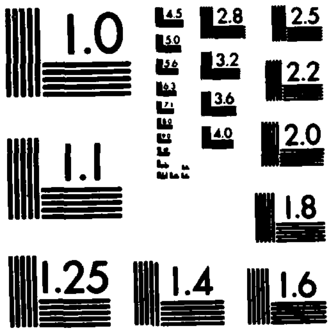
AD-A142 890 GRAND RIVER BASIN BOWMAN - HALEY DAM AND LAKE NORTH DAKOTA SEISMIC EVALUATION AND ANALYSIS(U) CORPS OF ENGINEERS OMAHA NE SEP 83 1/1

UNCLASSIFIED F/G 13/13 NL

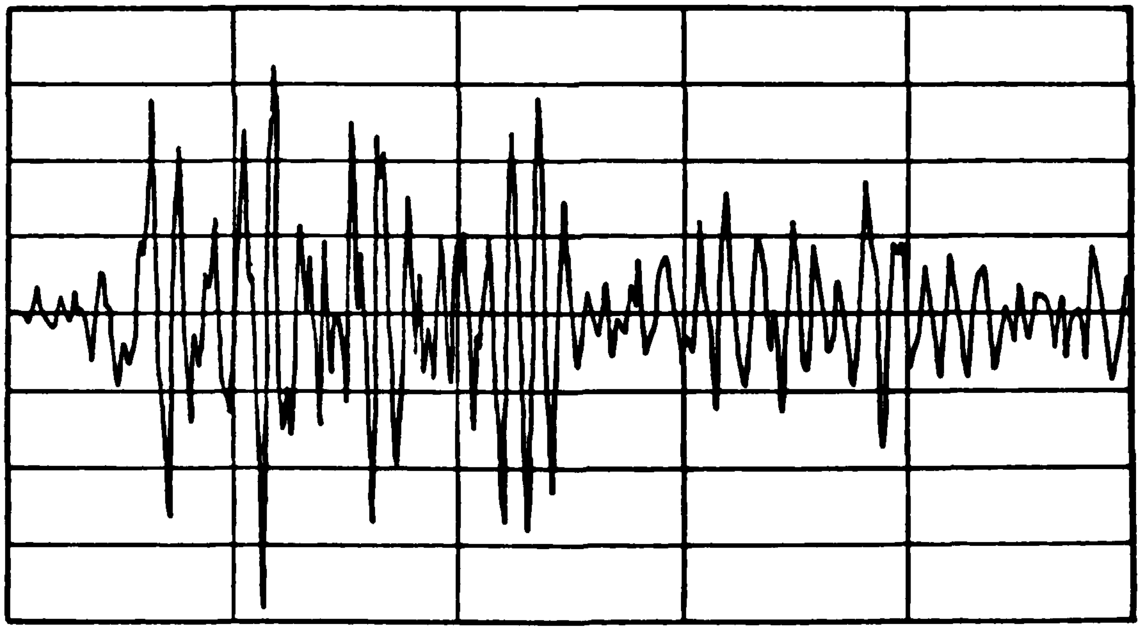


RECONNAISSANCE REPORT

September 1983

Grand River Basin
BOWMAN - HALEY DAM AND LAKE
North Dakota

SEISMIC EVALUATION AND ANALYSIS



US Army Corps
of Engineers
Omaha District

GRAND RIVER BASIN - HALEY, NORTH DAKOTA

BOWMAN-HALEY DAM AND LAKE

RECONNAISSANCE REPORT

SEISMIC EVALUATION AND ANALYSIS

SEPTEMBER 1983

U.S. ARMY ENGINEER DISTRICT, OMAHA

GRAND RIVER BASIN - HALEY, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE

RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

TABLE OF CONTENTS

RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

GRAND RIVER BASIN - HALEY, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE

1. **PURPOSE AND SCOPE.** The Omaha District in accordance with Engineering Regulation (ER) 1110-2-1806, "Earthwork Design and Analysis for Corps of Engineers Dams," dated 16 May 1983, is required to conduct detailed seismic evaluations of selected earthdams on sand foundations. The purpose of this Reconnaissance Report, prepared in accordance with appendix A of ER 1130-2-417 "Major Rehabilitation Program and Dam Safety Assurance Program," dated 30 November 1980, is to present a summary of available data necessary to determine the need for such an analysis. The scope of the report includes (1) a summary of preconstruction and construction data; (2) a preliminary seismic risk analysis; (3) an evaluation of the embankment materials ability to resist postulated earthquake shaking without detrimental effects; and (4) a summary of work required to complete the seismic evaluation of the site.

2. **PROJECT LOCATION AND DESCRIPTION.** Bowman-Haley Dam is located on the North Fork of Grand River in Bowman County, North Dakota. This location is about 6 miles upstream from the town of Haley, North Dakota and just downstream of the confluence with Spring Creek, a left bank tributary of the North Fork. The project controls runoff from 471 square miles. The dam is a rolled earth fill embankment, 79 feet high above the channel bottom and 5,730 feet long. The crest is at elevation 2794 and is 25 feet wide. An uncontrolled earthen cut and grassed emergency spillway is located in the right abutment. The spillway contains a soil cement scour cutoff and a fuse plug. The soil cement scour cutoff was provided to halt erosion of the spillway floor during periods of flow, and the fuse plug was designed to store 90 percent of the standard project flood but to fail when overtopped by floods of greater magnitude. The outlet works consists of a two level uncontrolled drop intake structure, 10-foot-diameter cast-in-place concrete service spillway conduit, a 30-inch-diameter low level gated conduit, and a Saint Anthony Falls type drop structure and stilling basin. A project location map, a vicinity map, and typical embankment sections are presented on plate 1.

3. SEISMIC EVALUATION CRITERIA.

3.1 SEISMIC HAZARD ANALYSIS. A preliminary hazard analysis has been performed for the site, based on a combined probabilistic-deterministic procedure modified from Cornell 1/. Cornell's method for calculating engineering seismic risks incorporates postulated earthquake magnitudes; point, line, and areal sources; and body wave attenuation into a statistical analysis. The modified procedure incorporates the estimated magnitudes for all earthquakes within the 111-year historical record, for a 200 kilometer radius about the site, and known or inferred geologic structures. The resulting seismotectonic map, shown on plate 2, subdivides the area about the site into seismotectonic zones. Each zone is defined for a relative consistency with existing geologic features and seismicity contained within them. Seismotectonic zones capable of being significant earthquake sources were used in the preliminary analysis. The preliminary seismic hazard analysis is presented in appendix A. Detailed descriptions of the earthquakes shown on plate 2 are presented in appendix B.

3.2 POSTULATED EARTHQUAKE. For the preliminary hazard analysis, only the seismotectonic zone expected to produce the highest site acceleration was evaluated. The highest site acceleration determined by this analysis for the 1000-year recurrence earthquake would be 0.070 g. This acceleration would be due to an earthquake occurring at a 5 kilometer (km) depth along a line representing the Williston Basin axis within a 200-mile radius of Bowman-Haley Dam.

4. EMBANKMENT.

4.1 EMBANKMENT FEATURES. Bowman-Haley Dam is a rolled, homogeneous, earthfill embankment with a central impervious core flanked upstream and downstream by more pervious random zones. The embankment is 79.0 feet high at its maximum section over the channel bottom, has a crest width of 25 feet and a length of 5,730 feet. The top of the embankment was built to elevation 2794.5 feet mean sea level (m.s.l.) which included a 0.5-foot overbuild to compensate for postconstruction consolidation and foundation settlement. The upstream slope is 1 vertical (1V) on 2.5 horizontal (2.5H) from the crest to

1/ Cornell, C. A., "Engineering Seismic Risk Analysis," Bulletin Seismic Society of America, Vol. 58, 1968, pp. 1583-1606.

El. 2769.0, and 1V on 3H to El. 2740; and the upstream berm is 1V on 8H to original ground. The downstream slope is 1V on 2.5H from the crest to El. 2769; 1V on 3H to El. 2744; and 1V on 3.5H to original ground. Wave protection is provided for the upstream slope between elevations 2740 and the top of the embankment at elevation 2794. The protection consists of 24 inches of riprap overlying 6 inches of spalls and 6 inches of bedding. The downstream slope was covered with 9 inches of topsoil and seeded for runoff erosion control. Seepage through the embankment is controlled by an internal pervious drain. The drain has a continuous 8-foot-wide inclined section, top elevation 2781, and several horizontal outlets evenly spaced on 100-foot-centers throughout the embankment, as shown on plates 3 and 4. Typical embankment sections 1-1, 2-2, and 3-3 are shown on plate 5.

4.2 COMPACTION EQUIPMENT. The compaction equipment used on this project was approved by the Corps of Engineers' Resident Engineer. A description of the compaction equipment used during construction is presented in table 1.

TABLE 1

COMPACTION EQUIPMENT USED IN CONSTRUCTION

Tamping Roller
- (a) Bros. Self-Propelled Roller
- (b) Model SP-255D with Cat. Engine 125 H.P.
- (c) 2 Drums, 5' x 5'
- (d) Tamping Feet
  - (1) Face area = 7 sq. in.
  - (2) Length = 8 in.
  - (3) Number of teeth per drum = 120
- (e) Weight on drums water ballasted = 31,000 lbs. or 3,100 lbs. per lin. ft. of drum

Tamping Roller
- (a) Bros. Self-Propelled Roller
- (b) Model SP-255E Ser. #1102 with A.C. Engine 167 H.P.
- (c) 2 Drums
- (d) Tamping Feet
  - (1) Face area = 12 sq. in.
  - (2) Length = 8 in.
- (e) Total weight, water ballasted = 35,000 lbs.
  Weight on drums = 31,000 lbs. or 3,100 lbs. per lin. ft. of drum

TABLE 1 (Cont'd)

Tamping Roller
- (a) Towed type - towed by Allis Chalmers HD-15 Tractor
- (b) Double drum = 10 lin. ft. total, each drum = 98 cu. ft.
- (c) Tamping Feet
  - (1) Face area - 8 sq. in.
  - (2) Length = 8 in.
- (d) Roller weight empty = 11,925 lbs.
  Roller weight as used = 30,937 lbs. or 3,094 lbs. per lin. ft.
- (e) Ballast - right drum = old concrete sand
  - left drum = Bowman Redi Mix sand

Rubber Tired Pneumatic Roller
- (a) Ferguson (4 wheel) - towed by Allis Chalmers HD-21 Dozer
- (b) 17' x 8' x 6'
- (c) Roller weight empty = 40,000 lbs.
  Roller weight as used - 21,960 lbs. per wheel

Vibratory Flatwheel Roller
- (a) Vibratow II - towed by Farmall "M" Tractor
- (b) Model VT2 Ser. #786
- (c) 3' x 5' Drum

Crawler Tractor
- (a) Weight = 40,000 lbs.

It was estimated that the percent of fill compacted by the various rollers was as follows:

2 - Bros. self-propelled tamping rollers	=	65%
1 - Towed tamping roller	=	25%
1 - 4 Wheel pneumatic (towed)	=	10%
1 - Towed vibratory flatwheel & power hand tampers	=	Insignificant

4.3 EMBANKMENT MATERIALS.

4.3.1 **Earthfill.** Material for the impervious core consists of lean clays (CL), clayey silts (ML), sandy clays (CL), and silts (ML). Material for the random zones consists of clays, silts and sands. Fat clays (CH) were used only in the upstream random fill zone. Material for berm fill is that material from required excavation which was too wet, and lignite material. Approximately 75 percent of the fill was obtained from the required spillway, outlet works, and cutoff trench excavations. The remainder of the required material, predominantly silt, was borrowed from a ridge north of the left abutment.

4.3.2 **Embankment Drain Material.** The material placed in the pervious fill sections of the embankment was clean, free draining sand having less than 10 percent finer than No. 200 mesh sieve size. This material was obtained from gravel terraces on the reservoir floor.

4.4 MATERIAL PLACEMENT AND COMPACTION.

4.4.1 **General.** Specifications required that the gradation and distribution of materials throughout the earthfill section of the dam would be such that the embankment would be free from lenses, pockets, streaks and layers of material differing substantially in texture or gradation from surrounding material. If the desired compaction of any portion of the embankment was not secured by the number of passes specified below, additional complete passes were made over the area of the designated portion until the desired compaction was obtained. Unless otherwise directed, compaction equipment was operated parallel to the axis of the dam. When approved, the Contractor was allowed to use other layer thicknesses, number of passes, and compaction equipment, provided the results were at least equal to those specified.

4.4.2 **Compacted Embankment Fill.** The embankment section consists of a central impervious core flanked by more pervious random zones. The materials were placed so as to provide a progressive increase in permeability from the center out toward each slope. Specifications required that the fill material be placed in approximately horizontal layers and compacted as shown in table 2.

TABLE 2

SPECIFIED COMPACTION PROCEDURES - EMBANKMENT FILL

Type Fill and Compaction Equipment	Maximum Uncompacted Lift Thickness (Inches)	Minimum No. of Passes
Impervious Fill		
Rubber-tired roller	12	3
Tamping roller	8	6
Power tampers	4	As Required to Obtain Desired Densities
Random Fill		
Rubber-tired roller	12	3
Tamping roller	8	6
Power tampers	4	As Required to Obtain Desired Densities

It was intended that the above procedures would provide a final density of at least 95% of maximum density. The moisture content was required to be within 2 percent above optimum moisture content to 4 percent below optimum. The optimum moisture content was determined in accordance with AASHO Standard T 99-57, Method "A". Field density was determined by sand cone, water balloon, and nuclear density methods. Portions of the fill which could not be compacted with rollers because of space restrictions, were placed in 4-inch loose lift layers and compacted with power tampers to the desired density.

4.4.3 Semicompacted Berms. The material for berm fill was material from required excavation that was unsuitable for compacted fill. This included material which was too wet, and lignite. Specifications required that the semicompacted berms be constructed in layers not exceeding 24 inches in thickness, except for the lignite. The lignite was placed in the berm as directed and spread in horizontal layers with an uncompacted thickness of 12 inches. Each lignite layer was compacted by four passes of the tamper type roller. Compaction for the other materials was accomplished by even routing of construction and hauling equipment over the layers. Moisture control was not specified, except that the upper limit could not exceed that which would permit the movement of equipment over the fill.

4.4.4 Pervious Fill. Pervious fill was dumped and spread to an uncompacted thickness of not more than 12 inches and was wetted, as directed, to facilitate compaction. The amount of water added to the material was approximately that which would produce substantial saturation when the material was in the compacted state. The entire surface of each layer was compacted by not less than three complete passes of rubber-tired rollers. A small percentage of the pervious fill was compacted, as directed, by a vibratory roller, and an even smaller percentage by a 40,000-lb. crawler tractor. A maximum uncompacted lift thickness of 4 inches and a minimum number of four complete passes were required when compacting with the crawler tractor.

4.5 EVALUATION OF EMBANKMENT LIQUEFACTION POTENTIAL. The construction records indicate that the central core of the embankment is comprised of impervious material and therefore, not subject to liquefaction. The construction records also indicate that the random fill sections that buttress the central core and the pervious fill were properly compacted to assure satisfactory performance. These materials are considered to have adequate resistance to postulated earthquake shaking, since it is generally agreed that virtually any well-built embankment can withstand moderate earthquake shaking with peak accelerations of 0.2 g and more with no detrimental effects.

5. FOUNDATION.

5.1 FOUNDATION EXPLORATIONS. The subsurface exploration program at Bowman-Haley Dam consisted of drilling 33 borings to varying depths, ranging from 18 to 114 feet. The purpose of the exploration program was to determine the embankment and outlet works foundation as well as borrow and emergency spillway area soil characteristics. Four initial borings were drilled in the right bank spillway location in the fall of 1959. The remaining borings were completed during 1963. These were located along the embankment centerline, in the outlet works location, in the right bank spillway location, and the alternate spillway location on the left bank. Disturbed jar and moisture samples were taken from these borings at every change of material and at intervals not greater than 5 feet in depth.

The locations of borings in the vicinity of the embankment centerline are shown in plan on plates 3 and 4 and in profile 4-4 presented on plate 6.

5.2 FOUNDATION CONDITIONS. The foundation at the dam site consists of alluvial soils in the flood plain and residual soils in the abutments. Ludlow Formation (bedrock) underlies these surface soils. The alluvium varies in thickness from about 2 to 25 feet and is predominantly fine sand and silty sand with minor amounts of lean and sandy clay, underlain by gravelly sand, clayey gravel and sandy gravel. The residual material mantles the abutments to a thickness of 0 to 5 feet and is generally friable, lean clay and fat clay. A gravel terrace overlain by colluvium is located in the left abutment and underlies a section of the embankment. At the centerline the gravel deposit is 1 to 3 feet thick. The Ludlow Formation is composed of soft to very stiff clays; medium dense to very dense, fine-grained sands; soft to hard, thin-bedded sandstones; soft shales and soft to hard lignites. The Ludlow is described primarily by soil terminology due to the poorly indurated characteristics of the material.

5.3 **FOUNDATION DESIGN.** Positive underseepage control was provided in the valley section from Sta. 29+00 to Sta. 60+00 by a cutoff trench through the alluvial sand and gravel. The bottom of the cutoff trench was raised and lowered in the field, as directed, to establish the trench bottom at the bottom of lignite layer "A" which overlies an impervious clayey sand horizon. The trench was excavated with 1 on 1 side slopes and a 25-foot bottom width, and backfilled with impervious material. A somewhat shallower trench with 1 on 1 side slopes and a 25-foot bottom width extending only through the sandy gravel zone and not to the "A" lignite layer was provided in the left abutment from Station 60+00 to Station 70+00. Since completion of the project, four seeps have developed along the "A" lignite layer in the left bank of the discharge channel near the stilling basin. No seeps have developed along the right bank. Seepage in this area is controlled by the cutoff trench which extends throughout the "A" lignite layer. The cutoff trenches are shown in the embankment profile presented on plate 6.

6. PROPOSED ADDITIONAL WORK TO COMPLETE SEISMIC EVALUATION.

6.1 **FIELD INVESTIGATION.** Standard Penetration Test (SPT) data, necessary to determine the potential of the valley foundation sands and gravels to resist liquefaction during earthquake shaking, are not available. The proposed initial field investigation would consist of seven Standard Penetration Test (SPT) borings drilled along the downstream toe of the dam. Continuous SPT results with split spoon samples would be obtained from each boring for the full 25-foot depth of the valley alluvium. The plan of proposed borings is presented on plates 3 and 4. Geologic sections 5-5 through 12-12, shown in plan view on plates 3 and 4 and in cross section on plates 7 and 8, are considered representative of foundation materials at the site. These cross sections also show the various reaches of the foundation proposed for initial investigation. The final field investigation, if necessary, would consist of companion borings that would generally recover representative, undisturbed sand and silt samples for laboratory cyclic triaxial testing.

6.2 **LABORATORY ANALYSIS.** Laboratory classification tests would be performed on all jar samples and undisturbed samples obtained from the exploratory borings. Mechanical Analysis Tests to the D_{10} grain size would be performed on all samples having a Unified Soil Classification of poorly graded Sand or Gravel (SP), well graded Sand or Gravel (SW), Silty Sand (SM-SP or SM), and Silt (ML). Cyclic Triaxial Tests and relative Density Tests would be performed on representative specimens of these nonplastic (cohesionless) materials. Atterberg Limits Tests, Moisture Tests, and Gradation Tests would be performed on all clayey materials to determine vulnerability to severe strength loss as a result of earthquake shaking. These soils are considered to have the following characteristics:

Percent finer than 0.005 mm sieve	<15%
Liquid Limit	<35
Water Content	>0.9 x Liquid Limit

If soils with these characteristics plot above the A-line on the plasticity chart, their cyclic loading characteristics would be determined by Cyclic Triaxial Tests.

6.3 <u>EVALUATION OF DATA TO DETERMINE FOUNDATION LIQUEFACTION POTENTIAL</u>. A procedure suggested by Seed 2/ would be used to evaluate foundation liquefaction potential. This procedure compares the cyclic shear strength resisting liquefaction, based on corrected SPT data, with the average shear stress induced by the postulated earthquake. These corrected blow counts would be increased by 7.5, as appropriate, using procedures developed in a recent study by Seed and Idriss 3/, which verified that certain silts and silty sands are less vulnerable to liquefaction than sands with similar corrected SPT resistance values. The foundation soil layers would be considered seismically stable when the computed safety factor is greater than 1.5, using this procedure.

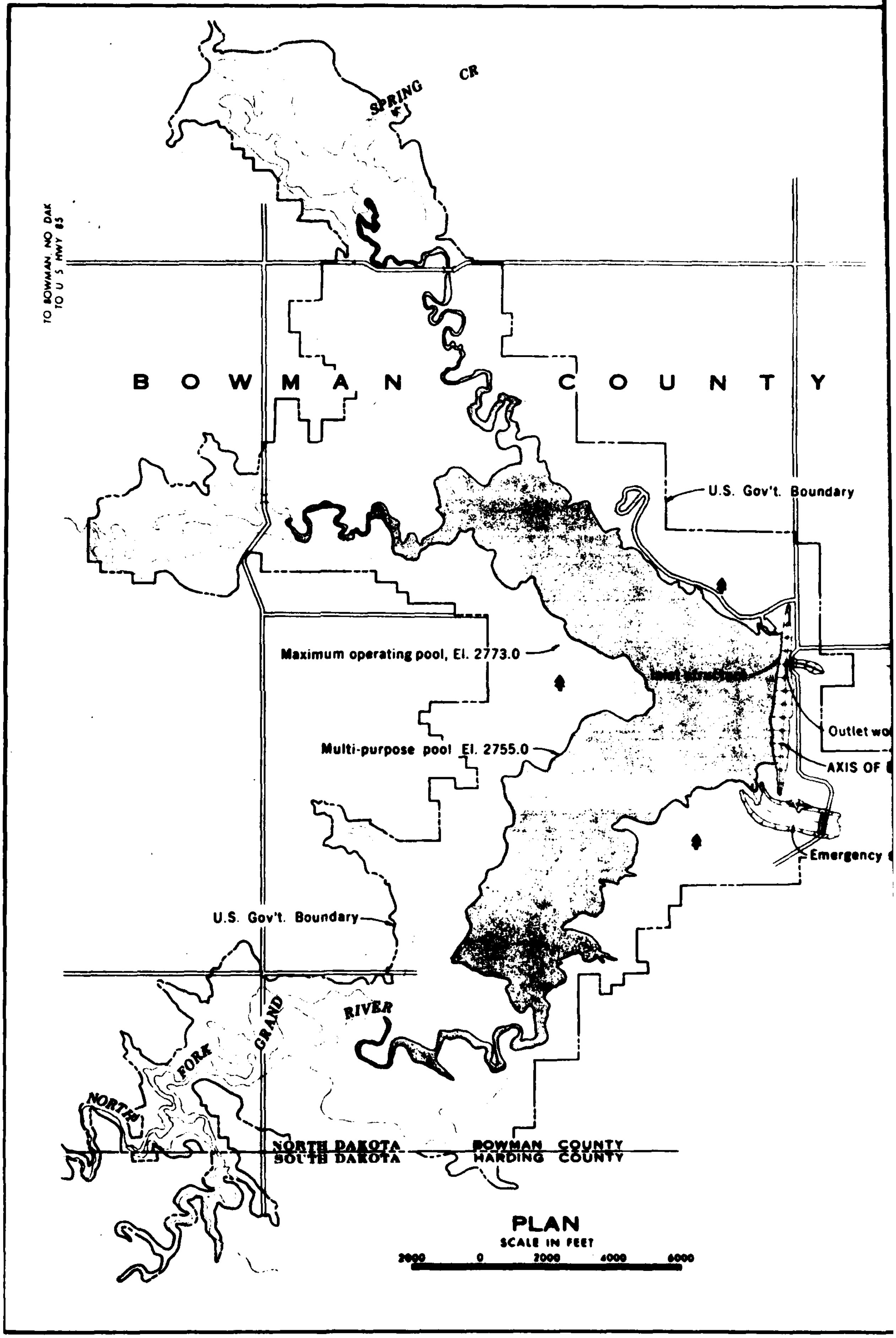
2/ Seed, H. B., "Soil Liquefaction and Cyclic Mobility Evaluation for Level Ground During Earthquakes," Journal of the Geotechnical Engineering Division, ASCE Vol. 105, No. GT2, Feb. 1979, pp. 201-255.

3/ Seed, H. B., Idriss, I. M., "Evaluation of Liquefaction Potential of Sand Deposits Based on Observations of Performance in Previous Earthquakes," In-Situ Testing to Evaluate Liquefaction Susceptibility, ASCE Conference, St. Louis, Oct. 26-31, 1981 (Preprint).

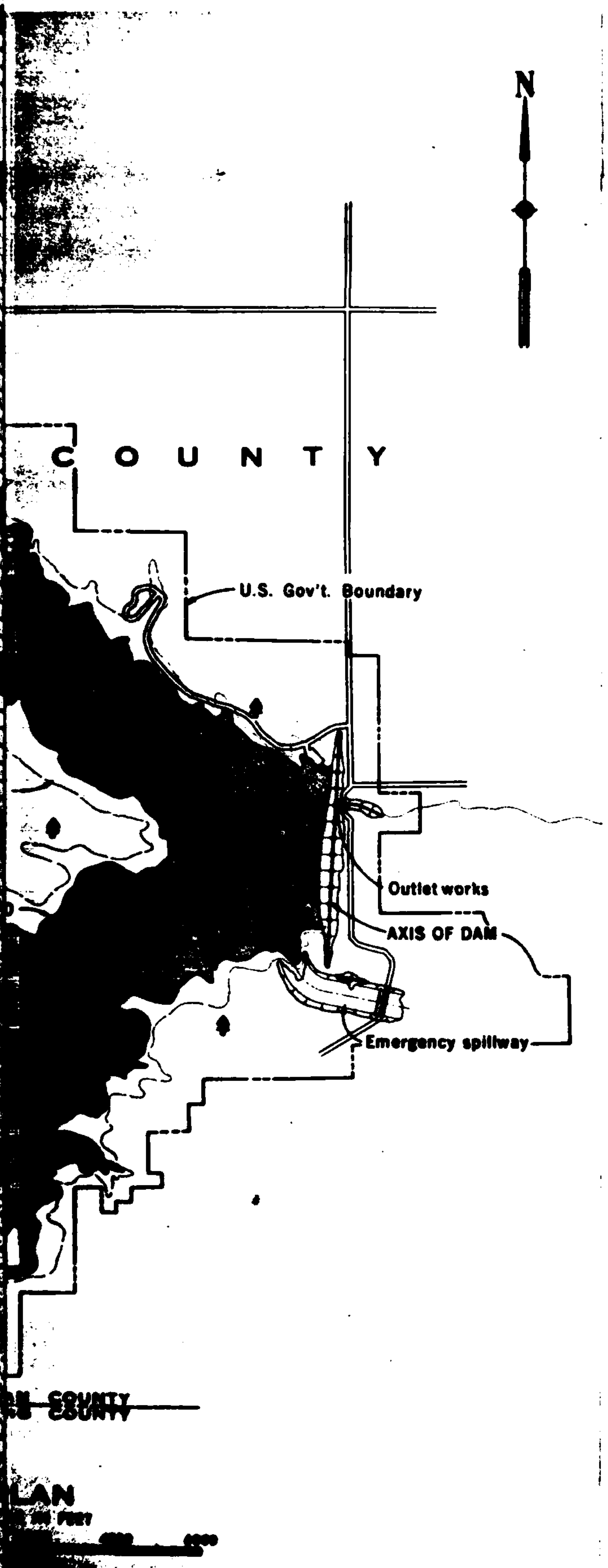
6.4 COST ESTIMATE FOR INITIAL SEISMIC EVALUATION REPORT.

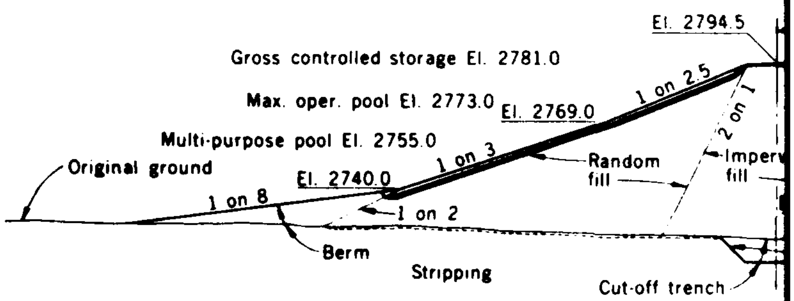
Drilling Costs	$ 33,000
Laboratory Costs	10,000
Office and Reproduction Costs	15,000
Total Cost	$ 58,000

7. RECOMMENDATION. Presently $50,000 is scheduled during FY 84 for preparation of the Seismic Evaluation Report for the Bowman-Haley Dam project. It is recommended that this reconnaissance report be approved as a basis for preparation of the Initial Report.

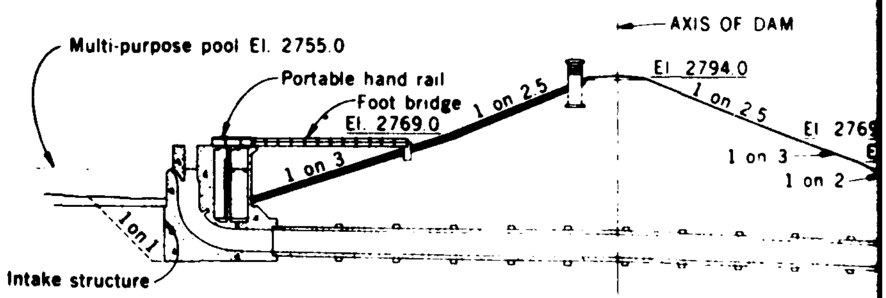

SPRING CR
TO BOWMAN, NO DAK
TO U S HWY 85
BOWMAN COUNTY
U.S. Gov't. Boundary
Maximum operating pool, El. 2773.0
Multi-purpose pool El. 2755.0
U.S. Gov't. Boundary
NORTH FORK GRAND RIVER
NORTH DAKOTA
SOUTH DAKOTA
BOWMAN COUNTY
HARDING COUNTY
SCALE IN FEET
2000 0 2000 4000 6000

PLAN



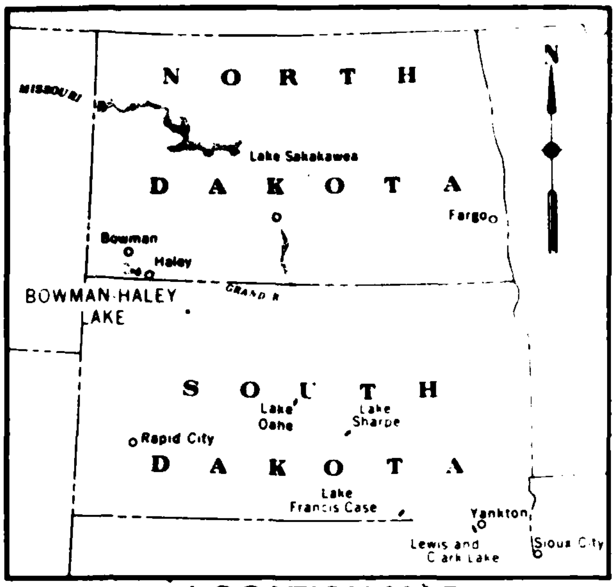


EMBANKMENT SE

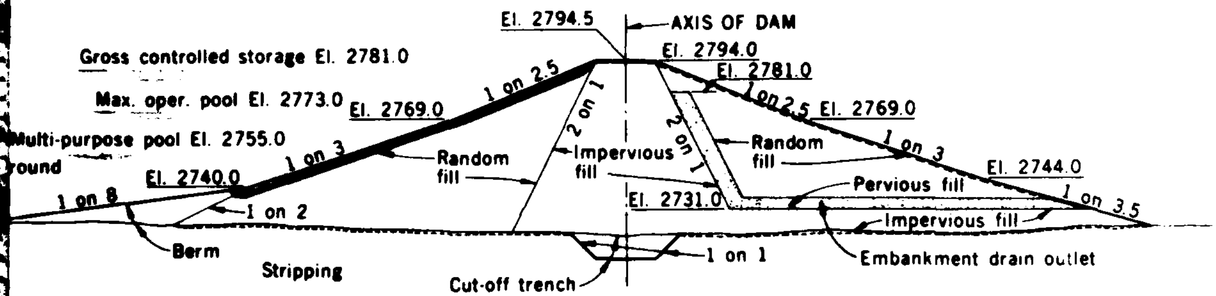


OUTLET WORKS PR

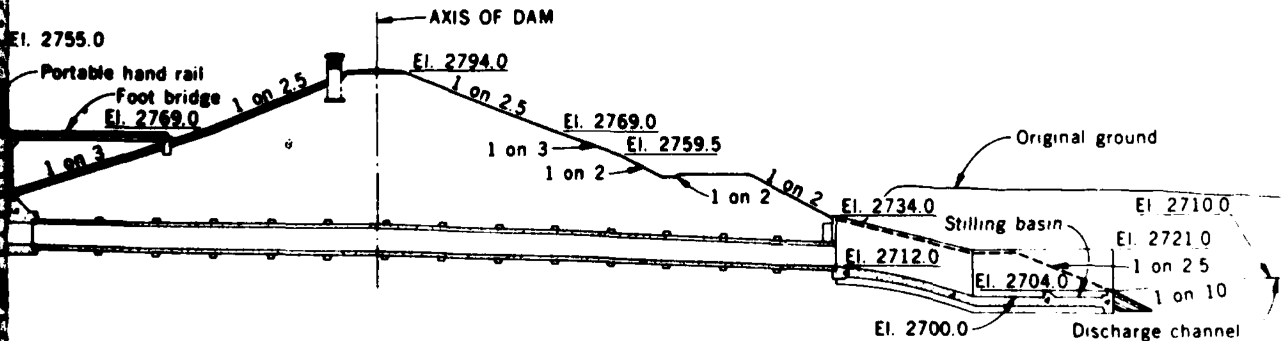
VICINI



LOCATION MAP



EMBANKMENT SECTION

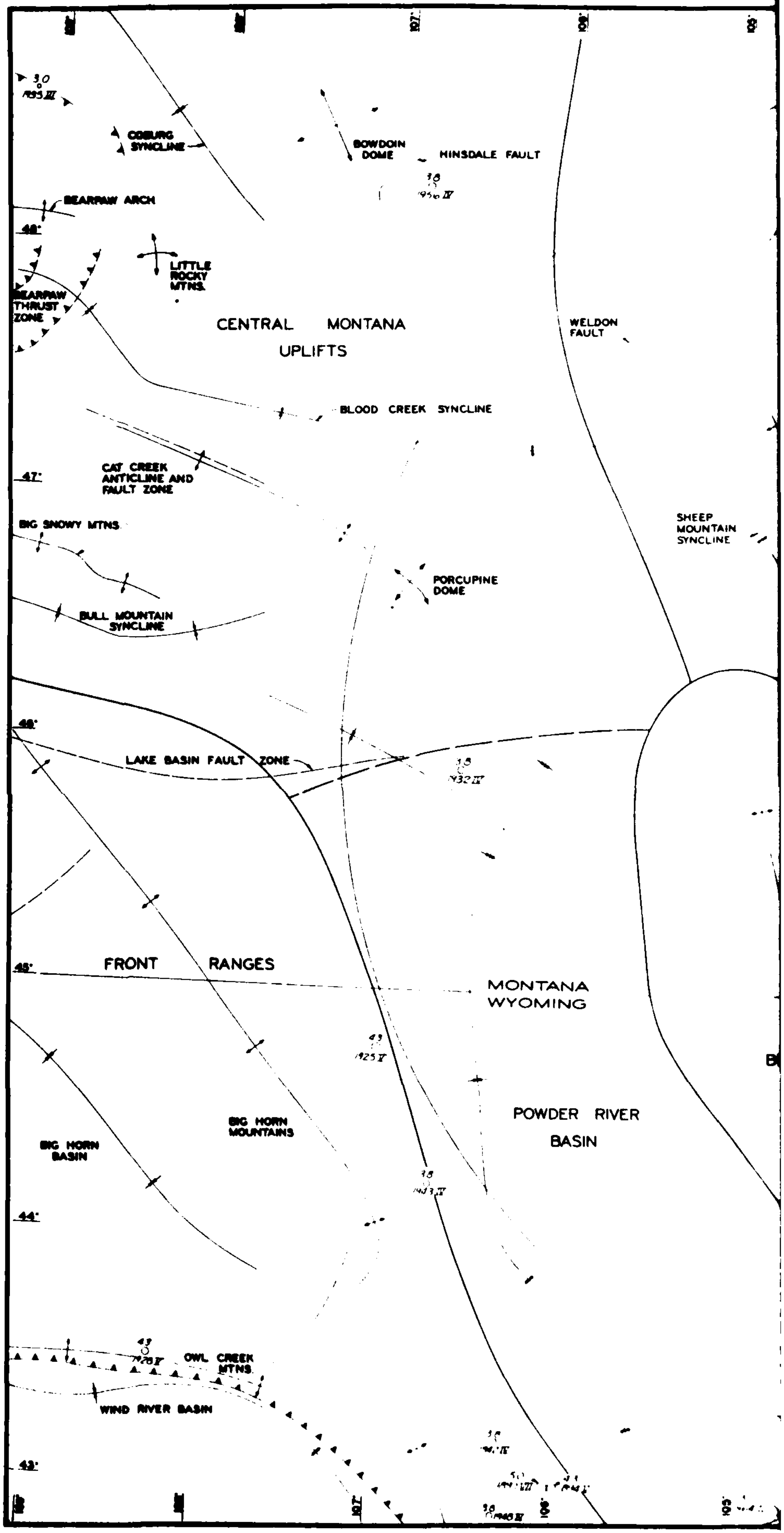


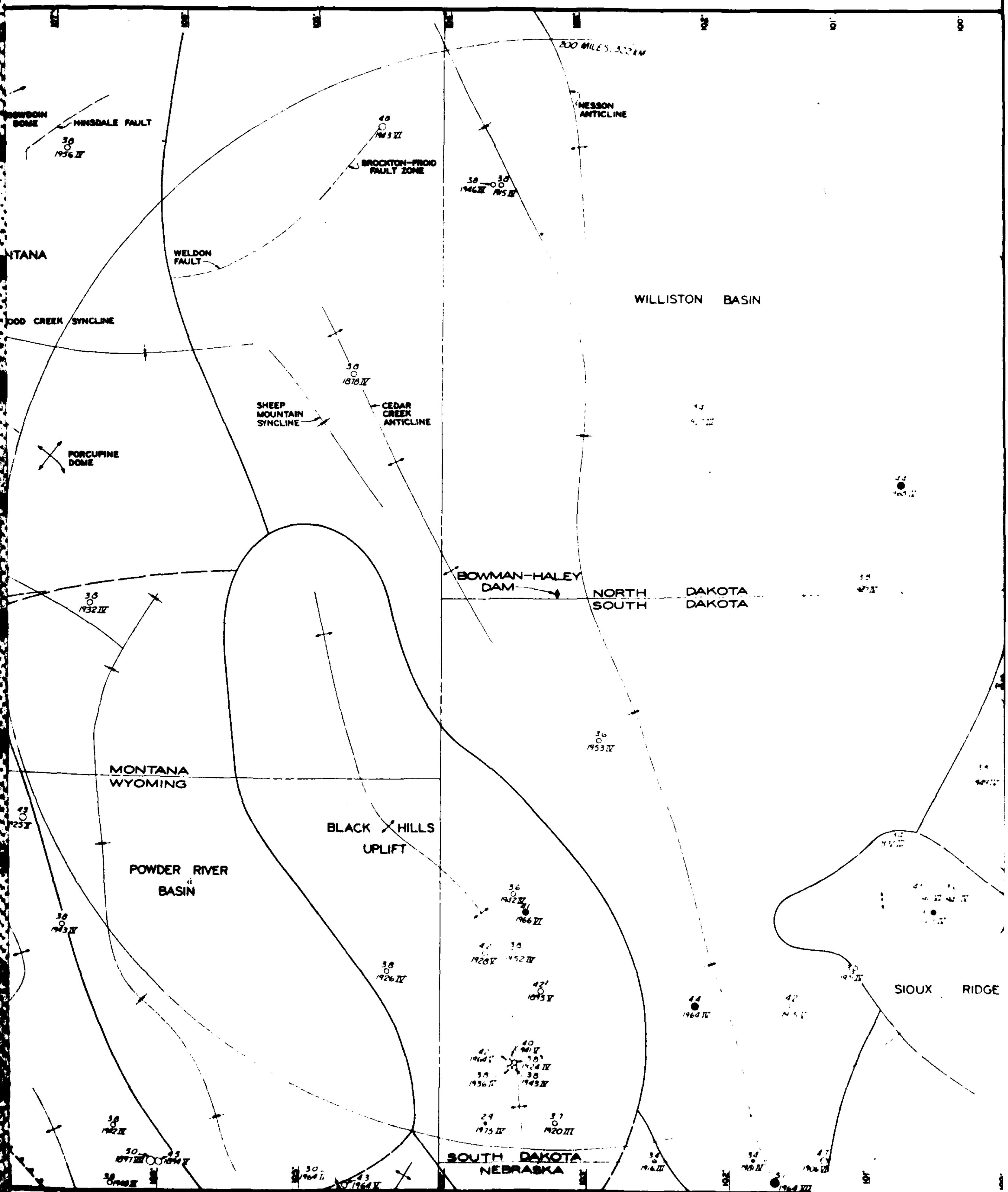
OUTLET WORKS PROFILE

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
VICINITY MAP, LOCATION MAP AND TYPICAL SECTIONS

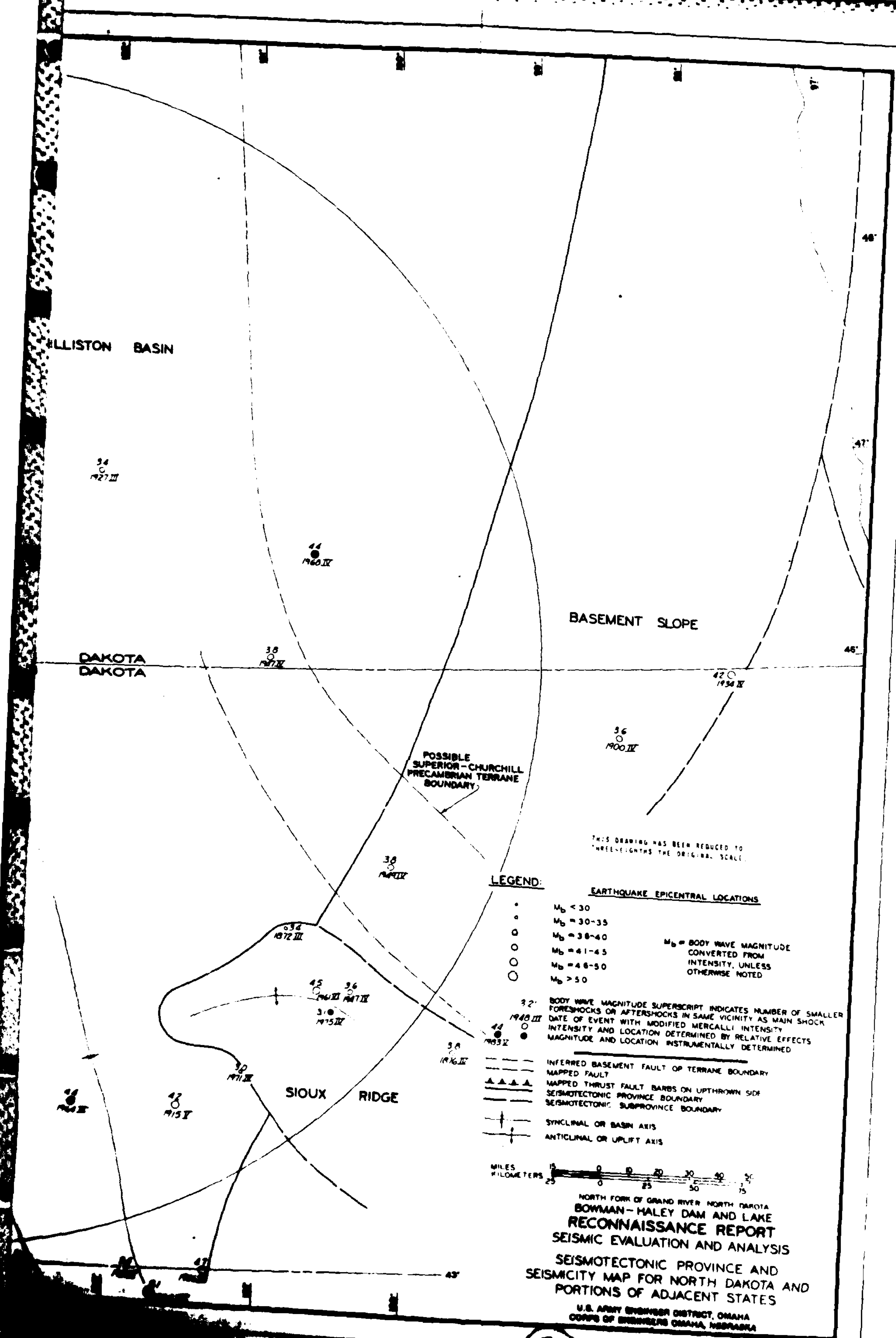
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

PLATE I


COBURG SYNCLINE
BOWDOIN DOME
HINSDALE FAULT
BEARPAW ARCH
48°
LITTLE ROCKY MTNS.
BEARPAW THRUST ZONE
CENTRAL MONTANA UPLIFTS
WELDON FAULT
BLOOD CREEK SYNCLINE
CAT CREEK ANTICLINE AND FAULT ZONE
47°
BIG SNOWY MTNS.
SHEEP MOUNTAIN SYNCLINE
PORCUPINE DOME
BULL MOUNTAIN SYNCLINE
46°
LAKE BASIN FAULT ZONE
45°
FRONT RANGES
MONTANA
WYOMING
POWDER RIVER BASIN
BIG HORN MOUNTAINS
BIG HORN BASIN
44°
OWL CREEK MTNS.
WIND RIVER BASIN
43°
107
106
105

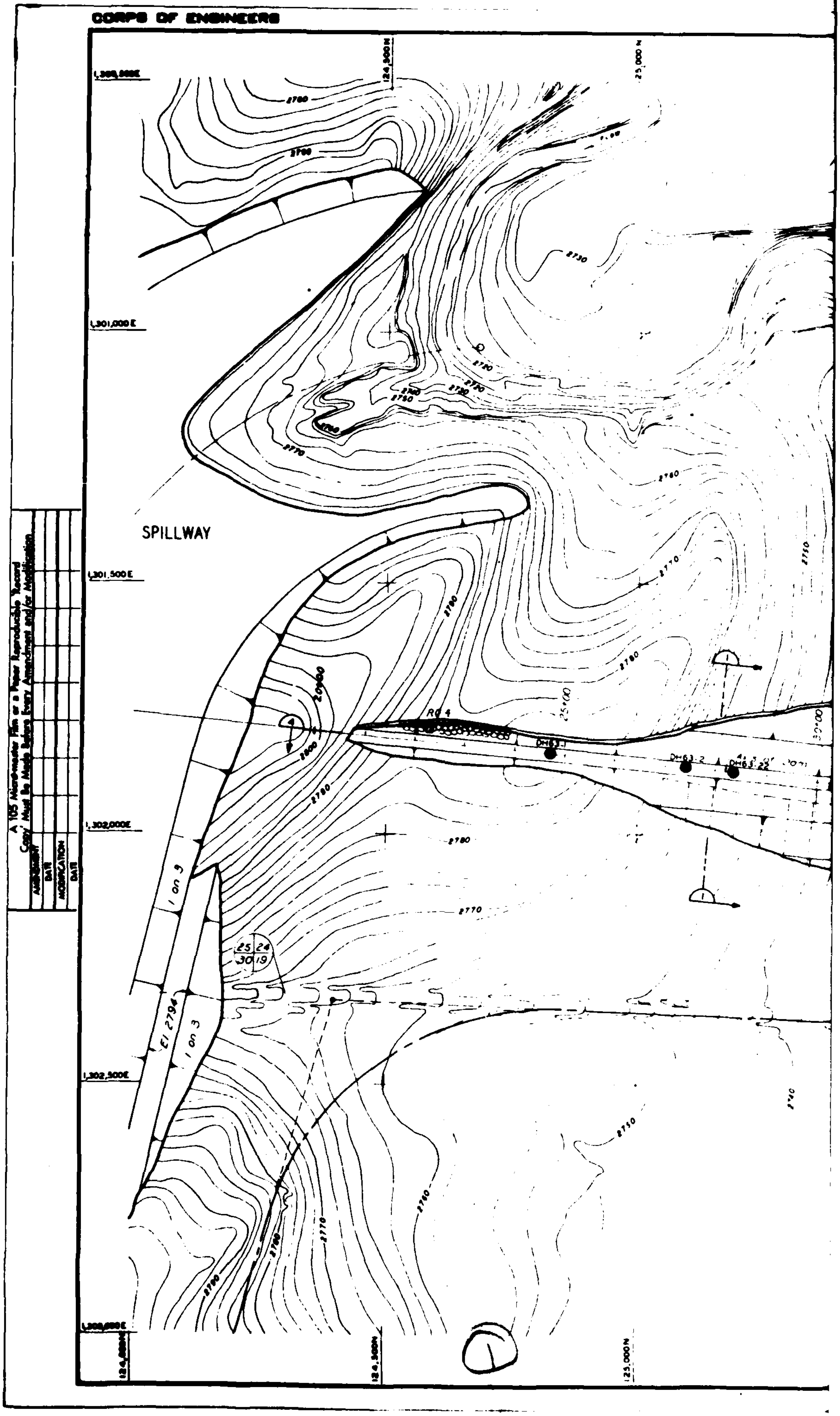


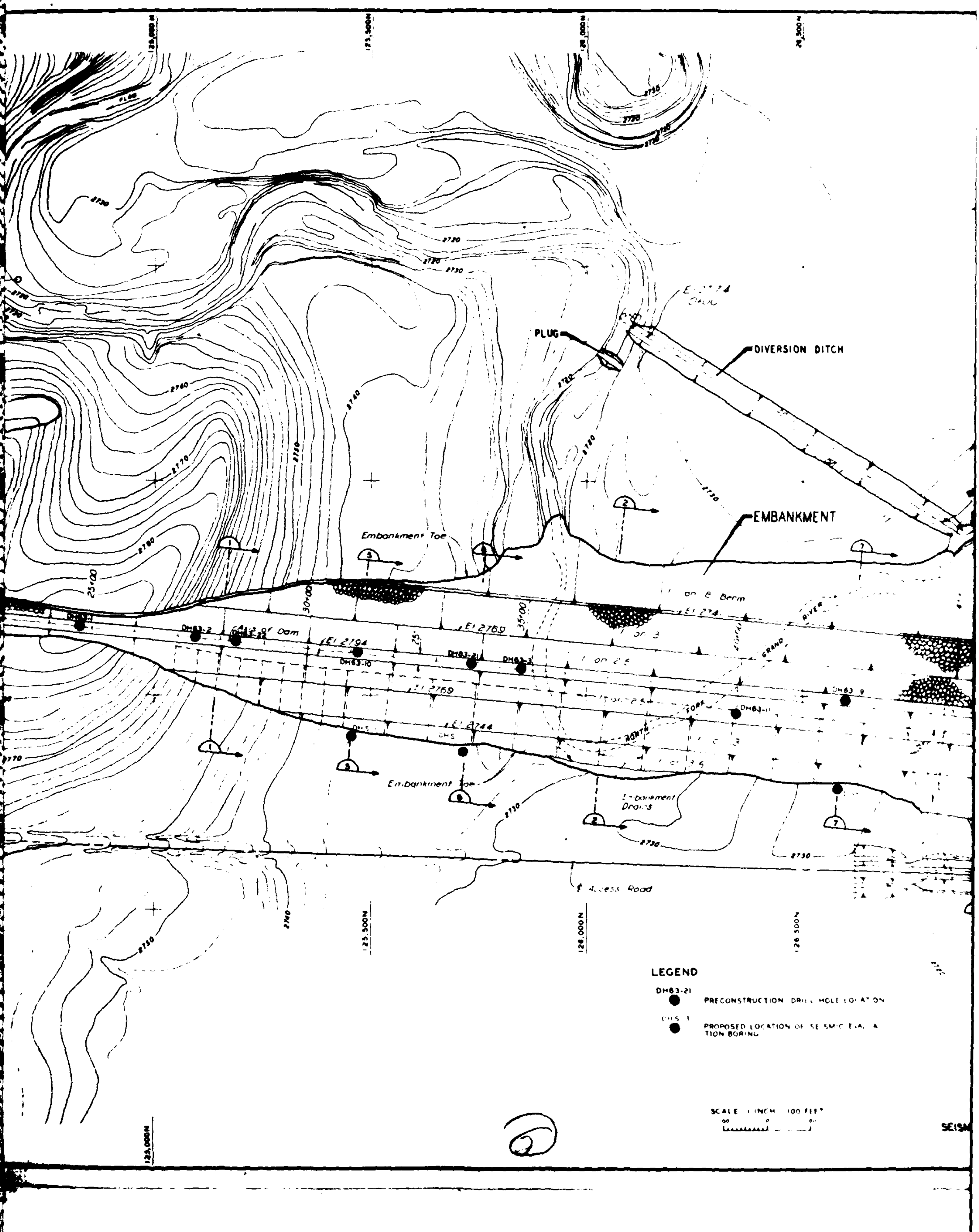
800 MILES, 322 KM
NESSON ANTICLINE
HINSDALE FAULT
BROCKTON-FROID FAULT ZONE
WELDON FAULT
NTANA
WILLISTON BASIN
OOD CREEK SYNCLINE
SHEEP MOUNTAIN SYNCLINE
CEDAR CREEK ANTICLINE
PORCUPINE DOME
BOWMAN-HALEY DAM
NORTH DAKOTA
SOUTH DAKOTA
MONTANA
WYOMING
BLACK HILLS UPLIFT
POWDER RIVER BASIN
SIOUX RIDGE
SOUTH DAKOTA
NEBRASKA


WILLISTON BASIN
BASEMENT SLOPE
DAKOTA
DAKOTA
POSSIBLE SUPERIOR-CHURCHILL PRECAMBRIAN TERRANE BOUNDARY
SIOUX RIDGE
46°
47°
45°
43°
THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.
LEGEND:
EARTHQUAKE EPICENTRAL LOCATIONS
Mb < 3.0
Mb = 3.0-3.5
Mb = 3.6-4.0
Mb = 4.1-4.5
Mb = 4.6-5.0
Mb > 5.0
Mb = BODY WAVE MAGNITUDE CONVERTED FROM INTENSITY, UNLESS OTHERWISE NOTED
BODY WAVE MAGNITUDE SUPERSCRIPT INDICATES NUMBER OF SMALLER FORESHOCKS OR AFTERSHOCKS IN SAME VICINITY AS MAIN SHOCK
DATE OF EVENT WITH MODIFIED MERCALLI INTENSITY
INTENSITY AND LOCATION DETERMINED BY RELATIVE EFFECTS
MAGNITUDE AND LOCATION INSTRUMENTALLY DETERMINED
INFERRED BASEMENT FAULT OR TERRANE BOUNDARY
MAPPED FAULT
MAPPED THRUST FAULT BARBS ON UPTHROWN SIDE
SEISMOTECTONIC PROVINCE BOUNDARY
SEISMOTECTONIC SUBPROVINCE BOUNDARY
SYNCLINAL OR BASIN AXIS
ANTICLINAL OR UPLIFT AXIS
MILES
KILOMETERS
NORTH FORK OF GRAND RIVER NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
SEISMOTECTONIC PROVINCE AND SEISMICITY MAP FOR NORTH DAKOTA AND PORTIONS OF ADJACENT STATES
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

3

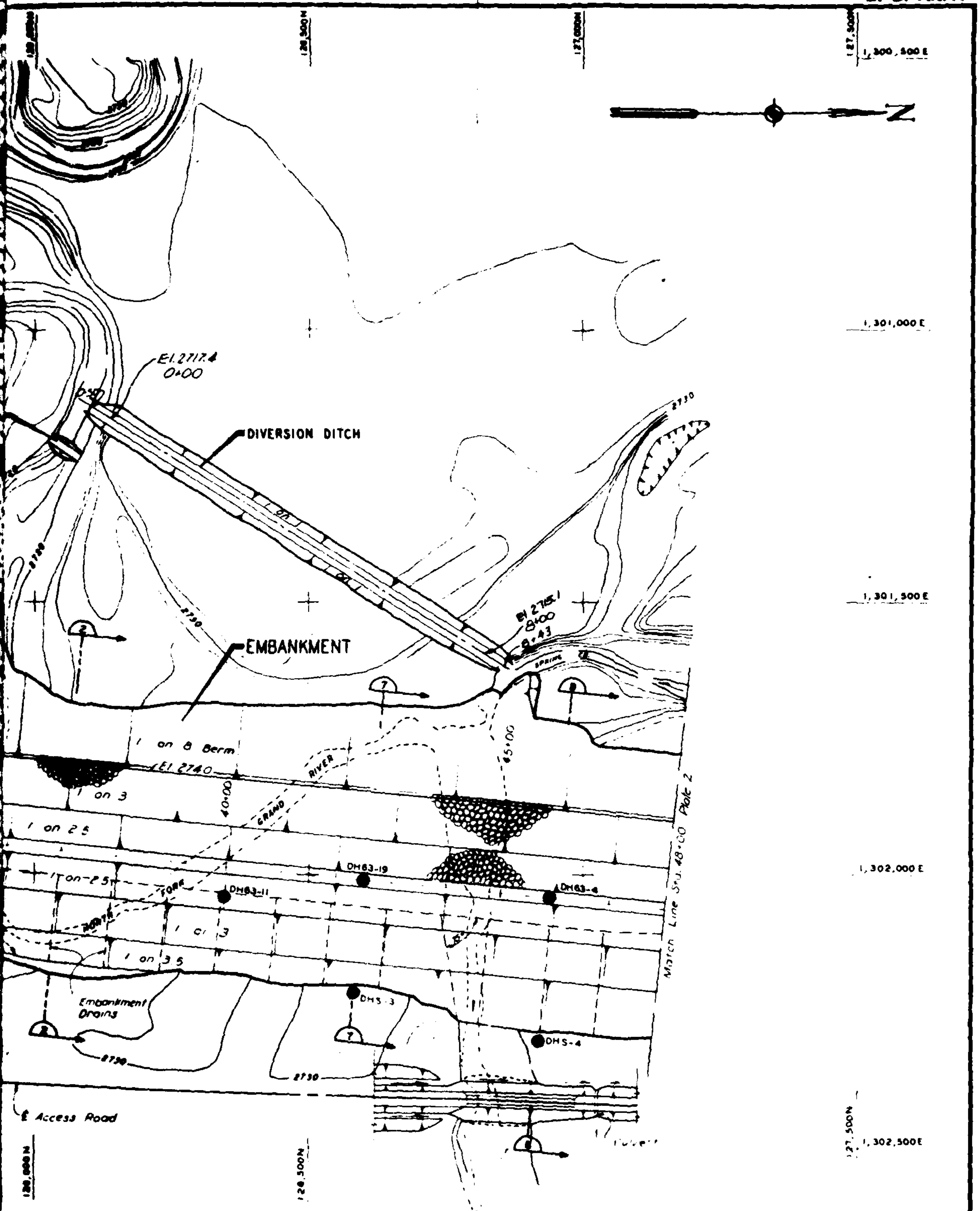
PLATE 2


CORPS OF ENGINEERS
SPILLWAY
1,300,500E
1,301,000E
1,301,500E
1,302,000E
1,302,500E
1,303,000E
124,500N
125,000N
RC 4
DH63-1
DH63-2
1 on 3
1 on 3
El 2794
2780
2770
2760
2750
A 105 Microfilm Film or a Paper Reproducible Record Copy Must Be Made Before Every Amendment and/or Modification
AMENDMENT
DATE
MODIFICATION
DATE



125,000 N
125,500 N
126,000 N
126,500 N
PLUG
DIVERSION DITCH
EMBANKMENT
Embankment Toe
Embankment Drains
Access Road
GRAND RIVER
NORTH FORK
El 2769
El 2794
El 2744
DH83-2
DH83-10
DH83-21
DH83-3
DH83-11
2730
2740
2750
2760
2770
2720
LEGEND
DH83-21
PRECONSTRUCTION DRILL HOLE LOCATION
PROPOSED LOCATION OF SEISMIC EVALUATION BORING
SCALE 1 INCH = 100 FEET
SEISM

U. S. ARMY



LEGEND

DH63-21 ● PRECONSTRUCTION DRILL HOLE LOCATION

DHS-3 ● PROPOSED LOCATION OF SEISMIC EVALUATION BORING

SCALE 1 INCH = 100 FEET

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
EMBANKMENT PLAN WITH ORIGINAL AND PROPOSED
SEISMIC EVALUATION FOUNDATION EXPLORATIONS (SHEET 1 OF 2)

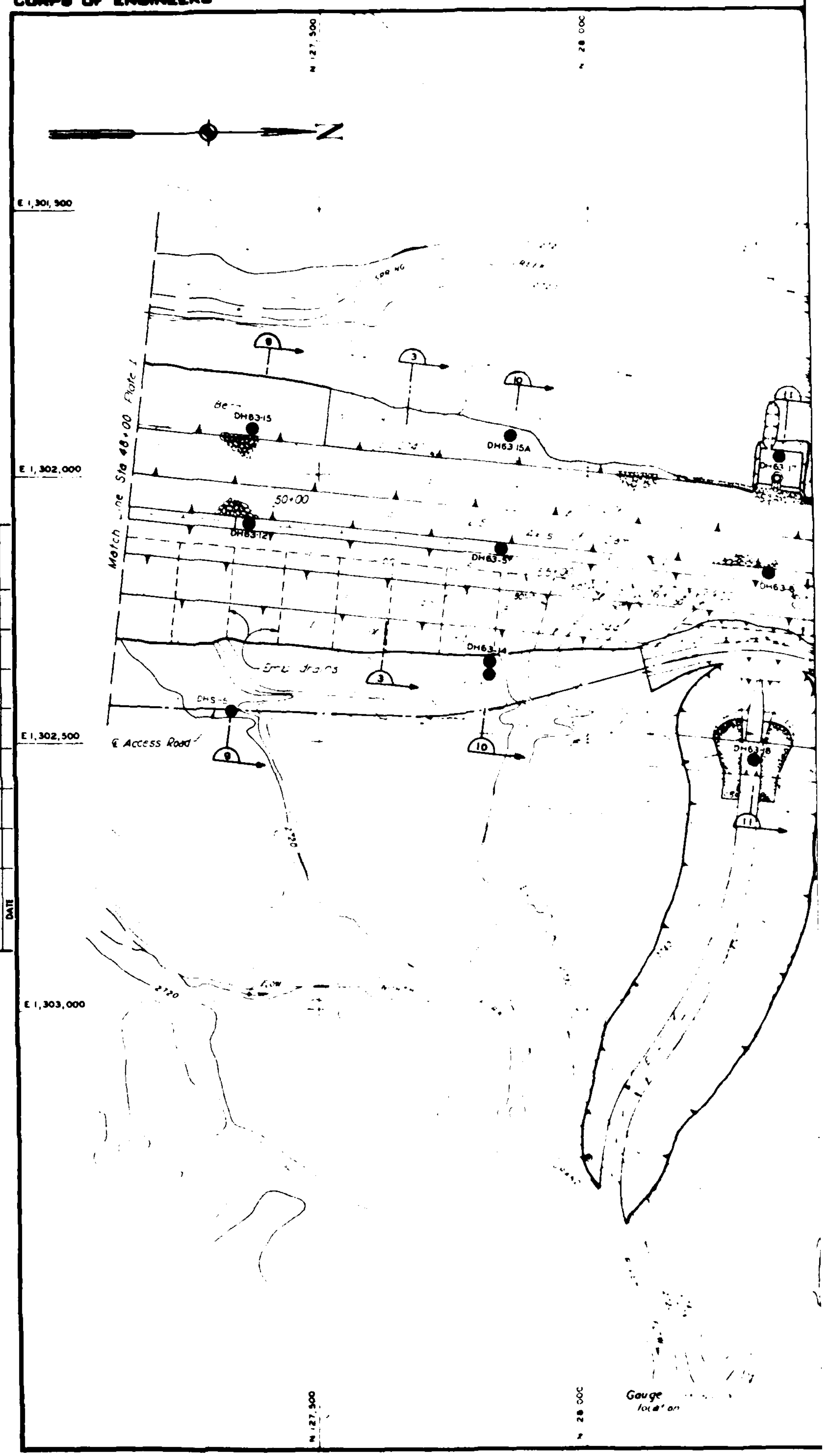
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

PLATE 3

CORPS OF ENGINEERS

A 105 Micro-master Film or a Paper Reproducible Record Copy Must Be Made Before Every Amendment and/or Modification

AMENDMENT	DATE	MODIFICATION	DATE



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N 128,000
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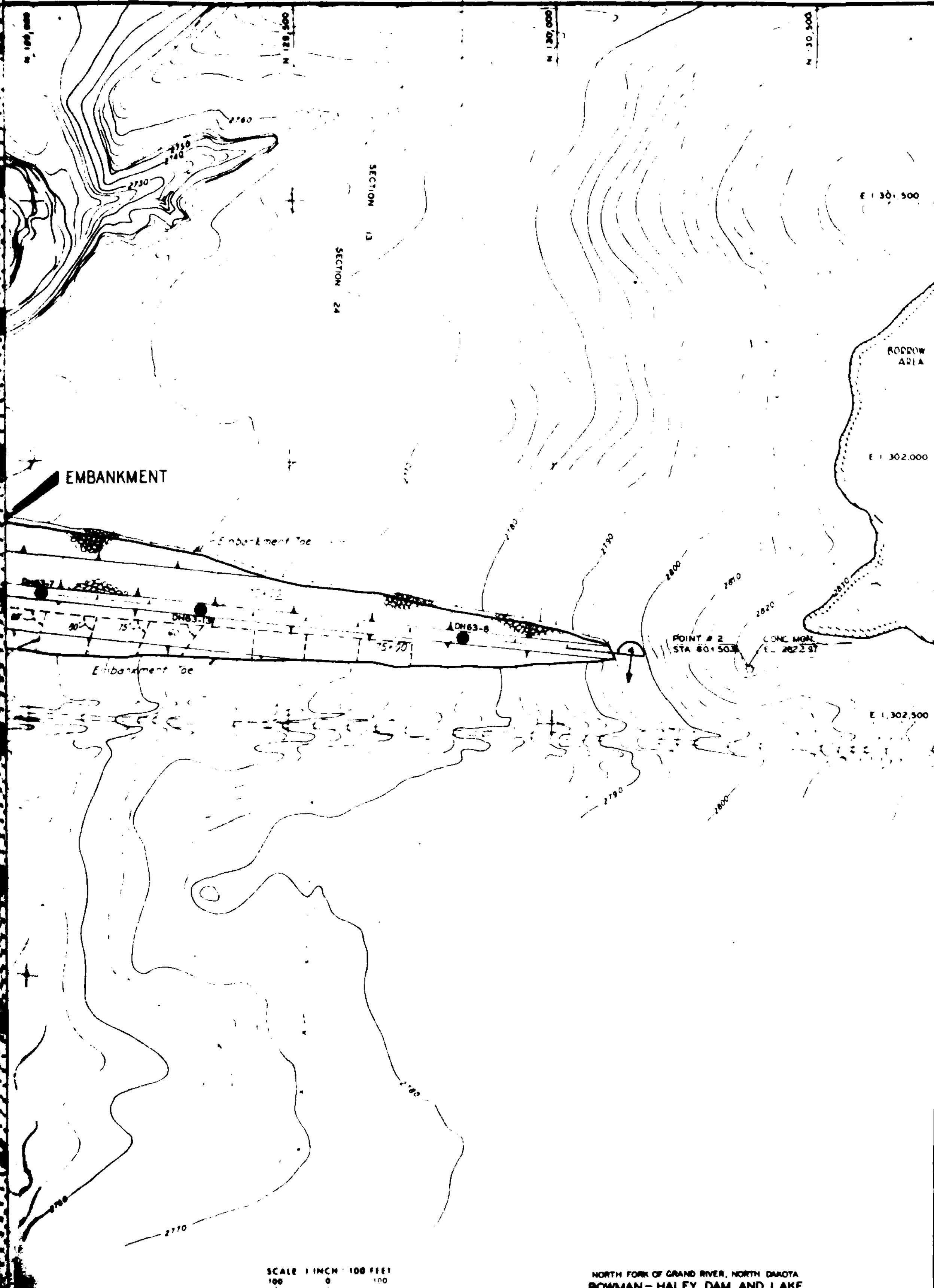
N
SPRING
CREEK
2720
2730
El 2740
DH63-15A
DH63-17
EMBANKMENT
Axis of Dam
DH63-5
DH63-6
DH63-20
DH63-7
DH63-14
DH63-18
55+00
60+00
65+00
El 2769
El 2744
El 2794
East Rd Approach
NORTH
FORK
GRAND
2740
2760
Gauge
location
SCALE 1 INCH = 100 FEET



NORTH FORK OF GRAND RIVER, NORTH DAKOTA

BOWMAN - HALEY DAM AND LAKE

RECONNAISSANCE REPORT

SEISMIC EVALUATION AND ANALYSIS

EMBANKMENT PLAN WITH ORIGINAL AND PROPOSED

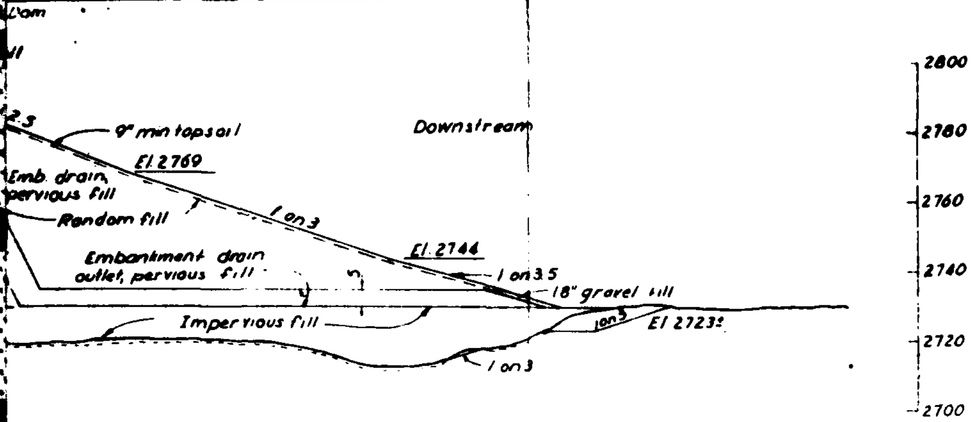
SEISMIC EVALUATION FOUNDATION EXPLORATIONS (SHEET 2 OF 2)

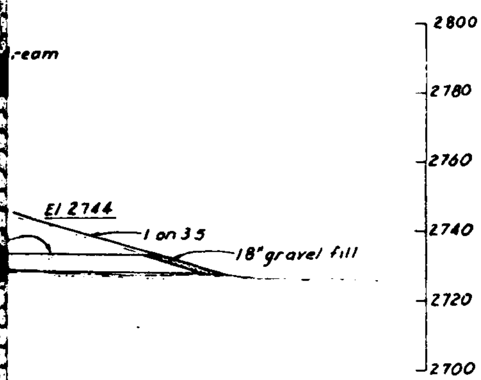
U.S. ARMY ENGINEER DISTRICT, OMAHA

CORPS OF ENGINEERS OMAHA, NEBRASKA

PLATE 4

(3)



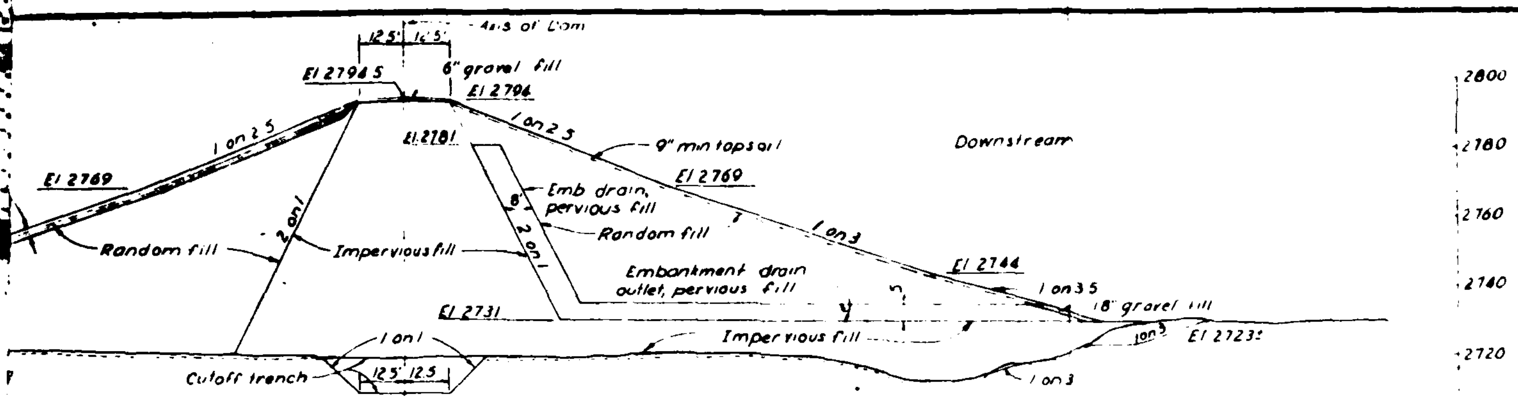


THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE.

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

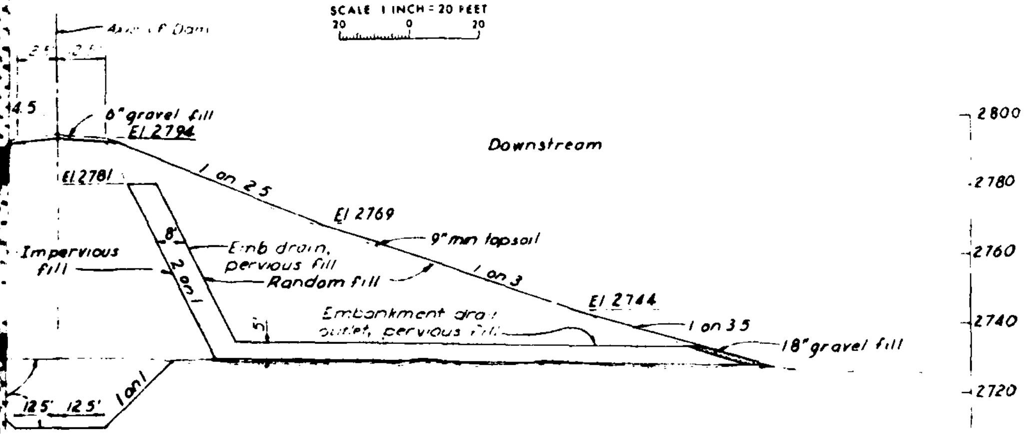
EMBANKMENT SECTIONS 1-1, 2-2 AND 3-3

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA



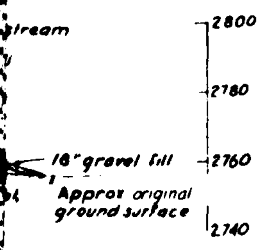
EMBANKMENT SECTION 1-1

SCALE: 1 INCH = 20 FEET
20 0 20



...ENT SECTION 2-2

...E 1 INCH = 20 FEET
0 20



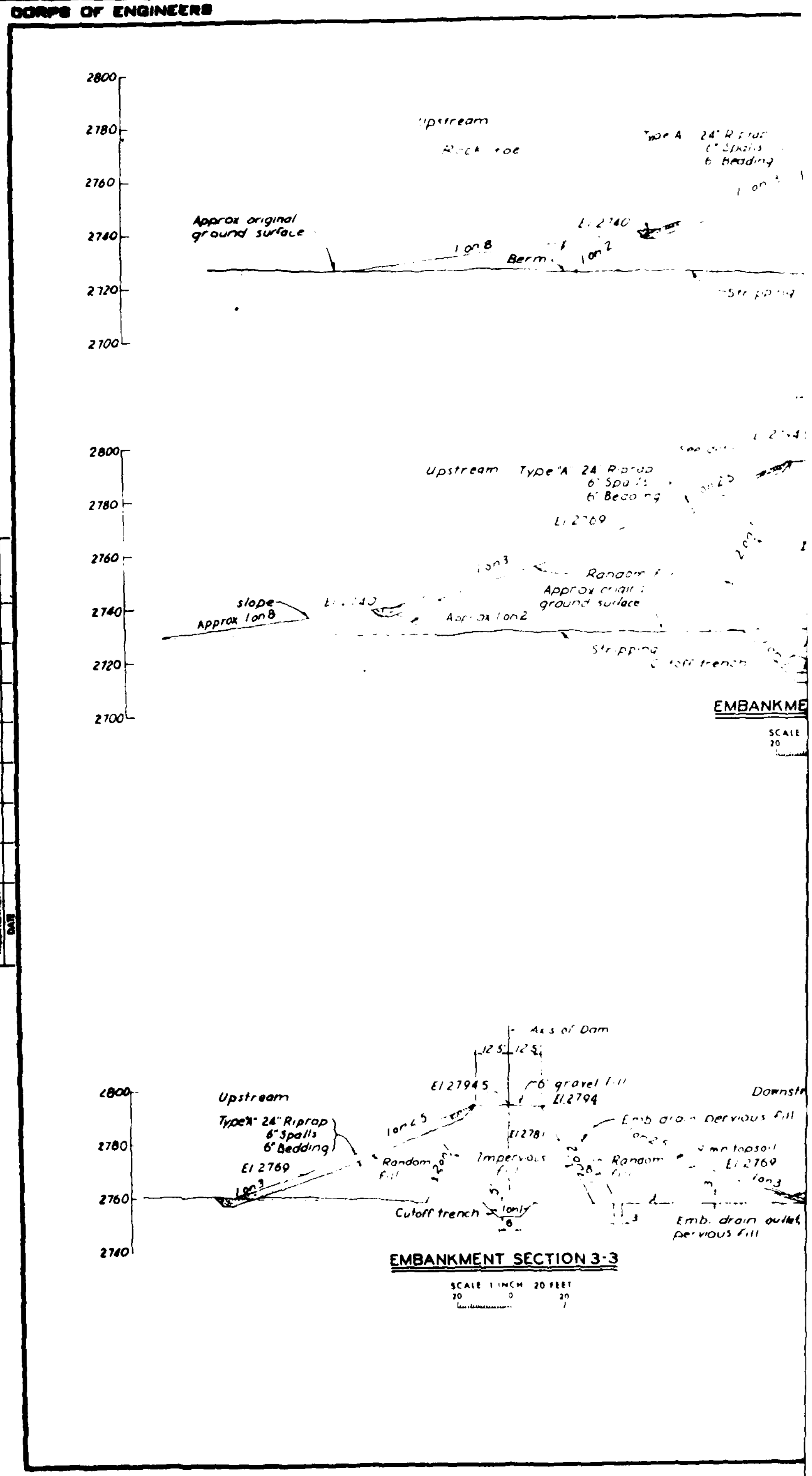
THIS DRAWING HAS BEEN REDUCED TO THREE-EIGHTHS THE ORIGINAL SCALE

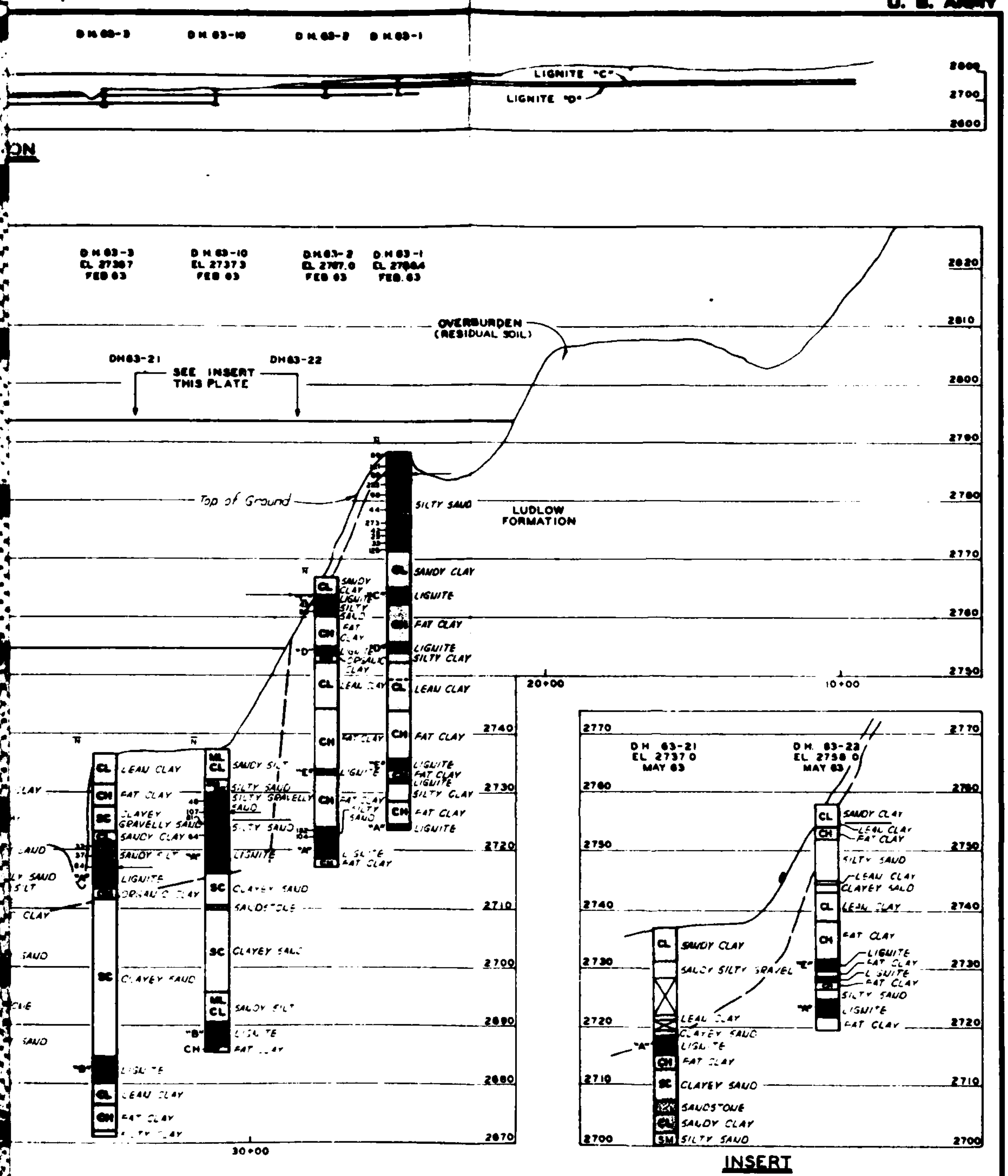
NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

EMBANKMENT SECTIONS 1-1, 2-2 AND 3-3

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

CORPS OF ENGINEERS





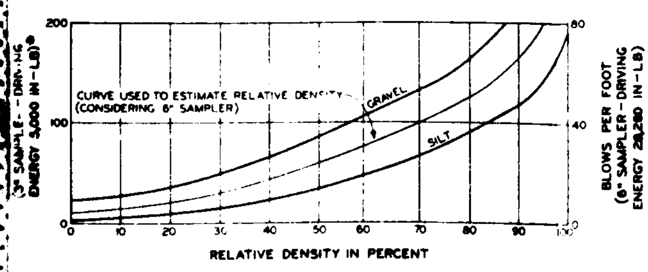


FIG 1 - RELATIONS BETWEEN DRIVING RESISTANCE OF SAMPLER N BLOWS PER FOOT AND RELATIVE DENSITY FOR GRANULAR SOILS

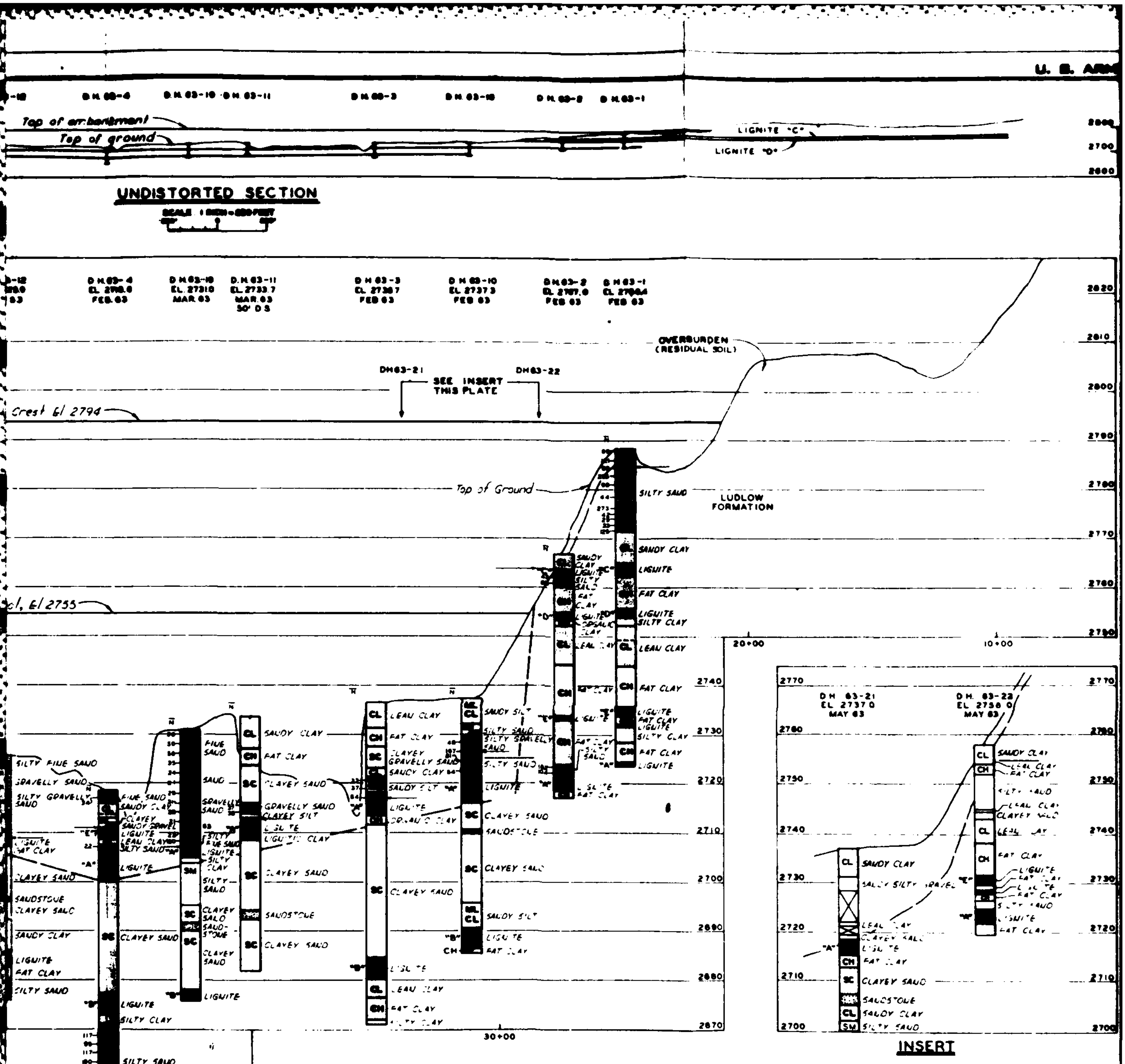
● REF BURMISTER, D.M., 1940 - "PRACTICAL METHODS FOR THE CLASSIFICATION OF SOILS," PURDUE CSMFE, P 129

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

GEOLOGIC PROFILE ALONG EMBANKMENT ℄, SECTION 4-4

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

PLATE 8



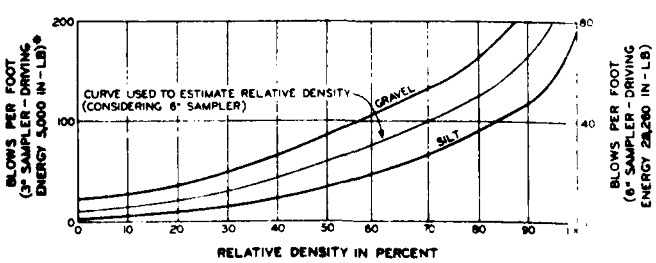


FIG 1 - RELATIONS BETWEEN DRIVING RESISTANCE OF SAMPLER IN BLOWS PER FOOT AND RELATIVE DENSITY FOR GRANULAR SOILS

* REF BURMISTER, D.M., 1940 - "PRACTICAL METHODS FOR THE CLASSIFICATION OF SOILS," PURDUE ISMFE, P 129

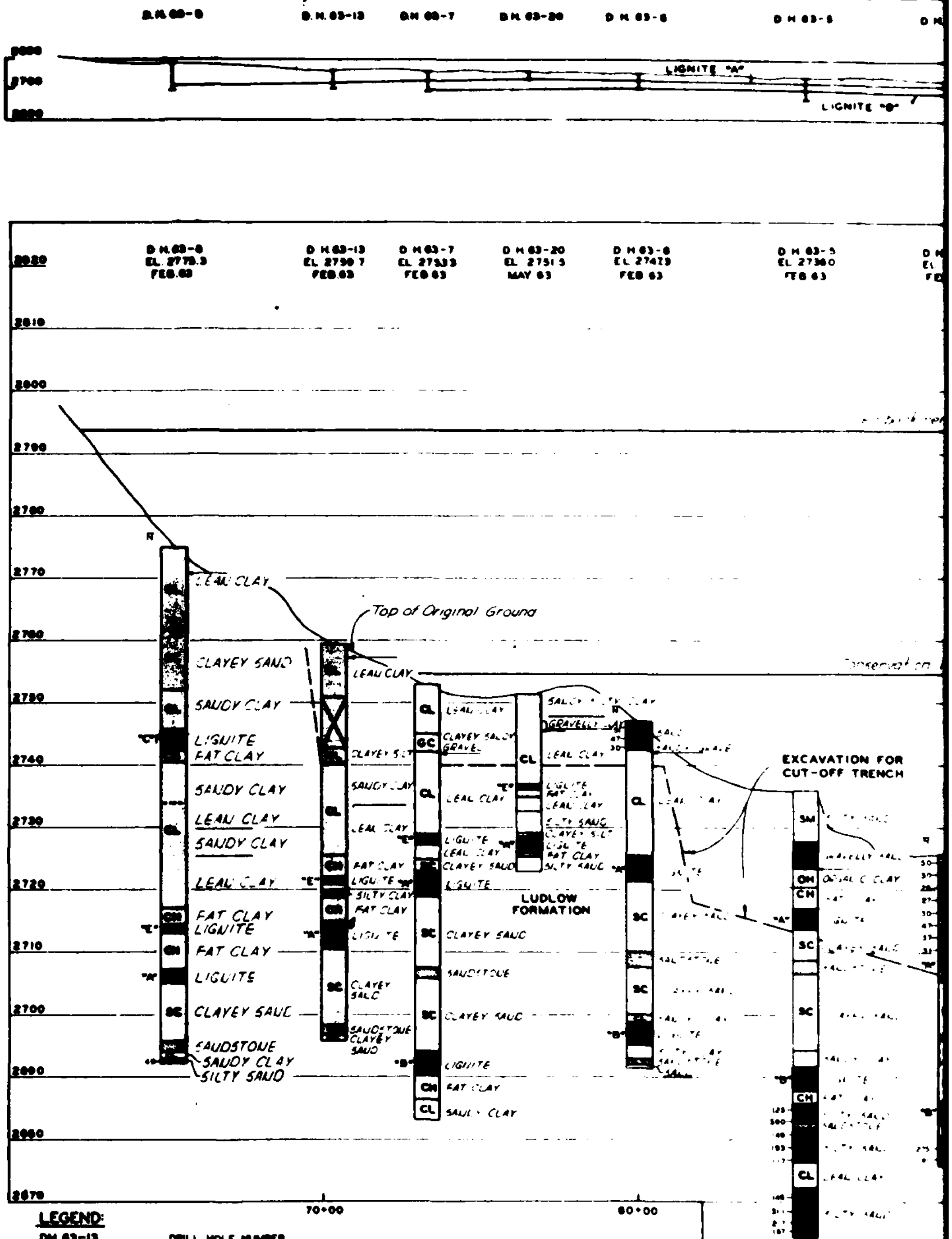
...ocene Age. As encountered in ...the area the Ludlow was described ...poorly indurated characteristic. ...sed when applicable.

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN - HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS

GEOLOGIC PROFILE ALONG EMBANKMENT ℄, SECTION 4-4

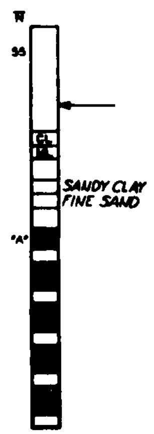
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

CORPS OF ENGINEERS



LEGEND:

DH 63-13	DRILL HOLE NUMBER
EL. 2750.7	ELEVATION AT TOP OF GROUND
FEB 63	DATE OF BORING



PENETRATION TEST RESULTS - THE NUMBER OF BLOWS REQUIRED TO DRIVE A 6 INCH SAMPLE BARREL ONE FOOT USING A 942 POUND WEIGHT FALLING 30 INCHES

TOP OF LUDLOW FORMATION

SOIL CLASSIFICATION BASED ON ATTERBERG LIMITS MECHANICAL ANALYSIS AND VISUAL INSPECTION

SOIL CLASSIFICATION BASED ON VISUAL INSPECTION IN THE FIELD

THE PRINCIPAL LIGNITES USED FOR CORRELATION ARE INDICATED BY THE LETTERS "A", "B", ETC

EST'D FROM FIG I RELATIVE DENSITY 0-48% (BLOWS/FT 0-25)

EST'D FROM FIG I RELATIVE DENSITY 49%-73% (BLOWS/FT 26-46)

EST'D FROM FIG I RELATIVE DENSITY 73%+ (BLOWS/FT 46+)

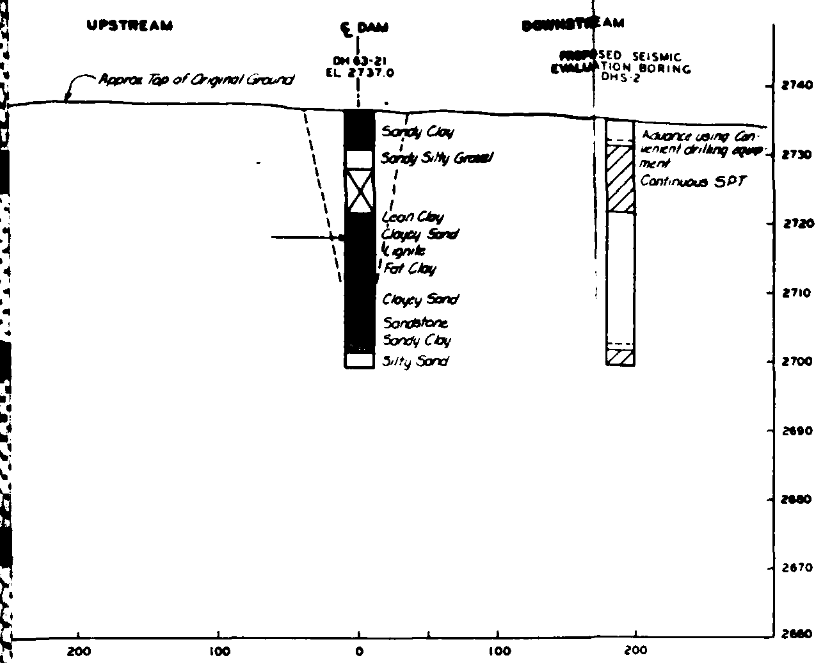
SOIL OR BEDROCK HAVING CLASSIFICATION OF LEAN CLAY (CL), FAT CLAY (CH), CLAYEY SAND (SC) OR CLAYEY GRAVEL (GC)

EMBANKMENT SE

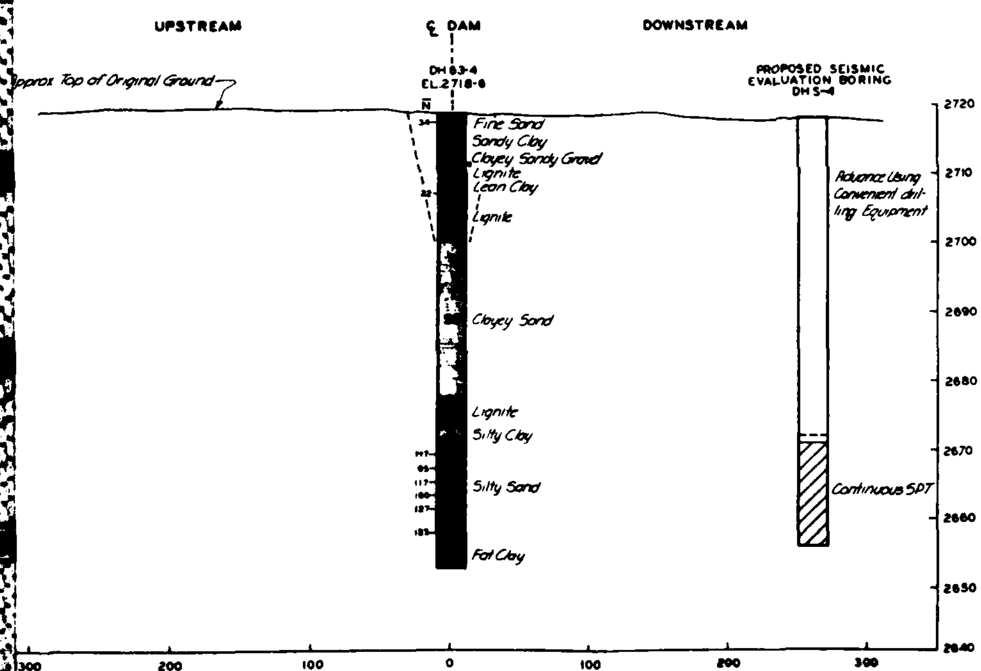
SCALE

GENERAL NOTES

Bedrock is the Ludlow formation o the borings and observed in outcrop primarily by soil terminology, due to of the material. Rock terminology w



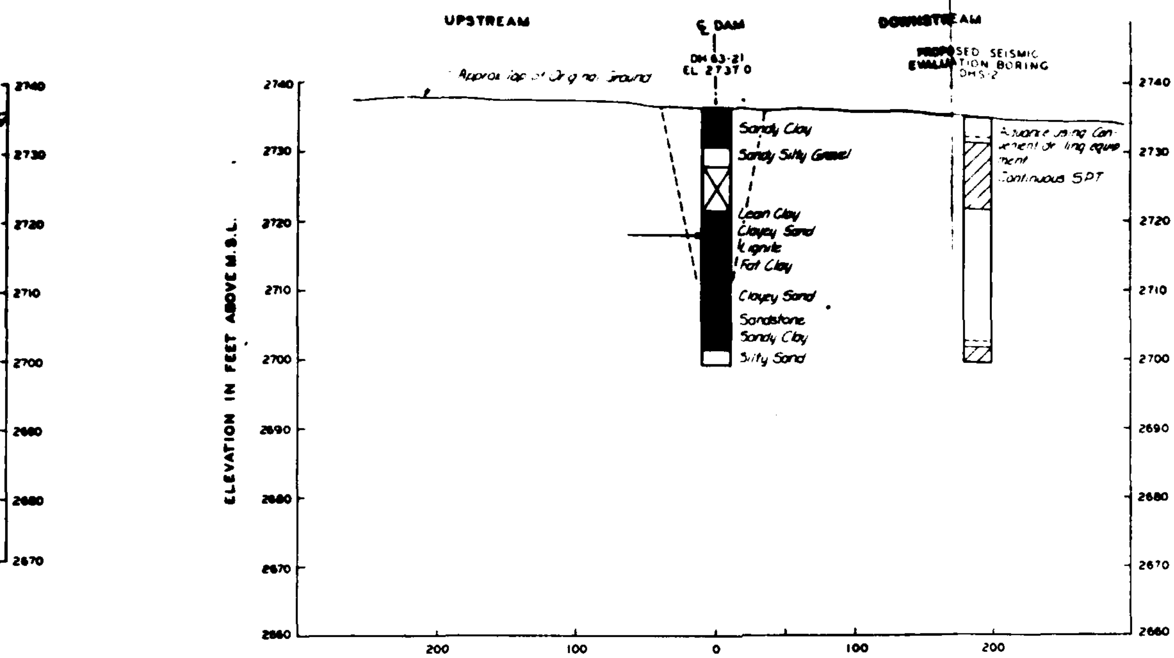
SECTION 6 - 6



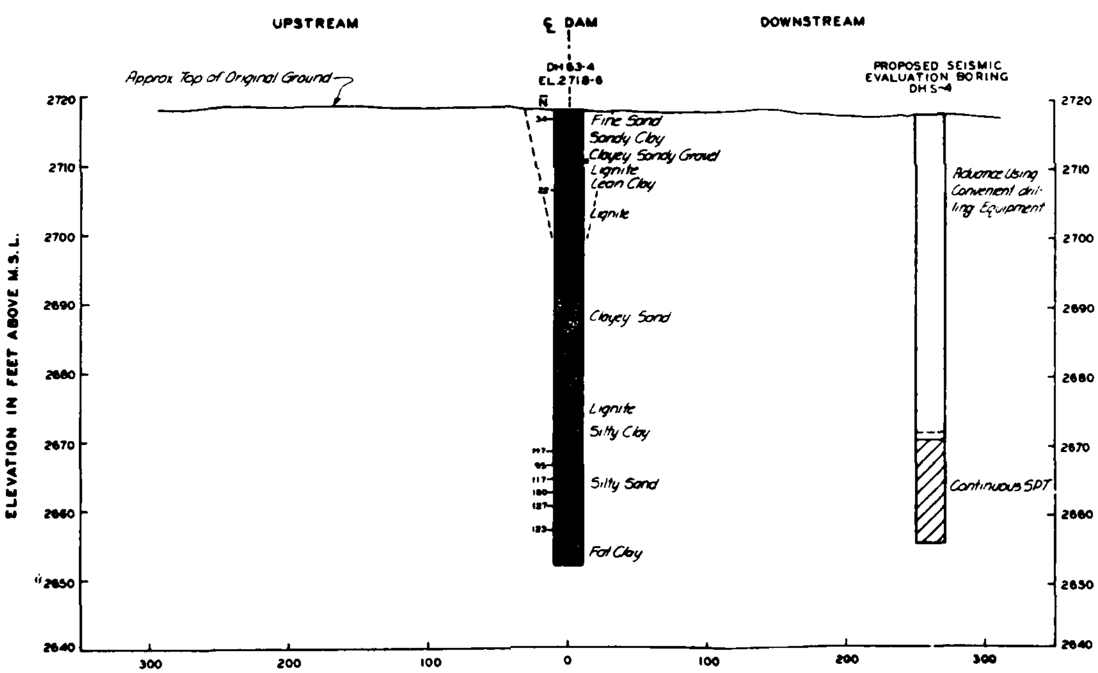
SECTION 8 - 8

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN - HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
GEOLOGIC SECTIONS 5 - 5 THRU 8 - 8 WITH ORIGINAL AND PROPOSED SEISMIC EVALUATION FOUNDATION EXPLORATIONS

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA



SECTION 6 - 6



SECTION 8 - 8

SCALE: VERT. 1 INCH = 10 FEET
HORIZ. 1 INCH = 50 FEET

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN-HALEY DAM AND LAKE
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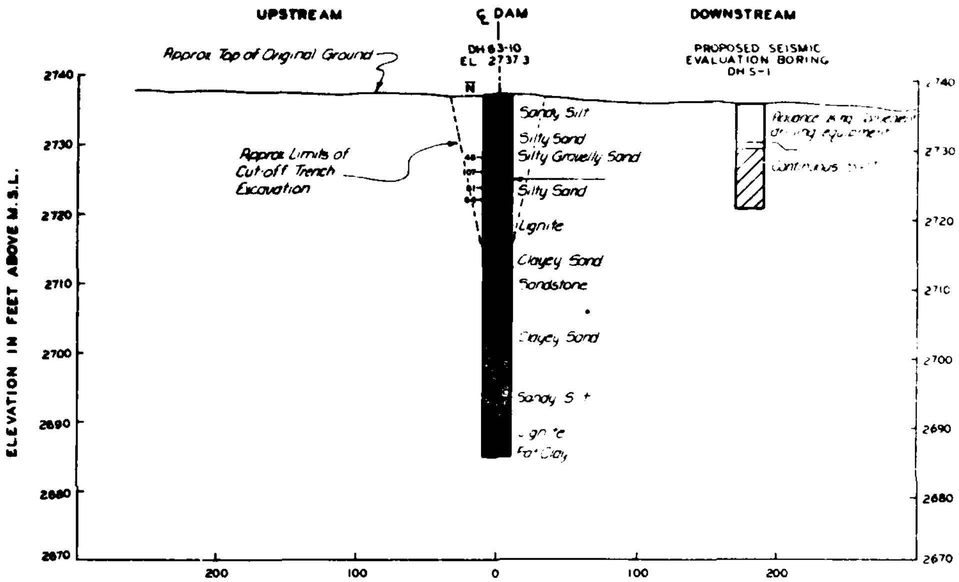
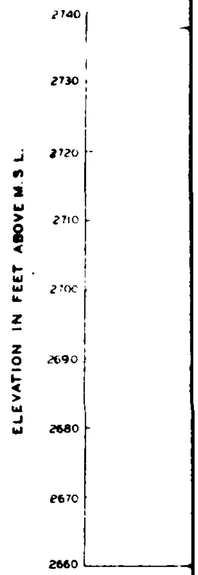
GEOLOGIC SECTIONS 5-5 THRU 8-8 WITH ORIGINAL AND PROPOSED SEISMIC EVALUATION FOUNDATION EXPLORATIONS

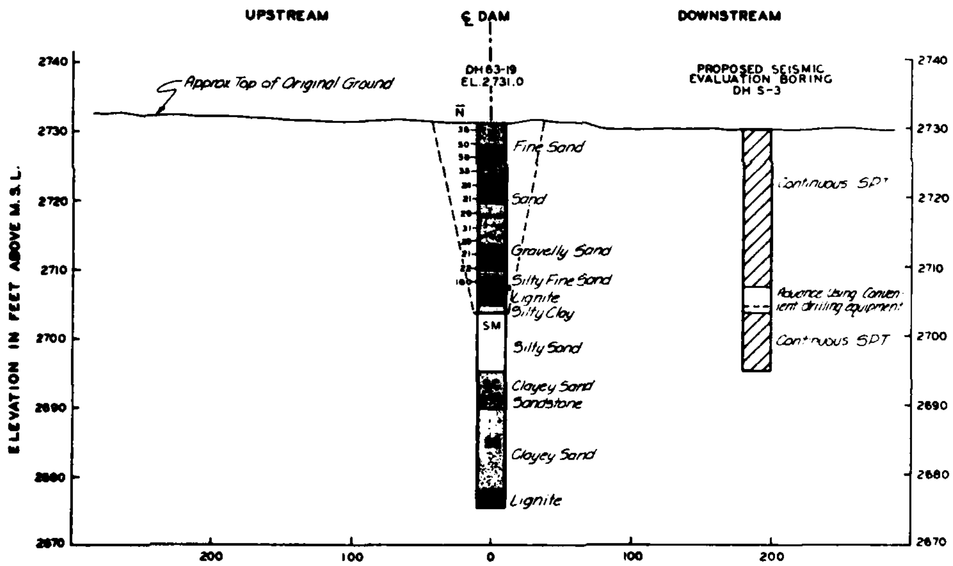
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

PLAT

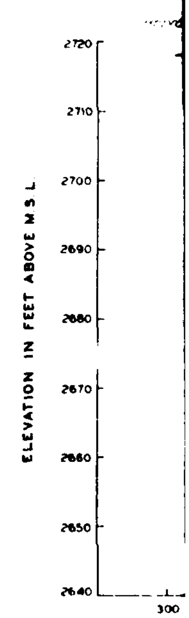


SECTION 5 - 5

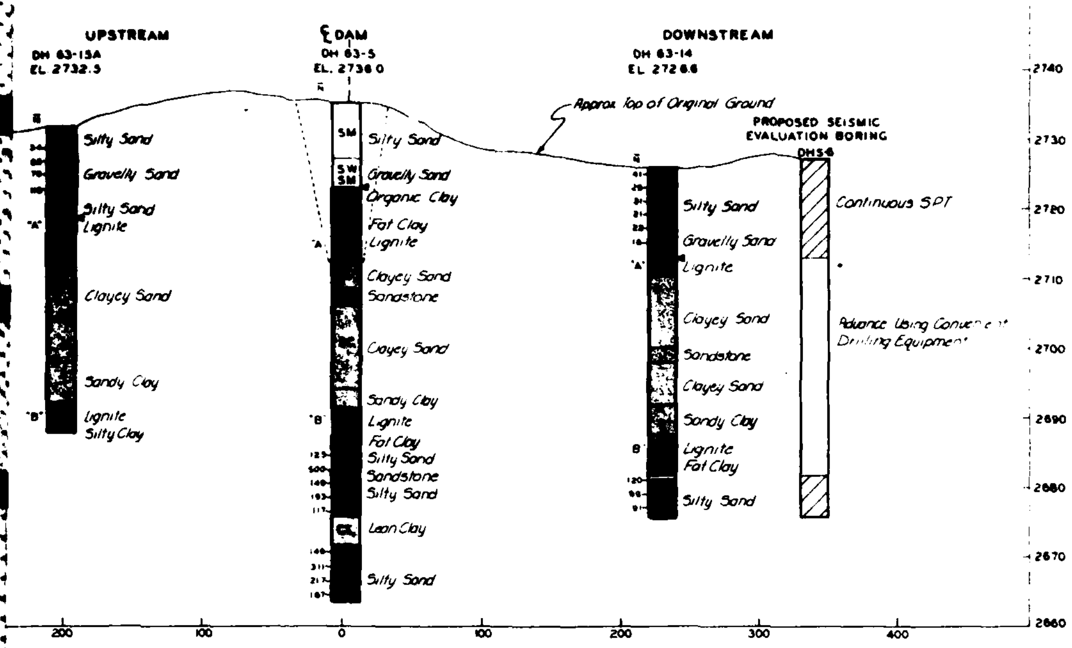




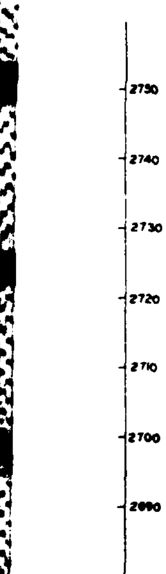
SECTION 7 - 7

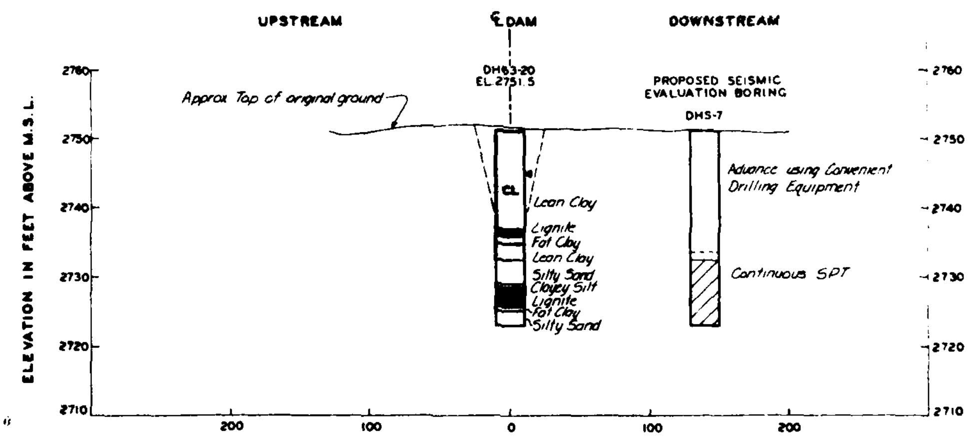


SCALE VERT 1 INCH = 10 FEET
HORIZ 1 INCH = 50 FEET



SECTION 10 - 10





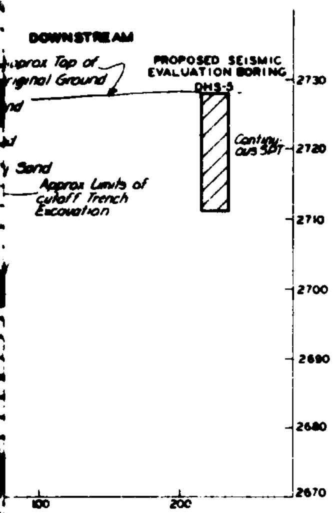
SECTION 12 - 12

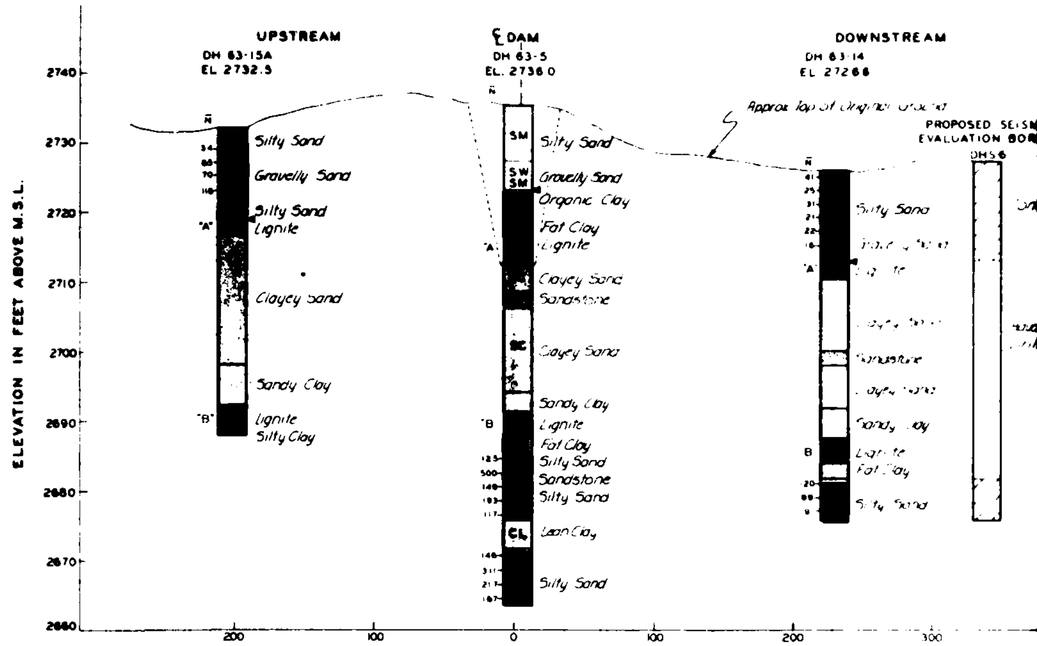
10 FEET
50 FEET

NORTH FORK OF GRAND RIVER, NORTH DAKOTA
BOWMAN - HALEY DAM AND LAKE
RECONNAISSANCE REPORT
SEISMIC EVALUATION AND ANALYSIS
GEOLOGIC SECTIONS 9 - 9 THRU 12 - 12 WITH ORIGINAL AND PROPOSED SEISMIC EVALUATION FOUNDATION EXPLORATIONS
U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

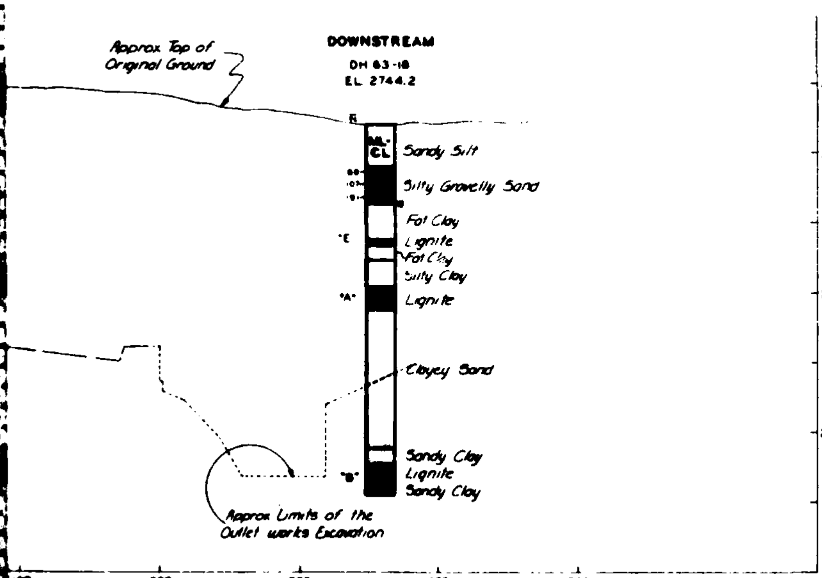
PLATE 8

(1)

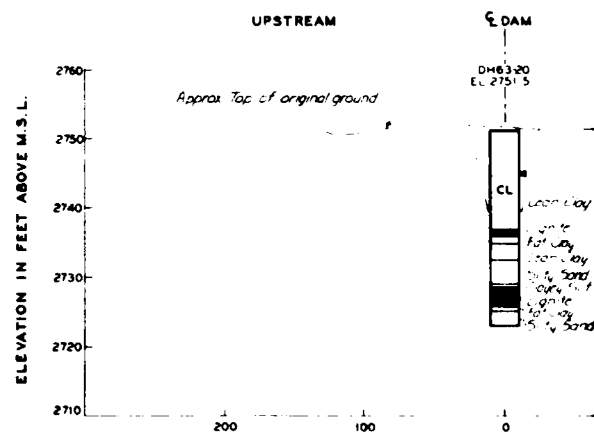




SECTION 10 - 10



SECTION 11 - 11



SECTION 12 - 12

SCALE: VERT. 1 INCH = 10 FEET
HORIZ. 1 INCH = 50 FEET

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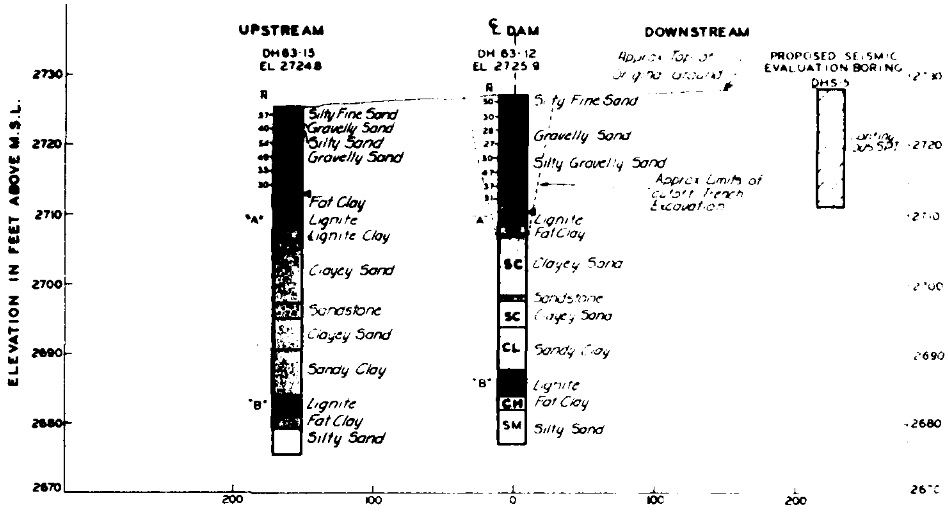
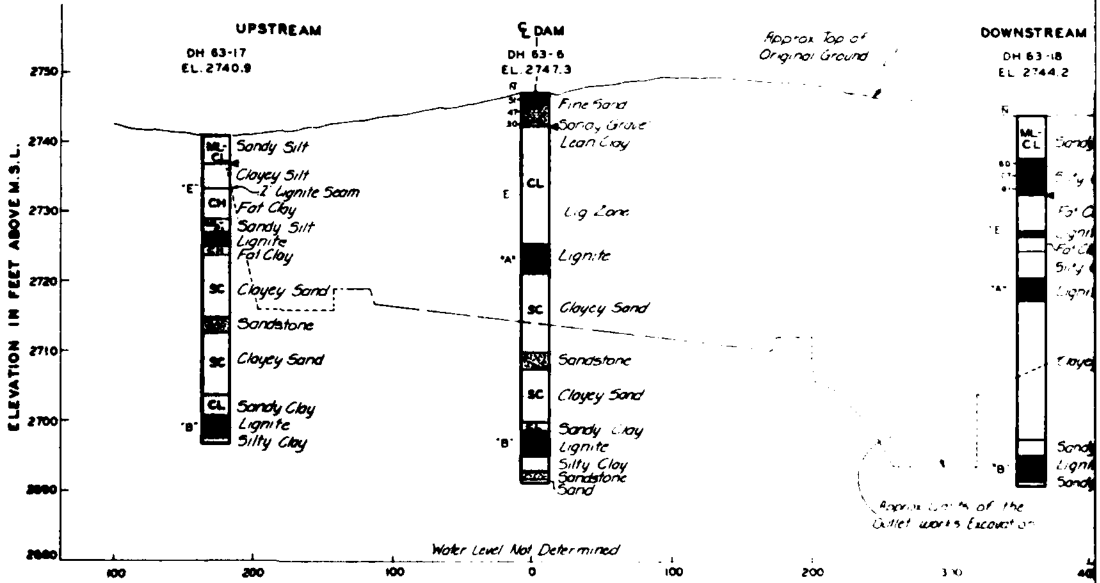


SECTION 9 - 9



SECTION 11 - 11

APPENDIX A

PRELIMINARY SEISMIC HAZARD ANALYSIS

OMAHA DISTRICT **COMPUTATION SHEET** CORPS OF ENGINEERS

PROJECT SEISMIC HAZARD ANALYSIS - BOWMAN-HALEY DAMSITE		
ITEM CONVERSION OF CORNELL AND MERZ COEFFICIENTS FOR EASTERN U.S.	BY BECKER	DATE
	CHKD. BY	DATE

ATTENUATION OF INTENSITY EQUATION FROM CORNELL AND MERZ AS QUOTED IN NUTTLI AND GUPTA (1976) UNITS OF DISTANCE ARE IN MILES, CONVERTING FOR USE OF KILOMETERS

$$I_{SITE} = 3.1 + I_{EPICENTER} - 1.3\ln(R_{MILES}) \quad (1) \qquad R_{MILE} = \frac{R_{KM}}{1.6}$$

$$= 3.1 + I_{EPICENTER} - 1.3\ln(R_{Km}/1.6)$$

$$= 3.1 + I_{EPICENTER} - 1.3[\ln(R_{Km}) - \ln(1.6)]$$

$$= 3.1 + I_{EPICENTER} + 1.3\ln 1.6 - 1.3\ln R_{Km}$$

$$= 3.1 + I_{EPICENTER} + .61 - 1.3\ln R_{Km}$$

$$I_{SITE} = 3.71 + I_{EPICENTER} - 1.3\ln R_{Km} \quad (2)$$

USING NUTTLI AND HERRMANN'S RELATION FOR MAGNITUDE AND EPICENTER INTENSITY (SEE 1978 WES MISC. PAPER S73-1 REPORT 12)

$$I_{EPICENTER} = 2.0m_b - 3.5 \quad (3)$$

SUBSTITUTING THIS INTO (2)

$$I_{SITE} = 3.71 + (2.0m_b - 3.5) - 1.3\ln R_{Km}$$

$$I_{SITE} = .21 + 2.0m_b - 1.3\ln R_{Km} \quad (4)$$

FOR CORNELL'S (1968) EQUATIONS FOR INTENSITY

$C_1 = .21$

$C_2 = 2.0$

$C_3 = 1.3$

HERRMANN'S (1981) EQUATIONS FOR MAXIMUM ACCELERATION

FOR $R \leq 15Km$

USE LESSER OF: $\log_{10} a = 0.55 + 0.50m_b - 0.83\log_{10}15 - 0.0019(15)$

$\ln_e a = 0.933m_b$

For $R \geq 15Km$: $\log_{10} a = 0.55 + 0.50m_b - 0.83\log_{10}R - 0.0019R$

MRO FORM 1 OCT 72 1550

FIGURE A1

OMAHA DISTRICT | COMPUTATION SHEET | CORPS OF ENGINEERS

PROJECT SEISMIC HAZARD ANALYSIS - BOWMAN-HALEY DAMSITE

ITEM CORNELL'S (1968) EQUATIONS FOR CALCULATING MAXIMUM INTENSITIES AT A SITE FROM A LINE SOURCE | BY BECKER | DATE | CHKD. BY | DATE

M_o = MAXIMUM MAGNITUDE QUAKE ALONG SOURCE RECURRING IN 1000 YRS

Δ = DISTANCE (Km) FROM DAM TO CLOSEST POINT ON SOURCE

h = FOCAL DEPTH - ASSUMED TO BE 20 Km.

$d = \sqrt{\Delta^2+h^2}$ = DISTANCE (Km) TO PT 20 Km BELOW CLOSEST PT ON SOURCE

ℓ = LENGTH OF SOURCE (Km)

b = .92 = SLOPE OF LINE RELATING CUM. ANN. FREQ. VS. MAGNITUDE

$\beta = b \ln 10 = 2.1$

$C_1 = .21$, $C_2 = 2.0$, $C_3 = 1.3$ } COEFFICIENTS FROM EQUATION RELATING INTENSITY TO MAGNITUDE
SEE PAGE A3

N_{M_o} = RECURRENCE ANNUAL FREQ. FOR M_o - CHOSEN AT .001

$\ell/2$ = HALF LENGTH OF SOURCE

$r_o = \sqrt{d^2+\ell^2/4}$ SEE DIAGRAM BELOW

$\hat{\nu}$ = EVENTS/YR/ℓ FREQUENCY OVER LENGTH OF SOURCE

$\gamma = \beta C_3/C_2 - 1 = .37$ USED IN DETERMINING GEOMETRY FACTOR G

$C = e^{(\beta(C_1/C_2 + M_o))} = e^{(2.1(\frac{.21}{2}+M_o))}$

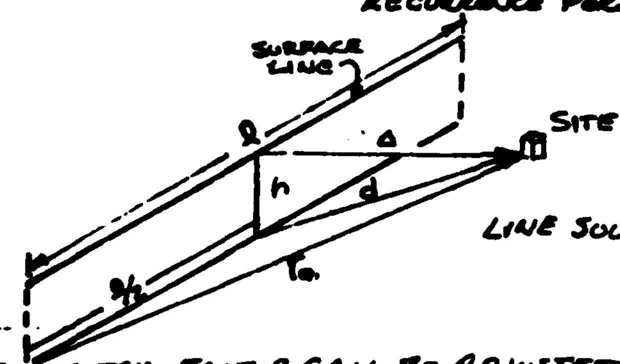
r_o/d = USED FOR DETERMINING T' FUNCTION VALUE

$$Q = \int_0^{\sec^{-1}(r_o/d)} \cos(u)^{\gamma-1} du$$ READ FROM GRAPH (SEE NEXT PAGE)

$G = (2/d^{\gamma})\,Q$ = GEOMETRY FACTOR FOR SOURCE

T_2 = RECURRENCE PERIOD OF EARTHQUAKE OF INTEREST

$i = \frac{C_2}{\beta} \ln(\hat{\nu}\, C G T_2)$ = MAX. INTENSITY AT SITE IN 1000 YRS GIVEN THAT MAX. MAGNITUDE OCCURRING ONCE IN 1000 YRS IS M_o (T_2 = 1000 YR RECURRENCE PERIOD)

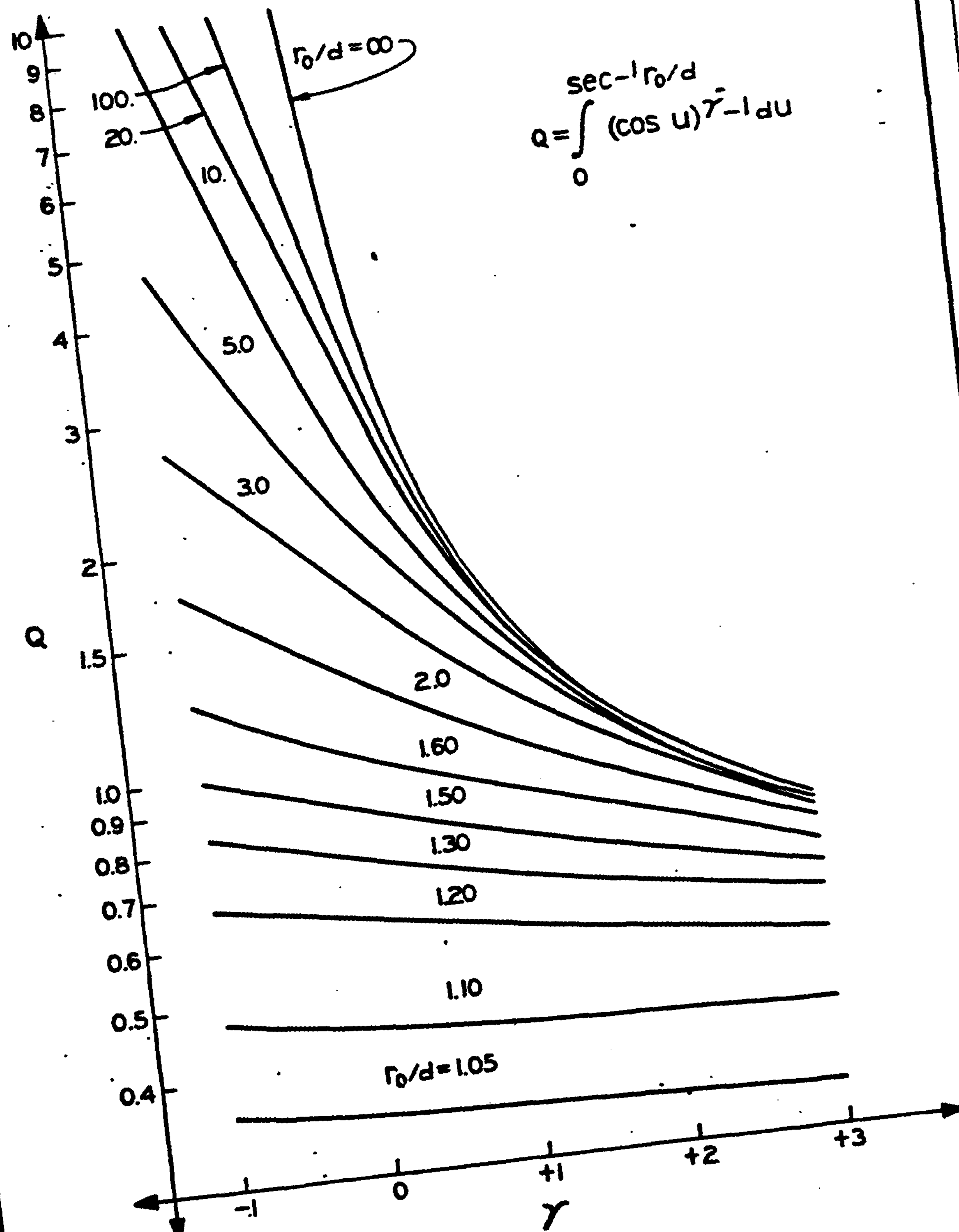


LINE SOURCE GEOMETRY

GEOMETRY FACTOR CAN BE ADJUSTED IF SITE IS NOT CENTERED RELATIVE TO SOURCE BY TREATING EACH SIDE OF THE SOURCE AS HALF OF DIFFERENT LENGTH FAULTS, THEN MULTIPLYING THE RESPECTIVE G FACTORS BY 1/2 AND SUMMING THEM. USING THE TOTAL G FACTOR, i CAN BE CALCULATED NORMALLY. A SIMILAR PROCESS CAN BE USED IF THE SOURCE LINE IS ENTIRELY SKEWED TO ONE SIDE; THE G FACTOR FOR THE 'MISSING' SEGMENT SUBTRACTED OFF.

MRO FORM 1550
1 OCT 72

FIGURE A2



SEISMIC EVALUATION

NUMERICAL VALUES OF INTEGRAL USED IN CALCULATION OF GEOMETRY FACTOR

U.S. ARMY ENGINEER DISTRICT, OMAHA
CORPS OF ENGINEERS OMAHA, NEBRASKA

FROM CORNELL (1968)

FIGURE A-3

OMAHA DISTRICT — COMPUTATION SHEET — CORPS OF ENGINEERS

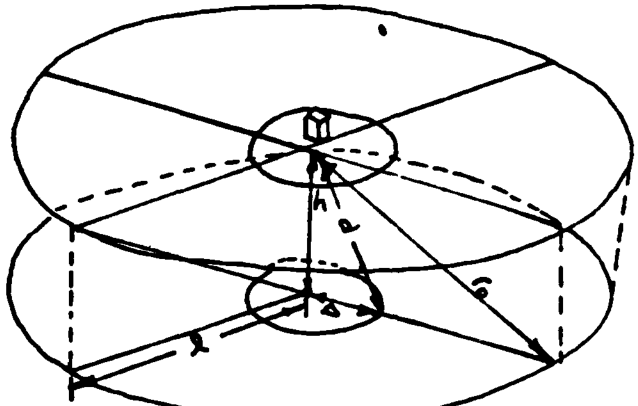
PROJECT: SEISMIC HAZARD ANALYSIS - BOWMAN - HALEY DAMSITE

ITEM: CORNELL'S (1968) EQUATIONS FOR CALCULATING MAX. INTENSITIES AT A SITE FROM AN ANNULAR SOURCE

BY: BECKER | DATE:

CHKD. BY: | DATE:

$m_0, h, b, \beta, N_{m_0}, C_1, C_2, C_3, C, \gamma, i$ - ALL REPRESENT SAME QUANTITIES AS FOR LINE SOURCE, AND ARE CALCULATED THE SAME WAY.



ANNULAR SOURCE GEOMETRY

ℓ = RADIUS OF OUTSIDE OF ANNULUS

Δ = RADIUS OF INSIDE OF ANNULUS (CAN BE ZERO)

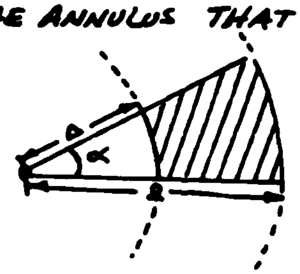
$d = \sqrt{h^2 + \Delta^2}$

$r_0 = \sqrt{h^2 + \ell^2}$

$\hat{\nu} = N_{m_0}/AREA = N_{m_0}/\pi(\ell^2 - \Delta^2)$ EVENTS PER YEAR PER UNIT AREA (km^2)

$G = \frac{2\pi}{(\gamma-1)d^{(\gamma-1)}}\left[1 - \left(\frac{r_0}{d}\right)^{-(\gamma-1)}\right]$ GEOMETRY FACTOR

GEOMETRY FACTOR CAN BE ADJUSTED FOR ONLY A SEGMENT OF AN ANNULUS BY MULTIPLYING G BY THE PORTION OF THE ANNULUS THAT THE SEGMENT SUBTENDS - $\alpha/360°$



$G_{segment} = \frac{\alpha}{360°} G_{annulus}$

α IN DEGREES

G FACTORS CAN BE SUMMED FOR SEVERAL ANNULAR SEGMENTS USED TO MODEL AN IRREGULAR AREAL SOURCE - $\hat{\nu}\, G_{TOT.} = \hat{\nu} \sum_{i=1}^{n} G_i$

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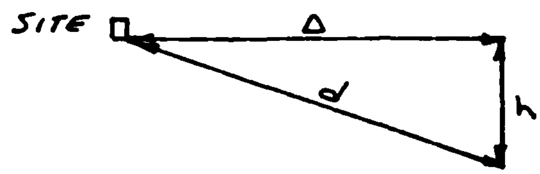
FIGURE A4

OMAHA DISTRICT	COMPUTATION SHEET		CORPS OF ENGINEERS
PROJECT SEISMIC HAZARD ANALYSIS - BOWMAN-HALEY DAMSITE			
ITEM CORNELL'S (1968) EQUATIONS FOR CALCULATING		BY BECKER	DATE
MAX. INTENSITIES AT A SITE FROM A PT. SOURCE		CHKD. BY	DATE

m_o, h, b, β, N_{m_o}, C_1, C_2, C_3, C, γ, i - ALL REPRESENT SAME QUANTITIES AS FOR LINE SOURCE, AND ARE CALCULATED THE SAME WAY.



Δ - DISTANCE TO PT. SOURCE FROM SITE (ALONG SURFACE)

$d = \sqrt{\Delta^2 + h^2}$ - DISTANCE TO FOCUS FROM SITE

$G = d^{-(\gamma+1)}$

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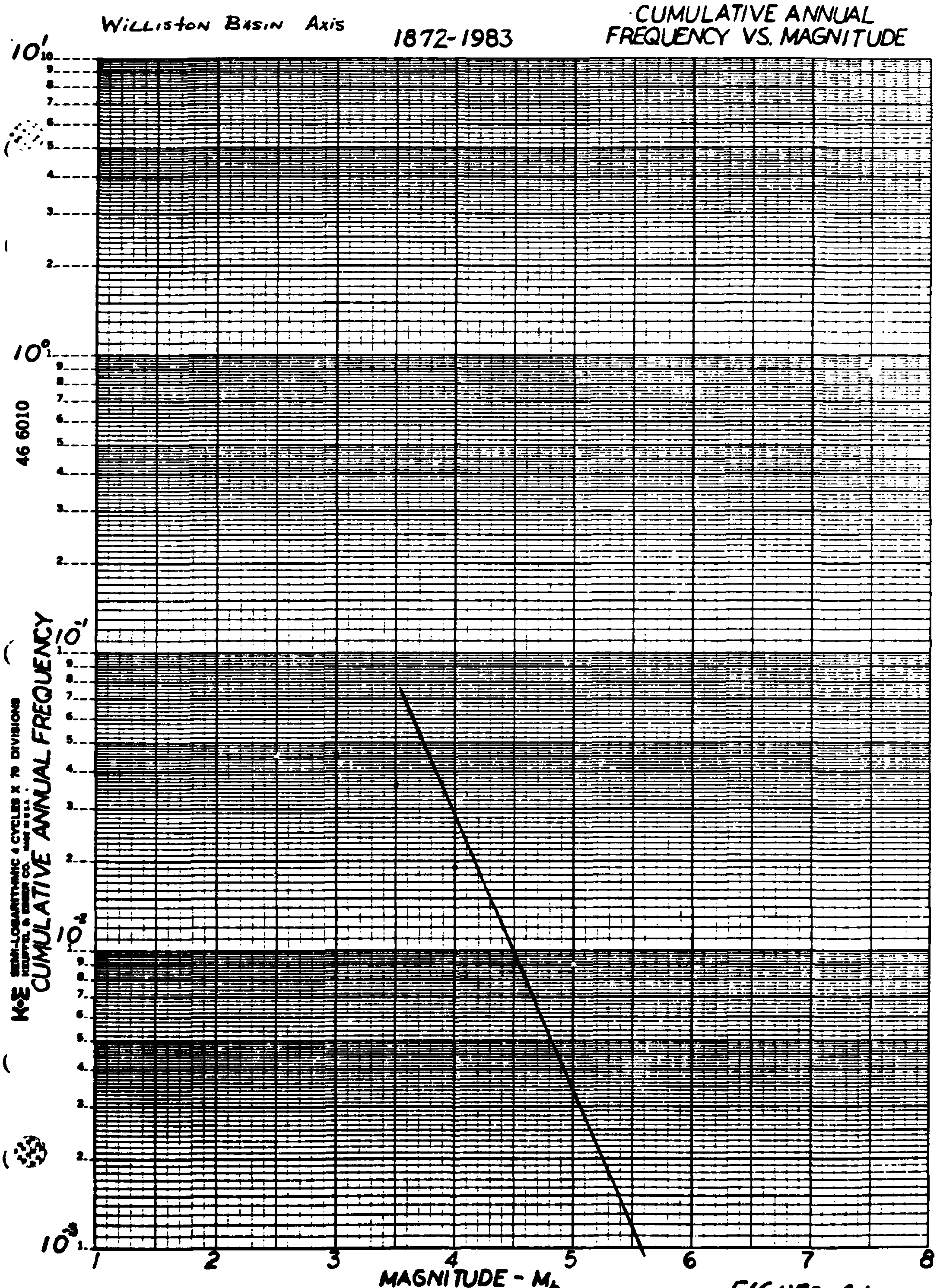
FIGURE A5



WILLISTON BASIN AXIS
1872-1983
CUMULATIVE ANNUAL FREQUENCY VS. MAGNITUDE
CUMULATIVE ANNUAL FREQUENCY
MAGNITUDE - M_b
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
1
2
3
4
5
6
7
8
K+E SEMI-LOGARITHMIC 4 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO.
46 6010

FIGURE A1-

```
 INPUT SITE NAME
? BOWMAN HALEY DAM
 INPUT SOURCE NAME
? WILLISTON BASIN AXIS
 ENTER DEPTH TO FOCUS, ACTUAL LENGTH OF SOURCE AND MO
 ALL DISTANCES IN KILOMETERS
? 5,631.5,5.6
 IS THE SOURCE SYMMETRIC ABOUT THE SITE?
 TYPE Y OR N.
? N
 CAN A LINE NORMAL TO THE SOURCE BE DRAWN
 FROM THE CLOSEST PT ON THE SOURCE TO THE SITE?
 TYPE Y OR N
? Y
 THE SOURCE WILL BE CONSIDERED AS 2 SEGMENT FAULTS
 OF DIFFERENT LENGTHS.  PLEASE ENTER DISTANCE FROM
 SITE TO SOURCE.
? 27.5

ENTER LENGTH OF SEGMENT 1
? 314.5

ENTER LENGTH OF SEGMENT 2
? 317.0

C1 =  .21
C2 = 2.00
C3 = 1.30

B = .92
BETA = B(LN10) = 2.10
NMO = .001

T = 1000.0
C =  159611.82

V = .001/ACTUAL SOURCE LENGTH =    .158E-05

GEOMETRY FACTOR=   .133E+01

(SUM OF GEOMETRY FACTOR)(V) =    .211E-05

I = (C2/BETA) LN((BV)(C)(T)) = 5.54

MB = (I+3.5)/2 = 4.52

LOG A = .55 + .5(MB) - .83LN15 - .0019(15) =    .181E+01

A =   63.973

ACCELERATION = .065 G

OR

LN A = .933(MB) =    4.218

A =   67.923
ACCELERATION = .069 G

END ANALYSIS OF  BOWMAN HALEY DAM
SOURCE AREA -- WILLISTON BASIN AXIS
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FIGURE A7

APPENDIX B

DETAILED DESCRIPTIONS
EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

APPENDIX B

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

Date	Locality Lat. N.	Long. W.	Intensity, MMI 1/ (Est'd Mag., m_b)	Description 2/
09 February 1872	Ft. Sully, SD 44°36'	100°46'	III (3.4)	The local earthquake was felt.
17 August 1876	Lower Brule Indian Reservation, SD 44°06'	99°36'	IV (3.8)	The shock lasted 7 seconds. Loud rumbling noises were heard.
15 April 1878	Glendive, MT 47°08'	104°41'	IV (3.8)	Three shocks at half hour intervals rent the ground for 500 yds. at Glendive, MT.
25 June 1894	Casper, WY 42°54'	106°18'	V (4.3)	Dishes fell to the floor. A number of people were thrown from their beds. The Platte River became thick with mud.
11 October 1895	Black Hills, SD 43°54'	103°18'	V (4.2)	The shock was felt at Rochford, Keystone, and Hill City, SD. Two aftershocks rocked houses and rattled dishes.
14 November 1897	Casper, WY 42°54'	106°18'	VII (5.0)	The Grand Central Hotel was damaged considerably, with 2 to 4 inch crack extending from third to first story. Frightened citizens dashed into the streets.

1/ Modified from Barstow, N.L., et al. "An Approach to Seismic Zonation for Siting Nuclear Electric Power Generating Facilities in the Eastern United States," U.S. Nuclear Regulatory Commission, NUREG/CR-1577, 1981.

2/ Modified from Docekal, J., 1970, Earthquakes of the Stable Interior, with Emphasis on the Midcontinent, v. 2, A dissertation presented the faculty of the graduate college in the University of Nebraska in partial fulfillment of requirements for the degree of Doctor of Philosophy, Ann Arbor, Michigan, University Microfilms Ltd., p. 1-332.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

Date	Locality Lat. N. Long. W.	Intensity, MMI 1/ (Est'd Mag., m_b)	Description 2/
14 March 1900	Aberdeen, SD 45°28' 98°28'	III-IV (3.6)	Two slight earthquakes were felt.
09 May 1906	South Dakota-Nebraska Border 43°00' 101°18'	VI (4.7)	The shock was felt in Rushville and Valentine, NE.
08 August 1915	Williston, ND 48°09' 103°38'	IV (3.8)	A shock was felt lasting 2 to 5 seconds which awakened residents, shook houses, and rattled dishes.
23 October 1915	Kadoka, SD 43°48' 101°30'	V (4.2)	The earthquake was felt.
24 February 1916	Pine Ridge, SD 43°00' 102°30'	III (3.4)	Two moderate shocks lasting a total of 45 seconds were felt.
14 July 1920	Oelrichs, SD 43°10' 103°13'	III (3.7)	A shock with no noise was reported as lasting a few seconds. The shock was also felt at Hot Springs, SD, where rumbling was heard.
30 December 1924	Hot Springs, SD 43°28' 103°32'	IV (3.8)	Several shocks occurred over a 20-minute period and were felt by many persons. The disturbance consisted of abrupt rocking accompanied by rumbling. At Rapid City, the ground vibrated in a north-south direction.
17 November 1925	Bighorn, WY 44°40' 107°00'	V (4.3)	An earthquake felt by many. It lasted 1.5 to 2.0 minutes. Rumbling was heard in the mountains and the ground trembled in a northeasterly-southeasterly direction. Affected to a lesser extent were: Buffalo, Dome Lake, Ft. Mckenzie, and Sheridan, WY.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

Date	Locality Lat. N.	Long. W.	Intensity, MMI 1/ (Est'd Mag., m_b)	Description 2/
01 May 1926	Osage, WY 43°59'	104°24'	IV (3.8)	The earthquake was distinctly felt. Objects moved and dishes shifted.
29 April 1927	Hebron, ND 45°54'	102°04'	III (3.4)	A trembling and rocking in an east-west direction was felt. Pictures moved, hanging objects swung.
13 February 1928	Near Thermopolis, WY 43°30'	108°12'	V (4.3)	Mine props loosened during the earthquake and later became tight.
16 November 1928	Black Hills, SD 44°07'	103°44'	V (4.2)	The shock was felt at Custer and Rockford, SD. Rocks fell on tracks and doors swung open.
10 January 1932	Colstrip, MT 45°54'	106°38'	IV (3.8)	Two severe shocks were felt. The first and strongest sounded like a muffled dynamite blast and shook a huge power shovel until its cables whipped.
29 January 1934	Newark, SD 45°54'	97°44'	IV (4.2)	The shock awakened several persons and rattled dishes.
16 October 1935	Chinook, MT 48°36'	109°14'	III (3.0)	A slight earthquake was reported.
30 October 1936	Hot Springs, SD 43°28'	103°32'	IV (3.8)	The tremor rattled dishes.
25 May 1941	Hot Springs, SD 43°28'	103°32'	IV-V (4.0)	The shock was also felt at Rapid City and Martin, SD. One wall cracked and hanging objects swayed.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

Date	Locality Lat. N. Long. W.	Intensity, MMI 1/ (Est'd Mag., m_b)	Description 2/
11 March 1942	Sturgis, SD 44°25' 103°31'	III-IV (3.6)	Distinct tremors were felt in a narrow strip in the northern Black Hills. Reports were received from Black Hawk, Lead, Fort Meade, Sturgis, Englewood, Trojan, Nevada Gulch, and Terraville. Rapid City reported that rumbling occurred and that the shaking lasted for 12 seconds.
11 December 1942	Casper-Columbine, WY 43°11' 106°18'		Many people were awakened by a sharp shock. Dishes rattled. It was also felt strongly at Edgerton and Glenrock, WY.
16 May 1943	Hot Springs, SD 43°28' 103°32'	IV (3.8)	Dishes rattled for 5 seconds at Hot Springs, SD, and southward for several miles.
24 June 1943	Homestead-Froid, MT 48°24' 104°30'	VI (4.8)	A strong shock was felt. Subterranean sounds were heard, basement walls cracked and a granary cracked severely.
06 September 1943	Buffalo, WY 44°21' 106°42'	IV (3.8)	A shock caused houses to creak and windows to rattle. Many people felt a swaying motion.
26 October 1946	Williston, ND 48°09' 103°38'	IV (3.8)	A slight shock lasting 5 seconds rattled dishes and was felt by many persons. Plentywood, MT, reported a very slight shock at the same time.
14 May 1947	Selfridge, ND 46°02' 100°57'	IV (3.8)	The shock was felt in the Missouri River Valley and possibly from Beulah, ND, to Pierre, SD.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

Date	Locality Lat. N.	Long. W.	Intensity, MMI 1/ (Est'd Mag., m_b)	Description 2/
16 May 1947	Pierre, SD 44°24'	100°18'	III-IV (3.6)	Pierre reported a slight shock lasting 2 seconds. A few persons felt the shock which rattled dishes.
27 August 1948	Casper, WY 42°51'	106°18'	IV (3.8)	An earthquake of a few seconds duration rattled loose objects. Buildings creaked.
03 June 1949	North Central South Dakota 45°00'	100°00'	IV (3.8)	The shock was felt in South Dakota and Nebraska.
15 November 1952	Pactola, SD 44°05'	103°31'	IV (3.8)	The sharp tremor startled people during the night.
21 December 1953	Zeona, SD 45°12'	102°54'	III-IV (3.6)	The earthquake caused a table to jump and rattle. A single observer made the report.
02 December 1956	Vandalia, MT 48°21'	106°52'	IV (3.8)	The shock stampeded cattle.
31 December 1961	Pierre, SD 44°24'	100°30'	V-VI (4.5)	Plaster cracked, a cement floor cracked, a clothes dryer moved several inches, and hundreds of fish leaped into the air along the Missouri River. Many people were alarmed.
24 March 1964	Hot Springs, SD 43°28'	103°32'	V (4.2)	The shock, lasting 3 to 5 seconds, was felt by many persons. Small rocks fell in Wind Cave. Small objects and windows rattled. Moderate rumbling noises were heard.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

Date	Locality Lat. N.	Long. W.	Intensity, MMI 1/ (Est'd Mag., m_b)	Description 2/
28 March 1964	Merriman, NE 42°54'	101°36'	VII (5.1)*	Dishes were shaken from tables, canned goods fell from shelves, cracks appeared in the road, and the banks of th[illegible] Niobrara River slump[illegible]our shocks were felt 4 [illegible]nutes apart. The shocks originated from the northwest and were accompanied by thunder-like noises. A number of towns reported slight damage consisting chiefly of cracked or fallen plaster and broken dishes. The depth of focus was about 41 km. The felt area was estimated to be 90,000 square miles.
26 August 1964	South Dakota 43°48'	102°12'	IV (4.4)*	The shock was recorded with a focal depth of 15 km.
21 August 1964	Keeline, WY 42°54'	104°42'	V (4.3)	The moderately strong shock was also f[illegible]usk, Lost Springs, Lanc[illegible] Creek, Jay Em, and Rode, WY.
21 August 1964	Keeline, WY 42°54'	104°42'	II (3.0)	A mild aftershock was felt.
26 June 1966	Keystone, SD 44°18'	103°43'	VI (4.1)*	The shock made well water muddy. One observer reported that he saw the ground move, buildings creak, and dishes rattle. At Rapid City, concrete steps cracked and pulled

* Magnitude was instrumentally determined.

DETAILED DESCRIPTIONS - EARTHQUAKES IN NORTH DAKOTA AND ADJACENT STATES

Date	Locality Lat. N.	Locality Long. W.	Intensity, MMI 1/ (Est'd Mag., m_b)	Description 2/
26 June 1966 (Cont'd)				away from houses, and various objects were shaken from walls. Moderately loud earth noises were heard.
08 July 1968	South Central North Dakota 46°30'	100°36'	IV (4.4)	A description is not available.
19 October 1971	South Dakota 44°00'	101°00'	IV (3.0)	The shock occurred between Philip and Pierre, SD. A description is not available.
16 May 1975	Edgemont, SD 43°14'	103°41'	IV (2.9)*	A description is not available.
25 August 1975	Pierre, SD 44°15'	100°27'	-- (3.1)*	A description is not available.
13 September 1981	Nebraska-South Dakota Border 43°00'	101°48'	IV (3.4)*	The shock was felt at Martin and Vetal, South Dakota.
03 March 1983	Stephan, SD 44°12'	99°18'	V (4.4)*	The shock was centered near Stephan, South Dakota. Minor damage was done to two nearby Indian reservations. The earthquake was felt from Sioux Falls to Pierre, South Dakota.

END

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