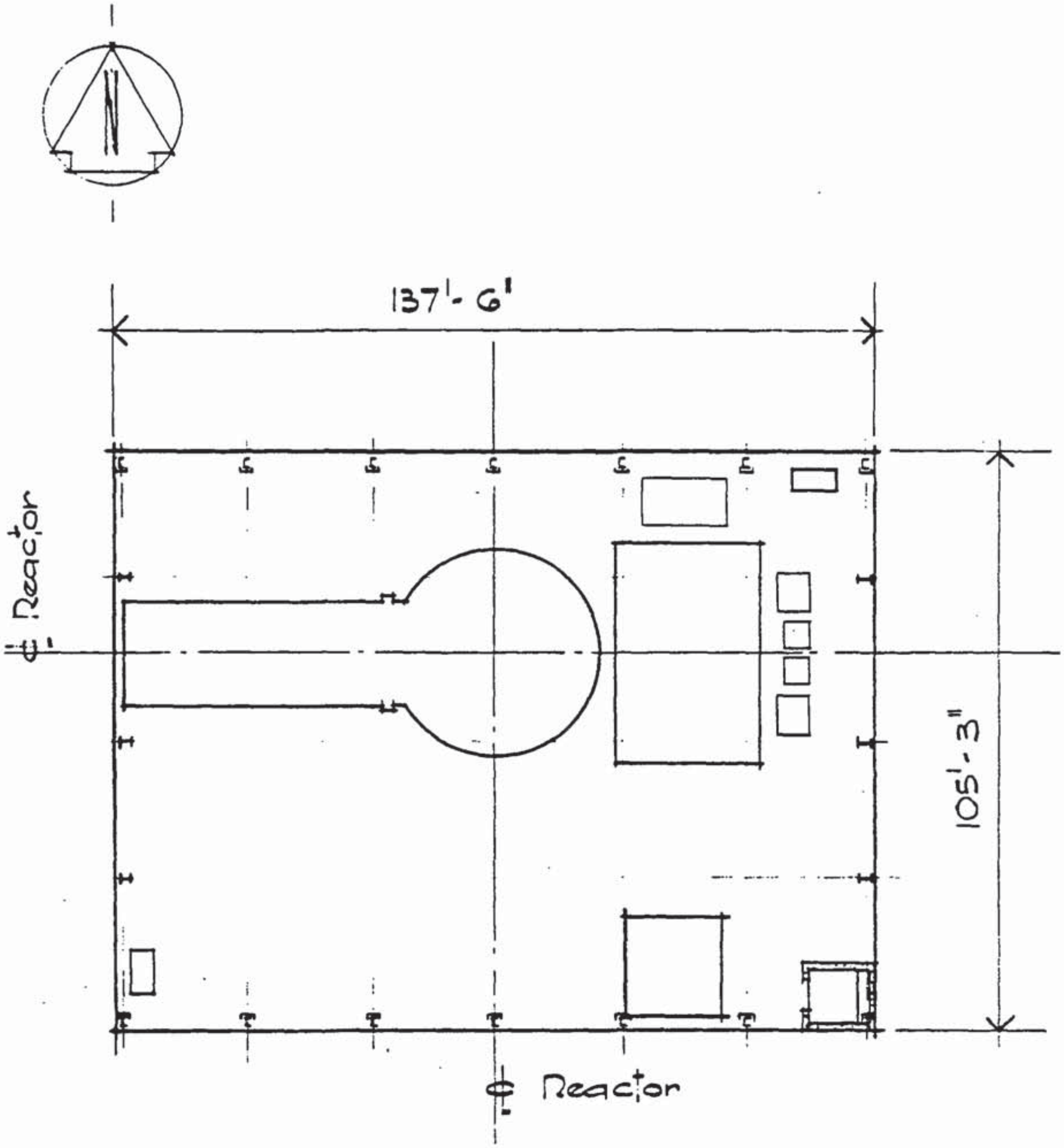
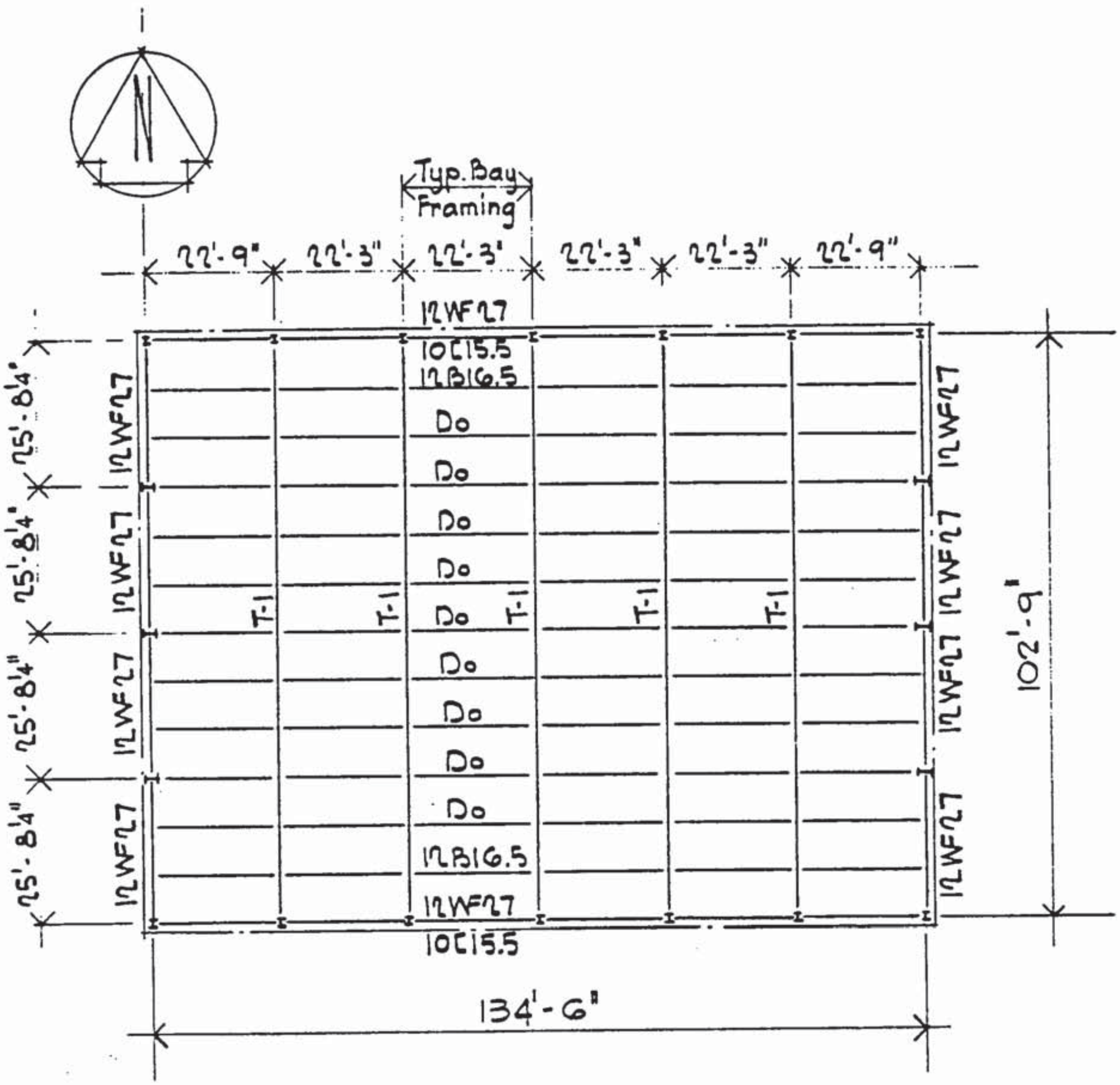


PLAN AT ELEV. 1027'-8"

SHEET 15



ROOF AT ELEV. 1073'-2"

SHEET 16