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DOCUMENTATION AND ANALYSIS OF ROCK ISLAND UNDERSEEPAGE DATA

by

Robert W. Cunny

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

- Piezometer data from 14 pre-1960 piezometer range sites in the Rock Island District (RID) were documented and analyzed to determine landside ($k_f/k_{b\ell}$) and riverside (k_f/k_{br}) permeability ratios. Only 7 of the 14 sites had complete data, which included piezometric pressures under both the riverside and landside slopes of the levee. Piezometer data obtained in 1979 from 15 new (1977) piezometer range sites were also reviewed, but because the calculated entrance

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20. ABSTRACT (Continued).

distances, among other things, were significantly greater than the distances to the exposed substratum at the riverbank, these latter data were considered in error and were not used for analysis.

Data from the seven old piezometer range sites indicated that $k_f/k_{b\ell}$ ranged from 1.1 to 90 and k_f/k_{br} ranged from 3.0 to 209. For design of berm widths using procedures based on a factor of safety against uplift, ratios of 100 and 200 were suggested (later referred to as WES (Waterways Experiment Station) suggested) for $k_f/k_{b\ell}$ and k_f/k_{br}, respectively. The WES suggested landside and riverside permeability ratios were as little as 1/8 and 1/31 of those provided by the Lower Mississippi Valley Division (LMVD) 1956 criteria and 1/4 to 1/8 of those used by the RID for design in 1960. Peizometric pressures predicted using WES suggested permeability ratios average about 77 percent of that predicted using LMVD criteria and 102 percent of that using RID criteria.

Berm widths were also calculated using LMVD, RID, and WES permeability ratios. Significantly reduced berm widths resulted from using either RID or WES criteria, the reduction ranging from 80 to about 72 percent, respectively, of that calculated using LMVD criteria.

Observed seepage performance from all 29 piezometer range sites was studied and compared with berm width calculations. In general, the berm formulas, which are based on a factor of safety against uplift, did not discriminate in any significant manner between those sites that had relatively good or poor seepage performance. Using WES suggested permeability ratios, 5 of the 16 sites where the seepage performance was relatively good required berms up to 407 ft wide; using LMVD criteria, 11 of the same 16 sites required berms up to 781 ft wide. (RID permeability ratios were assigned only to the 14 old piezometric range sites; therefore, RID berm widths are not compared with seepage performance.) At 13 sites where seepage performance was relatively poor, WES criteria indicated that 7 of the sites required no berms at all; LMVD criteria indicated that 6 of these same sites required no berms. It was concluded that berm formulas currently being used are not suitable for determining which sites need berms in the RID.

Berm criteria based on a creep ratio of 15 to 18, similar to that advanced in 1916 by Mr. W. G. Bligh in his book, Dams and Weirs, were also tried. While berm lengths were more reasonable than those mentioned above, these criteria also failed to adequately distinguish between those locations that need berms and those that do not. The creep ratio criteria indicated that all 16 of the sites that had relatively good seepage performance required berms up to 114 ft wide. At the 13 sites that had relatively poor performance, 11 required berms up to 137 ft wide and 2 required no berms at all. Thus, it was concluded that the creep ratio criteria also were not adequate.

It is recommended that additional field studies be undertaken to determine the detailed characteristics of locations where seepage performance has been relatively good but where the berm formulas indicate that berms are required, and where performance has been relatively poor but where current procedures indicate that no berms are required. Locations where these studies might be conducted have been suggested.

It is also recommended that the new piezometer range sites be maintained, that the piezometers be rejuvenated as may be necessary, and that piezometers be read daily whenever the river stage is 4 ft or so above the landside toe elevation.

PREFACE

The documentation and analysis of underseepage data from the Rock Island District (RID) was conducted for the RID by the U. S. Army Engineer Waterways Exeriment Station (WES) with funds provided by IAO's NCR-IA-78-C17 dated 26 January 1978, NCR-IA-78-C26, NCR-IA-78-B11, and NCR-IA-78-B12 dated 31 March 1978, NCR-IA-79-C19 dated 30 May 1979, and NCR-IA-80-C16 dated 17 January 1980.

The study was conducted during the period January 1978 through September 1979. Mr. R. W. Cunny, Soil Mechanics Division (SMD), Geotechnical Laboatory (GL), was the principal investigator. He was assisted by Messrs. P. G. Tucker and L. Devay and Dr. E. B. Perry, SMD, and Dr. J. W. Spotts, formerly of the WES. The analysis was made and the report was written by Mr. Cunny. The initial drafts of part of the procedures section and most of the site descriptions and data documentation were prepared by Messrs. Tucker and Devay. The work was conducted under the general direction of Mr. C. L. McAnear, Chief, SMD, and Mr. J. P. Sale, Chief, GL.

COL John L. Cannon, CE, and COL Nelson P. Conover, CE, were Commanders and Directors of the WES during the preparation and publication of this report. Mr. F. R. Brown was Technical Director.

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CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
inches	25.4	millimetres
miles	1.609344	kilometres

DOCUMENTATION AND ANALYSIS OF ROCK ISLAND UNDERSEEPAGE DATA

PART I: INTRODUCTION

Background

1. During the period 1950-1957, the Rock Island District (RID) began a series of studies leading toward the enlargement of levees along the upper Mississippi River. Part of the studies included the collection of piezometric pressure data to be used for the design of seepage berms to protect the levees from excessive underseepage that could result in piping and failure. Piezometer ranges were installed at a number of locations within the RID, and over a period of about 10 years, the piezometers were read whenever significant elevated river stages occurred. These data were studied by RID personnel and were used for the design of the levee enlargements that were built beginning in the early 1960's, but the data were never formally documented and reported in permanent form.

2. At this time (late 1970's), the RID is again planning enlargement of the levees at certain reaches of the river, and criteria that were used for design of the early levees are being reexamined. It is apparent that because of increased height and enlarged levee sections, some modification of the criteria may be warranted. The RID has been engaged in a program of reviewing their early design criteria and observed performance and has asked the U. S. Army Engineer Waterways Experiment Station (WES) to assist them in this review and the documentation of observed data.

Objective

3. Specifically, the WES was asked to do the following:

   a. Review and document piezometer data from fourteen 1950-1957 piezometer ranges for up to five high waters.

b. Calculate landside and riverside permeability ratios and compare with those recommended in Technical Memorandum TM 3-424* and those used by the RID.

c. Calculate piezometric pressure at landside toe and compare with that observed and that determined using TM 3-424* and RID permeability ratios.

d. Document performance observed during 1960, 1965, 1969, and 1973 high-water periods at fourteen 1950-1957 piezometer ranges and during 1965, 1969, 1973, and 1979 at fifteen 1977 piezometer ranges.

e. Review and analyze observed piezometer data obtained during 1979 high water at fifteen 1977 piezometer ranges.

f. Calculate factor of safety for uplift and compare with observed performance.

g. Review detailed 1951 piezometer data obtained from two ranges (Sny Island, Ranges A and B) and evaluate the potential for piezometric pressure time lag.

Scope

4. Data furnished by the RID for this review include aerial photographs, plan maps, cross sections, piezometer data, and performance observations for the following 14 so-called old pre-1960 piezometer sites installed in the 1950-1957 time frame:

Muscatine Island, Range A

Bay Island, Ranges C and D

Iowa River, Range A

Green Bay, Range A

Hunt, Range B

Fabius River, Range A

South Quincy, Range A

Sny Island, Ranges A, F, B, G, H, and I

Piezometer data were obtained from all the sites listed above in 1960; in other years, 1951, 1952, 1954, 1961, 1962, 1965, and 1969,

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* U. S. Army Engineer Waterways Experiment Station, CE. 1956 (Oct). "Investigation of Underseepage and Its Control, Lower Mississippi River Levees," Technical Memorandum 3-424, Vicksburg, Miss.

piezometer data were obtained from selected sites. Seepage performance observations were furnished for the years of 1960, 1965, 1969, and 1973.

5. In addition to the above, plan maps, cross sections, 1979 piezometer data, and 1965, 1969, 1973, and 1979 seepage performance observations were obtained from the following 15 new piezometer range sites installed in 1977:

Muscatine Island, Ranges MA, MB, and MC
Green Bay, Ranges GBA and GBB
Fabius River, Ranges FA and FB
South Qunicy, Range SQ
South River, Ranges SRA, SRB, and SRC
Sny Island, Ranges SA, SB, SC, and SD

Table 1 summarizes the river mile and levee station locations for the 14 old piezometer ranges and 15 new piezometer ranges.

6. Permeability ratios have been calculated for seven of the 1950-1957 piezometer sites for which complete piezometer data were available; design permeability ratios have been suggested; piezometric pressures for levee crest flood conditions have been calculated; berm widths based on factor of safety against uplift have been calculated; and seepage performance observations have been analyzed. Also, use of procedures for calculations of berm widths based on creep ratio criteria has been discussed, and recommendations have been made for further study.

PART II: PROCEDURES

Analysis of Piezometer Data

7. The amount of artesian pressure that will develop landward of a levee during a sustained high water is related to the dimensions and character of the foundation and the other factors illustrated in Figure 1. Definitions of the symbols used in Figure 1 are shown on the figure. However, a complete listing of all the nomenclature used in this report is included in Appendix B; this nomenclature is consistent with that used in EM 1110-2-1913.* Methods for determining values for the factors that were used for analysis of piezometer data from the piezometer ranges are discussed in the following paragraphs.

Net head H

8. The net head on a levee was the height of the river above the tailwater or average low ground surface near the landside levee toe. For prediction of maximum piezometric pressure and design of berm widths, the height of the river was determined by the net grade of the levee.

Distance from riverside levee toe to riverbank L_1

9. The distance L_1 from the riverside levee toe to the exposed pervious substratum at the riverbank was obtained from cross sections, plan maps, and aerial photographs.

Base width of levee and berm L_2

10. The distance L_2 or the base width of levee and berm was obtained from cross sections.

Slope of hydraulic grade line beneath levee M

11. The slope of the hydraulic grade line was determined from

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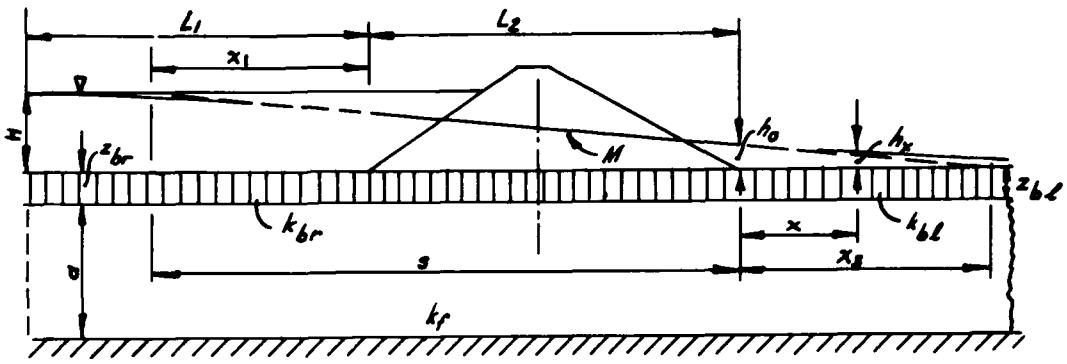
* Department of the Army, Office, Chief of Engineers. 1978 (Mar). "Engineering and Design, Design and Construction of Levees," Engineer Manual 1110-2-1913, Washington, D. C.



Notation:

d	Effective thickness
h_o	Net head beneath top stratum at landside levee toe measured above natural ground surface or tailwater
h_x	Net head beneath top stratum at distance x from levee toe
H	Net head on levee
k_f	Permeability of pervious substratum
L_1	Distance from riverside levee toe to river
L_2	Base width of levee and berm
M	Slope of hydraulic grade line, at middepth of pervious substratum, beneath levee
s	Distance from landside levee toe to effective source of seepage entry into the pervious substratum
x	Distance from toe of levee
x_1	Effective riverside blanket length
x_3	Distance from landside toe of levee or berm to effective seepage exit
$z_{b\ell}, k_{b\ell}$	Effective thickness and permeability of top stratum landward of the levee
z_{br}, k_{br}	Effective thickness and permeability of top stratum riverward of the levee

Figure 1. Generalized cross section of levee foundation and notation for underseepage analysis

readings of piezometers located beneath the levee during high water and the relation

$$M = \frac{\Delta h}{\ell}$$

where Δh is the difference in piezometer readings and ℓ is the horizontal distance between piezometers as shown in Figure 2. The formula is valid only with artesian flow conditions beneath the levee.

Effective source of seepage s

12. The effective source of seepage distance measured from the landside toe was determined by projecting the hydraulic grade line M until it intersected the river stage producing the gradient. Mathematically, s was determined from the equation (see Figure 2 for nomenclature)

$$s = \ell_1 + (H - h_1) \frac{\ell_2 - \ell_1}{h_2 - h_1}$$

or

$$s = \ell_1 + \frac{H - h_1}{M}$$

13. For sites without complete piezometer data, s can be calculated from the formula

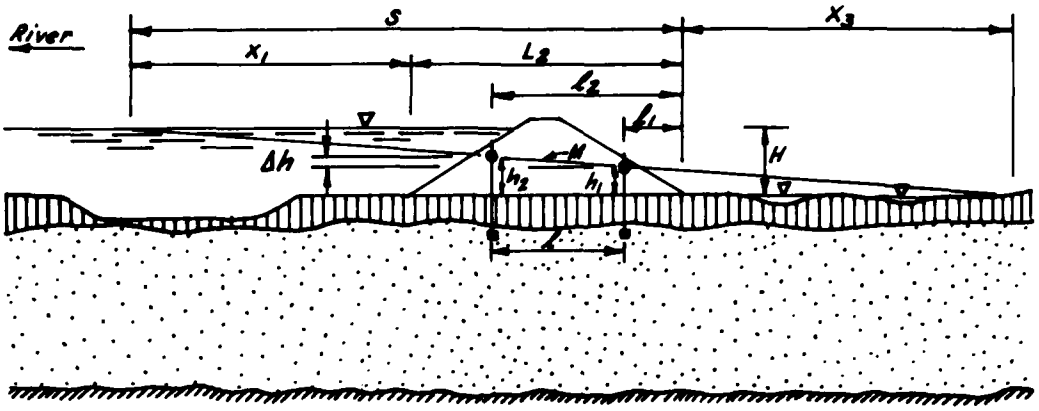
$$s = x_1 + L_2$$

where x_1 is determined as described below.

Effective riverside blanket length x_1

14. For sites without piezometer data, x_1 can be calculated from the formula

$$x_1 = \frac{\tanh (cL_1)}{c}$$



Notation:

Δh	Difference in piezometer readings
h_1, h_2	Substratum heads of two piezometers on a line perpendicular to the levee at distances ℓ_1 and ℓ_2, respectively, from landside levee toe
H	Wet head on levee
ℓ	Horizontal distance between piezometers
ℓ_1, ℓ_2	Respective distances from landside levee of toe to the piezometers installed on a line perpendicular to the levee
L_2	Base width of levee and berm
s	Effective source of seepage
x_1	Effective riverside blanket length
x_3	Distance from landside levee toe to effective seepage exit

Figure 2. Dimensioning for determination of M , s , and x_3 from piezometer readings

where

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{br}}\right)\left(z_{br}\right)\left(d\right)}}$$

and where the riverside permeability ratio k_f/k_{br} was assigned on the basis of analyses from other similar sites with complete piezometer data and z_{br} and d were determined as described in paragraphs 17 and 18.

Effective seepage exit x_3

15. The effective seepage exit distance was determined by projecting the hydraulic grade line M until it intersected the average ground surface or tailwater. Mathematically, x_3 was determined from the equation (see Figure 2 for identification of terms)

$$x_3 = h_1\left(\frac{\ell_2 - \ell_1}{h_2 - h_1}\right) - \ell_1$$

or

$$x_3 = \frac{h_1}{M} - \ell_1$$

16. For sites without complete piezometer data, x_3 was calculated from the formula

$$x_3 = \sqrt{\left(\frac{k_f}{k_{b\ell}}\right)\left(z_{b\ell}\right)\left(d\right)}$$

where the landside permeability ratio $k_f/k_{b\ell}$ was assigned on the basis of analyses from other similar sites with complete piezometer data, and $z_{b\ell}$ and d were determined as described below.

Effective thickness of the landward and the riverward top stratum, $z_{b\ell}$ and z_{br}

17. The total thickness of the multilayered top stratum determined from boring logs was transformed in a single stratum of relatively uniform permeability for seepage computations by multiplying each layer by a transformation factor and adding these to obtain a total transformed thickness. Table 2 lists the transformation factors as determined in TM 3-424.*

Effective thickness of pervious substratum d

18. The thickness of the pervious substratum is the thickness of the principal seepage carrying sand strata below the top stratum and above the bottom of the entrenched valley. For this study, it was determined by deep borings usually within a mile or so of the site being considered.

Permeability of the riverside and the landside top stratum and the pervious substratum, k_{br}, $k_{b\ell}$, k_f, respectively

19. For the analyses made for this study, individual determinations of top stratum and substratum permeabilities were not made. Only the landside permeability ratio $k_f/k_{b\ell}$ and the riverside permeability ratio k_b/k_{br} were determined. These are discussed below.

Riverside permeability ratio k_f/k_{br}

20. The riverside permeability was calculated from the formula

$$\frac{k_f}{k_{br}} = \frac{1}{(c^2)(z_{br})(d)}$$

where c was determined by trial and error from the equation

* U. S. Army Engineer Waterways Experiment Station, CE, op. cit. p. 6.

$$x_1 = \frac{\tanh\,(cL_1)}{c}$$

The above equation is appropriate for the condition of no significant riverside borrow pits, and

$$x_1 = s - L_2$$

where s, the effective source of seepage distance measured from the old levee toe, was determined by projection of observed piezometric data to the old levee crest elevation.

Landside permeability ratio $k_f/k_{b\ell}$

21. The landside permeability ratio was calculated from the formula

$$\frac{k_f}{k_{b\ell}} = \frac{\left(x_3\right)^2}{(z_{b\ell})(d)}$$

where x_3, the effective seepage exit distance measured from the toe of the old levee or berm, was determined from observed piezometric data projected to the average ground elevation near the landside toe or tailwater.

Calculations for Factor of Safety

22. For the calculation of factor of safety against uplift, additional factors were determined as described in the following paragraphs.

Critical thickness of the top stratum z_t

23. The critical thickness of the top stratum for determination of allowable pressure beneath the top stratum for design of berms or other seepage control measures is the total thickness of all strata overlying the top of the least pervious layer plus the transformed thickness of

the underlying more pervious top stratum. It may or may not be the same as the transformed thickness z_b ; z_t will equal z_b only when the least pervious stratum is at the ground surface.

Net head at landside toe of levee or berm h_o

24. For sites with adequate piezometer data, the net head beneath the top stratum at the landside toe of the levee or berm measured above natural ground or tailwater was determined by a linear projection of observed piezometric data to the new levee crest elevation or intermediate river stage and a linear interpolation between adjacent piezometers to determine the pressure head at the landside toe. If adequate piezometer data were not available, s and x_3 values were calculated from suggested permeability ratios, and h_o was determined from the formula

$$h_o = \frac{H\ (x_3)}{s + x_3}$$

Net head at distance x from the center line h_x

25. For sites with piezometer data, the net head beneath the top stratum at various distances from the center line and measured above the natural ground or tailwater was determined by linear projection of observed piezometric data to the new levee crest elevation or intermediate river stage and linear interpolation between adjacent piezometers to determine the pressure head at the desired location.

Gradient through the top stratum i

26. The gradient through the top stratum is the net head h_x divided by the critical thickness of the top stratum z_t .

Critical gradient i_c

27. The critical gradient through the top stratum is the gradient that produces an uplift pressure at the bottom of the top stratum equal to the pressure of the submerged weight of the top stratum, expressed as

$$i_c = \frac{\gamma'}{\gamma_w} = \frac{h_c}{z_t}$$

where

γ' = submerged unit weight of soil

γ_w = unit weight of water

h_c = critical head (described below)

For the analyses made herein, i_c was assumed 0.8.

Critical head h_c

28. The critical head is the net head measured at the bottom of the top stratum that produces an uplift pressure equal to the pressure of the submerged weight of the top stratum, defined by

$$h_c = i_c z_t$$

Factor of safety against uplift F

29. The factor of safety against uplift is the ratio of the submerged weight of the top stratum ($z_t \cdot \gamma'$) plus berm ($t \cdot \gamma$), if any, divided by the force produced by the net head above the ground or berm surface acting at the bottom of the top stratum, expressed as

$$F = \frac{\gamma'(z_t + t)}{(h_x)(\gamma_w)} = \frac{i_c(z_t + t)}{h_x}$$

Seepage Performance Observations

30. Seepage performance observations were made in 1960 during the high-water period, and the comments of the observers were recorded on cross sections of the 1950-1960 piezometer ranges furnished for study. During the 1965, 1969, and 1973 high-water periods, seepage performance observations were made of the entire RID levee system, and comments of

the observers were recorded on plan maps scaled 1 in.* = 400 ft. During the 1979 high-water period, seepage performance observations were made at the new 1977 piezometer range sites, and comments of the observers were furnished in a summary format for each piezometer range.

31. Different observers made the seepage performance observations at different times; thus, the verbal descriptions of their observations varied in perspective from place to place and from time to time. During the review of these data, an effort was made to reduce the descriptions to 13 common statements. These statements were coded to simplify documentation and are listed in what was believed to be an increasing order of severity of seepage as follows:

Code	Description
1a	Reported dry
1b	No seepage reported
1c	Through seepage
1d	Light toe seepage
1e	Heavy toe seepage
2a	Berm wet
2b	Water standing in low areas
2c	Fields wet or soft behind levee
3a	Light seepage beyond toe
3b	Heavy seepage beyond toe
4a	Pin boils
4b	Sand boils
4c	Large boils

Coded seepage observations are documented in tables for each of the piezometer sites. At those locations where piezometer data were available for estimation of piezometric pressure, a calculated factor of safety against uplift is also shown.

Berm Width Calculations

32. Calculations for berm width X_{sp}, based on factor of safety

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 4.

against uplift for semipervious berm material, have been made at each piezometer site. Figure 3 gives the formula for X_{sp} as presented in TM 3-424.* The net head on the levee is based on the elevation of the top of the existing levee and average ground elevation in the first 100 ft or so landward of the existing levee or berm toe. The seepage entry and exit distances are based on selected riverward and landward permeability ratios. Values of the parameters used for the calculation of X_{sp} are listed in tables that are presented subsequently.

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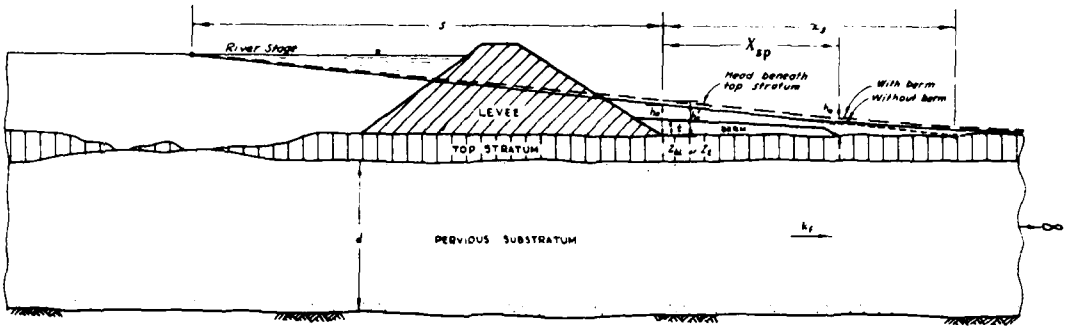
* U. S. Army Engineer Waterways Experiment Station, CE, op. cit. p. 6.



Formula for semipervious berm width:

$$X_{sp} = \frac{-A + \sqrt{A^2 - 24(2 + r)\left(1 + sc - \frac{H}{h_a}\right)}}{2c(2 + r)}$$

where

X_{sp} = semipervious berm width

$A = 6 + 3\ sc\ (r + 1)$

s = effective seepage entry distance

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{b\ell}}\right)\left(z_{b\ell}\right)\left(d\right)}}$$

$r = i_o/i_1$

i_o = allowable upward gradient at landside levee toe = 0.8/F

i_1 = allowable upward gradient at berm toe = 0.8

H = net head on levee

h_a = allowable head at berm toe = $(i_1)(z_t)$

z_t = critical thickness of landside top stratum

$k_f/k_{b\ell}$ = landside permeability ratio

$z_{b\ell}$ = effective thickness of landside top stratum

d = effective thickness of pervious substratum

F = factor of safety against uplift at levee toe; 1.5 used for RID study

and

h_o = net head beneath top stratum at landside levee toe without berm

h'_o = net head beneath top stratum at landside levee toe with berm

t = thickness of berm

Figure 3. Sketch and formulas for calculating semipervious berm width

PART III: OLD PIEZOMETER RANGE SITES

Muscatine Island, Range A

33. The Muscatine Island Levee District is located on the west bank of the Mississippi River about 30 miles downstream from Rock Island, Illinois. A piezometer range site, Range A, was established in March 1957 within the pool area of Lock and Dam 17. The site was located at river mile 448.8 and levee sta 325+07 at a relatively straight reach on the main channel side of the river (Figure 4).

Description of site

34. The geologic profile in Figure 5 was derived from selected deep borings located near the east and west banks of the river.* Boring MID27 at river mile 449.9 was nearest to Range A. The top stratum generally consisted of about 4 to 5 ft of alluvial clayey soil. This was underlain by about 93 ft of poorly graded brown and gray glacial sands. The bedrock was of the middle and upper Devonian Formation.

35. Figure 6 shows a cross section of the site with the original levee ground surface, the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 8.2 to 9.2 ft thick and generally consists of alternating layers of sand and clay. In the first 125 ft landward of the original levee berm and 50 ft landward of the new levee berm, the top 2 to 3 ft appear to be sand, which may be directly exposed to the river at a distance of about 60 ft riverward of the levee center line.

36. The old levee crest elevation** was 552.6, and the average ground elevation at the old berm toe was 541.0. Construction for the

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* K. E. Jensen, et al. 1971 (25 May). "Recent Explorations in the Mississippi River Flood Plain Between Muscatine, Iowa, and Dallas City, Illinois, and Between Warsaw, Illinois, and Belleview, Illinois;" a letter report to Dr. Richard C. Anderson, Chairman, Department of Geology, Augustana College, Rock Island, Ill., 61201, on file in the Rock Island District Office.

** All elevations (el) cited herein are in feet referred to mean sea level (msl).

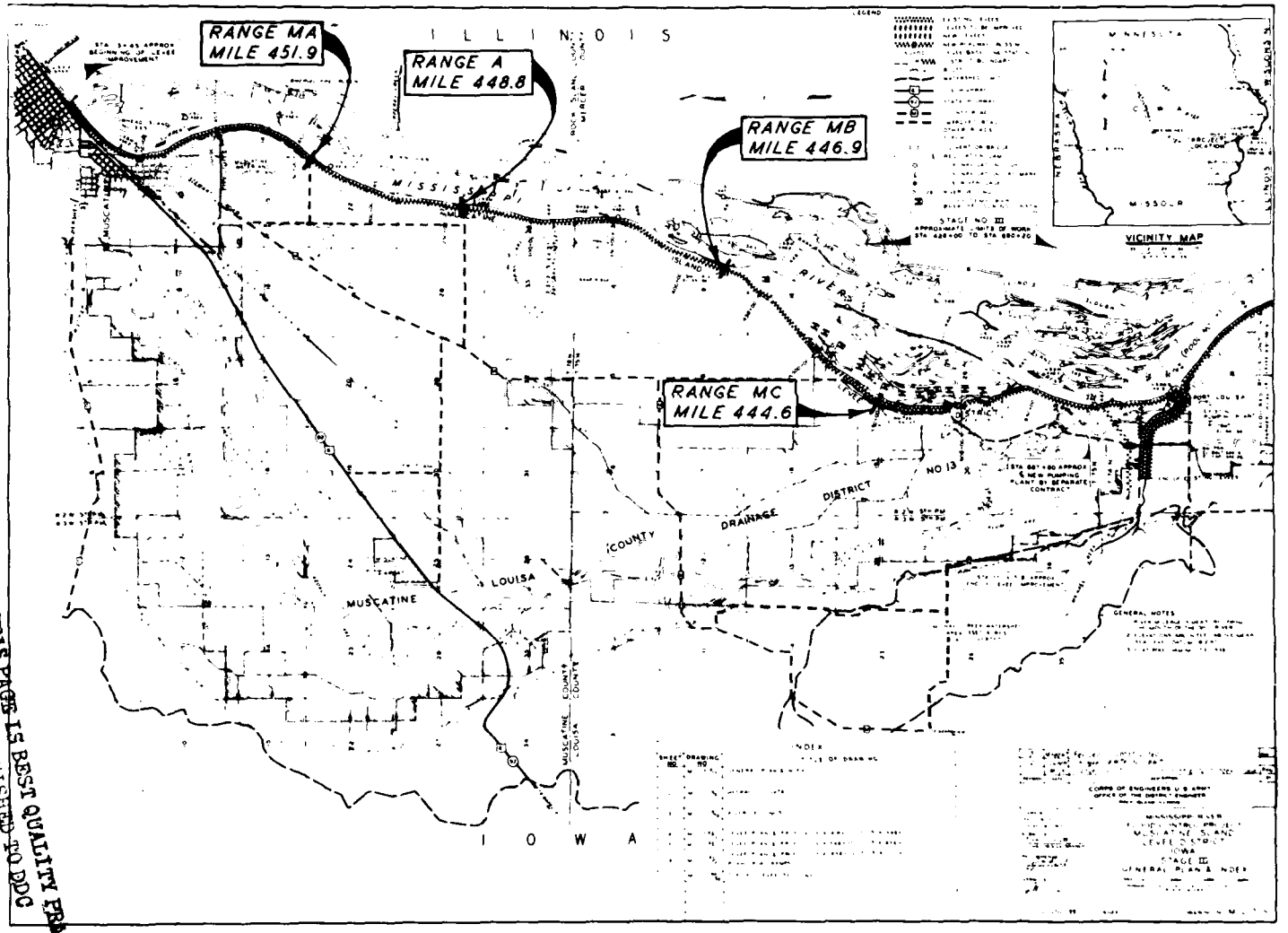

Figure 4. General plan of Muscatine Island Levee District

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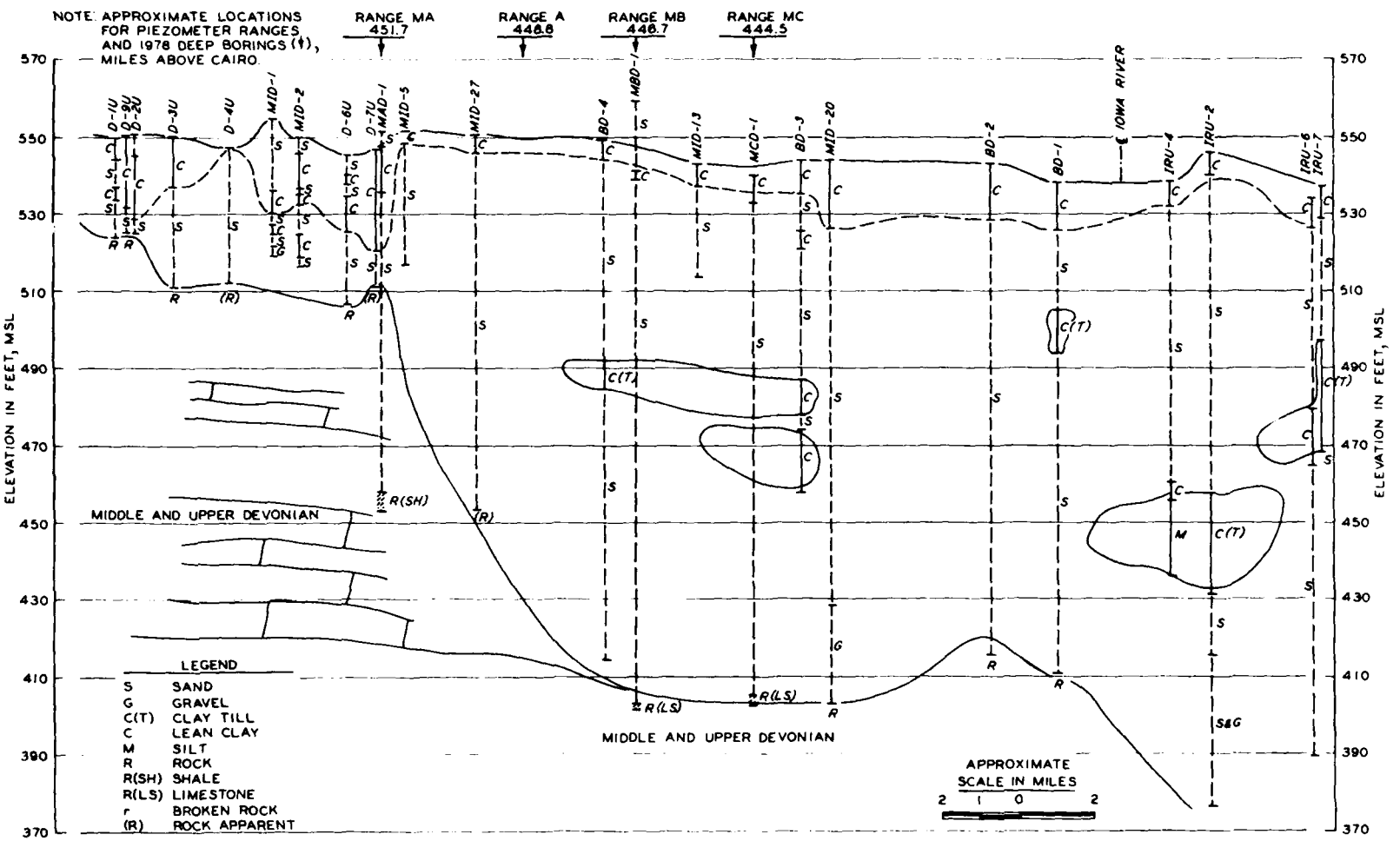

Figure 5. Geologic profile in vicinity of Muscatine Island Levee District

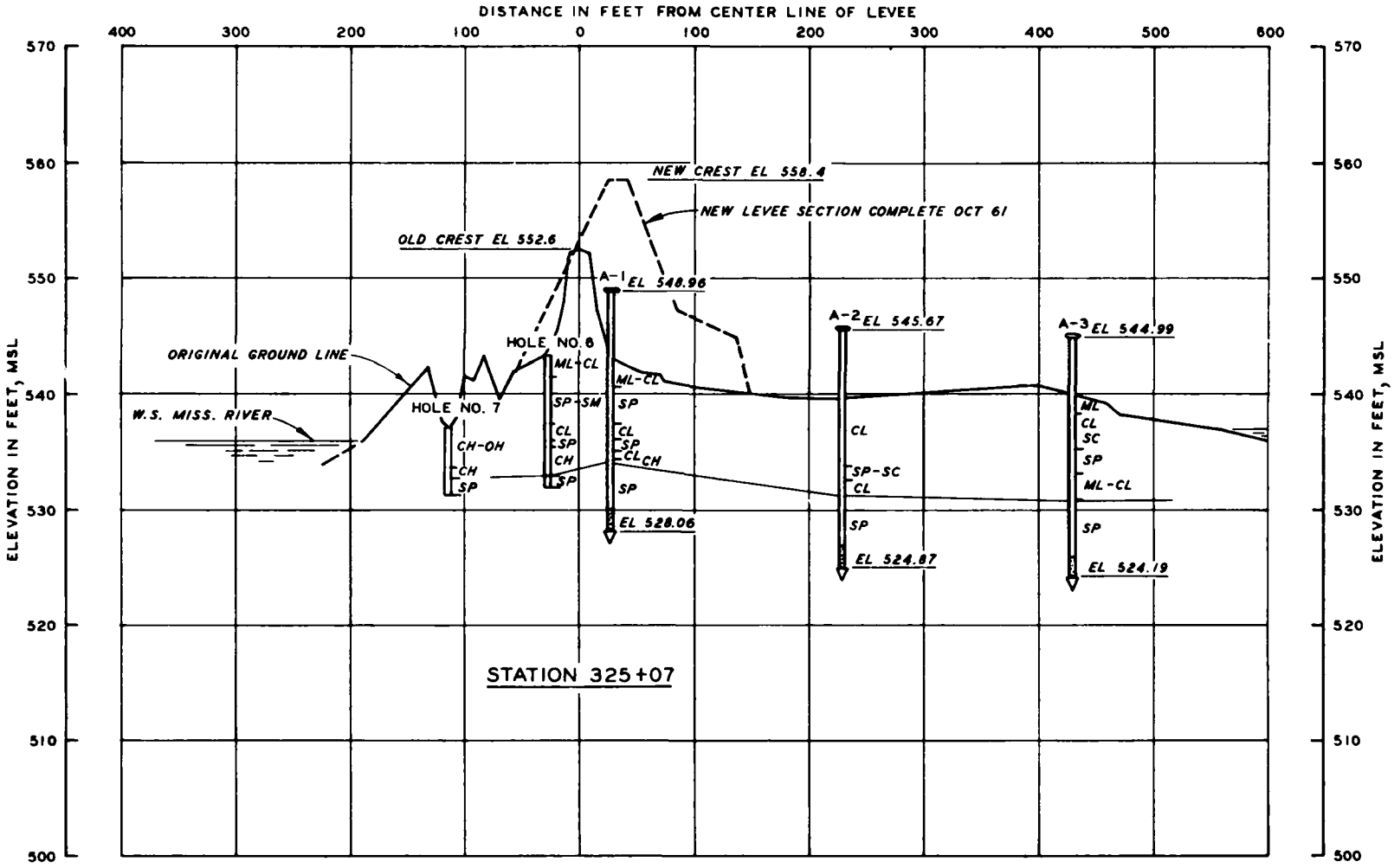

Figure 6. Cross section of Muscatine Island, Piezometer Range A

levee enlargement began in July 1960 and was completed in October 1961. The new levee grade is el 558.4. The exposed pervious substratum at the riverbank was estimated to be 255 ft east of the center line of the levee.

History of underseepage

37. Since the installation of the piezometer range in 1957, only two observations of seepage have been recorded. On 3 April 1960, when the river crested at el 547.72, a little toe seepage was observed, and a great deal of water was reported standing in the road ditch and low areas near the old berm toe. In April 1969, two boils were located beyond the new berm toe when the river crested at el 550.1. No seepage was reported in 1965 and 1975 when higher river stages were experienced.

Analysis of piezometer data

38. The readings from piezometers A-1, A-2, and A-3 in Table 3 are for four different dates. In 1969, no data were obtained from piezometer A-1; thus, it was presumably lost during the construction of the levee enlargement. In Figure 7, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 558.4 can be estimated. Also shown in Figure 7 are estimated piezometric elevation heads for the old levee berm toe and the new berm toe where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

39. At this piezometer range, no riverside piezometer was installed. Therefore, seepage entrance s and seepage exit x_3 distances should not be calculated following procedures presented in paragraphs 12 and 15. However, to illustrate the type of problem that can be encountered, s and x_3 have been calculated using 1960 piezometric pressures from the landside piezometers A-1 and A-2, the two closest to the center line of the levee, and the procedures that would have been appropriate only if both piezometers had been under the levee. Also, s and x_3 have

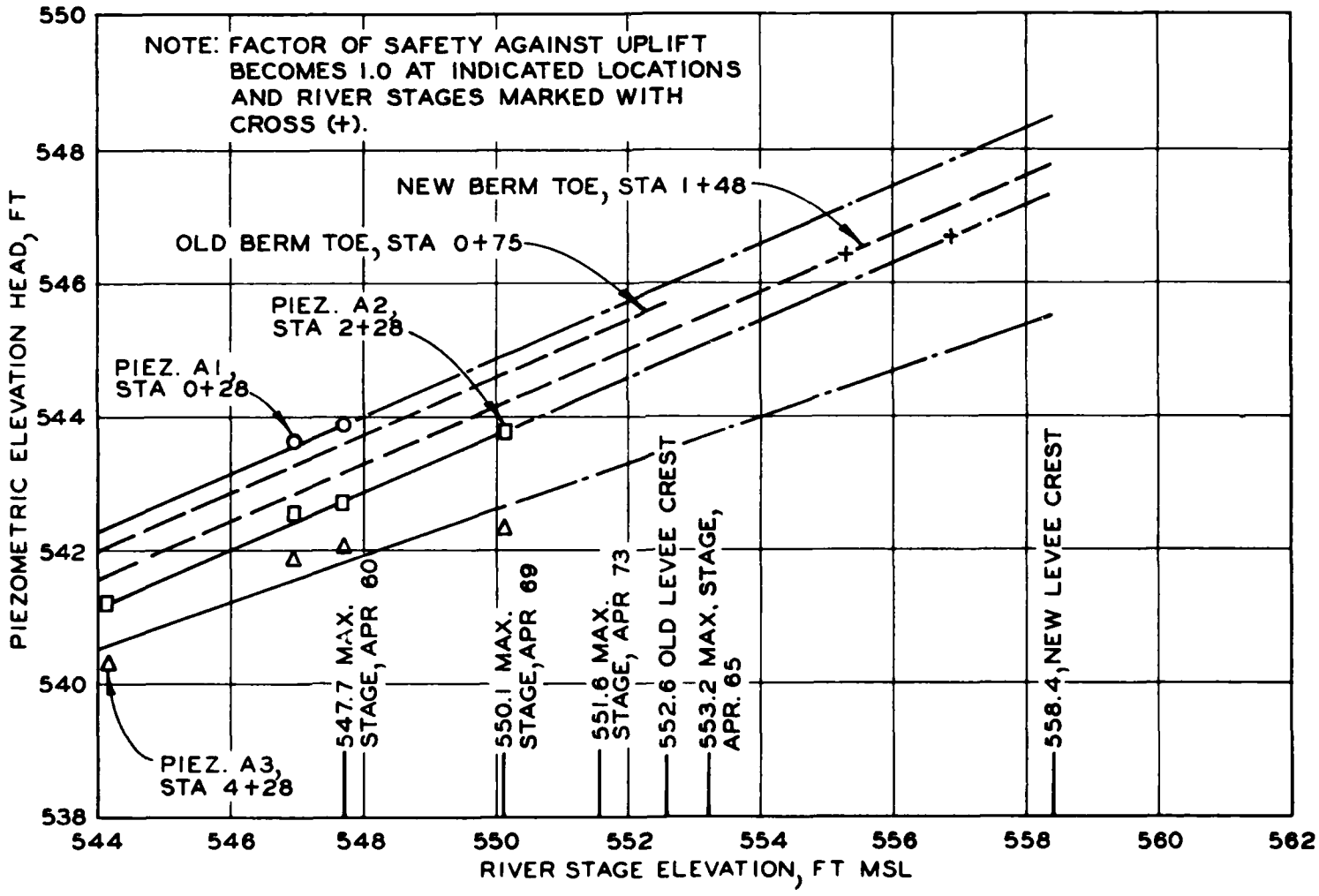

Figure 7. Piezometric elevation head versus river stage, Muscatine Island, Range A

been calculated using 1969 piezometric pressure data from piezometers A-2 and A-3 located 228 and 428 ft landward of the center line of the levee. The average ground elevation landward of the levee toe selected for all the x_3 calculations was 541.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 3 are plotted versus the river stage in Figure 8. For the old crest elevation of 552.6, s was 1150 ft and x_3 was 786 ft. For the new crest elevation of 558.4, s was estimated to be 1700 ft and x_3 was 1200 ft. It should be noted that the calculated s values of 1150 and 1700 ft are significantly greater than the 330-ft distance to the exposed pervious substratum at the riverbank and thus must be considered unreliable; these large values of s and x_3 no doubt would have been substantially smaller had a riverside piezometer been available.

Permeability ratio

40. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee berm toe) was 4.0 ft, $d = 93$ ft, x_3 (for the old crest elevation) was 786 ft, and the calculated $k_f/k_{b\ell}$ was 1660. If a riverside piezometer had been available for the calculation of pressure gradients, there is no doubt that the calculated $k_f/k_{b\ell}$ would have been significantly smaller.

41. Because of the question regarding the reliability of the computed effective seepage exit distance, an alternate procedure for calculating $k_f/k_{b\ell}$ was attempted using the following formula for piezometric pressure beneath a pervious top stratum:

$$e^{cx} = \frac{h_o}{h_x}$$

where

e = the base of the Naperian logarithms

= 2.71828

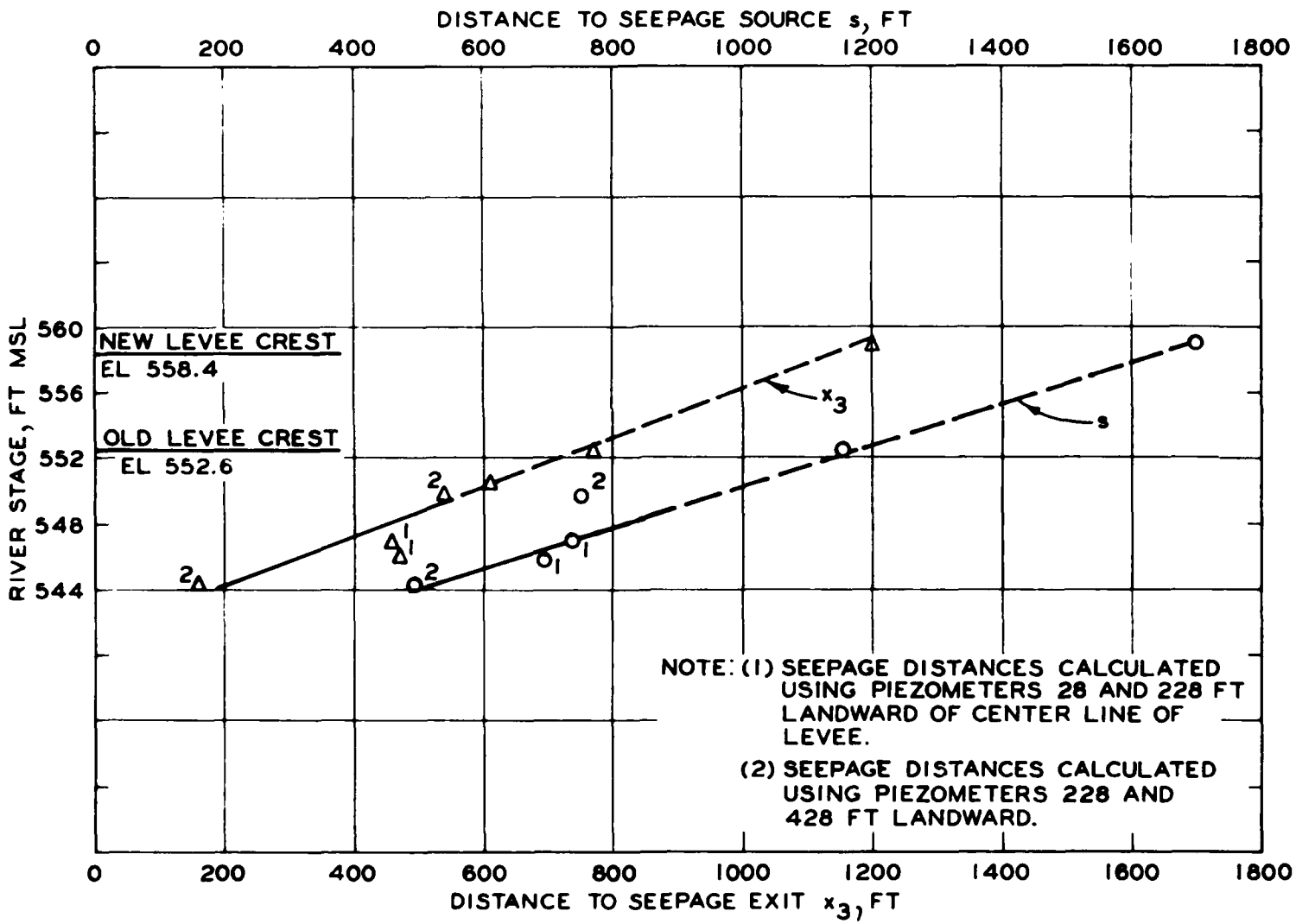

Figure 8. Distances to seepage source and seepage exit, Muscatine Island, Range A

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{b\ell}}\right)\left(z_{b\ell}\right)\left(d\right)}}$$

For the other terms in the formula, see Figure 1. Using ground elevations of 541.0 and 539.7 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 545.7 and 544.8, $k_f/k_{b\ell}$ was calculated to be 9400 when the river is at the old crest elevation of 552.6. This permeability ratio is very unrealistically high; thus, a reliable landside permeability ratio cannot be determined with data available from this site. Also, since no reliable estimate of seepage entrance distance could be made, no riverside permeability ratio could be calculated.

Calculated factors of safety

42. The projected piezometric data in Figure 7 have been used to calculate uplift factors of safety at the old berm toe, the new berm toe, and piezometers A-2 and A-3 for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 4 presents these factors of safety and the data necessary to make the calculations.

43. The type of seepage observed during the flood stages is also shown in Table 4. It is interesting to note that when pin boils beyond the berm toe were reported in 1969, the factor of safety was 1.6; when light toe seepage was observed in 1960, the factor of safety was 1.4; with water standing in low areas in 1960, the factor of safety ranged from 1.4 to 2.3; and when no seepage was reported, the factor of safety ranged as low as 1.2. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.8 to 1.4.

Bay Island, Range C

44. The Bay Island Drainage and Levee District No. 1 is on the east bank of the Mississippi River about 35 miles downstream from Rock Island, Illinois. Two piezometer range sites, Ranges C and D, were established in 1953 within the pool area of Lock and Dam 17 (Figure 9).

45. The geologic profile in Figure 10 was derived from selected deep borings located near the east and west banks of the river. Boring BD4 at river mile 446 was nearest to Range C, and Boring BD3 at about river mile 442 was closest to Range D. The top stratum generally consisted of 4 to 6 ft of alluvial clayey soil. This was underlain by about 135 ft of poorly graded brown and gray glacial sands and gravels. Two intrusions of glacial clays till were indicated. The bedrock was of the Devonian Formation.

Description of site

46. Piezometer Range C site was established on 25 March 1953. The site was at river mile 446.7 and levee sta 330+00 on the outside bank at a moderate band of the main channel of the river (Figure 9). The range line was immediately north of a berm that began at sta 330+00 and continued southward. Figure 11 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 6.2 to 3.3 ft thick and generally consists of about 1.5 ft of organic lean clay overlying lean clay.

47. The old levee crest elevation was 550.8, and the average ground elevation at the levee toe was 542.6. Construction for the levee enlargement began in March 1963 and was completed in January 1965. The new levee grade is el 556.6.

48. A ditch and road parallel to the river was approximately 296 ft landward of the center line of the levee between sta 330+00 and 382+00. The ground elevation 296 ft landward was 540.6. The exposed pervious substratum at the bank of the Mississippi River was estimated to be 710 ft west of the center line of the levee. The piezometer range was reported as destroyed on 14 April 1969.

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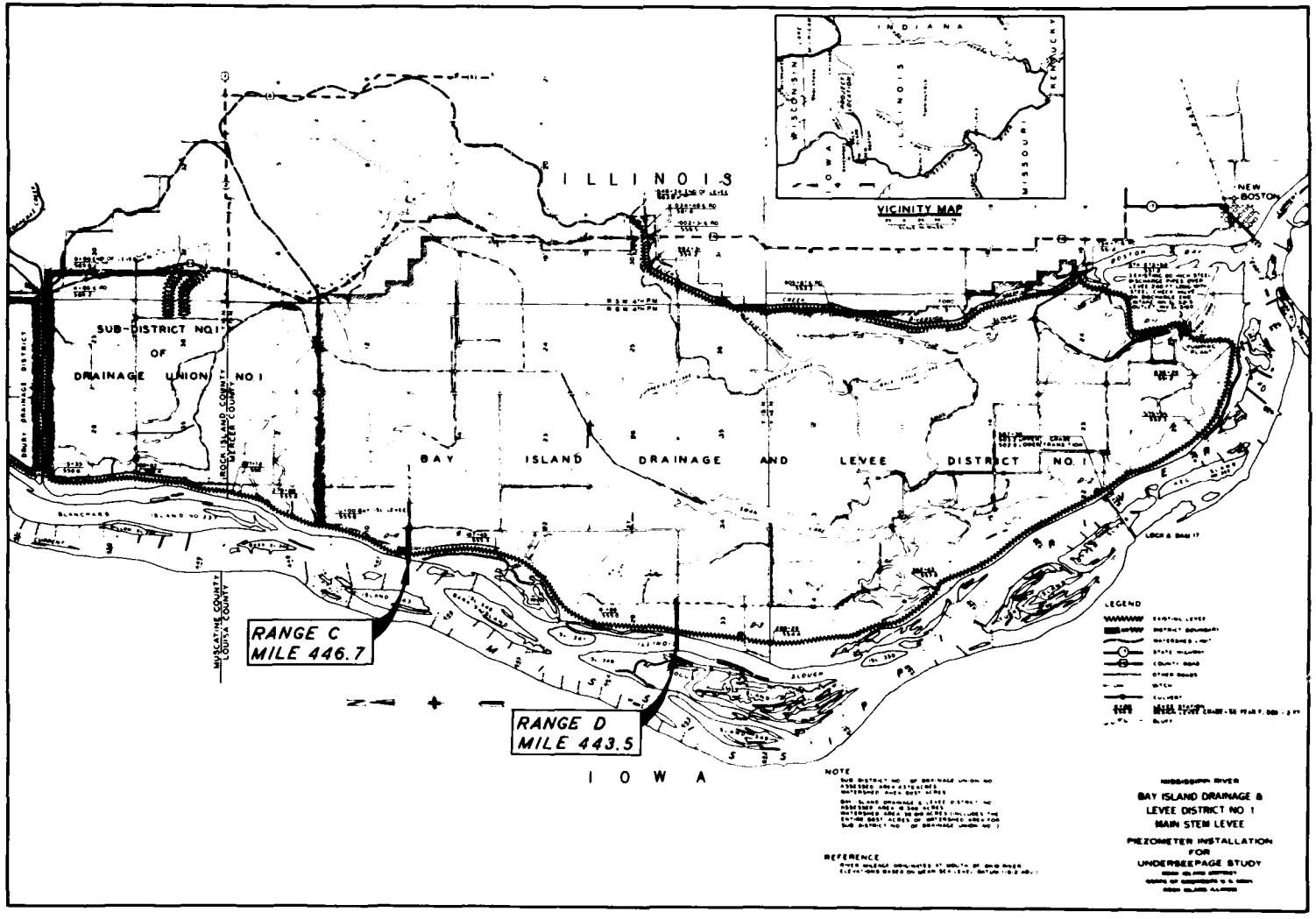

Figure 9. General plan of Bay Island Drainage and Levee District

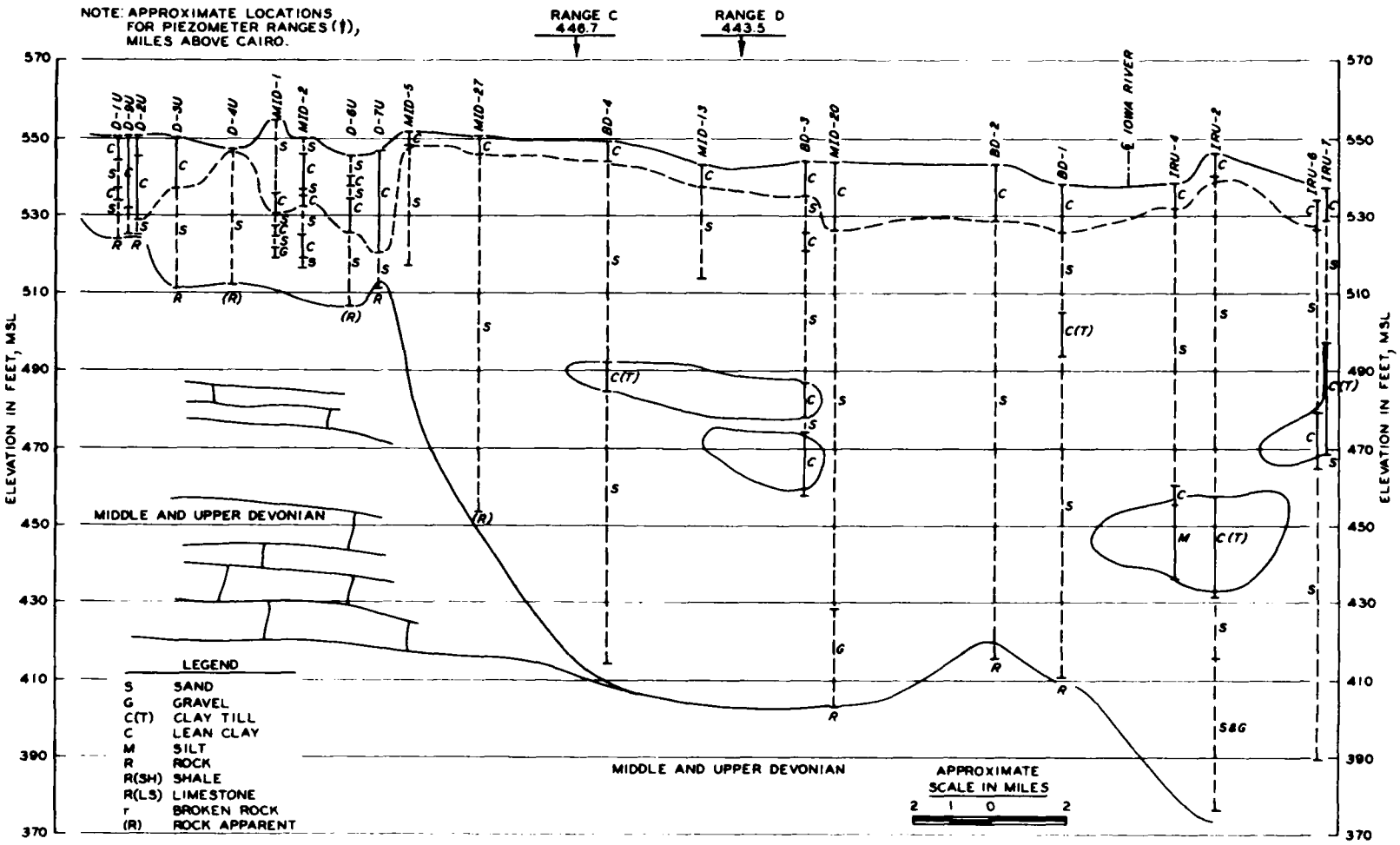

Figure 10. Geologic profile in vicinity of Bay Island Drainage and Levee District

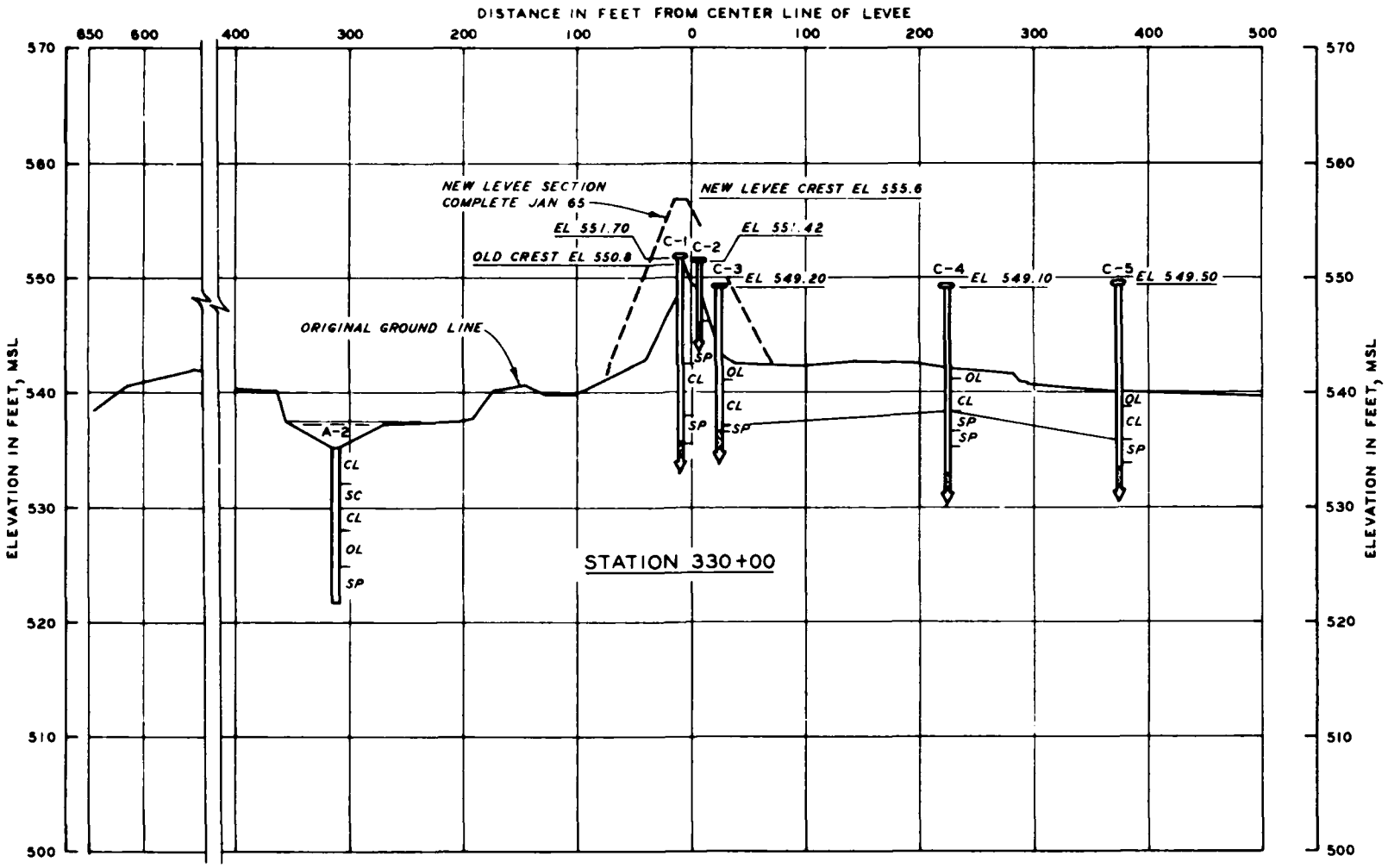

Figure 11. Cross section of Bay Island, Piezometer Range C

History of underseepage

49. Since the installation of the piezometer range in 1953, three observations of seepage have been recorded. On 10 May 1960, when the river crested at el 545.9, a little toe seepage was observed, and a great deal of water was reported standing in the road ditch and low areas. Shortly after completion of the levee enlargement, the river crested at el 552.6 in April 1965, a light toe seepage was reported, and a series of pin boils were located in the ditch between sta 330+00 and 382+00. In April 1969, the fields behind the levee were wet when the river crested at el 549.5.

Analysis of piezometer data

50. The readings from piezometers C-1, C-3, C-4, and C-5 in Table 5 are for five different dates. In Figure 12, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 556.0 can be estimated. Also shown in Figure 12 are estimated piezometric elevation heads for the old levee toe, the new levee toe, and the ditch 296 ft landward of the levee center line where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

51. Data from piezometers C-1 and C-3 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 542.6. In addition, s and x_3 were also calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 5 are plotted versus the river stage in Figure 13. For the old crest elevation of 550.8, s was 307 ft and x_3 was 158 ft. For the new crest elevation of 556.6, s was estimated to be 420 ft and x_3 was 260 ft.

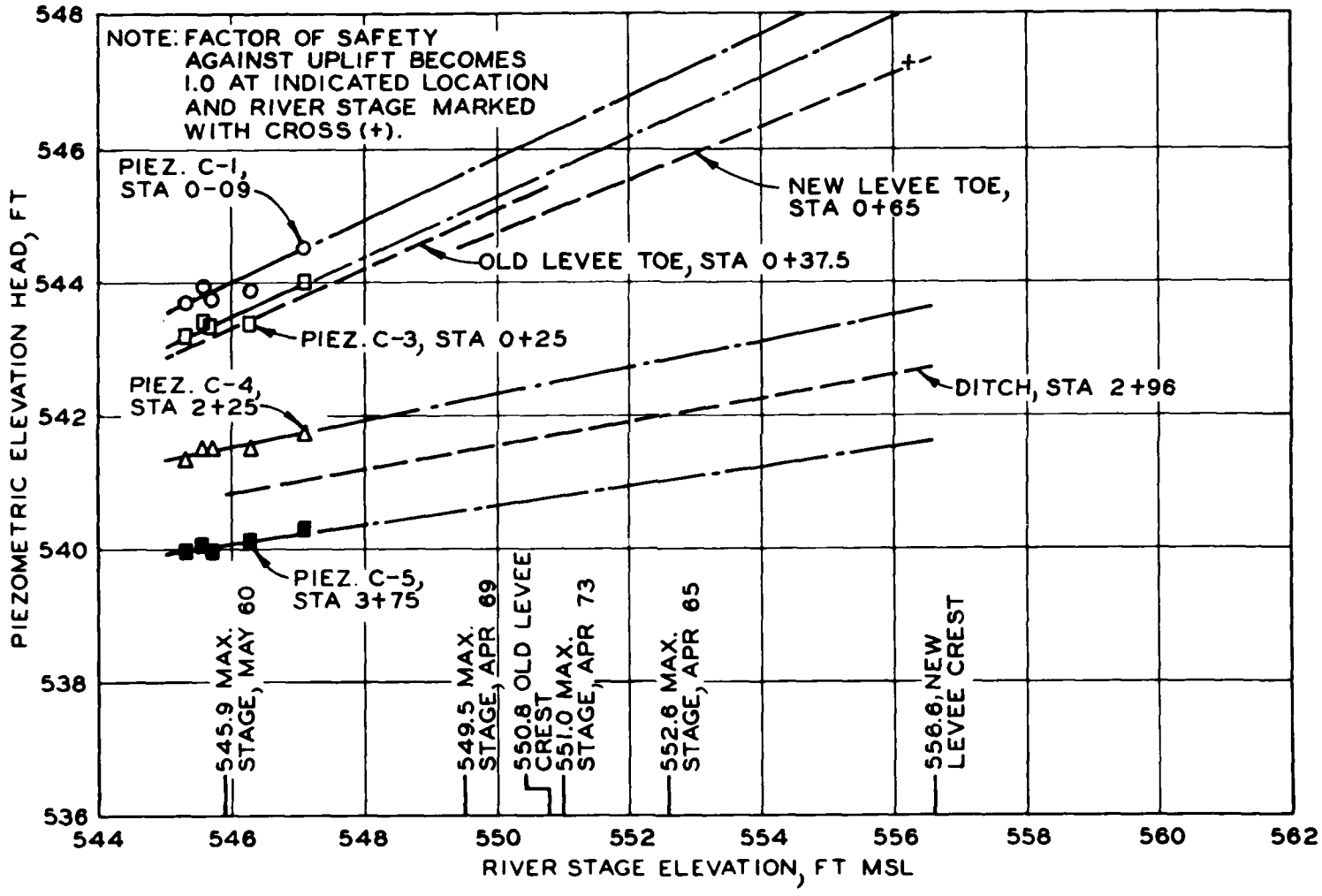

Figure 12. Piezometric elevation head versus river stage, Bay Island, Range C

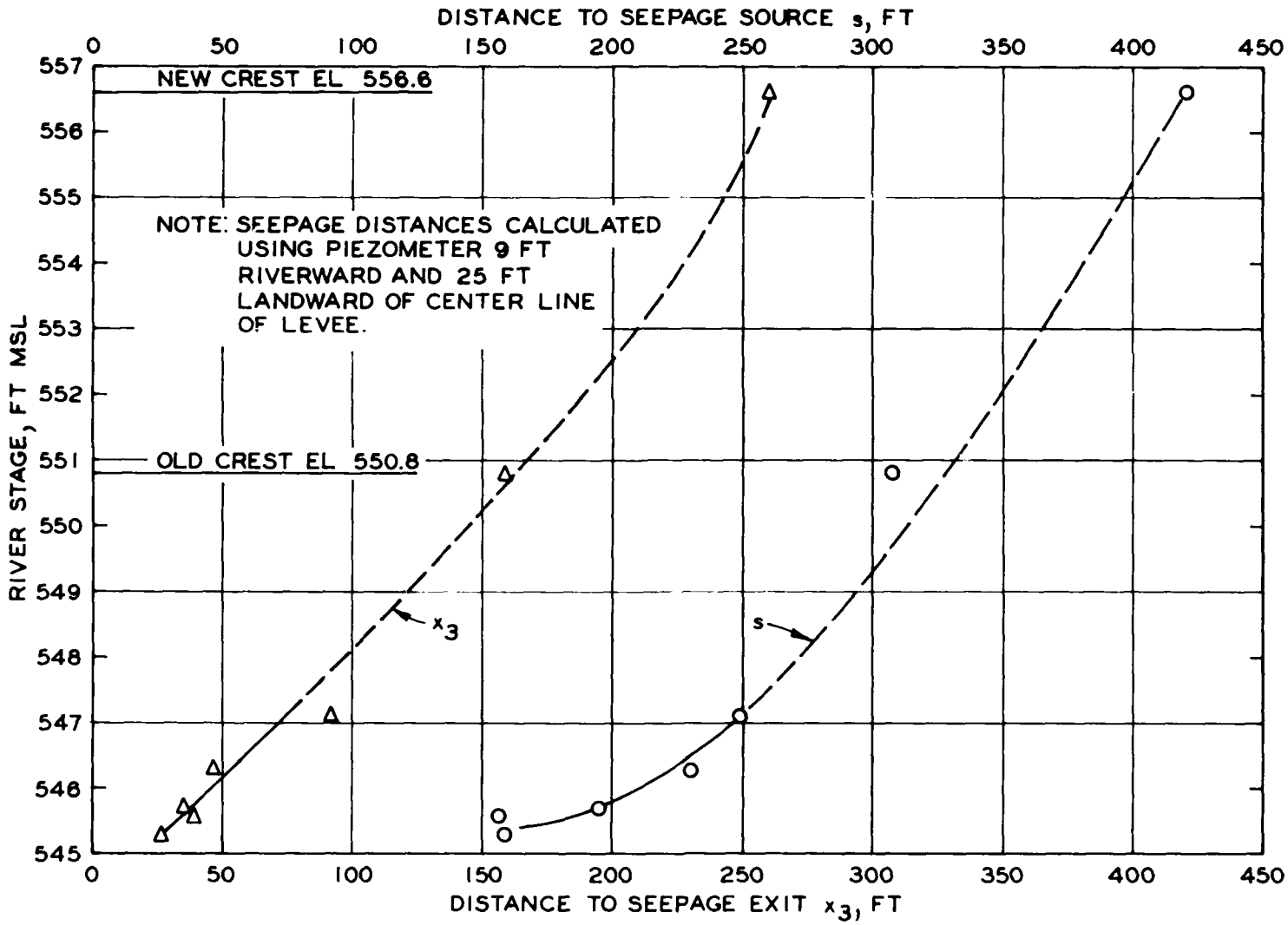

Figure 13. Distances to seepage source and seepage exit, Bay Island, Range C

Permeability ratio

52. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ at the old levee toe was 5.5 ft, $d = 135$ ft , x_3 (for the old crest elevation) was 158 ft, and the calculated $k_f/k_{b\ell}$ was 34.

53. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh (cL_1)}{c}$. For these calculations, $x_1 = 229.5$ ft , $L_1 = 670$ ft , $c = 0.00433$, $z_{br} = 10.0$ ft, $d = 135$ ft , and $k_f/k_{br} = 40$.

Calculated factors of safety

54. The projected peizometric data in Figure 12 have been used to calculate uplift factors of safety at the levee toe and the ditch 296 ft landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 6 presents these factors of safety and the data necessary to make the calculations.

55. The type of seepage observed during the flood stages is also shown in Table 6. It is interesting to note that when pin boils were reported in the ditch in 1965, the factor of safety was 2.0; when fields were wet and soft in 1969, the factor of safety was 3.2; when toe seepage was observed in 1960 and 1965, the factor of safety ranged from 1.5 to 6.3; and when no seepage was reported, the factor of safety ranged as low as 1.9. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.0 to 1.2.

Bay Island, Range D

Description of site

56. This piezometer range site was established on 27 March 1953.

The site was at river mile 443.5 and levee sta 502+49 near the bank of the Illinois slough of the Mississippi River (Figure 9). The levee at this location was separated from the main channel of the river by about a mile of timbered land and meandering water channels. Figure 14 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 12.0 to 14.1 ft thick and generally consists of about 0.5 to 2.7 ft of organic lean clay overlying low to highly plastic clay.

57. The old levee crest elevation was 552.1, and the average ground elevation at the levee toe was 539.0. Construction for the levee enlargement began in March 1963 and was completed in January 1965. The new levee grade is el 555.4. The exposed pervious substratum at the bank of the slough at the piezometer range was estimated to be 185 ft west of the center line of the levee. Piezometers D-4 and D-5 were read in April of 1969, but no data were obtained from piezometers D-1 and D-3; it is presumed that these latter piezometers were destroyed during the levee enlargement operation during the period 1963 to 1965. Piezometer D-2, an embankment piezometer, was reported as destroyed in April 1960.

History of underseepage

58. Since the installation of the piezometer range in 1953, three observations of seepage have been recorded. On 3 April 1960, light toe seepage was observed, one small sand boil running with clear water was located near piezometer D-4, and water was reported standing in all low areas. In 1965, light toe seepage was reported; in 1969, some very heavy toe seepage; and in 1973, no seepage.

Analysis of piezometer data

59. The readings from piezometers D-1, D-3, D-4, and D-5 in Table 7 are for five different dates. In Figure 15, piezometer data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 555.4 can be estimated. Also shown in Figure 15 are estimated piezometric elevation heads for the new levee toe. This

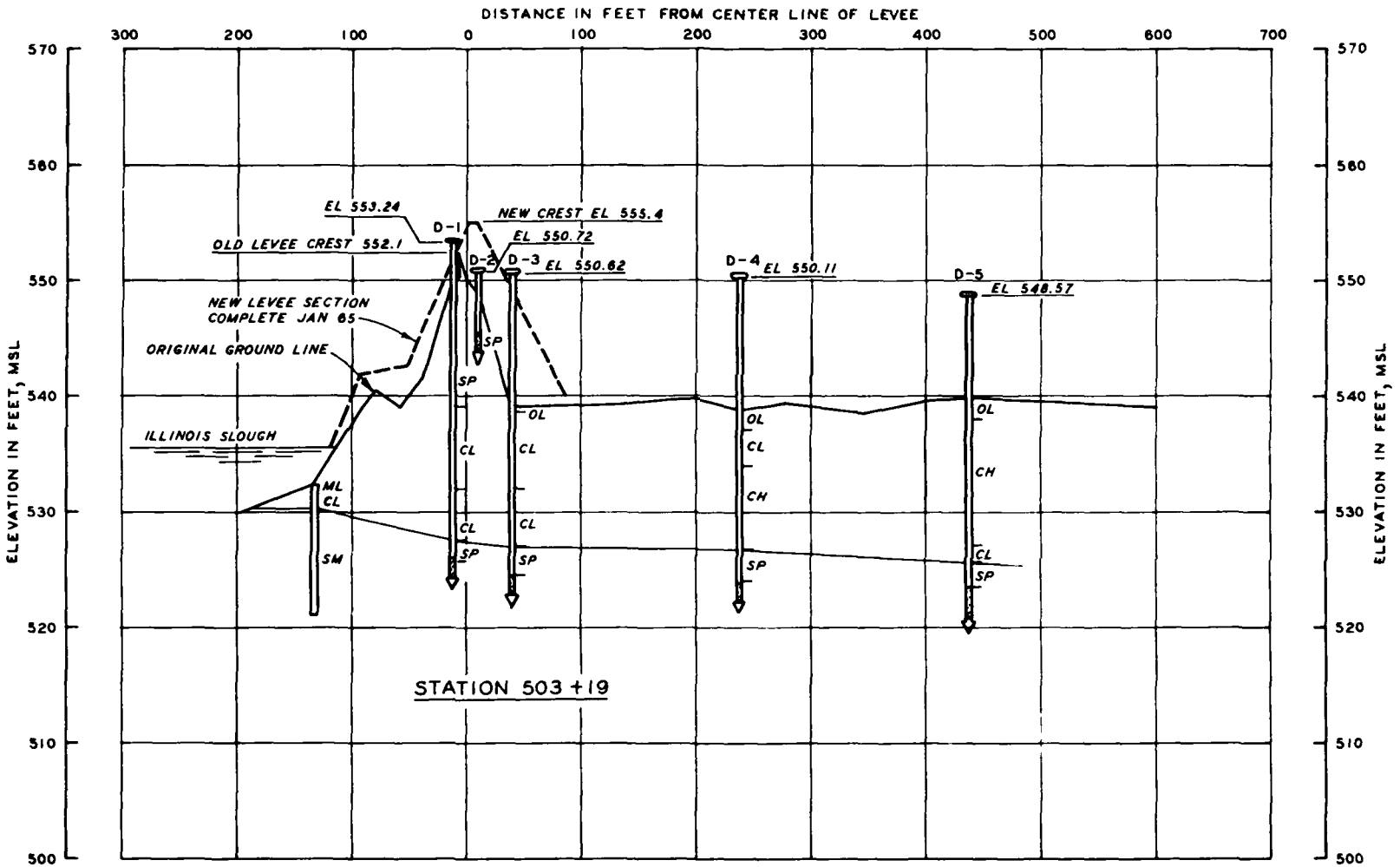

Figure 14. Cross section of Bay Island, Piezometer Range D

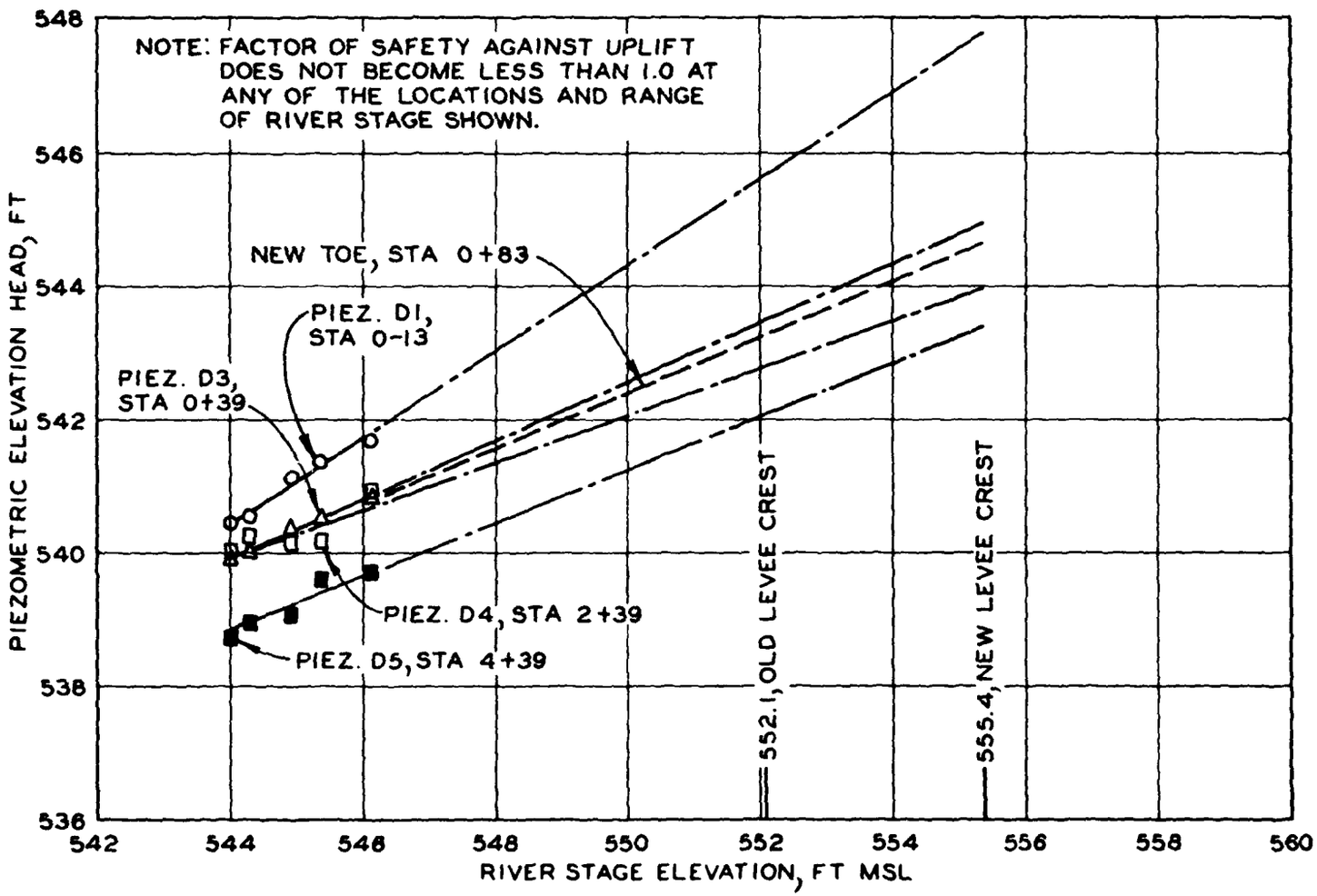

Figure 15. Piezometric elevation head versus river stage, Bay Island, Range D

plot of piezometric elevation head was determined by linear interpolation of the projected heads for piezometers D-3 and D-4 to the intermediate location between the piezometers. Since piezometer D-3 was located at the old levee toe, piezometric pressure heads at the old levee toe are the same as those recorded for piezometer D-3.

60. Data from piezometers D-1 and D-3 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 539.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 7 are plotted versus river stage in Figure 16. For the old crest elevation of 552.1, s was 203 ft and x_3 was 106 ft. For the new crest elevation of 555.4, s was estimated to be 163 ft and x_3 was 102 ft.

Permeability ratio

61. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 12 ft, $d = 130$ ft , x_3 (for the old crest elevation) was 106 ft, and the calculated $k_f/k_{b\ell}$ was 7.2.

62. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh (cL_1)}{c}$. For these calculations, $x_1 = 114$ ft , $L_1 = 135$ ft , $c = 0.00561$ ft , $z_{br} = 12.0$ ft , $d = 130$ ft , and $k_f/k_{br} = 20$.

Calculated factors of safety

63. The projected piezometric data in Figure 15 have been used to calculate uplift factors of safety at the levee toe for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for

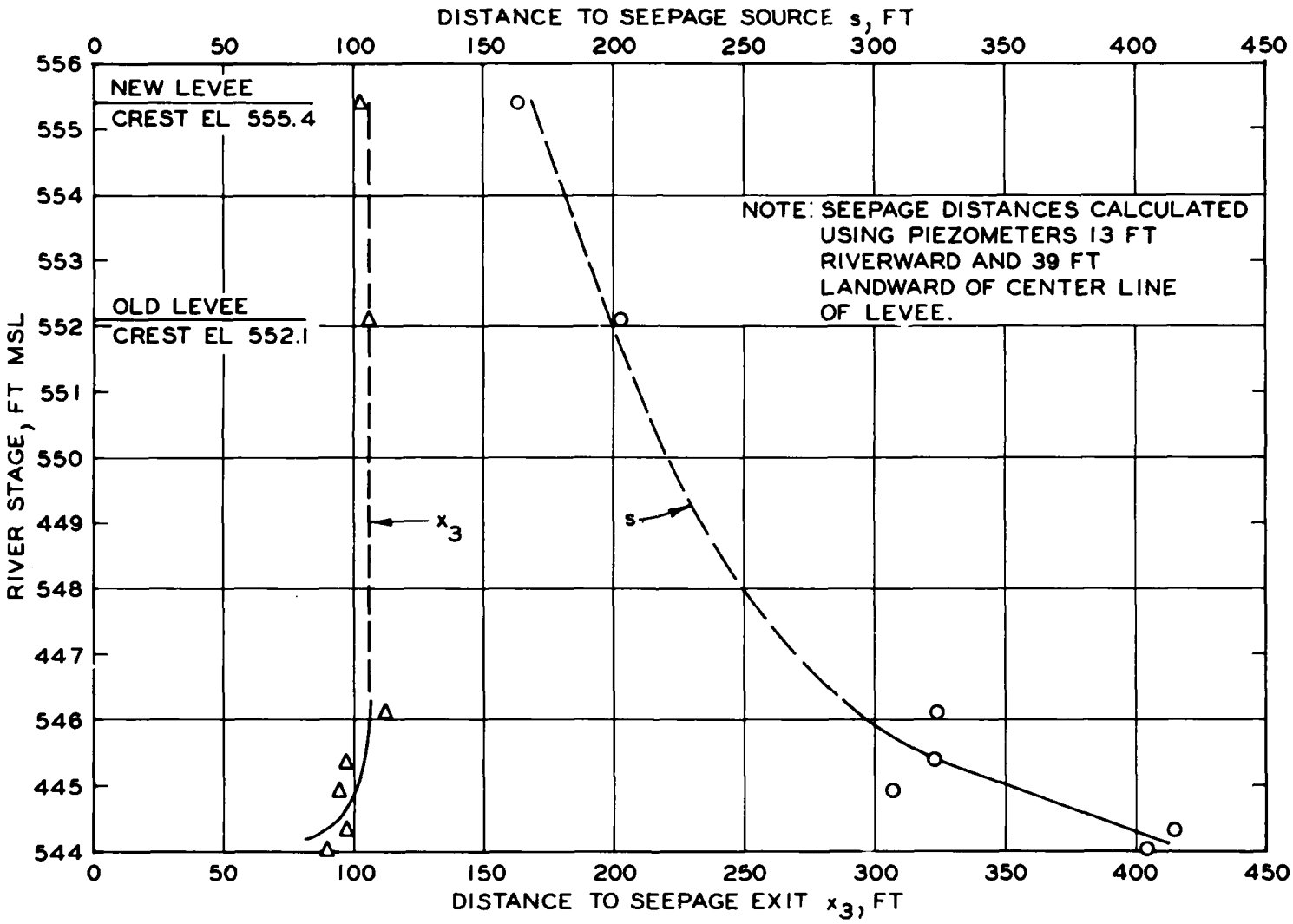

Figure 16. Distances to seepage source and seepage exit, Bay Island, Range D

a river stage equal to the crest of the levee. Table 8 presents these factors of safety and the data necessary to make the calculations.

64. The type of seepage observed during the flood stages is also shown in Table 8. It is interesting to note that when pin boils were reported in the vicinity of piezometer D-4 in 1960, the factor of safety was 4.2, whereas in 1969, and in 1973 when no seepage was reported, the factor of safety ranged as low as 2.4. When light toe seepage and standing water were observed in 1960 and light toe seepage again in 1965, the factor of safety ranged from 3.3 to 5.3. When heavy toe seepage was noted in 1969, the factor of safety was 5.5. When no seepage was reported in 1973, the factor of safety at the landside toe was estimated to be 3.6. The calculated factor of safety for a river stage equal to the crest of the new levee ranges as low as 1.8.

Iowa River, Range A

65. The Iowa River-Flint Creek Levee District No. 16 is located on the west bank of the Mississippi River about 15 miles upstream from Burlington, Iowa. One piezometer range site, Range A, was established in April 1957 within the pool area of Lock and Dam 18. The site was at river mile 418.8 and levee sta 391+00 adjacent to the main channel side of the river (Figure 17).

Description of site

66. Figure 18 shows a geologic profile of the area. Boring IRU 19 at about river mile 416.3 was the closest deep boring to this range. Borings IRU 14 and IRU 15 located approximately 0.6 mile upstream are relatively shallow borings extending to a depth of only about 35 ft. These borings indicate that the top stratum of claylike materials is about 5 ft thick and is underlain by about 114 ft of pervious material.

67. Figure 19 presents a cross section of the site showing the original and new levee sections, the foundation, and piezometer locations. The top stratum consists generally of lean clay with some thin strata of silt and fat clay and ranges in thickness from 4.4 to 5.8 ft.

68. The old levee crest elevation was 538.9, and the average

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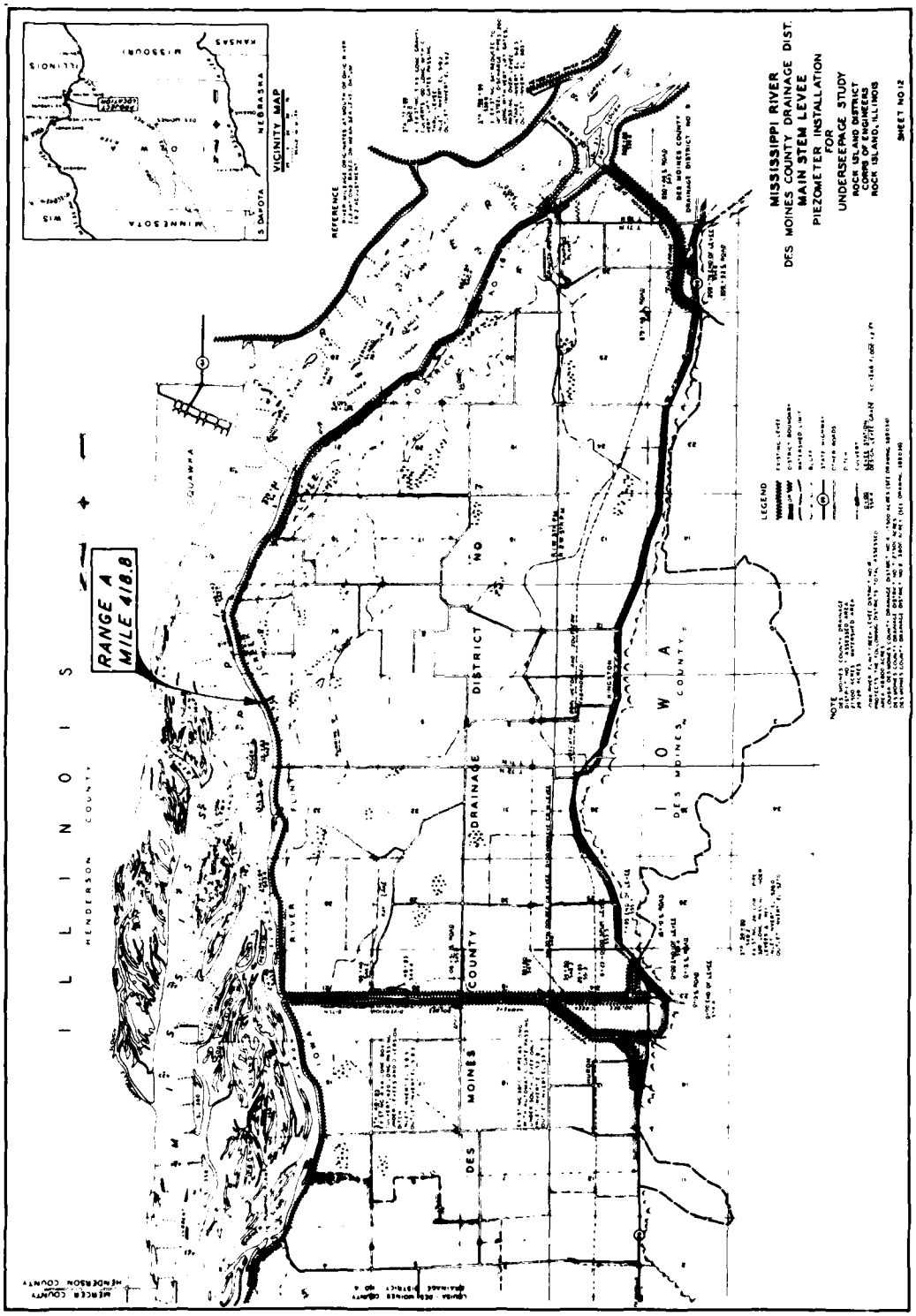

Figure 17. General plan of Iowa River-Flint Creek Levee District No. 16

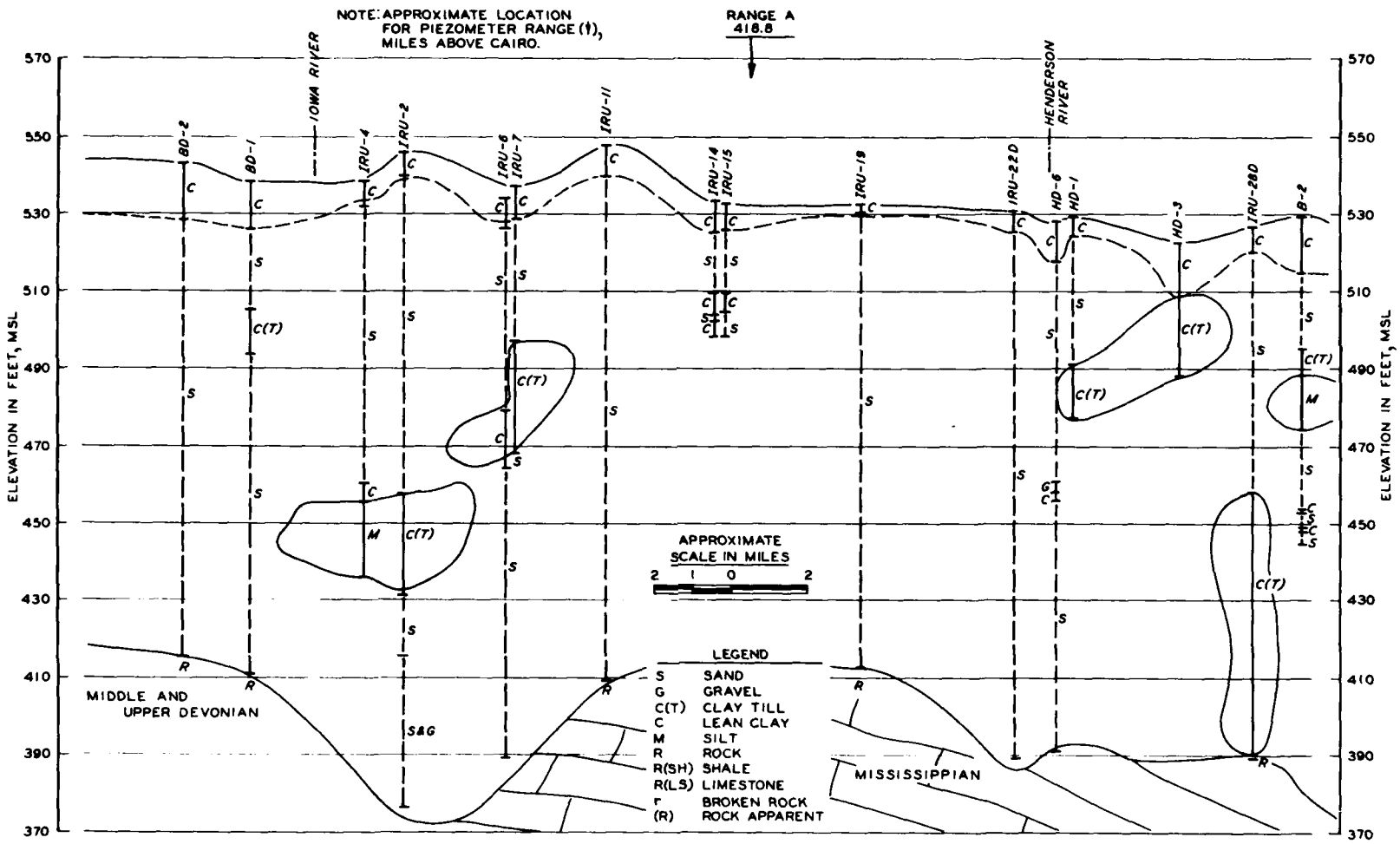

Figure 18. Geologic profile in vicinity of Iowa River

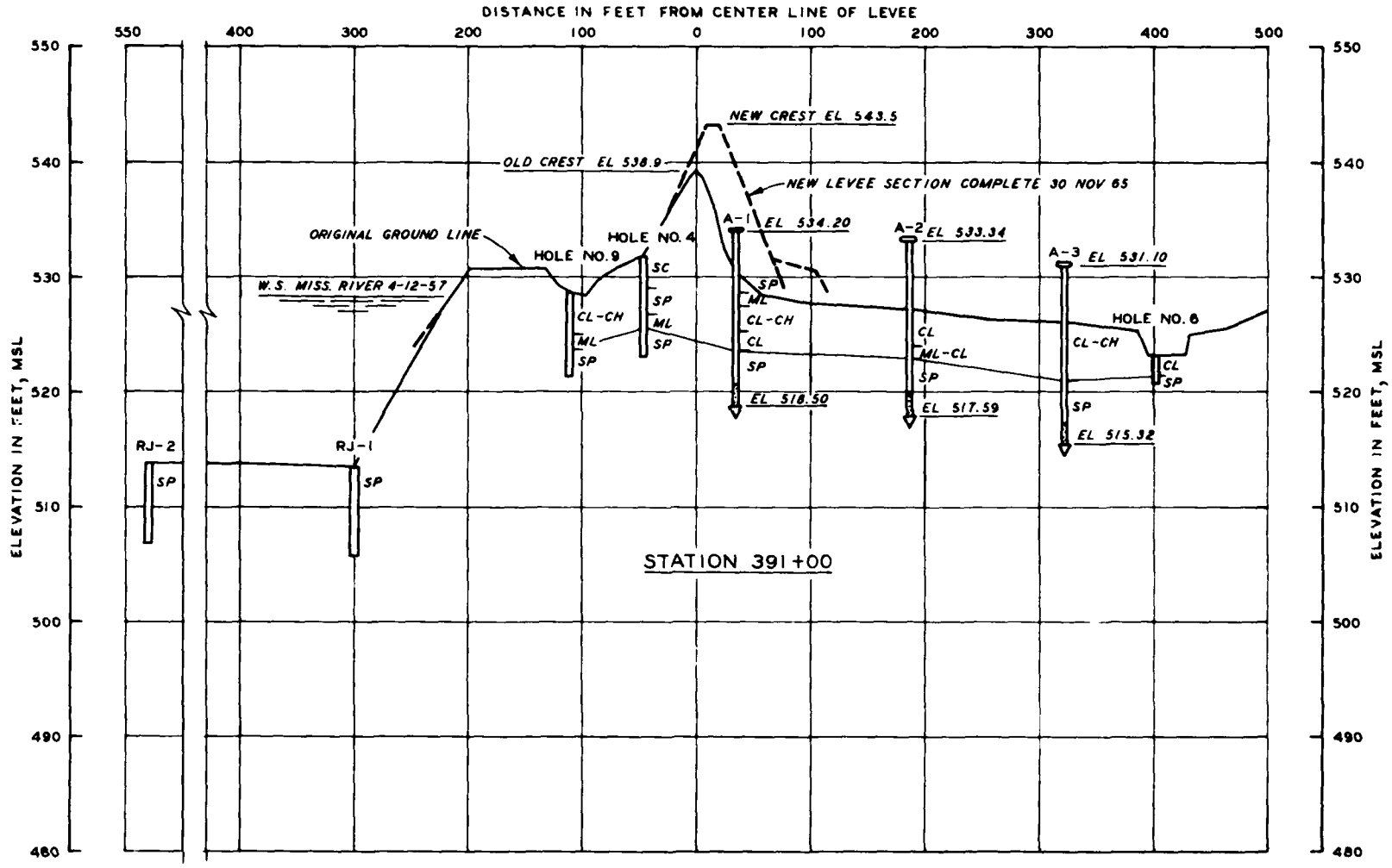

Figure 19. Cross section of Iowa River, Piezometer Range A

ground elevation at the levee toe was 528.5. Construction for the levee enlargement began in August 1963 and was completed in November 1965. The new levee grade is el 543.5. The exposed pervious substratum at the bank at the Mississippi River was estimated to be 240 ft east of the center line of the levee. A 2-ft-deep ditch about 40 ft wide was located about 400 ft landward of the center line of the levee. During construction of the levee enlargement, a 30-ft-wide berm about 3 ft thick was added at the levee toe.

History of underseepage

69. Since the installation of the piezometer range in 1957, three observations of seepage have been recorded. On 3 April 1960, when the river crested at el 535.4, a very small amount of toe seepage was observed. On 28 April 1965, when the river crested at el 538.9, the berm was reported wet, and pin boils were located in the area of the ditch 395 ft landward of the center line of the levee. In April 1969, when the river crested at el 535.9, the berm was reported moist. In April 1973, when the river crested at el 539.8, no seepage was observed.

Analysis of piezometer data

70. The readings from piezometers A-1, A-2, and A-3 in Table 9 are for two different dates. In Figure 20, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 543.5 can be estimated. Also shown in Figure 20 are estimated piezometric elevation heads for the old levee toe, the new berm toe, and the ditch 395 ft landward of the center line of the levee. These latter plots of piezometric elevation heads were determined by linear interpolation of projected heads for the piezometer locations to the intermediate locations between the piezometers.

71. At this piezometer range, no riverside piezometer was installed. Therefore, the effective seepage source s and the effective seepage exit x_3 distances were calculated for each date of piezometer observation using piezometric pressures recorded by piezometers A-1 and A-2, the two piezometers that were closest to the center line of the levee. The average ground elevation landward of the levee toe selected for

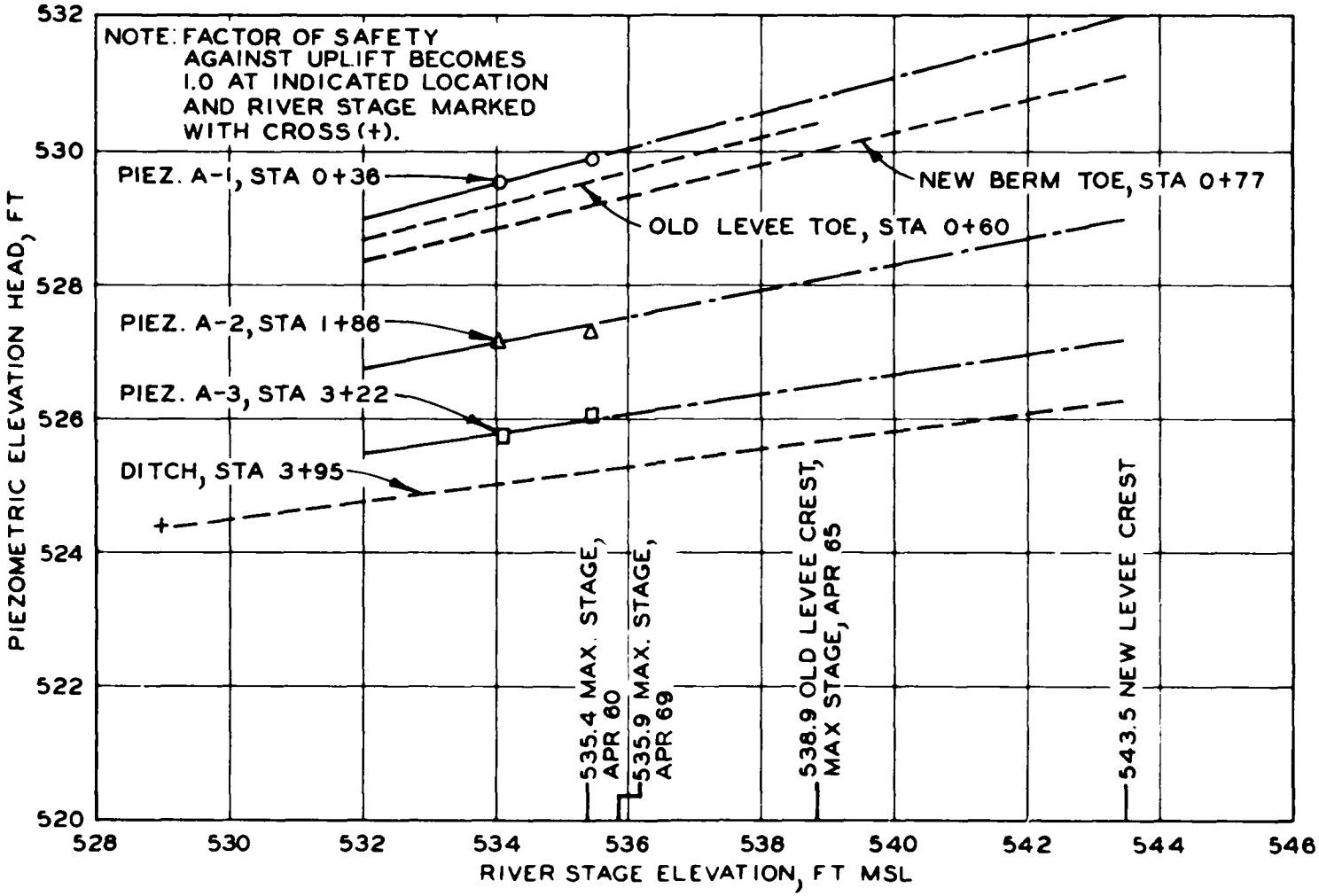

Figure 20. Piezometric elevation head versus river stage, Iowa River, Range A

these calculations was 528.5. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 9 are plotted versus the river stage in Figure 21. For the old crest elevation of 538.9, s was 474 ft and x_3 was 104 ft. For the new crest elevation of 543.5, s was estimated to be 599 ft and x_3 was 151 ft. It should be noted that the calculated s values of 474 and 599 ft are significantly greater than the 300-ft distance to the exposed pervious substratum at the riverbank. Therefore, if a riverside piezometer had been available, the calculated values of both s and x_3 would probably have been smaller.

Permeability ratio

72. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 5.0 ft, $d = 114$ ft , x_3 (for the old levee crest elevation) was 104 ft, and the calculated $k_f/k_{b\ell}$ was 19. If a riverside piezometer had been available at this range, it is likely that the seepage exit distance would have been smaller; thus, the calculated $k_f/k_{b\ell}$ would also have been smaller.

73. The alternate procedure involving the formula $e^{cx} = ho/hx$ for calculating $k_f/k_{b\ell}$ as described in paragraph 41 was also used for this site. Using ground elevations of 528.5 and 527.2 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 530.45 and 528.1, $k_f/k_{b\ell}$ was calculated to be 47. This is about the same as that previously computed, so at this site both methods are in fair agreement even though both may be high. Since no reliable estimate of seepage entrance distances could be made, no riverside permeability ratio could be calculated for this site.

Calculated factors of safety

74. The projected piezometric data in Figure 20 have been used to calculate uplift factors of safety at the old levee toe, the new berm toe, and the ditch 395 ft landward of the center line of the levee for

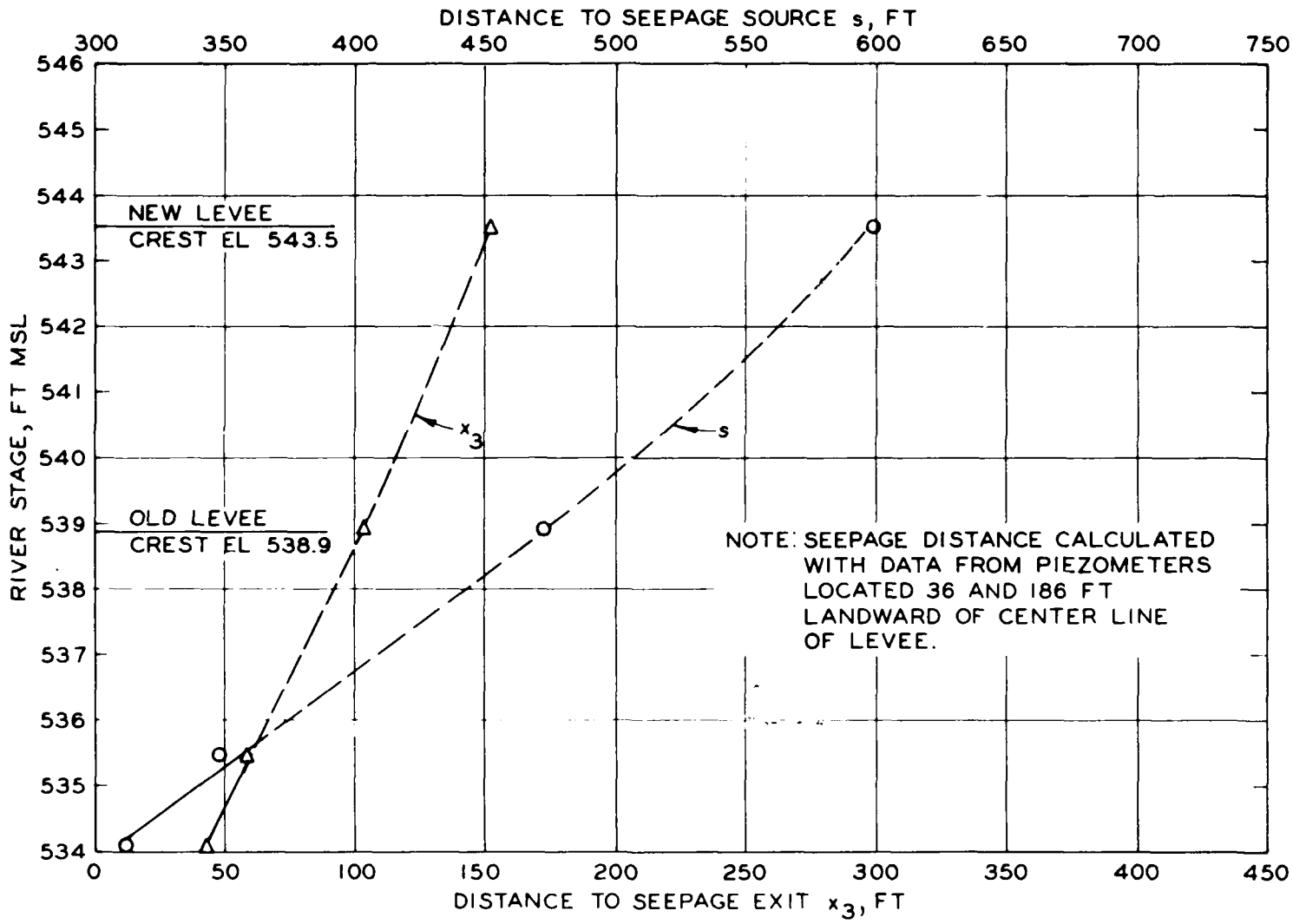

Figure 21. Distances to seepage source and seepage exit, Iowa River, Range A

the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as a critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 10 presents these factors of safety and the data necessary to make the calculations.

75. The type of seepage observed during the flood stages is also shown in Table 10. It is interesting to note that when pin boils were reported in the general area in 1965, the factor of safety in the ditch 395 ft landward of the center line of the levee was 0.5. When the berm was reported wet in 1965 and moist in 1969, the factors of safety were 2.4 and 4.0, respectively, at the berm toe. When light toe seepage was observed in 1960, the factor of safety at the levee toe was 3.6. On other occasions when no seepage was observed, the factors of safety ranged from 0.5 to 2.4. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.4 in the ditch to 1.4 at the berm toe.

Green Bay, Range A

76. The Green Bay Levee and Drainage District No. 2 is on the west bank of the Mississippi River about 10 miles downstream from Burlington, Iowa. One piezometer range site, Range A, was established in April 1957 within the pool area of Lock and Dam 19. The site was at river mile 390.8 and levee sta 652+70 on the main channel side of the river but in an area that may receive some protection from islands immediately upstream (Figure 22).

Description of the site

77. The geologic profile in Figure 23 was derived from selected deep borings located near the west bank of the river. Boring GBD1 near river mile 390 was the nearest deep boring to the piezometer range. The top stratum generally consisted of 4 to 9 ft of lean to fat clay. This

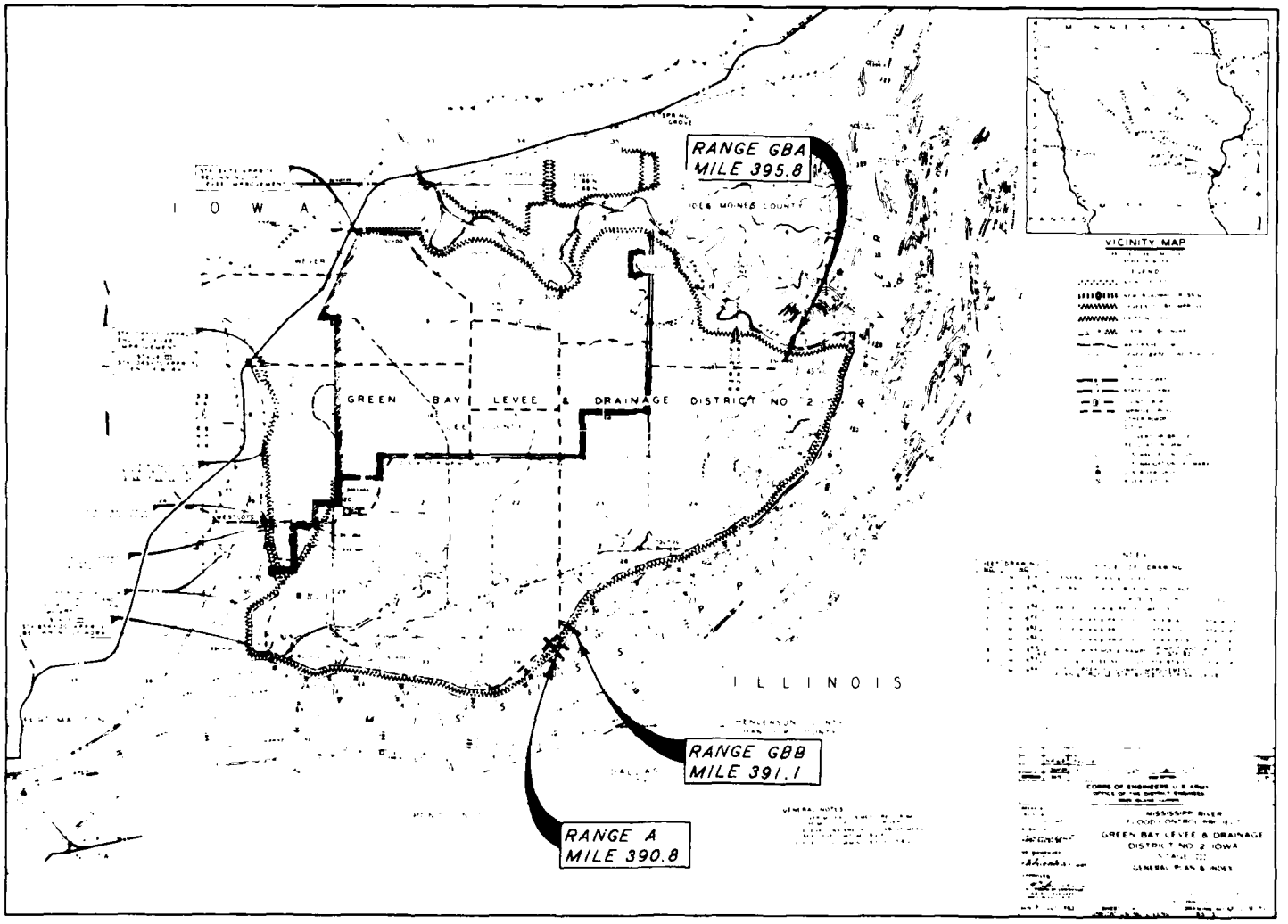

Figure 22. General plan of Green Bay Levee and Drainge District No. 2

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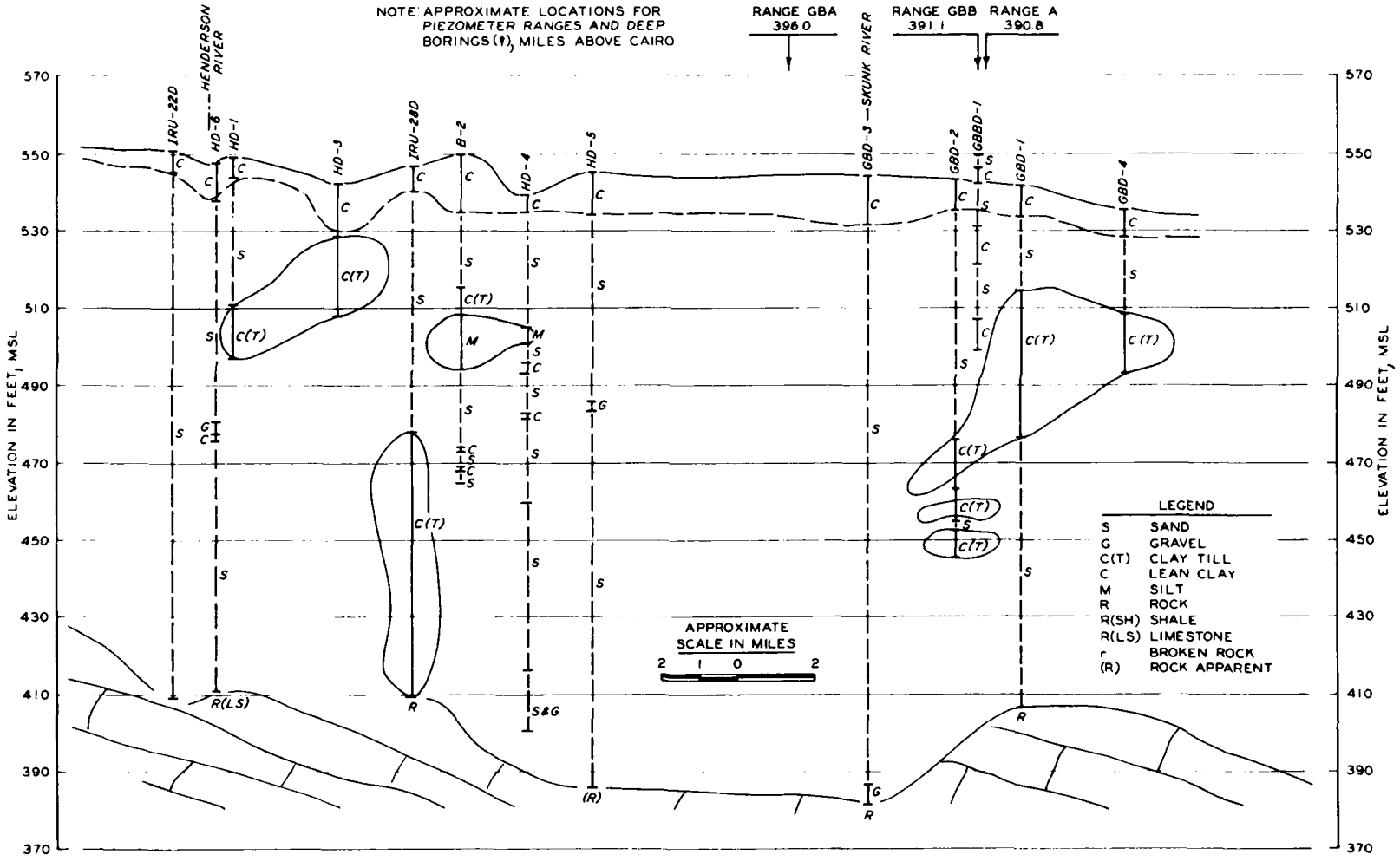

Figure 23. Geologic profile in vicinity of Green Bay Drainage District

was underlain by a 126 ft stratum of pervious materials with a 38-ft-thick inclusion of clay till beginning at a depth of 28 ft. Bedrock was of the Mississippi formation.

78. Figure 24 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 4.0 to 9.1 ft thick and consists of lean to fat claylike material.

79. The elevation of both the old and new levee crests is 529.9. Construction for the levee enlargement began in August 1965 and was completed in November 1965.

80. Two ditches were located landward of the levee. The first was 50 ft wide with the near edge only 80 ft landward of the center line, and the second was about 30 ft wide with the center 700 ft from the center line of the levee. The exposed pervious substratum at the bank of the river is estimated to be 555 ft from the center line of the levee.

History of underseepage

81. Since the installation of the piezometer range in 1957, four observations of seepage have been recorded. In April 1960, with a river stage of el 526.1, light toe seepage and standing water in low areas were observed. In April 1965, when the river crested at el 526.5, through seepage was reported and the levee was saturated one-third the distance up the slope. In April 1969, when the river crested at el 524.4, pin boils were noted in a seepage ditch near the levee toe. In April 1973, when the river crested at el 526.8, light toe seepage and pin boils in a ditch were reported.

Analysis of piezometer data

82. The readings from piezometers A-1, A-2, and A-3 in Table 11 are for three different dates. In Figure 25, piezometric data are plotted, and piezometric elevation heads are projected to a river stage of el 529.9, the elevation of both the old and new levee crests. With this projection, piezometric pressures for all river stages up to el 529.9 ft can be estimated. Also shown in Figure 25 are estimated piezometric elevation heads for the old levee toe, the ditch near the old levee toe, the new levee toe, and the ditch 700 ft landward of the

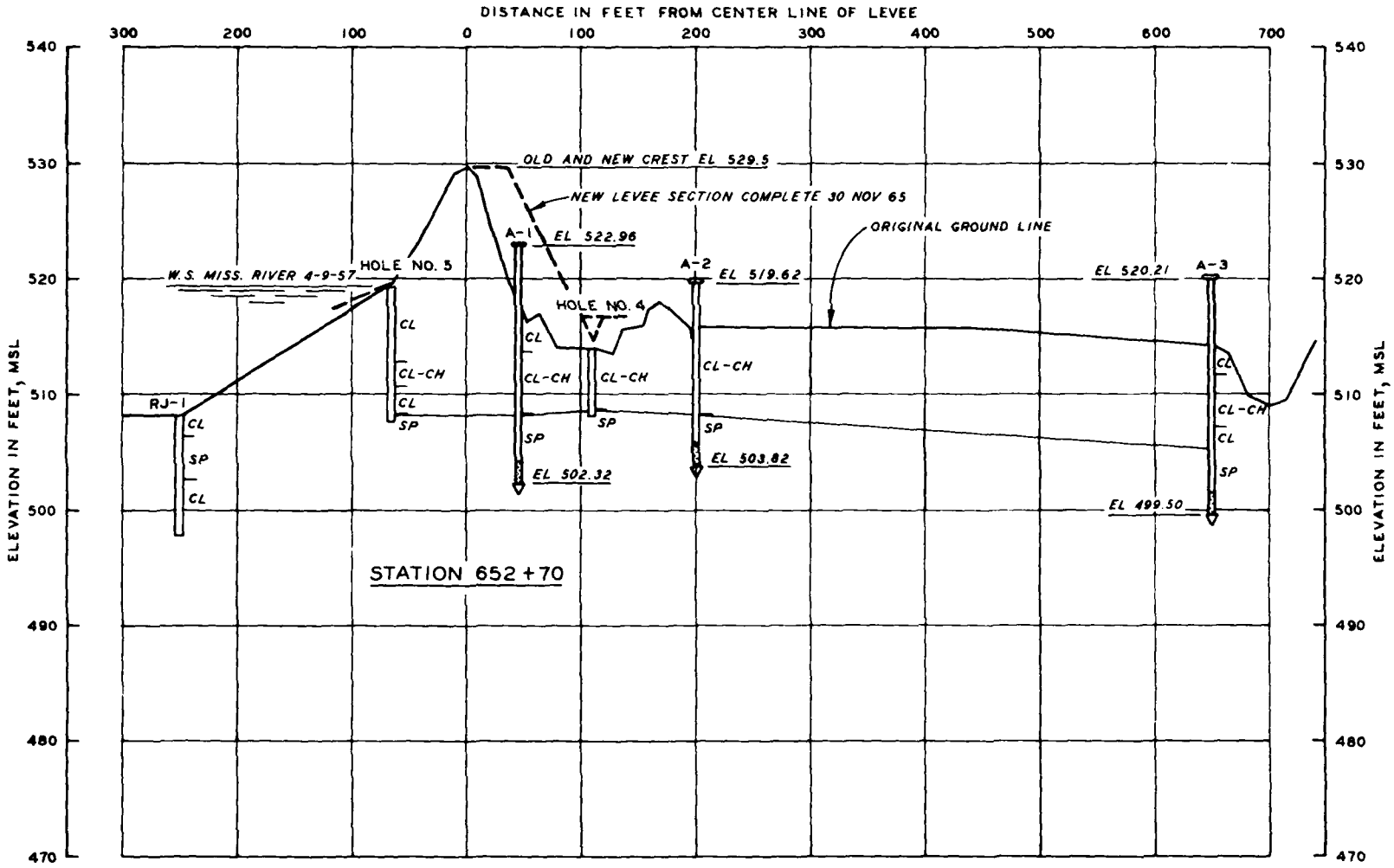

Figure 24. Cross section of Green Bay, Piezometer Range A

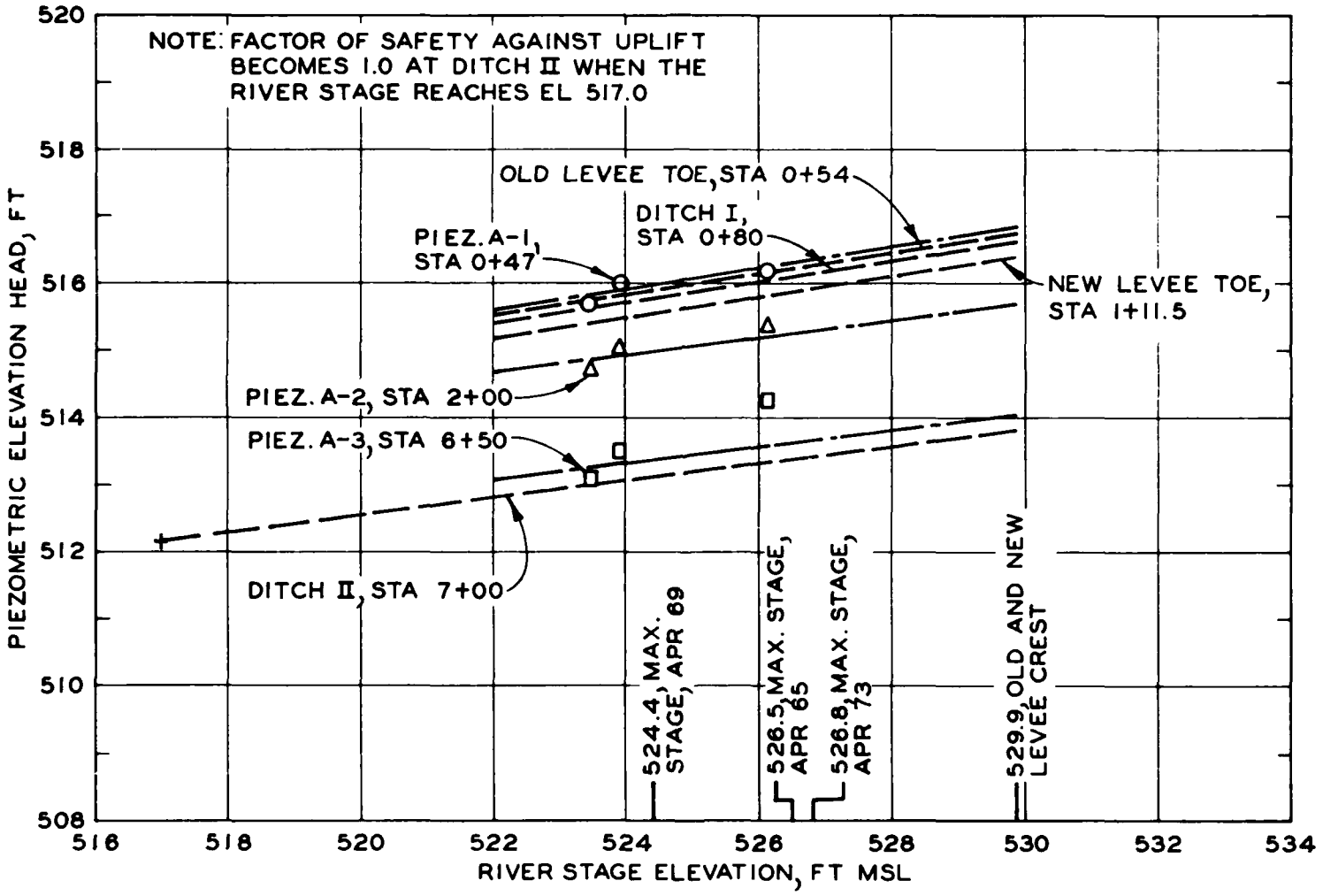

Figure 25. Piezometric elevation head versus river stage, Green Bay, Range A

levee. These latter plots of piezometric elevation heads were determined by linear interpolation of the projection heads for the piezometer locations to the intermediate locations between the piezometers.

83. At this piezometer range, there was no piezometer riverward of the center line of the levee. Therefore, the two landward piezometers closest to the levee, A-1 and A-2, were used to calculate the effective source s and the effective seepage exit x_3 distances for each date of piezometer observation. The tailwater elevation landward of the levee toe for these calculations was assumed to be 515.0. In addition, s and x_3 were also calculated for the river stage equal to the levee crest elevation using piezometer data projected to el 529.9. The s and x_3 values listed in Table 11 are plotted versus river stage in Figure 26. For the levee crest elevation of 529.9, s was 1690 ft and x_3 was 209 ft. It should be noted that the calculated s value of 1690 ft is significantly greater than the estimated 609-ft distance to the exposed pervious substratum at the riverbank. This is no doubt at least partially due to the fact that no riverside piezometer was available at this range, and the pressure gradient between the first two landward piezometers was flatter than that which would have been reported had piezometric data from under the riverside slope of the levee been available. Therefore, both the calculated s and x_3 values are larger than that which might otherwise have been expected.

Permeability ratio

84. The landside permeability ratio was calculated for a flood stage equal to the levee crest elevation, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 8.0 ft, $d = 88$ ft , $x_3 = 209$ ft , and the calculated $k_f/k_{b\ell}$ was 66. The calculated $k_f/k_{b\ell}$ is no doubt somewhat larger than that which might have been calculated had there been a riverside piezometer at this particular range. No riverside permeability ratio was calculated for this site because no reliable estimate of effective seepage entrance distance could be made from available piezometer data.

85. Because of the question regarding the reliability of the computed effective seepage exit distance, the alternate procedure

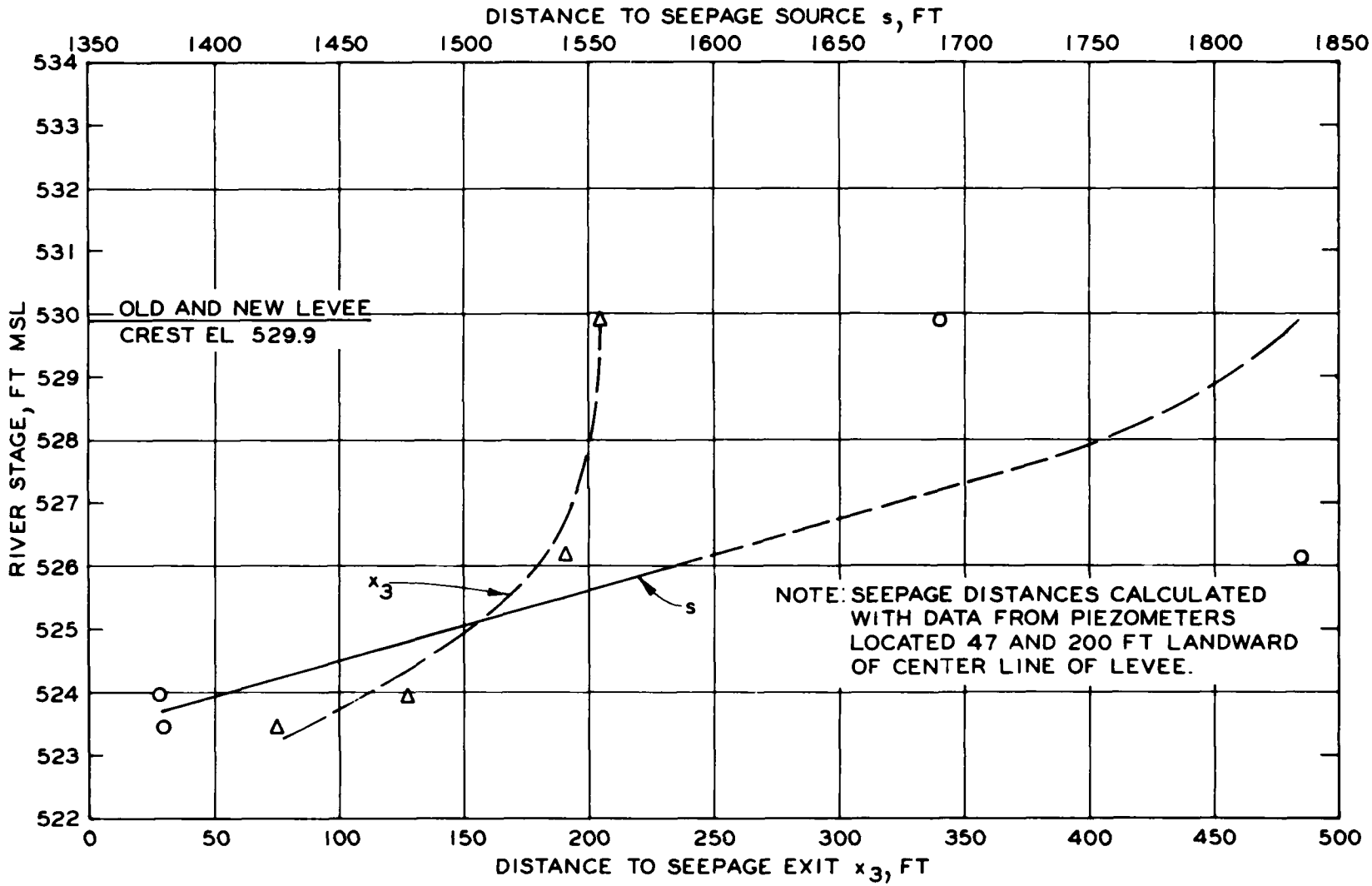

Figure 26. Distances to seepage source and seepage exit, Green Bay, Range A

involving the formula $e^{cx} = ho/hx$ for calculating $k_f/k_{b\ell}$ (see paragraph 41) was also used for this site. Using ground elevations of 516.3 and 514.5 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 516.8 and 515.7, $k_f/k_{b\ell}$ was calculated to be 42. This is less than the 62 calculated above and appears reasonable, but because of the irregular nature of the ground surface, its reliability is difficult to judge.

Calculated factors of safety

86. The projected piezometric data in Figure 25 have been used to calculate uplift factors of safety at the old levee toe, the new levee toe, the ditch near the old levee toe, and the ditch 700 ft landward of the levee for peak flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of the factor of safety were also made for a river stage equal to the crest of the levee. Table 12 presents these factors of safety and the data necessary to make the calculations.

87. The type of seepage observed during the flood stages is also shown in Table 12. It is interesting to note that when pin boils were reported in a seepage ditch near the levee in 1969, the estimated pressure head elevation was below the ground elevation at the new levee toe and the factor of safety was indeterminate. Therefore, the pin boils apparently must have been in a ditch not shown with the new levee section. Pin boils were also reported in April 1973, but at this time, the observer did not indicate whether pin boils were in a seepage ditch near the levee toe or in the ditch 700 ft landward of the levee. The factor of safety at the ditch 700 ft landward of the levee was 0.7, and it is most likely that pin boils were occurring in this ditch if, in fact, the bottom of the ditch was at el 509.0 at this time. In 1960, with water standing in low areas, the factor of safety was 2.2. In 1965, when through seepage was noted at the old levee toe and the landside slope was wet and saturated one-third the height of the levee, the

estimated pressure head elevation was equal to the ground elevation; therefore, the pressure head above ground was zero and the factor of safety was again indeterminate. A similar situation occurred at the old levee toe in 1960 and the new levee toe in 1973 when the estimated pressure head was actually below the ground surface elevation when light toe seepage was observed. In these last three instances, this observed seepage quite clearly was through seepage and not underseepage. In 1965, when no seepage was noted in the ditch near the old levee toe, the factor of safety was 2.1. In 1965 and 1969, when no seepage was reported in the ditch 700 ft landward of the center line of the levee, the factor of safety was 0.7. For a river stage equal to the levee crest el 529.9, it is estimated that the piezometric pressure head at the new levee toe will be below the ground surface; therefore, the factor of safety will be indeterminate or in effect infinity. If the bottom elevation of the ditch 700 ft landward of the levee still is 509.0, the calculated factor of safety when the river stage is at the levee crest el 529.9 will be 0.7.

Hunt, Range B

88. The Hunt Drainage District is on the east bank of the Mississippi River about 25 miles upstream from Quincy, Illinois. A piezometer range site, Range B, was established in April 1957 within the pool area of Lock and Dam 20. The site was located at river mile 357.7 and levee sta 139+25 on the slack-water side of the river (Figure 27). It is separated from the main channel by about 1/4 mile of timbered ground.

Description of site

89. The geologic profile in Figure 28 was derived from selected deep borings located on the east and west banks of the river. Boring DMD 2 was closest to piezometer Range B and was located about 1.2 miles downstream. The top stratum generally consisted of 5 to 10 ft of alluvial clayey soil. This was underlain by about 112 ft of pervious sands and gravel. The bedrock was of the Mississippian Formation.

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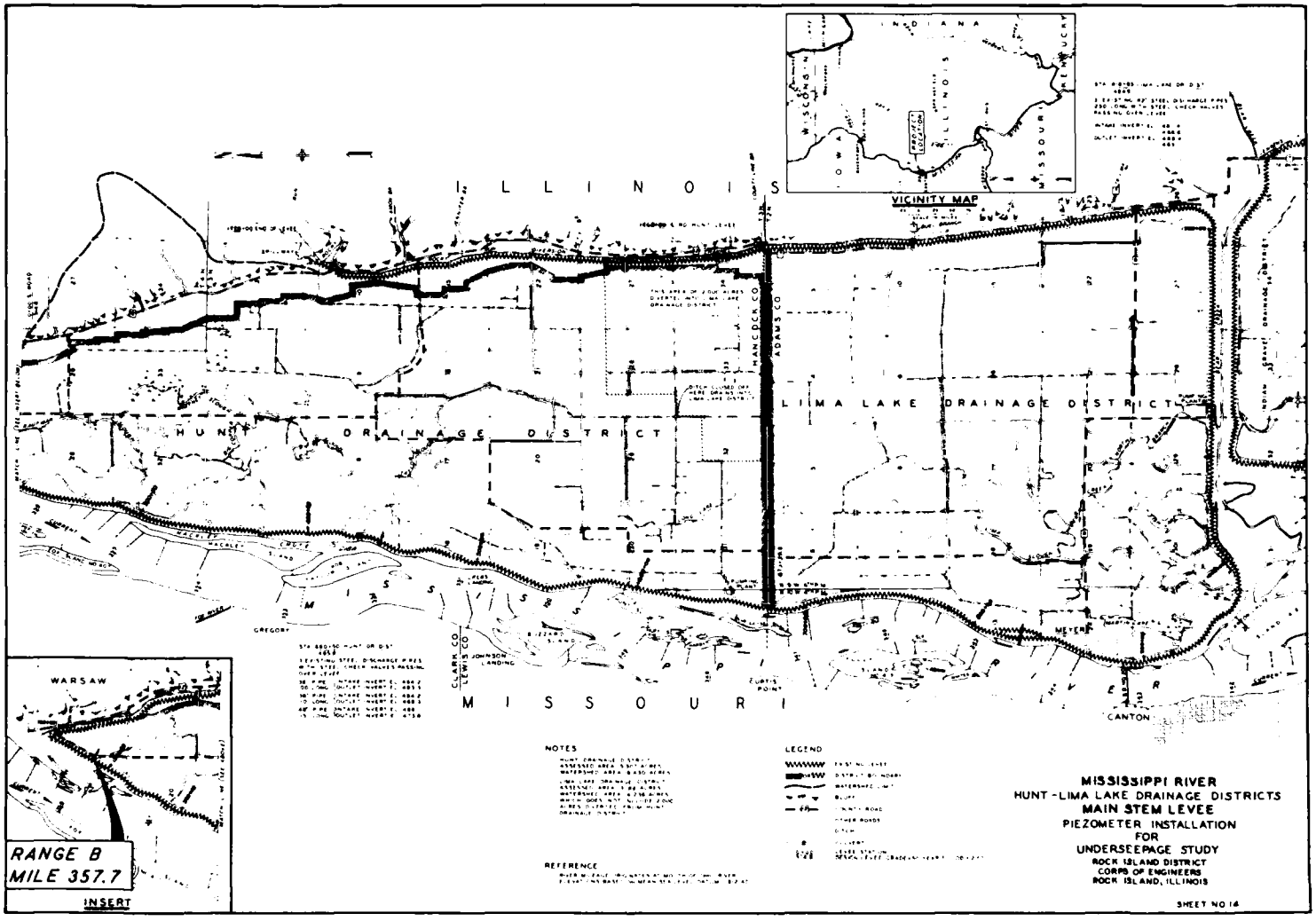

Figure 27. General plan of Hunt-Lima Lake Drainage Districts

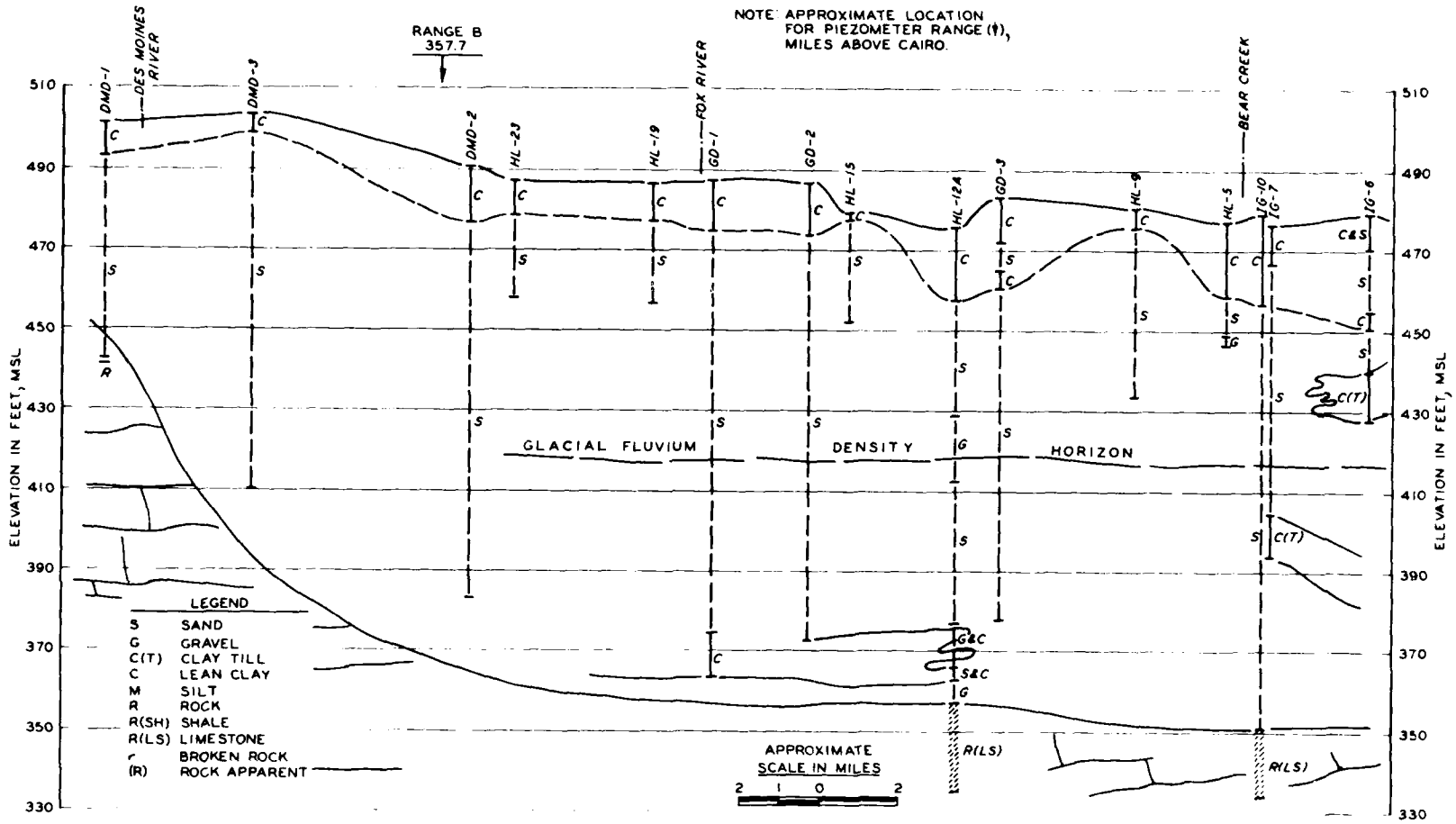

Figure 28. Geologic profile in vicinity of Hunt Drainage District

90. Figure 29 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 5.3 to 8.2 ft thick and generally consists of silt to lean clay material landward of the levee.

91. The old levee crest elevation was 499.5, and the average ground elevation at the levee toe was 487.5. Construction for the levee enlargement began in July 1960 and was completed in September 1961. The new levee grade is el 501.5. The exposed pervious substratum at the bank of the river is estimated to be 1300 ft west of the center line of the levee.

History of underseepage

92. Since the installation of the piezometer range in 1957, only two observations of seepage have been recorded. In 1960, toe seepage was observed running across the road, and water was reported standing in low areas. In 1969, medium underseepage and wet fields were noted landward of the levee. No observations of seepage were reported during the high waters of April 1965 and April 1973.

Analysis of piezometer data

93. The readings from piezometers B-1, B-2, and B-3 in Table 13 are for three different dates. In Figure 30, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 501.5 can be estimated. Also shown in Figure 30 are estimated piezometric elevation heads for the old levee and the new levee toe where underseepage was reported in 1969. These latter plots of piezometric elevation heads were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

94. Data from piezometers B-1 and B-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observations. Average ground elevation landward of the levee toe selected for these calculations was 487.5. In additon, s and x_3 were calculated for river stages equal

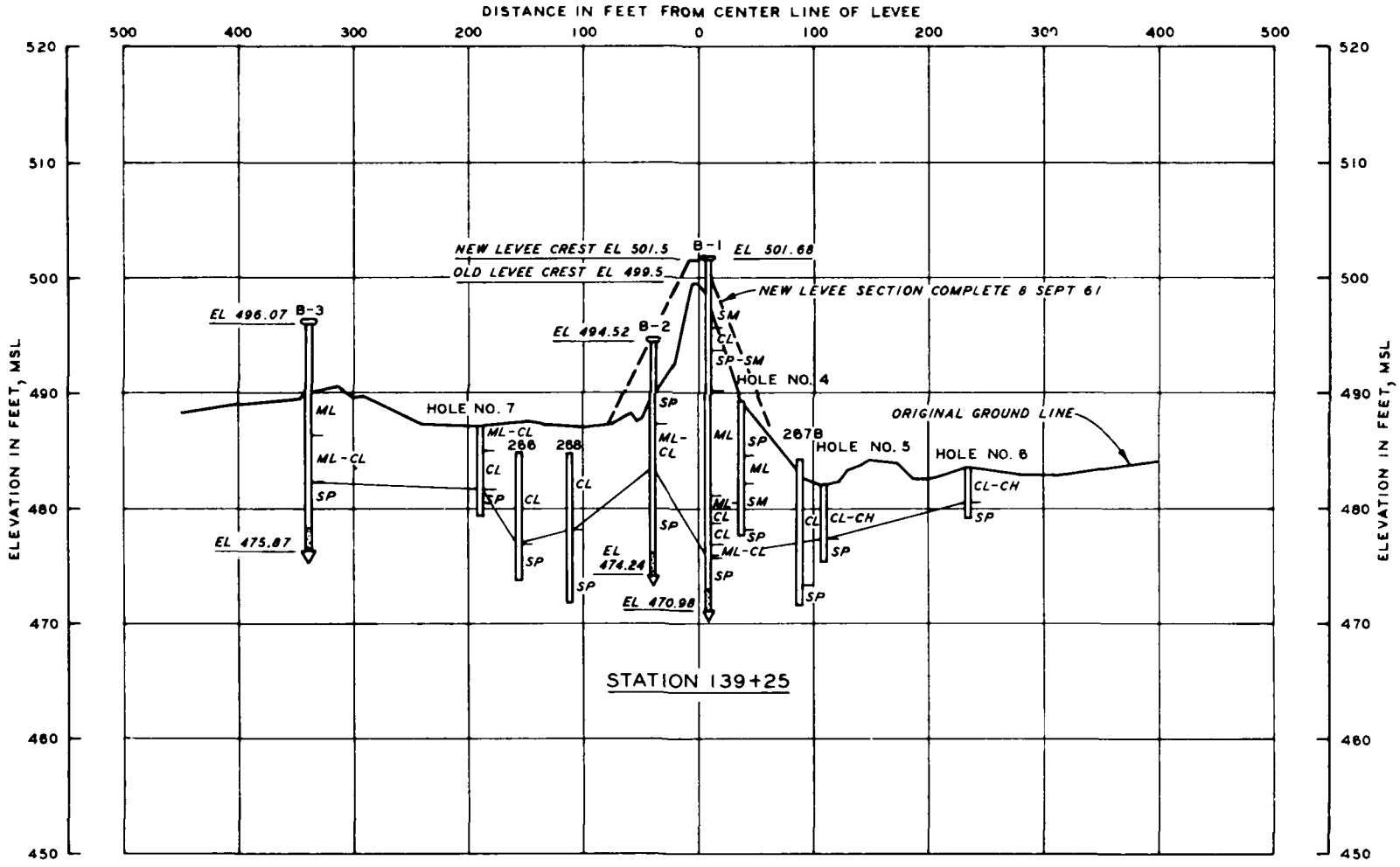

Figure 29. Cross section of Hunt, Piezometer Range B

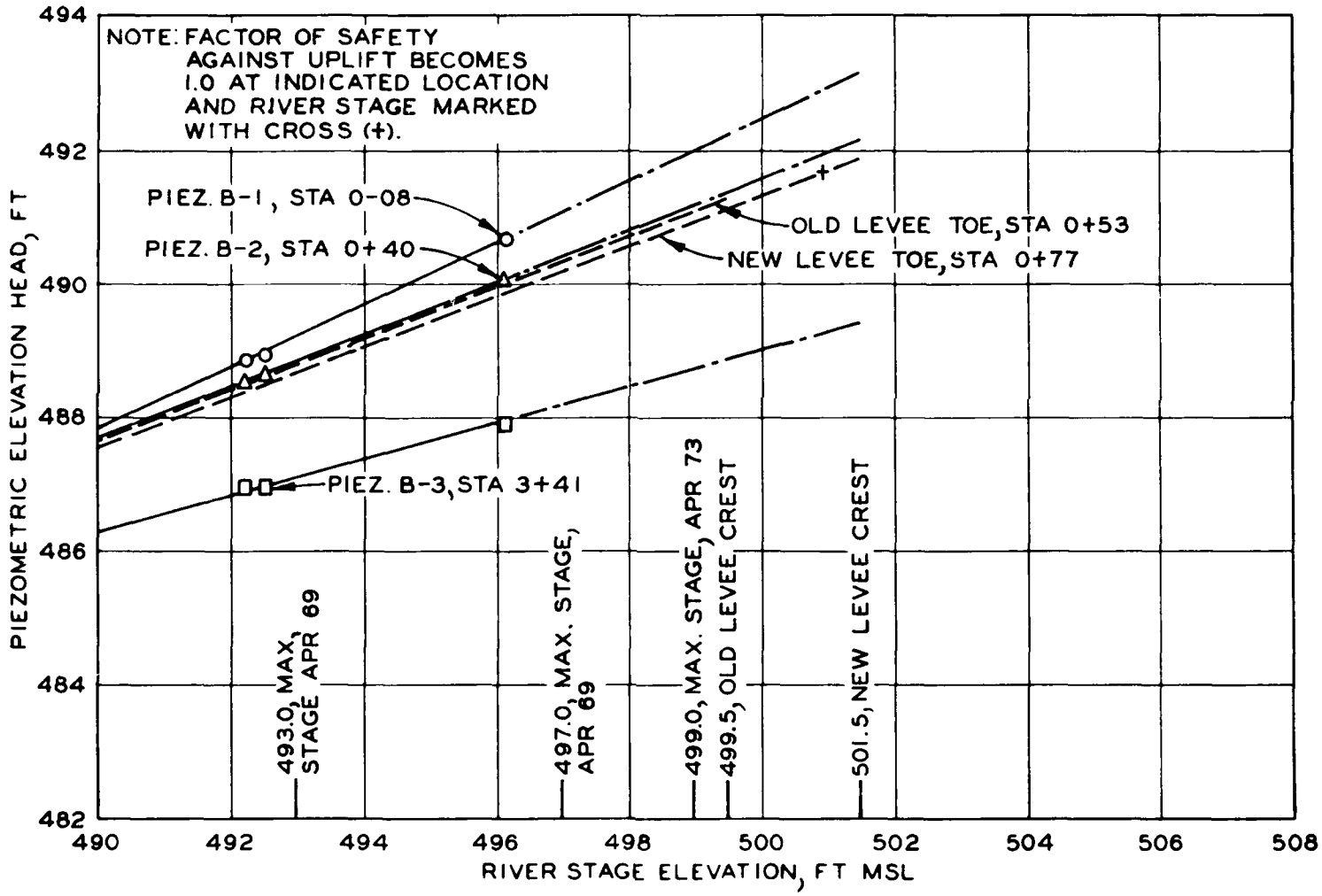

Figure 30. Piezometric elevation head versus river stage, Hunt, Range B

to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 13 are plotted versus the river stage in Figure 31. For the old crest elevation of 499.5, s was 445 ft and x_3 was 195 ft. For the new crest elevation of 501.5, s was estimated to be 459 ft and x_3 was 227 ft.

Permeability ratio

95. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 5.3 ft, $d = 112$ ft , x_3 (for the old crest elevation) was 195 ft, and the calculated $k_f/k_{b\ell}$ was 64.

96. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh (cL_1)}{c}$. For these calculations, $x_1 = 342$ ft , $L_1 = 1350$ ft , $c = 0.00292$ ft , $z_{br} = 5.0$ ft, $d = 112$ ft , and $k_f/k_{br} = 209$.

Calculated factors of safety

97. The projected peizometric data in Figure 30 have been used to calculate uplift factors of safety at the new levee toe for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 14 presents these factors of safety and the data necessary to make the calculations.

98. The type of seepage observed during the flood stages is also shown in Table 14. It is interesting to note that when moderate underseepage and wet fields were reported behind the levee in 1969, the factor of safety was 2.5; when toe seepage and standing water were observed in 1960, the factor of safety was 1.7; when no seepage was reported in 1965 and 1973, the factors of safety were 1.4 and 1.2,

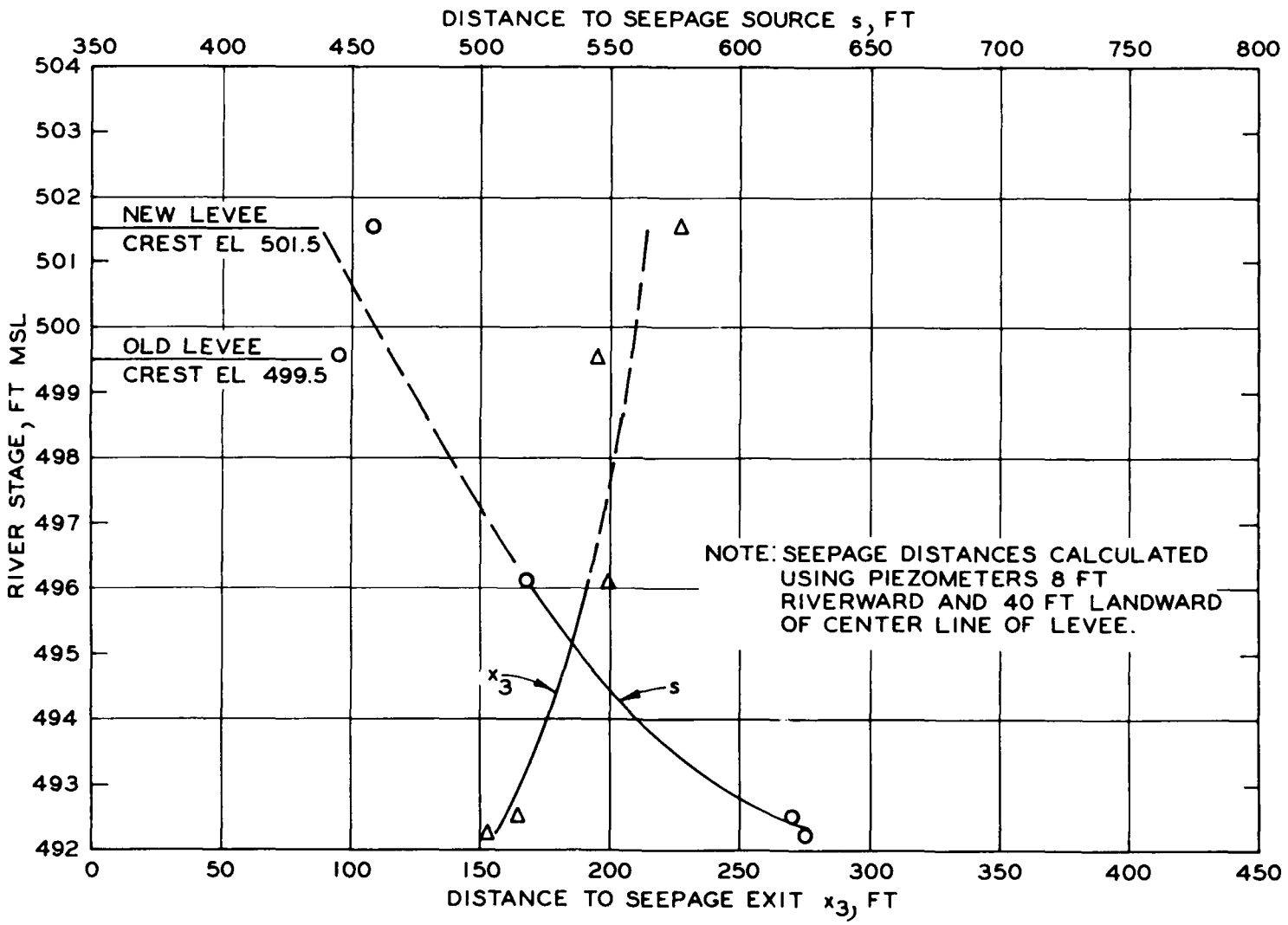

Figure 31. Distances to seepage source and seepage exit, Hunt, Range B

respectively. The calculated factor of safety for a river stage equal to the crest of the new levee was 1.0.

Fabius River, Range A

99. The Fabius River Drainage District is on the west bank of the Mississippi River directly across from Quincy, Illinois. A piezometer range site, Range A, was established in 1957 within the pool area of Lock and Dam 21. The site was located at river mile 328.4 and levee sta 339+49 on the main channel side of the river but in an area that may receive some protection from islands immediately upstream (Figure 32).

Description of site

100. The geologic profile in Figure 33 was derived from selected deep borings located on the east and west banks of the river. Boring F16 at river mile 328.5 was nearest to Range A. The top stratum generally consisted of about 4 ft of alluvial clayey soil. This was underlain by about 117 ft of poorly graded brown and gray glacial sands. One 8-ft intrusion of silt and two 7- to 9-ft intrusions of glacial clay till were indicated. The bedrock was of the Mississippian Formation.

101. Figure 34 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 7.7 to 11.1 ft thick and generally consists of 5 to 7 ft of lean clay overlying clayey silt or sandy silt.

102. The old levee crest elevation was 484.9, and the average ground elevation at the levee toe was 474.5. Construction for the levee enlargement began 30 May 1961 and was completed 14 February 1963. The new levee grade is el 489.8. The top of the bank of the Mississippi River was approximately 300 ft east of the center line of the levee. The piezometer range was reported as destroyed on 14 April 1969.

History of underseepage

103. Since the installation of the piezometer range in 1957, only two observations of seepage have been reported. On 7 April 1960, the

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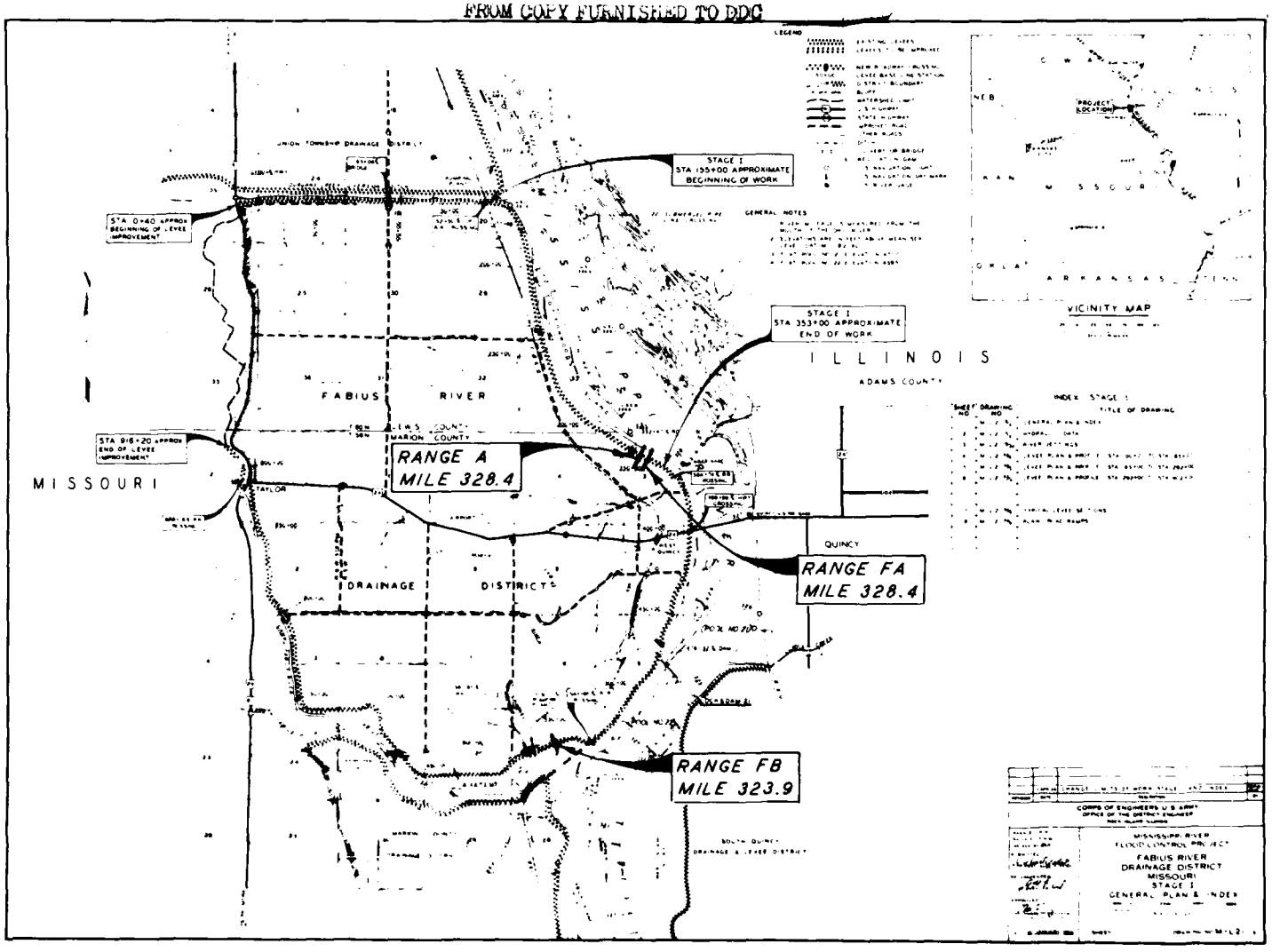

Figure 32. General plan of Fabius River Drainage District

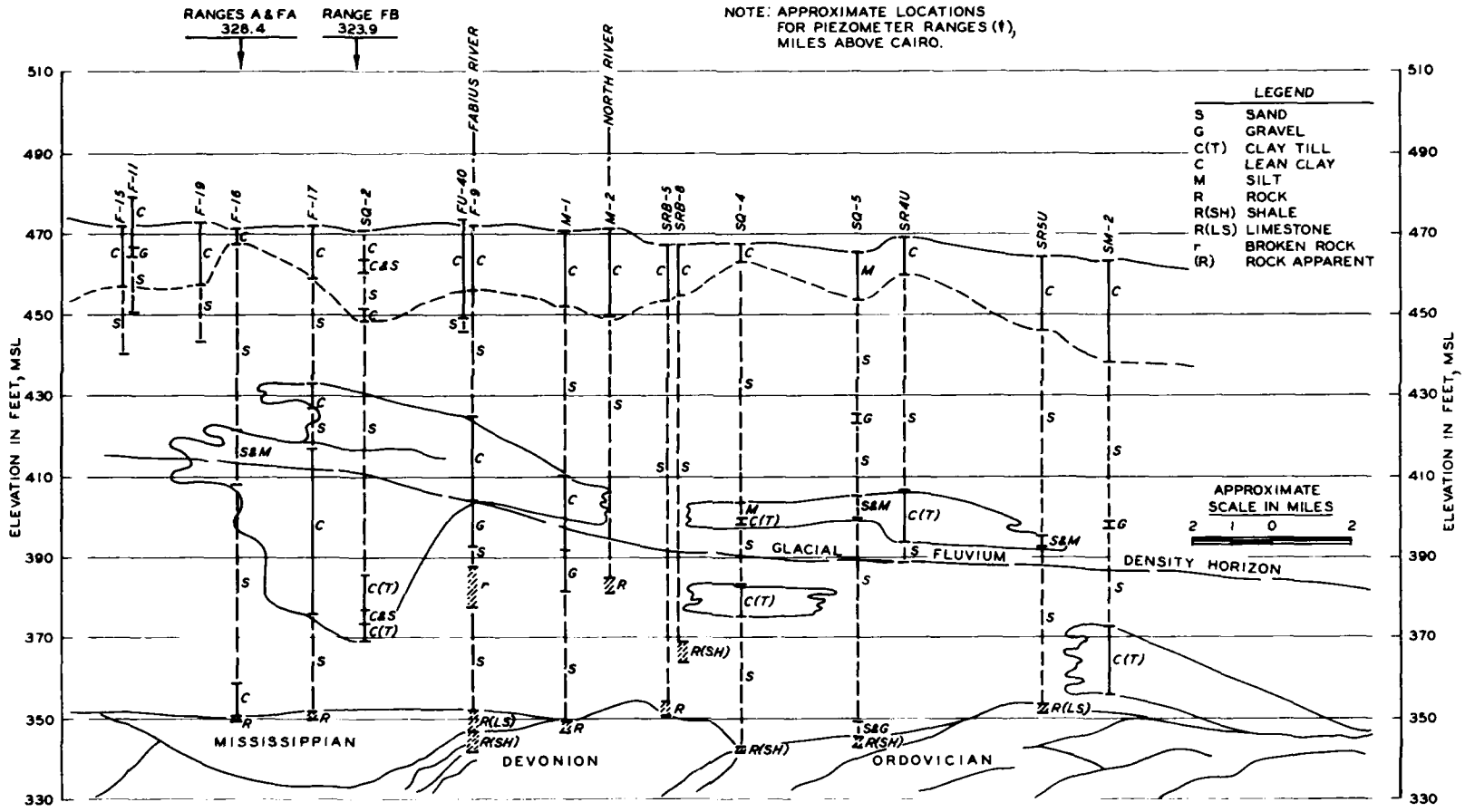

Figure 33. Geologic profile in vicinity of Fabius River Drainage District

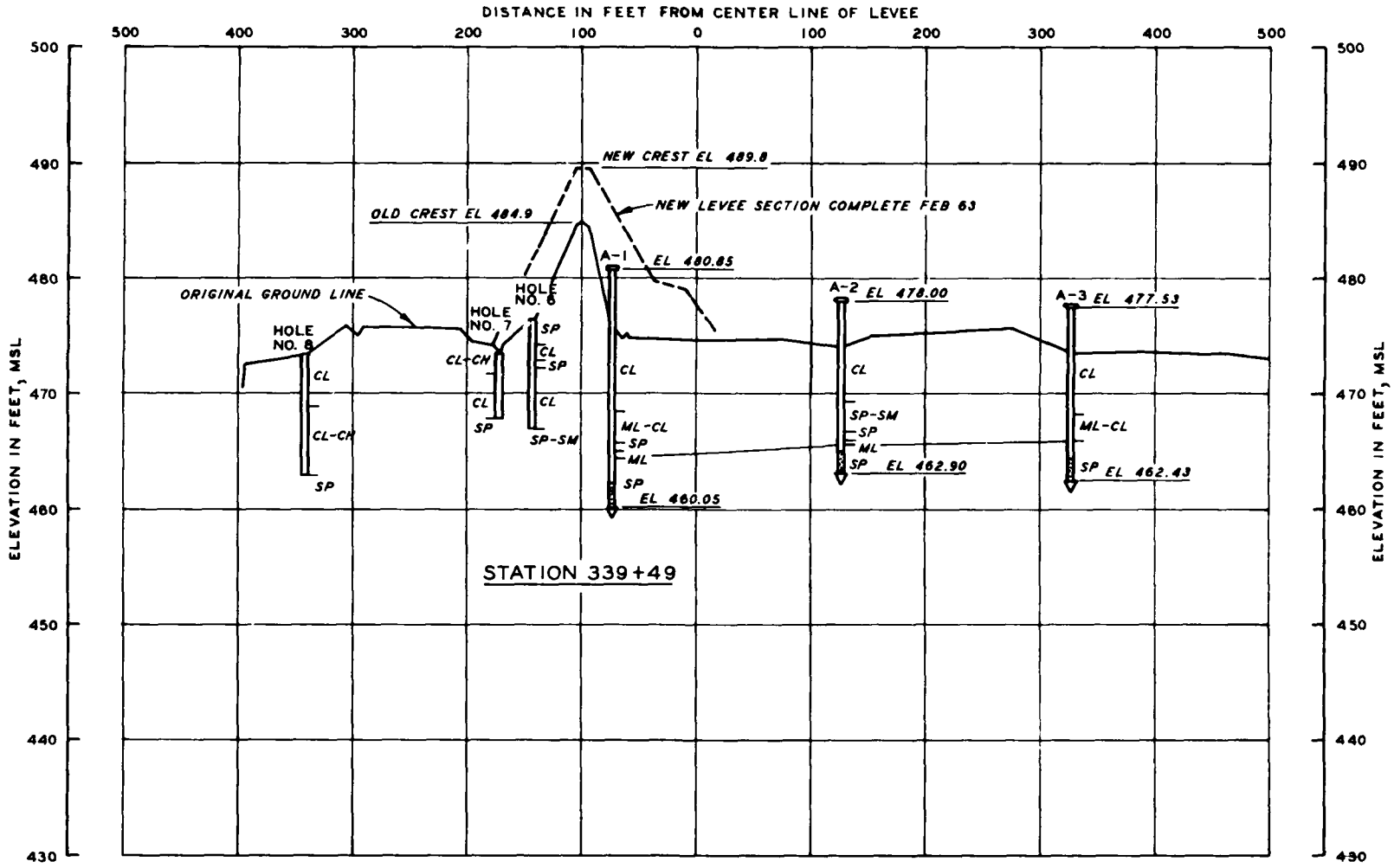

Figure 34. Cross section of Fabius River, Piezometer Range A

river crested at el 483.47, heavy toe seepage was noted, and three sand boils were located in the area of piezometer A-1, all of which had discharged some sand. In May 1965, when the river crested at el 483.9, light toe seepage was observed. However, no seepage was reported in 1969. In 1973, the levee was overtopped; seepage data were not obtained for this flood.

Analysis of piezometer data

104. The readings from piezometers A-1, A-2, and A-3 in Table 15 are for three different dates. In Figure 35, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 489.8 can be estimated. Also shown in Figure 35 are estimated piezometric elevation heads at the old levee toe and the new berm toe where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

105. At this piezometer range, no riverside piezometer was installed. Therefore, the effective seepage source s and the effective seepage exit x_3 distances were calculated for each date of piezometer observation using piezometric pressures recorded by piezometers A-1 and A-2, the two piezometric pressures recorded by piezometers A-1 and A-2, the two piezometers that were closest to the center line of the levee. The average ground elevation landward of the levee toe selected for these calculations was 474.5. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 15 are plotted versus the river stage in Figure 36. For the old crest elevation of 484.9, s was 542 ft and x_3 was 228 ft. For the new crest elevation of 489.8, s was estimated to be 531 ft and x_3 was 215 ft. It should be noted that the calculated s values of 552 and 537 ft are significantly greater than the 335-ft distance to the exposed pervious substratum at the riverbank.

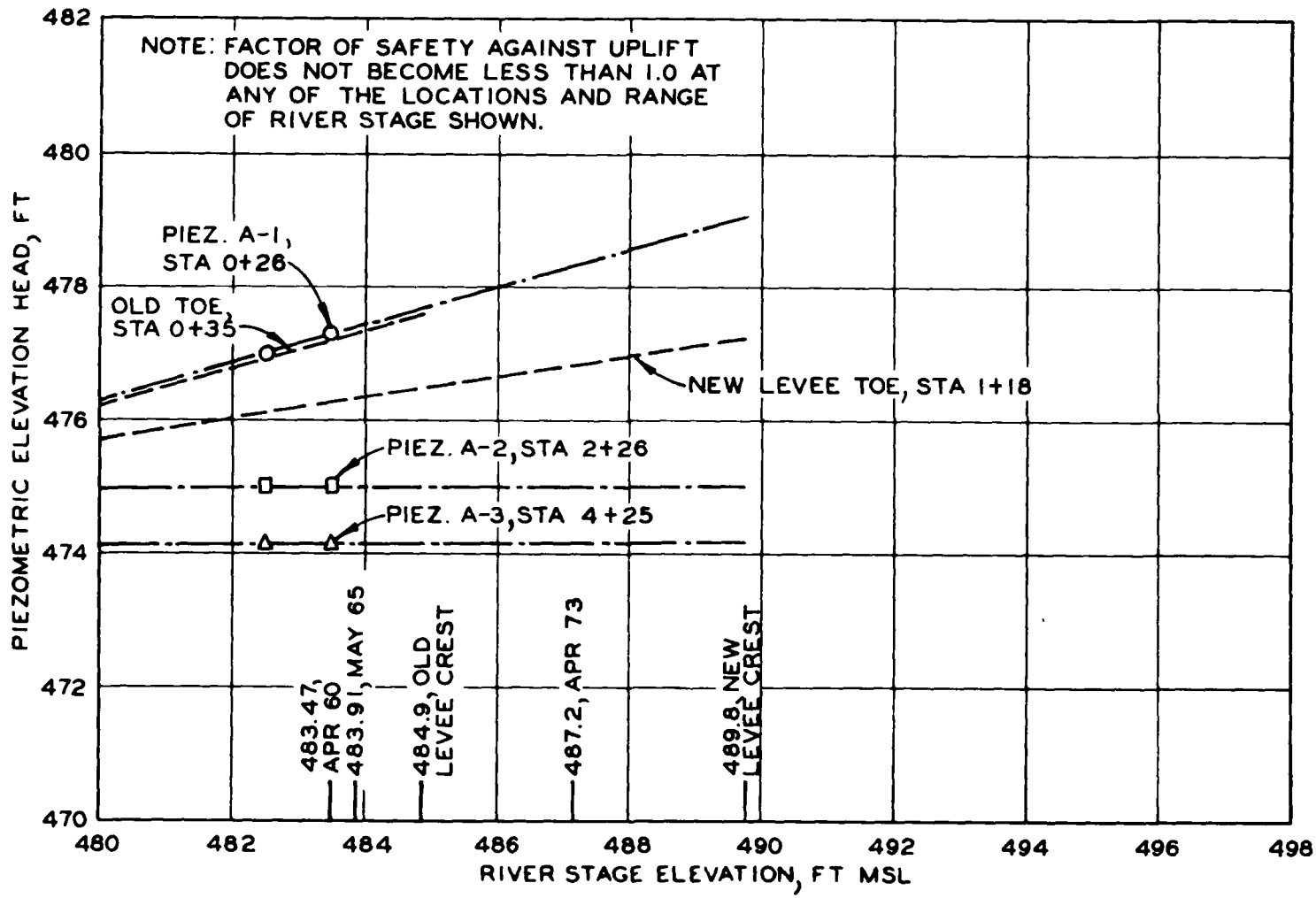

Figure 35. Piezometric elevation head versus river stage, Fabius River, Range A

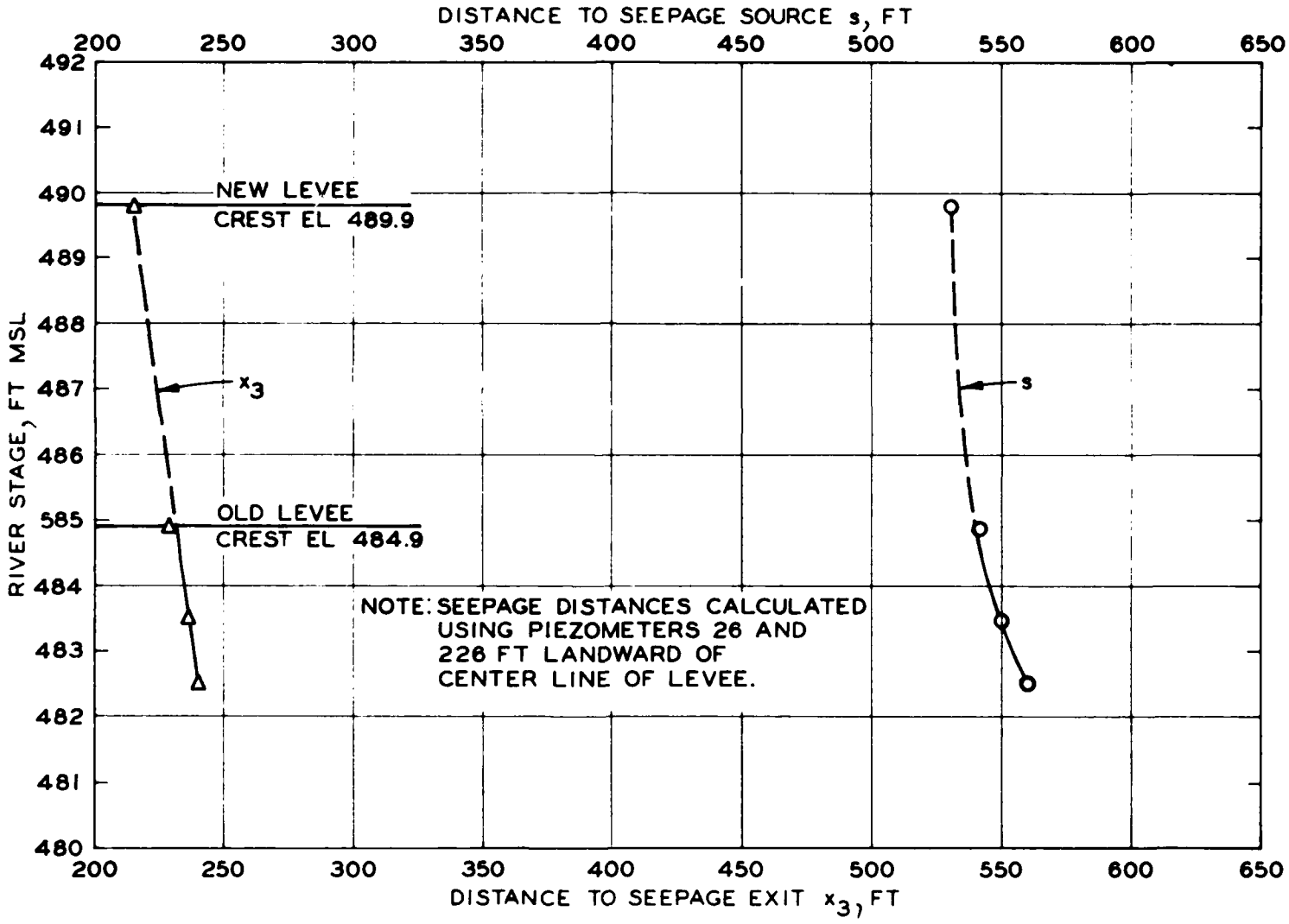

Figure 36. Distances to seepage source and seepage exit, Fabius River, Range A

Permeability ratio

106. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 8.7 ft, d = 117 ft , x_3 (for the old crest elevation) was 228 ft, and the calculated $k_f/k_{b\ell}$ was 51. If a riverside piezometer had been available at this range, it is possible that the pressure gradient used to calculate the effective seepage distances would have been greater, and the seepage exit distance would have been smaller; thus, the calculated $k_f/k_{b\ell}$ might have been smaller. No riverside permeability ratio was calculated for this site because no reliable estimate of effective seepage entrance distance could be made from available piezometer data.

107. Because of the question regarding the reliability of the computed effective seepage exit distances, the alternate procedure involving the formula $e^{cx} = ho/h_x$ for calculated $k_f/k_{b\ell}$ (see paragraph 41) was also used for this site. Using ground elevations of 474.5 and 474.0 for the landside toe and location of piezometer A-2, respectively, and projected piezometric elevation heads of 477.6 and 475.0, $k_f/k_{b\ell}$ was calculated to be 82. This ratio is larger than the value calculated above but is of the same order of magnitude.

Calculated factors of safety

108. The projected piezometric data in Figure 35 have been used to calculate uplift factors of safety at the toes of the levees or berms for the flood stages of 1960, 1965, and 1969. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 16 presents these factors of safety and the data necessary to make the calculations.

109. The type of seepage observed during the flood stages is also shown in Table 16. It is interesting to note that when sand boils were

located at piezometer A-1 in 1960, the factor of safety was 4.6; when toe seepage was observed in 1960 and 1965, the factor of safety ranged from 2.6 to 11.0. In 1969, the river stage did not get high enough to produce piezometric elevation heads above the ground surface. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 4.2 to 10.6.

South Quincy, Range A

110. The South Quincy Drainage and Levee District is on the east bank of the Mississippi River about 8 miles downstream from Quincy, Illinois. One piezometer range site, Range A, was established in 1957 within the pool area of Lock and Dam 22. The site was located at river mile 319.1 and levee sta 321+23 on the slack-water side of the river (Figure 37). It is separated from the main channel by a secondary channel or chute and a timbered island totaling about 1/2 mile in width as shown on the plan map of the area.

Description of site

111. The geologic profile in Figure 38 was derived from selected deep borings located near the east and west banks of the river. Boring SQ5 at river mile 317.8 was nearest to Range A. The top stratum generally consisted of 7 to 12 ft of alluvial silty soil. This was underlain by about 110 ft of poorly graded brown and gray glacial sands and gravels. One 5-ft intrusion of silty sand was indicated. The bedrock was shale.

112. Figure 39 shows a cross section of the site with the original and new levee sections, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 4.3 to 6.8 ft thick and generally consists of lean clay or silt.

113. The old levee crest elevation was 481.40, and the average ground elevation in a 30-ft-wide ditch near the toe of the old levee or berm (109 ft landward of the center line of the levee) was 464.2. Construction for the levee enlargement began in April 1966 and was completed in October 1967. The new levee grade is el 482.4. The riverside levee toe is immediately adjacent to the top of the bank of the secondary

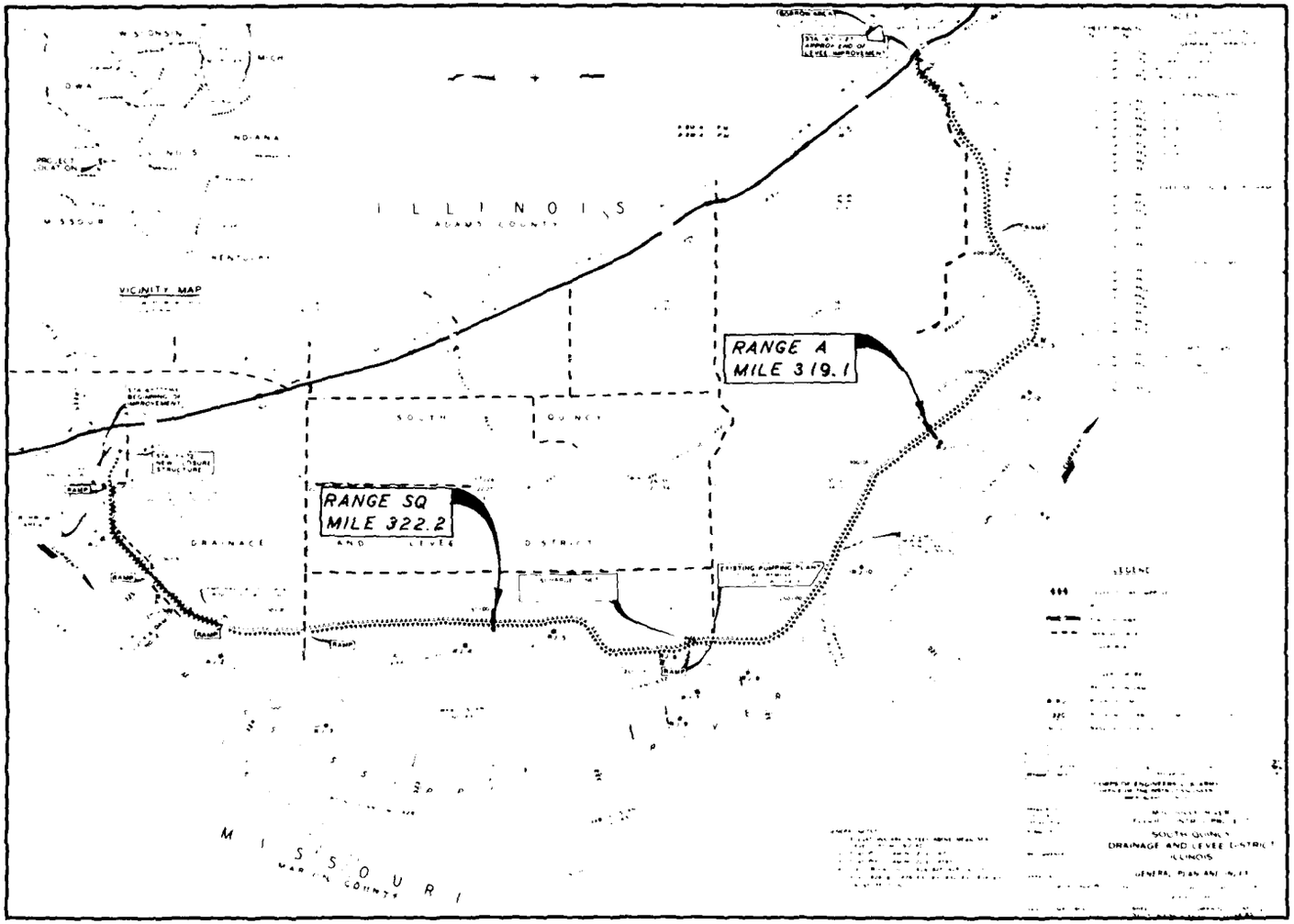

Figure 37. General plan of South Quincy Drainage and Levee District

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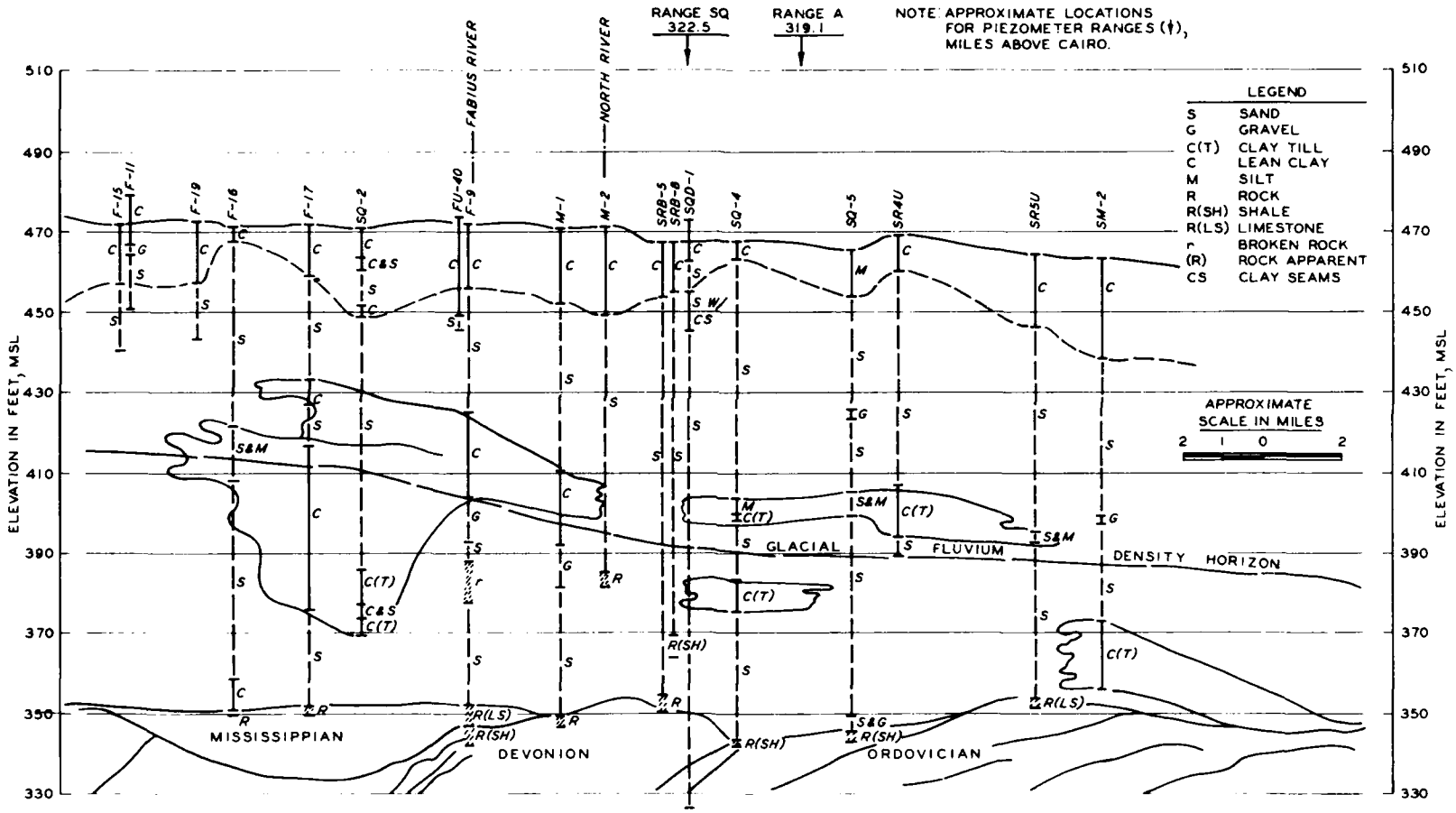

Figure 38. Geologic profile in vicinity of South Quincy Drainage and Levee District

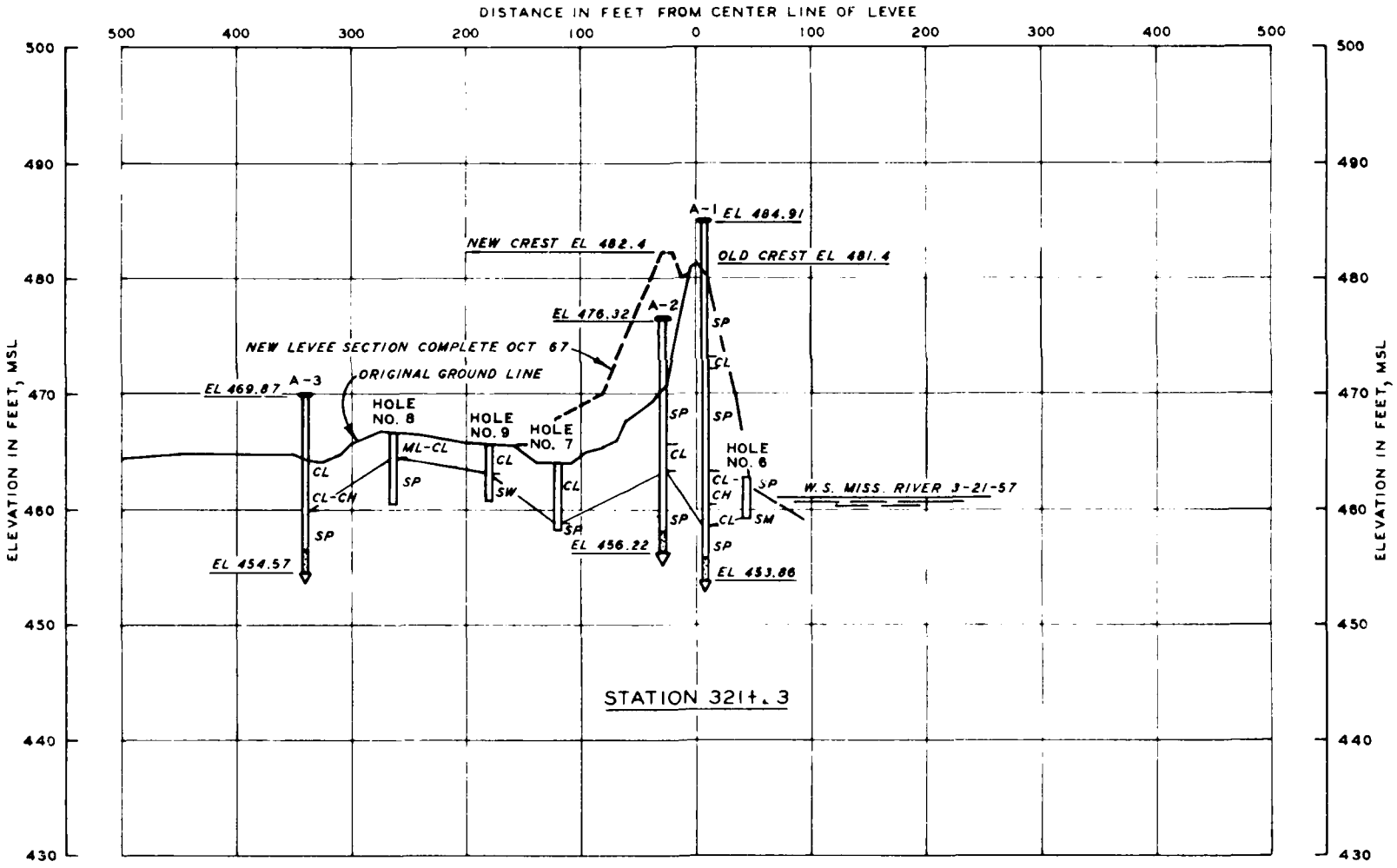

Figure 39. Cross section of South Quincy, Piezometer Range A

channel of the river. The exposed pervious substratum was estimated to be 90 ft from the center line of the levee.

History of underseepage

114. Since the installation of the piezometer range in 1957, three observations of seepage have been recorded. On 7 May 1960, the river crested at el 478.3; a little toe seepage was noted, and a great deal of water was reported standing in the road ditch and low areas. In April 1969 and April 1973, the berm was wet, and heavy to moderate seepage at the toe and beyond the toe was observed when the river crested at el 475.1 and 482.85, respectively.

Analysis of piezometer data

115. The readings from piezometers A-2 and A-3 in Table 17 are for five different dates. (Piezometer A-1 had been destroyed prior to collection of data.) In Figure 40, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 482.8 can be estimated. Also shown in Figure 40 are estimated piezometric elevation heads for the toe of the old levee or berm, the new berm toe, the ditch 109 ft landward of the center line of the levee, and a point 100 ft landward of the center line of the levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

116. Since at this piezometer range the riverside piezometer A-1 had been destroyed, the effective seepage source s and the effective seepage exit x_3 distances were calculated for each data of piezometer observation using piezometric pressures recorded by piezometers A-2 and A-3. The average ground elevation landward of the levee toe selected for these calculations was 466.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 17 are plotted versus the river stage in Figure 41. For the old crest elevation of 481.4, s was 854 ft and x_3 was 293 ft.

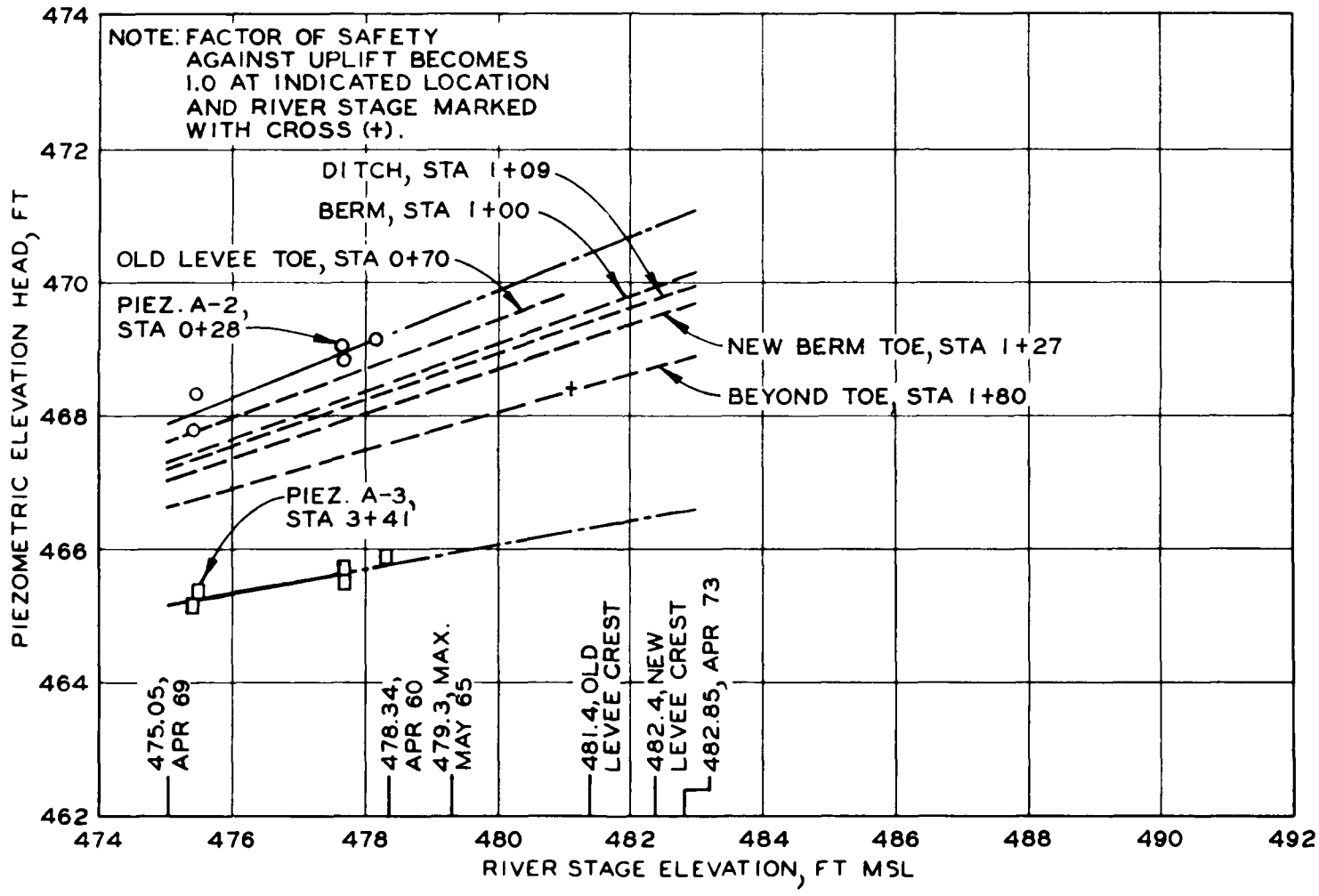

Figure 40. Piezometric elevation head versus river stage, South Quincy, Range A

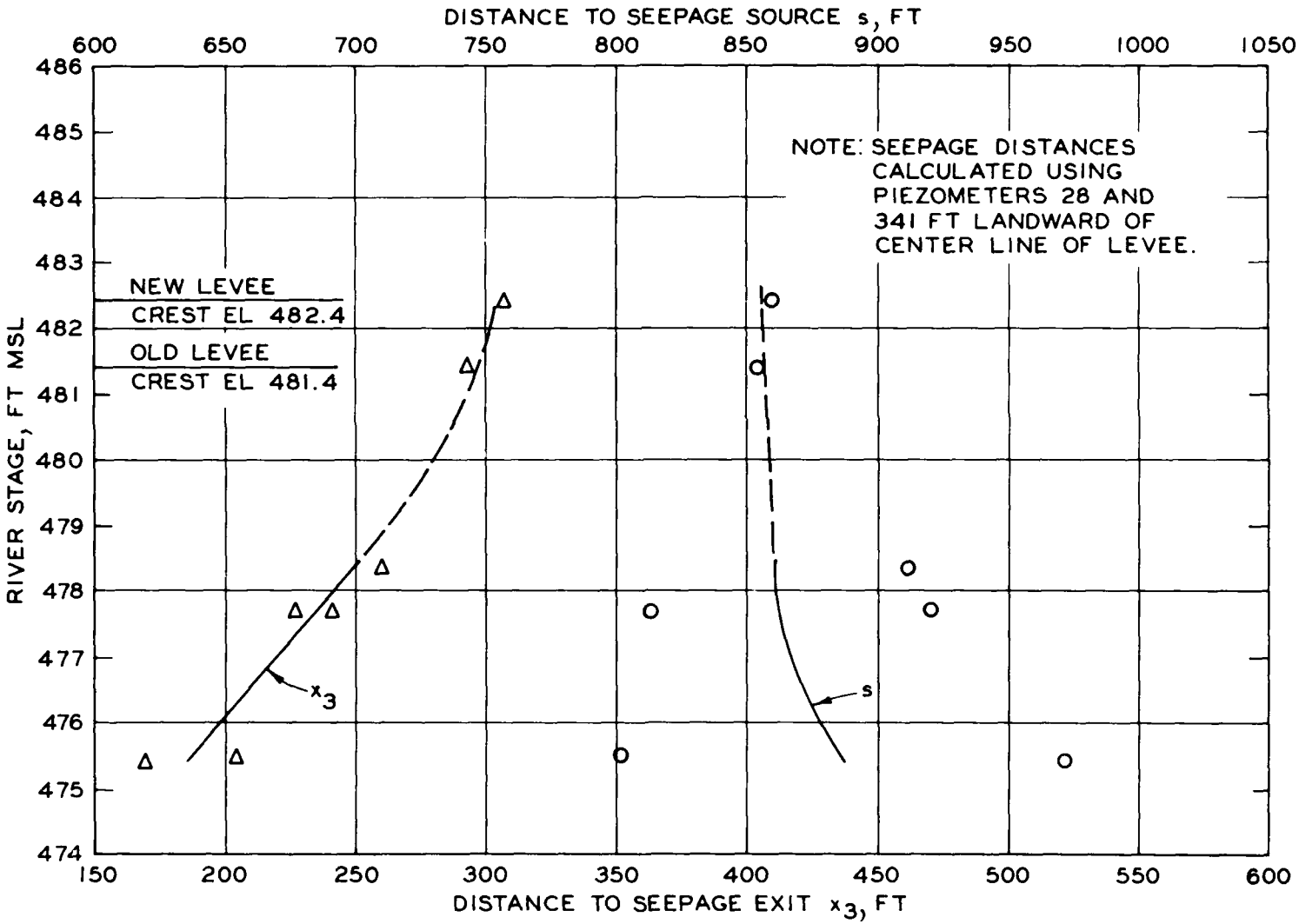

Figure 41. Distances to seepage source and seepage exit, South Quincy, Range A

For the new crest elevation of 482.4, s was estimated to be 860 ft and x_3 was 307 ft. It should be noted that the calculated s values are significantly greater than the 160-ft distance to the exposed pervious substratum at the riverbank.

Permeability ratio

117. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the toe of the old levee or berm) was 4.8 ft, d = 110 ft , x_3 (for the old crest elevation) was 293 ft, and the calculated $k_f/k_{b\ell}$ was 163. If a riverside piezometer had been available at this range, it is more than likely that the pressure gradient used to calculate the effective seepage distances would have been larger, and the seepage exit distance would have been smaller; thus, the calculated $k_f/k_{b\ell}$ more than likely would have been smaller. No riverside permeability ratio was calculated for this site because no reliable estimate of effective seepage entrance distance could be made from available piezometer data.

118. Because of the question regarding reliability of the computed effective seepage exit distance, the alternate procedure involving the formula $e^{cx} = ho/hx$ for calculating $k_f/k_{b\ell}$ (see paragraph 41) was also used for this site. Using ground elevations of 466.0 and 464.3 for the landside toe and location of piezometer A-3, respectively, and projected piezometric elevation heads of 470.0 and 466.3, $k_f/k_{b\ell}$ was calculated to be 262. This is larger than that calculated above; thus, both methods are apparently giving values on the high side.

Calculated factors of safety

119. The projected piezometric data in Figure 40 have been used to calculate uplift factors of safety at the old and new levee toes, and at 100, 109, and 180 ft landward of the center line of the levee, as appropriate, for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of

factor of safety were also made for a river stage equal to the new crest of the levee. Table 18 presents these factors of safety and the data necessary to make the calculations.

120. The type of seepage observed during the flood stages is also shown in Table 18. When heavy to moderate seepage was reported beyond the toe in 1969 and 1973, the factor of safety was 4.0 and 0.8, respectively. When water was observed in low areas and in the ditch in 1960, the factor of safety was 2.3 and 1.0, respectively. When heavy seepage was reported over the berm in 1973, the factor of safety was 6.9; in 1969, when the berm was reported as wet and soft in spots, the piezometric pressure head did not rise above the surface of the berm; thus, presumably the berm seepage must have been the result of through seepage and not underseepage. With heavy toe seepage in 1969 and 1973, the factor of safety at the berm toe was 4.2 and 2.8, respectively. With light toe seepage in 1960, the factor of safety was 3.4. When no seepage was reported, the factor of safety ranged from 1.0 to 3.8. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.9 to 1.5.

Sny Island, Range A

121. The Sny Island Levee Drainage District is on the east bank of the Mississippi River about 12 to 55 miles downstream from Quincy, Illinois. Six piezometer range sites, Ranges A, F, B, G, H, and I, were established in the period 1950 to 1954 within the pool areas of Locks and Dams 22 and 24 (Figure 42).

122. The geologic profile in Figure 43 was derived from selected deep borings located near the east bank of the river. The top stratum generally consisted of about 7 to 29 ft of alluvial clayey soil. This was underlain by about 100 ft of poorly graded brown and gray glacial sands and gravels. One significant exception to the 100-ft-thick pervious stratum is in the vicinity of Range F at about 300 river miles above Cairo where the bedrock is significantly higher and the pervious stratum was only about 34 ft thick. The bedrock was of the Ordovician Formation.

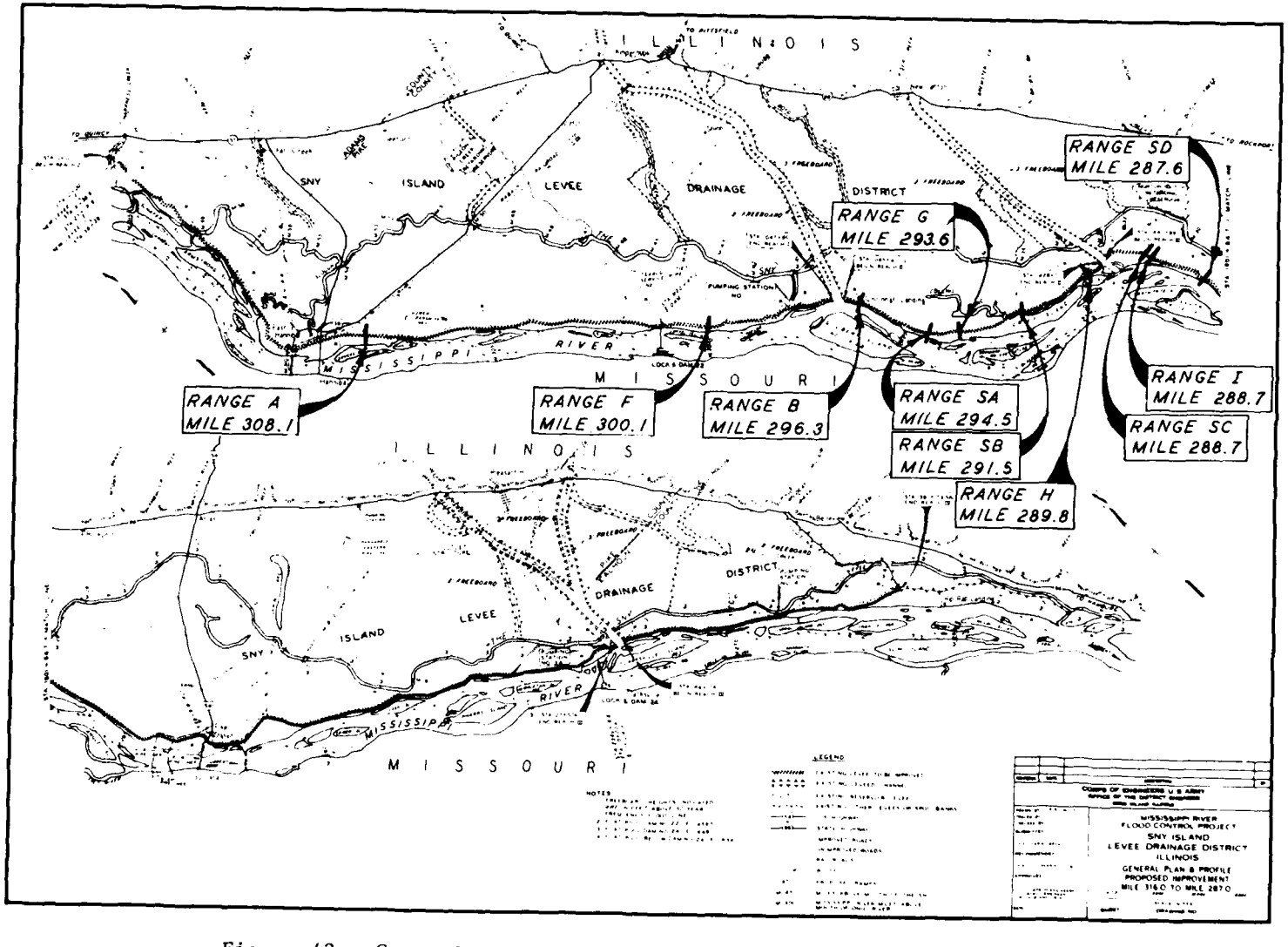

Figure 42. General plan of Sny Island Levee Drainage District

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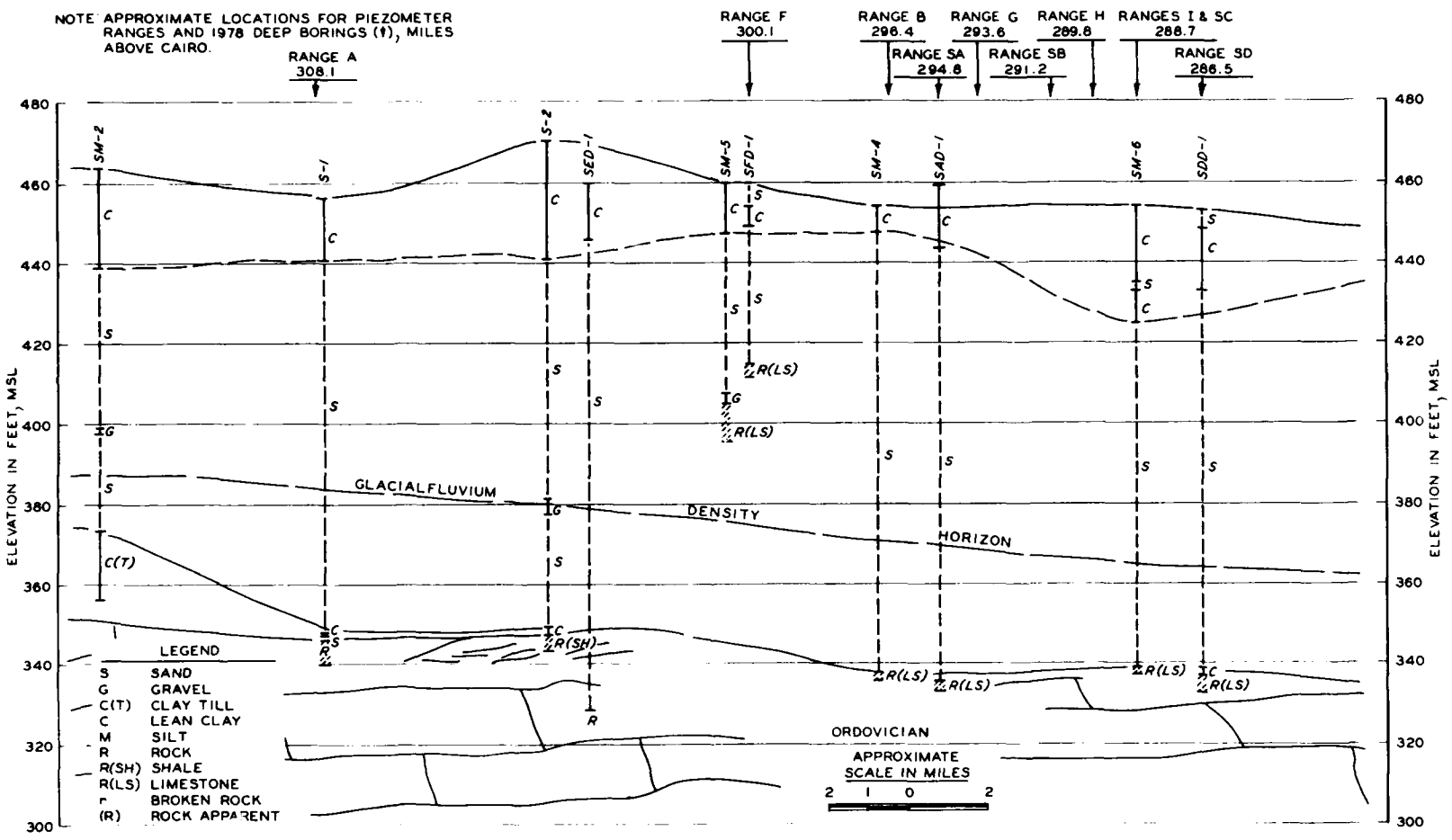

Figure 43. Geologic profile in vicinity of Sny Island Levee Drainage District

Description of site

123. Piezometer Range A site was established in November 1950. The site was located at river mile 308.1 and levee sta 444+10.8 on the slackwater side of the river (Figure 42). It is separated from the main channel by more than 1/2 mile of islands, water channels, and timbered ground. Figure 44 shows a cross section of the site with the original and new levee sections, original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 12.5 to 20.1 ft thick and generally consists of lean clay overlying about 1 ft of silty sand.

124. The old levee crest elevation was 474.4, and the average ground elevation at the levee toe was 465.4. Construction for the levee enlargement began in November 1965 and was completed in November 1967. The new levee grade is el 477.2.

125. The center line of a 34-ft-wide borrow pit and ditch running parallel to the levee was located approximately 97 ft landward of the center line of the levee. Ground elevation at the lowest point in the borrow pit (114 ft landward of the center line) was 461.7. One road was located immediately adjacent to the old levee toe while another, which ran at 45 deg to the center line of the levee, was intersected by this piezometer range at approximately 422 ft landward of the center line of the levee. The levee is located immediately adjacent to the bank of an old channel or chute of the river. The exposed pervious substratum was estimated to be 202 ft from the center line of the levee.

History of underseepage

126. Since the installation of the piezometer range in 1950, four observations of seepage have been reported. On 17 April 1960, the river crested at el 471.1; a little toe seepage was observed, and water was reported standing in the road ditch and low areas. When the river crested at el 473.1 in May 1965, very heavy toe seepage was observed, the levee was saturated one-third the distance up the landside slope, and a pinboil carrying a little sand was reported in the road adjacent to the levee toe. In April 1969, when the river crested at el 469.1, water stood in the fields behind the levee. When the river crested at

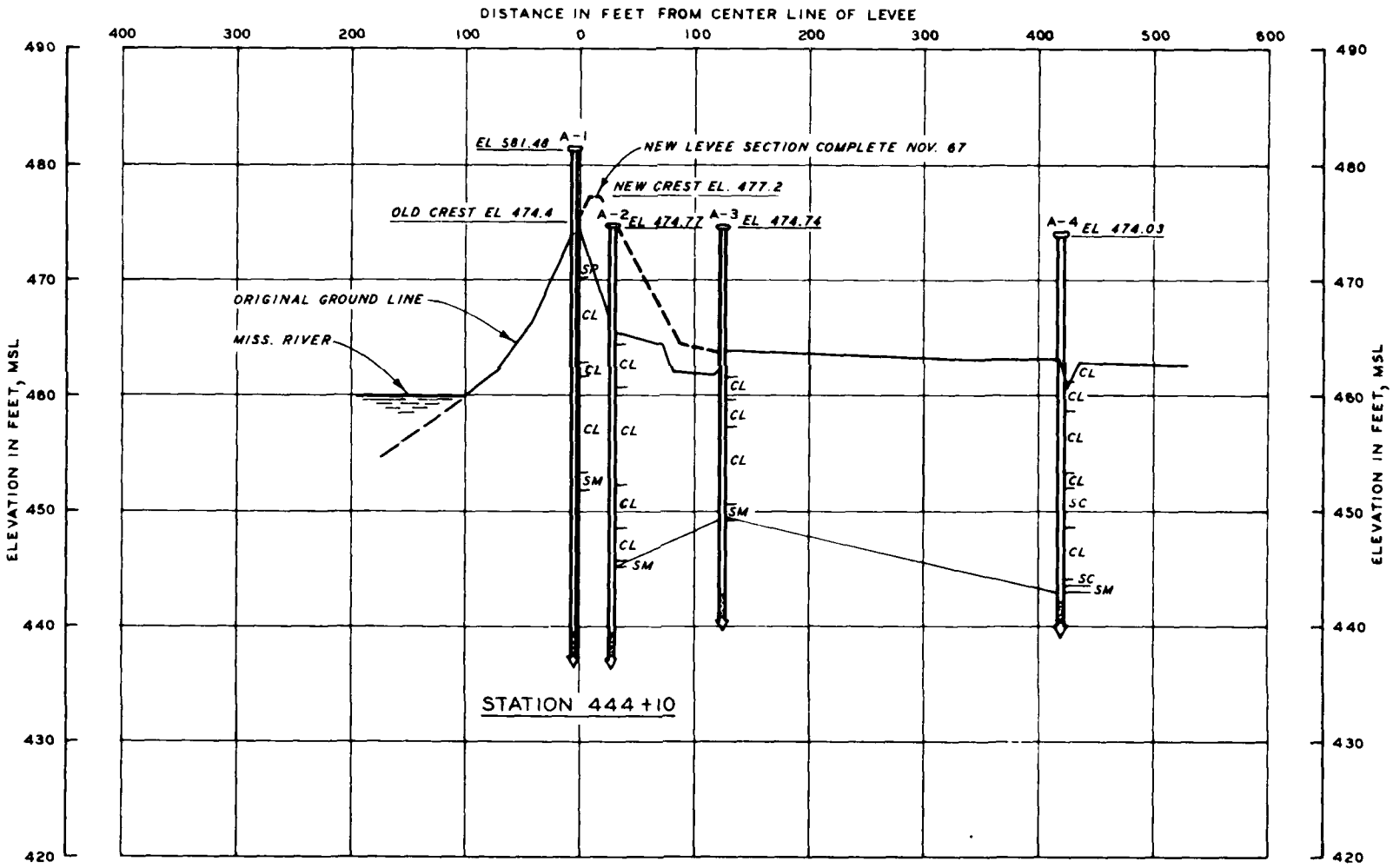

Figure 44. Cross section of Sny Island, Piezometer Range A

el 476.8 in 1973, heavy seepage was reported at the toe and 1 ft up the landside slope.

Analysis of piezometer data

127. The readings from piezometers A-1, A-2, A-3, and A-4 in Table 19 are for five different dates. In Figure 45, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 477.2 can be estimated. Also shown in Figure 45 are estimated piezometric elevation heads for the old levee toe, the center line of the levee road, the new levee toe, the road ditch, and the borrow pit 80-114 ft landward of the center line of the levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

128. Data from piezometers A-1 and A-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The tailwater elevation landward of the levee toe for these calculations was assumed to be 463.8. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 19 are plotted versus the river stage in Figure 46. For the old crest elevation of 474.4, s was 225 ft and x_3 was 370 ft. For the new crest elevation of 477.2, s was estimated to be 225 ft and x_3 was 420 ft. It should be noted that the calculated s value of 225 ft is somewhat less than the distance from the ditch at the landside toe to the exposed pervious substratum at the riverbank.

Permeability ratio

129. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 13.8 ft, $d = 110$ ft , x_3 (for the old crest elevation)

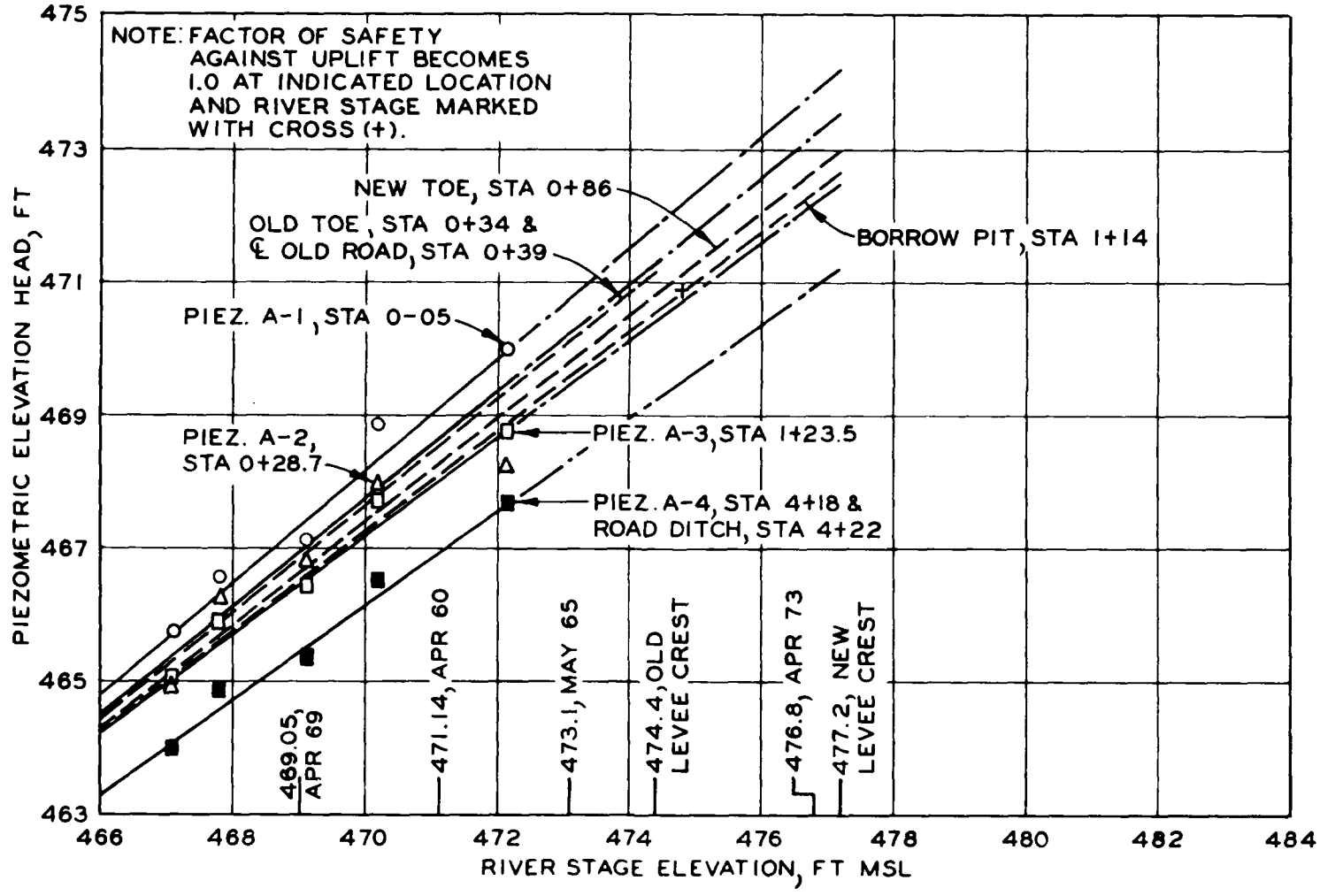

Figure 45. Piezometric elevation head versus river stage, Sny Island, Range A

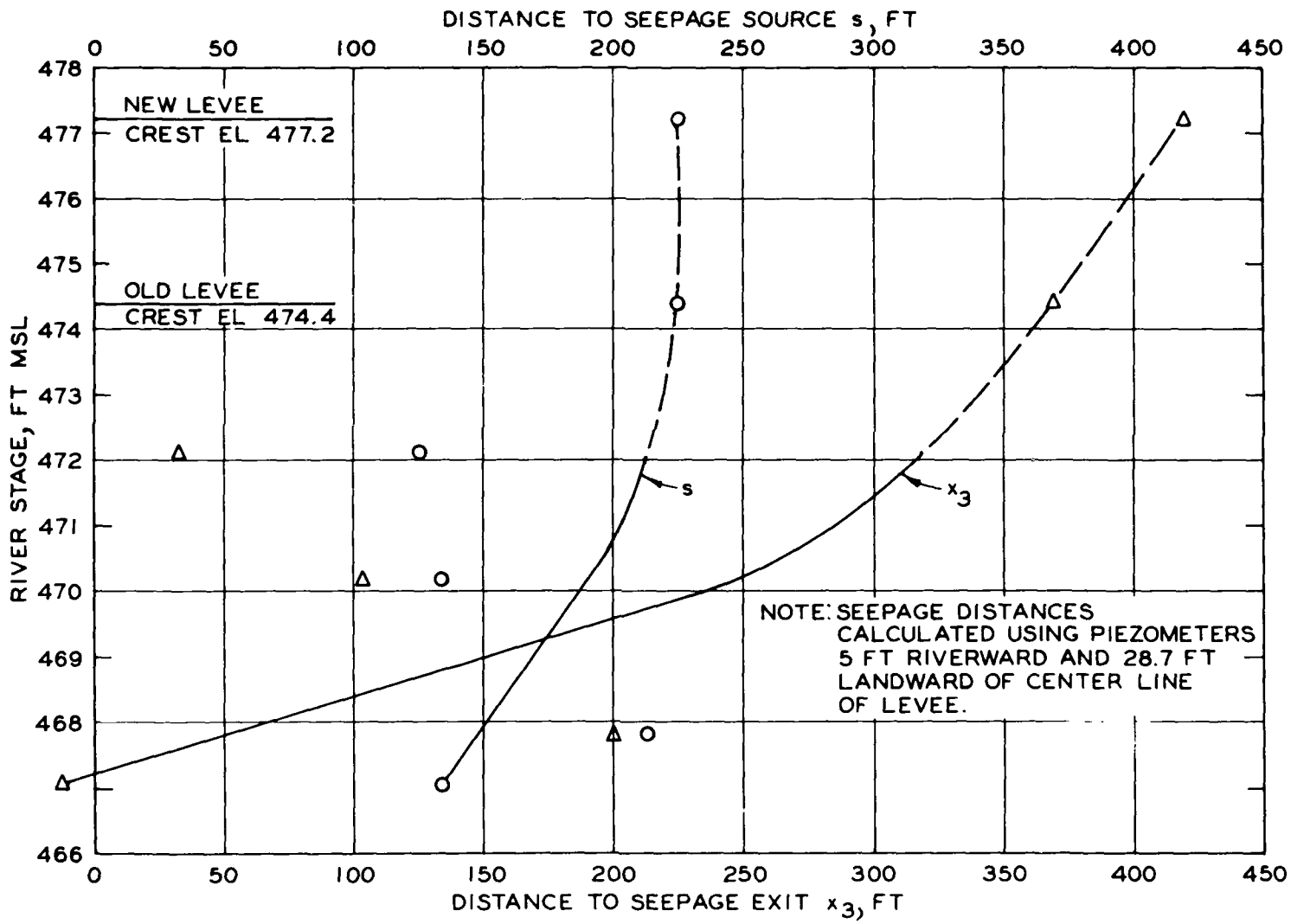

Figure 46. Distances to seepage source and seepage exit, Sny Island, Range A

was 370 ft, and the calculated $k_f/k_{b\ell}$ was 90.

130. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh (cL_1)}{c}$.

For these calculations, $x_1 = 102$ ft , $L_1 = 159$ ft , $c = 0.00861$ ft , $z_{br} = 6.0$ ft , $d = 110$ ft , and $k_f/k_{br} = 20$.

Calculated factors of safety

131. The projected piezometric data in Figure 45 have been used to calculate the factors of safety at the old and new levee toes, the center line of the road, the road ditch, and the borrow pit from 80 to 114 ft landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 20 presents these factors of safety and the data necessary to make the calculations.

132. The type of seepage observed during the flood stages is also shown in Table 20. It is interesting to note that when pinboils were reported in the levee road in 1965, the factor of safety was 3.1; when water was observed standing in the fields in 1960 and 1969, the factor of safety ranged from 1.4 to 3.0; when heavy toe seepage was observed in 1965 and 1973, the factor of safety ranged from 1.6 to 3.2; when light toe seepage was reported in 1960, the factor of safety was 4.9; and when no seepage was reported, the factor of safety ranged from 1.2 to 6.9. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.2 to 1.9.

Sny Island, Range F

Description of site

133. This piezometer range site was established in November 1954. The site was located at river mile 300.1 and levee sta 886+17 on the

slack-water side of the river (Figure 42). It is over 1/2 mile from the main channel in an area that appears to be protected from the main force of the river by an island and dikes. Figure 47 shows a cross section of the site with the original and new levee sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 4.8 to 10.0 ft thick and generally consists of about 2 to 4 ft of lean clay overlying silt and silty sand. The thickness of the pervious substratum was estimated to be about 34 ft.

134. The old levee crest elevation was 469.0, and the average ground elevation at the levee toe was 458.6. Construction for the levee enlargement began in November 1965 and was completed in November 1967. The new levee grade is el 472.8.

135. A road ditch parallel to the river was located approximately 92 ft landward of the center line of the levee. The ground elevation 92 ft landward was 456.9. The exposed pervious substratum at the bank of a chute of the river was estimated to be 560 ft west of the center line of the levee.

History of underseepage

136. Since the installation of the piezometer range in 1954, three observations of seepage have been recorded. On 8 April 1960, when the river crested at el 462.6, a great deal of toe seepage was noted, several small sand boils were seen in the road, a great deal of water was observed standing in the road ditch and low areas, and two sand boils were seen in an old borrow pit, presumably in the low area about 317 ft landward of the center line of the levee. In May 1965, when the river crested at el 468.8, a series of pinboils were located in the road and ditch between sta 885+00 and 890+00. In April 1969, when the river crested at el 465.2, the levee was reported dry. In April 1973, the berm was reported wet, and light toe seepage was noted when the river crested at 474.2.

Analysis of piezometer data

137. The readings from piezometers F-1, F-2, F-3, and F-4 in Table 21 are for six different dates. In Figure 48, piezometric data

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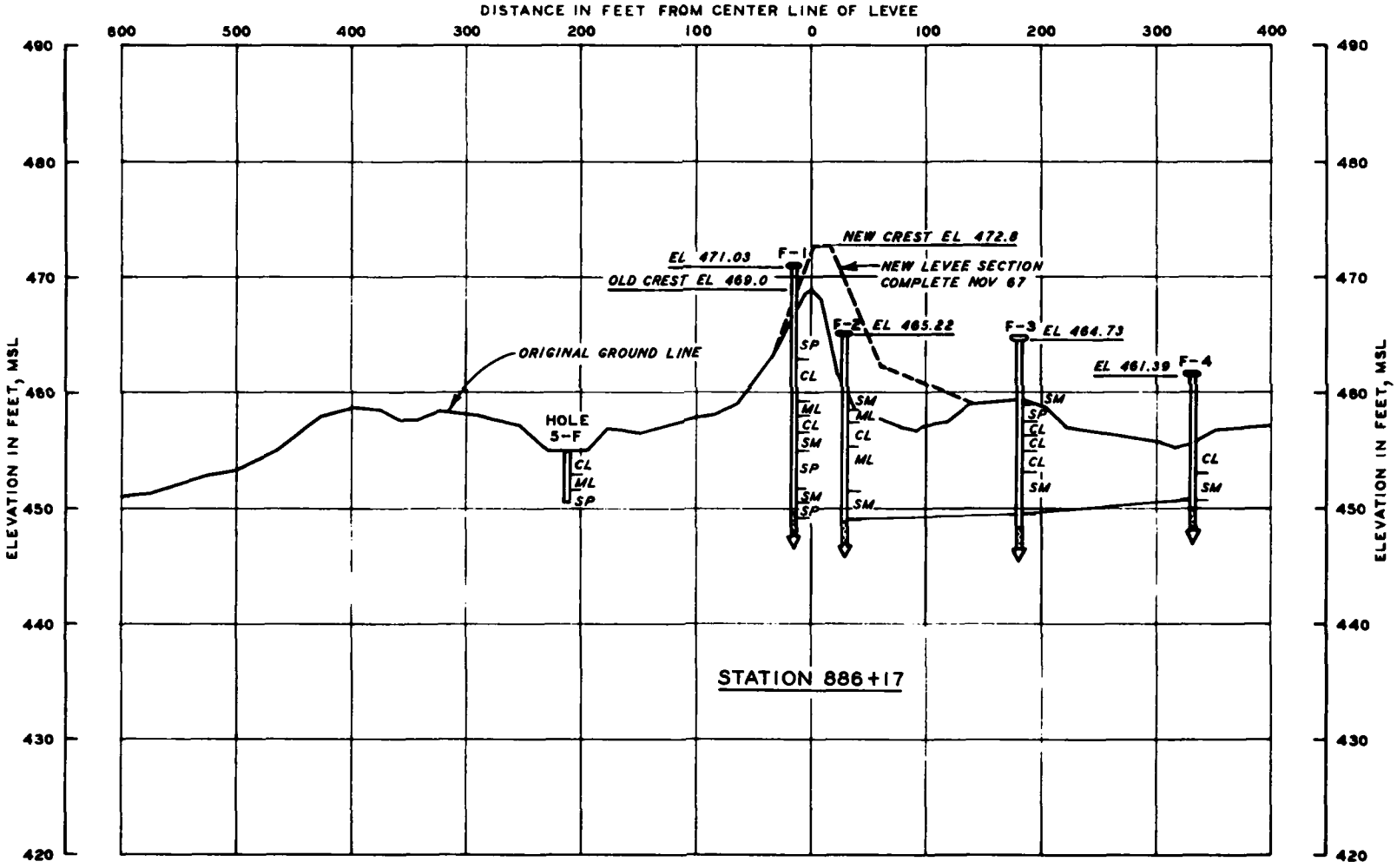

Figure 47. Cross section of Sny Island, Piezometer Range F

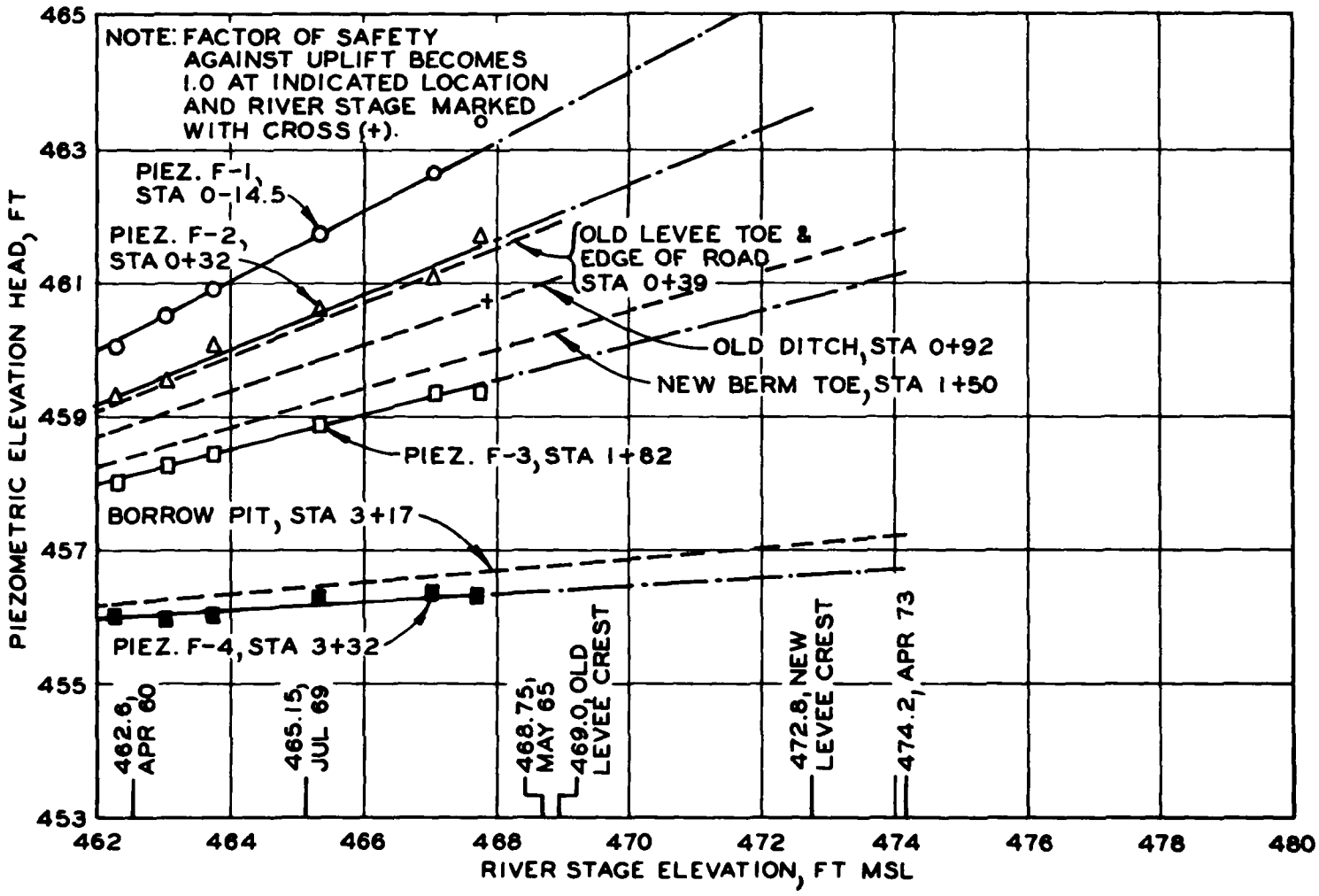

Figure 48. Piezometric elevation head versus river stage, Sny Island, Range F

are plotted, and piezometric elevation heads are projected to a river stage of el 474.2 (1.4 ft greater than the new levee crest), so that the piezometric pressure for all river stages up to el 474.2, the 1973 flood crest, can be estimated. Also shown in Figure 48 are estimated piezometric elevation heads for the old levee toe, the new berm toe, the old ditch, and the low areas 317 ft landward of the center line levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

138. Data from piezometers F-1 and F-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 458.6. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 21 are plotted versus the river stage in Figure 49. For the old crest elevation of 469.0, s was 207 ft and x_3 was 90 ft. For the new crest elevation of 472.8, s was estimated to be 219 ft and x_3 was 108 ft.

Permeability ratio

139. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 7.6 ft, $d = 34$ ft , x_3 (for the old crest elevation) was 90 ft, and the calculated $k_f/k_{b\ell}$ was 31.

140. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh (cL_1)}{c}$.

For these calculations, $x_1 = 103$ ft , $L_1 = 495$ ft , $c = 0.00971$, $z_{br} = 4.0$ ft , $d = 34$ ft , and $k_f/k_{br} = 78$.

Calculated factors of safety

141. The projected piezometric data in Figure 48 have been used to

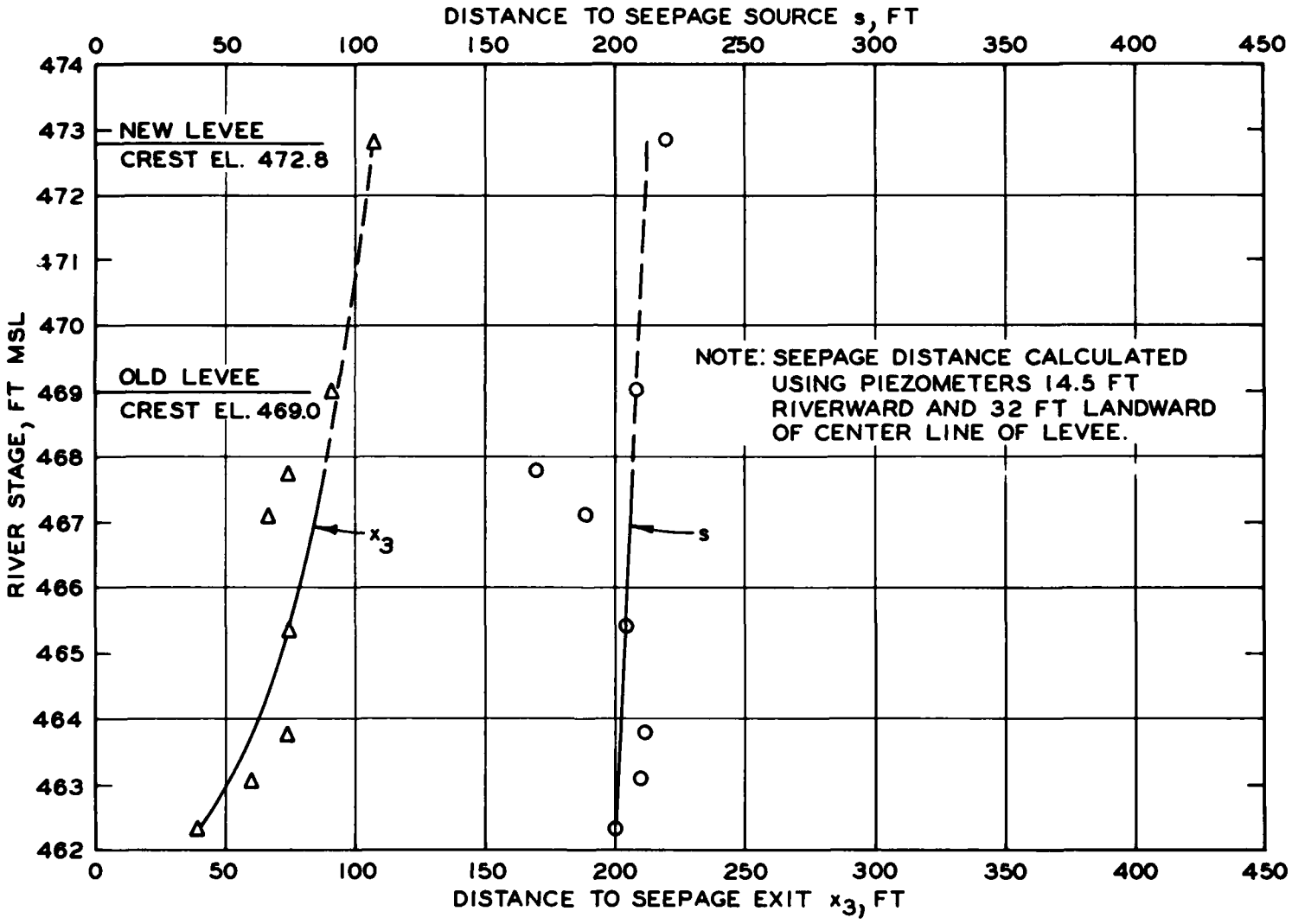

Figure 49. Distances to seepage source and seepage exit, Sny Island, Range F

calculate uplift factors of safety at the old levee toe, the berm toe, and the ditch and old borrow pit, 92 and 317 ft, respectively, landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 22 presents these factors of safety and the data necessary to make the calculations.

142. The type of seepage observed during the flood stages is also shown in Table 22. It is interesting to note that when sand boils developed in the borrow pit in 1960 with the river stage at el 462.6, the factor of safety was 2.2; also, in 1960, when pin boils were seen in the road, the factor of safety was 1.9; and when heavy toe seepage was reported, the factor of safety was 15.8. In 1965, with the river stage at el 468.8 ft, the factor of safety ranged from 0.9 to 1.6 when pin boils were noted in the road and road ditch. In 1973, with the river stage at el 474.2 (1.4 above the new crest elevation), the factor of safety at the new berm toe was 1.8 when the new levee berm was reported damp and light toe seepage was noted. In 1969, when the river crested at el 465.2 and the landside was reported dry, the factor of safety ranged from 1.8 to 26.5. In 1960, 1965, and 1973 at locations where no seepage was reported, the factors of safety ranged from 1.1 to 3.1. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.2 to 4.1.

Sny Island, Range B

Description of site

143. This piezometer range site was established in November of 1950. The site was located at river mile 296.3 and levee sta 1079+71 on the outside bank of the main channel at a moderate bend of the river (Figure 42). Figure 50 shows a cross section of the site with the

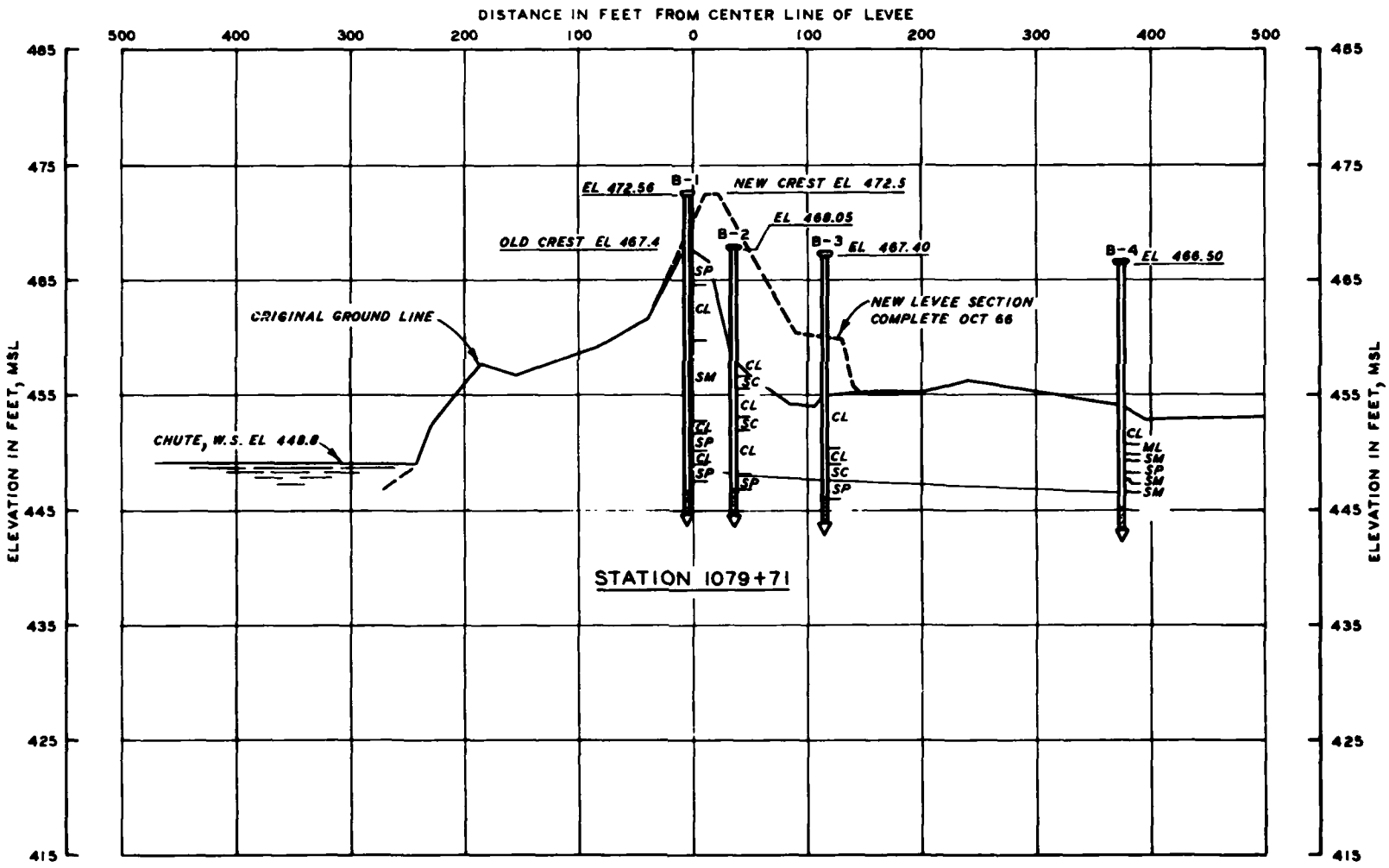

Figure 50. Cross section of Sny Island, Piezometer Range B

original and new levee sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 6.2 to 9.7 ft thick and generally consists of about 5.5 ft of lean clay overlying clayey sand.

144. The old levee crest elevation was 467.4, and the average ground elevation at the levee toe was 454.2. Construction for the levee enlargement began on 6 December 1965 and was completed on 15 October 1966. The new levee grade is el 472.5.

145. A road and ditch parallel to the river were located approximately 48 and 103 ft, respectively, landward of the center line of the levee. The ground elevations 48 and 103 ft landward were 456.8 and 454.0, respectively. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 242 ft west of the center line of the levee. The piezometer range was reported as destroyed on 14 April 1969.

History of underseepage

146. Since the installation of the piezometer range, three observations of seepage have been recorded. On 8 April 1960, when the river crested at el 465.7, a great deal of toe seepage was noted, several small sand boils were seen in the road running clear water, and water was reported standing in the road ditch and low areas. In May 1965, when the river crested at el 466.8, no seepage was noted. In 1969, when the river crested at el 464.6, light seepage was observed at the berm toe. In April 1973, when the river crested at el 472.0 ft, the berm was reported wet and water was seen flowing from the landside slope, which was saturated 1 ft above the ground.

Analysis of piezometer data

147. The readings from piezometers B-1, B-2, B-3, and B-4 in Table 23 are for five different dates. In Figure 51, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 472.5 can be estimated. Also shown in Figure 51 are estimated piezometric elevation heads for the old levee toe, the new berm toe, the road and ditch 48 and 103 ft, respectively,

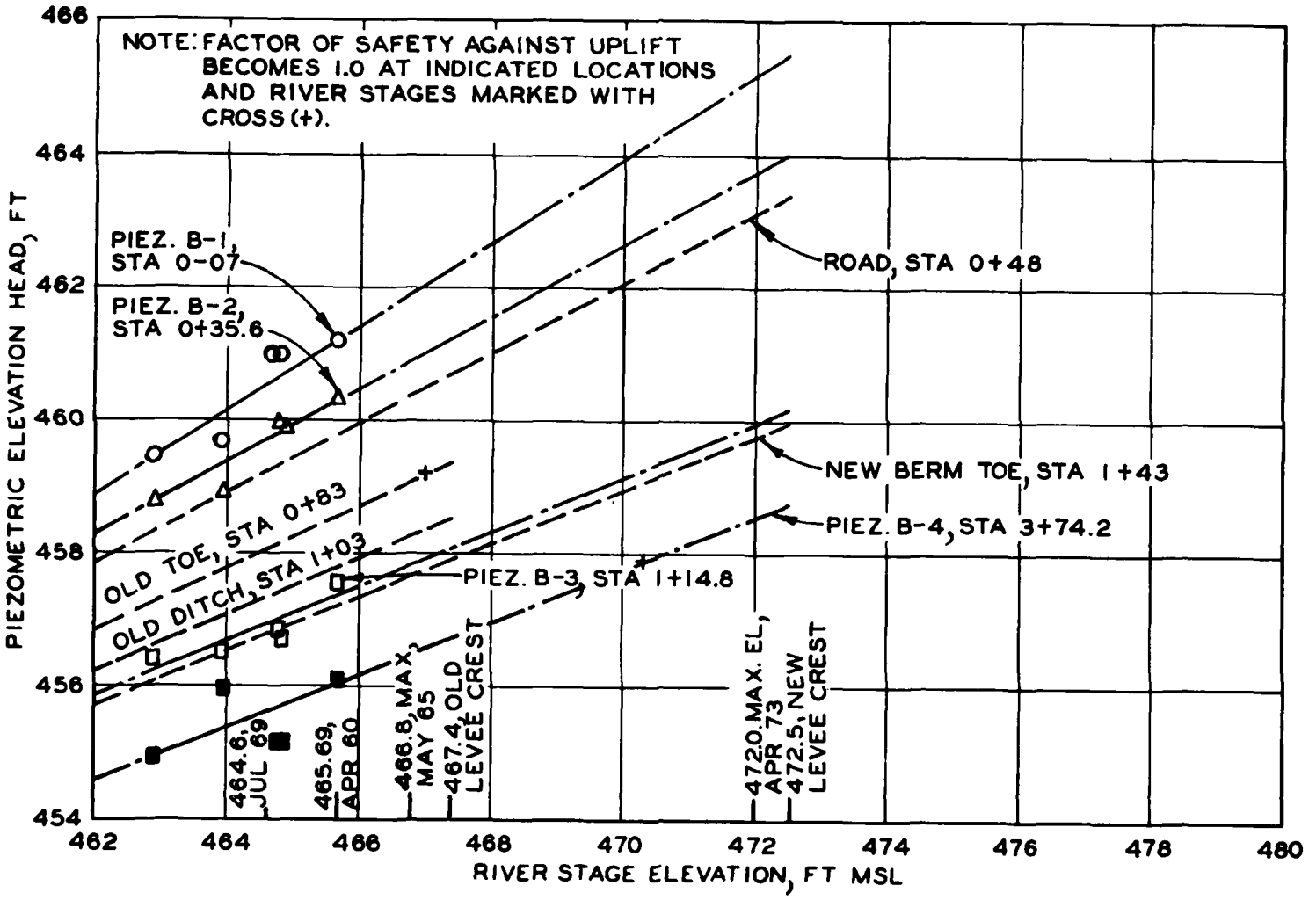

Figure 51. Piezometric elevation head versus river stage, Sny Island, Range B

landward of the center line of the levee, and a point on the new berm 115 ft landward of the center line of the levee where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

148. Data from piezometers B-1 and B-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The tailwater elevation landward of the levee toe for these calculations was assumed to be 455.0. In addition, s and x_3 were calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 23 are plotted versus the river stage in Figure 52. For the old crest elevation of 467.4, s was 288 ft and x_3 was 193 ft. For the new crest elevation of 472.5, s was estimated to be 286 ft and x_3 was 211 ft.

Permeability ratio

149. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 6.3 ft, $d = 110$ ft , x_3 (for the old crest elevation) was 193 ft, and the calculated $k_f/k_{b\ell}$ was 54.

150. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh (cL_1)}{c}$. For these calculations, $x_1 = 120$ ft , $L_1 = 157$ ft , $c = 0.00632$, $z_{br} = 4.6$ ft , $d = 110$ ft , and $k_f/k_{br} = 50$.

Calculated factors of safety

151. The projected piezometric data in Figure 51 have been used to calculate uplift factors of safety at the levee and berm toes, the road, the ditch, and the point on the new berm for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the

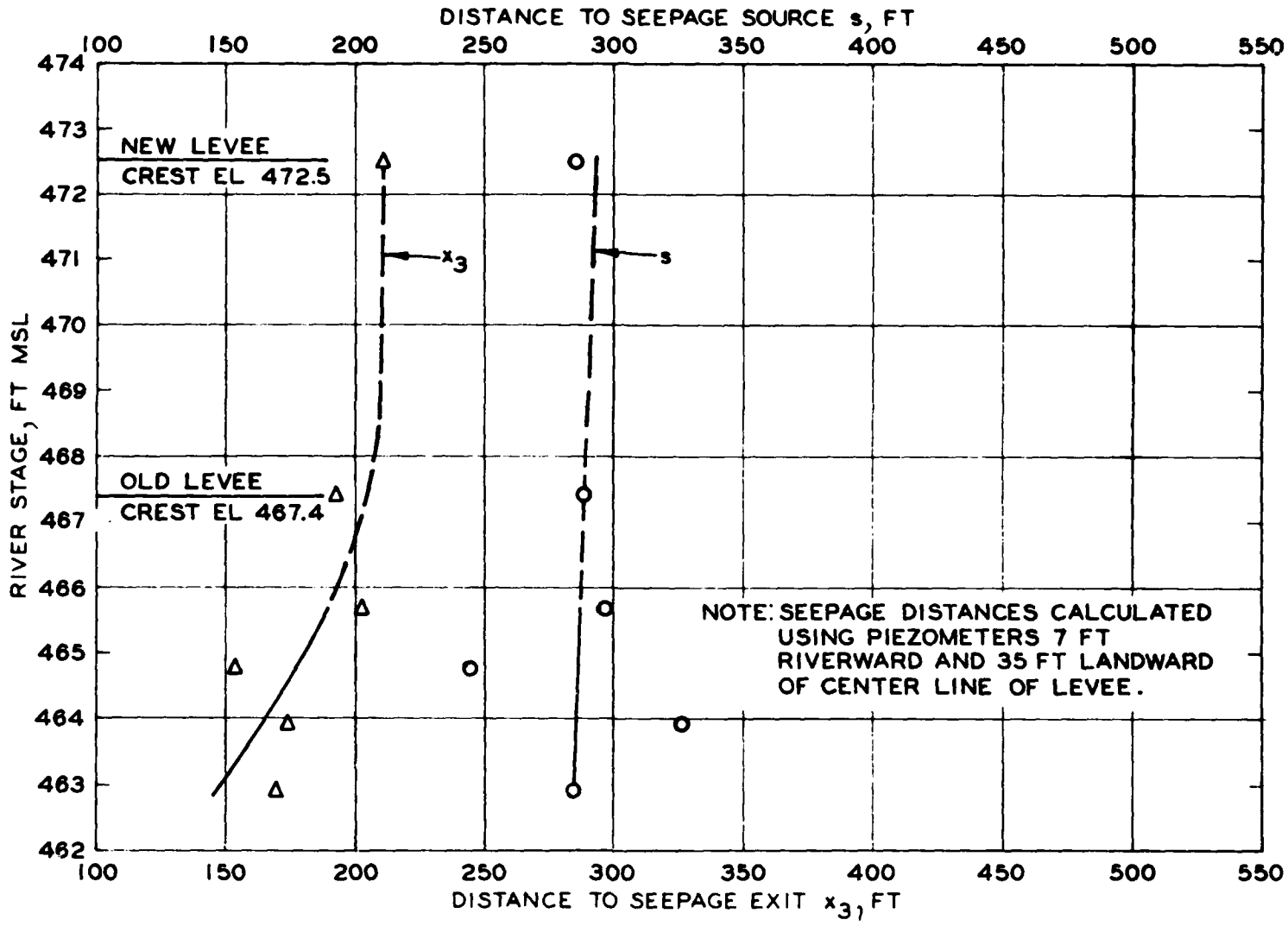

Figure 52. Distances to seepage source and seepage exit, Sny Island, Range B

appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 24 presents these factors of safety and the data necessary to make the calculations.

152. The type of seepage observed during the flood stages is also shown in Table 24. When pin boils were reported in 1960 and 1973, the factors of safety were 2.3 and 0.8, respectively. At locations where water was seen standing in low areas in 1960, the factors of safety ranged from 1.1 to 1.3. When the berm was reported wet in 1973, the piezometer had not reached the surface; therefore, in this instance, the wetness must have been caused by through seepage. When toe seepage was reported in 1960 and 1969, the factors of safety were 3.6 and 5.7, respectively. When saturation was observed 1 ft up the landside slope in 1973 (through seepage), the factor of safety was 1.5. At other times and other locations when no seepage was reported, the factors of safety ranged from 1.0 to 2.9, respectively. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 0.8 to 99.

Sny Island, Range G

Description of site

153. This piezometer range site was established in December 1954. The site was located at river mile 293.6 and levee sta 1197+24 on the slack-water side of the river (Figure 42). It is over 1/2 mile from the main channel, and the ground in front of the levee is lower than the surrounding ground. Figure 53 shows a cross section of the site with the original ground surface, the original and new levee sections, the foundation, and piezometer locations. A slough or secondary water channel passes immediately in front of the levee. The relatively impervious top stratum ranges from 7.1 to 11.0 ft thick and generally consists of about 5.9 ft of lean clay overlying silty sand.

154. The old levee crest elevation was 467.4, and the average ground elevation at the levee toe was 454.1. Construction for the levee

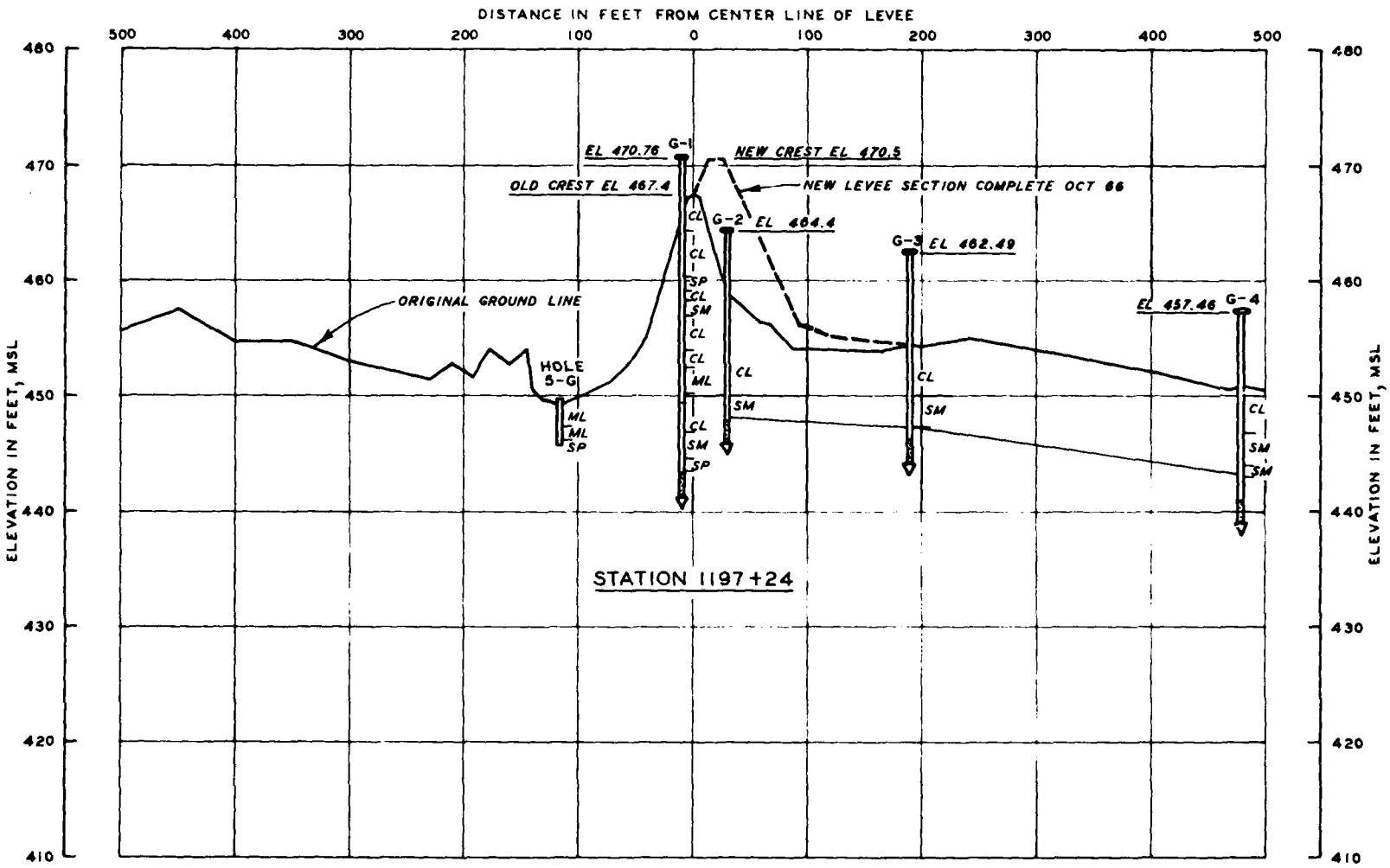

Figure 53. Cross section of Sny Island, Piezometer Range G

enlargement began 6 December 1965 and was completed 15 October 1966. The new levee grade is el 470.5.

155. A road parallel to the river was located approximately 68 ft landward of the center line of the levee. The ground elevation 68 ft landward was 456.3. The exposed pervious substratum was estimated to be 1155 ft west of the center line of the levee. Only piezometer G1 was reported "found remaining" on 14 April 1969.

History of underseepage

156. Since the installation of the piezometer range, three observations of seepage have been recorded. On 6 April 1960, when the river crested at el 462.8, a little toe seepage was noted. In May 1965, when the river crested at el 465.45, no seepage was reported. In 1969, when the river crested at el 464.2, light seepage was observed beyond the toe. In April 1973, when the river crested at 470.5, moderate through seepage was reported about 4 to 5 ft up the slope.

Analysis of piezometer data

157. The readings from piezometers G-1, G-3, and G-4 in Table 25 are for three different dates. In Figure 54, piezometric data are plotted, and piezometric elevation heads are projected to a river stage equal to the new levee crest so that the piezometric pressure for all river stages up to el 470.5 can be estimated. Also shown in Figure 54 are estimated piezometric elevation heads for the old levee toe and the new levee toe where various types of seepage have been reported during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers. Data obtained from piezometer G-4 indicate that the piezometer was not functioning properly; therefore, no projection of piezometric pressure was made for this piezometer location.

158. Piezometer G-2 was destroyed before any data could be obtained from this first landside piezometer location. Therefore, piezometers G-1 and G-3 were used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe

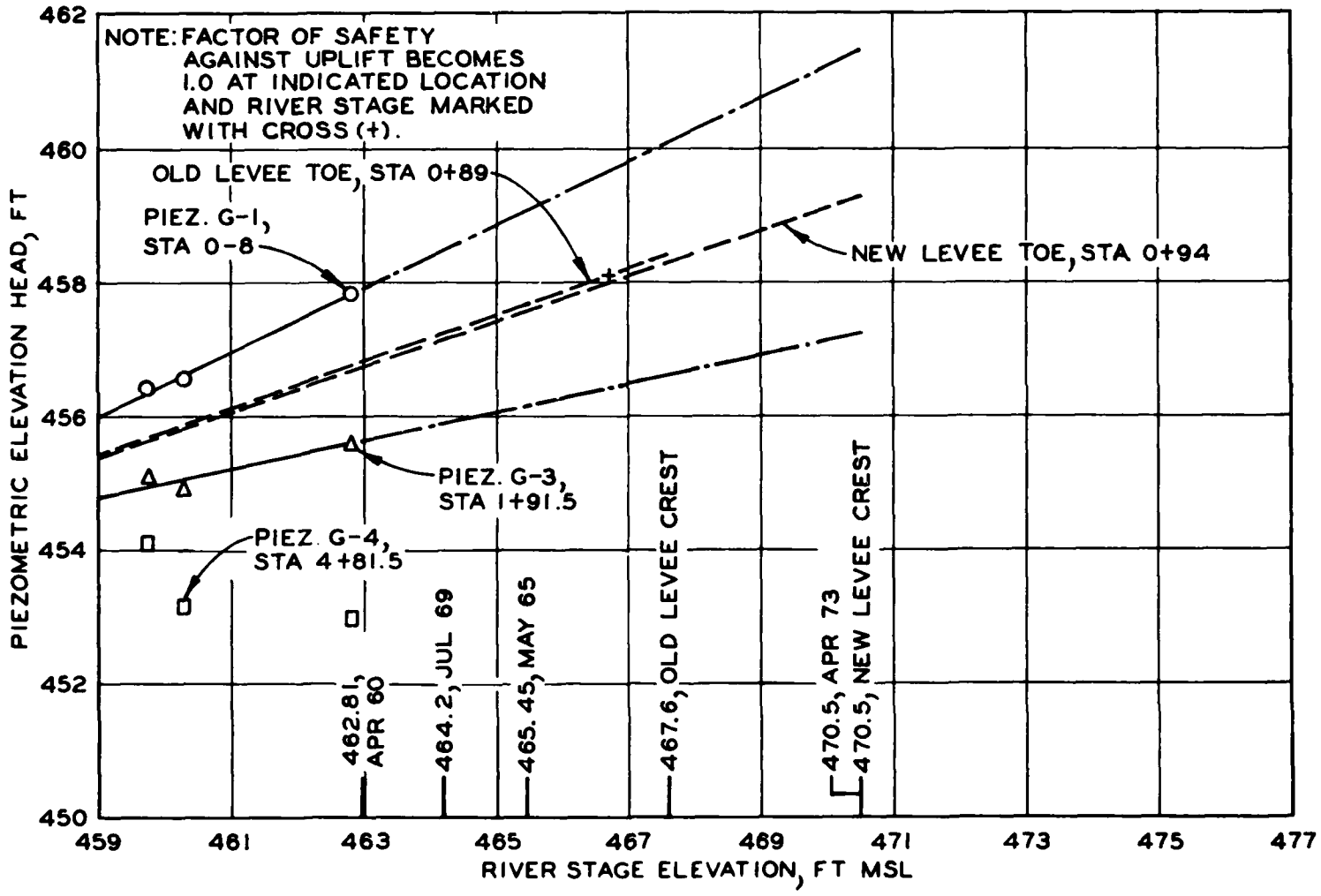

Figure 54. Piezometric elevation head versus river stage, Sny Island, Range G

selected for these calculations was 454.1. In addition, s and x_3 were also calculated for river stages equal to the old and new levee crest using piezometer data projected to these elevations. The s and x_3 values listed in Table 25 are plotted versus the river stage in Figure 55. For the old crest elevation of 467.4, s was 513 ft and x_3 was 245 ft . For the new crest elevation of 470.5, s was estimated to be 514 ft and x_3 was 246 ft. If piezometer data had been available from the location of G-2, it is most likely that these calculated seepage distances would have been smaller.

Permeability ratio

159. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old levee toe) was 5.0 ft, $d = 112$ ft , x_3 (for the old crest elevation) was 245 ft, and the calculated $k_f/k_{b\ell}$ was 107. If piezometer data had been available from the location of G-2, x_3 probably would have been smaller, and the calculated $k_f/k_{b\ell}$ would also have been smaller.

160. Since the piezometer at the landside toe was destroyed before useful data could be collected and the calculated entrance distance is large by an unknown amount, a riverside permeability ratio based on piezometer data was not calculated for this site.

Calculated factors of safety

161. The projected piezometric data in Figure 54 have been used to calculate uplift factors of safety at the old and new levee toes and the location of piezometer G-3 for flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safety were also made for a river stage equal to the new crest of the levee. Table 26 presents these factors of safety and the data necessary to make the calculations.

162. The type of seepage observed during the flood stages is also shown in Table 26. In 1969, when the river crested at el 464.2 and

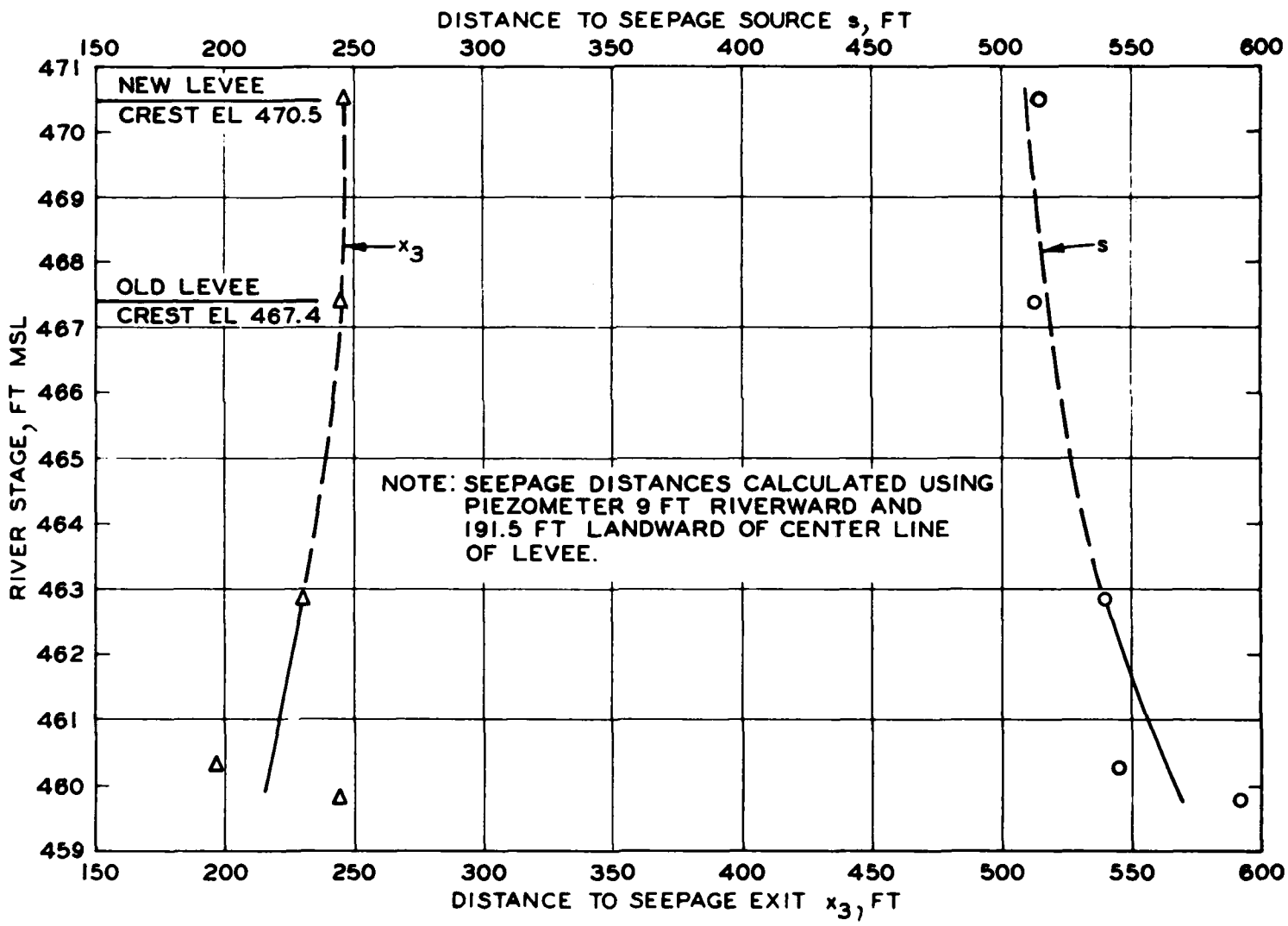

Figure 55. Distances to seepage source and seepage exit, Sny Island, Range G

light seepage was reported beyond the toe, the factor of safety at the location of piezometer G-3 was 3.0. In 1960, when the river crested at el 462.8 and very light toe seepage was observed, the factor of safety was 1.5. In 1973, when the river crested at el 470.5 and through seepage was noted 4 to 5 ft up the levee slope, the factor of safety at the new levee toe was 2.0. At other times and locations when no seepage was reported, the factor of safety ranged from 1.1 to 8.3. The calculated factor of safety for a river stage equal to the crest of the new levee ranged from 1.5 to 1.9.

Sny Island, Range H

Description of site

163. This piezometer range site was established in November 1954. The site was located at river mile 289.8 and levee sta 1399+99 at a recessed "U" shaped section of the levee that apparently surrounds a 1000-ft reach, which at some time in the past experienced extensive bank failures (Figure 42). The area now is about 1/2 mile from the main channel of the river and is protected by two islands and other timbered ground and channels. Figure 56 shows a cross section of the site with the original and new levee cross sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 5.5 to 7.5 ft thick and generally consists of about 3 to 6 ft of lean clay overlying silt and silty clay. The thickness of the pervious substratum was estimated to be 105 ft.

164. The old levee crest elevation was 465.3. Construction for the levee enlargement began in December 1965 and was completed in October 1966. The new levee grade is el 468.4.

165. A road and ditch parallel to the river was located approximately 40 and 200 ft, respectively, landward of the center line of the levee. The ground elevation 200 ft landward was 448.5. The exposed pervious substratum at the bank of the channel of the river was estimated to be 725 ft west of the center line of the levee.

History of underseepage

166. Since the installation of the piezometer range in 1954, only

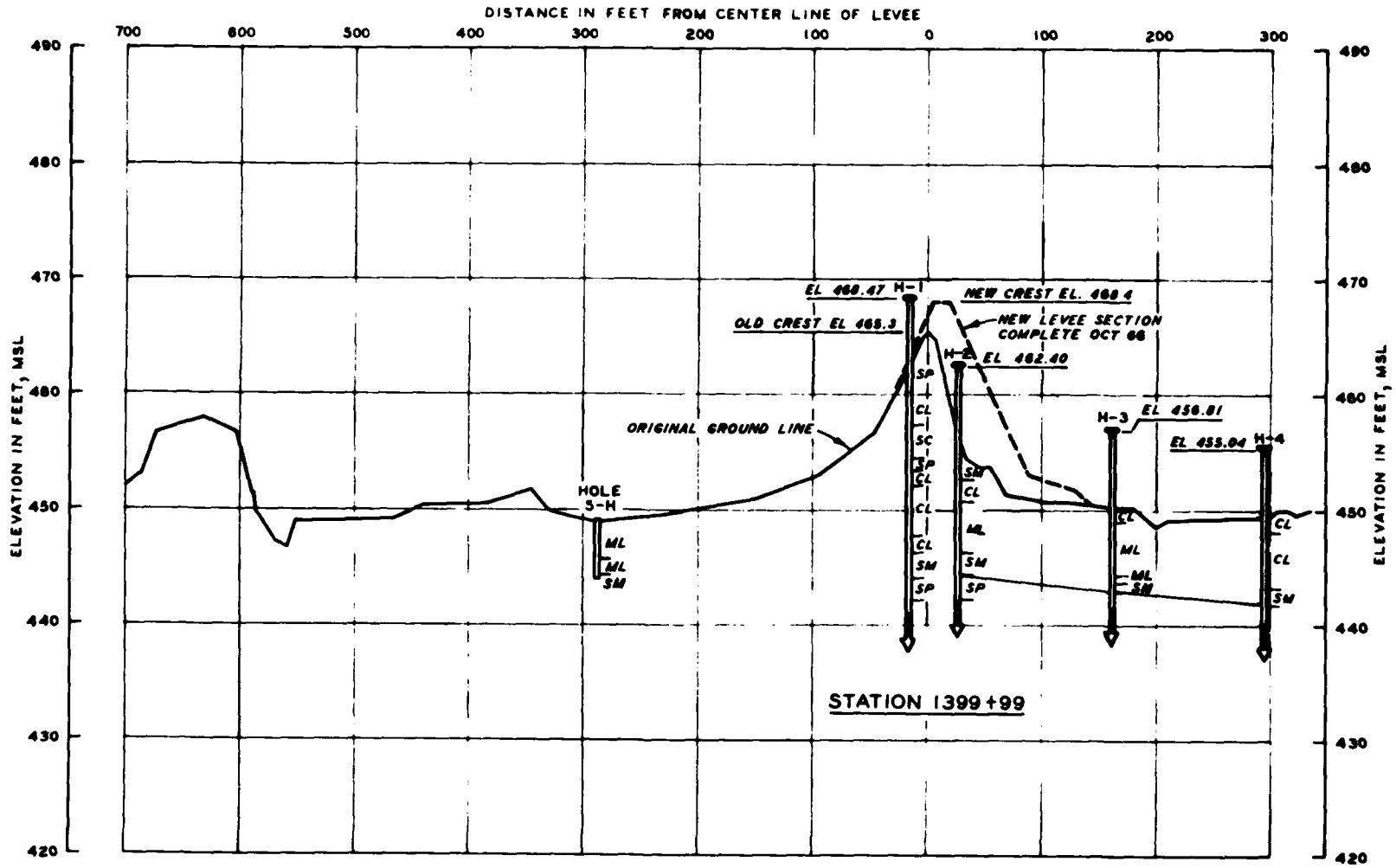

Figure 56. Cross section of Sny Island, Piezometer Range H

two observations of seepage have been reported. On 8 April 1960, when the river crested at el 462.6, a little toe seepage was noted, and a great deal of water was reported standing in the low areas. On 24 April 1973, when the river crested at el 468.6, some through seepage was observed halfway up the levee slope. In 1965 and 1969, no seepage was reported.

Analysis of piezometer data

167. The readings from piezometers H-1, H-2, H-3, and H-4 in Table 27 are for three different dates. In Figure 57, piezometric data are plotted, and piezometric elevation heads are projected to a river stage of el 468.6 (0.2 ft greater than the new levee crest), so that the piezometric pressure for all river stages up to the elevation of the 1973 flood crest can be estimated. Also shown in Figure 57 are estimated piezometric elevation heads for the old berm toe, the new berm toe, and the ditch 200 ft landward of the center line of the levee where various types of seepage have been reported or could have been expected during past flood stages of the river. These latter plots of piezometric elevation head were determined by linear interpolation of the projected heads for the piezometer locations to the intermediate locations between the piezometers.

168. Data from piezometers H-1 and H-2 were also used to calculate the effective seepage source s and the effective seepage exit x_3 distances for each date of piezometer observation. The average ground elevation landward of the levee toe selected for these calculations was 449.0. In addition, s and x_3 were also calculated for river stages equal to the old and new levee crests using piezometer data projected to these elevations. The s and x_3 values listed in Table 27 are plotted versus the river stage in Figure 58. For the old crest elevation of 465.3, s was 157 ft and x_3 was 26 ft. For the new crest elevation of 468.4, s was estimated to be 170 ft and x_3 was 35 ft.

Permeability ratio

169. The landside permeability ratio was calculated for flood stages equal to both the old and new crest elevations, using the blanket formula $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$. For this site, $z_{b\ell}$ (at the old berm

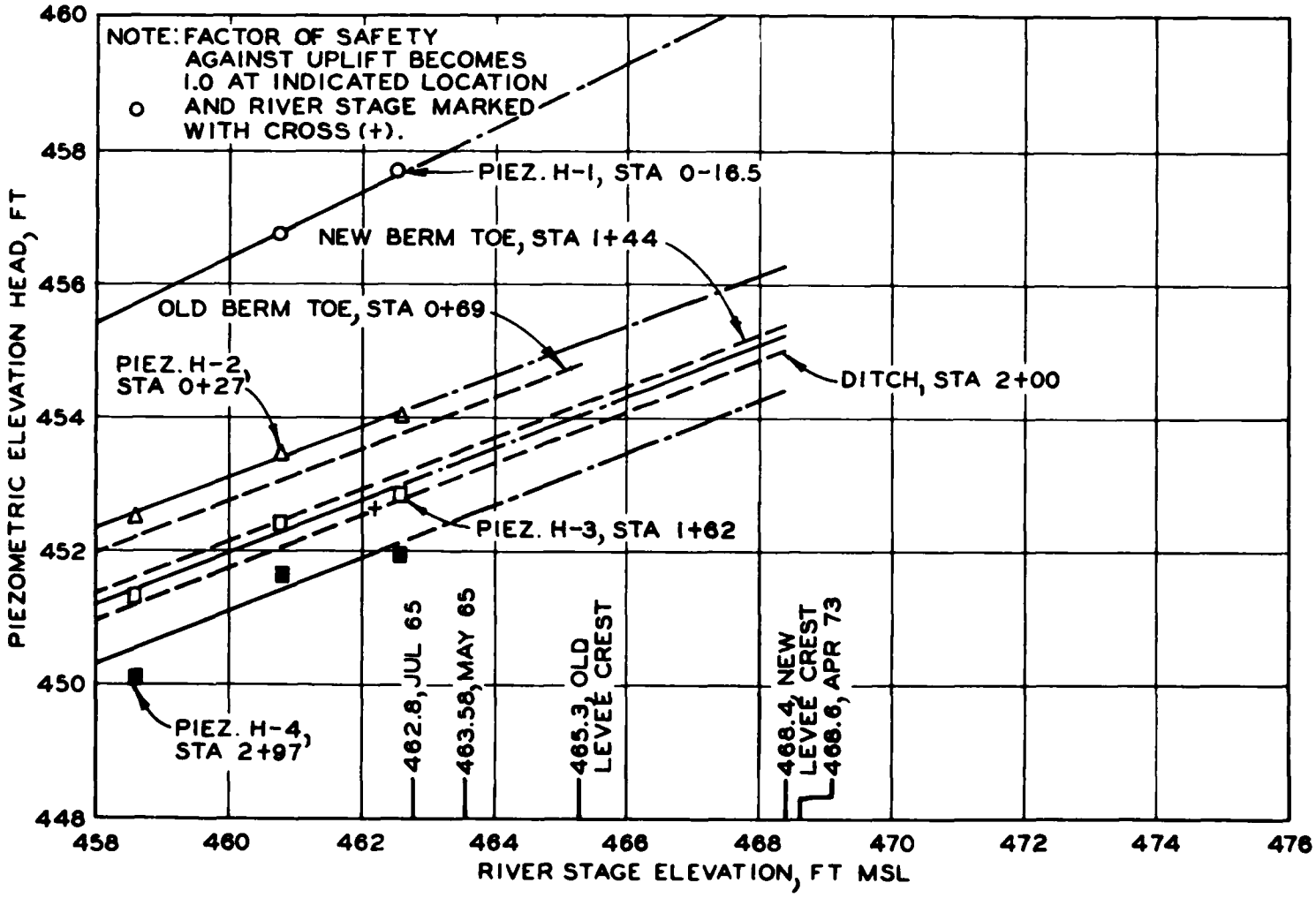

Figure 57. Piezometric elevation head versus river stage, Sny Island, Range H

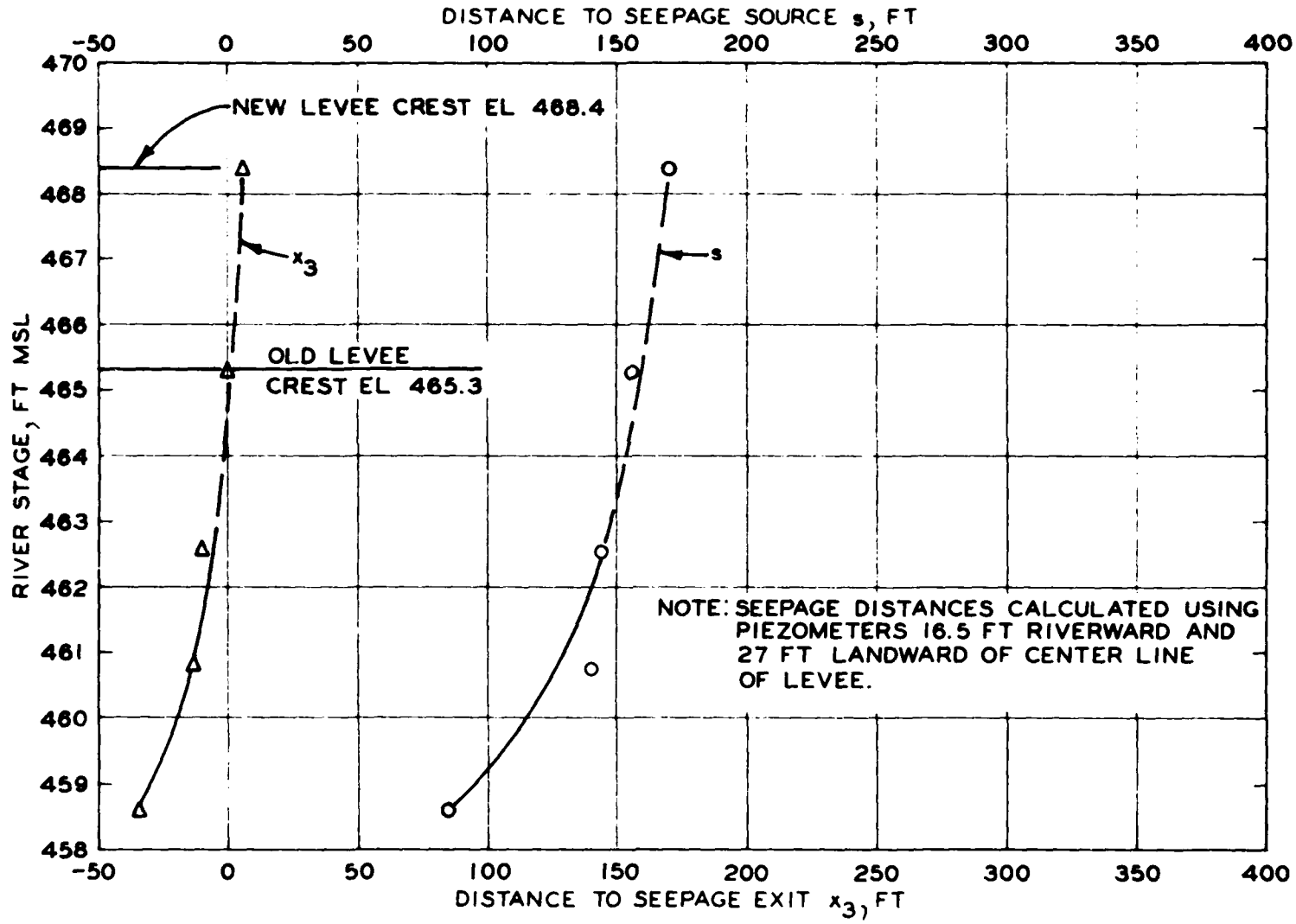

Figure 58. Distances to seepage source and seepage exit, Sny Island, Range H

toe) was 6.1 ft, $d = 105$ ft , x_3 (for the old crest elevation) was 26 ft, and the calculated $k_f/k_{b\ell}$ was 1.1.

170. The riverside permeability ratio was calculated for the old levee crest, using the formula $k_f/k_{br} = 1/[(c^2)(z_{br})(d)]$ where c was determined by trial and error from the formula $x_1 = \frac{\tanh (cL_1)}{c}$. For these calculations, $x_1 = 40$ ft , $L_1 = 677$ ft , $c = 0.0250$, $z_{br} = 5.0$ ft , $d = 105$ ft , and $k_f/k_{br} = 3.0$.

Calculated factors of safety

171. The projected piezometric data in Figure 57 have been used to calculate uplift factors of safety at the old and new berm toes and the ditch 200 ft landward of the center line of the levee for the flood stages of 1960, 1965, 1969, and 1973. The factor of safety was calculated as the critical head divided by the piezometric head above the ground estimated by the projection and interpolation of the observed piezometric data to the appropriate flood stage and distance landward of the center line of the levee. Calculations of factor of safey were also made for a river stage equal to the new crest of the levee. Table 28 presents these factors of safety and the data necessary to make the calculations.

172. The type of seepage observed during the flood stages is also shown in Table 28. In 1960, when the river crested at el 462.6 and light toe seepage was observed, the factor of safety was 2.0 at the old berm toe; in the ditch where water was seen standing, the factor of safety was 1.0. It is of particular interest to note that in 1965, 1969, and 1973 with river crests of el 463.6, 462.8, and 468.6, respectively, no seepage was reported in the ditch and the factors of safety at the ditch were 0.9, 1.0, and 0.6, respectively. In 1973, when through seepage was noted, the factor of safety at the new berm toe was 1.0. At other times when no seepage was reported, the factors of safety at the old or new berm toe ranged from 1.7 to 1.9. The calculated factors of safety for a river stage equal to the crest of the new levee (el 468.4) ranged from 0.6 to 1.0.

Sny Island, Range I

Description of site

173. This piezometer range site was established in November 1954. The site was located at river mile 288.7 and levee sta 1502+00 on the slack-water side of the river (Figure 42). It is separated from the main channel by about a mile of islands, channels, chutes, and timbered ground. Figure 59 shows a cross-section of the site with the original and new levee sections, the original ground surface, the foundation, and piezometer locations. The relatively impervious top stratum is lean clay ranging from 11.3 to 13.3 ft thick.

174. The old levee crest elevation was 464.6, and the average ground elevation at the levee toe was 455.3. Construction for the levee enlargement began in December 1965 and was completed in October 1966. The new levee grade is el 468.8.

175. A road running parallel to the levee was located approximately 33 ft landward of the center line of the levee. The ground elevation 33 ft landward was 456.5. The exposed pervious substratum at the bank of a channel of the river was estimated to be 570 ft west of the center line of the levee. Piezometers I-1 and I-4 were reported as damaged on 6 April 1960.

History of underseepage

176. Since the installation of the piezometer range in 1954, only two observations of seepage have been recorded. On 6 April 1960, when the river crested at el 460.48, a little toe seepage, water standing in low areas, and several pinboils on the road were reported. In April 1973, when the river stage was el 468.2, heavy seepage over the road and through seepage 2 to 3 ft up the slope of the levee were observed. In 1965, no seepage was noted, and in 1969 the landside of the levee was reported dry.

Analysis of piezometer data

177. The readings from piezometers I-1, I-2, I-3, and I-4 in Table 29 are for just one time on 6 April 1960. Data from piezometers I-1 and I-2 were used to calculate the effective seepage source s and

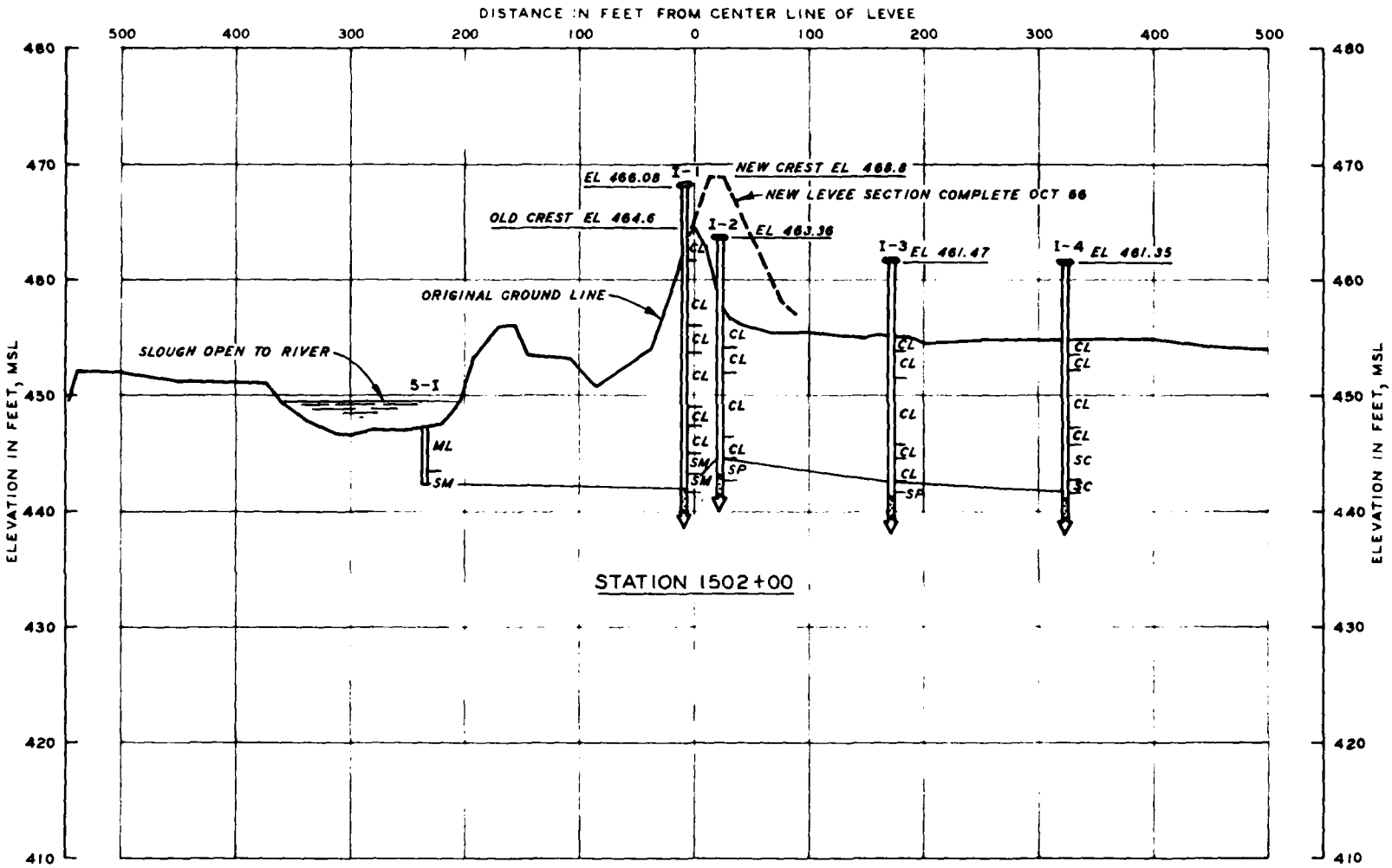

Figure 59. Cross section of Sny Island, Piezometer Range I

the effective seepage exit x_3 distances for the single date for which readings were recorded, as presented in Table 29. However, since only one set of piezometer reading had been obtained, piezometric pressures could not be projected to the old and new levee crest elevations, and seepage entrance and exit distances and landside and riverside permeability ratios for these other elevation heads could not be calculated. However, piezometric elevation heads for the April 1960 performance observations for the old levee toe, a low spot 72 ft landward of the center line of the levee, and the old levee road about 33 ft landward of the center line of the levee were determined by the linear interpolation of the recorded piezometer elevations to these intermediate locations between the piezometers (Table 30).

Calculated factors of safety

178. Factors of safety for the 1960 flood have been calculated as the critical head divided by the piezometric head above the ground for the old levee toe, a low spot, the old road, and piezometers I-3 and I-4 locations. Table 30 presents these factors of safety and the data necessary to make the calculations.

179. The type of seepage observed on 6 April 1960 is also shown in Table 30. The factor of safety was 6.0 in the road where pinboils were noted on the road in 1960; 3.8 in low areas where water was seen standing; and 10.1 at the old toe where light seepage was observed.

PART IV: NEW PIEZOMETER RANGE SITES

180. During 1977, the RID installed 15 new piezometer range sites. These sites are described and results of 1979 piezometer readings are discussed in this section.

Muscatine Island, Range MA

181. A general plan and a geologic profile of the Muscatine Island Levee District have been previously presented in Figures 4 and 5, respectively, with the description of the old piezometer range sites. Three new piezometer range sites, Ranges MA, MB, and MS, were established in July 1977.

Description of site

182. Piezometer Range MA site is located at Mississippi River mile 451.9 and levee sta 161+13 (Figure 60). The cross section of the site (Figure 61) shows the levee, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 3.9 to 10.9 ft thick and generally consists of clayey sand.

183. The levee crest elevation is 560.8, and the average ground elevation 100 ft landward of the levee toe is 549.1. Construction for the levee enlargement began in July 1960 and was completed in October 1961.

184. The cross section in Figure 61 shows that the top of the bank of the main channel of the Mississippi River is immediately adjacent to the levee. The exposed pervious substratum was estimated to be 53 ft from the center line of the levee.

History of underseepage

185. Since the completion of the river enlargement in 1969, only one observation of underseepage has been reported. On 27 March 1973, when the river crested at el 552.4, it was reported that conditions were "bad in corner" with water "ponded" in the vicinity of the piezometer range. In 1965 and 1969, when the river crested at el 554.7 and 551.1, respectively, the levee was reported as dry. In 1979, when the river

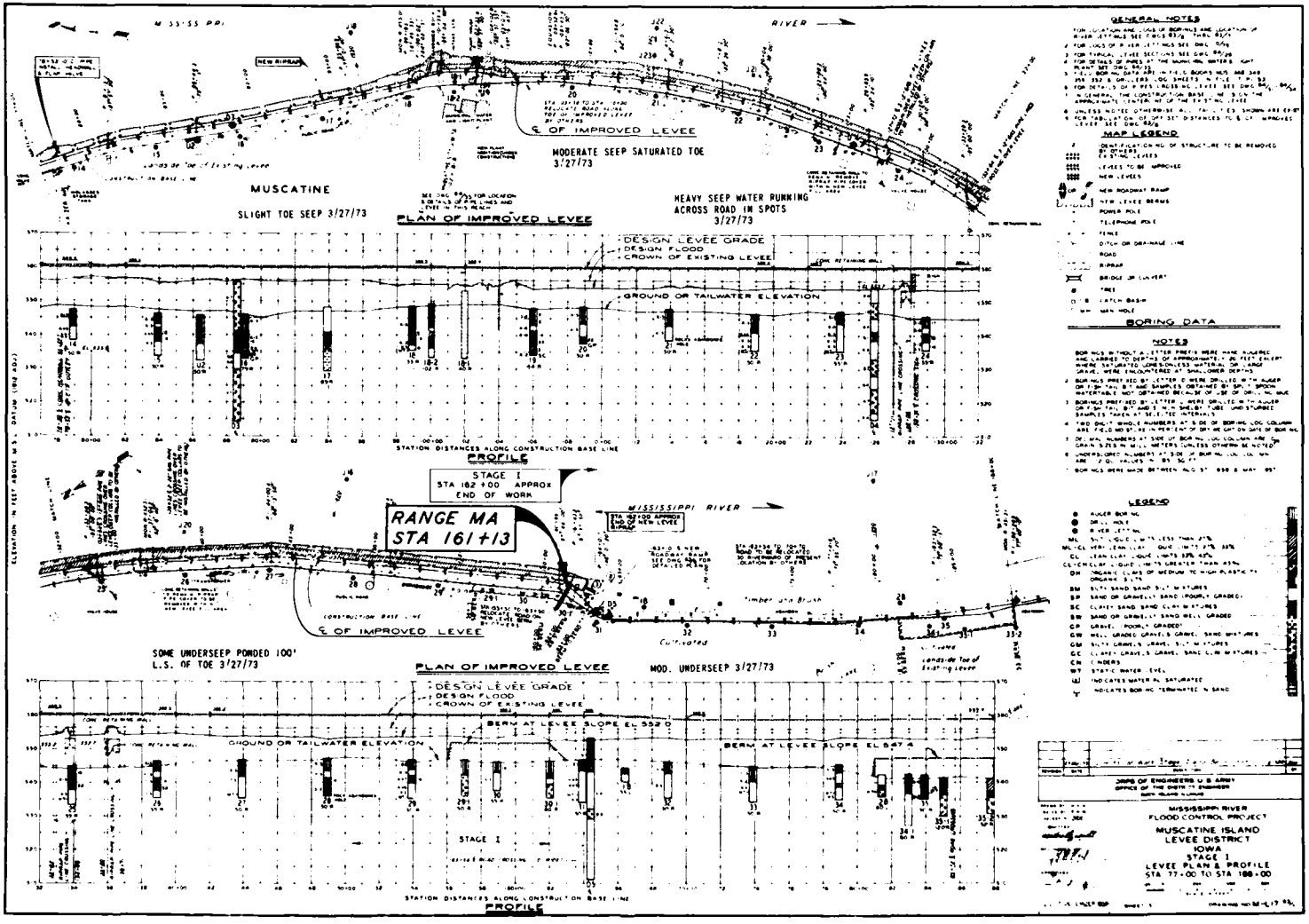

Figure 60. Levee plan and profile in vicinity of Muscatine Island, Piezometer Range MA

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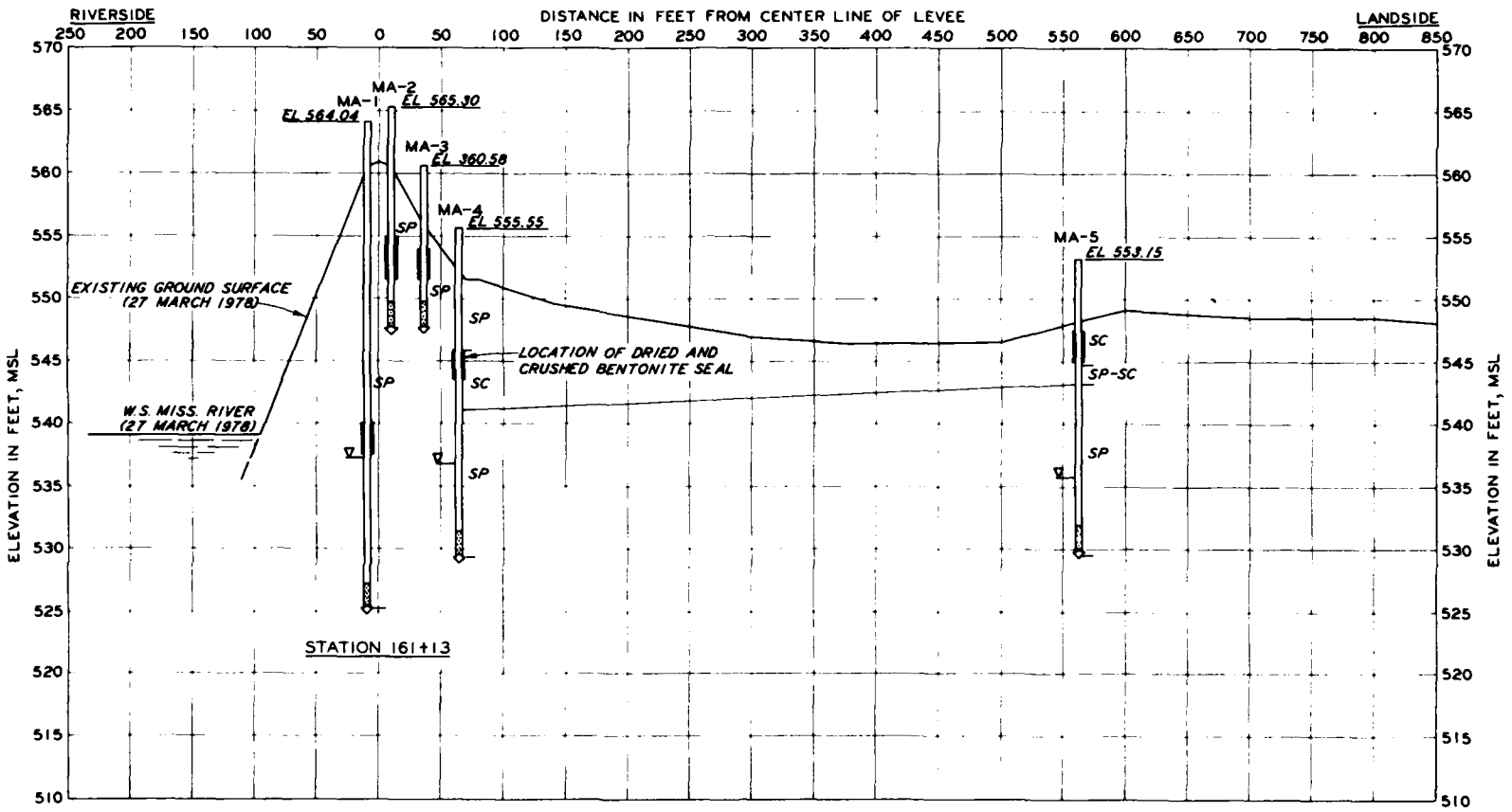

Figure 61. Cross section of Muscatine Island, Piezometer Range MA

reached el 553.04, the newly installed piezometers were read, the levee was inspected, and no seepage distress was reported. Table 31 lists the 1979 piezometer readings.

186. Table 32 presents a summary of observed performance with details of the foundation conditions. In 1979, the estimated piezometric pressure head did not rise above the ground elevation at any of the observation points; therefore, no factors of safety against uplift could be calculated.

Analysis of piezometer data

187. The piezometer readings in Table 31 are for 12 April 1979; it may be noted that the water level was below ground surface at all piezometer locations. One additional set of readings had been obtained on 23 March 1979, but at this time, the river stage and water levels were even lower; thus, this latter set of readings is not listed. With only one set of readings, and this for nonartesian conditions, it is not possible to make an analysis of the data.

Muscatine Island, Range MB

Description of site

188. Piezometer Range MB site is located at Mississippi River mile 446.9 and levee sta 425+91 (Figure 62). The cross section of the site in Figure 63 shows the levee, the foundation, and piezometer locations. The riverside piezometer MB-1 was driven the last 8 ft to its installed elevation. The relatively impervious top stratum ranges from 0.0 to 5.4 ft thick and generally consists of clayey sand.

189. The levee crest elevation is 558.5, and the average ground elevation landward of the levee is 540.0. Construction for the levee enlargement began in July 1960 and was completed in October 1961.

190. The cross section in Figure 63 indicates that the top of the bank of the river is about 250 ft east of the center line of the levee. However, Figure 4 indicates that this is a chute of the river and that the main channel is located about 2500 ft to the east. The exposed pervious substratum was estimated to be 267 ft from the center line of the levee.

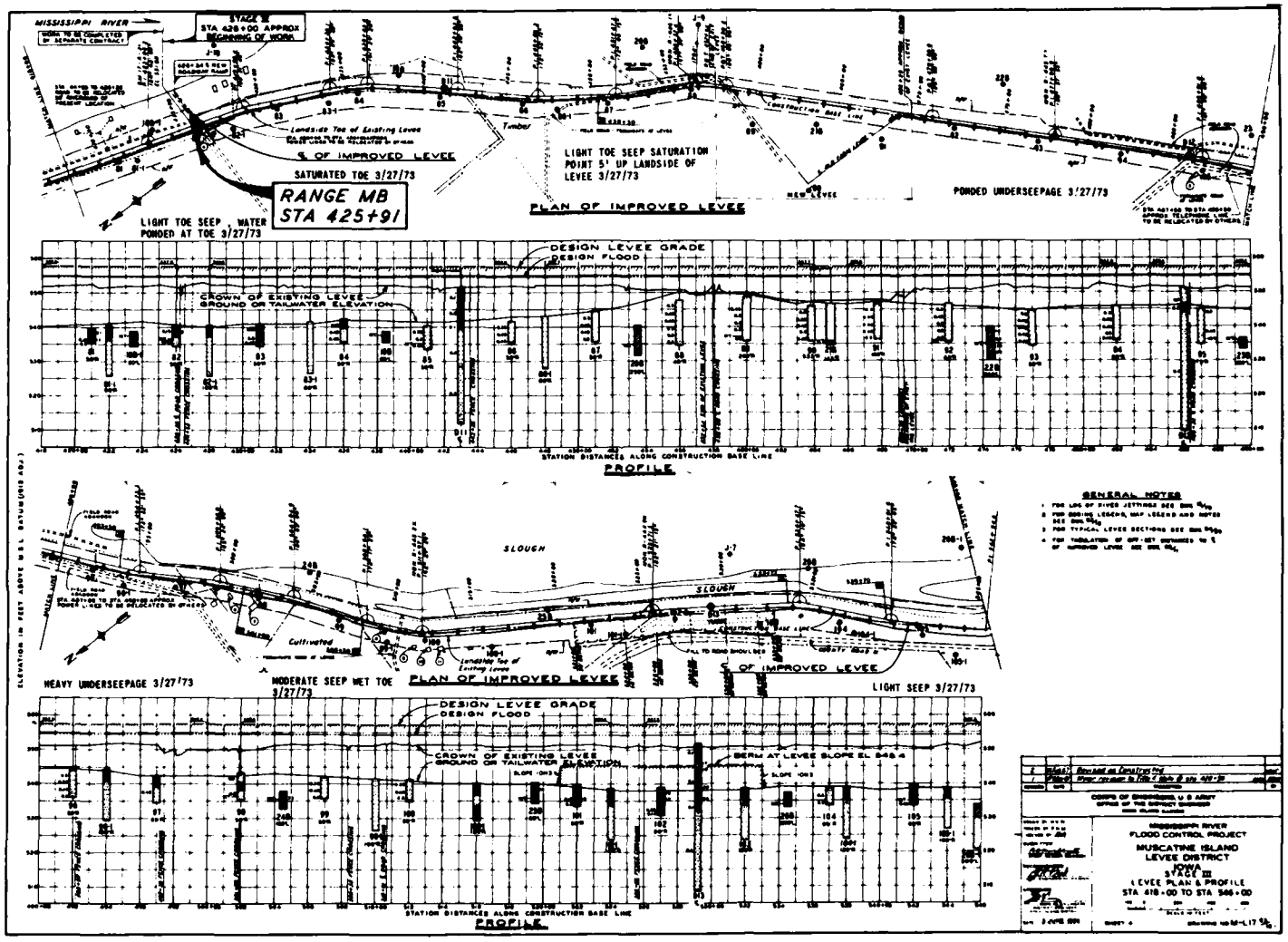

Figure 62. Levee plan and profile in vicinity of Muscatine Island, Piezometer Range MB

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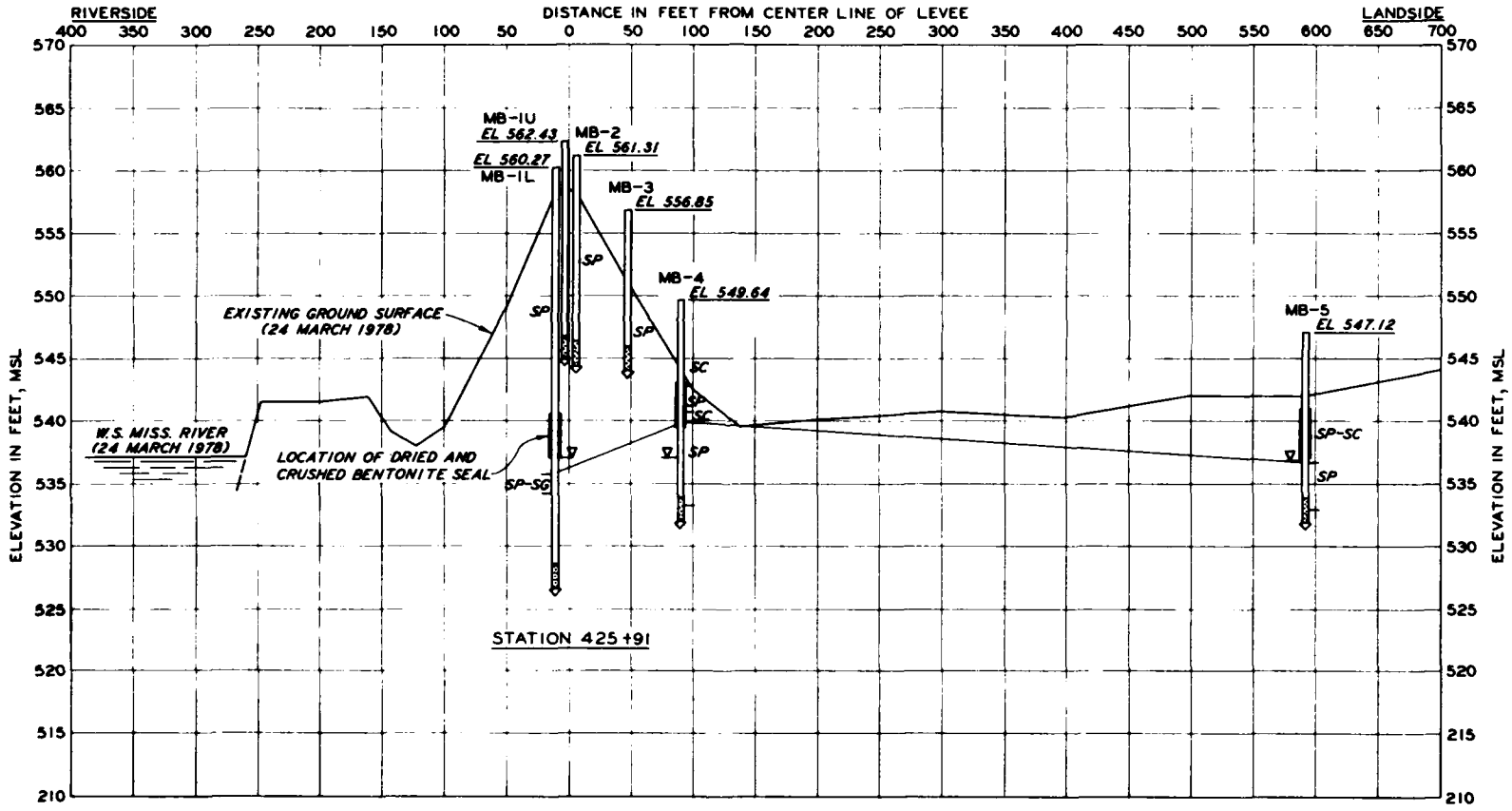

Figure 63. Cross section of Muscatine Island, Piezometer Range MB

History of underseepage

191. Since the completion of the levee enlargement in 1961, four observations of underseepage have been reported. In 1969, when the river crested at el 549.5, light toe seepage was reported, and the fields were wet or soft behind the levee. In 1973, when the river crested at el 551.1, water was reported "ponded at toe." In 1965, when the river crested at el 552.7, light toe seepage was noted. In 1979, when the river reached el 546.27, the newly installed piezometers were read, the levee was inspected, and water was reported standing in low areas. Table 33 lists the 1979 piezometer readings.

192. Table 34 presents a summary of observed performance with details of the foundation conditions. In 1979, the calculated factor of safety against uplift ranged from 0.7 at a low spot 400 ft landward from the center line of the levee to 4.3 at the location of piezometer MB-5.

Analysis of piezometer data

193. The two sets of piezometer readings in Table 33 represent one each in March and April of 1979. It may be noted that although the river stage differed by only 0.28 ft, readings from all the piezometers differed by 1.0 ft or more. Thus, the piezometric pressure must not have fully responded to the rising river stage in March, and analysis of the data is not warranted. In any event, it is believed that at least three sets of data are required for reliable projection of the data to other river stages and other ground locations.

Muscatine Island, Range MC

Description of site

194. Piezometer Range MC site is located at Mississippi River mile 444.6 and levee sta 549+30 (Figure 64). The cross section of the site in Figure 65 shows the levee, the foundation, and piezometer locations. Piezometers MC-1 and MC-4 were driven the last 8 and 5 ft, respectively, to their installed elevations. The relatively impervious top stratum ranges from 2.1 to 5.1 ft thick and generally consists of lean clay overlying intrusions of clayey sand.

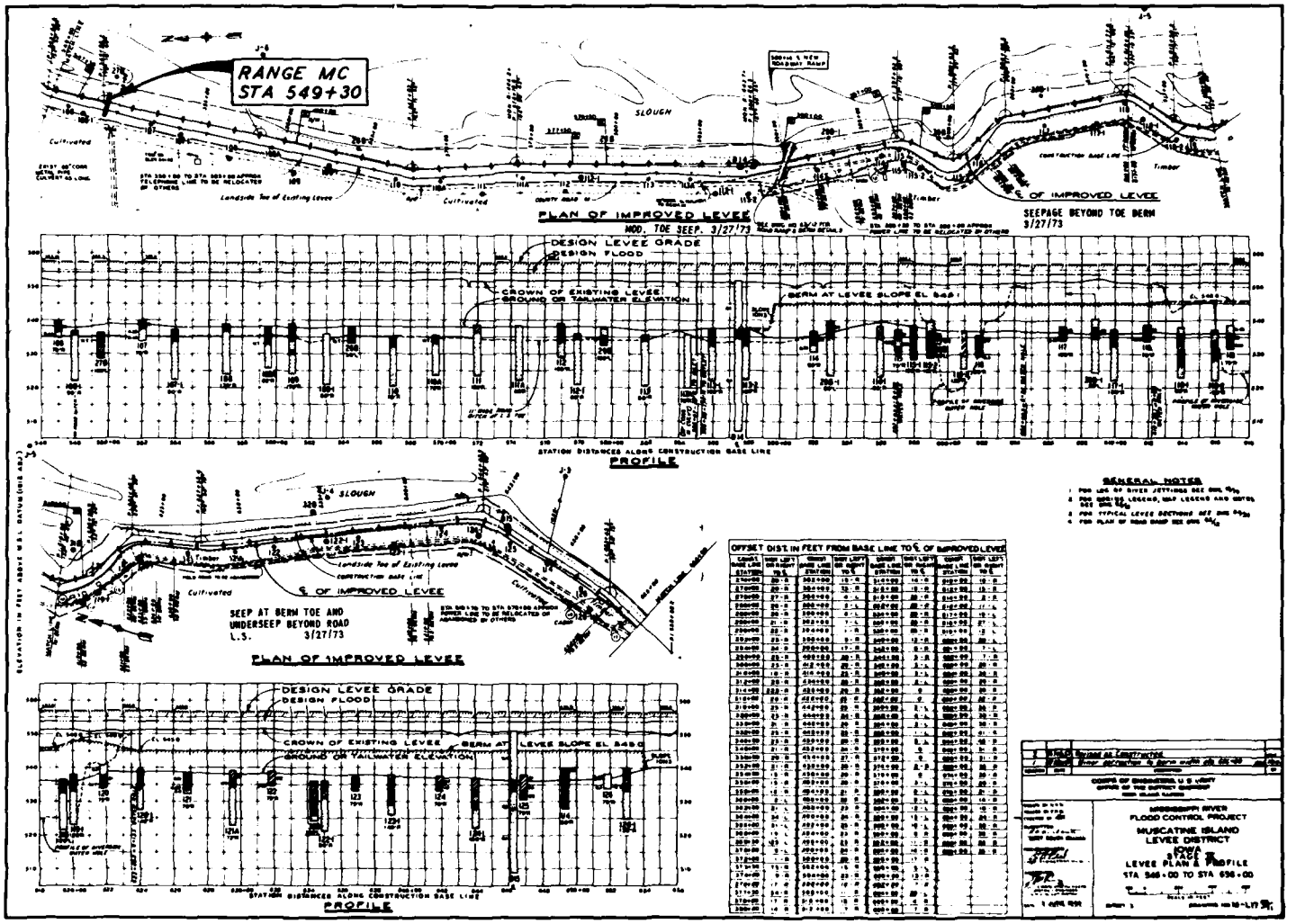

Figure 64. Levee plan and profile in vicinity of Muscatine Island, Piezometer Range MC

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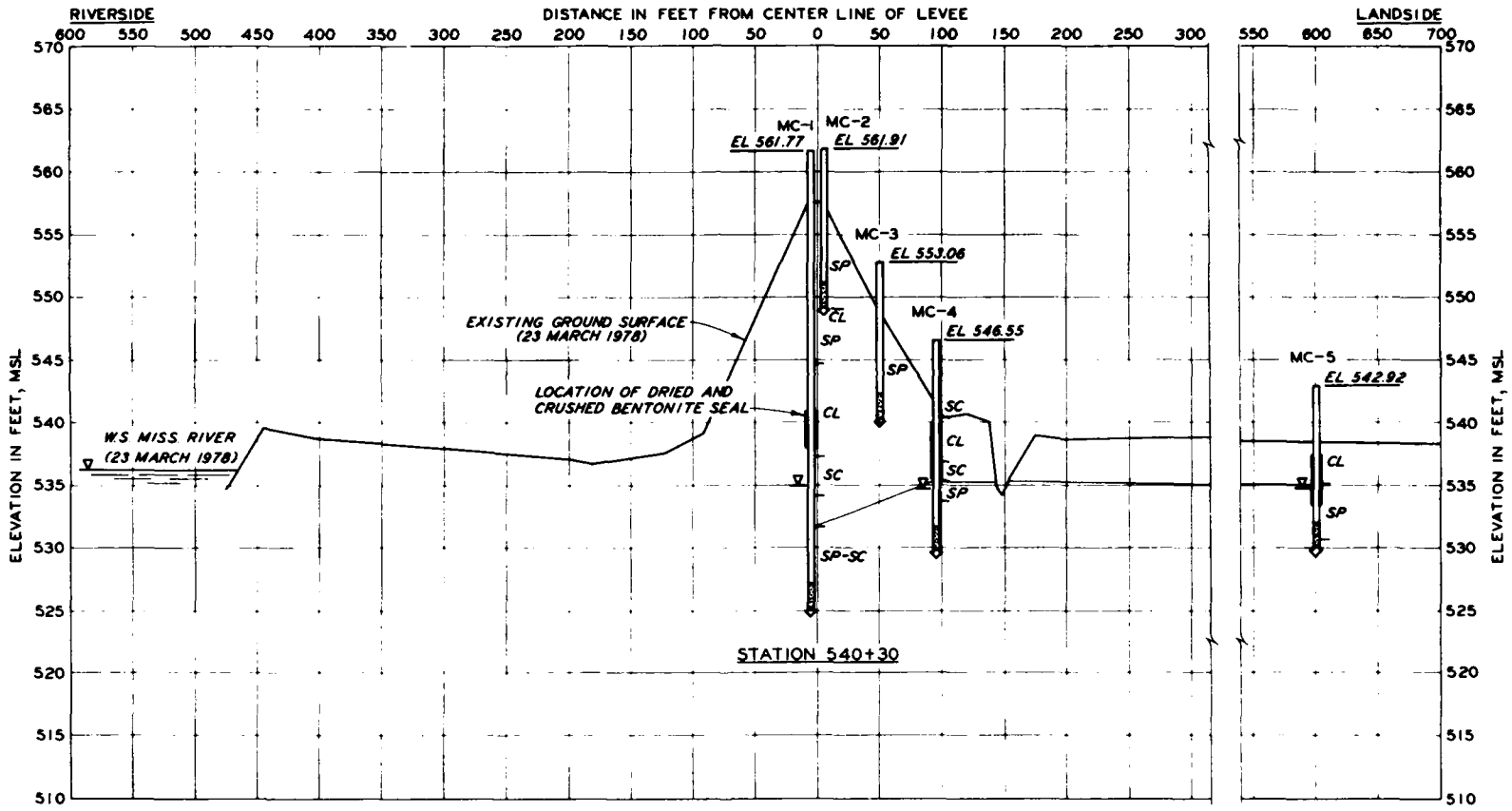

Figure 65. Cross section of Muscatine Island, Piezometer Range MC

195. The levee crest elevation is 557.7, and the average ground elevation landward of the levee is 538.8. Construction for the levee enlargement began in September 1962 and was completed in November 1962.

196. Figure 65 shows that the exposed pervious substratum at the bank of the Mississippi River is about 592 ft from the center line of the levee. However, Figure 4 indicates that this is a chute or slough of the river and that the main channel is about 5400 ft or so to the east.

History of underseepage

197. Since the completion of the levee enlargement in 1962, only two observations of underseepage have been reported. In April 1969, when the river crested at el 548.9, a road ditch was reported to be full of water and a "good flow" established. In 1979, when the river reached el 545.87, the newly installed piezometers were read, the levee was inspected, and the area was reported dry except for water standing in the ditch. Table 35 lists the 1979 piezometer readings.

198. Table 36 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure in general did not rise above the ground elevation except in the bottom of the ditch, and the factor of safety uplift was zero because no clay-like material was seen at this particular location.

Analysis of piezometer data

199. The two sets of piezometer readings in Table 35 represent one each in March and April of 1979. It may be noted that although the river stage increased by 0.57 ft, readings from one of the piezometers decreased by 1.5 ft and at the two other piezometer locations increased by 0.7 ft and over 3 ft. Thus, the piezometric pressure either had not fully responded to the rising river stage in March or for some other reason was not responding properly. For whatever reason, analysis of the data is not warranted.

Green Bay, Range GBA

200. A general plan and a geologic profile of the Green Bay Levee

District have been previously presented in Figures 22 and 23, respectively, with the description of the old piezometer range sites. Two new piezometer ranges, Ranges GBA and GBB, were established in July 1977.

Description of site

201. Piezometer Range GBA site is located at Mississippi River mile 395.8 at levee sta 343+50, one mile up, and on the south bank of the Skunk River (Figure 66). The cross section of the site in Figure 67 shows the levee, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 8.8 ft to 12.3 ft thick and generally consists of lean clay and fat clay.

202. The levee crest elevation is 533.5, and the average ground elevation landward of the levee is 519.5. Construction for the levee enlargement began in August 1964 and was completed in December 1965.

203. The exposed pervious substratum at the bank of the Skunk River was estimated to be 535 ft north of the center line of the levee.

History of underseepage

204. Since the completion of the levee enlargement in 1965, two observations of underseepage have been reported. In 1978, when the levee crested at el 530.8, light toe seepage was reported. In 1979, when the river reached el 527.10, the newly installed piezometers were read, the levee was inspected, and water was reported standing in low areas landward of the levee. Table 37 lists the 1979 piezometer readings.

205. Table 38 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure rose from 0.2 to 0.5 ft above the ground surface at two locations, and the calculated factor of safety against uplift ranged from 61 to 18.

Analysis of piezometer data

206. The one set of piezometer readings in Table 37 is for 12 April 1979. An earlier set of readings in March had been attempted, but risers for two of the piezometers had been destroyed. These were replaced on 12 April for the April readings. However, with only one set of readings, it is not possible to make an analysis of the data.

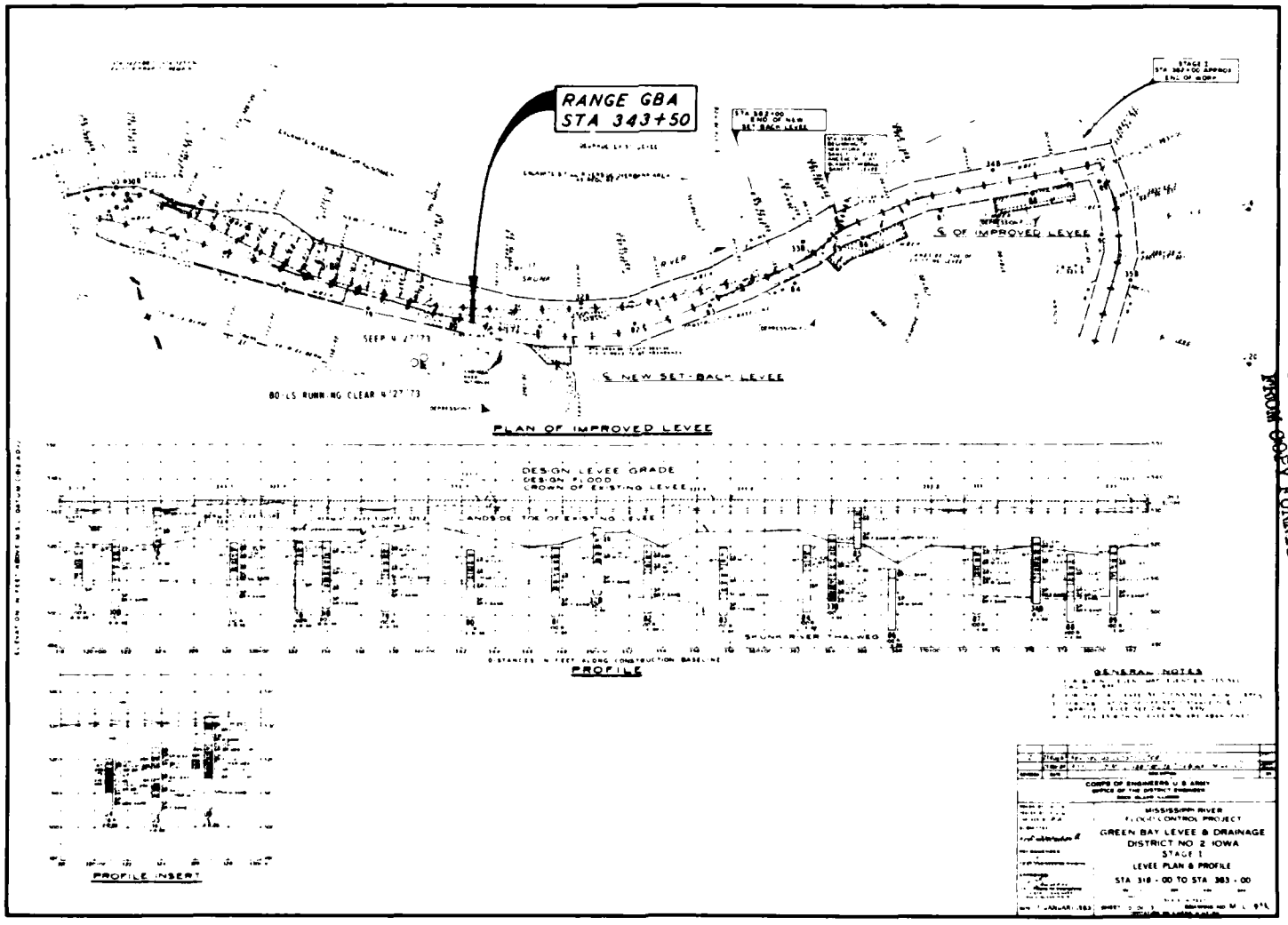

Figure 66. Levee plan and profile in vicinity of Green Bay, Piezometer Range GBA

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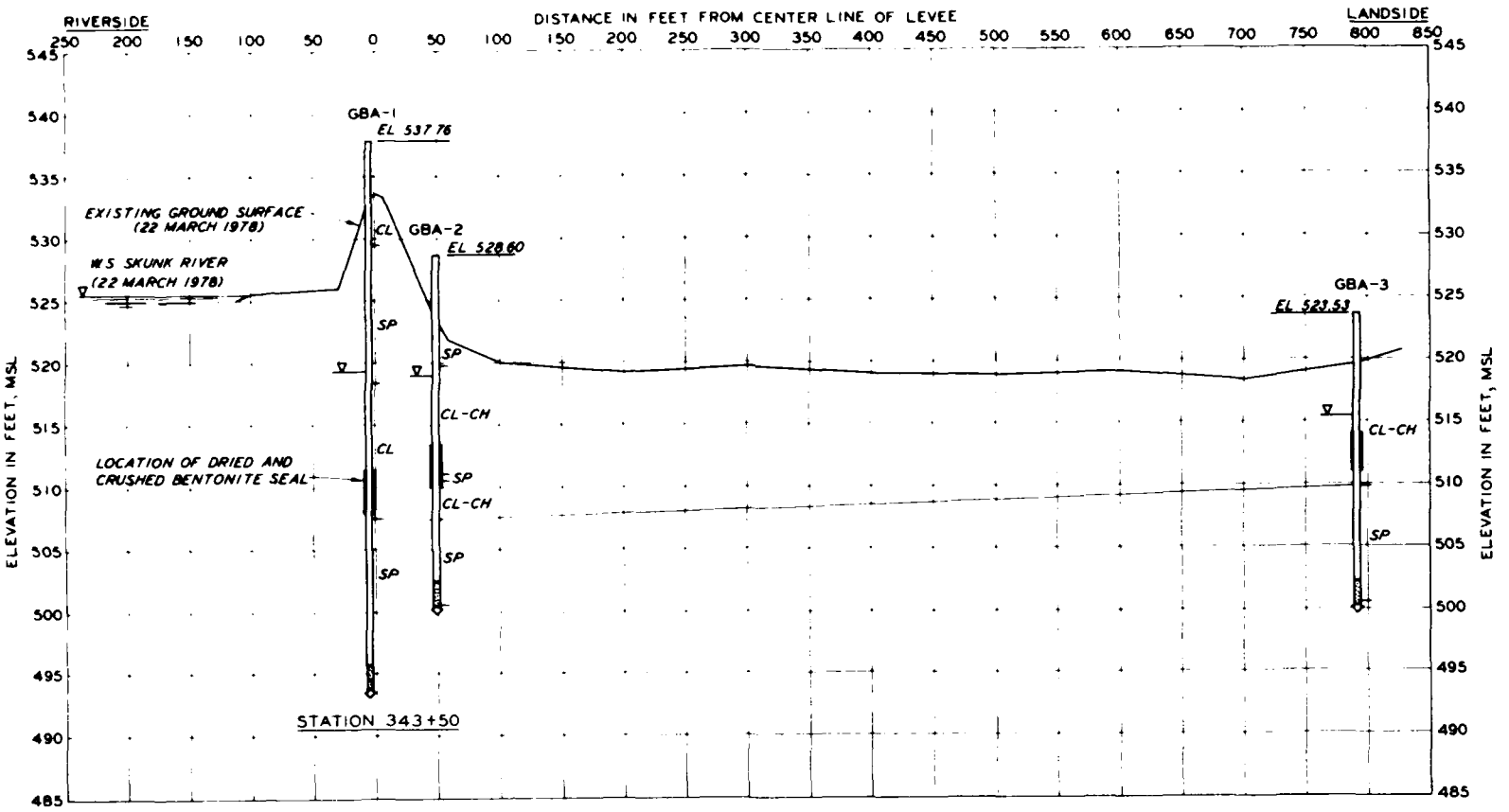

Figure 67. Cross section of Green Bay, Piezometer Range GBA

Green Bay, Range GBB

Description of site

207. Piezometer Range GBB site is located at Mississippi River mile 391.1 and levee sta 637+88 (Figure 68). The cross section of the site in Figure 69 shows the levee, the foundation, and piezometer locations. The riverside piezometer GBB-1 was driven the last 6 ft to its installed elevation. The relatively impervious top stratum ranges from 7.3 to 18.2 ft thick and generally consists of lean clay and fat clay.

208. The levee crest elevation is 530.0, and the average ground elevation landward of the levee is 516.5. Construction for the levee enlargement began in August 1965 and was completed in November 1965.

209. The exposed pervious substratum at the bank of the Mississippi River was estimated to be 397 ft east of the center line of the levee.

History of underseepage

210. Since 1965, four observations of underseepage have been reported. In 1965 and 1973, with river crests of el 528.0 and 528.6, respectively, sand boils were reported in a ditch 206 ft from the center line of the levee. In 1969, when the river crested at el 525.7, slight to moderate toe seepage was noted. In 1979, when the river reached el 524.90, the newly installed piezometers were read, the levee was inspected, and some water was reported ponded between the levee and the ditch. Table 39 lists the 1979 piezometer readings.

211. Table 40 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric level rose from 4.4 to 0.7 ft above the bottom of the ditches 206 and 396 ft landward of the levee, respectively, and the calculated factors of safety against uplift ranged from 1.3 to 13.

Analysis of piezometer data

212. The one set of piezometer readings in Table 39 is for 12 April 1979. An earlier set of readings had been attempted in March, but at that time, the riverside piezometer had a lower reading than three of the four landside piezometers. Thus, the piezometers must not have fully responded to the rising river stage in March, and so they

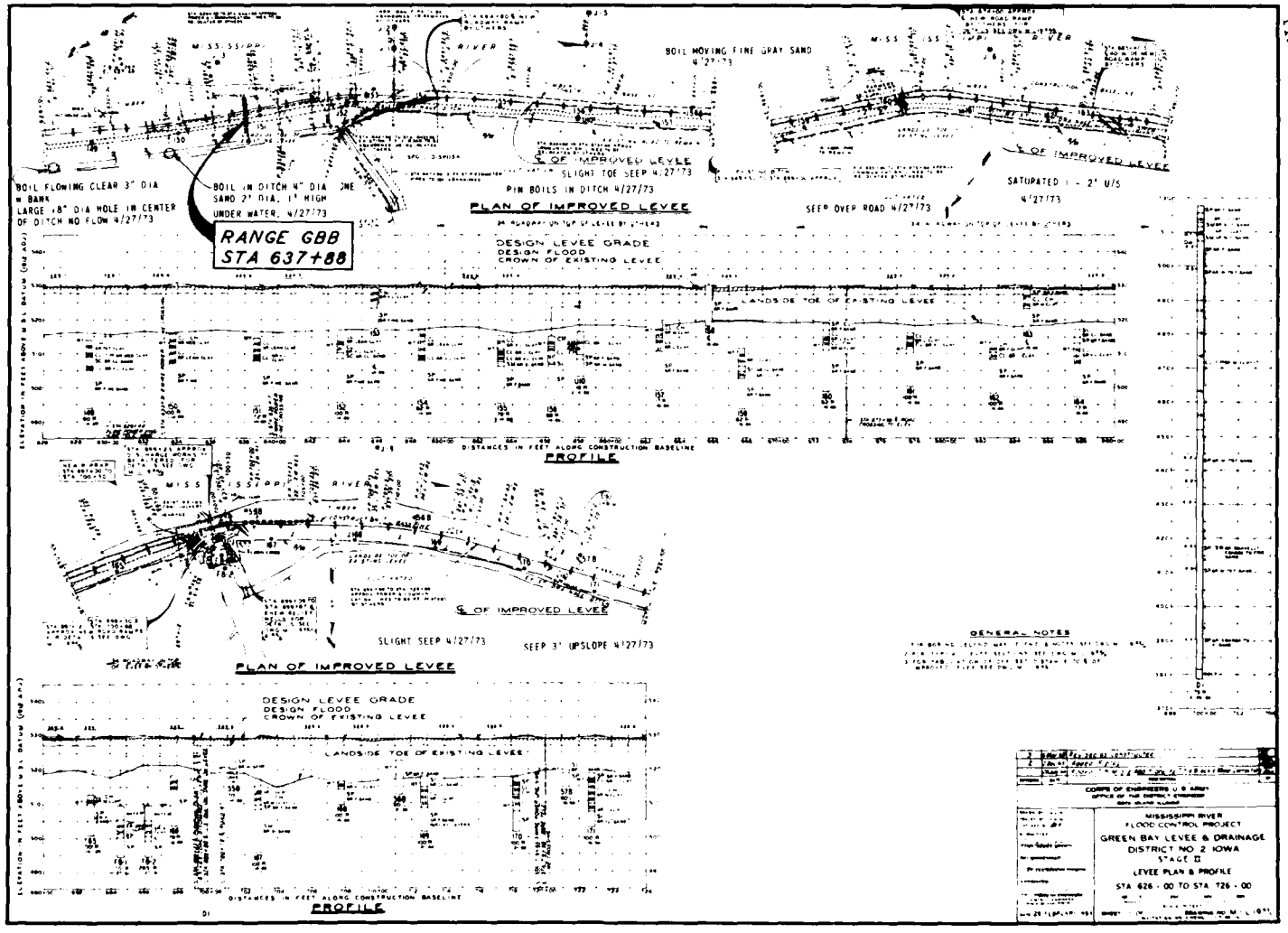

Figure 68. Levee plan and profile in vicinity of Green Bay, Piezometer Range GBB

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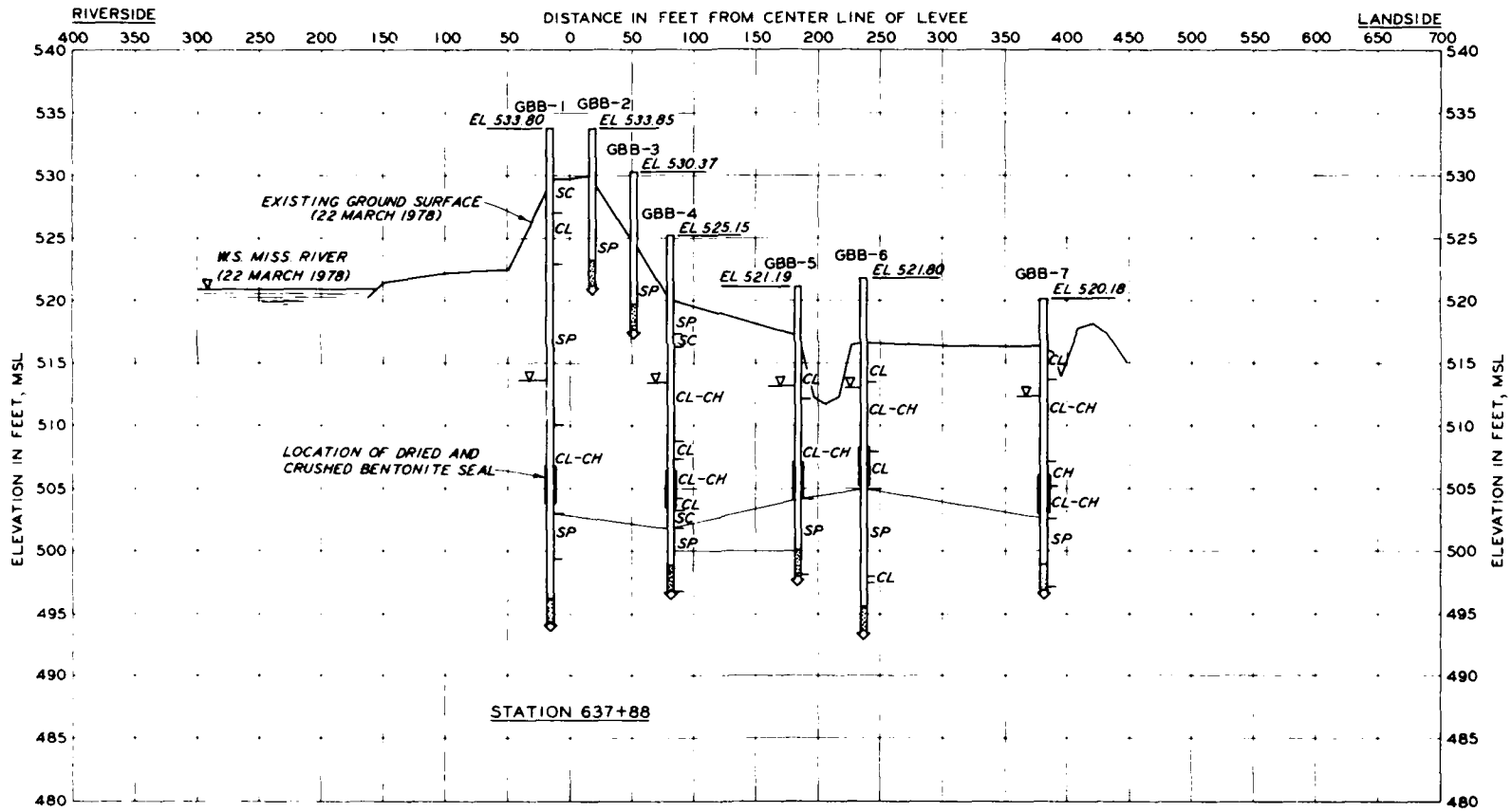

Figure 69. Cross section of Green Bay, Piezometer Range GBB

are not shown in the table. Further analysis of the one set of readings is not warranted.

Fabius River, Range FA

213. A general plan and a geologic profile of the Fabius River Levee District have been previously presented in Figures 32 and 33, respectively, with the description of the old piezometer range sites. Two new piezometer ranges, Ranges FA and FB, were established in July 1977.

Description of site

214. Piezometer Range FA site is located at Mississippi River mile 328.4 and levee sta 341+43 (Figure 70). Figure 32 shows the range to be on the main channel of the river. The cross section of the site in Figure 71 shows the levee, the foundation, and piezometer locations. Piezometers FA-1 and FA-5 were driven the last 7 and 6 ft, respectively. The relatively impervious top stratum ranges from 10.0 to 10.8 ft thick and generally consists of lean and fat clay. The exposed pervious substratum at the bank of the river was estimated to be 384 ft from the center line of the levee.

215. The levee crest elevation is 489.8, and the average ground elevation landward of the levee is 475.0. Construction for the levee enlargement began in April 1960 and was completed in September 1961.

History of underseepage

216. Since the completion of the levee enlargement in 1961, only two observations of underseepage have been reported. In 1965, when the river crested at el 483.9, light toe seepage was reported. In 1979, when the river reached el 480.31, the newly installed piezometers were read, the levee was inspected, some seepages water was reported flowing in the field, and water was ponded landward of the levee. Table 41 lists the 1979 piezometer readings. This section of levee was overtopped in 1973.

217. Table 42 presents a summary of observed performance with details of the foundation conditions. In 1979, the calculated factor of safety against uplift 641 ft landward of the levee was 7.3.

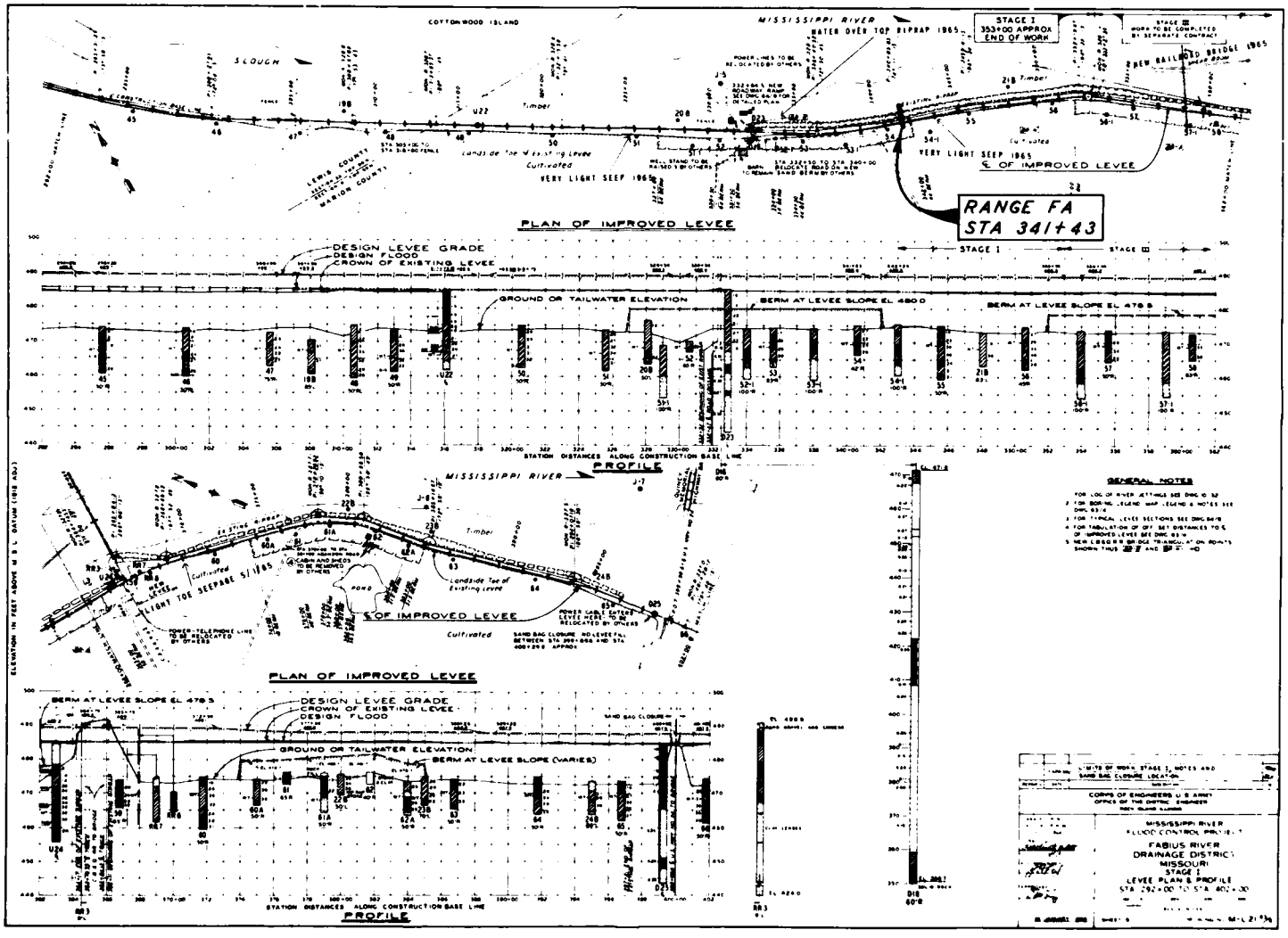

Figure 70. Levee plan and profile in vicinity of Fabius River, Piezometer Range FA

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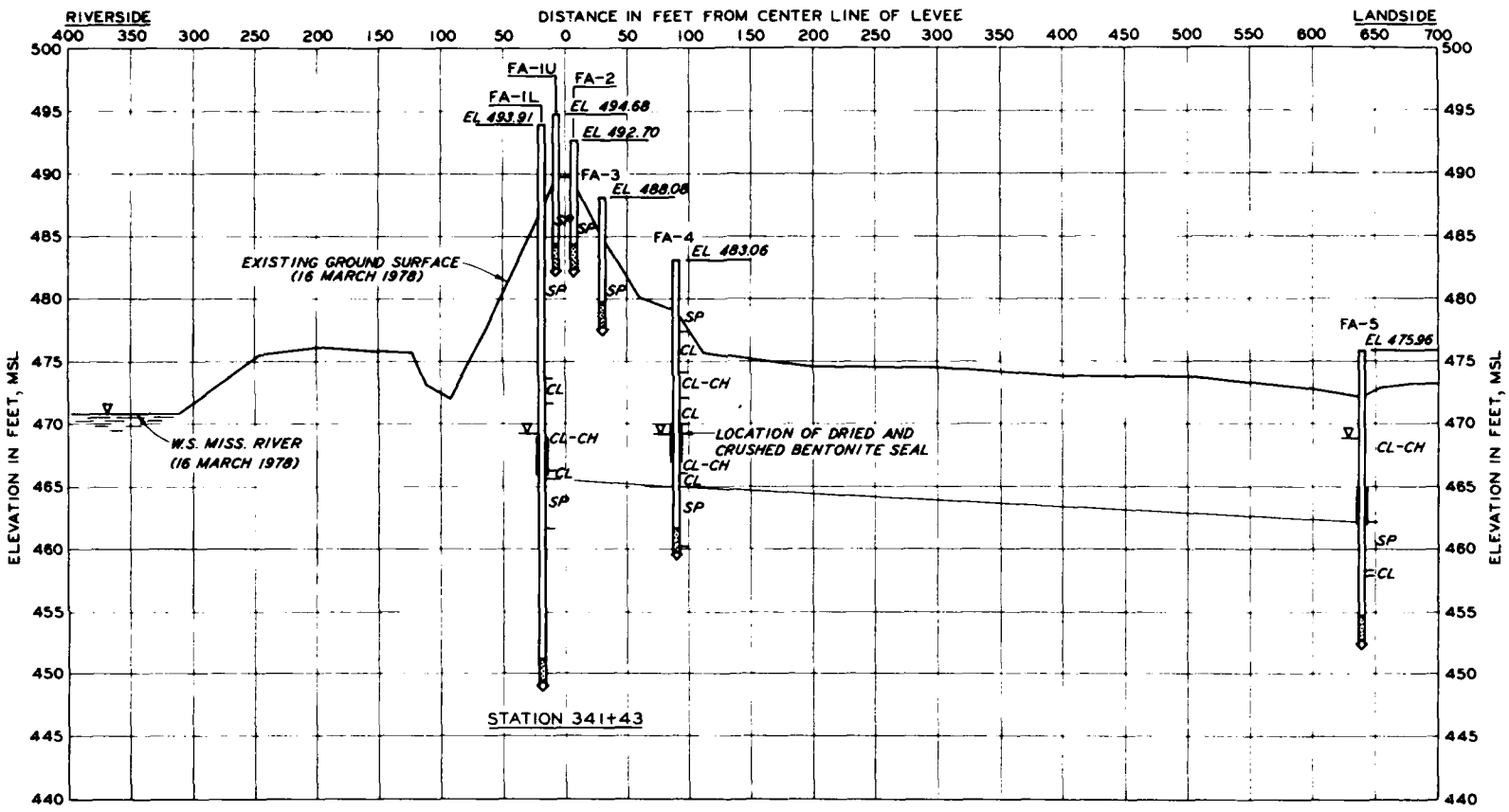

Figure 71. Cross section of Fabius River, Piezometer Range FA

Analysis of piezometer data

218. The one set of piezometer readings in TAble 41 is for 11 April 1979. An earlier set of readings was attempted on 22 March 1979, but at that time, the landside toe piezometer had a piezometric pressure 1.5 ft lower than the piezometer 641 ft landside of the center line. Thus, only one set of readings is listed in the table, and no further analysis is made.

Fabius River, Range FB

Description of site

219. Piezometer Range FB site is located at Mississippi River mile 323.9 on the north bank of the Fabius River Diversion Ditch at levee sta 565+53 (Figure 72). The cross section of the site in Figure 73 shows the levee, the foundation, and piezometer locations. The riverside piezometer FB-1 was driven the last 11 ft to its installed elevation. The relatively impervious top stratum ranges from 4.5 to 6.8 ft thick and generally consists of lean and fat clay overlying clayey sand. The exposed pervious substratum at the bank of the diversion channel was estimated to be 877 ft from the center line of the levee.

220. The levee crest elevation is 487.9, and the average ground elevation landward of the levee is 466.5. Construction for the levee enlargement bagan in July 1961 and was completed in June 1967.

History of underseepage

221. Since the beginning of construction of the levee enlargement in 1961, three observations of underseepage have been reported. In 1965 and 1969, with river crests of el 481.3 and 477.0, respectively, sand boils were reported in a swale at a distance estimated to be about 126 ft landward of the center line of the levee. In 1979, when the river reached el 478.01, the newly installed piezometers were read, the levee was inspected, some toe seepage was reported crossing a road, and several small boils were in the area. Table 43 lists the 1979 piezometer readings. This area was overtopped in 1973.

222. Table 44 presents a summary of observed performance with

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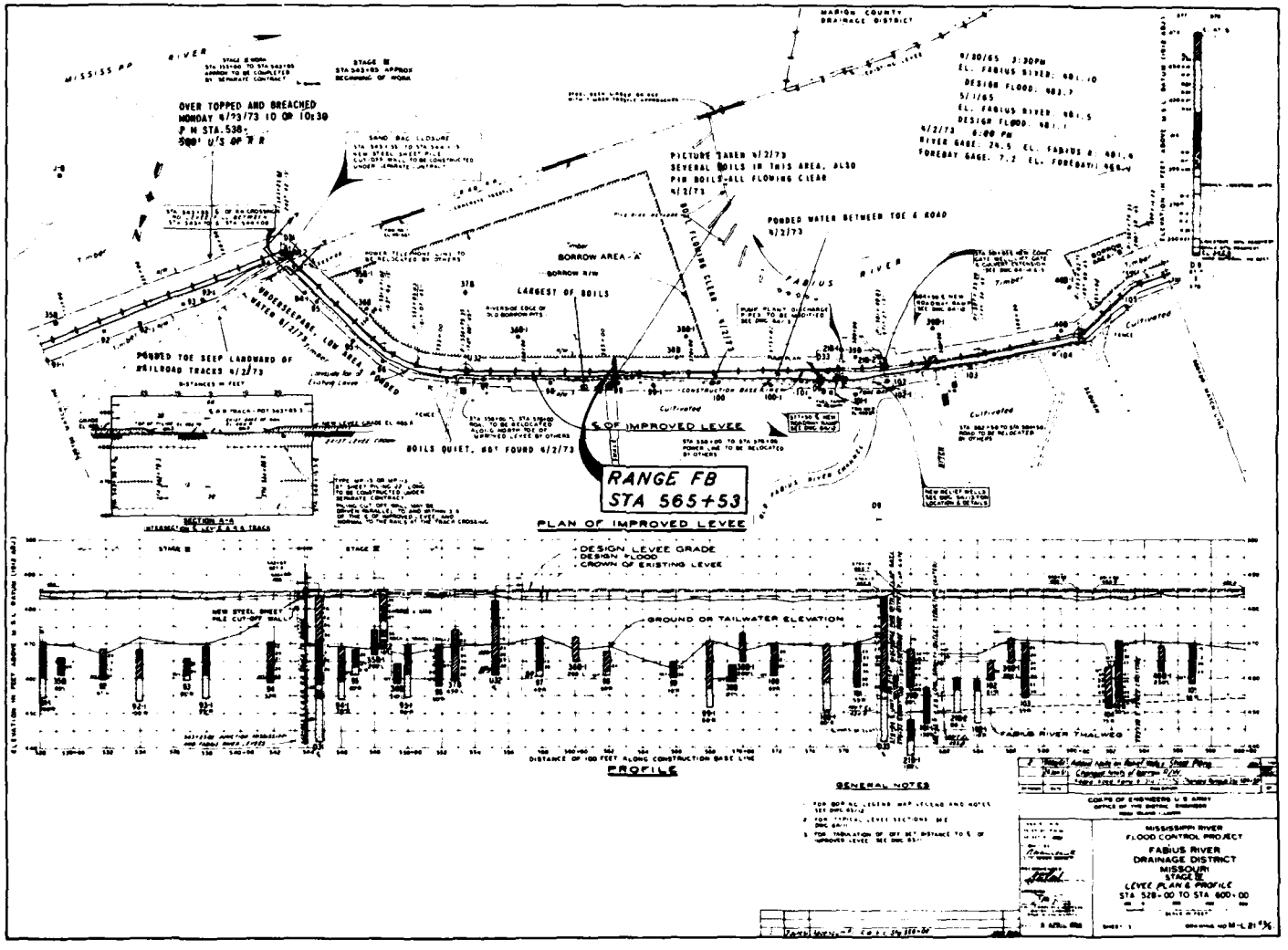

Figure 72. Levee plan and profile in vicinity of Fabius River, Piezometer Range FB

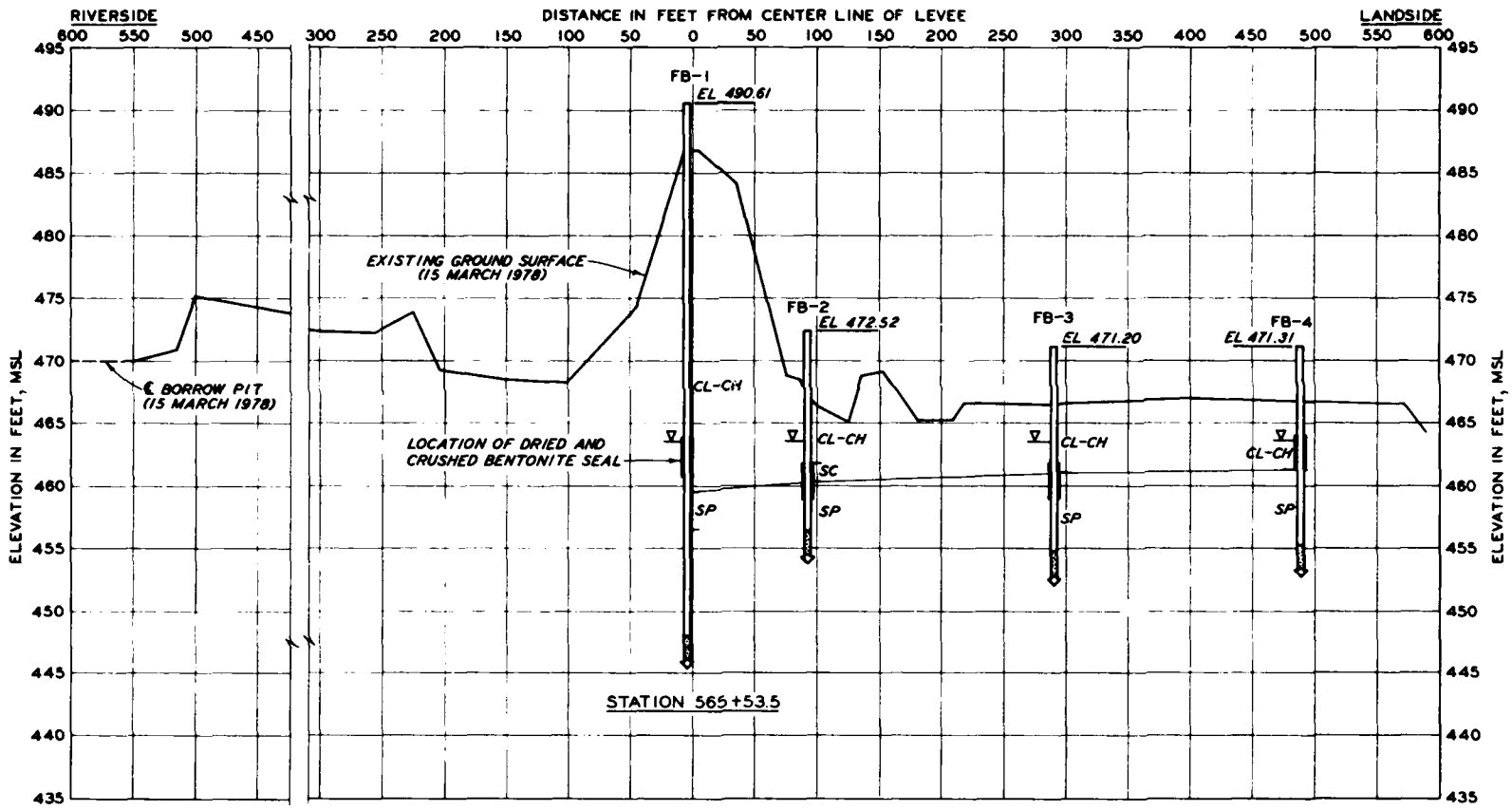

Figure 73. Cross section of Fabius River, Piezometer Range FB

details of the foundation conditions. In 1979, the piezometric pressure ranged from 1.9 to 3.8 ft above the ground surface where seepage was reported, and the calculated factor of safety against uplift ranged from 2.8 to 1.0.

Analysis of piezometer data

223. The set of piezometer readings in Table 43 is for 10 April 1979. One earlier set of readings was attempted on 22 March 1979, but at that time, the riverside piezometer had a pressure 2.2 ft lower than the landside toe piezometer. Thus, the piezometers must not have fully responded to the March river rise, and so the early readings are not included in the table. No analysis has been made for the one set of readings listed.

South Quincy, Range SQ

224. A general plan and a geologic profile of South Quincy Drainage and Levee District have been previously presented in Figures 37 and 38, respectively, with a description of the old piezometer range sites. A new piezometer range, Range SQ, was established in August 1977.

Description of site

225. Piezometer Range SQ site is located at Mississippi River mile 322.2 and levee sta 155+34 on the bank of the Texas Chute (Figure 74). The cross section of the site in Figure 75 shows the levee, the foundation, and piezometer locations. Piezometers SQ-1, SQ-4, and SQ-5 were driven the last 6, 5, and 7 ft, respectively. The relatively impervious top stratum ranges from 5.3 to 7.3 ft thick and generally consists of lean clay overlying clayey sand.

226. The levee crest elevation is 486.2, and the average ground elevation landward of the levee is 470.5. Construction for the levee enlargement began in July 1966 and was completed in October 1967.

227. The exposed pervious substratum at the bank of the Texas Chute was estimated to be 721 ft west of the center line of the levee. Figure 37 indicates the chute is narrow and is a meandering type channel.

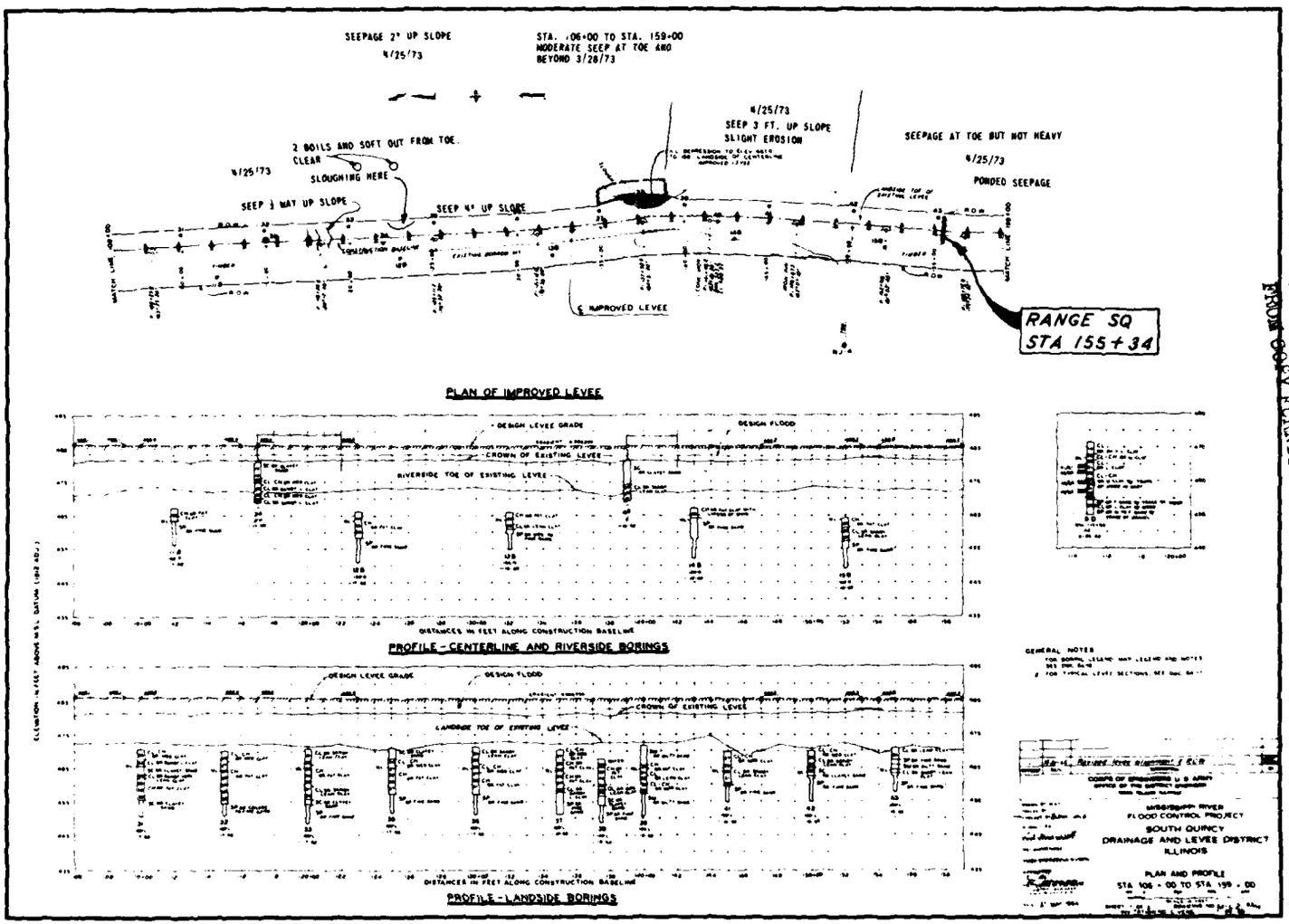

Figure 74. Levee plan and profile in vicinity of South Quincy, Piezometer Range SQ

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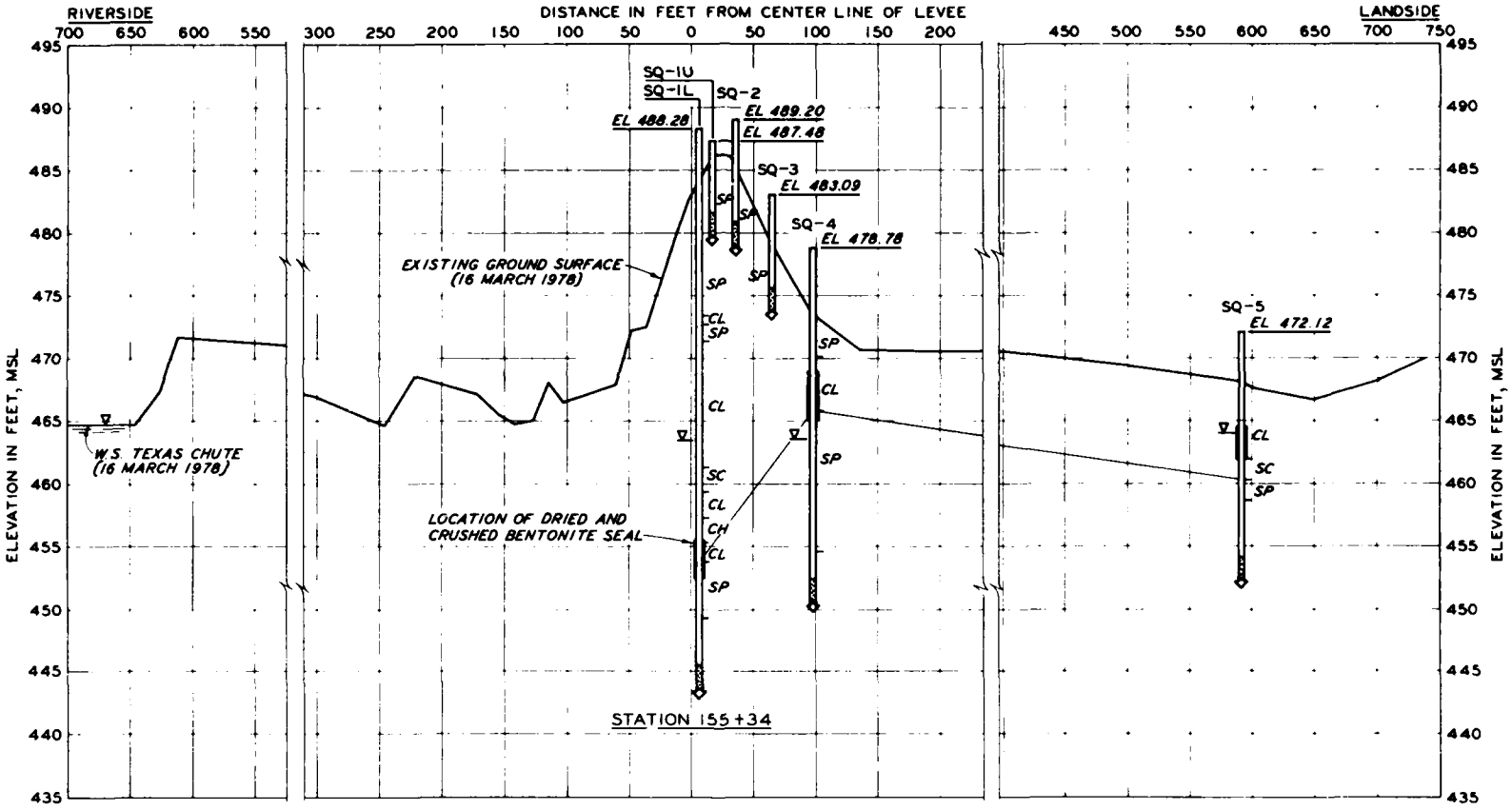

Figure 75. Cross section of South Quincy, Piezometer Range SQ

The main channel of the Mississippi River is located an additional 3500 ft to the west.

History of underseepage

228. Since the completion of the levee enlargement in 1967, three observations of underseepage have been reported. In 1973, when the river crested at el 484.1, light to moderate seepage was noted at the toe with moderate seepage reported to be present beyond the toe. Also, in 1973, water was reported "ponded" in low areas. Moderate seepage at the toe of the levee and beyond was also reported in 1969 with a river crest of el 476.4. In 1979, when the river reached el 477.48, the newly installed piezometers were read, the levee was inspected, numerous pin boils were observed about 300 ft landward of the levee, and seepage water was reported in the fields. Table 45 lists the 1979 piezometer readings.

229. Table 46 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 0.2 to 0.4 ft above the ground surface where seepage was reported, and the calculated factor of safety ranged from 28 to 14.

Analysis of piezometer data

230. The two sets of piezometer readings in Table 45 are for two different dates in April. A third set of readings was obtained on 22 March, but at this time, the water level in the riverside slope piezometer (SQ-1L) was 1.0 ft lower than that in the landside toe piezometer (SQ-4). Piezometer SQ-1L and perhaps others must not have fully responded to the rise in river stage at this time; therefore, readings from 22 March are not included in the table.

231. Although it is believed that at least three sets of piezometer readings should be required for projection of piezometer pressures for a river stage at the levee crest, Figure 76 presents a plot of the two sets of data from 11 and 13 April and shows the piezometric pressures projected to the levee crest elevation of 486.2. Although these projections should be considered tentative, a seepage entrance distance of 277 ft, a seepage exit distance of 79 ft, a landside permeability ratio of 8.6, and riverside permeability ratio of 3.2 were calculated.

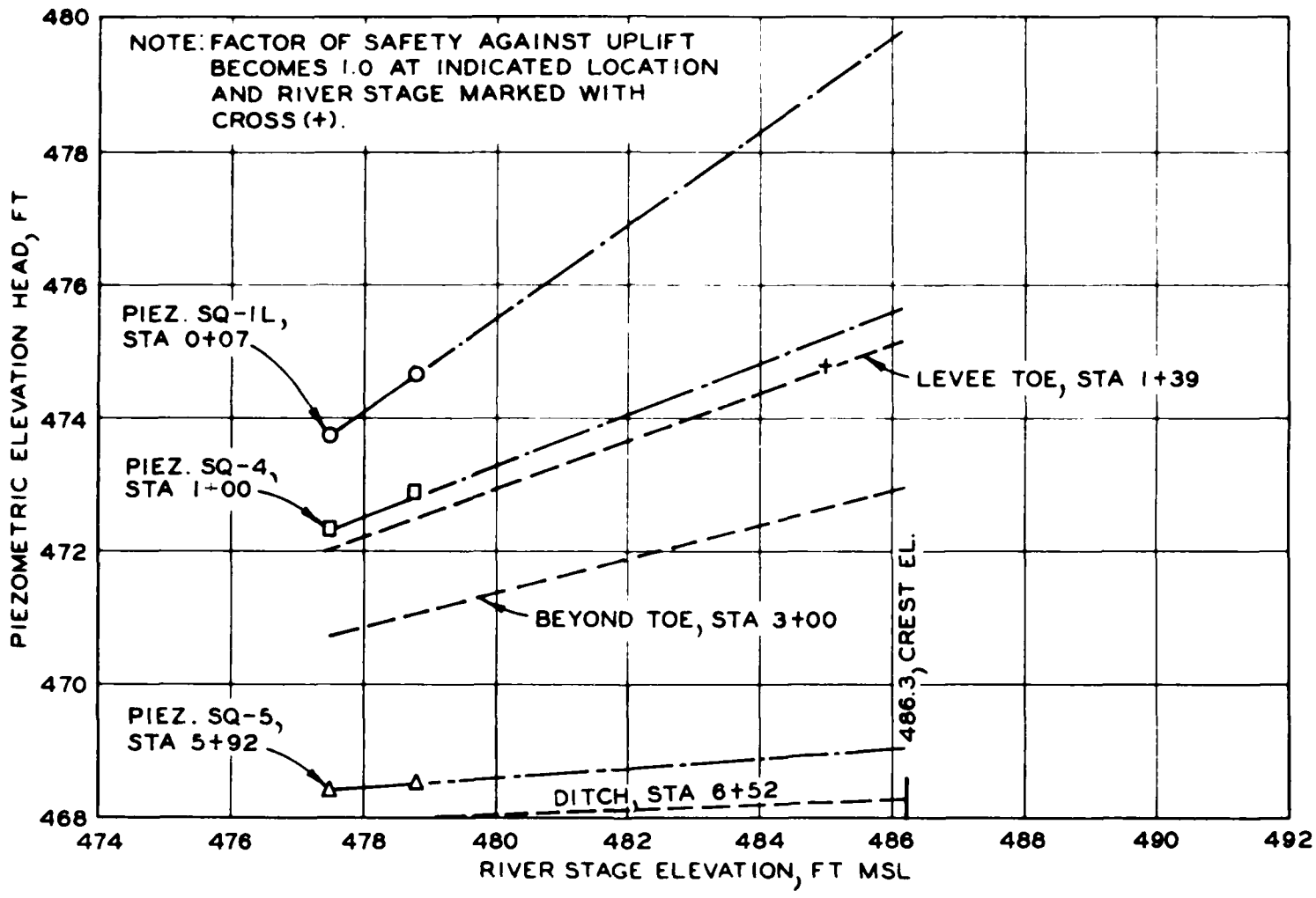

Figure 76. Piezometric elevation head versus river stage, South Quincy, Range SQ

South River, Range SRA

232. The South River Drainage District is located on the west bank of the Mississippi River about 5 to 8 miles downstream from Quincy, Illinois. Three piezometer ranges, Ranges SRA, SRB, and SRC, were established in August 1977 (Figure 77). The geologic profile of the area in Figure 78 was based on selected deep borings on both the east and west banks of the Mississippi River. Ground conditions generally consist of about 9 to 19 ft of lean clay overburden underlain by about 93 to 113 ft of fine to coarse sand with a few intrusions of clay till up to 12 ft thick.

Description of site

233. Piezometer Range SRA site is located at river mile 317.7 and levee sta 315+73 on the main channel of the river (Figure 79). The cross section of the site in Figure 80 shows the levee, the foundation, and piezometer locations. Piezometers SRA-1 and SRA-4 were driven the last 10 and 4 ft, respectively. The relatively impervious top stratum ranges from 3.3 to 8.0 ft thick and generally consists of lean clay and fat clay. Figure 80 also shows the locations of dried and crushed bentonitic seals in the piezometer bore holes.

234. The levee crest elevation is 483.0, and the average ground elevation landward of the levee is 468.3. Construction for the levee enlargement began in August 1963 and was completed in November 1964.

235. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 187 ft east of the center line of the levee.

History of underseepage

236. Since the completion of the levee enlargement in 1964, three observations of underseepage have been reported. In 1965 and 1973, with river crests of el 478.6 and 482.1, respectively, moderate toe seepage was reported. In 1979, when the river reached el 476.29, the newly installed piezometers were read, the levee was inspected, and the water was reported ponded in the fields. Table 47 lists the 1979 piezometer readings.

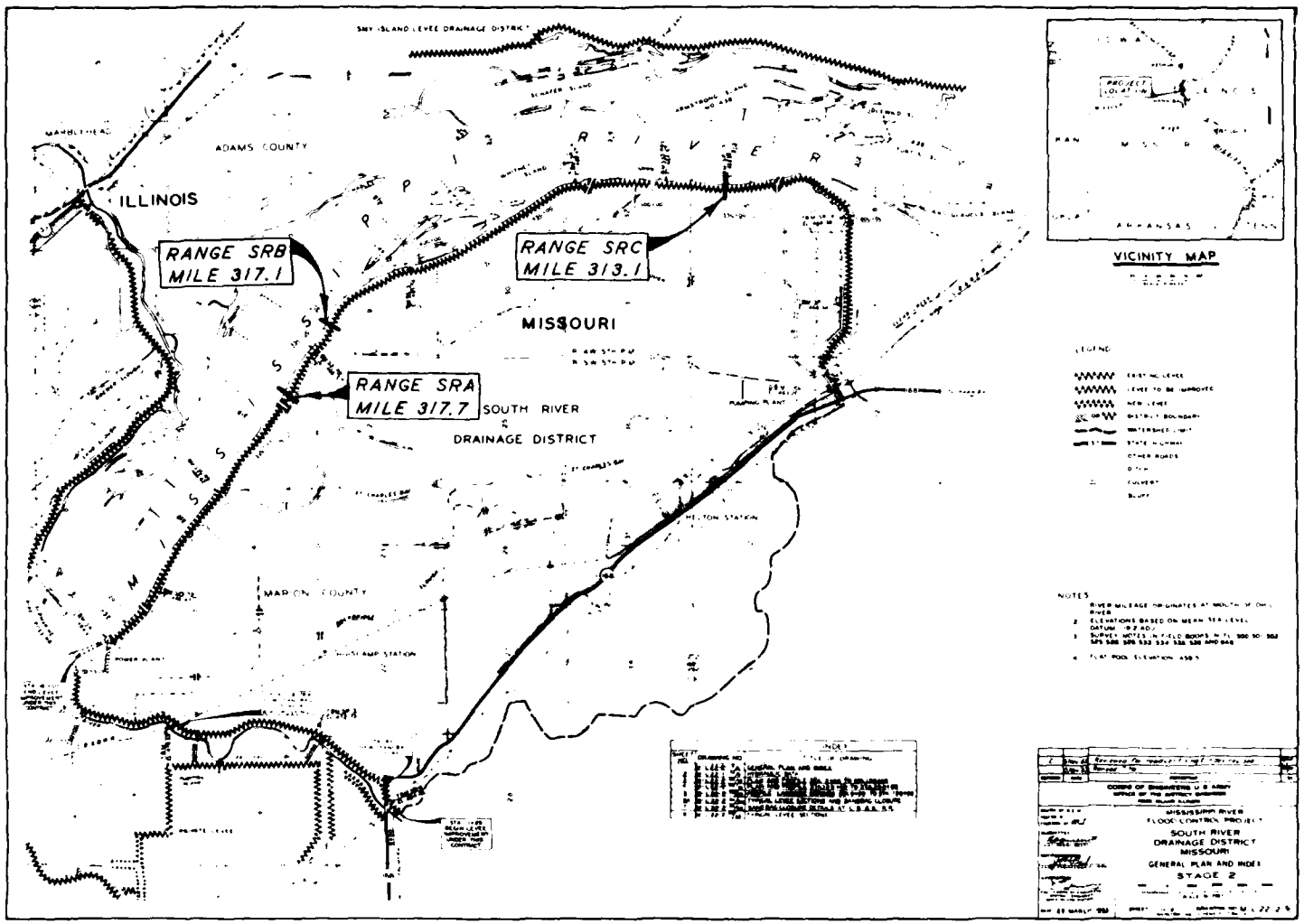

Figure 77. General plan of South River Drainage District

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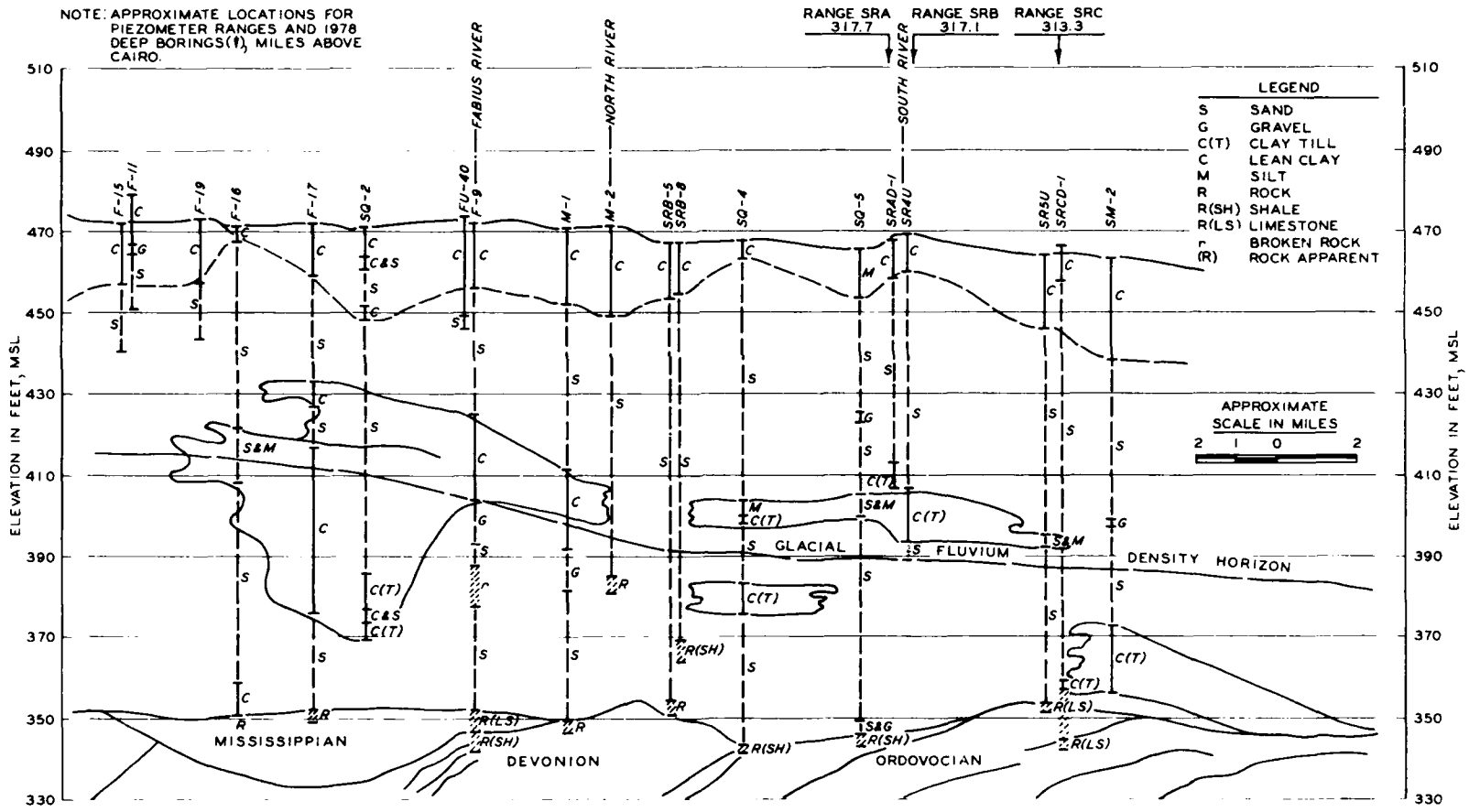

Figure 78. Geologic profile in vicinity of South River Drainage District

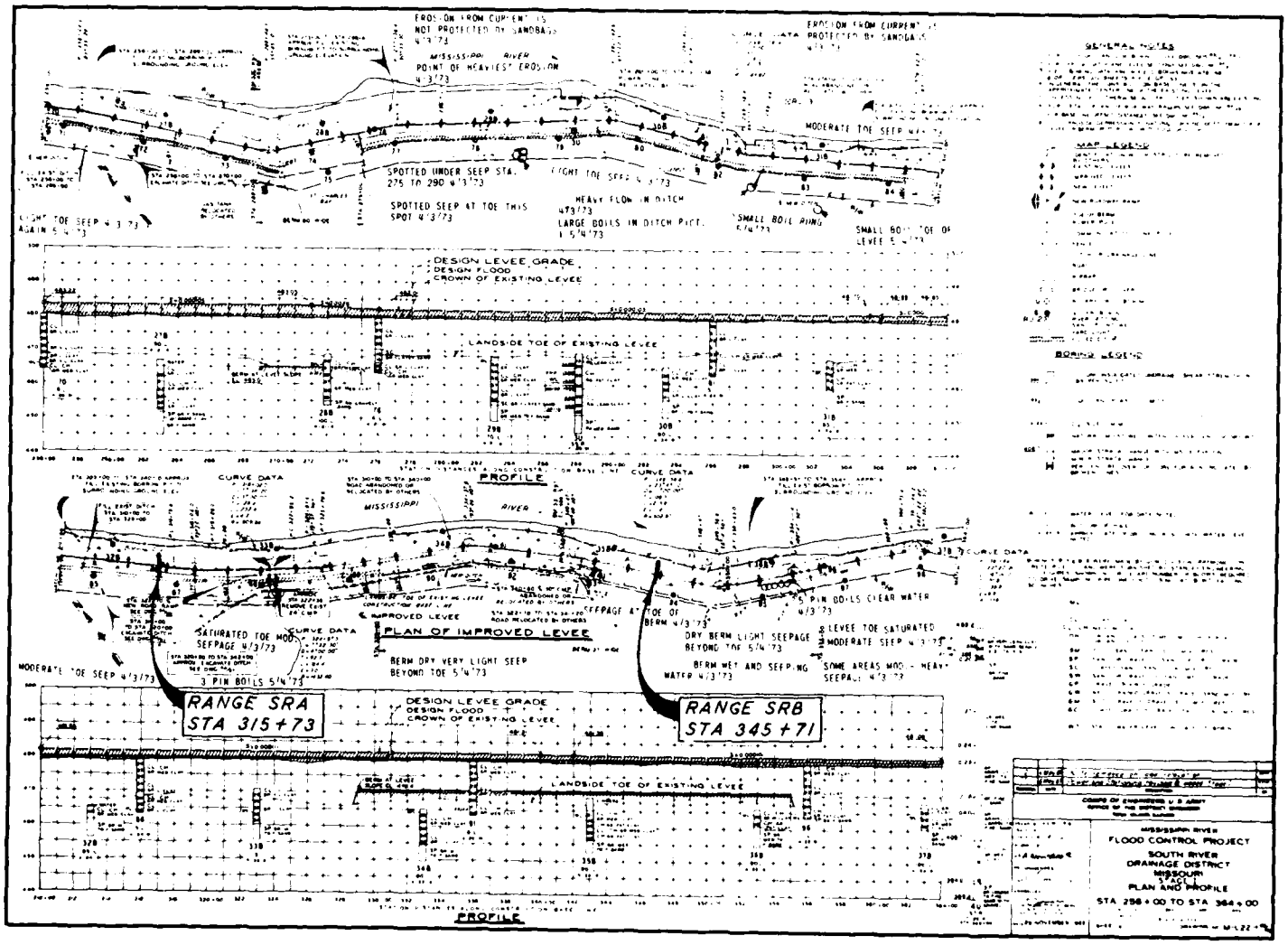

Figure 79. Levee plan and profile in vicinity of South River, Piezometer Ranges SRA and SRB

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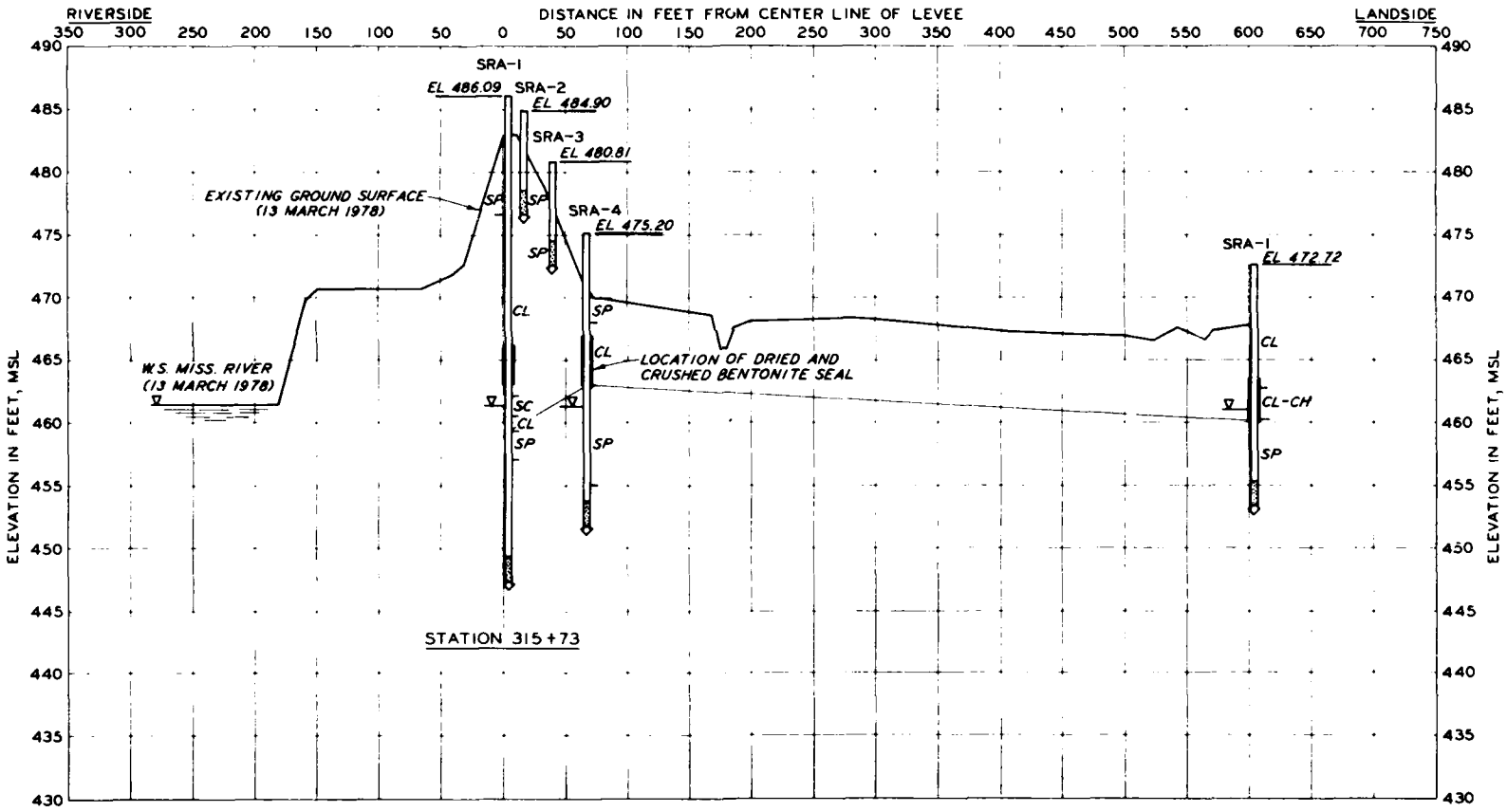

Figure 80. Cross section of South River, Piezometer Range SRA

237. Table 48 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure was about 0.8 ft above the ground surface where ponding was reported, and the calculated factor of safety against uplift was 6.0.

Analysis of piezometer data

238. In Figure 81, the three sets of piezometer readings in Table 47 are plotted, and piezometric pressures are projected to the levee crest elevation of 483.0. A seepage entrance distance of 745 ft and a seepage exit distance of 192 ft were calculated. It should be noted that the calculated seepage entrance distance of 745 ft measured from the landside toe is considerably greater than the 262 ft distance to the exposed substratum at the riverbank. Since the distance to the effective source of seepage should not be greater than the distance to the exposed pervious substratum, the 1979 piezometer data must be considered suspect. The specific cause of the difficulty with the piezometer readings is not known. It is not likely that the riverbank has become silted up, but it is possible that the riverside piezometer may have become partially plugged during installation and therefore was not responding as fast as it should. Another possibility is that the dried and crushed bentonitic seals in piezometer bore holes may not have been fully effective in their first high-water season, and one or more of the landside piezometers may have been effected by percolation of surface water from above. In any event, additional data are required before a reliable rational analysis can be made.

South River, Range SRB

Description of site

239. Piezometer range SRB site is located at river mile 317.1 and levee sta 345+71 on the main channel of the river (Figure 79). The cross section of the site in Figure 82 shows the levee, the foundation, and piezometer locations. The riverside piezometer SRB-1 was driven the last 8 ft to its installed elevation. The relatively impervious top stratum ranges from 7.3 to 11.4 ft thick and generally consists of alternating layers of sand and clay. Figure 82 also shows the locations

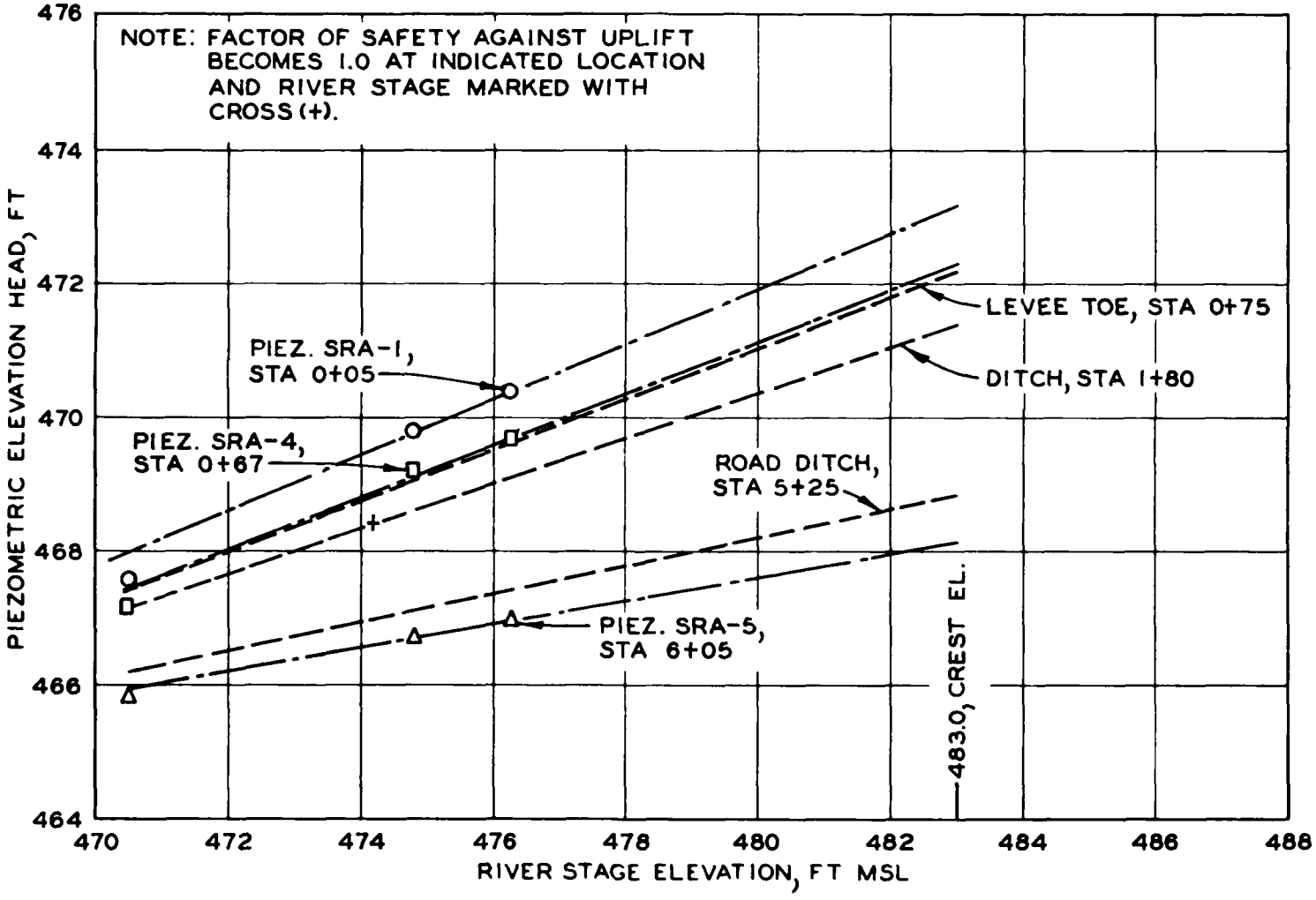

Figure 81. Piezometric elevation head versus river stage, South River, Range SRA

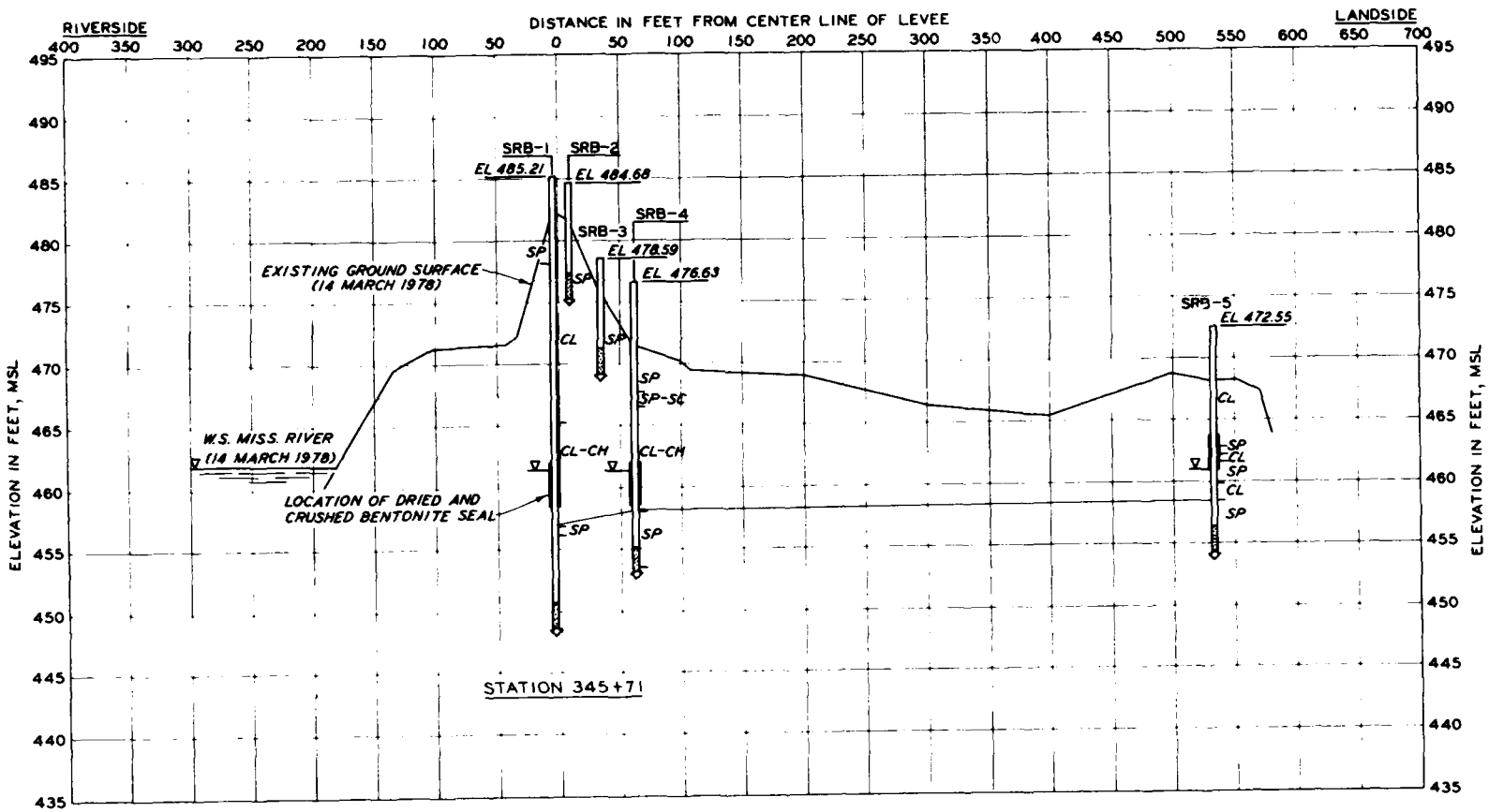

Figure 82. Cross section of South River, Piezometer Range SRB

of dried and crushed bentonite seals in the piezometer bore holes.

240. The levee crest elevation is 482.2, and the average ground elevation landward of the levee is 469.0. Construction for the levee enlargement began in August 1963 and was completed in November 1964.

241. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 212 ft east of the center line of the levee.

History of underseepage

242. Since the completion of the levee enlargement in 1964, three observations of underseepage have been reported. Two of these occurred in 1973 when the river crested at el 481.8; one reported light seepage beyond the toe, while another observed seepage at the levee toe. In 1979, when the river reached el 476.06, the newly installed piezometers were read, the levee was inspected, and water was reported ponded in the fields. Table 49 lists the 1979 piezometer readings.

243. Table 50 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure was 0.8 ft above the ground surface where ponding was reported, and the calculated factor of safety against uplift was 7.2.

Analysis of piezometer data

244. In Figure 83, the three sets of piezometer readings in Table 49 are plotted, and piezometric pressures are projected to the levee crest elevation of 482.2. Seepage entrance and seepage exit distances of 323 and 49 ft, respectively, were calculated. It shall be noted that the calculated seepage entrance distance of 323 ft measured from the landside toe is greater than the 275-ft distance to the exposed substratum at the riverbank. Since the distance to the effective source of seepage should not be greater than the distance to the exposed substratum, the 1979 piezometer data must be considered suspect. The specific cause of the difficulty with the data is not known. It is not likely that silting has occurred at the riverbank, but it may be that the riverside piezometer may have been partially plugged or that the bentonite seals in the piezometer boreholes may not have been fully effective during 1979, the first high-water season after installation. In any event, additional

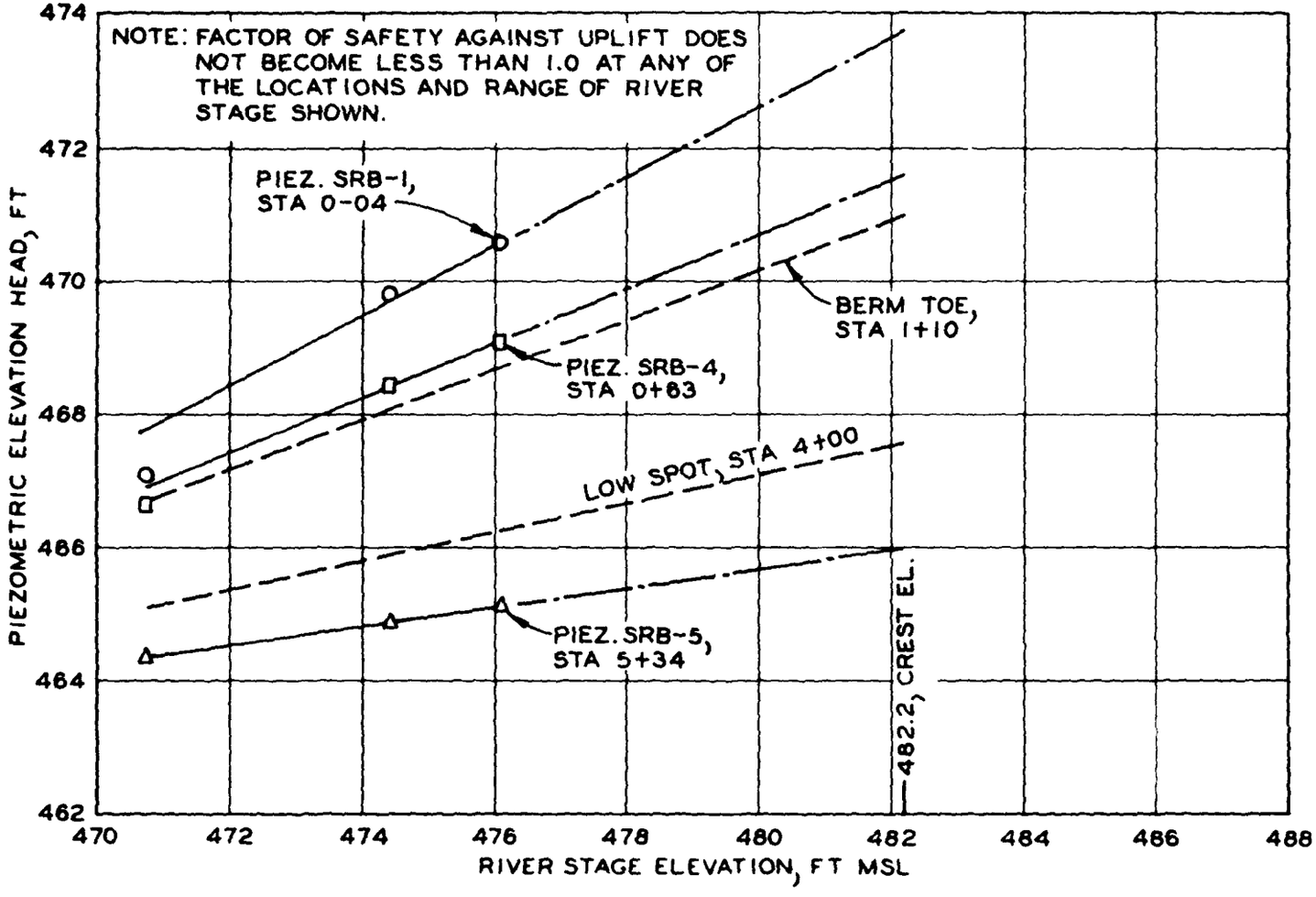

Figure 83. Piezometric elevation head versus river stage, South River, Range SRB

data are necessary before a reliable rational analysis can be made.

South River, Range SRC

Description of site

245. Piezometer Range SRC site is located at river mile 313.1 and levee sta 560+46 on the main channel of the river (Figure 84). The cross section of the site in Figure 85 shows the levee, the foundation, and piezometer locations. Piezometers SRC-1, SRC-4, and SRC-5 were driven the last 10, 5, and 5 ft, respectively. The relatively impervious top stratum ranges from 8.4 to 13.1 ft thick and generally consists of fat and lean clay with intrusions of sand.

246. The levee crest elevation is 480.2, and the average ground elevation 100 ft landward of the levee toe is 466.8. Construction for the levee enlargement began in August 1963 and was completed in November 1964.

247. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 240 ft east of the center line of the levee.

History of underseepage

248. Since the completion of the levee enlargement in 1964, three observations of underseepage have been reported. In 1965, when the river crested at el 476.2, many pin boils were observed in a ditch approximately 510 ft landward of the center line of the levee. In 1973, with a river crest el of 480.0, light seepage was noted at the levee toe. In 1979, when the river reached el 474.30, the newly installed piezometers were read, the levee was inspected, and some water was reported ponded in the fields downstream. Table 51 lists the 1979 piezometer readings.

249. Table 52 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure was 4.6 ft above the ground surface of the ditch when ponding was reported downstream, and the calculated factor of safety against uplift was 1.5.

Analysis of piezometer data

250. The two sets of piezometer readings in Table 51 are for 10 and 13 April 1979. One additional set of readings was obtained on 22

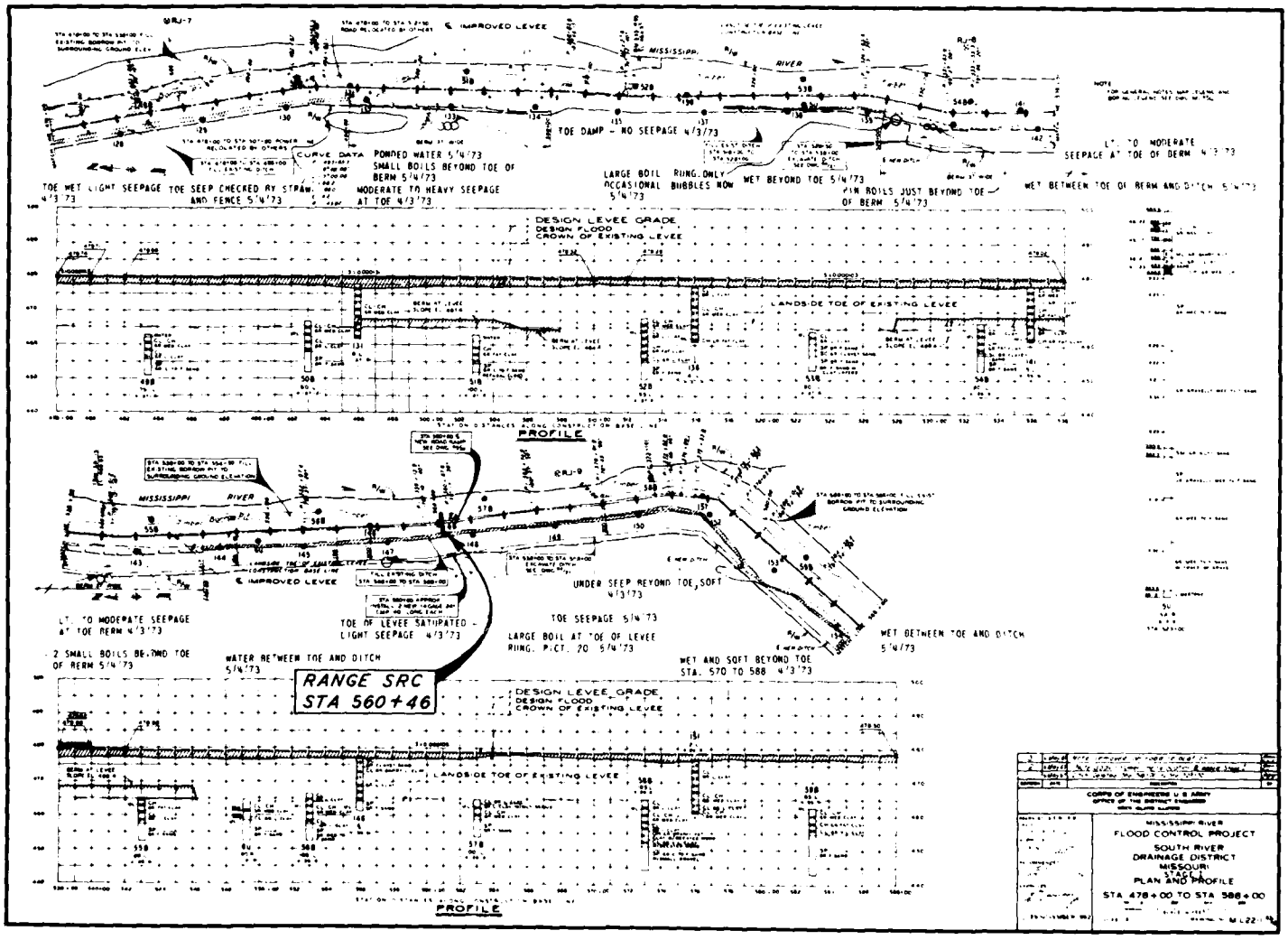

Figure 84. Levee plan and profile in vicinity of South River, Piezometer Range SRC

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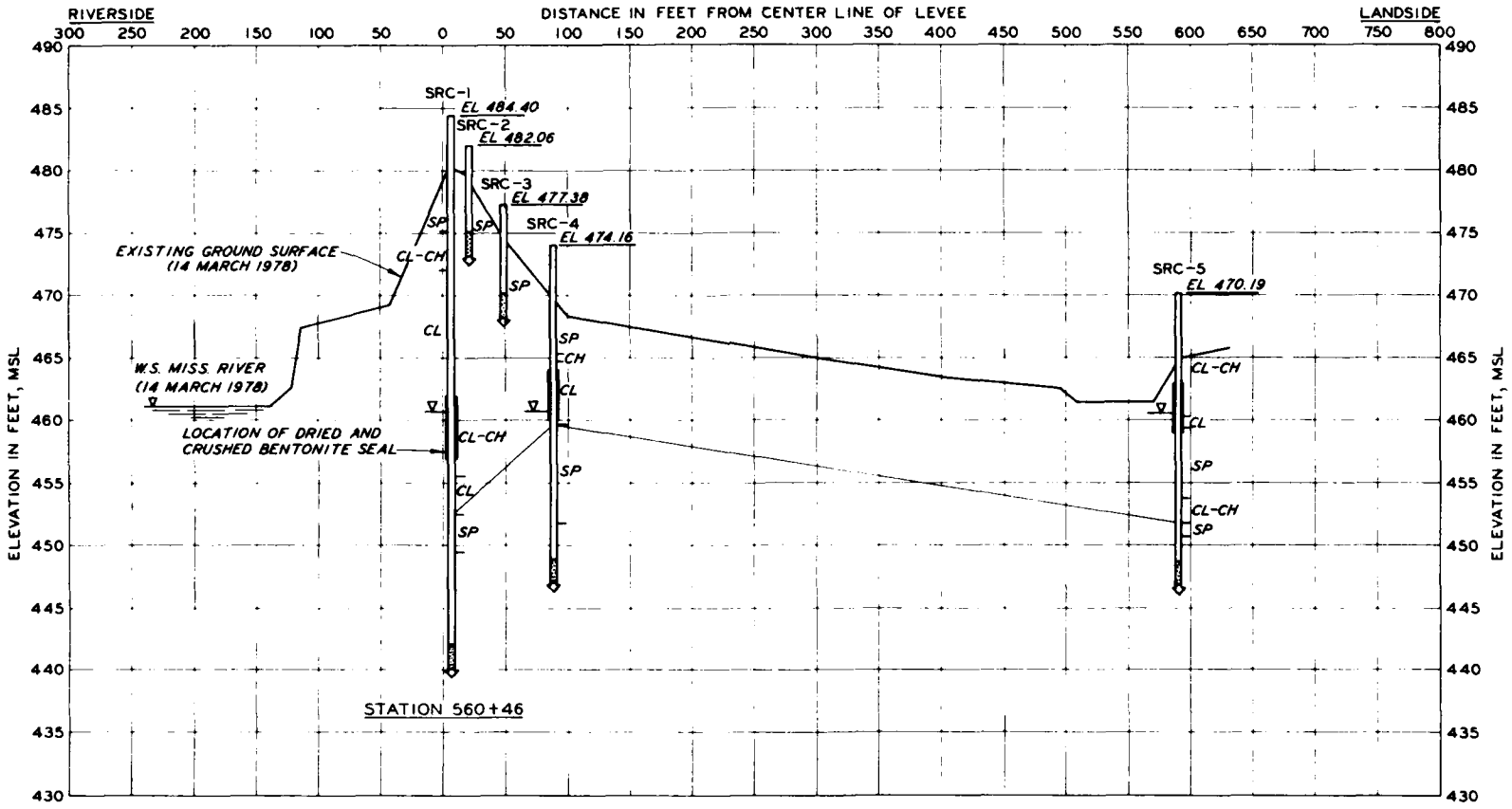

Figure 85. Cross section of South River, Piezometer Range SRC

March, but on this date the riverside piezometer reading was 1.2 ft lower than that from the landside toe piezometer; therefore, the 22 March readings are not listed in the table.

251. Although at least three sets of piezometer readings are generally desired for projection of piezometric pressures, Figure 86 presents a plot of the data from two dates for this piezometer range and shows the piezometric pressures that were projected to the levee crest elevation of 480.2. A seepage entrance distance of 460 ft and a seepage exit distance of 223 ft were calculated. It should be noted that the calculated seepage entrance distance of 460 ft measured from the landside toe is greater than the 240-ft distance to the riverbank. Since this should not be possible, the piezometer data should be considered suspect. The specific cause for the difficulty with the data is not known; it is not likely that the riverbank has silted up, and it is evident that additional data are necessary before a reliable and rational analysis can be made.

Sny Island, Range SA

252. A general plan of Sny Island Levee Drainage District and a geologic profile have been previously presented in Figures 42 and 43, respectively, with the description of the old piezometer range sites. Four new piezometer ranges, Ranges SA, SB, SC, and SD, were established in August 1977.

Description of site

253. Piezometer Range SA site is located at Mississippi River mile 294.5 and levee sta 1153+52 on the main channel of the river (Figure 87). The cross section of the site in Figure 88 shows the levee, the foundation, and piezometer locations. Piezometers SA-1 and SA-4 were driven the last 3 and 7 ft, respectively, during installation. The relatively impervious top stratum ranges from 9.4 to 10.4 ft thick and generally consists of lean to fat clay overlying clayey sand.

254. The levee crest elevation is 471.0, and the average ground elevation landward of the levee is 453.5. Construction for the levee enlargement began in December 1965 and was completed in October 1966.

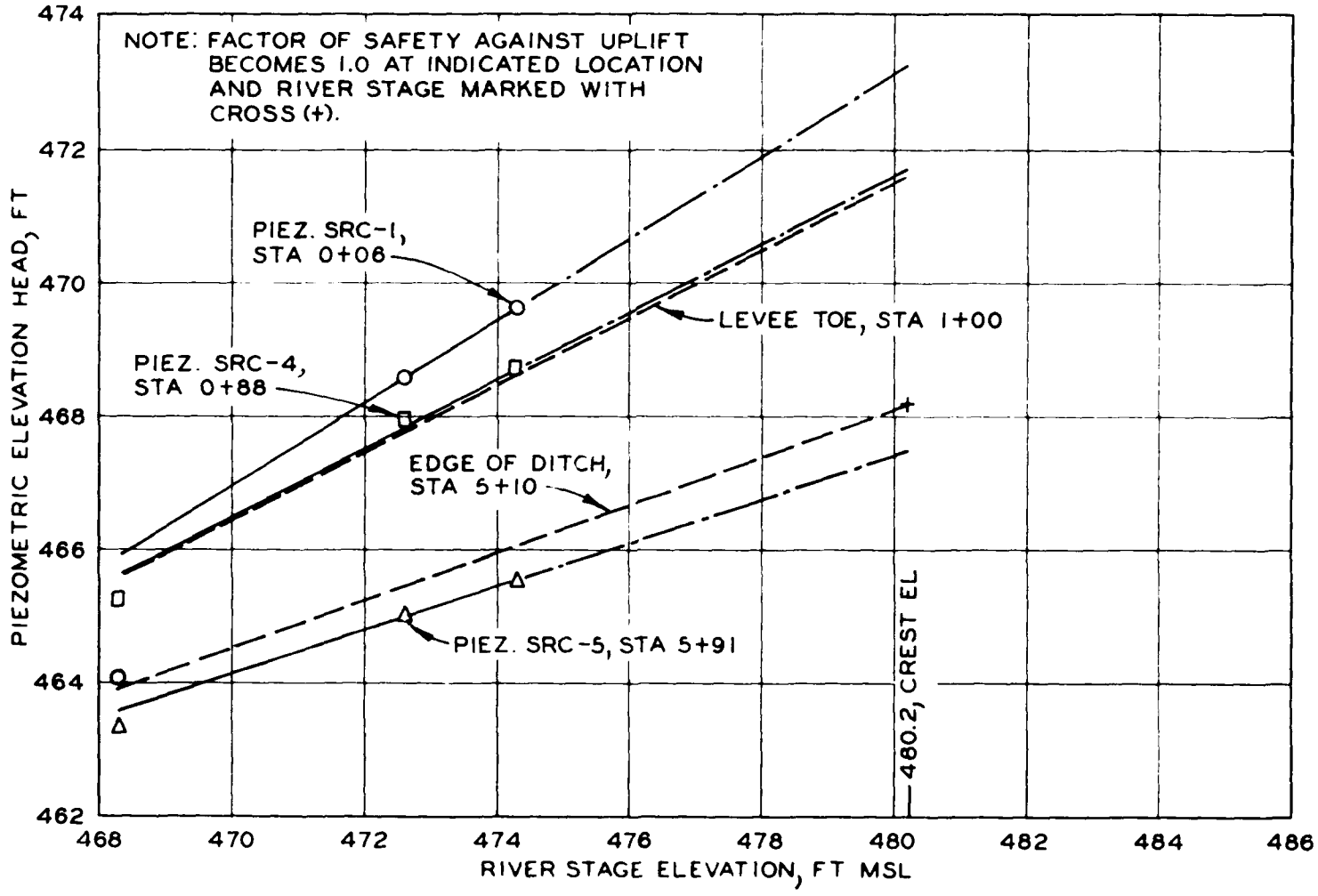

Figure 86. Piezometric elevation head versus river stage, South River, Range SRC

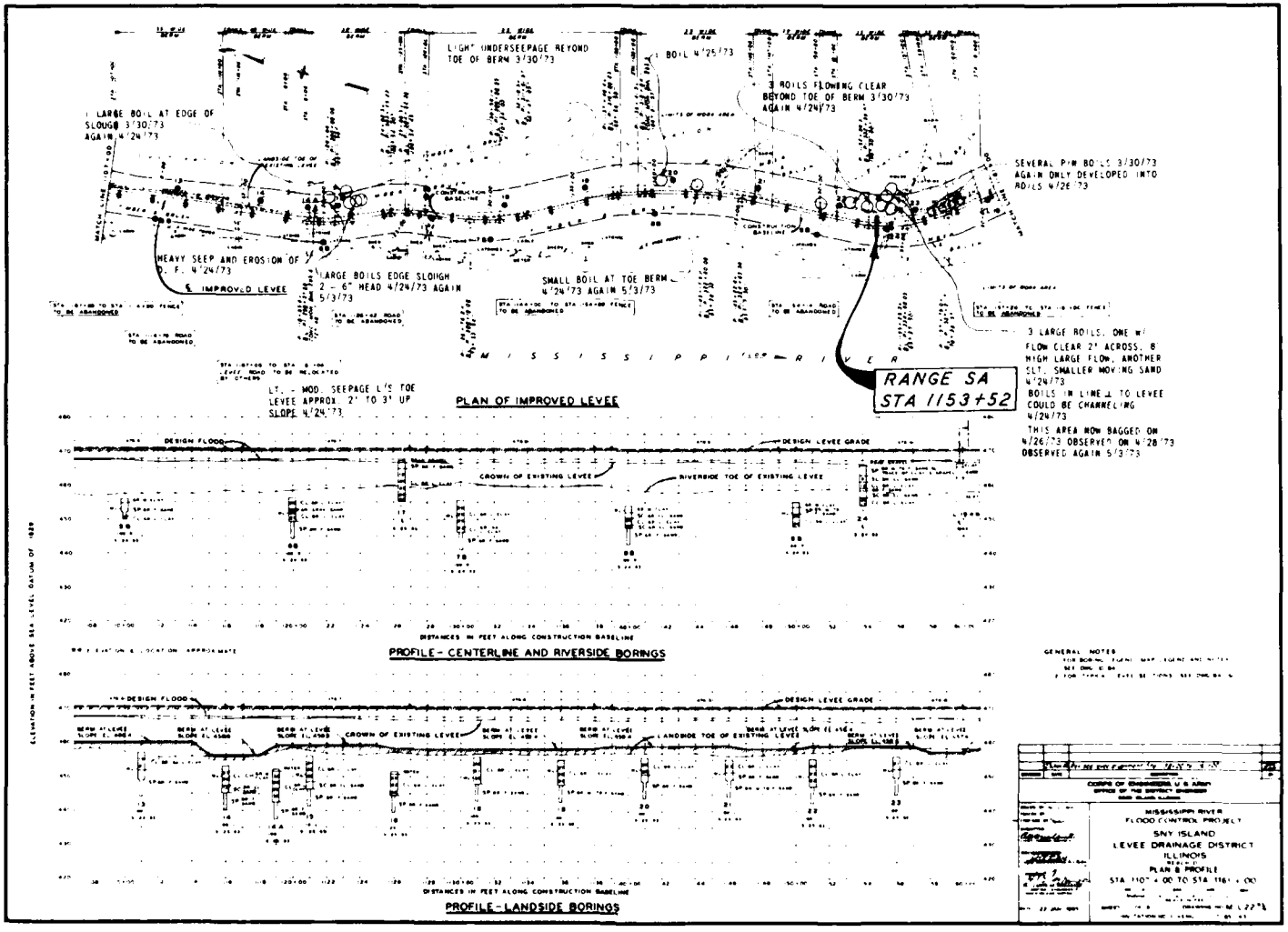

Figure 87. Levee plan and profile in vicinity of Sny Island, Piezometer Range SA

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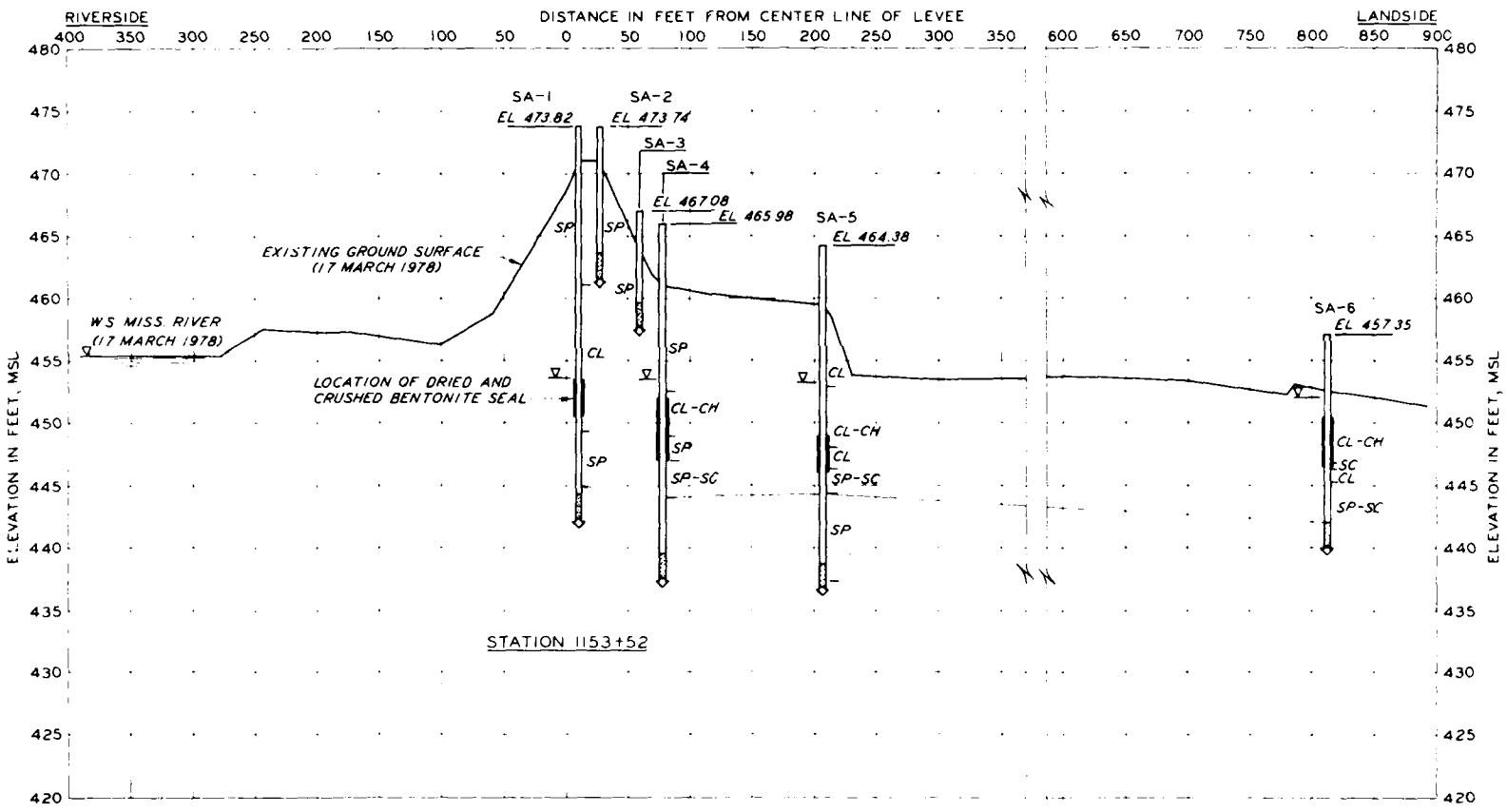

Figure 88. Cross section of Sny Island, Piezometer Range SA

255. The exposed pervious substratum at the bank of the main channel of the river was estimated to be 378 ft west of the center line of the levee.

History of underseepage

256. Since the completion of the levee enlargement in 1966, three observations of underseepage have been reported. In 1973, when the river crested at el 471.0, large boils erupted, some flowing clear water and some carrying sand. In 1969, light underseepage beyond the toe of the levee was observed with a river crest of el 464.3. In February 1974, a large berm was placed at this site. In 1979, when the river reached el 462.92, the newly installed piezometers were read, the levee was inspected, several pin boils were noted beyond the new berm, and water was reported ponded in the area and flowing in the fields. Table 53 lists the 1979 piezometer readings.

257. Table 54 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 2.8 to 0.7 ft above the ground where seepage was reported, and the calculated factor of safety against uplift ranged from 2.3 to 10.

Analysis of piezometer data

258. The one set of piezometer readings in Table 53 is for 14 April 1979. The piezometers were read on two other dates, but the data are not considered reliable. On 21 March, the piezometer SA-4 reading was 2.5 ft lower than piezometer SA-5; thus, at least some of the piezometers must not have fully responded to the river rise on this date. On 10 April, the piezometer SA-4 reading was 1.4 ft higher than piezometer SA-1, and it is believed that one or the other or both of these piezometers were not responding properly. On 14 April, no reading was obtained from piezometer SA-6. No analysis of piezometric data can be made from this range with data currently available.

Sny Island, Range SB

Description of site

259. Piezometer Range SB site is located on the east bank of the

Mississippi River at mile 291.5 and levee sta 1311+92 (Figure 89). The cross section of the site in Figure 90 shows the levee, the foundation, and piezometer locations. The riverside piezometer SB-1 was driven the last 3 ft to its installed elevation. The relatively impervious top stratum ranges from 3.0 to 7.2 ft thick and generally consists of lean clay with an intrusion of clayey sand.

260. The levee crest elevation is 469.6, and the average ground elevation landward of the levee is 450.3. Construction for the levee enlargement began in December 1965 and was completed in October 1966.

261. The cross section in Figure 90 indicates that the top of the bank of the Mississippi River is immediately adjacent to the levee riverside slope. However, Figures 46 and 89 indicate that the bank shown is apparently from an old channel or slough and the main channel of the river is about a mile to the west. From Figure 90, it was estimated that the exposed pervious substratum was 112 ft from the center line of the levee.

History of underseepage

262. Since the completion of the levee enlargement in 1966, two observations of underseepage have been reported. In 1973, when the river crested at el 469.3, sand boils approximately 115 ft from the center line of the levee and through seepage were reported. In 1969, with a river crest of el 463.5, light seepage beyond the levee toe was observed. In 1979, when the river reached el 462.01, the newly installed piezometers were read, the levee was inspected, and no seepage distress was noted in the area. Table 55 lists the 1979 piezometer readings.

263. Table 56 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 4.8 to 2.6 ft above the ground surface at locations where seepage distress had been reported at higher river stages in other years, and the calculated factor of safety against uplift ranged from 0.8 to 2.1.

Analysis of piezometer data

264. In Figure 91, the three sets of piezometer data in Table 55 are plotted and piezometric pressures are projected to the levee crest

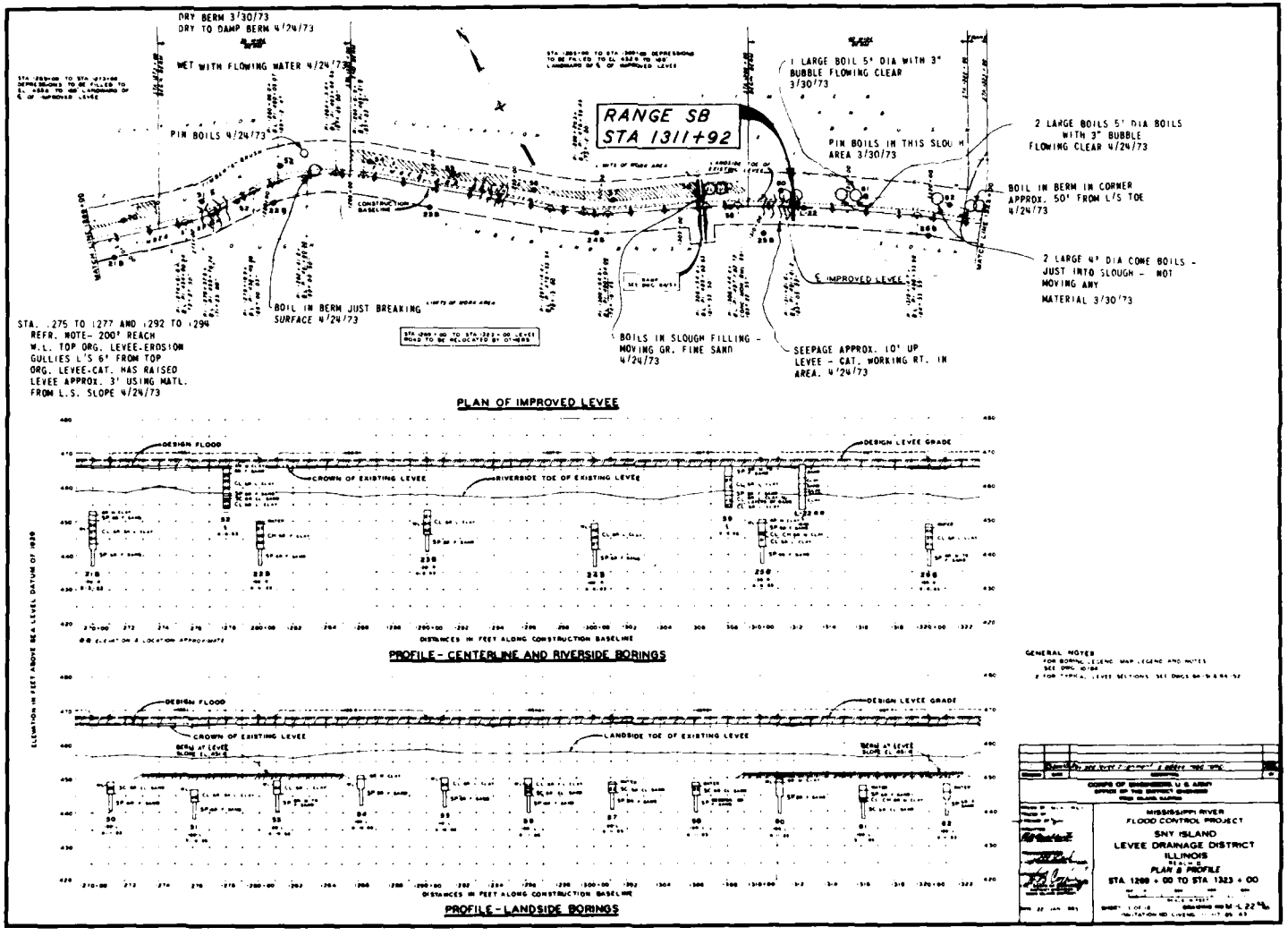

Figure 89. Levee plan and profile in vicinity of Sny Island, Piezometer Range SB

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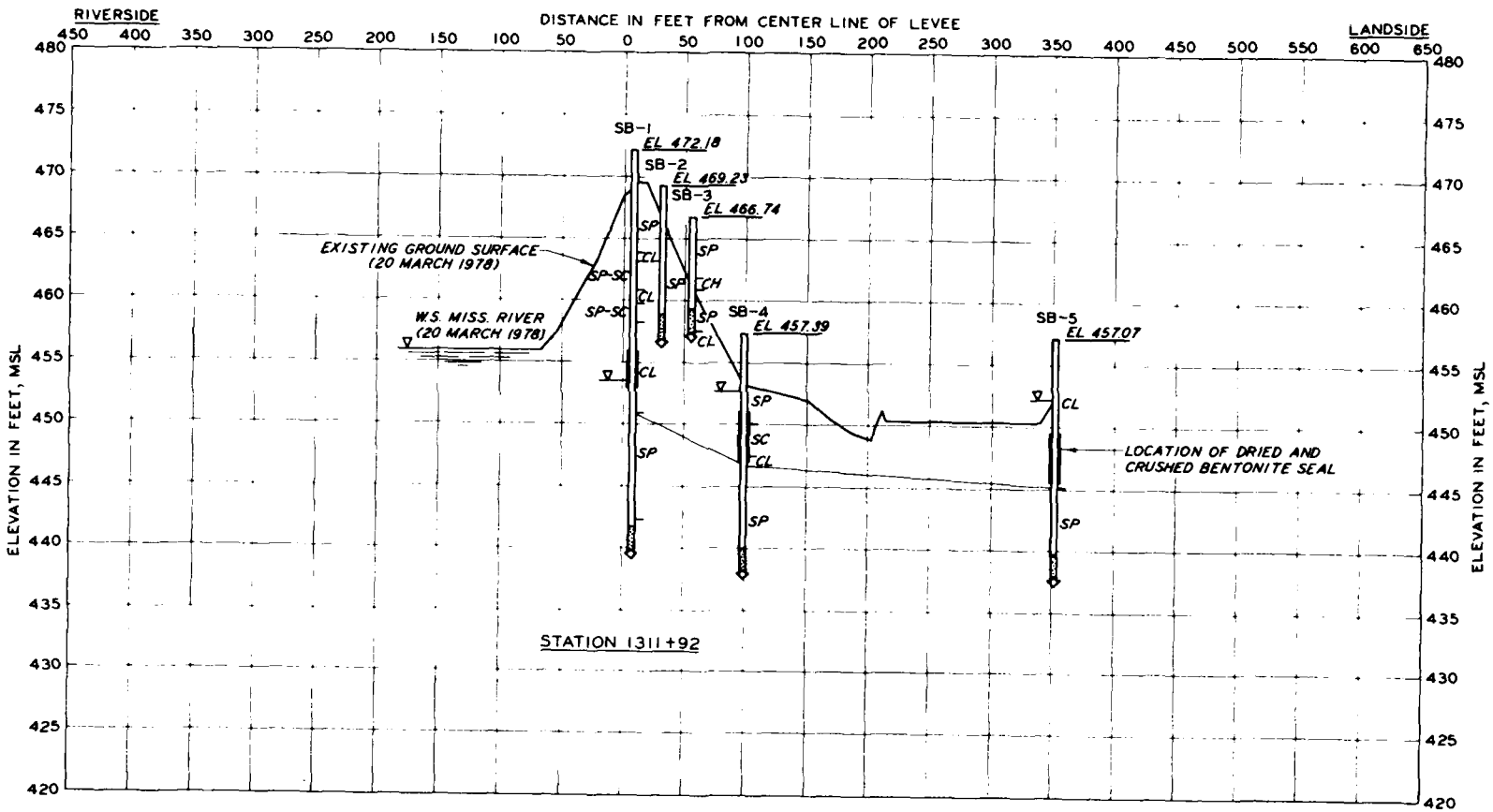

Figure 90. Cross section of Sny Island, Piezometer Range SB

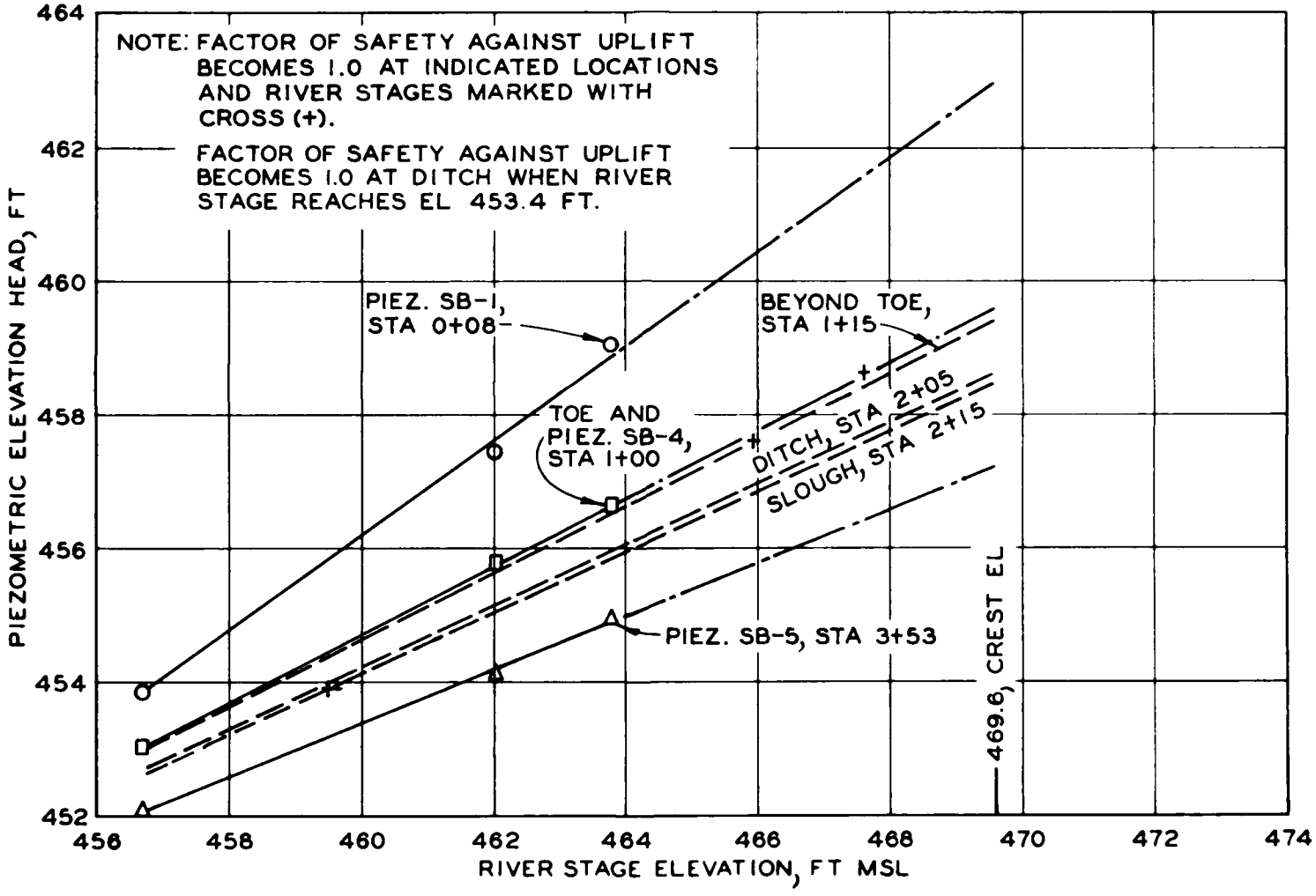

Figure 91. Piezometric elevation head versus river stage, Sny Island, Range SB

elevation of 469.6. A seepage entrance of 271 ft and a seepage exit distance of 252 ft were calculated. It should be noted that the calculated seepage entrance distance of 271 ft measured from the landside toe is greater than the 212-ft distance to the exposed pervious substratum at the riverbank. This indicates that either some silting may have occurred in the slough immediately adjacent to the levee or the piezometers are not responding properly. In either event, it is believed that additional data must be collected before a reliable and rational analysis can be made.

Sny Island, Range SC

Description of site

265. Piezometer Range SC site is located at Misissippi River mile 288.7 and levee sta 1501+77 (Figure 92). The cross section of the site in Figure 93 shows the levee, the foundation, and piezometer locations. The riverside piezometer SC-1 was driven the last 5 ft to its installed elevation. The relatively impervious top stratum ranges from 13.5 to 19.3 ft thick and generally consists of alternating layers of lean to fat clay and sand to clayey sand.

266. The levee crest elevation is 468.5, and the average ground elevation landward of the levee is 455.0. Construction for the levee enlargement began in July 1966 and was completed in June 1968.

267. The cross section in Figure 93 indicates that the top of the bank of a slough or chute of the river is approximately 160 ft west of the center line of the levee. The additional distance to the river is crossed by at least two water channels or sloughs. From Figure 93, it was estimated that the exposed pervious substratum was 465 ft from the center line of the levee.

History of underseepage

268. Since the completion of the levee enlargement in 1968, two observations of underseepage have been reported. In 1973, with a river crest of el 467.9, heavy through seepage 2 to 3 ft up the levee slope was observed. In 1979, when the river reached el 460.03, the newly

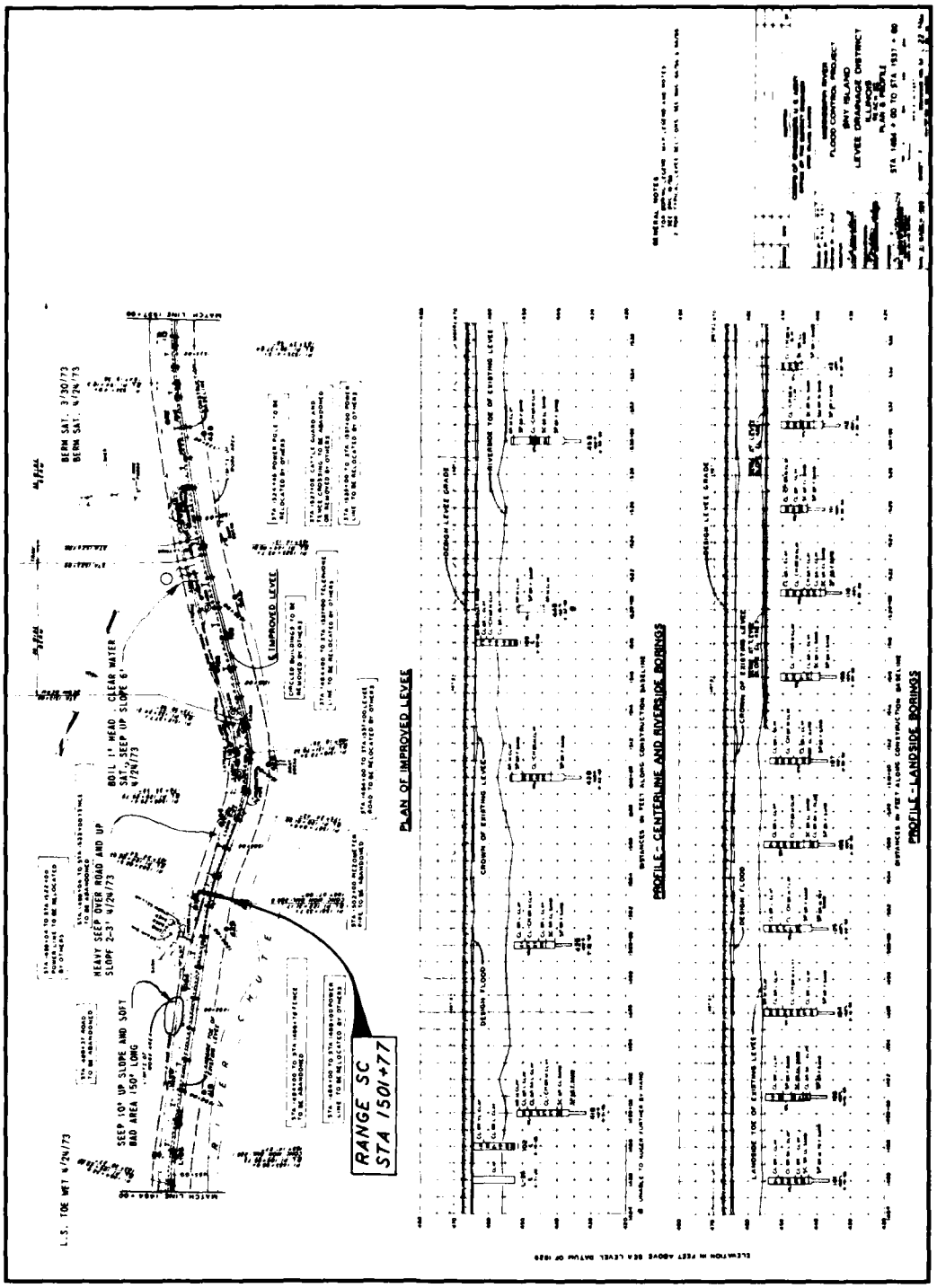

Figure 92. Levee plan and profile in vicinity of Sny Island, Piezometer Range SC

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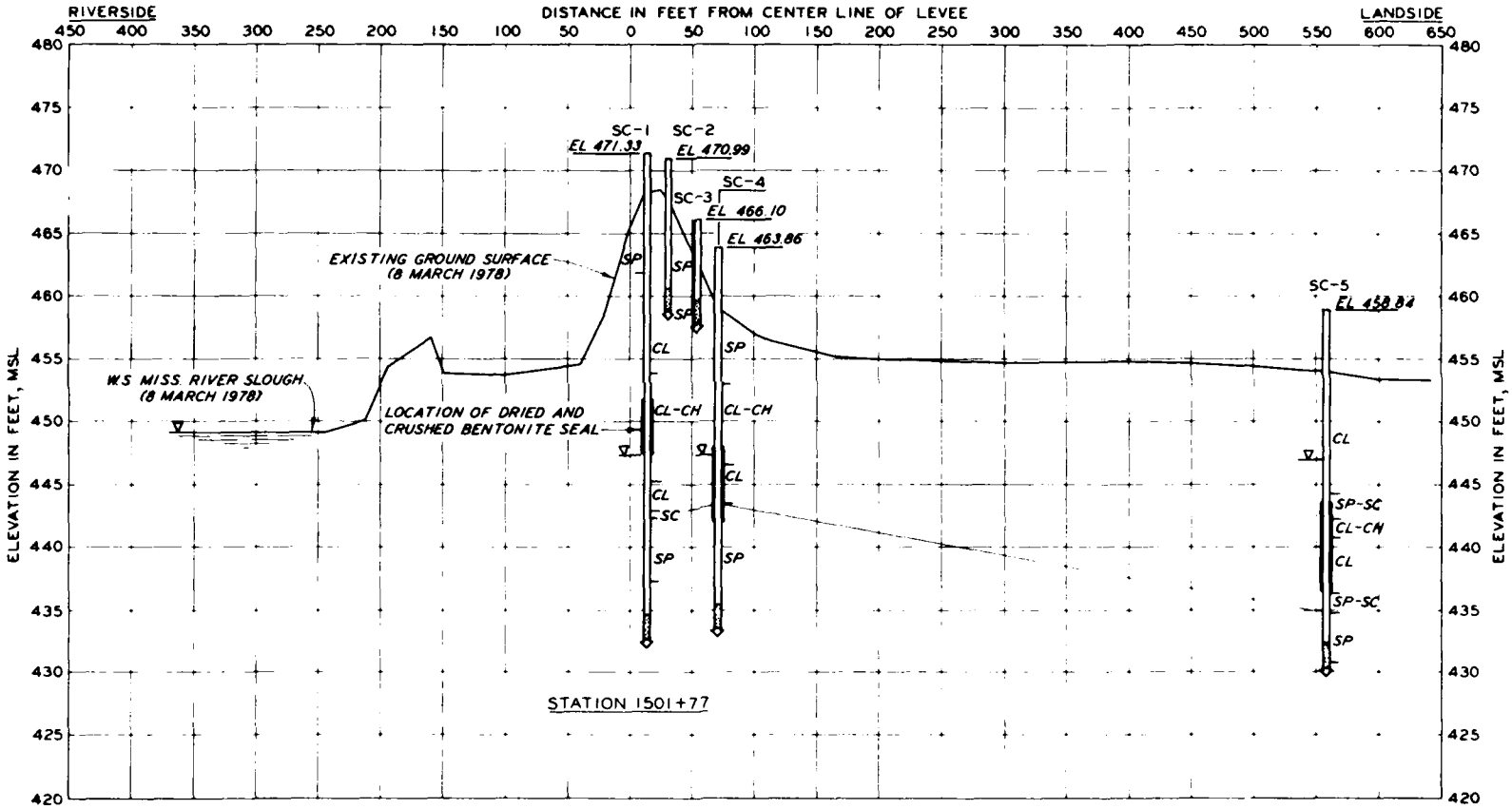

Figure 93. Cross section of Sny Island, Piezometer Range SC

installed piezometers were read, the levee was inspected, the levee toe was reported saturated, and water was seeping over the road and ponding in the fields. Table 57 lists the 1979 piezometer readings.

269. Table 58 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 1.3 to 0.8 ft above the ground surface where seepage was reported, and the calculated factor of safety against uplift ranged from 8.3 to 18.

Analysis of piezometer data

270. The three sets of piezometer readings in Table 57 are for three different dates. An inspection of the data suggests that the river stage listed on 21 March may be about 5 ft high; however, the data have been checked and el 460.35 is what is listed in the original record. Since the reported river stage is so clearly out of line, the data for 21 March have not been used for projection of piezometric pressures. Thus, in Figure 94, just the data from 10 and 14 April are plotted, and piezometric pressures are projected to a levee crest elevation of 468.5. A seepage entrance distance of 667 ft and a seepage exit distance of 815 ft were calculated.

271. It should be noted that the calculated seepage entrance distance of 667 ft measured from the landside toe is greater than the estimated 565-ft distance to the exposed pervious substratum at the riverbank. This indicates either that some silting may have occurred in the slough nearest the levee or that the piezometers are not responding properly. In either event, it is believed that more data must be obtained before a reliable and rational analysis can be made.

Sny Island, Range SD

Description of site

272. Piezometer Range SD site is located at Mississippi River mile 287.6 and levee sta 1559+23 (Figure 95). The cross section of the site in Figure 96 shows the levee, the foundation, and piezometer locations. The relatively impervious top stratum ranges from 10.8 to 15.7 ft thick

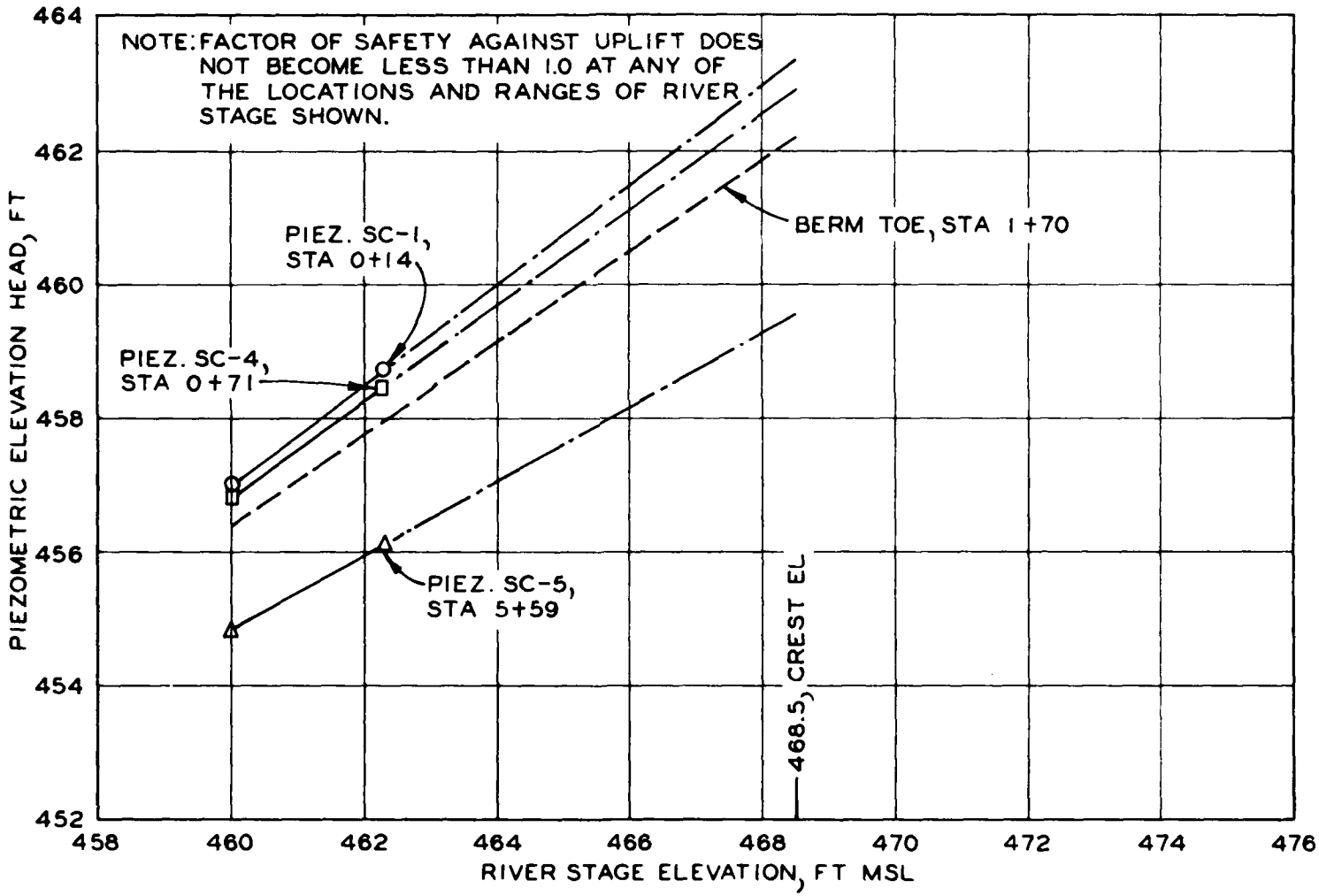

Figure 94. Piezometric elevation head versus river stage, Sny Island, Range SC

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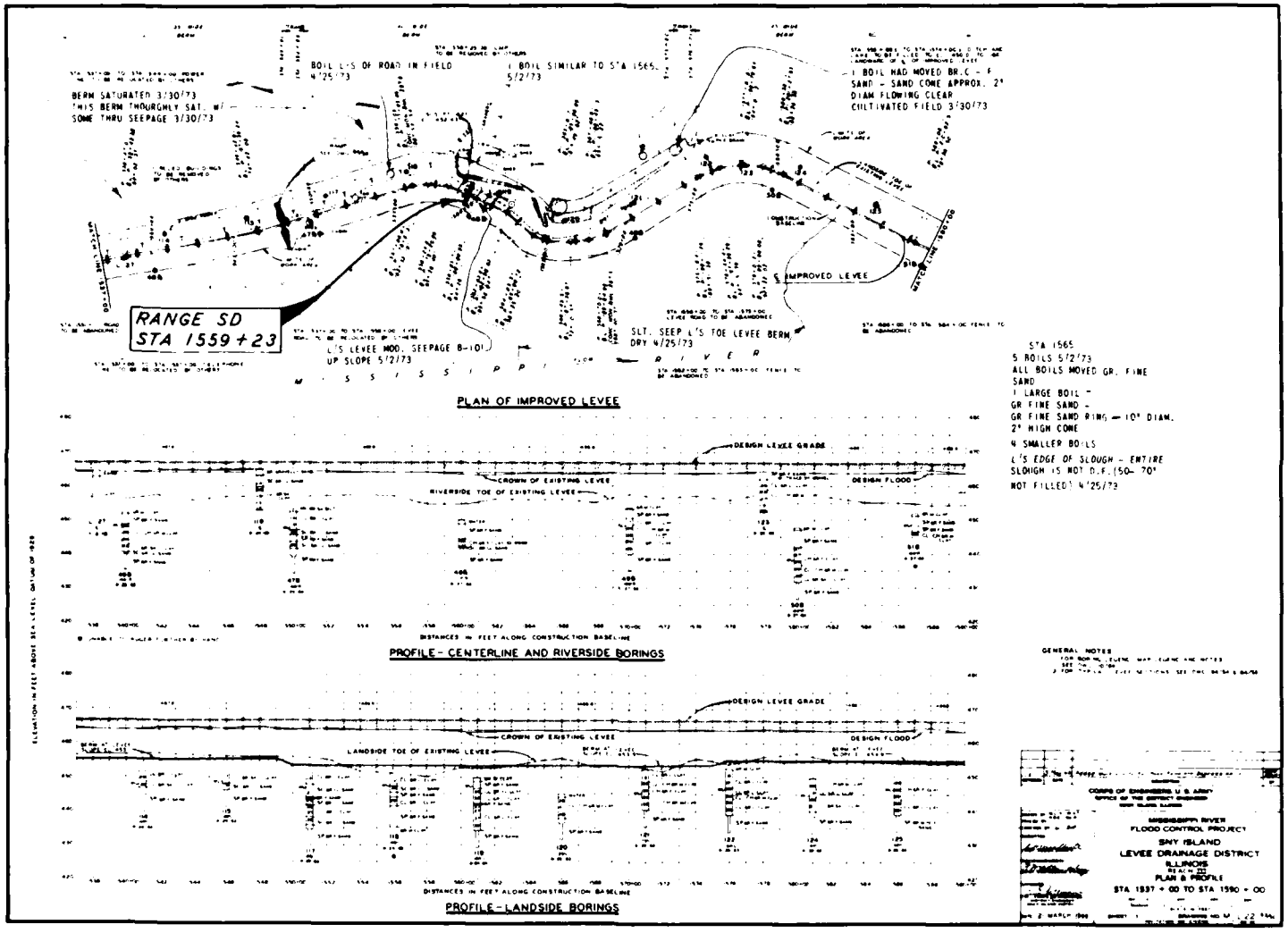

Figure 95. Levee plan and profile in vicinity of Sny Island, Piezometer Range SD

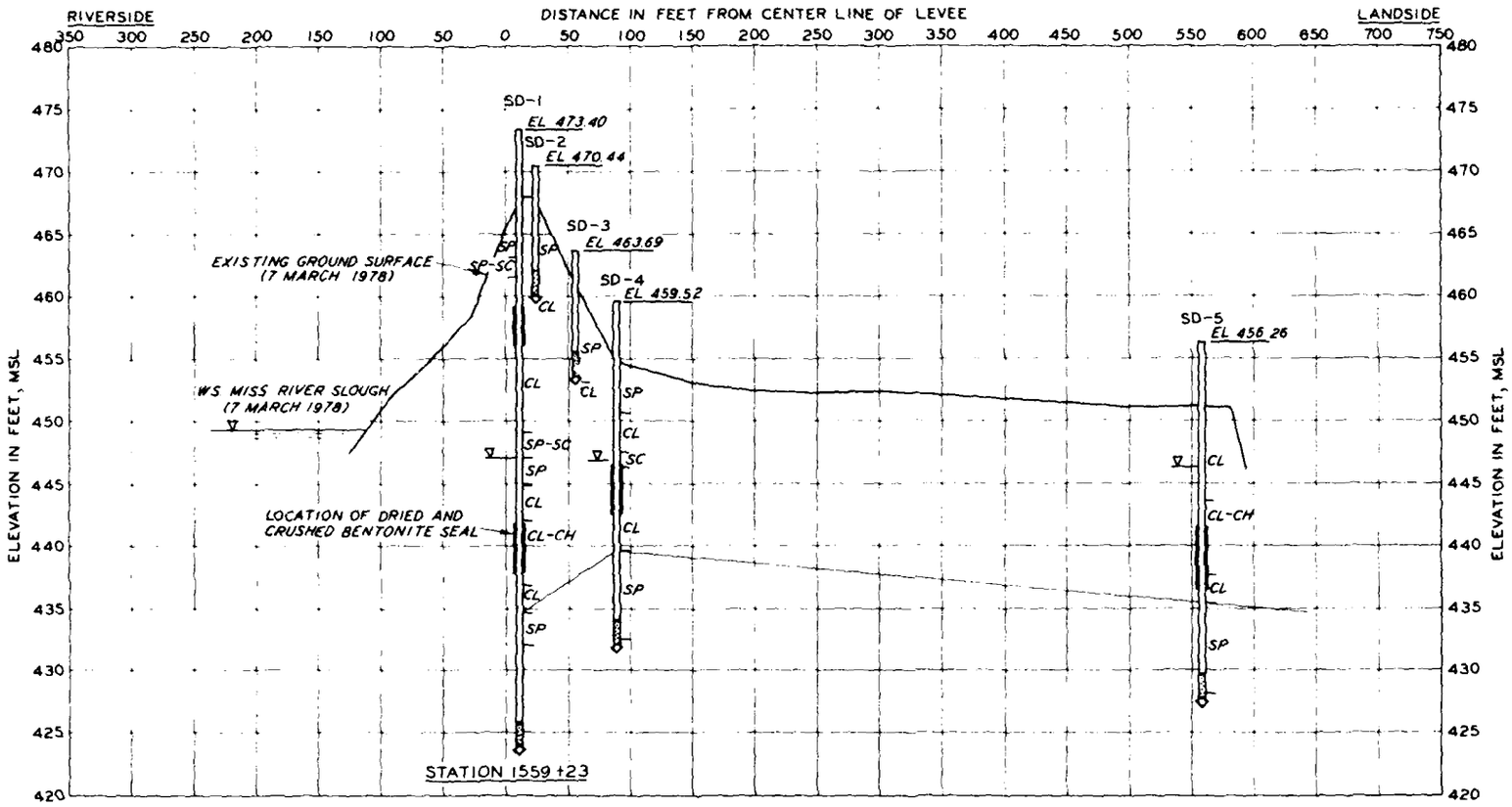

Figure 96. Cross section of Sny Island, Piezometer Range SD

and generally consists of lean to fat clay with some clayey sand. Figure 96 also shows the locations of dried and crushed bentonite seals in the piezometer bore holes. The riverside piezometer SD-1 was driven the last 9 ft to its installed elevation.

273. The levee crest elevation is 468.0, and the average ground elevation landward of the levee is 452.5. Construction for the levee enlargement began in July 1966 and was completed in June 1968.

274. The cross section in Figure 96 indicates that the levee is immediately adjacent to a slough of the river. This is confirmed by Figure 95 that shows that the main channel of the river is about 500 ft to the west. From Figure 96, the exposed pervious substratum was estimated to be 219 ft from the center line of the levee.

History of underseepage

275. Since the completion of the levee enlargement in 1968, three observations of underseepage have been reported. In 1969, when the river crested at el 461.8, the fields far beyond the levee toe were reported as "just damp." In 1973, when the river crested at el 467.4, moderate through seepage was observed 8 to 10 ft up the levee slope. In 1979, when the river reached el 459.80, the newly installed piezometers were read, the levee was inspected, the berm was reported dry for the most part, but some water was ponded in the fields. Table 59 lists the 1979 piezometer readings.

276. Table 60 presents a summary of observed performance with details of the foundation conditions. In 1979, the piezometric pressure ranged from 6.1 to 1.1 ft above the ground surface where seepage was reported, and the calculated factor of safety against uplift ranged from 1.4 to 11.

Analysis of piezometer data

277. In Figure 97, the three sets of piezometer data in Table 59 are plotted, and piezometric pressures are projected to the levee crest elevation of 468.0. A seepage entrance distance of 830 ft and a seepage exit distance of 674 ft were calculated. The calculated seepage distance of 830 ft measured from the landside toe is considerably greater than the estimated 308 ft to the exposed substratum at the slough or

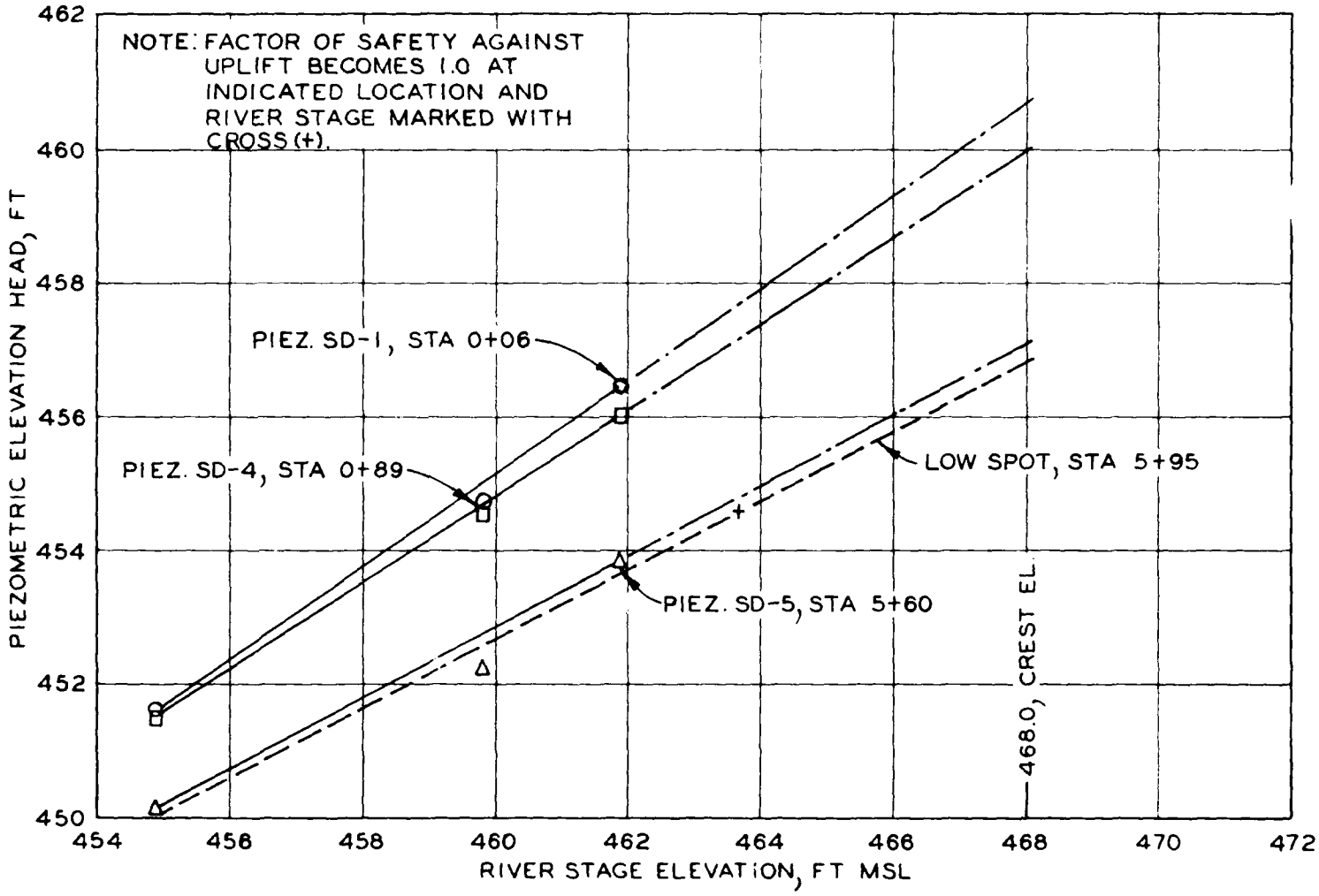

Figure 97. Piezometric elevation head versus river stage, Sny Island, Range SD

the approximate 600 ft to the main channel of the river. Since the effective source of seepage should not be greater than the distance to the exposed substratum at the riverbank, the 1979 piezometer data must be considered suspect. The specific reason for the difficulty with the data is not known, but it is possible that the screen for the riverside piezometer SD-1 may have become partially plugged and therefore was not responding properly. Another possibility is that the bentonite seals in the landside piezometer bore holes were not fully effective, and through seepage or percolating surface water was effecting the landside toe piezometer reading. In any event, additional data are required before reliable and rational analysis of the data can be made.

PART V: DISCUSSION AND ANALYSIS

Permeability Ratios

278. Of the 14 old (1950-1960) piezometer range sites, only 7 had complete piezometer observations, which included piezometric pressure measurements under both the landside and riverside slopes of the levee. The pressure gradient under the levee in general was significantly greater than that landward of the levee. Since this significantly influences the calculated effective seepage entrance and exit distances that, in turn, are used to calculate piezometric pressures and permeability ratios, only the 7 old sites with complete piezometer data were used for analysis of permeability ratios.

279. Of the 15 new (1977) piezometer range sites, only 5 had at least three sets of piezometer readings that had no gross errors, such as a landside piezometer having a piezometric elevation head higher than that for the riverside piezometer or another piezometer closer to the river. However, for each of these 5 piezometer ranges, the calculated seepage entrance distance was greater than the distance to the exposed pervious substratum at the riverbank; thus, the data was probably not reliable. A total of 49 piezometers were installed at the 15 new sites, and 22 of these were driven 3 to 11 ft to their placement depth. Thirteen of the fifteen riverside piezometers were driven, and these were the ones that seemed to produce the suspect readings. It is possible that the driven piezometers may have become partially plugged during installation, but it is also possible that some other factor is responsible for the difficulty. In any event, none of the 1979 piezometer data from the new piezometer range sites was used for analysis of permeability ratios.

280. The seven old sites with complete piezometer data were Bay Island, Ranges C and D; Hunt, Range B; and Sny Island, Ranges A, F, B, and H. Table 61 presents the data necessary for making calculations for landside permeability ratios. Locations for the riverside and landside piezometers were obtained from field survey notes; the location and

average ground elevation of the landside toe were obtained by inspection of the cross section of the piezometer range; the transformed landside top stratum thickness at the old toe was determined by interpolation between the borings made for the piezometers; the pervious substratum thickness was obtained from the generalized geologic profile; the projected piezometric pressures for the riverside and first landside piezometers for a river stage at the old crest elevation were obtained from the linear projection of the individual plots of piezometer head versus river stage shown in the previous sections; and the effective seepage exit distance was the distance from the old toe to the point where the linear projection of the hydraulic gradient line under the levee intersects the average ground elevation. Landside permeability ratios calculated from the formula

$$\frac{k_f}{k_{b\ell}} = \frac{(x_3)^2}{(z_{b\ell})(d)}$$

ranged from 1.1 to 90.

281. Table 62 presents the data necessary for making calculations for riverside permeability ratios. Riverside and landside toe locations were determined by examination of the piezometer range cross sections; the distance from the riverside toe to the river was determined by examination of the cross sections, plan maps, and aerial photographs; the effective seepage source distance was the distance from the old toe to the point where the linear projection of the hydraulic gradient line intersects the elevation of the old levee crest; the effective blanket length was simply the effective seepage source distance minus the base width of the levee; the effective thickness of the riverside top stratum was determined by examination of riverside boring data when available and inspection of the cross section; the constant c was determined by trial and error from the equation for effective blanket length $x_1 = \frac{\tanh (cL_1)}{c}$; and the pervious substratum thickness was obtained from the generalized geologic profile. Riverside permeability ratios calculated from the formula

$$\frac{k_f}{k_{br}} = \frac{1}{(c)^2(z_{br})(d)}$$

ranged from 3.0 to 209.

282. In Figure 98, both the landside and riverside permeability ratios are plotted versus effective top stratum thickness. In the 1956 Lower Mississippi Valley Division (LMVD) study it had been found that the permeability ratio generally increased with the increasing top stratum thickness. However, for the limited number of RID data points plotted in Figure 98, no such trend can be identified. For design purposes, if factor of safety against uplift criteria are to be used, it may be that an upper bound landside permeability ratio of 100 would be sufficient for top stratum thicknesses up to 15 ft or so, and such is suggested.

283. As was the case for the landside permeability ratio, the plot of the riverside permeability ratio also does not suggest a consistent variation with thickness of top stratum. However, rather than arbitrarily suggesting an upper bound riverside permeability ratio that would be unconservative, the ratios of the permeability ratios have been calculated as shown in Table 63 and are plotted on the right-hand side of Figure 98. The ratios of the permeability ratios range from 0.2 to 3.3, and from an inspection of the plotted points, a fair mean value may be about 2. Thus, it is suggested that a riverside permeability ratio of 200 be used for design purposes for top stratum up to 15 ft thick if factor of safety against uplift criteria are to be used.

284. In Table 64, WES suggested landside and riverside permeability ratios are compared with LMVD 1956 criteria and RID 1960 design values for all 14 old piezometer ranges. The WES suggested landside permeability ratio is 2.5 to 8 times smaller than LMVD criteria and 0.6 to 4 times smaller than RID design values. At the same time, the WES landside ratio is on the average about 2 to 3 times larger than the actual calculated landside permeability ratio; therefore, LMVD criteria and RID 1960 design values may have been on the high side and perhaps over conservative. However, the degree of over conservatism is

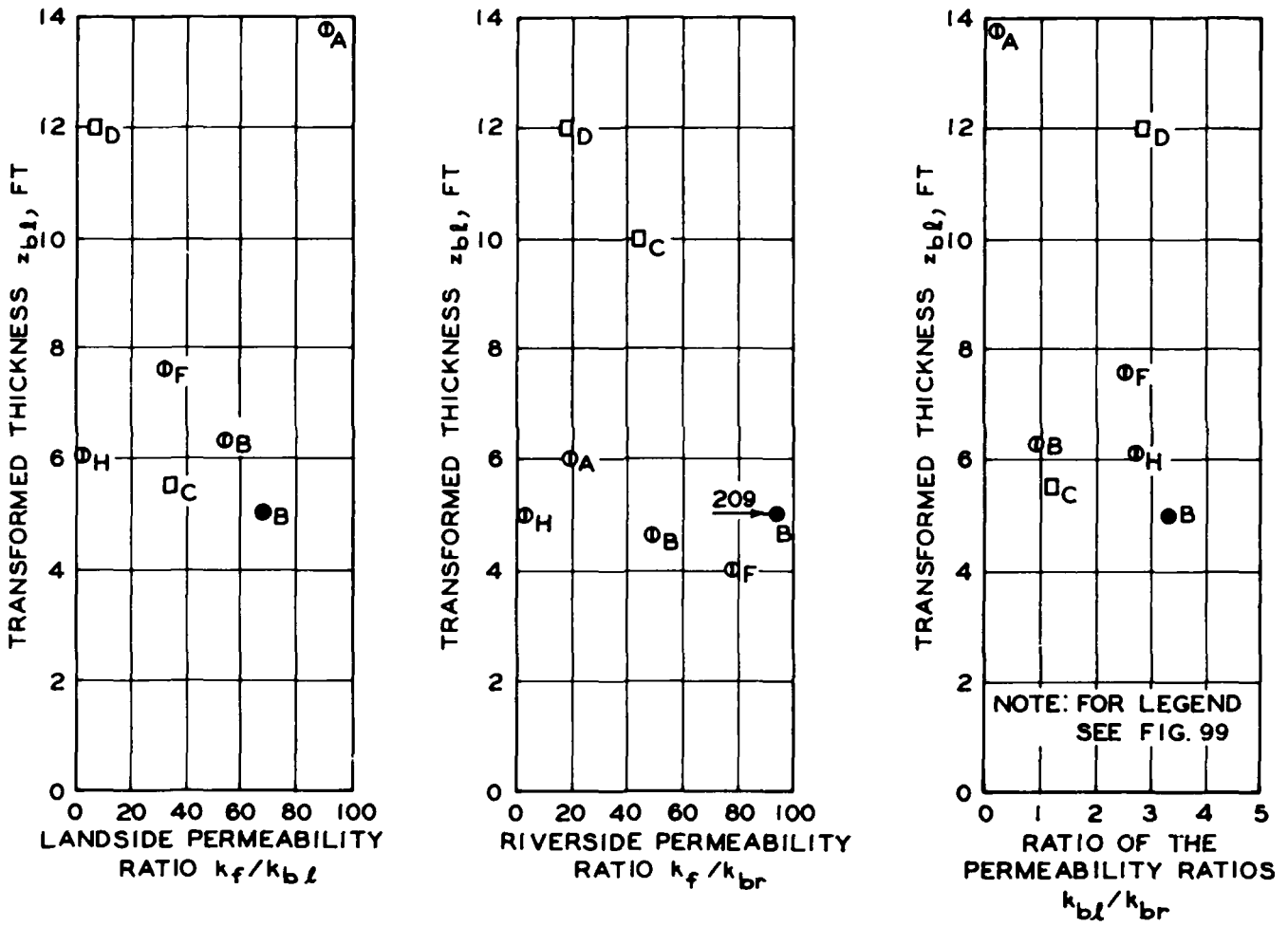

Figure 98. Permeability ratios versus transformed thickness of top stratum

determined not only by the landside permeability ratio but also by the riverside permeability ratio since both affect the piezometric pressure at the landside toe. Thus, the riverside permeability ratio must be examined also.

285. As may be noted in Table 64, WES suggested riverside permeability ratios are 7.8 to 31 times smaller than LMVD criteria, and 1.0 to 8 times smaller than RID 1960 design values. Thus, WES suggested riverside permeability ratios are smaller and quite a bit more conservative than either LMVD or RID values because a smaller riverside permeability ratio will result in a shorter calculated entrance distance and thus a larger calculated piezometric pressure at the landside levee toe. However, the net effect of both the landside and riverside permeability ratios being smaller can only be assessed by calculations of piezometric pressures at the levee toe and calculations of berm width. These calculations are presented in the following paragraphs.

Calculated Toe Pressures and Berm Widths

286. For the old and new piezometers, respectively, Tables 65 and 66 present the basic data required for calculation of toe pressures and berm widths. Table 67 lists the effective seepage distances for the new levee sections at the old piezometer range sites using LMVD, RID, and WES permeability ratios. The seepage exit distance x_3 was obtained from the formula

$$x_3 = \sqrt{\left(\frac{k_f}{k_{b\ell}}\right)(z_{b\ell})(d)}$$

and the seepage entrance distance s was obtained from the formula

$$s = x_1 + L_2$$

where

$$x_1 = \frac{\tanh\,(cL_1)}{c}$$

and

$$c = \frac{1}{\sqrt{\left(\frac{k_f}{k_{br}}\right)(z_{br})(d)}}$$

287. Table 68 summarizes the predicted piezometric heads at the landside toe and calculated berm widths for the new levee sections at the old piezometer range sites for permeability ratios advanced by LMVD, RID, and WES. The predicted piezometric head h_o was determined from the formula

$$h_o = \frac{H\ (x_3)}{s + x_3}$$

and the berm width was calculated using the formula for a semipervious berm shown in Figure 3.

288. Table 69 presents the effective seepage entrance distances for the new piezometer range sites using LMVD and WES permeability ratios and the predicted piezometric heads at the landside toe. Table 70 lists the calculated berm widths using the formula for a semipervious berm for the new piezometer range sites.

Comparison of predicted
piezometric pressure heads

289. Table 71 compares the predicted piezometric heads at the landside toes for water at the levee crest at the old piezometer range sites. It may be noted that even though the WES landside permeability ratio was almost always significantly smaller than that for either LMVD criteria or RID data, WES predicted piezometer heads ranged from 29 percent smaller to 10 percent greater and averaged only 19 percent smaller than that for LMVD criteria and averaged about the same for RID data.

290. Table 72 compares the predicted piezometric heads at the landside toe for the new piezometer range sites. It may be noted that WES predicted heads ranged from 36 to 10 percent smaller and averaged

26 percent smaller than that for LMVD criteria. Thus, even though WES landside permeability ratios were as little as one-eighth the LMVD ratio and one-fourth the RID ratio, the predicted pressures were never less than 0.64 times LMVD or RID values. This is partly because the pressures are not only a function of the square root of the permeability ratios, but also because the pressures are related to the geometry of the cross sections and the riverside permeability ratios.

291. In an attempt to determine the relative effect of the riverside and landside permeability ratios, Figure 99 has been prepared showing the ratio of WES/LMVD predicted piezometric pressures versus the ratios of WES/LMVD landside and riverside permeability ratios for all 29 piezometer range sites studies. In the left-hand plot of the figure, a general increase in the pressure ratio with increasing ratios of landside permeability ratios may be seen as should be expected, but the relationship certainly is not unique or clear cut. On the right-hand side of the figure where one might expect to see a decrease in the ratio of predicted piezometric pressure with increasing ratios of riverside permeability ratios, no such pattern is evident. Thus, it may be noted that for the 29 sites studied, geometric details of the levee cross section and riverside blanket have a significant influence on the effect of changes in the permeability ratios.

292. This may be illustrated by examination of the data points from Hunt, Range B, and Sny Island, Range G. These were the only two sites where the predicted pressures increased even though the landside permeability ratios decreased by a factor of 4. For these two sites, the riverside permeability ratios decreased by a factor of 12.5. This decrease in itself was not noteworthy, but what was significant was that these two sites were the sites with the longest riverside blankets (over 1000 ft) and the change in riverside permeability ratio became more important than the change in landside permeability ratio. Thus, the net effect of changes to both the landside and riverside permeability ratios cannot be prejudged but can be determined only by making the calculations that take into account the geometry of the site as well as the permeability ratios.

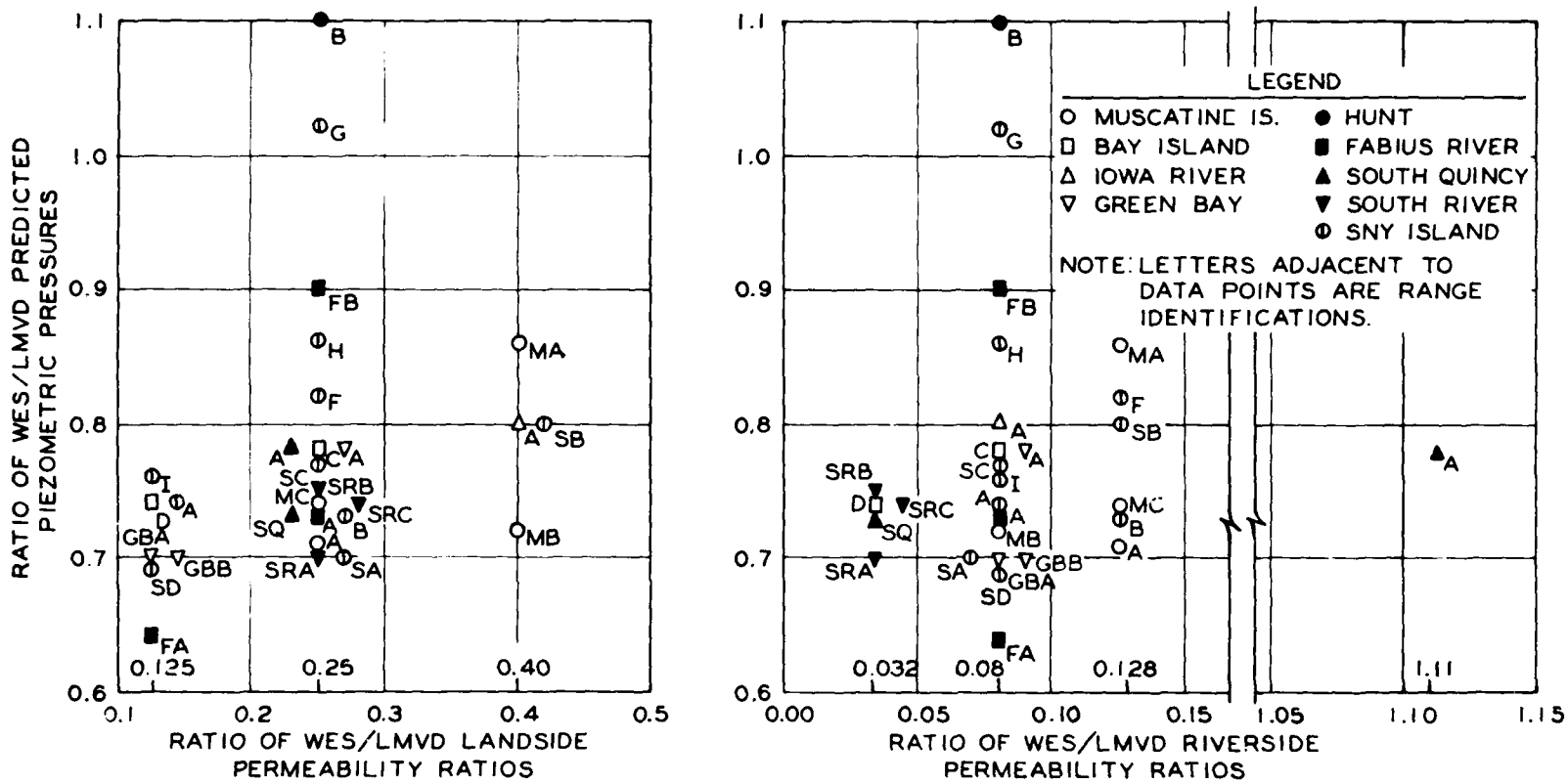

Figure 99. Relationship between predicted piezometric pressures and landside and riverside permeability ratios for 29 piezometer range sites

Comparison of calculated berm widths

293. Table 73 summarizes and compares calculated berm widths for the old and new piezometer range sites. The berm widths calculated for the old piezometer range sites using LMVD 1956 criteria ranged up to 521 ft, whereas those using RID 1960 design and WES 1979 suggested criteria ranged up to 105 and 179 ft, respectively. Of perhaps more significance, however, was the total berm width required. For the 14 old piezometer range sites, the total berm width required using LMVD 1956 criteria was 2280 ft, whereas for RID and WES criteria, 466 and 521 ft were required, a net reduction of 80 and 77 percent, respectively.

294. For the 15 new piezometer range sites, RID design criteria were not available, but the total berm width required using LMVD and WES criteria was 2420 and 768 ft, respectively. The reduction of berm width required using WES suggested criteria was 68 percent.

295. Another factor perhaps of some significance is the number of sites not requiring any berm at all. Using LMVD criteria, 11 of 29 (or 38 percent) of the old and new sites required no berm. Using RID 1960 design criteria, 8 of 14 (or 57 percent) of the old sites required no berm, and using WES criteria, 18 of 29 (or 62 percent) of the old and new sites required no berm. A comparison of the calculated berm widths with observed performance is made in the following paragraphs.

Seepage Performance Observations

296. Seepage performance observations made available for this evaluation were recorded in somewhat different ways for different flood years. For the 1960 data, seepage observations were recorded on cross-section sheets for the old piezometer ranges together with tabulated river stages and piezometer readings. In 1979, seepage observations were made at the time piezometer readings were taken at the new piezometer ranges, and the observations were furnished in a summary format for each piezometer range. In 1965, 1969, and 1973 when most of the piezometers at the old piezometer ranges had been lost primarily because

of levee enlargement construction activity, seepage observations were recorded on plan maps scaled 1 in. = 400 ft , and the observed distress generally covered reaches rather than specific locations. Therefore, it is to be expected that the observations from 1960 and 1979 would be more site specific than those from 1965, 1969, and 1973.

Categories of performance

297. Words used to describe the observed seepage performance varied some from year to year, no doubt because different individuals made the observations at different locations at different times. For the purpose of this evaluation, the observations have been interpreted to fit into the 13 categories listed in paragraph 31 and shown on the performance tables for each of the piezometer sites.

298. The different categories were arranged in what was thought to be in increasing order or severity. In the case of light and heavy toe seepage, it was thought that this condition was largely the result of through seepage; it is also possible that it was a combination of through seepage and underseepage, but the amount contributed by one source or the other could not be ascertained.

Performance locations

299. Frequently, the location of the reported seepage could not be determined with any degree of precision. Of course, when seepage was reported at the toe, that location and distance from the center line of the levee was easily established. For other situations, such as fields wet and soft, seepage beyond the toe, or a statement to the effect that pin boils were in the area, judgment had to be exercised to establish a location so that factors such as top stratum thickness and factor of safety against uplift could be determined. If a ditch or low area was shown on the cross section, the boils would be assumed to be at that location, but sometimes more than one ditch or more than one low area would be shown in the cross section; for these cases, the locations of the notations on the plan maps required some judgment to establish the distance from the center line for evaluation purposes.

300. Locations listed for documentation of seepage observations are shown on the tables of performance observations and calculated

factors of safety for each individual piezometer range. The locations of the landside piezometers and the toe of the levee or berm were always listed. In addition, if seepage was observed in a low spot, road, or ditch, that location was also listed. The number of observation points changed from year to year because of levee or berm construction or because of levee overtopping.

301. Table 74 presents the number of seepage observation locations at each piezometer range for the different years of observation. The number of locations ranged from two to seven for the individual piezometer ranges but averaged about four. The total number of observation locations for the 14 old piezometer lines ranged from 46 to 64 for the years 1960 to 1973, and for the 15 new piezometer lines, from 58 to 66 for the years 1965 to 1979.

Number of seepage observations

302. Seepage observations were made at the old piezometer range lines during the flood years 1960, 1965, 1969, and 1973. As may be noted in Table 75, the maximum river stage generally occurred in 1973, followed in order by 1965, 1969, and 1960. However, the largest number of seepage observations, expressed either as a total or as a percent of total number of observation locations, occurred in 1960 when the maximum river stage was generally the lowest. The next largest number of seepage observations occurred in 1973 when the river stage at 10 of the 14 locations being studied was the highest. In 1965 and 1969, the number of observations was about the same when the maximum river stage was at an intermediate level.

303. At the new piezometer range sites, seepage observations were made during the flood years 1965, 1969, 1973, and 1979. As shown in Table 76, the maximum river stage generally occurred in 1973, followed in order by 1965, 1969, and 1979. Again, as was noted for the old piezometer range sites, the maximum number of seepage observations for the sites occurred in 1979 when the maximum river stage was generally the lowest, next in 1973 when the river stage was generally the highest, and then in 1969 and 1965 when the maximum river stage was at an intermediate level.

304. The reason that the largest numbers of seepage observations were made at the old and new piezometer sites in 1960 and 1979, respectively, when the maximum river stages were generally lowest is probably related to the fact that these reported observations were made specifically for the piezometer ranges, whereas in other years the observations were more general and covered general conditions landward of the levee. An inspector would probably make a more detailed examination at a piezometer range line if he was reporting conditions at that line rather than general conditions for several miles of levee.

Severity of seepage observations

305. One other aspect of the seepage observation is that generally more severe seepage conditions were reported in 1960 and 1979 than in 1965, 1969, and 1973 even though the river stage was lowest in 1960 and 1979. This is illustrated in Figure 100 for the old piezometer range sites where observed performance is plotted against river head. Shown in Figure 100 are all the instances when with a higher river stage less severe performance was reported than in previous years with a lower river stage. A total of 25 such instances is shown in Figure 100. This situation did not consistently happen at all locations, as shown in Figure 101, where 9 instances are plotted in which more severe performance was reported for a higher river stage; but the large majority of cases went the other way, and what appears to be the case is that a much more detailed inspection was conducted in 1960 than in 1965 and 1973. There is some evidence that the inspection in 1969 was more detailed than that in 1965 and 1973, but the difference is not of significant consequence.

306. Figure 102 shows a similar plot of data for the new piezometer range sites with 21 instances in which a lower river head resulted in more severe performance. This is contrary to what would be expected since a lower river head should produce less severe performance, but in 1979 at these ranges, this was not the case. The significance of these observations is simply that the generalized seepage inspections made in 1965, 1969, and 1973 were not as detailed or specific as those made at the piezometer range lines in 1960 and 1979; and it is probable that

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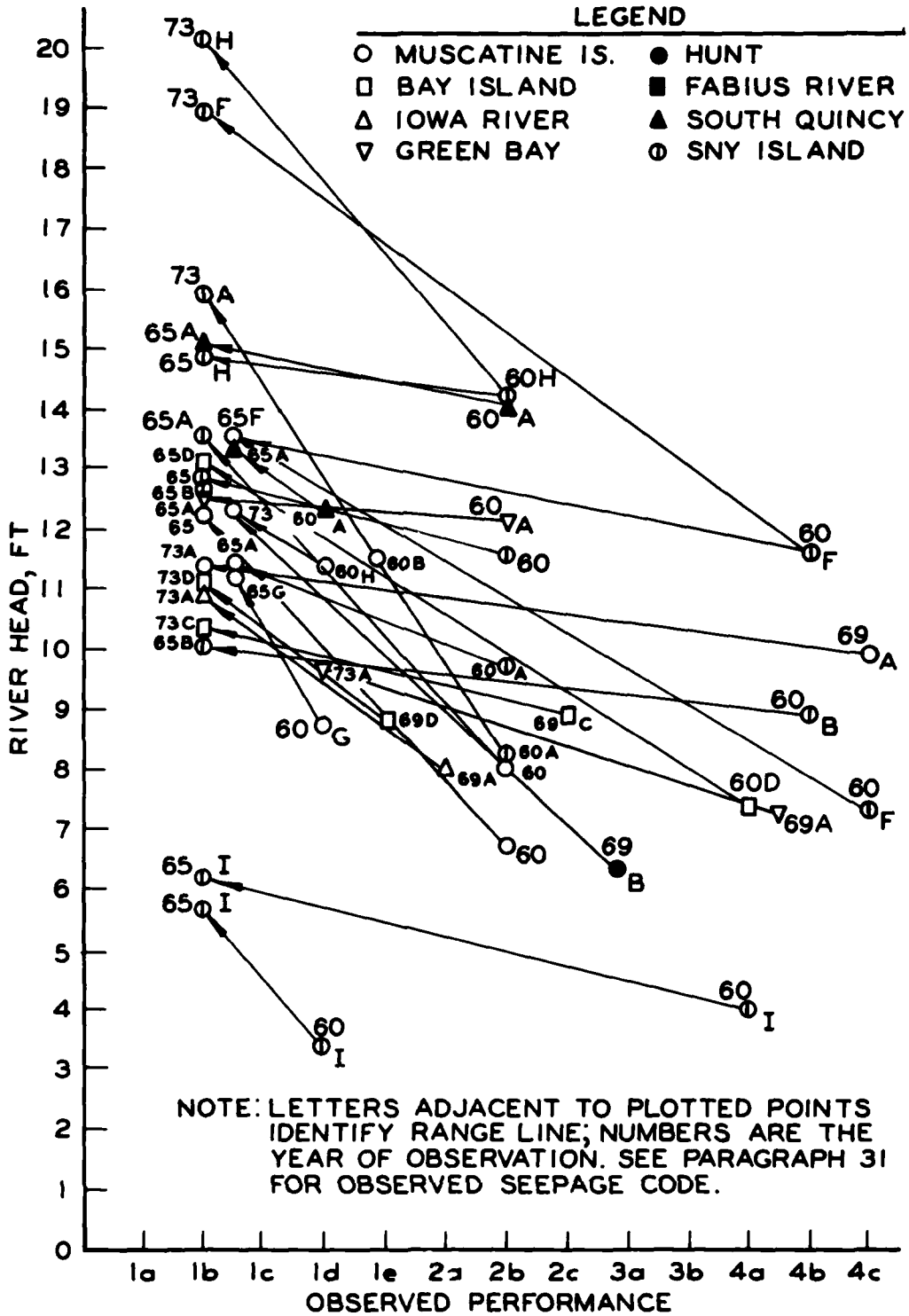


Figure 100. Observed performance versus river head at old piezometer range sites showing higher river heads resulting in less severe performance

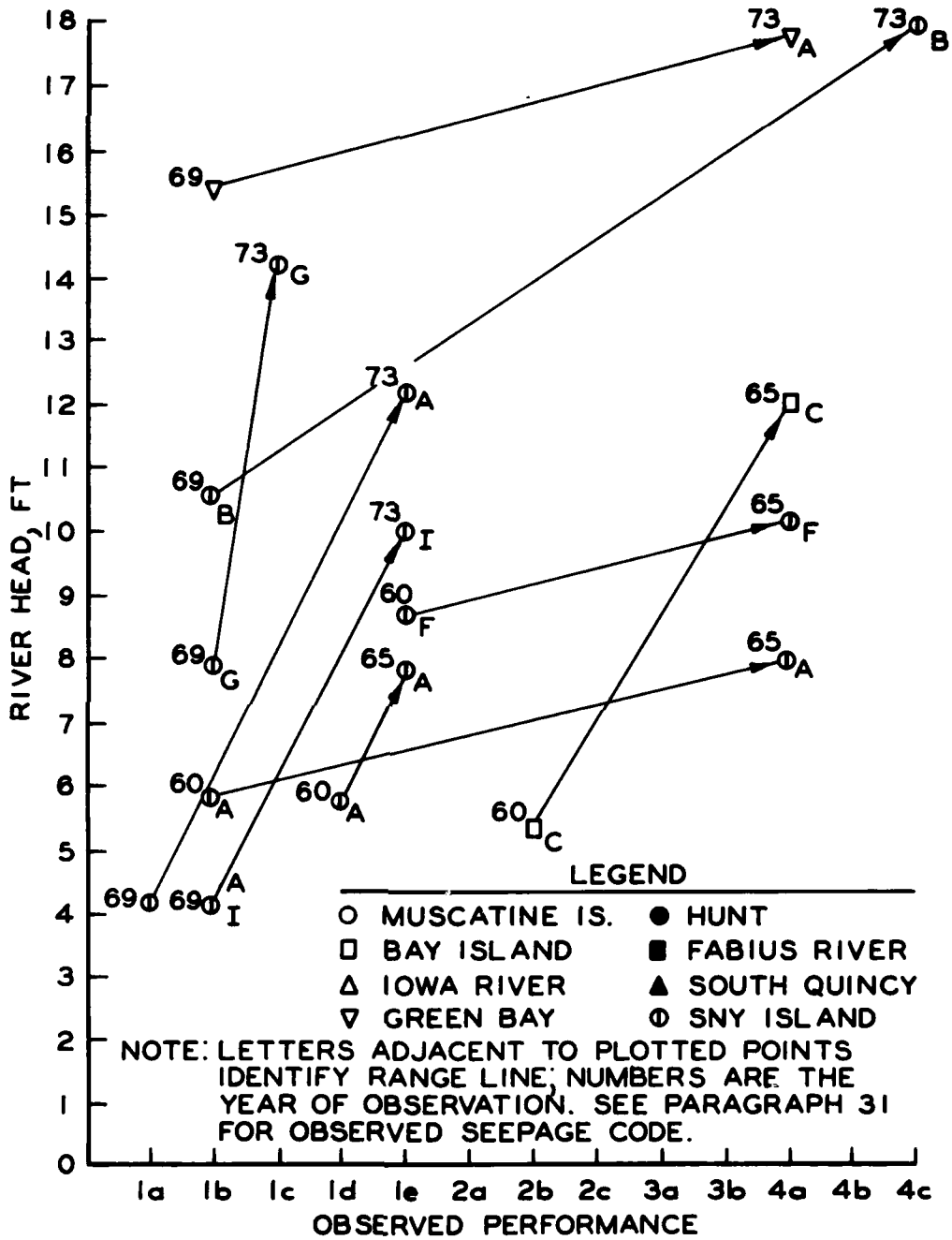


Figure 101. Observed performance versus river head at old piezometer range sites showing higher river head resulting in more severe performance

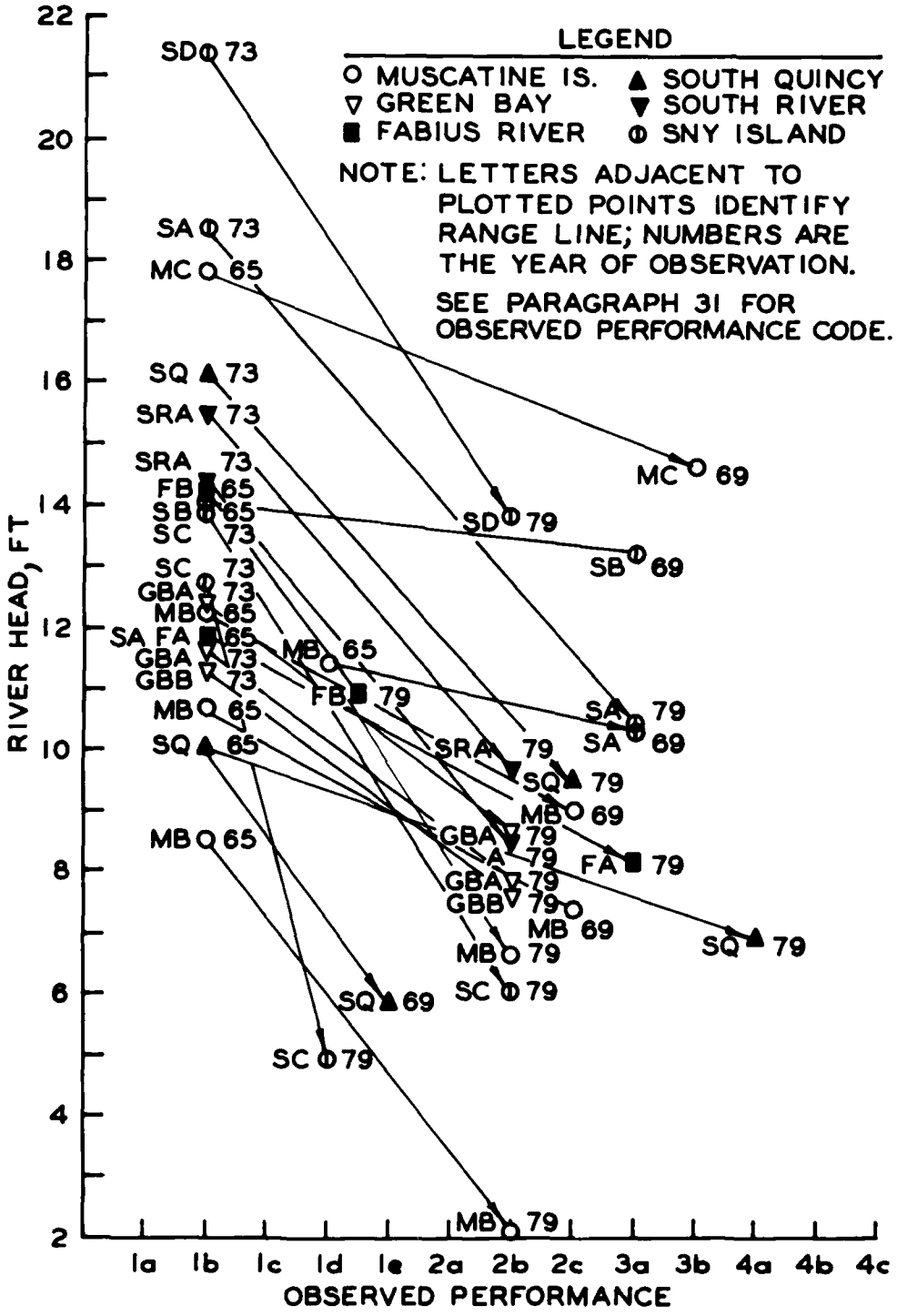


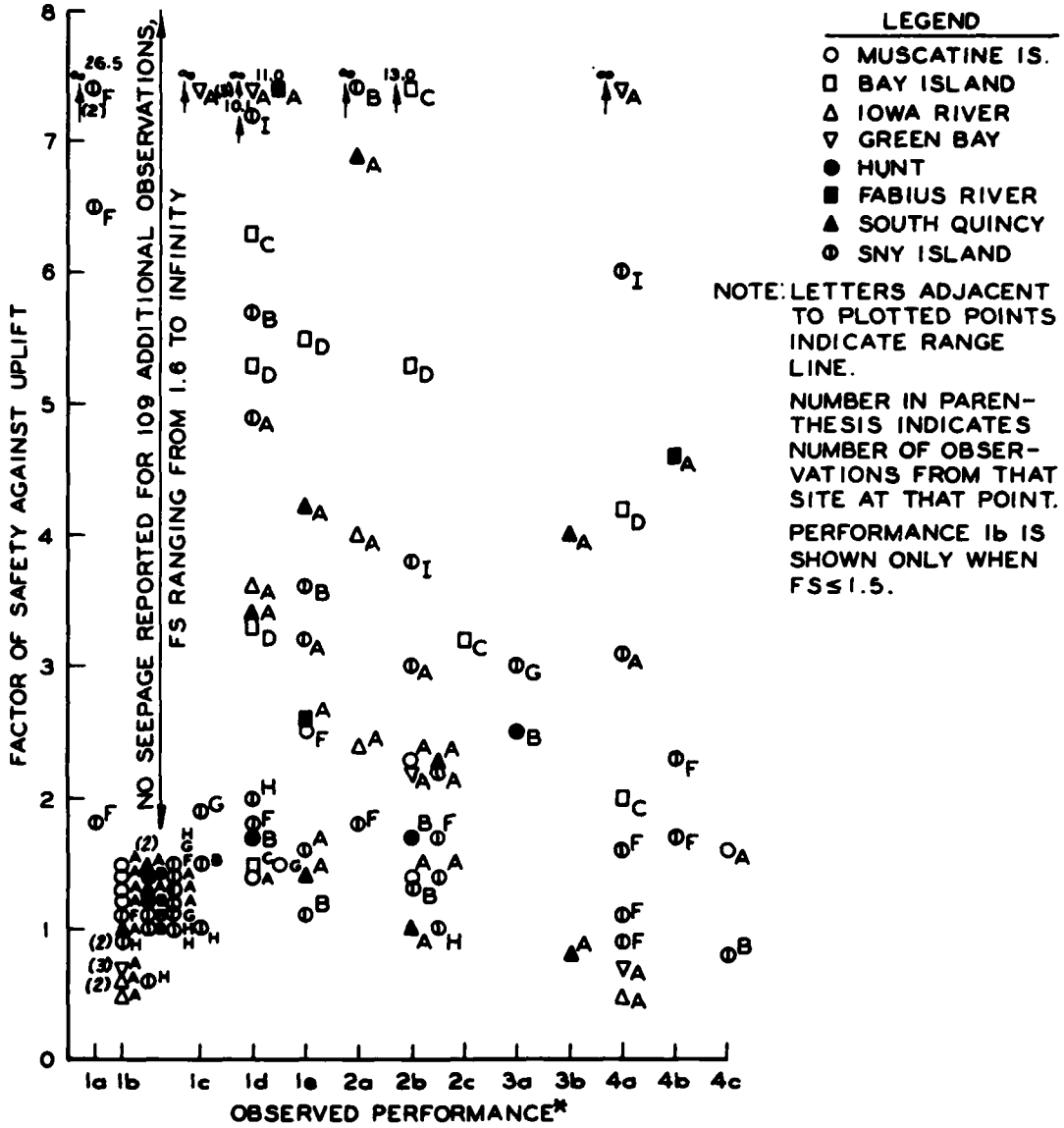
Figure 102. Observed performance versus river head at new piezometer range sites showing lower river head resulting in more severe performance

if more detailed inspections had been made at the seepage observation locations identified for this study, more seepage would have been reported.

Comparison with factor of safety

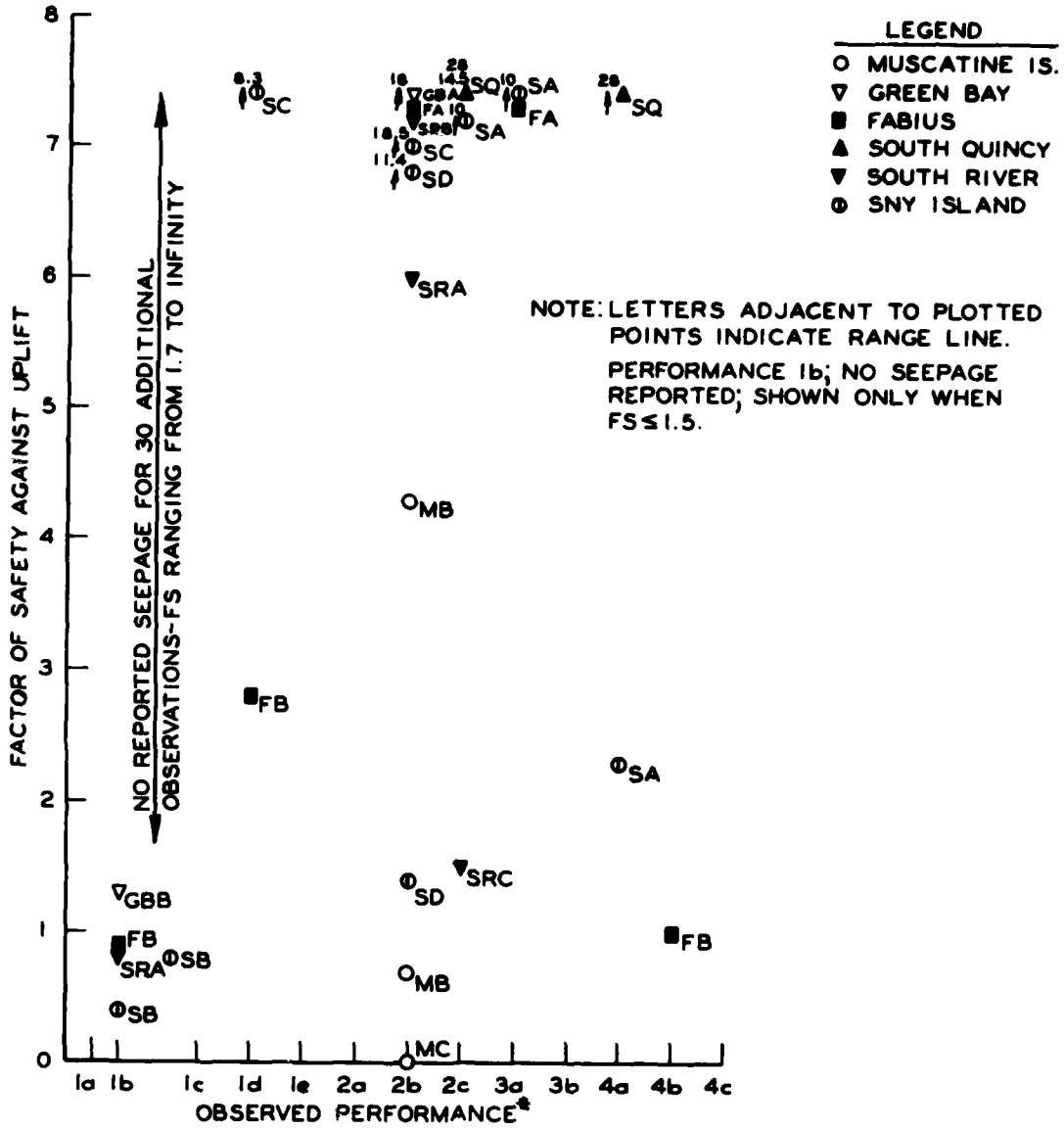
307. Although the degree of detail in reported seepage observations may not have been consistent, it still will be instructive to compare observed performance with calculated factors of safety against uplift. Figure 103 shows this comparison for the old piezometer range sites. This figure also generally shows a shotgun pattern with the factor of safety ranging from 0.5 to something greater than 6.0 for just about any type of observed performance. However, there are at least two very significant observations that may be drawn from this plot. The first is that a high calculated factor of safety against uplift is no guarantee that there will be no boils; the second, and perhaps more significant, is that a low calculated factor of safety against uplift apparently is not a reliable indication of potential danger. This latter point is demonstrated by the large number of instances in which the calculated factor of safety ranged from 0.5 to 1.5 and no seepage was reported. This suggests that even though seepage probably was occurring, it was occurring in such a harmless way that the inspector either did not see it or thought it to be insignificant.

308. The factor of safety against uplift at the new piezometer range sites could be calculated only for the 1979 data (Figure 104). Although there are a relatively small number of data points, the pattern is similar to that obtained for the old piezometer range sites. One other observation that may or may not be significant though is the relatively large number of high factors of safety in areas with standing water to light seepage beyond the toe. This could be indicative of significant pressure relief by natural seepage through the top stratum or perhaps the ponding and runoff or rainwater. Heavy rain was reported at Green Bay on 11 April 1979, but at other locations on 10, 11, and 12 April, berms and fields were reported dry.



* 1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage
2a - Berm wet
2b - Water standing in low areas
2c - Fields wet and soft behind levee
3a - Light seepage beyond toe
3b - Heavy seepage beyond toe
4a - Pin boils
4b - Sand boils
4c - Large boils

Figure 103. Observed performance versus factor of safety against uplift at old piezometer range sites, 1960, 1965, 1969, and 1973 data



* 1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage
2a - Berm wet
2b - Water standing in low areas
2c - Fields wet and soft behind levee
3a - Light seepage beyond toe
3b - Heavy seepage beyond toe
4a - Pin boils
4b - Sand boils
4c - Large boils

Figure 104. Observed performance versus factor of safety against uplift at new piezometer range sites, 1979 data

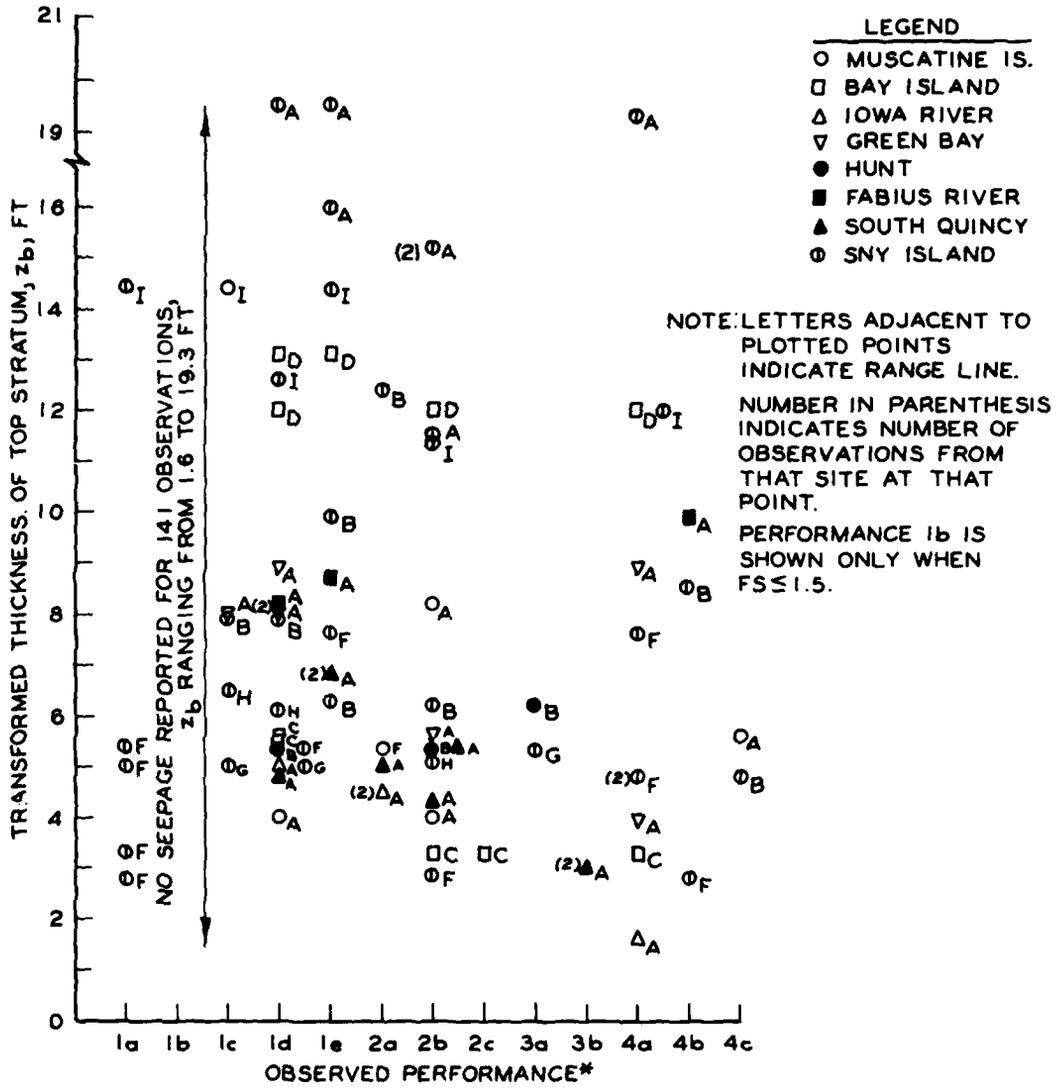
Comparison with
thickness of top stratum

309. To examine the relationship between thickness of top stratum and observed performance, plots of transformed thickness of top stratum versus observed performance have been prepared and are shown in Figures 105 and 106 for the old and new piezometer range sites, respectively. Again, a more or less shotgun pattern is shown in each of these figures with more or less any type of performance being noted for any top stratum ranging from 0 to 19+ ft. In Figure 105 for the old piezometer range sites, there may be a trend for increasing severity of performance with decreasing top stratum thickness, but this trend is not observed in Figure 106 for the new piezometer range sites. The conclusion to be drawn from these two figures appears to be that top stratum thickness alone does not control the occurrence and severity of seepage.

Comparison of observed performance and calculated berm width

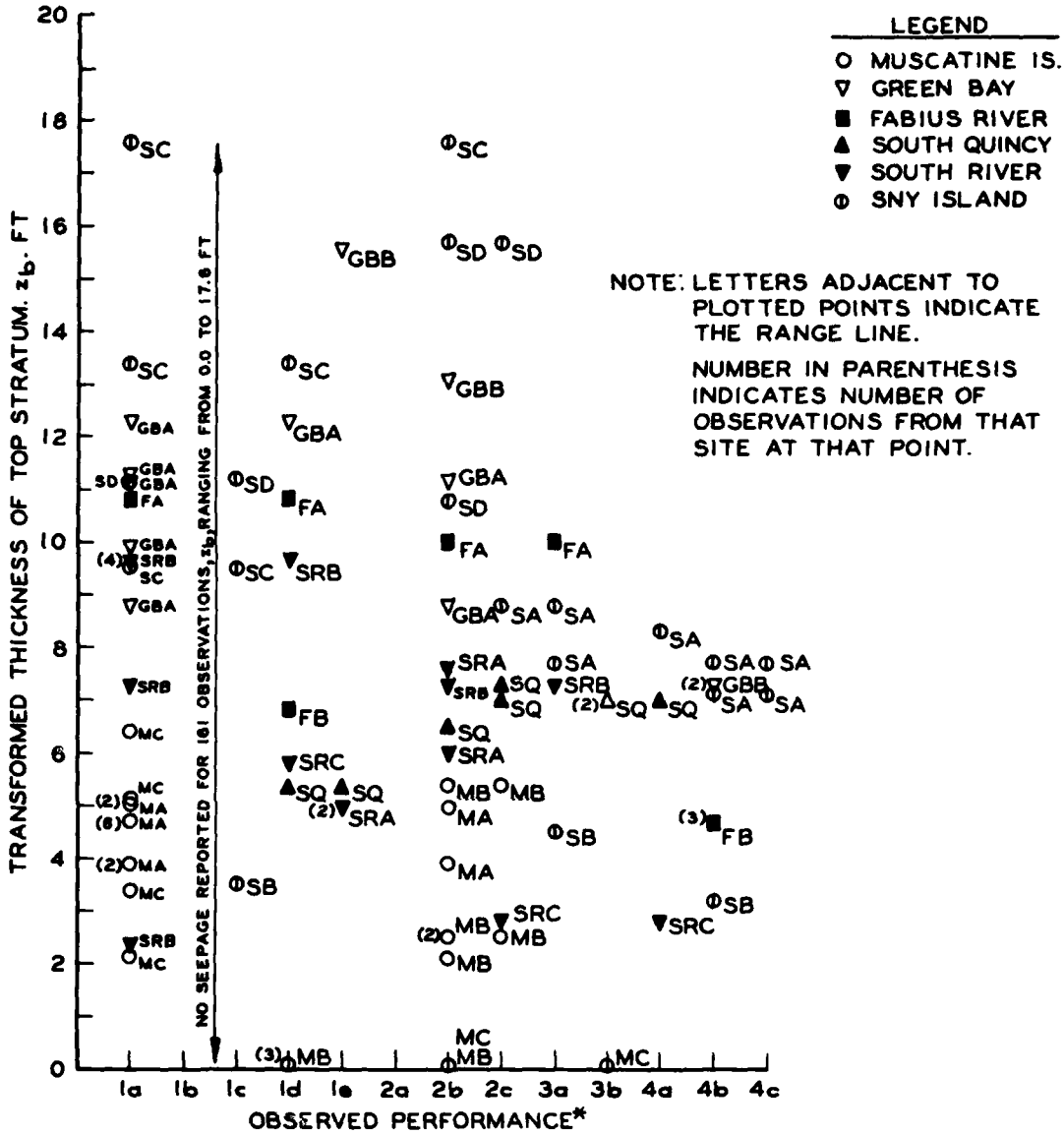
310. Table 77 presents a summary of berm widths calculated using WES suggested permeability ratios and the worst observed performance at the toe of the levee or berm and at locations landward of the toe. Also shown in this table are the maximum head and the observed head at the location of the worst performance when it was observed. Further inspection of the table reveals that the worst observed performance occurred at heads ranging from as little as one-third to 100 percent of the maximum design head. It also may be noted that the worst observed performance occurred at the toe of the levee or berm at only 4 of the 29 sites and that not uncommonly the worst performance was observed at distances ranging from 100 to over 500 ft landward of the levee toe.

311. The two plots in Figure 107 show the relationship between calculated berm width and worst observed performance. The first is berm width calculated using WES criteria versus worst observed performance anywhere landward of the levee toe, and the second is berm width versus worst observed performance within the first 100 ft landward of the levee toe. There is nothing magic about the first 100 ft landward of the



* 1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage
2a - Berm wet
2b - Water standing in low areas
2c - Fields wet and soft behind levee
3a - Light seepage beyond toe
3b - Heavy seepage beyond toe
4a - Pin boils
4b - Sand boils
4c - Large boils

Figure 105. Observed performance versus transformed thickness of top stratum at old piezometer range sites, 1960, 1965, 1969, and 1973 data



* 1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage
2a - Berm wet
2b - Water standing in low areas
2c - Fields wet and soft behind levee
3a - Light seepage beyond toe
3b - Heavy seepage beyond toe
4a - Pin boils
4b - Sand boils
4c - Large boils

Figure 106. Observed performance versus transformed thickness of top stratum at new piezometer range sites, 1965, 1969, 1973, and 1979 data

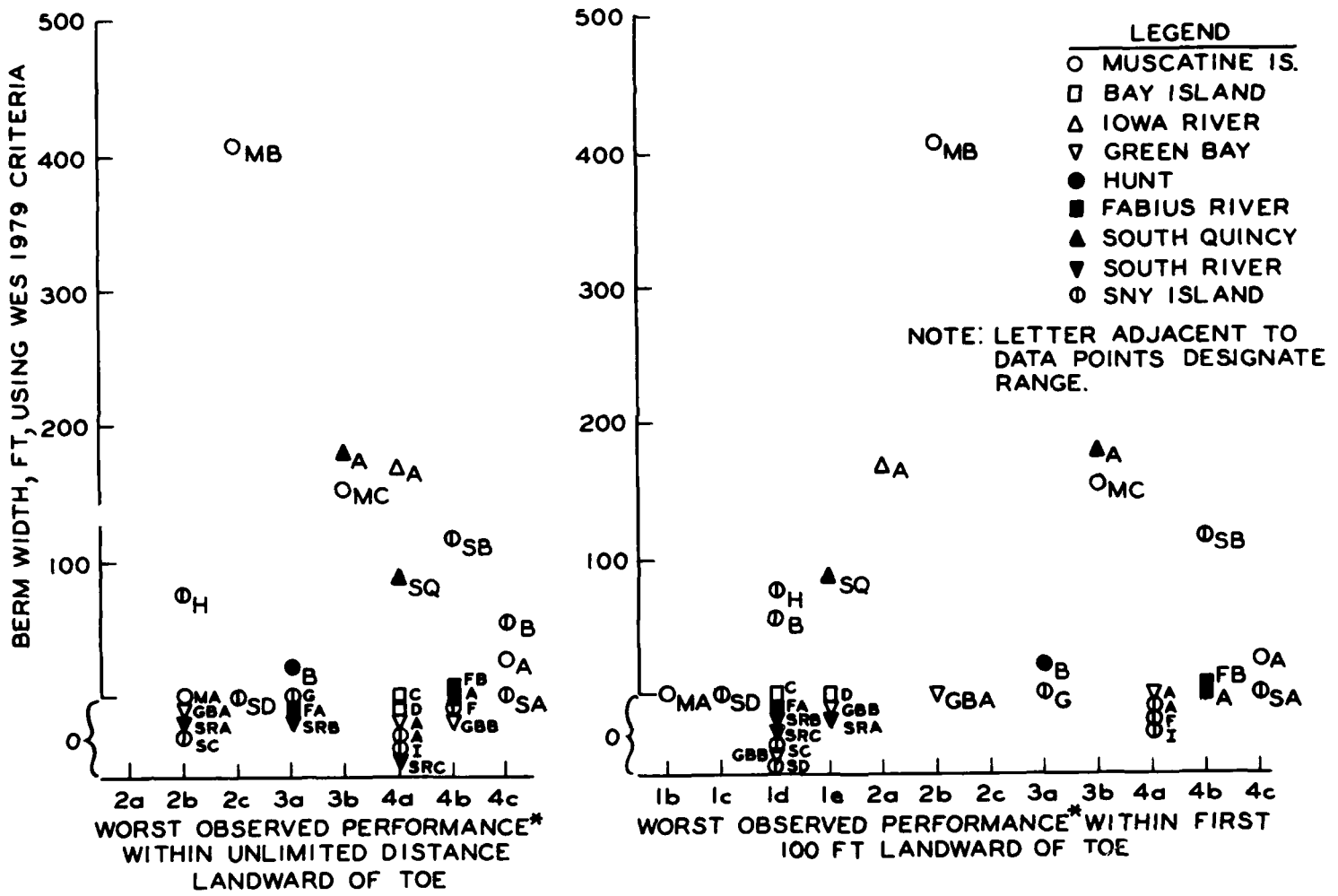


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Figure 107. Calculated berm width compared with worst observed performance

levee toe, but it is believed that the first 100 ft is the area that should be examined most carefully if there is a potential seepage problem.

312. Both plots in Figure 107 indicate that no one-to-one correlation exists between calculated berm width and seepage performance. The maximum berm widths (up to 407 ft) are calculated for conditions where the fields were wet and soft or where seepage occurred relatively harmlessly. At areas where large sand boils were observed (the most serious seepage condition), the berm formula indicated that either a maximum berm of 54 ft or no berm at all would be required. This observation strongly supports a long held concern that berm formulas that calculate the length of berm required to maintain a factor of safety against uplift are not appropriate for locations where seepage pressures can be uniformly and harmlessly dissipated.

313. Before leaving the question of the appropriateness of berm formulas for providing protection against underseepage, it should be noted that berm widths calculated with LMVD 1956 criteria ranged from 193 to 332 ft at Muscatine Island, Range A, and Sny Island, Ranges B and SA, where the large sand boils were observed. These berm lengths would cover the areas with large sand boils. However, it also must be recognized that berms up to 781 ft wide were indicated using the same LMVD criteria at Muscatine Island Range MB where the worst seepage condition observed was wet and soft fields, and berm lengths over 100 ft long were calculated at eight other sites where the performance within the first 100 ft from the levee toe was no worse than water standing in the fields. Also, at Sny Island, Range SA, where sand boils were observed in 1973 and a 100-ft berm was added in 1974, pin boils were observed at the berm toe in 1979 with a significantly lower head of water. This latter observation is evidence that the addition of a berm will not prevent the occurrence of boils; it may only move the boils further away from the center line of the levee.

314. To further evaluate the merits of LMVD 1956 and WES 1979 criteria for berm width calculations, Table 78 has been prepared showing only when berm formulas indicate that a berm is or is not required.

The piezometer range sites are grouped into two categories. The first group includes 16 sites where the worst observed performance within the first 100 ft landward of the levee ranged from no reported seepage to fields wet or soft; the second group includes the remaining 13 sites where the worst observed performance ranged from light seepage beyond the toe to large sand boils. Also shown in Table 78 is the head that occurred when the worst seepage was observed. An inspection of these data indicates that at the ranges where the performance has been relatively good, the head has ranged from 4.8 to 17.9 ft, and at the sites where the performance has been relatively poor, the head has ranged from 4.0 to 17.0 ft. Thus, the magnitude of the head itself is not a factor in the grouping of the sites by performance.

315. Other data in Table 78 indicate that at the 16 sites where the performance has been relatively good, LMVD criteria require berms up to 781 ft wide at 11 of the sites, whereas WES criteria require berms up to 407 ft wide at 5 of the sites. At the 13 sites where the performance has been relatively poor, LMVD criteria require berms up to 521 ft wide at 7 of the sites, whereas WES criteria require berms up to 179 ft wide at 6 of the sites. Thus, while WES criteria was better than LMVD criteria in identifying sites that did not require berms, neither WES or LMVD criteria satisfactorily identified more than about one-half the sites that probably should have berms. Further, the calculated berm lengths do not appear reasonable; those much in excess of 100 ft are probably longer than necessary and those less than 100 ft probably should be longer so as to move the potentially harmful seepage further from the center line of the levee. Thus, some alternate procedure is necessary for identifying sites that require berms and then for establishing the berm length required. One possible alternate procedure is discussed in the following paragraphs.

Application of Creep Ratio Criteria

316. In 1910, Mr. W. G. Bligh advanced his theory that the safety of masonry dams on earth foundations depends on the length of the

percolation path which is along the line of contact of the structure and its foundation. In 1916, he published the following values of creep-head ratios that he believed would make dams safe from piping failure:*

	Safe Ratio
River beds of light silt or sand, of which 60 percent passes the 100-mesh seive, as those of the Nile or the Mississippi Rivers	18
Fine micaceous sand, of which 80 percent passes a 75-mesh sieve, as in Himalayan rivers and in such rivers as the Colorado	15
Coarse-grained sands, as in Central and South India	12
Boulders or shingle and gravel and sand mixed	5 to 9

Although it is recognized that an earth levee on a stratified earth foundation is different from a masonry dam on a noncohesive foundation bedding, it is believed that something similar to Bligh's creep ratio might be considered for establishing requirements for berms and berm widths.

317. Table 79 summarizes the design head, levee width, an foundation top stratum for each of the piezometer range sites, again grouped by performance in the first 100 ft landward of the levee toe. The top stratum generally consisted of lean clay, although in a few cases the top stratum was either poorly graded sand, organic lean clay, or silt. The levee itself was generally hydraulic sand fill, although in some locations old clay levees constitute a core or other part of the existing section.

318. To make a berm width calculation using creep ratio criteria, a creep ratio coefficient has to be selected for the levee and foundation. The Mississippi River sands in the RID generally have a D_{10} size, which ranges from 0.1 to 0.4 mm; thus, they appear to be coarser than the first two sands in Bligh's list but probably finer than the

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* W. G. Bligh. 1916. Dams and Weirs, American Technical Society, Chicago, Ill., p 155.

coarse-grained sands in Central and South India. Thus, a creep ratio of 15 has been chosen for example calculations for all the sites except where the top stratum was silt and a creep ratio of 18 was selected. A required creep length has been calculated simply as the product of the creep ratio and head and is listed in Table 79 along with the required berm width, which is simply the required creep length minus the levee width.

319. Using the above-described criteria, berm widths ranging from 17 to 114 ft are required for all the sites where the performance has been relatively good. At the sites where the performance has been relatively poor, berm widths ranging from 15 to 137 ft are required at all locations except Sny Island, Ranges F and SA, where no berm is indicated. Sny Island, Ranges F and SA, are locations where pin boils and large sand boils have been observed at the levee toes in the past.

320. Calculated berm widths based on creep ratio criteria have been plotted versus worst observed performance in the first 100 ft in Figure 108. While there is a trend of increasing berm width with more severe performance, it is disappointing that the criteria do not indicate that berms are required at all locations where the performance has been relatively poor. Less serious, but nevertheless of some concern, it would have been better if the criteria had indicated that no berm was required at least at some of the sites where the performance has been relatively good.

321. While creep ratio criteria generally indicate a requirement for shorter berms than those indicated by the factor of safety against uplift criteria, neither criteria satisfactorily discriminate between those sites that require berms and those that do not. Therefore, it appears that additional research is required to develop better procedures for calculating berm requirements. In the interim, the best procedure may be to rely on performance observations; and where boils and heavy seepage have been noted within the first 100 ft or so from the levee toe, berms about 100 ft or so wide should be provided.

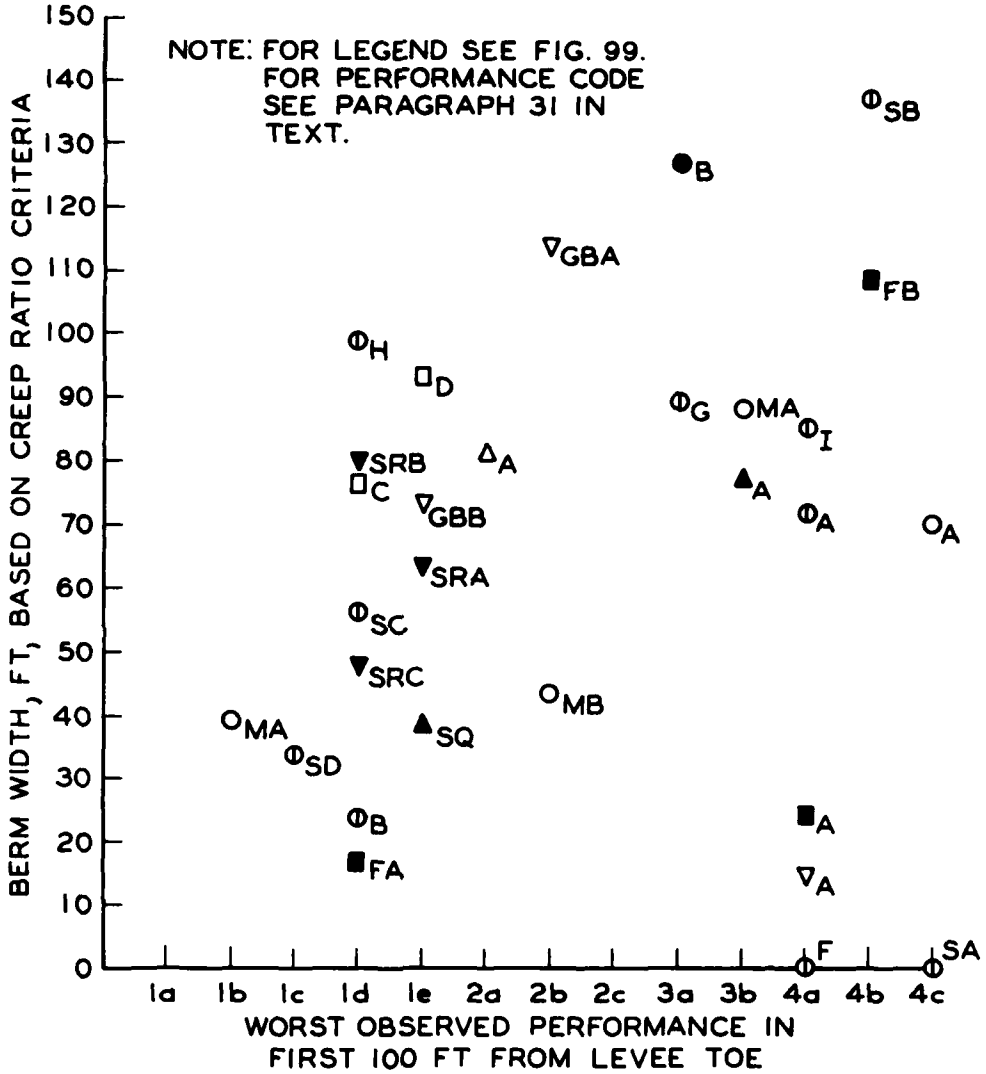

Figure 108. Berm width based on creep ratio criteria versus worst observed performance in first 100 ft from levee toe

PART VI: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

322. On the basis of the study of 29 piezometer range sites, the following conclusions were made:

a. Only seven of the sites had adequate data for reliable calculation of landside and riverside permeability ratios. At these sites, the landside permeability ratio ranged from 1.1 to 90, and the riverside permeability ratio ranged from 3.0 to 209. For design purposes, using factor of safety against uplift criteria, it was suggested that landside and riverside permeability ratios of 100 and 200 be used.

b. Some piezometers at the new piezometer range sites are not functioning properly.

c. Based on seepage performance data furnished, a berm width formula using factor of safety against uplift for design criteria does not adequately identify those locations requiring berms or those locations not requiring berms in the RID. This formula also indicates that very wide berms are required at many locations. These statements holds for both LMVD and WES suggested permeability ratios.

d. Berm width calculations using creep ratio criteria provide more reasonable berm widths but do not adequately discriminate between those sites requiring berms and those not requiring berms.

e. Additional research is needed to develop rational procedures for the design of berms for levees.

f. The 1951 piezometer data from the 1950 piezometers installed at Sny Island, Ranges A and B, indicate that there was no significant or systematic time lag in these piezometer readings. In isolated cases where it appears that there may have been some time lag, the situation can be explained by differences in time for recording river stage and piezometer level, the sudden initiation or decrease in underseepage nearby, or simply errors in piezometer readings.

Recommendations

323. Based on the findings of this study, it is recommended that:

a. All piezometers at the new piezometer range sites be tested to determine if they are free draining. If not, they should be surged or pumped to eliminate their sluggish response or replaced.

b. Additional field studies be undertaken to determine the detailed subsurface characteristics of locations where seepage performance has been relatively good and poor and where berms are required and are not required, respectively. Sites where performance has been relatively good but where berm formulas indicate that berms are required include the following:

Locations	Worst Performance First 100 ft
Iowa River, Range A	2a
Sny Island, Range B	1d
Sny Island, Range H	1d
Muscatine Island, Range MB	2b
South Quincy, Range SQ	1c

Sites where performance has been relatively poor but where berm formulas indicate that no berms are required include the following:

Locations	Worst Performance First 100 ft
Green Bay, Range A	4a
Sny Island, Range A	4a
Sny Island, Range F	4a
Sny Island, Range G	3a
Sny Island, Range I	4a
Sny Island, Range SA	4c

c. Two or three sites from each of the categories above be studied in depth. Perhaps of most significance will be detailed mapping to identify locations of natural pressure relief if such exist. Detailed geologic stratification and physical properties of near surface and subsurface soils will also be of interest.

d. The new piezometer range sites be maintained and be read daily whenever the river is 4 ft or so above the landside toe elevation.

Table 1

Summary of Piezometer Range Locations

Old Piezometer Ranges					New Piezometer Ranges				
Levee District	Range	River-bank	River Mile	Levee Sta	Levee District	Range	River-bank	River Mile	Levee Sta
Muscatine Island	A	W	448.8	325+07	Muscatine Island	MA	W	451.9	161+13
						MB		446.9	425+91
						MC		444.6	549+30
Bay Island	C	E	446.7	330+00					
	D		443.5	502+19					
Iowa River	A	W	418.8	391+00					
Green Bay	A	W	390.8	652+70	Green Bay	GBA	W	395.8*	343+50
						GBB		391.1	637+88
Hunt	B	E	357.7	139+25					
Fabius River	A	W	328.4	339+49	Fabius River	FA	W	328.4	341+43
						FB		323.9	565+53
South Quincy	A	E	319.1	321+23	South Quincy	SQ	E	322.2	155+34
					South River	SRA	W	317.7	315+73
						SRB		317.1	345+71
						SRC		313.1	560+46
Sny Island	A	E	308.1	444+10	Sny Island	SA	E	294.5	1153+52
	F		300.1	886+17		SB		291.5	1311+92
	B		296.3	1079+71		SC		288.7	1501+77
	G		293.6	1197+24		SD		287.6	1559+23
	H		289.8	1399+99					
	I		288.7	1502+00					

* Piezometer Range GBA is actually located on the south bank of the Skunk River about one mile upstream from the confluence with the Mississippi River.

Table 2

Thickness Transformation Factors for Top Strata

Soil Type		
LMVD	Unified Soil Class. System	Transformation Factor*
	Thickness of Clay, < 5 ft	
Clay	Fat clay (CH)	1
Silty clay	Lean clay (CL)	1
Clay silt	Silt (ML)	1
Sandy silt	Silt, sandy (ML)	3/4 to 1
Silty sand	Silty sand (SM)	1/5 if z < 10 ft; 0 if z > 10 ft
Very fine sand	Fine sand	0
Alternating clay and silt strata with depth		1
	Thickness of Clay, > 5 ft	
Clay	Fat clay (CH)	1
Silty clay	Lean clay (CL)	1
Clay silt	Silt (ML)	1/2
Sandy silt	Silt, sandy (ML)	1/4 to 1/2 if z < 10 ft; 0 if z > 10 ft
Silty sand	Silty sand (SM)	1/10 if z < 10 ft; 0 if z > 10 ft
Very fine sand	Fine sand	0
Alternating clay and silt strata with depth		1

* Based on measurement of natural seepage at 16 sites in the Lower Mississippi River Valley.

Table 3

Piezometer Data and Calculated Seepage Source and Exit Distances, Muscatine Island, Range A

Date	River Stage el	Piezometer No. and Elevation Head A-1	A-2	A-3					Seepage Distance Source s* ft	Exit x_3* ft
2 Apr 60	546.96	543.61	542.57	541.81					691.2	454.9
3 Apr 60	547.72	543.81	542.67	542.01					732.9	446.0
14 Apr 69	544.14	-	541.17	540.24					485.7	189.6
29 Apr 69	550.14	-	543.75	542.32					740.7	537.6
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	552.6	546.0	544.8						1150	786
New	558.4	548.5	547.3						1700	1200

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 4

Performance Observations and Calculated Factors of Safety, Muscatine Island, Range A

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Berm Toe	New Berm Toe	
Distance from levee center line, ft	28	228	428	75	148	
Ground el	543.1	539.7	540.0	541.0	540.2	
Bottom of top stratum el	534.0	531.0	531.0	533.2	532.4	
Top stratum thickness z	9.1	8.7	9.2	7.8	7.8	
Transformed thickness z_b, z_t	4.7, 9.1	8.2, 8.7	6.9, 9.2	4.0, 7.8	5.6, 7.8	
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$	7.3	7.0	7.4	6.2	6.2	
Critical head el	550.4	546.7	547.6	547.2	546.4	
High-water observation date Apr 1960						
River stage el 547.7						
Seepage observation*	1b	2b	1b	1d, 2b	-	
Estimated pressure head el	543.8	542.7	542.0	545.5		
Pressure head above ground h_x, ft	0.7	3.0	1.8	4.5		
Factor of safety h_c/h_x	10.4	2.3	4.1	1.4		
High-water observation date Apr 1965						
River stage el 553.2						
Seepage observation*	-	1b	1b	-	1b	
Estimated pressure head el		545.1	543.7		545.5	
Pressure head above ground h_x, ft		5.4	3.5		5.3	
Factor of safety h_c/h_x		1.3	2.1		1.2	
High-water observation date Apr 1969						
River stage el 550.1						
Seepage observation*	-	1b	1b	-	4c	
Estimated pressure head el		543.7	542.6		544.2	
Pressure head above ground h_x, ft		4.0	2.4		4.0	
Factor of safety h_c/h_x		1.8	3.1		1.6	

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 4 (Concluded)

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Berm Toe	New Berm Toe	
Distance from levee center line, ft		228	428		148	
Ground el		539.7	540.2		540.2	
Critical head, $h_c = i_c z_t$		7.0	7.4		6.2	
Critical head el		546.7	547.6		546.4	
High-water observation date Apr 1973						
River stage el 551.6						
Seepage observation*	-	1b	1b	-	1b	
Estimated pressure head el		544.4	543.1		544.8	
Pressure head above ground h_x, ft		4.7	2.9		4.6	
Factor of safety h_c/h_x		1.5	2.6		1.4	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 558.4						
Projected pressure head, el		547.3	545.5	-	547.8	
Pressure head above ground h_x, ft		7.6	5.3		7.6	
Factor of safety h_c/h_x		0.9	1.4		0.8	

Table 5

Piezometer Data and Calculated Seepage Source and Exit Distances, Bay Island, Range C

Date	River Stage el	Piezometer No. and Elevation Head C-1	C-3	C-4	C-5				Seepage Distance Source s* ft	Exit x_3* ft
14 May 54	543.30	543.66	543.16	541.30	539.95				158	26
16 May 54	545.58	543.90	543.38	541.48	540.02				156	38
2 Apr 60	546.26	543.82	543.37	541.45	540.05				231	46
3 Apr 60	547.11	544.43	543.98	541.70	540.30				249	92
4 Apr 60	545.70	543.70	543.24	541.44	539.95				194	35
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	550.8	546.2	545.6						307	158
New	556.6	548.9	548.2						420	260

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 6

Performance Observations and Calculated Factors of Safety, Bay Island, Range C

Location identification		Piez. C-3	Piez. C-4	Piez. C-5	Old Toe	New Toe	Ditch
Distance from levee center line, ft		25	225	375	375	65	296
Ground el		543.3	542.0	539.7	542.6	542.7	540.6
Bottom of top stratum el		537.1	538.3	535.8	537.1	537.1	537.3
Top stratum thickness z		6.2	3.7	3.9	5.5	5.6	3.3
Transformed thickness z_b, z_t		6.2, 6.2	3.7, 3.7	3.9, 3.9	5.5, 5.5	5.6, 5.6	3.3, 3.3
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$		5.0	3.0	3.1	4.4	4.5	2.6
Critical head el		548.3	545.0	542.8	547.0	547.2	543.2
High-water observation date	May 1960						
River stage el	545.9						
Seepage observation*		1b	1b	1b	1d	-	2b
Estimated pressure head el		543.4	541.5	540.0	543.3		540.8
Pressure head above ground h_x, ft		0.1	-0.5	0.3	0.7		0.2
Factor of safety h_c/h_x		-	-	10.3	6.3		13.0
High-water observation date	Apr 1965						
River stage el	552.6						
Seepage observation*		-	1b	1b	-	1d	4a
Estimated pressure head el			542.8	541.0		545.7	541.9
Pressure head above ground h_x, ft			0.8	1.3		3.0	1.3
Factor of safety h_c/h_x			3.8	2.4		1.5	2.0
High-water observation date	Apr 1969						
River stage el	549.5						
Seepage observation*		-	1b	1b	-	1b	2c
Estimated pressure head el			542.2	540.6		544.5	541.4
Pressure head above ground h_x, ft			0.2	0.9		1.8	0.8
Factor of safety h_c/h_x			15.0	3.4		2.5	3.2

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 6 (Concluded)

Location identification	Piez. C-3	Piez. C-4	Piez. C-5	*Old Toe*	*New Toe*	*Ditch*
Distance from levee center line, ft		225	375		65	296
Ground el		542.0	539.7		542.7	540.6
Critical head, $h_c = i_c z_t$		3.0	3.1		4.5	2.6
Critical head el		545.0	542.8		547.2	543.2
High-water observation date Apr 1973						
River stage el 551.0						
Seepage observation*	-	lb	lb	-	lb	lb
Estimated pressure head el		542.5	540.8		545.1	541.6
Pressure head above ground h_x, ft		0.5	1.1		2.4	1.0
Factor of safety h_c/h_x		6.0	2.8		1.9	2.6
High-water observation date _____						
River stage el _____						
Seepage observation*				-		
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 556.6						
Projected pressure head, el	-	543.6	541.6	-	547.3	542.7
Pressure head above ground h_x, ft	-	1.6	1.9	-	4.6	2.1
Factor of safety h_c/h_x	-	1.9	1.6	-	1.0	1.2

Table 7

Piezometer Data and Calculated Seepage Source and Exit Distances, Bay Island, Range D

Date	River Stage el	Piezometer No. and Elevation Head D-1	D-3	D-4	D-5				Seepage Distance Source s* ft	Exit x_3* ft
14 May 54	544.03	540.44	539.91	539.93	538.73				404	89
16 May 54	544.32	540.55	540.01	540.21	538.96				415	97
2 Apr 60	545.39	541.27	540.48	540.16	539.60				323	97
3 Apr 60	546.13	541.68	540.83	540.96	539.71				324	112
4 Apr 60	544.94	541.14	540.38	540.14	539.07				312	94
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	552.1	545.7	543.5						203	106
New	555.4	547.9	544.9						163	102

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 8

Performance Observations and Calculated Factors of Safety, Bay Island, Range D

Location identification	Piez. D-3	Piez. D-4	Piez. D-5	Old Toe	New Toe
Distance from levee center line, ft	39	239	439	39	87
Ground el	539.0	538.7	539.8	539.0	540.0
Bottom of top stratum el	527.0	526.7	525.7	527.0	526.9
Top stratum thickness z	12.0	12.0	14.1	12.0	13.1
Transformed thickness z_b, z_t	12.0, 12.0	12.0, 12.0	14.1, 14.1	12.0, 12.0	13.1, 13.1
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	9.6	9.6	11.3	9.6	10.5
Critical head el	548.6	548.3	551.1	548.6	550.5
High-water observation date Apr 60					
River stage el 546.1					
Seepage observation*	1b	4a	1b	1d & 2b	-
Estimated pressure head el	540.8	541.0	539.7	540.8	
Pressure head above ground h_x, ft	1.8	2.3	-0.1	1.8	
Factor of safety h_c/h_x	5.3	4.2	-	5.3	
High-water observation date Apr 65					
River stage el 551.8					
Seepage observation*	-	1b	1b	-	1d
Estimated pressure head el		542.7	542.0		543.2
Pressure head above ground h_x, ft		4.0	2.2		3.2
Factor of safety h_c/h_x		2.4	5.1		3.3
High-water observation date Apr 69					
River stage el 548.8					
Seepage observation*		1b	1b	-	1e
Estimated pressure head el		541.6	540.8		541.9
Pressure head above ground h_x, ft		2.9	1.0		1.9
Factor of safety h_c/h_x		3.3	11.3		5.5

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 8 (Concluded)

Location identification	Piez. D-3	Piez. D-4	Piez. D-5	Old Toe	New Toe	
Distance from levee center line, ft		239	439		87	
Ground el		538.7	539.8		540.0	
Critical head, $h_c = i_c z_t$		9.6	11.3		10.5	
Critical head el		548.3	551.1		550.5	
High-water observation date Apr 73						
River stage el 551.1						
Seepage observation*	-	lb	lb	-	lb	
Estimated pressure head el		542.5	541.3		542.9	
Pressure head above ground h_x, ft		3.8	1.5		2.9	
Factor of safety h_c/h_x		2.5	7.5		3.6	
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 555.4						
Projected pressure head, el	-	544.0	543.4	-	544.7	
Pressure head above ground h_x, ft		5.3	3.6		4.7	
Factor of safety h_c/h_x		1.8	3.1		2.2	

Table 9

Piezometer Data and Calculated Seepage Source and Exit Distances, Iowa River, Range A

Date	River Stage el	Piezometer No. and Elevation Head A-1	A-2	A-3					Seepage Distance Source s* ft	Exit x_3* ft
3 Apr 60	535.45	529.50	527.34	526.07					349	59
4 Apr 61	534.10	529.55	527.19	525.73					313	43

Projection to Old and New Levee Crest Elevations

	Levee Crest el									
Old	538.9	530.8	528.1						474	104
New	543.5	532.0	529.0						599	151

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 10

Performance Observations and Calculated Factors of Safety, Iowa River, Range A

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe	Ditch
Distance from levee center line, ft	36	186	322	60	108	395
Ground el	530.3	527.2	526.1	528.5	527.9	523.1
Bottom of top stratum el	523.6	522.8	520.8	523.5	523.4	521.5
Top stratum thickness z	6.7	4.4	5.3	5.0	4.5	1.6
Transformed thickness z_b, z_t	6.7, 6.7	4.4, 4.4	5.3, 5.3	5.0, 5.0	4.5, 4.5	1.6, 1.6
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	5.4	3.5	4.2	4.0	3.6	1.3
Critical head el	535.7	530.7	530.3	532.5	531.5	524.4
High-water observation date Apr 60						
River stage el 535.4						
Seepage observation*	1b	1b	1b	1d	-	1b
Estimated pressure head el	529.9	527.3	526.1	529.6		525.2
Pressure head above ground h_x, ft	-0.4	0.1	0	1.1		2.1
Factor of safety h_c/h_x	-	35.0	-	3.6		0.6
High-water observation date Apr 65						
River stage el 538.9						
Seepage observation*	-	1b	1b	-	2a	4a
Estimated pressure head el		528.1	526.5		529.4	525.7
Pressure head above ground h_x, ft		0.9	0.4		1.5	2.6
Factor of safety h_c/h_x		3.9	10.5		2.4	0.5
High-water observation date Apr 69						
River stage el 535.9						
Seepage observation*	-	1b	1b	-	2a	1b
Estimated pressure head el		527.5	526.1		528.8	525.3
Pressure head above ground h_x, ft		0.3	0		0.9	2.2
Factor of safety h_c/h_x		11.7	-		4.0	0.6

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 10 (Concluded)

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe	Ditch
Distance from levee center line, ft		186	322		108	
Ground el		527.2	526.1		527.9	523.1
Critical head, $h_c = i_c z_t$		3.5	4.2		3.6	1.3
Critical head el		530.7	530.3		531.5	524.4
High-water observation date Apr 73						
River stage el 538.8						
Seepage observation*	-	lb	lb	-	lb	lb
Estimated pressure head el		528.1	526.5		529.4	525.7
Pressure head above ground h_x, ft		0.9	0.4		1.5	2.6
Factor of safety h_c/h_x		3.9	10.5		2.4	0.5
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 543.5						
Projected pressure head, el		529.0	527.2	-	530.4	526.3
Pressure head above ground h_x, ft		1.8	1.1		2.5	3.2
Factor of safety h_c/h_x		1.9	3.8		1.4	0.4

Table 11

Piezometer Data and Calculated Seepage Source and Exit Distances, Green Bay, Range A

Date	River Stage el	Piezometer No. and Elevation Head A-1	A-2	A-3					Seepage Distance Source s* ft	Exit x_3* ft
4 Apr 60	526.13	516.24	515.40	514.31					1834	193
9 Apr 62	523.95	515.95	515.04	513.54					1378	127
5 Apr 61	523.46	515.63	514.74	513.08					1379	75
		Projection to Old and New Levee Crest Elevations								
	Levee Crest el									
Old	529.9	516.9	515.7						1690	209
New	529.9	516.9	515.7						1690	209

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 12

Performance Observations and Calculated Factors of Safety, Green Bay, Range A

Location identification	Piez. A-2	Piez. A-3	Old Toe	Ditch I	New Toe	Ditch II
Distance from levee center line, ft	200	650	54	80	112	700
Ground el	515.7	514.5	516.3	514.0	517.1	509.0
Bottom of top stratum el	508.2	505.4	508.3	508.3	508.2	505.0
Top stratum thickness z	7.5	9.1	8.0	5.7	8.9	4.0
Transformed thickness z_b, z_t	7.5, 7.5	9.1, 9.1	8.0, 8.0	5.7, 5.7	8.9, 8.9	4.0, 4.0
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	6.3	7.3	6.4	4.6	7.1	3.2
Critical head el	521.7	521.8	522.7	518.6	524.2	512.2
High-water observation date Apr 60						
River stage el 526.1						
Seepage observation*	1b	1b	1d	2b	-	1b
Estimated pressure head el	515.4	514.3	516.2	516.1		513.5
Pressure head above ground h_x, ft	-0.3	-0.2	-0.1	2.1		4.5
Factor of safety h_c/h_x	-	-	-	2.2		0.7
High-water observation date Apr 65						
River stage el 526.5						
Seepage observation*	1b	1b	1c, 1d	1b	-	1b
Estimated pressure head el	515.3	513.7	516.3	516.2		513.5
Pressure head above ground h_x, ft	-0.4	-0.8	0	2.2		4.5
Factor of safety h_c/h_x	-	-	-	2.1		0.7
High-water observation date Apr 69						
River stage el 524.4						
Seepage observation*	1b	1b	-	-	4a	1b
Estimated pressure head el	515.0	513.5			515.6	513.3
Pressure head above ground h_x, ft	-0.7	-1.0			-1.5	4.3
Factor of safety h_c/h_x	-	-			-	0.7

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 12 (Concluded)

Location identification	Piez. A-2	Piez. A-3	Old Toe	Ditch I	New Toe	Ditch II
Distance from levee center line, ft	200	650			112	700
Ground el	515.7	514.5			517.1	509.0
Critical head, $h_c = i_c z_t$	6.0	7.3			7.1	3.2
Critical head el	521.7	521.8			524.2	512.2
High-water observation date Apr 73						
River stage el 526.8						
Seepage observation*	1b	1b	-	-	1d	4a
Estimated pressure head el	515.3	513.8			516.0	513.5
Pressure head above ground h_x, ft	-0.4	-0.7			-1.1	4.5
Factor of safety h_c/h_x	-	-			-	0.7
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 529.9						
Projected pressure head, el	515.7	514.1			516.5	513.8
Pressure head above ground h_x, ft	0	-0.4			-0.6	4.8
Factor of safety h_c/h_x	-	-			-	0.7

Table 13

Piezometer Data and Calculated Seepage Source and Exit Distances, Hunt, Range B

Date	River Stage el	Piezometer No. and Elevation Head B-1	B-2	B-3					Seepage Distance Source s* ft	Exit x_3* ft
4 Apr 60	496.13	490.63	490.05	487.92					516	198
5 Apr 61	492.54	488.93	488.62	486.91					620	160
6 Apr 61	492.23	488.85	488.56	486.99					620	152
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	499.5	492.3	491.4						445	195
New	501.5	493.2	492.2						459	227

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 14

Performance Observations and Calculated Factors of Safety, Hunt, Range B

Location identification		Piez. B-1	Piez. B-2	Piez. B-3	Old Toe	New Toe	
Distance from levee center line, ft		-8	40	341	53	77	
Ground el		497.9	489.5	490.2	487.5	486.7	
Bottom of top stratum el		475.8	483.2	482.0	482.2	480.5	
Top stratum thickness z			6.3	8.2	5.3	6.2	
Transformed thickness z_b, z_t			6.3, 6.3	8.2, 8.2	5.3, 5.3	6.2, 6.2	
Critical gradient i_c			0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$			5.0	6.6	4.2	5.0	
Critical head el			494.5	496.8	491.7	491.7	
High-water observation date	Apr 60						
River stage el	496.1						
Seepage observation*		-	1b	1b	1d, 2b	-	
Estimated pressure head el			490.1	487.9	490.0		
Pressure head above ground h_x, ft			0.6	-2.3	2.5		
Factor of safety h_c/h_x			8.3	-	1.7		
High-water observation date	Apr 65						
River stage el	497.0						
Seepage observation*		-	-	1b	-	1b	
Estimated pressure head el				488.2		490.2	
Pressure head above ground h_x, ft				-2.0		3.5	
Factor of safety h_c/h_x				-		1.4	
High-water observation date	Apr 69						
River stage el	493.0						
Seepage observation*		-	-	1b	-	3a	
Estimated pressure head el				487.1		488.7	
Pressure head above ground h_x, ft				-3.1		2.0	
Factor of safety h_c/h_x				-		2.5	

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 14 (Concluded)

Location identification	Piez. B-1	Piez. B-2	Piez. B-3	Old Toe	New Toe	
Distance from levee center line, ft		40	341	53	77	
Ground el		489.5	490.2	487.5	486.7	
Critical head, $h_c = i_c z_t$		5.0	6.6	4.2	5.0	
Critical head el		494.5	496.8	491.7	491.7	
High-water observation date Apr 73						
River stage el 499.0						
Seepage observation*	-	-	1b	-	1b	
Estimated pressure head el			488.8		491.0	
Pressure head above ground h_x, ft			-1.4		4.3	
Factor of safety h_c/h_x			-		1.2	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 501.5						
Projected pressure head, el	493.2	492.2	489.4	-	491.9	
Pressure head above ground h_x, ft		2.7	0		5.2	
Factor of safety h_c/h_x		1.9	-		1.0	

Table 15

Piezometer Data and Calculated Seepage Source and Exit Distances, Fabius River, Range A

Date	River Stage el	Piezometer No. and Elevation Head A-1	A-2	A-3					Seepage Distance Source s* ft	Exit x_3* ft
4 Apr 60	482.52	477.00	475.00	474.13					561	241
7 Apr 60	483.47	477.30	475.03	474.13					553	238
7 Apr 60	483.46	477.30	475.02	474.18					549	237
		Projection to Old and New Levee Crest Elevations								
	Levee Crest el									
Old	484.9	477.7	475.0						542	228
New	489.8	479.1	475.0						531	215

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 16

Performance Observations and Calculated Factors of Safety, Fabius River, Range A

Location identification		Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe	
Distance from levee center line, ft		26	226	425	35	118	
Ground el		475.6	474.0	473.7	474.5	475.7	
Bottom of top stratum el		464.5	465.5	466.0	464.5	465.0	
Top stratum thickness z		11.1	8.5	7.7	10.0	10.7	
Transformed thickness z_b, z_t		9.9, 9.9	5.7, 5.7	6.6, 6.6	8.7, 8.7	8.2, 8.2	
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$		7.9	4.6	5.3	7.0	6.6	
Critical head el		483.5	478.6	479.0	481.5	482.3	
High-water observation date	Apr 60						
River stage el	483.5						
Seepage observation*		4b	1b	1b	1e	-	
Estimated pressure head el		477.3	475.0	474.2	477.2		
Pressure head above ground h_x, ft		1.7	1.0	0.5	2.7		
Factor of safety h_c/h_x		4.6	4.6	10.6	2.6		
High-water observation date	Apr 65						
River stage el	483.9						
Seepage observation*		-	1b	1b	-	1d	
Estimated pressure head el			475.0	474.2		476.3	
Pressure head above ground h_x, ft			1.0	0.5		0.6	
Factor of safety h_c/h_x			4.6	10.6		11.0	
High-water observation date	Apr 69						
River stage el	479.5						
Seepage observation*		-	1b	1b	-	1b	
Estimated pressure head el			475.0	474.2		475.7	
Pressure head above ground h_x, ft			1.0	0.5		0	
Factor of safety h_c/h_x			4.6	10.6		-	

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 16 (Concluded)

Location identification	Piez. A-1	Piez. A-2	Piez. A-3	Old Toe	New Berm Toe	
Distance from levee center line, ft		226	425		118	
Ground el		474.0	473.7		457.7	
Critical head, $h_c = i_c z_t$		4.6	5.3		6.6	
Critical head el		478.6	479.0		482.3	
High-water observation date Apr 73						
River stage el 487.8		Levee overtopped; no seepage data obtained				
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 489.8						
Projected pressure head, el	-	475.1	474.2	-	477.2	
Pressure head above ground h_x, ft		1.1	0.5		1.5	
Factor of safety h_c/h_x		4.2	10.6		4.4	

Table 17

Piezometer Data and Calculated Seepage Source and Exit Distances, South Quincy, Range A

Date	River Stage el	Piezometer No. and Elevation Head A-1	A-2	A-3					Seepage Distance Source s* ft	Exit x_3* ft
4 Apr 60	477.69		469.02	465.50					813	227
6 Apr 60	477.70	Destroyed	468.85	465.70					921	241
7 Apr 60	478.34		469.17	465.87					912	259
23 Mar 62	475.41		467.74	465.16					972	169
10 Apr 62	475.48		468.32	465.37					802	204
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	481.4		470.5	466.3					854	293
New	482.4		470.9	466.5					860	307

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 18

Performance Observations and Calculated Factors of Safety, South Quincy, Range A

Location identification	Piez. A-2	Piez. A-3	Beyond Toe	Old Berm Toe	New Berm Toe	Ditch
Distance from levee center line, ft	28	341	180	70	127	109
Ground el	470.5	464.3	466.0	466.0	465.8	464.2
Bottom of top stratum el	463.5	460.0	463.0	461.2	459.0	458.8
Top stratum thickness z	7.0	4.3	3.0	4.8	6.8	5.4
Transformed thickness z_b, z_t	2.0, 7.0	4.3, 4.3	3.0, 3.0	4.8, 4.8	6.8, 6.8	5.4, 5.4
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	5.6	3.4	2.4	3.8	5.4	4.3
Critical head el	476.1	467.7	468.4	469.8	471.2	468.5
High-water observation date Apr 60						
River stage el 478.3						
Seepage observation*	-	2b	1b	1d	-	2b
Estimated pressure head el		465.8	467.6	468.8		468.4
Pressure head above ground h_x, ft		1.5	1.6	1.4		4.2
Factor of safety h_c/h_x		2.3	1.5	3.4		1.0
High-water observation date May 65						
River stage el 479.3						
Seepage observation*	-	1b	1b	1b	-	1b
Estimated pressure head el		465.9	467.9	469.2		468.7
Pressure head above ground h_x, ft		1.6	1.9	1.8		4.5
Factor of safety h_c/h_x		2.1	1.3	2.6		1.0
High-water observation date Apr 69						
River stage el 475.1						
Seepage observation*	-	1b	3b	-	1e	-
Estimated pressure head el		465.2	466.6		467.1	
Pressure head above ground h_x, ft		0.9	0.6		1.3	
Factor of safety h_c/h_x		3.8	4.0		4.2	

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 18 (Concluded)

Location identification	Piez. A-2	Piez. A-3	Beyond Toe	Old Toe	New Berm Toe	On New Berm
Distance from levee center line, ft		341	180		127	100
Ground el		464.3	466.0		465.8	469.0
Critical head, $h_c = i_c z_t$		3.4	2.4		5.4	7.6
Critical head el		467.7	468.4		471.2	476.6
High-water observation date Apr 73						
River stage el 482.9						
Seepage observation*	-	1b	3b	-	1e	2a
Estimated pressure head el		466.6	468.9		469.6	470.1
Pressure head above ground h_x, ft		2.3	2.9		3.8	1.1
Factor of safety h_c/h_x		1.5	0.8		1.4	6.9
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 482.4						
Projected pressure head, el	-	466.5	468.8	-	469.5	-
Pressure head above ground h_x, ft		2.2	2.8		3.7	
Factor of safety h_c/h_x		1.5	0.9		1.5	

Table 19

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range A

Date	River Stage el	Piezometer No. and Elevation Head A-1	A-2	A-3	A- 4				Seepage Distance Source s* ft	Exit x_3* ft
13 May 51	471.27	469.40	469.26	468.59	467.04				478	1094
5 May 52	469.13	467.07	466.84	466.44	465.38				387	394
5 Apr 60	470.20	468.88	467.97	467.74	466.53				134	103
7 Apr 60	472.14	469.98	468.22	468.59	467.68				126	33
7 Apr 61	467.83	466.58	466.25	465.93	464.87				213	199
22 Mar 62	467.09	465.78	464.87	465.04	464.00				134	-12
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	474.4	471.9	471.3						225	370
New	477.2	474.3	473.6						225	420

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 20

Performance Observations and Calculated Factors of Safety, Sny Island, Range A

Location identification	Piez. A-2	Piez. A-3	Piez. A-4	Old Toe	Center Line of Old Road at Levee	Old Borrow Pit
Distance from levee center line, ft	28.7	123.5	418	34	39	114
Ground el	466.3	463.6	463.1	465.4	465.3	461.7
Bottom of top stratum el	445.2	449.5	443.0	445.4	445.5	449.2
Top stratum thickness z	21.1	14.1	20.1	20.0	19.8	12.5
Transformed thickness z_b, z_t	20.7, 20.7	13.2, 13.2	17.2, 19.0	19.5, 19.5	19.3, 19.3	11.5, 11.5
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	16.6	10.6	15.2	15.6	15.4	9.2
Critical head el	482.9	474.2	478.3	481.0	480.7	470.9
High-water observation date 17 Apr 60						
River stage el 471.14						
Seepage observation*	-	1b	1b	1d	1b	2b
Estimated pressure head el		468.0	466.9	468.6	468.6	468.2
Pressure head above ground h_x, ft		4.4	3.8	3.2	3.3	6.5
Factor of safety h_c/h_x		2.4	4.0	4.9	4.7	1.4
High-water observation date May 65						
River stage el 473.10						
Seepage observation*	-	1b	1b	1e	4a	1b
Estimated pressure head el		469.5	468.4	470.2	470.2	469.6
Pressure head above ground h_x, ft		5.9	5.3	4.8	4.9	7.9
Factor of safety h_c/h_x		1.8	2.9	3.2	3.1	1.2
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

(Continued)

* *Code performance:*

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet 3a - Light seepage beyond toe
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 20 (Continued)

Location identification	Piez. A-2	Piez. A-3	Piez. A-4	Riverside Old Ditch	New Toe	Road Ditch
Distance from levee center line, ft				80	86	422
Ground el				462.2**	464.6	461.0
Bottom of top stratum el				447.6	447.8	443.0
Top stratum thickness z				14.6	16.8	18.0
Transformed thickness z_b, z_t				13.8, 13.8	16.0, 16.0	15.2, 17.0
Critical gradient i_c				0.8	0.8	0.8
Critical head, $h_c = i_c z_t$				11.0	12.8	13.6
Critical head el				473.2	477.4	474.6
High-water observation date 7 Apr 60						
River stage el 471.14						
Seepage observation*				1b		2b
Estimated pressure head el				468.4		467.0
Pressure head above ground h_x, ft				6.2		6.0
Factor of safety h_c/h_x				1.8		2.3
High-water observation date May 65						
River stage el 473.10						
Seepage observation*				1b		1b
Estimated pressure head el				469.8		468.4
Pressure head above ground h_x, ft				7.6		7.4
Factor of safety h_c/h_x				1.4		1.8
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

(Continued)

** Tailwater assumed to be 463.8 for old crest permeability ratio calculations.

(Sheet 2 of 3)

Table 20 (Concluded)

Location identification		Piez. A-2	Piez. A-3	Piez. A-4	Old Toe	New Toe	Road Ditch
Distance from levee center line, ft			123.5	418		86	422
Ground el			463.6	463.1		464.6	461.0
Critical head, $h_c = i_c z_t$			10.6	15.2		12.8	13.6
Critical head el			474.2	478.3		477.4	474.6
High-water observation date	Apr 69						
River stage el	469.05						
Seepage observation*		-	1b	1b	-	1b	2b
Estimated pressure head el			466.6	465.5		466.6	465.5
Pressure head above ground h_x, ft			3.0	2.4		2.0	4.5
Factor of safety h_c/h_x			3.5	6.3		6.4	3.0
High-water observation date	Apr 73						
River stage el	476.8						
Seepage observation*		-	1b	1b	-	1e	1b
Estimated pressure head el			472.3	471.0		472.7	471.0
Pressure head above ground h_x, ft			8.7	7.9		8.1	10.0
Factor of safety h_c/h_x			1.2	1.9		1.6	1.3
Projected performance							
River stage (new levee crest) el	477.2						
Projected pressure head, el			472.6	471.3		473.0	471.3
Pressure head above ground h_x, ft			9.0	8.2		8.4	10.3
Factor of safety h_c/h_x			1.2	1.9		1.5	1.3

(Sheet 3 of 3)

Table 21

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range F

Date	River Stage el	Piezometer No. and Elevation Head F-1	F-2	F-3	F-4				Seepage Distance Source s* ft	Exit x_3* ft
1 Apr 60	463.76	460.91	460.08	458.44	456.03				211	74
5 Apr 60	465.35	461.71	460.60	458.88	456.29				204	75
8 Apr 60	467.07	462.60	461.07	459.34	456.36				188	67
6 Apr 61	463.05	460.49	459.73	458.27	455.95				208	61
22 Mar 62	462.29	460.03	459.32	458.01	456.03				200	39
2 May 65	467.78	463.43	461.69	459.37	456.38				168	74
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	469.0	463.6	462.0						207	90
New	472.8	465.6	463.6						219	108

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 22

Performance Observations and Calculated Factors of Safety, Sny Island, Range F

Location identification	Piez. F-3	Piez. F-4	Road Ditch	Old Toe	New Berm Toe	Borrow Pit
Distance from levee center line, ft	182	322	92	39	150	317
Ground el	459.5	455.8	456.9	458.6	459.0	455.3
Bottom of top stratum el	449.5	450.7	449.3	449.2	449.4	450.5
Top stratum thickness z	10.0	5.1	7.6	9.4	9.6	4.8
Transformed thickness z_b, z_t	5.0, 6.9	3.3, 3.3	4.8, 4.8	7.6, 7.9	5.4, 6.6	2.8, 2.8
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	5.5	2.6	3.8	6.3	5.3	2.2
Critical head el	465.0	458.4	460.7	464.9	564.3	457.5
High-water observation date Apr 60						
River stage el 467.1						
Seepage observation*	1b	1b	4a	1e	-	2b, 4b
Estimated pressure head el	459.3	456.3	460.4	461.1		456.6
Pressure head above ground h_x, ft	-0.2	0.5	3.5	2.5		1.3
Factor of safety h_c/h_x	-	5.2	1.1	2.5		1.7
High-water observation date May 65						
River stage el 468.8						
Seepage observation*	1b	1b	4a	4a	-	1b
Estimated pressure head el	459.8	456.4	461.1	461.9		456.8
Pressure head above ground h_x, ft	0.3	0.6	4.2	3.3		1.5
Factor of safety h_c/h_x	18.3	4.3	0.9	1.6		1.5
High-water observation date Jul 69						
River stage el 465.2						
Seepage observation*	1a	1a	-	-	1a	1a
Estimated pressure head el	458.8	456.2			459.2	456.5
Pressure head above ground h_x, ft	-0.7	0.4			0.2	1.2
Factor of safety h_c/h_x	-	6.5			26.5	1.8

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 22 (Concluded)

Location identification	Piez. F-3	Piez. F-4	Road Ditch	Old Toe	New Berm Toe	Borrow Pit
Distance from levee center line, ft	182	322			150	317
Ground el	459.5	455.8			459.0	455.3
Critical head, $h_c = {}_c z_t$	5.5	2.6			5.3	2.2
Critical head el	465.0	458.4			564.3	457.5
High-water observation date Apr 73						
River stage el 474.2						
Seepage observation*	1b	1b	-	-	1d, 2a	1b
Estimated pressure head el	461.2	456.8			461.9	457.3
Pressure head above ground h_x, ft	1.7	1.0			2.0	2.0
Factor of safety h_c/h_x	3.2	2.6			1.8	1.1
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 472.8						
Projected pressure head, el	460.8	456.7	-	-	461.4	457.1
Pressure head above ground h_x, ft	1.3	0.9			2.4	1.8
Factor of safety h_c/h_x	4.2	2.9			2.2	1.2

Table 23

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range B

Date	River Stage el	Piezometer No. and Elevation Head B-1	B-2	B-3	B-4				Seepage Distance Source s* ft	Exit x_3* ft
27 Apr 51	462.90	459.52	458.78	456.40	454.92				285	170
12 May 51	464.78	461.00	459.97	456.85	455.14				246	158
13 May 51	464.83	461.01	459.95	456.72	455.15				244	152
1 May 52	463.93	459.71	458.95	456.52	455.95				327	174
8 May 60	465.69	461.26	460.35	457.58	456.10				297	203
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	467.4	462.3	461.2						288	193
New	472.5	465.6	464.1						286	211

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 24

Performance Observations and Calculated Factors of Safety, Sny Island, Range B

Location identification	Piez. B-2	Piez. B-3	Piez. B-4	Old Toe	Old Road	Old Ditch
Distance from levee center line, ft	36	115	374	83	48	103
Ground el	458.2	455.1	454.1	454.2**	456.8	454.0
Bottom of top stratum el	448.3	447.7	446.5	447.9	448.3	447.8
Top stratum thickness z	9.9	7.4	7.6	6.3	8.5	6.2
Transformed thickness z_b, z_t	9.9, 9.9	7.4, 7.4	4.8, 4.8	6.3, 6.3	8.5, 8.5	6.2, 6.2
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	7.9	5.9	3.8	5.0	6.8	5.0
Critical head el	466.1	461.0	457.9	459.2	463.6	459.0
High-water observation date Apr 60						
River stage el 465.7						
Seepage observation*	1e	1b	1b	1e	4b	2b
Estimated pressure head el	460.4	457.4	456.1	458.6	459.8	457.8
Pressure head above ground h_x, ft	2.2	2.3	2.0	4.4	3.0	3.8
Factor of safety h_c/h_x	3.6	2.6	1.9	1.1	2.3	1.3
High-water observation date May 65						
River stage el 466.8						
Seepage observation*	1b	1b	1b	1b	1b	1b
Estimated pressure head el	460.9	457.9	456.5	459.1	460.4	458.3
Pressure head above ground h_x, ft	2.7	2.8	2.4	4.9	3.6	4.3
Factor of safety h_c/h_x	2.9	2.1	1.6	1.0	1.9	1.2
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

** Tailwater assumed to be 455.0 for old crest permeability ratio circulation.

Table 24 (Continued)

Location identification	Piez. B-2	Piez. B-3	Piez. B-4	New Berm	New Berm Toe	
Distance from levee center line, ft			374	115	143	
Ground el			454.1	460.1	455.7	
Bottom of top stratum el				447.7	447.8	
Top stratum thickness z				12.4	7.9	
Transformed thickness z_b, z_t				12.4, 12.4	7.9, 7.9	
Critical gradient i_c				0.8	0.8	
Critical head, $h_c = i_c z_t$			3.8	9.9	6.3	
Critical head el			457.9	470.0	462.0	
High-water observation date 1969						
River stage el 464.6						
Seepage observation*			1b	1b	1d	
Estimated pressure head el			455.6	457.0	456.8	
Pressure head above ground h_x, ft			1.5	-3.1	1.1	
Factor of safety h_c/h_x			2.5	-	5.7	
High-water observation date Apr 73						
River stage el 472.0						
Seepage observation*			4c	2a	1c	
Estimated pressure head el			458.6	459.8	460.0	
Pressure head above ground h_x, ft			4.5	-0.3	4.3	
Factor of safety h_c/h_x			0.8	-	1.5	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

(Continued)

Table 24 (Concluded)

Location identification	Piez. B-2	Piez. B-3	Piez. B-4	New Berm	New Berm Toe	
Distance from levee center line, ft			374	115	143	
Ground el			454.1	460.1	455.7	
Critical head, $h_c = i_c z_t$			3.8	9.9	6.3	
Critical head el			457.9	470.0	462.0	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 472.5						
Projected pressure head, el			458.8	460.2	460.0	
Pressure head above ground h_x, ft			4.7	0.1	4.3	
Factor of safety h_c/h_x			0.8	99	1.5	

(Sheet 3 of 3)

Table 25

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range G

Date	River Stage el	Piezometer No. and Elevation Head G-1	G-2	G-3	G-4				Seepage Distance Source s* ft	Seepage Distance Exit x_3* ft
6 Apr 60	462.81	457.80		455.55	452.96				541	231
7 Apr 61	460.28	456.55	Destroyed	454.89	453.15				545	197
22 Mar 62	459.76	456.41		455.06	454.11				592	244
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	467.4	460.1		456.6					513	245
New	470.5	461.5		457.2					514	246

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 26

Performance Observations and Calculated Factors of Safety, Sny Island, Range G

Location identification		Piez. G-2	Piez. G-3	Piez. G-4	Old Toe	New Toe
Distance from levee center line, ft		30	191.5	481.5	89	94
Ground el		459.0	454.5	451.0	454.1	456.3
Bottom of top stratum el		448.0	447.4	443.4	447.9	447.8
Top stratum thickness z		11.0	7.1	7.6	6.2	8.5
Transformed thickness z_b, z_t		9.9, 9.9	5.3, 5.3	4.8, 4.8	5.0, 5.0	5.0, 7.2
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$		7.9	4.2	3.8	4.0	5.8
Critical head el		466.9	458.7	454.8	458.1	462.1
High-water observation date	6 Apr 60					
River stage el	462.8					
Seepage observation*		-	1b	1b	1d	-
Estimated pressure head el			455.6		456.8	
Pressure head above ground h_x, ft			1.1		2.6	
Factor of safety h_c/h_x			3.8		1.5	
High-water observation date	May 65					
River stage el	465.4					
Seepage observation*		-	1b	1b	1b	-
Estimated pressure head el			456.2		457.6	
Pressure head above ground h_x, ft			1.7		3.5	
Factor of safety h_c/h_x			2.5		1.1	
High-water observation date	1969					
River stage el	464.2					
Seepage observation*		-	3a	1b	-	1b
Estimated pressure head el			455.9			457.0
Pressure head above ground h_x, ft			1.4			0.7
Factor of safety h_c/h_x			3.0			8.3

Insufficient data for estimation of pressure head

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 26 (Concluded)

Location identification	Piez. G-2	Piez. G-3	Piez. G-4	Old Toe	New Toe	
Distance from levee center line, ft		191.5	481.5		94	
Ground el		454.5	451.0		456.3	
Critical head, $h_c = i_c z_t$		4.2	3.8		5.8	
Critical head el		458.7	454.8		462.1	
High-water observation date Apr 73						
River stage el 470.5						
Seepage observation*	-	1b	1b	-	1c	
Estimated pressure head el		457.3	-		459.3	
Pressure head above ground h_x, ft		2.8			3.0	
Factor of safety h_c/h_x		1.5			1.9	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 470.5						
Projected pressure head, el		457.2			459.3	
Pressure head above ground h_x, ft		2.8			3.0	
Factor of safety h_c/h_x		1.5			1.9	

Table 27

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range H

Date	River Stage el	Piezometer No. and Elevation Head H-1	H-2	H-3	H-4				Seepage Distance Source s* ft	Exit x_3* ft
6 Apr 60	460.79	456.69	453.44	452.41	451.61				140	-13
8 Apr 60	462.56	457.67	454.00	452.81	451.94				143	-10
7 Apr 61	458.59	458.57	452.44	451.24	450.07				86	-34
Projection to Old and New Levee Crest Elevations										
	Levee Crest el									
Old	465.3	459.0	455.1						156	26
New	468.4	460.4	456.3						170	35

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 28

Performance Observations and Calculated Factors

of Safety, Sny Island, Range H

Location identification	Piez. H-2	Piez. H-3	Piez. H-4	Old Berm Toe	New Berm Toe	Ditch
Distance from levee center line, ft	27	162	297	69	144	200
Ground el	456.3	450.1	449.3	451.3	450.3	448.5
Bottom of top stratum el	444.3	443.0	441.8	444.1	441.8	443.0
Top stratum thickness z	12.0	7.1	7.5	7.2	7.1	5.5
Transformed thickness z_b, z_t	6.5, 10.3	6.6, 6.6	6.1, 6.1	6.1, 6.1	6.5, 6.5	5.1, 5.1
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	8.2	5.3	4.9	4.9	5.2	4.1
Critical head el	464.5	455.4	454.2	456.2	455.5	452.6
High-water observation date Apr 60						
River stage el 462.6						
Seepage observation*	-	1b	1b	1d	-	2b
Estimated pressure head el		452.9	452.1	453.7		452.7
Pressure head above ground h_x, ft		2.8	2.8	2.4		4.2
Factor of safety h_c/h_x		1.9	1.8	2.0		1.0
High-water observation date May 65						
River stage el 463.6						
Seepage observation*	-	1b	1b	1b	-	1b
Estimated pressure head el		453.4	452.5	454.1		453.1
Pressure head above ground h_x, ft		3.3	3.2	2.8		4.6
Factor of safety h_c/h_x		1.6	1.5	1.7		0.9
High-water observation date 1969						
River stage el 462.8						
Seepage observation*	-	1b	1b	-	1b	1b
Estimated pressure head el		453.0	452.2		453.2	452.8
Pressure head above ground h_x, ft		2.9	2.9		2.9	4.3
Factor of safety h_c/h_x		1.8	1.7		1.8	1.0

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 28 (Concluded)

Location identification	Piez. H-2	Piez. H-3	Piez. H-4		New Berm Toe	Ditch
Distance from levee center line, ft		162	297		144	200
Ground el		450.1	449.3		450.3	448.5
Critical head, $h_c = i_c z_t$		5.3	4.9		5.2	4.1
Critical head el		455.4	454.2		455.5	452.6
High-water observation date Apr 73						
River stage el 468.6						
Seepage observation*	-	1b	1b		1c	1b
Estimated pressure head el		455.3	454.5		455.5	455.1
Pressure head above ground h_x, ft		5.2	5.2		5.2	6.6
Factor of safety h_c/h_x		1.0	0.9		1.0	0.6
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 468.4						
Projected pressure head, el		455.2	454.4		455.4	455.0
Pressure head above ground h_x, ft		5.1	5.1		5.1	6.5
Factor of safety h_c/h_x		1.0	1.0		1.0	0.6

Table 29

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range I

Date	River Stage el	Piezometer No. and Elevation Head I-1	I-2	I-3	I-4				Seepage Distance Source s* ft	Exit x_3* ft
6 Apr 60	460.48	458.28	458.14	456.93	456.05				569	579

Projection to Old and New Levee Crest Elevations

	Levee Crest el									
Old	464.6	Data not sufficient to project to levee crest elevations								
New	468.8									

* All calculated values for s and x_3 in this table are based on old toe locations and average ground elevations.

Table 30

Performance Observations and Calculated Factors of Safety, Sny Island, Range I

Location identification	Piez. I-2	Piez. I-3	Piez. I-4	Old Toe	Center Line of Old Road	Row Fence
Distance from levee center line, ft	22	172	322	26	33	72
Ground el	458.0	455.2	454.8	457.1	456.5	455.3
Bottom of top stratum el	444.5	442.5	441.5	444.5	444.5	440.0
Top stratum thickness z	13.5	12.7	13.3	12.6	12.0	11.3
Transformed thickness z_b, z_t	13.5, 13.5	12.7, 12.7	13.3, 13.3	12.6, 12.6	12.0, 12.0	11.3, 11.3
Critical gradient i_c	0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$	10.8	10.2	10.6	10.1	9.6	9.0
Critical head el	468.8	465.4	465.4	467.2	466.1	464.3
High-water observation date 6 Apr 60						
River stage el 460.48						
Seepage observation*	-	1b	1b	1d	4a	2b
Estimated pressure head el		456.9	456.1	458.1	458.1	457.7
Pressure head above ground h_x, ft		1.7	1.3	1.0	1.6	2.4
Factor of safety h_c/h_x		6.0	8.2	10.1	6.0	3.8
High-water observation date May 65						
River stage el 462.7						
Seepage observation*	-	1b	1b	1b	1b	1b
Estimated pressure head el		-	-	Data not sufficient for estimation of pressure head		
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 30 (Concluded)

Location identification	Piez. I-2	Piez. I-3	Piez. I-4	New Toe	New Road	
Distance from levee center line, ft		172	322	75	?	
Ground el		455.2	454.8	458.2		
Bottom of top stratum el				443.8		
Top stratum thickness z				14.4		
Transformed thickness z_b, z_t				14.4, 14.4		
Critical gradient i_c				0.8		
Critical head, $h_c = i_c z_t$		10.2	10.6	11.5		
Critical head el		465.4	465.4	469.7		
High-water observation date Jul 69						
River stage el 462.3						
Seepage observation*		1a	1a	1a	1a	
Estimated pressure head el		-	-	Data not sufficient for estimation of pressure head		
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
High-water observation date Apr 73						
River stage el 468.2						
Seepage observation*		1b	1b	1e, 1c	1e	
Estimated pressure head el		-	-	Data not sufficient for estimation of pressure head		
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 31

Piezometer Data and Calculated Seepage Source and Exit Distances, Muscatine Island, Range MA

Date	River Stage el	Piezometer No. and Elevation Head							Seepage Distance	
		MA-1	MA-2	MA-3	MA-4	MA-5			Source s* ft	Exit x_3* ft
12 Apr 79	548.04	546.34	Dry	Dry	546.05	544.45			1790	-
		Projection to Levee Crest Elevations								
	Levee Crest el									
1979	560.8									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 32

Performance Observations and Calculated Factors of Safety, Muscatine Island, Range MA

Location identification		Piez. MA-4	Piez. MA-5	Toe	Low Spot		
Distance from levee center line, ft		64	562	70	400		
Ground el		552.0	548.2	551.5	546.4		
Bottom of top stratum el		541.1	543.2	541.1	542.5		
Top stratum thickness z		10.9	5.0	10.4	3.9		
Transformed thickness z_b, z_t		4.7, 10.9	5.0, 5.0	4.7, 10.4	3.9, 3.9		
Critical gradient i_c		0.8	0.8	0.8	0.8		
Critical head, $h_c = i_c z_t$		8.7	4.0	8.3	3.1		
Critical head el		560.7	552.2	559.8	549.5		
High-water observation date	Apr 65						
River stage el	554.7						
Seepage observation*		1a	1a	1a	1a		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	Apr 69						
River stage el	551.1						
Seepage observation*		1a	1a	1a	1a		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	552.4						
Seepage observation*		1a	2b	1a	2b		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 32 (Concluded)

Location identification	Piez. MA-4	Piez. MA-5	Toe	Low Spot		
Distance from levee center line, ft	64	562	70	400		
Ground el	552.0	548.2	551.5	546.4		
Critical head, $h_c = i_c z_t$	8.7	4.0	8.3	8.3		
Critical head el	560.7	552.2	559.8	454.7		
High-water observation date 12 Apr 79						
River stage el 548.04						
Seepage observation*	lb	lb	lb	lb		
Estimated pressure head el	546.0	544.4	546.0	545.0		
Pressure head above ground h_x, ft	-6.0	-3.8	-5.5	-1.4		
Factor of safety h_c/h_x	-	-	-	-		
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 560.8						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 33

Piezometer Data and Calculated Seepage Source and Exit Distances, Muscatine Island, Range MB

Date	River Stage el	Piezometer No. and Elevation Head MB-1L	MB-1U	MB-2	MB-3	MB-4	MB-5		Seepage Distance Source s* ft	Exit x_3* ft
23 Mar 79	545.99	543.57	Destroyed	Dry	Dry	542.94	540.72		512	401
12 Apr 79	546.27	544.57		Dry	544.25	544.14	543.12		523	877

Projection to Levee Crest Elevations

	Levee Crest el									
1979	558.5									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 34

Performance Observations and Calculated Factors of Safety, Muscatine Island, Range MB

Location identification		Piez. MB-4	Piez. MB-5	Toe	Low Spot		
Distance from levee center line, ft		91	594	138	400		
Ground el		544.2	542.1	539.7	540.5		
Bottom of top stratum el		540.0	536.7	539.7	538.0		
Top stratum thickness z		4.2	5.4	0	2.5		
Transformed thickness z_b, z_t		2.1, 4.2	5.4, 5.4	0, 0	2.5, 2.5		
Critical gradient i_c		0.8	0.8	0.8	0.8		
Critical head, $h_c = i_c z_t$		3.4	4.3	0	2.0		
Critical head el		547.6	546.4	539.7	542.5		
High-water observation date	1965						
River stage el	552.7						
Seepage observation*		1b	1b	1d	1b		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	549.5						
Seepage observation*		1b	2c	1d	2c		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	551.1						
Seepage observation*		1b	1b	1d	2b		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 34 (Concluded)

Location identification	Piez. MB-4	Piez. MB-5	Toe	Low Spot		
Distance from levee center line, ft	91	594	138	400		
Ground el	544.2	542.1	539.7	540.5		
Critical head, $h_c = i_c z_t$	3.4	4.3	0	2.0		
Critical head el	547.6	546.4	539.7	542.5		
High-water observation date 12 Apr 79						
River stage el 546.27						
Seepage observation*	2b	2b	2b	2b		
Estimated pressure head el	544.1	543.1	544.0	543.5		
Pressure head above ground h_x, ft	-0.1	1.0	4.3	3.0		
Factor of safety h_c/h_x	-	4.3	0	0.7		
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 558.5						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 35

Piezometer Data and Calculated Seepage Source and Exit Distances, Muscatine Island, Range MC

Date	River Stage el	Piezometer No. and Elevation Head MC-1	MC-2	MC-3	MC-4	MC-5			Seepage Distance Source s* ft	Exit x_3* ft
23 Mar 79	545.30	540.37	Dry	Dry	537.35	533.22			273	-
12 Apr 79	545.87	538.87	546.01	540.26	538.05	536.82			970	-

Projection to Levee Crest Elevations

	Levee Crest el									
1979	557.7									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 36

Performance Observations and Calculated Factors of Safety, Muscatine Island, Range MC

Location identification		Piez. MC-4	Piez. MC-5	Toe	Low Spot	Bottom of Ditch	
Distance from levee center line, ft		96	593	103	200	150	
Ground el		541.7	538.4	540.4	538.6	534.3	
Bottom of top stratum el		535.3	535.0	535.3	536.5	534.3	
Top stratum thickness z		6.4	3.4	5.1	2.1	0	
Transformed thickness z_b, z_t		6.4, 6.4	3.4, 3.4	5.1, 5.1	2.1, 2.1	0, 0	
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$		5.1	2.7	4.1	1.7	0	
Critical head el		546.8	541.1	544.5	540.3	534.3	
High-water observation date	1965						
River stage el	552.1						
Seepage observation*		1b	1b	1b	1b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	548.9						
Seepage observation*		1b	1b	1b	1b	3b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	550.4						
Seepage observation*		1b	1b	1b	1b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 36 (Concluded)

Location identification	Piez. MC-4	Piez. MC-5	Toe	Low Spot	Bottom of Ditch	
Distance from levee center line, ft	96	593	103	200	150	
Ground el	541.7	538.4	540.4	538.6	534.3	
Critical head, $h_c = i_c z_t$	5.1	2.7	4.1	1.7	0	
Critical head el	546.8	541.1	544.5	540.3	534.3	
High-water observation date 12 Apr 79						
River stage el 545.87						
Seepage observation*	1a	1a	1a	1a	2b	
Estimated pressure head el	538.0	533.2	537.9	537.0	537.5	
Pressure head above ground h_x, ft	-3.7	-5.2	-2.5	-1.6	3.2	
Factor of safety h_c/h_x	-	-	-	-	0	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 557.7						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 37

Piezometer Data and Calculated Seepage Source and Exit Distances, Green Bay, Range GBA

Date	River Stage el	Piezometer No. and Elevation Head							Seepage Distance	
		GBA-1	GBA-2	GBA-3					Source s* ft	Exit x_3* ft
12 Apr 79	527.10	520.96	520.45	516.93					746	40
		Projection to Levee Crest Elevations								
	Levee Crest el									
1979	533.5									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 38

Performance Observations and Calculated Factors of Safety, Green Bay, Range GBA

Location identification		Piez. GBA-2	Piez. GBA-3		Berm Toe	Low Spot #1	Low Spot #2
Distance from levee center line, ft		49.5	79.2		100	200	700
Ground el		523.3	519.6		520.0	519.2	518.4
Bottom of top stratum el		507.5	509.7		507.7	508.0	509.6
Top stratum thickness z		15.8	9.9		12.3	11.2	8.8
Transformed thickness z_b, z_t		11.3, 15.8	9.9, 9.9		12.3, 12.3	11.2, 11.2	8.8, 8.8
Critical gradient i_c		0.8	0.8		0.8	0.8	0.8
Critical head, $h_c = i_c z_t$		12.6	7.9		9.8	9.0	7.0
Critical head el		535.9	527.5		529.8	528.2	525.4
High-water observation date	1969						
River stage el	527.3						
Seepage observation*		1a	1a		1a	1a	1a
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	530.8						
Seepage observation*		1b	1b		1d	1b	1b
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	12 Apr 79						
River stage el	527.10						
Seepage observation*		1b	1b		1b	2b	2b
Estimated pressure head el		520.4	516.9		520.2	519.7	517.3
Pressure head above ground h_x, ft		-2.9	-2.7		0.2	0.5	-1.1
Factor of safety h_c/h_x		-	-		61	18	-

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 38 (Concluded)

Location identification	Piez. GBA-2	Piez. GBA-3		Berm Toe	Low Spot #1	Low Spot #2
Distance from levee center line, ft	49.5	792		100	200	700
Ground el	523.3	519.6		520.0	519.2	518.4
Critical head, $h_c = i_c z_t$	12.6	7.9		9.8	9.8	7.0
Critical head el	535.9	527.5		529.8	528.2	525.4
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 533.5						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 39

Piezometer Data and Calculated Seepage Source and Exit Distances, Green Bay, Range GBB

Date	River Stage el	Piezometer No. and Elevation Head							Seepage Distance	
		GBB-1	GBB-2	GBB-3	GBB-4	GBB-5	GBB-6	GBB-7	Source s* ft	Exit x_3* ft
12 Apr 79	524.90	517.90	523.15	521.17	517.35	516.34	516.10	514.78	1355	142
Projection to Levee Crest Elevations										
	Levee Crest el									
1979	530.0									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 40

Performance Observations and Calculated Factors of Safety, Green Bay, Range GBB

Location identification		Levee Toe & Piez. GBB-4	Piez. GBB-5	Piez. GBB-6	Piez. GBB-7	Bottom of Ditch	Bottom of Road Ditch
Distance from levee center line, ft		82	184	237	382	206	396
Ground el		520.0	517.3	516.7	516.4	511.8	514.0
Bottom of top stratum el		501.8	504.2	505.0	502.6	504.5	502.5
Top stratum thickness z		18.2	13.1	11.7	13.8	7.3	11.5
Transformed thickness z_b, z_t		15.6, 18.2	13.1, 13.1	11.7, 11.7	13.8, 13.8	7.3, 7.3	11.5, 11.5
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$		14.6	10.5	9.4	11.0	5.8	9.2
Critical head el		534.6	527.8	526.1	527.4	517.6	523.2
High-water observation date	1965						
River stage el	528.0						
Seepage observation*		1b	1b	1b	1b	4b	1b
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	525.7						
Seepage observation*		1e	1b	1b	1b	1b	1b
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	528.6						
Seepage observation*		1b	1b	1b	1b	4b	1b
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 40 (Concluded)

Location identification	Levee Toe & Piez. GBB-4	Piez. GBB-5	Piez. GBB-6	Piez. GBB-7	Bottom of Ditch	Bottom of Road Ditch
Distance from levee center line, ft	82	184	237	382	206	396
Ground el	520.0	517.3	516.7	516.4	511.8	514.0
Critical head, $h_c = i_c z_t$	14.6	10.5	9.4	11.0	5.8	9.2
Critical head el	534.6	527.8	526.1	527.4	517.6	523.2
High-water observation date 12 Apr 79						
River stage el 524.90						
Seepage observation*	1b	2b	1b	1b	1b	1b
Estimated pressure head el	517.4	516.3	516.1	514.8	516.2	514.7
Pressure head above ground h_x, ft	-2.6	-1.0	-0.6	-1.6	4.4	0.7
Factor of safety h_c/h_x	-	-	-	-	1.3	13.1
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 530.0						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 41

Piezometer Data and Calculated Seepage Source and Exit Distances, Fabius River, Range FA

Date	River Stage el	Piezometer No. and Elevation Head FA-1L	FA-1U	FA-2	FA-3	FA-4	FA-5		Seepage Distance Source s* ft	Exit x_3* ft
11 Apr 79	480.31	476.11	482.18	482.10	477.78	475.46	473.26		829	53

Projection to Levee Crest Elevations

	Levee Crest el									
1979	489.8									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 42

Performance Observations and Calculated Factors of Safety, Fabius River, Range FA

Location identification		Piez. FA-4	Piez. FA-5	Berm Toe	Other		
Distance from levee center line, ft		91	641	114			
Ground el		479.0	472.2	475.6			
Bottom of top stratum el		464.9	462.2	464.8			
Top stratum thickness z		14.1	10.0	10.8			
Transformed thickness z_b, z_t		12.4, 14.1	10.0, 10.0	10.8, 10.8			
Critical gradient i_c		0.8	0.8	0.8			
Critical head, $h_c = i_c z_t$		11.3	8.0	8.6			
Critical head el		490.3	480.2	484.2			
High-water observation date	1965						
River stage el	483.9						
Seepage observation*		1b	1b	1d			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	479.5						
Seepage observation*		1b	1b	1b			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	487.9	Overtopped					
Seepage observation*							
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 42 (Concluded)

Location identification	Piez. FA-4	Piez. FA-5	Berm Toe			
Distance from levee center line, ft	91	641	114			
Ground el	479.0	472.2	475.6			
Critical head, $h_c = i_c z_t$	11.3	8.0	8.6			
Critical head el	490.3	480.2	484.2			
High-water observation date 11 Apr 79						
River stage el 480.31						
Seepage observation*	1b	2b-3a	1a			
Estimated pressure head el	475.5	473.3	475.4			
Pressure head above ground h_x, ft	-3.5	1.1	-0.2			
Factor of safety h_c/h_x	-	7.3	-			
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 489.8						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 43

Piezometer Data and Calculated Seepage Source and Exit Distances, Fabius River, Range FB

Date	River Stage el	Piezometer No. and Elevation Head FB-1	FB-2	FB-3	FB-4				Seepage Distance Source s* ft	Exit x_3* ft
10 Apr 79	478.01	470.61	469.02	468.90	468.31				561	148

Projection to Levee Crest Elevations

	Levee Crest el									
1979	487.0									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 44

Performance Observations and Calculated Factors of Safety, Fabius River, Range FB

Location identification		Toe & Piez. FB-2	Piez. FB-3	Piez. FB-4	Low Spot	Center Line of Ditch	Other
Distance from levee center line, ft		93	291	490	126	196	
Ground el		467.1	466.5	466.6	465.2	465.2	
Bottom of top stratum el		460.3	461.2	461.3	460.5	460.7	
Top stratum thickness z		6.8	5.3	5.3	4.7	4.5	
Transformed thickness z_b, z_t		6.8, 6.8	5.3, 5.3	5.3, 5.3	4.7, 4.7	4.5, 4.5	
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$		5.4	4.2	4.2	3.8	3.6	
Critical head el		472.5	470.7	470.8	469.0	468.8	
High-water observation date	1965						
River stage el	481.3						
Seepage observation*		1b	1b	1b	4b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	477.0						
Seepage observation*		1b	1b	1b	4b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el		Overtopped					
Seepage observation*							
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 44 (Concluded)

Location identification	Toe & Piez. FB-2	Piez. FB-3	Piez. FB-4	Low Spot	Center Line of Ditch	Other
Distance from levee center line, ft	93	291	490	126	196	
Ground el	467.1	466.5	466.6	465.2	465.2	
Critical head, $h_c = i_c z_t$	5.4	4.2	4.2	3.8	3.6	
Critical head el	472.5	470.7	470.8	469.0	468.8	
High-water observation date 10 Apr 79						
River stage el 478.01						
Seepage observation*	1d	1b	1b	4b	1b	
Estimated pressure head el	469.0	468.9	468.3	469.0	469.0	
Pressure head above ground h_x, ft	1.9	2.4	1.7	3.8	3.8	
Factor of safety h_c/h_x	2.8	1.8	2.5	1.0	0.9	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 487.0						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 45

Piezometer Data and Calculated Seepage Source and Exit Distances, South Quincy, Range SQ

Date	River Stage el	Piezometer No. and Elevation Head SQ-1L	SQ-1U	SQ-2	SQ-3	SQ-4	SQ-5		Seepage Distance Source s* ft	Exit x_3* ft
11 Apr 79	477.48	473.78	479.58	481.50	473.49	472.38	468.42		378	86
13 Apr 79	478.78	474.68	Dry	478.60	473.69	472.88	468.52		344	84
Projection to Levee Crest Elevations										
	Levee Crest el									
1979	486.2	479.8				475.7	469.1		277	79
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 46

Performance Observations and Calculated Factors of Safety, South Quincy, Range SQ

Location identification		Piez. SQ-4	Piez. SQ-5	Levee Toe	Bottom of Ditch	Point Beyond Toe	
Distance from levee center line, ft		100	592	139	652	300	
Ground el		473.5	468.0	470.6	466.7	470.6	
Bottom of top stratum el		465.8	460.7	465.3	460.2	463.6	
Top stratum thickness z		7.7	7.3	5.3	6.5	7.0	
Transformed thickness z_b, z_t		4.4, 7.7	7.3, 7.3	5.3, 5.3	6.5, 6.5	7.0, 7.0	
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$		6.2	5.8	4.2	5.2	5.6	
Critical head el		479.7	473.8	474.8	471.9	476.2	
High-water observation date	1965						
River stage el	480.6						
Seepage observation*		1b	1b	1b	1b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	476.4						
Seepage observation*		1b	1b	1e	1b	3b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	484.1						
Seepage observation*		1b	1b	1d	2b	3b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 46 (Concluded)

Location identification	Piez. SQ-4	Piez. SQ-5	Levee Toe	Bottom of Ditch	Point Beyond Toe	
Distance from levee center line, ft	100	592	139	652	300	
Ground el	473.5	468.0	470.6	466.7	470.6	
Critical head, $h_c = i_c z_t$	6.2	5.8	4.2	5.2	5.6	
Critical head el	479.7	473.8	474.8	471.9	476.2	
High-water observation date 11 Apr 79						
River stage el 477.48						
Seepage observation*	1b	2c	1b	1b	4a-2c	
Estimated pressure head el	472.4	468.4	472.0	467.9	470.8	
Pressure head above ground h_x, ft	-1.1	0.4	1.4	1.2	0.2	
Factor of safety h_c/h_x	-	14.5	3.0	4.3	28.0	
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 486.2						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 47

Piezometer Data and Calculated Seepage Source and Exit Distances, South River, Range SRA

Date	River Stage el	Piezometer No. and Elevation Head SRA-1	SRA-2	SRA-3	SRA-4	SRA-5			Seepage Distance Source s* ft	Exit x_3* ft
22 Mar 79	470.47	467.59	Dry	Dry	467.20	465.82			-	-
10 Apr 79	474.79	469.79	467.10	472.21	469.20	466.72			595	-
13 Apr 79	476.29	470.39	470.39	472.26	469.70	466.97			600	19
		Projection to Levee Crest Elevations								
	Levee Crest el									
1979	483.0	473.2			472.3	468.2			745	192
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 48

Performance Observations and Calculated Factors of Safety, South River, Range SRA

Location identification		Piez. SRA-4	Piez. SRA-5	Levee Toe	Ditch	Road Ditch	
Distance from levee center line, ft		67	605	75	180	525	
Ground el		471.0	467.8	470.0	465.8	466.6	
Bottom of top stratum el		463.0	460.2	463.0	462.5	460.6	
Top stratum thickness z		8.0	7.6	7.0	3.3	6.0	
Transformed thickness z_b, z_t		5.0, 8.0	7.6, 7.6	5.0, 7.0	3.3, 3.3	6.0, 6.0	
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$		6.4	6.1	5.6	2.6	4.8	
Critical head el		477.4	473.9	475.6	468.4	471.4	
High-water observation date	1965						
River stage el	478.6						
Seepage observation*		1b	1b	1e	1b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	474.2						
Seepage observation*		1b	1b	1b	1b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	482.1						
Seepage observation*		1b	1b	1e	1b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 48 (Concluded)

Location identification	Piez. SRA-4	Piez. SRA-5	Levee Toe	Ditch	Road Ditch	
Distance from levee center line, ft	67	605	75	180	525	
Ground el	471.0	467.8	470.0	465.8	466.6	
Critical head, $h_c = i_c z_t$	6.4	6.1	5.6	2.6	4.8	
Critical head el	477.4	473.9	475.6	478.4	471.4	
High-water observation date 13 Apr 79						
River stage el 476.29						
Seepage observation*	1b	2b	1b	1b	2b	
Estimated pressure head el	469.7	467.0	469.7	469.1	467.4	
Pressure head above ground h_x, ft	-1.3	-0.8	-0.3	3.3	0.8	
Factor of safety h_c/h_x	-	-	-	0.8	6.0	
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 483.0						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 49

Piezometer Data and Calculated Seepage Source and Exit Distances, South River, Range SRB

Date	River Stage el	Piezometer No. and Elevation Head SRB-1	SRB-2	SRB-3	SRB-4	SRB-5			Seepage Distance Source s* ft	Exit x_3* ft
22 Mar 79	470.76	467.11	Dry	Dry	466.63	464.35			576	-
10 Apr 79	474.41	469.81	474.98	469.29	468.43	464.85			290	-
13 Apr 79	476.06	470.66	474.98	469.69	469.13	465.15			303	5.7
Projection to Levee Crest Elevations										
	Levee Crest el									
1979	482.2	473.8			471.6	466.0			323	49
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 50

Performance Observations and Calculated Factors of Safety, South River, Range SRB

Location identification		Piez. SRB-4	Piez. SRB-5	Berm Toe	Low Spot		
Distance from levee center line, ft		63	534	110	400		
Ground el		471.5	468.2	469.4	465.5		
Bottom of top stratum el		458.0	458.4	458.0	458.2		
Top stratum thickness z		13.5	9.8	11.4	7.3		
Transformed thickness z_b, z_t		9.7, 13.5	2.3, 9.8	9.7, 11.4	7.3, 7.3		
Critical gradient i_c		0.8	0.8	0.8	0.8		
Critical head, $h_c = i_c z_t$		10.8	7.8	9.1	5.8		
Critical head el		482.3	476.0	478.5	471.3		
High-water observation date	1965						
River stage el	478.3						
Seepage observation*		1a	1a	1a	1a		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	473.9						
Seepage observation*		1b	1b	1b	1b		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	481.8						
Seepage observation*		1a	1b	1d	3a		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 50 (Concluded)

Location identification	Piez. SRB-4	Piez. SRB-5	Berm Toe	Low Spot		
Distance from levee center line, ft	63	534	110	400		
Ground el	471.5	468.2	469.4	465.5		
Critical head, $h_c = i_c z_t$	10.8	7.8	9.1	5.8		
Critical head el	482.3	476.0	478.5	471.3		
High-water observation date 13 Apr 79						
River stage el 476.06						
Seepage observation*	1b	1b	1a	2b		
Estimated pressure head el	469.1	465.2	468.7	466.3		
Pressure head above ground h_x, ft	-2.4	-3.0	-0.7	0.8		
Factor of safety h_c/h_x	-	-	-	7.2		
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 482.2						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 51

Piezometer Data and Calculated Seepage Source and Exit Distances, South River, Range SRC

Date	River Stage el	Piezometer No. and Elevation Head SRC-1	SRC-2	SRC-3	SRC-4	SRC-5			Seepage Distance Source s* ft	Exit x_3* ft
10 Apr 79	472.60	468.60	472.46	467.68	467.96	465.09			606	47
13 Apr 79	474.30	469.65	472.41	467.73	468.76	465.59			522	104
		Projection to Levee Crest Elevations								
	Levee Crest el									
1979	480.2	473.3			471.8	467.5			460	223
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 52

Performance Observations and Calculated Factors of Safety, South River, Range SRC

Location identification		Piez. SRC-4	Piez. SRC-5	Levee Toe	Edge of Ditch		
Distance from levee center line, ft		88	591	100	510		
Ground el		469.7	464.8	468.3	461.5		
Bottom of top stratum el		459.7	451.7	459.5	453.1		
Top stratum thickness z		10	13.1	8.8	8.4		
Transformed thickness z_b, z_t		5.6, 10	7.5, 13.1	5.8, 8.8	2.8, 8.4		
Critical gradient i_c		0.8	0.8	0.8	0.8		
Critical head, $h_c = i_c z_t$		8.0	10.5	7.0	6.7		
Critical head el		477.7	475.3	475.3	468.2		
High-water observation date	1965						
River stage el	476.2						
Seepage observation*		1b	1b	1b	4a		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	471.7						
Seepage observation*		1b	1b	1b	1b		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	480.0						
Seepage observation*		1b	1b	1d	1b		
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 52 (Concluded)

Location identification	Piez. SRC-4	Piez. SRC-5	Levee Toe	Edge of Ditch		
Distance from levee center line, ft	88	591	100	510		
Ground el	469.7	464.8	468.3	461.5		
Critical head, $h_c = i_c z_t$	8.0	10.5	7.0	6.7		
Critical head el	477.7	475.3	475.3	468.2		
High-water observation date 13 Apr 79						
River stage el 474.30						
Seepage observation*	1b	1b	1b	2c		
Estimated pressure head el	468.8	465.6	468.7	466.1		
Pressure head above ground h_x, ft	-0.9	0.8	0.4	4.6		
Factor of safety h_c/h_x	-	13.1	17.5	1.5		
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 480.2						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

AD-A083 138 ARMY ENGINEER WATERWAYS EXPERIMENT STATION VICKSBURG--ETC F/G 13/2
DOCUMENTATION AND ANALYSIS OF ROCK ISLAND UNDERSEEPAGE DATA.(U)
MAR 80 R W CUNNY NCR-IA-78-C17
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Table 53

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range SA

Date	River Stage el	Piezometer No. and Elevation Head SA-1	SA-2	SA-3	SA-4	SA-5	SA-6		Seepage Distance Source s* ft	Exit x_3* ft
14 Apr 79	464.62	460.02	461.14	460.28	459.08	457.68	-		549	244

Projection to Levee Crest Elevations

	Levee Crest el									
1979	471.0									
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 54

Performance Observations and Calculated Factors of Safety, Sny Island, Range SA

Location identification		Levee Toe & Piez. SA-4	Piez. SA-5	Piez. SA-6	Old Toe	Beyond Toe	New Berm Toe**
Distance from levee center line, ft		78	208	813	120	150	232
Ground el		460.8	459.5	452.5	454.0	454.0	453.7
Bottom of top stratum el		444.0	444.3	442.1	444.1	444.2	444.3
Top stratum thickness z		16.8	15.2	10.4	9.9	9.8	9.4
Transformed thickness z_b, z_t		5.0, 13.3	14.0, 14.0	8.8, 8.8	7.1, 7.1	7.7, 7.7	8.3, 8.3
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	0.8
Critical head, $h_c = i_c z_t$		10.6	11.2	7.0	5.7	6.2	6.6
Critical head el		471.4	470.7	459.5	459.7	460.2	460.3
High-water observation date	1965						
River stage el	465.9						
Seepage observation*		1b	1b	1b	1b	1b	-
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	464.3						
Seepage observation*		1b	1b	1b	1b	3a	-
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	471.0						
Seepage observation*		1b	1b	1b	4b & 4c	4b & 4c	-
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage
2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee
3a - Light seepage beyond toe
3b - Heavy seepage beyond toe
4a - Pin boils
4b - Sand boils
4c - Large boils

** Large berm was built in 1974.

Table 54 (Concluded)

Location identification	Levee Toe & Piez. SA-4	Piez. SA-5	Piez. SA-6	Old Toe	Beyond Toe	New Berm Toe
Distance from levee center line, ft	78	208	813	120	150	232
Ground el	460.8	459.5	452.5	454.0	454.0	453.7
Critical head, $h_c = i_c z_t$	10.6	11.2	7.0	5.7	6.2	0.6
Critical head el	471.4	470.7	459.5	459.7	460.2	460.3
High-water observation date 10 Apr 79						
River stage el 462.92						
Seepage observation*	1b	1b	2c-3a	-	-	4a
Estimated pressure head el	460.3	457.1	453.2			456.5
Pressure head above ground h_x, ft	-0.5	-2.4	0.7			2.8
Factor of safety h_c/h_x	-	-	10			2.3
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 471.0						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 55

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range SB

Date	River Stage el	Piezometer No. and Elevation Head SB-1	SB-2	SB-3	SB-4	SB-5			Seepage Distance Source s* ft	Exit x_3* ft
21 Mar 79	456.69	453.88	Dry	Dry	453.09	452.07			419	325
10 Apr 79	462.01	457.48	457.13	454.84	455.79	454.17			339	299
14 Apr 79	463.78	459.08	458.58	456.64	456.74	454.97			277	253
Projection to Levee Crest Elevations										
	Levee Crest el									
1979	469.6	463.0			459.6	456.8			271	252
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 56

Performance Observations and Calculated Factors of Safety, Sny Island, Range SB

Location identification		Toe & Piez. SB-4	Piez. SB-5	Ditch	Slough	Beyond Toe	
Distance from levee center line, ft		100	353	205	215	115	
Ground el		453.2	452.2	448.8	450.3	452.8	
Bottom of top stratum el		446.5	445.0	445.8	445.8	446.8	
Top stratum thickness z		6.7	7.2	3.0	4.5	6.0	
Transformed thickness z_b, z_t		3.5, 6.7	7.2, 7.2	3.0, 3.0	4.5, 4.5	3.2, 6.0	
Critical gradient i_c		0.8	0.8	0.8	0.8	0.8	
Critical head, $h_c = i_c z_t$		5.4	5.8	2.4	3.6	4.8	
Critical head el		458.6	458.0	451.2	453.9	457.6	
High-water observation date	1965						
River stage el	464.4						
Seepage observation*		1b	1b	1b	1b	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	463.5						
Seepage observation*		1b	1b	1b	3a	1b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	469.3						
Seepage observation*		1c	1b	1b	1b	4b	
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 56 (Concluded)

Location identification	Toe & Piez. SB-4	Piez. SB-5	Ditch	Slough	Beyond Toe	
Distance from levee center line, ft	100	353	205	215	115	
Ground el	453.2	452.2	448.8	450.3	452.8	
Critical head, $h_c = i_c z_t$	5.4	5.8	2.4	3.6	4.8	
Critical head el	458.6	458.0	451.2	453.9	457.6	
High-water observation date 10 Apr 79						
River stage el 462.01						
Seepage observation*	lb	lb	lb	lb	lb	
Estimated pressure head el	455.8	454.2	455.1	455.1	455.7	
Pressure head above ground h_x, ft	2.6	2.0	6.3	4.8	2.9	
Factor of safety h_c/h_x	2.1	2.9	0.4	0.8	1.7	
High-water observation date _____						
River stage el _____						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 469.6						
Projected pressure head, el	459.6	457.2	458.6	458.5	459.4	
Pressure head above ground h_x, ft	6.4	5.0	9.8	8.2	6.6	
Factor of safety h_c/h_x	0.8	1.2	0.2	0.4	0.7	

Table 57

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range SC

Date	River Stage el	Piezometer No. and Elevation Head SC-1	SC-2	SC-3	SC-4	SC-5			Seepage Distance Source s* ft	Exit x_3* ft
21 Mar 79	460.35	(?)453.23	Dry	457.68	453.16	449.04			5884	-
10 Apr 79	460.03	457.03	458.29	457.68	456.86	454.84			1092	427
14 Apr 79	462.33	458.78	459.29	458.53	458.46	456.14			718	498
		Projection to Levee Crest Elevations								
	Levee Crest el									
1979	468.5	463.4			462.9	459.6			667	815
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 58

Performance Observations and Calculated Factors of Safety, Sny Island, Range SC

Location identification		Piez. SC-4	Piez. SC-5	Berm Toe			
Distance from levee center line, ft		71	559	170			
Ground el		459.0	454.0	455.2			
Bottom of top stratum el		443.4	434.7	441.7			
Top stratum thickness z		15.6	19.3	13.5			
Transformed thickness z_b, z_t		9.5, 15.6	17.6, 18.5	13.4, 13.5			
Critical gradient i_c		0.8	0.8	0.8			
Critical head, $h_c = i_c z_t$		12.5	14.8	10.8			
Critical head el		471.5	468.8	466.0			
High-water observation date	1965						
River stage el	463.0						
Seepage observation*		1b	1b	1b			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	462.3						
Seepage observation*		1a	1a	1a			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	467.9						
Seepage observation*		1c	1b	1b			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 58 (Concluded)

Location identification	Piez. SC-4	Piez. SC-5	Berm Toe			
Distance from levee center line, ft	71	559	170			
Ground el	459.0	454.0	455.2			
Critical head, $h_c = i_c z_t$	12.5	14.8	10.8			
Critical head el	471.5	468.8	466.0			
High-water observation date 10 Apr 79						
River stage el 460.03						
Seepage observation*	1b	2b	1d			
Estimated pressure head el	456.9	454.8	456.5			
Pressure head above ground h_x, ft	-2.1	0.8	1.3			
Factor of safety h_c/h_x	-	18.5	8.3			
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 468.5						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 59

Piezometer Data and Calculated Seepage Source and Exit Distances, Sny Island, Range SD

Date	River Stage el	Piezometer No. and Elevation Head SD-1	SD-2	SD-3	SD-4	SD-5			Seepage Distance Source s* ft	Exit x_3* ft
21 Mar 79	454.84	451.60	Dry	453.39	451.52	450.16			3444	-
10 Apr 79	459.80	454.60	460.04	453.69	454.52	452.26			5478	1058
14 Apr 79	461.90	456.50	460.14	455.09	456.02	453.86			1017	436
Projection to Levee Crest Elevations										
	Levee Crest el									
1979	468.0	460.8			460.0	457.1			830	674
New										

* Calculated values for s and x_3 are based on 1979 landside toe location and average ground elevation.

Table 60

Performance Observations and Calculated Factors of Safety, Sny Island, Range SD

Location identification		Levee Toe & Piez. SD-4	Piez. SD-5	Low Spot			
Distance from levee center line, ft		89	560	595			
Ground el		454.7	451.2	446.0			
Bottom of top stratum el		439.5	435.5	535.2			
Top stratum thickness z		15.2	15.7	10.8			
Transformed thickness z_b, z_t		11.2, 15.2	15.7, 15.7	10.8, 10.8			
Critical gradient i_c		0.8	0.8	0.8			
Critical head, $h_c = i_c z_t$		12.2	12.6	8.6			
Critical head el		466.9	463.8	454.6			
High-water observation date	1965						
River stage el	462.4						
Seepage observation*		1b	1b	1b			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1969						
River stage el	461.8						
Seepage observation*		1b	2c	1b			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							
High-water observation date	1973						
River stage el	467.4						
Seepage observation*		1c	1b	1b			
Estimated pressure head el							
Pressure head above ground h_x, ft							
Factor of safety h_c/h_x							

(Continued)

* Code performance:

1a - Reported dry
1b - No seepage reported
1c - Through seepage
1d - Light toe seepage
1e - Heavy toe seepage

2a - Berm wet
2b - Water standing in low areas
2c - Fields wet or soft behind levee

3a - Light seepage beyond toe
3b - Heavy seepage beyond toe

4a - Pin boils
4b - Sand boils
4c - Large boils

Table 60 (Concluded)

Location identification	Levee Toe & Piez. SD-4	Piez. SD-5	Low Spot			
Distance from levee center line, ft	89	560	595			
Ground el	454.7	451.2	446.0			
Critical head, $h_c = i_c z_t$	12.2	12.6	8.6			
Critical head el	466.9	463.8	454.6			
High-water observation date 10 Apr 79						
River stage el 459.80						
Seepage observation*	1a	2b	2b			
Estimated pressure head el	454.5	452.3	452.1			
Pressure head above ground h_x, ft	0	1.1	6.1			
Factor of safety h_c/h_x	-	11.4	1.4			
High-water observation date						
River stage el						
Seepage observation*						
Estimated pressure head el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						
Projected performance						
River stage (new levee crest) el 468.0						
Projected pressure head, el						
Pressure head above ground h_x, ft						
Factor of safety h_c/h_x						

Table 61

Summary of Basic Data for Calculation of Landside Permeability Ratios for Old Sites with Complete Piezometer Data

Levee District and Range	Dist. from Center Line: River-side Piez. ft	Dist. from Center Line: Land-side Toe Piez. ft	Dist. from Center Line: Land-side Toe ft	Projected Piez. Pressure: River-side Piez.	Projected Piez. Pressure: Land-side Toe Piez.	Avg. Ground el	Eff. Seepage Exit Dist. x_3* ft	Trans. Landside Top-Stratum Thick-ness $z_{b\ell}$ ft	Perv. Sub-stratum Thick-ness d ft	Landside Permeability Ratio $k_f/k_{b\ell}$**
Bay Island										
Range C	-9	25	37.5	546.2	545.6	542.6	158	5.5	135	34
Range D	-13	39	39	545.7	543.5	539.0	106	12.0	130	7.2
Hunt	-8	40	53	492.3	491.4	487.5	195	5.0	112	64
Sny Island										
Range A	-5	28.7	80	471.9	471.3	463.8	370	13.8	110	90
Range F	-14.5	31.5	39	463.6	462.0	458.6	90	7.6	34	31
Range B	-7	35.6	83	462.3	461.2	455.0	193	6.3	110	54
Range H	-16.5	27	69	459.0	455.1	449.0	26	6.1	105	1.1

* Determined from observed piezometric pressures projected to old crest elevation.

** $k_f/k_{b\ell} = (x_3)^2/z_{b\ell}d$.

Table 62

Summary of Basic Data for Calculation of Riverside Permeability Ratios for Old Sites with Complete Piezometer Data

Levee District and Range	Distance from Center line: River-side Toe ft	Distance from Center line: Land-side Toe ft	Dist. to River L_1 ft	Effective Seepage Source s* ft	Effective Blanket: Length x_1 ft	Effective Blanket: Thickness z_{br} ft	c**	Pervious Sub-stratum Thick-ness d ft	Riverside Permeability Ratio k_f/k_{br}†
Bay Island									
Range C	-40	37.5	670	307	229.5	10	0.00433	135	40
Range D	-50	39	135	203	114	12	0.00501	130	20
Hunt	-50	53	1300	445	342	5	0.00292	112	209
Sny Island									
Range A	-43	80	159	225	102	6	0.00861	110	20
Range F	-65	39	495	207	103	4	0.00971	34	78
Range B	-85	83	157	288	120	4.6	0.00632	110	50
Range H	-48	69	677	157	40	5	0.02500	105	3.0

* Determined from observed piezometric pressures projected to old crest elevation.

** A constant determined from the equation $x_1 = \frac{\tanh(cL_1)}{c}$.

† $k_f/k_{br} = 1 \Big/ \left[(c^2)(z_{br}d)\right]$.

Table 63

Summary of Permeability Ratios for Old Sites with Complete Piezometer Data

Levee District and Range	Permeability Ratio Landside $k_f/k_{b\ell}$	Permeability Ratio Riverside k_f/k_{br}	Top-Stratum Permeability Ratio $k_{b\ell}/k_{br}$
Bay Island			
Range C	34	40	1.2
Range D	7.2	20	2.8
Hunt	64	209	3.3
Sny Island			
Range A	90	20	0.2
Range F	31	78	2.5
Range B	54	50	0.9
Range H	1.1	3.0	2.7
Suggested for design	100		2

Table 64

Summary of Top-Stratum Thickness and Permeability Ratios for Old Levee Sections at Old Piezometer Range Sites

Levee District and Range	Top-Stratum Transformed Thickness		Permeability Ratio, k_f/k_b							
			LMVD 1956 Criteria		RID 1960 Design		WES 1979 Calculated		WES 1979 Suggested	
	Land-side $z_{b\ell}$	River-side z_{br}	Land-side*	River-side**	Land-side	River-side	Land-side	River-side	Land-side	River-side
Muscatine Island	4.0	4.5	250	1560	100	200	-	-	100	200
Bay Island										
Range C	5.5	10	400	2500	100	400	34	44	100	200
Range D	12.0	12	800	6250	400	1600	7.2	19	100	200
Iowa River	5.0	5.5	400	2500	100	400	-	-	100	200
Green Bay	8.0	7	400	2500	100	400	-	-	100	200
Hunt	5.0	5	400	2500	100	400	64	212	100	200
Fabius River	8.7	9	400	2500	100	400	-	-	100	200
South Quincy	4.8	0.3	250	180	60	800	-	-	100	200
Sny Island										
Range A	13.8	6	800	2500	400	1600	90	20	100	200
Range F	7.6	4	400	1560	100	400	31	78	100	200
Range B	6.3	4.6	400	1560	100	400	54	50	100	200
Range G	5.0	5.5	400	2500	100	400	-	-	100	200
Range H	6.1	5	400	2500	100	400	1.1	3.0	100	200
Range I	12.6	5	800	2500	400	400	-	-	100	200

* From TM 3-424, Table 38, page 265 (see footnote on page 20).
** From TM 3-424, Table 37, page 256 (see footnote on page 20).

Table 65

Summary of Basic Data for Calculation of Piezometric Pressures and Berm Widths for New Levee Sections at Old Piezometer Range Sites

Levee District and Range	New Crest el	Dist. from Center Line of Levee: River-side Toe ft	Dist. from Center Line of Levee: Land-side Toe ft	Avg. Ground el	Net Head H ft	Top Stratum Transformed Thickness: $z_{b\ell}$ ft	Top Stratum Transformed Thickness: z_{br} ft	Top Stratum Transformed Thickness: z_t ft	Pervious Sub-stratum Thick-ness d ft	Dist. to River L_1 ft	Base Width of Levee L_2 ft
Muscatine Island	558.4	-55	148	540.2	18.2	5.6	4.5	7.8	93	200	203
Bay Island											
Range C	556.6	-68	65	542.7	13.9	5.6	10	5.6	135	670	133
Range D	555.4	-52	86	540.0	15.4	13.1	12	13.1	130	135	138
Iowa River	543.5	-45	108	527.9	15.6	4.5	5.5	4.5	114	195	153
Green Bay	529.9	-65	112	517.1	12.8	8.9	7	8.9	88	490	177
Hunt	501.5	-62	77	486.7	14.8	6.2	5	6.2	112	1300	139
Fabius River	489.8	-80	118	475.0	14.8	8.2	9	8.2	117	220	198
South Quincy	482.4	-45	127	465.8	16.6	6.8	0.3	6.8	110	45	172
Sny Island											
Range A	477.2	-43	86	463.8	13.4	13.8	6	14.6	110	159	129
Range F	472.8	-65	150	459.0	13.8	5.4	4	6.6	34	495	215
Range B	472.5	-85	143	455.7	16.8	7.9	4.6	7.9	110	157	228
Range G	470.5	-50	94	455.0	15.5	5.0	5.5	7.2	112	1105	144
Range H	468.4	-48	144	449.0	19.4	6.5	5	6.5	105	677	192
Range I	468.8	-40	75	455.5	13.3	14.4	5	14.4	87	530	115

Table 66

Summary of Basic Data for Calculation of Piezometric Pressures and Berm Widths at New Piezometric Range Sites

Levee District and Range	Levee Crest el	Dist. from Center Line of Levee: River-side Toe ft	Dist. from Center Line of Levee: Land-side Toe ft	Avg. Ground el	Net Head H ft	Top-Stratum Transformed Thickness: $z_{b\ell}$ ft	Top-Stratum Transformed Thickness: z_{br} ft	Top-Stratum Transformed Thickness: z_t ft	Pervious Sub-stratum Thick-ness d ft	Dist. to River L_1 ft	Base Width of Levee L_2 ft
Muscatine Island											
Range MA	560.8	-53	70	550.0	10.8	4.7	1	10.9	77	0	123
Range MB	558.5	-97	138	540.0	18.5	1.0	5	1.0	136	170	235
Range MC	557.7	-90	103	539.0	18.7	5.1	4.6	5.1	125	402	193
Green Bay											
Range GBA	533.5	-30	59	520.0	13.5	11.2	9	14.1	154	505	89
Range GBB	530.0	-48	82	516.5	13.5	14.5	7	18.2	126	349	130
Fabius River											
Range FA	489.8	-91	114	475.0	14.8	10.8	7.9	10.8	109	293	205
Range FB	487.0	-100	100	466.5	20.5	6.8	9	6.8	52	777	200
South Quincy											
Range SQ	486.2	-49	139	470.5	15.7	5.3	14.3	5.3	136	672	198
South River											
Range SRA	483.0	-65	75	469.4	13.6	5.0	11	7.0	46	122	140
Range SRB	482.2	-40	63	470.0	12.2	9.7	13	13.5	54	172	103
Range SRC	480.2	-43	100	467.5	12.7	5.8	10	8.8	113	197	143
Sny Island											
Range SA	471.0	-100	232	453.5	17.5	8.3	6	8.3	110	278	332
Range SB	469.6	-53	100	450.3	19.3	3.5	3.2	6.7	95	59	153
Range SC	468.5	-39	100	455.5	13.0	9.5	8	13.6	86	426	139
Range SD	468.0	-95	89	453.5	14.5	11.2	8.6	15.2	102	124	184

Table 67

Summary of Permeability Ratios and Effective Seepage Distances for New Levee Sections at Old Piezometer Range Sites

Levee District and Range	LMVD 1956 Criteria				RID 1960 Design				WES 1979 Suggested			
	Permeability Ratio k_f/k_b		Seepage Distance		Permeability Ratio k_f/k_b		Seepage Distance		Permeability Ratio k_f/k_b		Seepage Distance	
	Land-side	River-side	Exit x_3 ft	Entr. s ft	Land-side	River-side	Exit x_3 ft	Entr. s ft	Land-side	River-side	Exit x_3 ft	Entr. s ft
Muscatine Island	400	1560	456	399	100	200	228	376	100	200	228	376
Bay Island												
Range C	400	2500	550	775	100	400	275	664	100	200	275	579
Range D	800	6250	1167	273	400	1600	825	273	100	200	413	270
Iowa River	250	2500	358	346	100	400	226	339	100	200	226	330
Green Bay	400	2500	560	643	100	400	280	552	100	200	280	487
Hunt	400	2500	527	1086	100	400	264	608	100	200	264	473
Fabius River	400	2500	619	417	100	400	310	410	100	200	310	403
South Quincy	400	180	547	212	60	800	212	216	100	200	273	213
Sny Island												
Range A	800	2500	1102	287	400	1600	779	287	100	200	390	279
Range F	400	1560	271	579	100	400	135	442	100	200	135	379
Range B	400	1560	590	383	100	400	295	379	100	200	295	373
Range G	400	2500	473	1027	100	400	237	629	100	200	237	494
Range H	400	2500	522	800	100	400	261	605	100	200	261	506
Range I	800	2500	1001	604	400	400	708	471	100	200	354	394

Table 68

Summary of Predicted Piezometric Heads at Landside Toe and Calculated Berm Widths for New Levee Sections at Old Piezometer Range Sites

Levee District and Range	LMVD 1956 Criteria			RID 1960 Design			WES 1979 Suggested		
	Predicted Piez. Head at Toe		Calculated Berm Width	Predicted Piez. Head at Toe		Calculated Berm Width	Predicted Piez. Head at Toe		Calculated Berm Width
	h_o ft	el	X_{sp} ft	h_o ft	el	X_{sp} ft	h_o ft	el	X_{sp} ft
Muscatine Island	9.7	549.9	242	6.9	547.1	25	6.9	547.1	25
Bay Island									
Range C	5.8	548.5	165	4.1	546.8	None	4.5	547.2	None
Range D	12.5	552.5	215	11.6	551.6	87	9.3	549.3	None
Iowa River	7.9	535.8	343	6.2	534.1	162	6.3	534.2	167
Green Bay	6.0	523.0	None	4.3	521.4	None	4.7	521.8	None
Hunt	4.8	491.5	None	4.5	491.2	None	5.3	492.0	20
Fabius River	8.8	483.8	211	6.4	481.4	None	6.4	481.4	None
South Quincy	12.0	477.8	521	8.2	474.4	105	9.3	475.1	179
Sny Island									
Range A	10.6	474.4	None	9.8	473.6	None	7.8	471.6	None
Range F	4.4	463.4	None	3.2	462.2	None	3.6	462.6	None
Range B	10.2	465.9	332	7.4	463.1	51	7.4	463.1	54
Range G	4.9	459.9	None	4.2	459.2	None	5.0	460.0	None
Range H	7.7	456.7	251	5.9	454.9	36	6.6	455.6	76
Range I	8.3	463.8	None	8.0	463.5	None	6.3	461.8	None

Table 69

Summary of Predicted Piezometric Heads at Landside Toe for New Piezometer Range Sites

Levee District and Range	LMVD 1956 Criteria*						WES 1979 Suggested Perm. Ratios					
	Permeability Ratios k_f/k_b		Effective Seepage Distances		Predicted Piezometric Heads at Toe		Permeability Ratios k_f/k_b		Effective Seepage Distances		Predicted Piezometric Heads at Toe	
	Land-side	River-side	Exit x_3 ft	Entr. s ft	h_o ft	el	Land-side	River-side	Exit x_3 ft	Entr. s ft	h_o ft	el
Muscatine Island												
Range MA	250	1650	301	123	7.7	557.7	100	200	190	123	6.6	556.6
Range MB	250	2500	184	404	5.8	545.8	100	200	116	394	4.2	544.2
Range MC	400	1560	505	572	8.8	547.8	100	200	252	474	6.5	545.5
Green Bay												
Range GBA	800	2500	1175	582	9.0	529.0	100	200	415	481	6.3	526.3
Range GBB	800	2500	1209	473	9.7	526.2	100	200	427	416	6.8	523.3
Fabius River												
Range FA	800	2500	970	494	9.8	484.8	100	200	343	457	6.3	481.3
Range FB	400	2500	376	866	6.2	472.7	100	200	188	502	5.6	472.1
South Quincy												
Range SQ	400	6250	537	861	6.0	476.5	100	200	268	691	4.4	474.9
South River												
Range SRA	400	6250	303	262	7.3	476.7	100	200	152	256	5.1	474.5
Range SRB	400	6250	458	275	7.6	477.6	100	200	229	264	5.7	475.7
Range SRC	400	6250	512	340	7.6	475.1	100	200	256	329	5.6	473.1
Sny Island												
Range SA	400	2500	604	606	8.7	462.2	100	200	302	566	6.1	459.6
Range SB	250	1560	288	212	11.1	461.4	100	200	182	211	8.9	459.2
Range SC	400	2500	572	551	6.6	462.1	100	200	286	442	5.1	460.6
Range SD	800	2500	956	308	11.0	464.5	100	200	338	305	7.6	461.1

* From TM 3-424 (see footnote, page 20).

Table 70

Summary of Calculated Berm Widths for New Piezometer Range Sites

Levee District and Range	LMVD 1956 Criteria*					WES 1979 Suggested Perm. Ratios				
	Permeability Ratios k_f/k_b		Effective Seepage Distances		Calculated Berm Width	Permeability Ratios k_f/k_b		Effective Seepage Distances		Calculated Berm Width
	Land-side	River-side	Exit x_3 ft	Entr. s ft	X_{sp} ft	Land-side	River-side	Exit x_3 ft	Entr. s ft	X_{sp} ft
Muscatine Island										
Range MA	250	1650	301	123	None	100	200	190	123	None
Range MB	250	2500	184	404	781	100	200	116	394	407
Range MC	400	1560	505	572	516	100	200	252	474	152
Green Bay										
Range GBA	800	2500	1175	582	None	100	200	415	481	None
Range GBB	800	2500	1209	473	None	100	200	427	416	None
Fabius River										
Range FA	800	2500	970	494	133	100	200	343	457	None
Range FB	400	2500	376	866	59	100	200	188	502	6
South Quincy										
Range SQ	400	6250	537	861	233	100	200	268	691	86
South River										
Range SRA	400	6250	303	262	92	100	200	152	256	None
Range SRB	400	6250	458	275	None	100	200	229	264	None
Range SRC	400	6250	512	340	45	100	200	256	329	None
Sny Island										
Range SA	400	2500	604	606	193	100	200	302	566	None
Range SB	250	1560	288	212	266	100	200	182	211	117
Range SC	400	2500	572	551	None	100	200	286	442	None
Range SD	800	2500	956	308	102	100	200	338	305	None

* From TM 3-424 (see footnote, page 20).

Table 71

Comparison of Predicted Piezometric Heads at Old Piezometer Range Sites

Levee District and Range	Piezometric Head, h_o			h_o Ratio	
	LMVD	RID	WES	WES/LMVD	WES/RID
Muscatine Island	9.7	6.9	6.9	0.71	1.00
Bay Island					
Range C	5.8	4.1	4.5	0.78	1.10
Range D	12.5	11.6	9.3	0.74	0.80
Iowa River	7.9	6.2	6.3	0.80	1.02
Green Bay	6.0	4.3	4.7	0.78	1.09
Hunt	4.8	4.5	5.3	1.10	1.18
Fabius River	8.8	6.5	6.4	0.73	0.98
South Quincy	12.0	8.2	9.3	0.78	1.13
Sny Island					
Range A	10.6	9.8	7.8	0.74	0.80
Range F	4.4	3.2	3.6	0.82	1.13
Range B	10.2	7.4	7.4	0.73	1.00
Range G	4.9	4.2	5.0	1.02	1.19
Range H	7.7	5.9	6.6	0.86	1.12
Range I	8.3	8.0	6.3	0.76	0.79
			Average	0.81	1.02

Table 72

Comparison of Predicted Piezometric Heads at New Piezometer Range Sites

Levee District and Range	Piezometric Head, h_o LMVD Criteria	Piezometric Head, h_o WES Criteria	h_o Ratio WES/LMVD
Muscatine Island			
Range MA	7.7	6.6	0.86
Range MB	5.8	4.2	0.72
Range MC	8.8	6.5	0.74
Green Bay			
Range GBA	9.0	6.3	0.70
Range GBB	9.7	6.8	0.70
Fabius River			
Range FA	9.8	6.3	0.64
Range FB	6.2	5.6	0.90
South Quincy			
Range SQ	6.0	4.4	0.73
South River			
Range SRA	7.3	5.1	0.70
Range SRB	7.6	5.7	0.75
Range SRC	7.6	5.6	0.74
Sny Island			
Range SA	8.7	6.1	0.70
Range SB	11.1	8.9	0.80
Range SC	6.6	5.1	0.77
Range SD	11.0	7.6	0.69
		Average	0.74

Table 73

Comparison of Calculated Berm Widths at Old and New Piezometer Range Sites

Levee District and Range		Calculated Berm Widths, ft		
		LMVD 1956 Criteria	RID 1960 Design	WES 1979 Suggested
Old Piezometer Range Sites				
Muscatine Island	A	242	25	25
Bay Island	C	165	0	0
Bay Island	D	215	87	0
Iowa River	A	343	162	167
Green Bay	A	0	0	0
Hunt	B	0	0	20
Fabius River	A	211	0	0
South Quincy	A	521	105	179
Sny Island	A	0	0	0
Sny Island	F	0	0	0
Sny Island	B	332	51	54
Sny Island	G	0	0	0
Sny Island	H	521	36	76
Sny Island	I	0	0	0
Total		2280	466	521
Percent LMVD		-	20	23
New Piezometer Range Sites				
Muscatine Island	MA	0	-	0
Muscatine Island	MB	781	-	407
Muscatine Island	MC	516	-	152
Green Bay	GBA	0	-	0
Green Bay	GBB	0	-	0
Fabius River	FA	133	-	0
Fabius River	FB	59	-	6
South Quincy	SQ	233	-	86
South River	SRA	92	-	0
South River	SRB	0	-	0
South River	SRC	45	-	0
Sny Island	SA	193	-	0
Sny Island	SB	266	-	117
Sny Island	SC	0	-	0
Sny Island	SD	102	-	0
Total		2420		768
Percent LMVD		-		32

Table 74

Summary of Number of Seepage Observation Locations at Old and New Piezometer Range Sites

Levee District and Range		Number of Seepage Observation Locations 1960	1965	1969	1973	1979
		Old Pizometer Range Sites				
Muscatine Island	A	4	3	3	3	-
Bay Island	C	5	4	4	4	-
Bay Island	D	4	3	3	3	-
Iowa River	A	5	4	4	4	-
Green Bay	A	5	5	4	4	-
Hunt	B	3	2	2	2	-
Fabius River	A	4	3	3	-*	-
South Quincy	A	4	4	3	4	-
Sny Island	A	7	7	4	4	-
Sny Island	F	5	5	4	4	-
Sny Island	B	6	6	3	3	-
Sny Island	G	3	3	3	3	-
Sny Island	H	4	4	4	4	-
Sny Island	I	5	5	4	4	-
Total		64	58	48	46	
		New Piezometer Range Sites				
Muscatine Island	MA	-	4	4	4	4
Muscatine Island	MB	-	4	4	4	4
Muscatine Island	MC	-	5	5	5	5
Green Bay	GBA	-	-**	5	5	5
Green Bay	GBB	-	6	6	6	6
Fabius River	FA	-	3	3	-*	3
Fabius River	FB	-	5	5	-*	5
South Quincy	SQ	-	5	5	5	5
South River	SRA	-	5	5	5	5
South River	SRB	-	4	4	4	4
South River	SRC	-	4	4	4	4
Sny Island	SA	-	5	5	5	5
Sny Island	SB	-	5	5	5	5
Sny Island	SC	-	3	3	3	3
Sny Island	SD	-	3	3	3	3
Total			61	66	58	66

* Overtopped.
** Under construction.

Table 75

Summary of River Stage and Number of Seepage Observations at Old Piezometer Range Sites

Levee District and Range	Year															
	1960				1965				1969				1973			
	River Stage		Seepage Observations		River Stage		Seepage Observations		River Stage		Seepage Observations		River Stage		Seepage Observations	
	el	Rank	No.	Rank	el	Rank	No.	Rank	el	Rank	No.	Rank	el	Rank	No.	Rank
Muscatine Island	547.7	4	3	1	553.2	1	0	3	550.1	3	1	2	551.6	2	0	4
Bay Island																
Range C	545.9	4	2	2	552.6	1	2	1	549.5	3	1	3	551.0	2	0	4
Range D	546.1	4	3	1	551.8	1	1	3	548.8	3	1	2	551.1	2	0	4
Iowa River	535.4	4	1	3	538.9	1	2	1	535.9	3	1	2	538.8	2	0	4
Green Bay	526.1	3	2	2	526.5	2	2	3	524.4	4	1	4	526.8	1	2	1
Hunt	496.1	3	2	1	497.0	2	0	4	493.0	4	1	2	499.0	1	0	3
Fabius River	483.5	3	2	1	483.9	2	1	2	-	-	0	-	487.8	1	-	-
South Quincy	478.3	3	3	2	479.3	2	0	4	475.1	4	2	3	482.9	1	3	1
Sny Island																
Range A	471.1	3	3	1	473.1	2	2	2	469.0	4	1	3	476.8	1	1	4
Range F	462.6	4	4	1	468.8	2	2	2	465.2	3	0	4	474.2	1	2	3
Range B	465.7	3	4	1	466.8	2	0	4	464.6	4	1	3	472.0	1	3	2
Range G	462.8	4	1	2	465.4	2	0	4	464.2	3	1	1	470.5	1	1	3
Range H	462.6	4	2	1	463.6	2	0	3	462.8	3	0	4	468.6	1	1	2
Range I	460.5	4	3	1	462.7	2	0	3	462.3	3	0	4	468.2	1	3	2
Total			35				12				11				16	
Percent of total observation locations*			55				21				23				35	

* Total number of observation locations is shown in Table 74.

Table 76

Summary of River Stage and Number of Seepage Observations at New Piezometer Range Sites

Levee District and Range	Year															
	1965				1969				1973				1979			
	River Stage		Seepage Observations		River Stage		Seepage Observations		River Stage		Seepage Observations		River Stage		Seepage Observations	
	el	Rank	No.	Rank	el	Rank	No.	Rank	el	Rank	No.	Rank	el	Rank	No.	Rank
Muscatine Island																
Range MA	554.7	1	0	2	551.1	3	0	3	552.4	2	2	1	548.0	4	0	4
Range MB	552.7	1	1	4	549.5	3	3	2	551.1	2	2	3	546.3	4	4	1
Range MC	552.1	1	0	3	548.9	3	1	1	550.4	2	0	4	545.9	4	1	2
Green Bay																
Range GBA	-	-	-	-	527.3	2	0	3	530.8	1	1	2	527.1	3	2	1
Range GBB	528.0	2	1	2	525.7	3	1	4	528.6	1	1	1	524.9	4	1	3
Fabius River																
Range FA	483.9	2	1	2	479.5	4	0	3	487.9	1	-	-	480.3	3	2	1
Range FB	481.3	1	1	2	477.0	3	1	3	-	-	-	-	478.1	2	2	1
South Quincy																
Range SQ	480.6	2	0	4	476.4	4	2	3	484.1	1	3	1	477.5	3	3	2
South River																
Range SRA	478.6	2	1	3	474.2	4	0	4	482.1	1	1	2	476.3	3	2	1
Range SRB	478.3	2	0	3	473.9	4	0	4	481.8	1	2	1	476.1	3	1	2
Range SRC	476.2	2	1	1	471.7	4	0	4	480.0	1	1	3	474.3	3	1	2
Sny Island																
Range SA	465.9	2	0	4	464.3	3	1	3	471.0	1	4	1	462.9	4	3	2
Range SB	464.4	2	0	3	463.5	3	1	2	469.3	1	2	1	462.0	4	0	4
Range SC	463.0	2	0	3	462.3	3	0	4	467.9	1	1	2	460.0	4	2	1
Range SD	462.4	2	0	4	461.8	3	1	2	467.4	1	1	3	459.8	4	2	1
Total			6				11				21				26	
Percent of total observation locations*			10				17				36				39	

* Total number of observation locations is shown in Table 74.

Table 77

Summary of Calculated Berm Widths and Worst Observed Performance at Old and New Piezometer Range Sites

Levee District and Range		Calculated Berm Width*	Max Head** H ft	Worst Observed Performance† River Head Obs. ft	Per-cent Max	At Toe	Other than at Toe with Dist. from toe, ft
Old Piezometer Range Sites							
Muscatine Island	A	25	18.2	9.9	54	4c	- -
Bay Island	C	0	16.0	12.0	75	1d	4a, 231
Bay Island	D	0	16.7	7.4	44	1e	4a, 200
Iowa River	A	167	20.4	15.8	77	2a	4a, 287
Green Bay	A	0	12.8	7.3	57	4a	4a, 588
Hunt	B	20	14.8	6.3	43	3a	- -
Fabius River	A	0	14.2	7.9	56	4b	- -
South Quincy	A	179	16.4	16.9	103	1e	3b, 53
Sny Island	A	0	11.9	7.8	66	1e	4a, 5
Sny Island	F	0	17.5	11.8	67	4a	4b, 278
Sny Island	B	54	18.4	17.9	97	1d	4c, 231
Sny Island	G	0	16.0	9.7	61	1d	3a, 98
Sny Island	H	76	19.9	14.1	71	1d	2b, 131
Sny Island	I	0	12.3	4.0	33	1e	4a, 7
New Piezometer Range Sites							
Muscatine Island	MA	0	14.4	6.0	42	1b	2b, 330
Muscatine Island	MB	407	18.0	9.0	50	2b	2c, 262
Muscatine Island	MC	152	23.4	14.6	62	1b	3b, 47
Green Bay	GBA	0	14.3	7.9	55	1d	2b, 100
Green Bay	GBB	0	18.2	16.8	92	1e	4b, 124
Fabius River	FA	0	17.6	8.1	46	1d	3a, 527
Fabius River	FB	6	21.8	16.1	74	1d	4b, 33
South Quincy	SQ	86	15.6	6.9	44	1e	4a, 161
South River	SRA	0	16.4	9.7	59	1e	2b, 450
South River	SRB	0	16.7	16.3	98	1d	3a, 290
South River	SRC	0	18.7	14.7	79	1d	4a, 410
Sny Island	SA	0	17.0	17.0	100	4c	- -
Sny Island	SB	117	16.8	16.5	98	1c	4b, 15
Sny Island	SC	0	13.3	4.8	36	1d	2b, 389
Sny Island	SD	0	16.8	10.6	63	1d	2c, 506

* Berm width calculated using WES 1979 suggested criteria.

** New levee crest elevation minus ground elevation at worst observed performance.

† See paragraph 31 in text for observed performance code.

Table 78

Comparison of Berm Calculation Results and Observed Performance at Old and New Piezometer Range Sites

Levee District and Range		Obs. Head H ft	Berm Required (Calculated Length, ft) LMVD 1956 Criteria Yes	LMVD 1956 Criteria No	WES 1979 Suggested Criteria Yes	WES 1979 Suggested Criteria No
Worst Observed Performance: Category 1b to 2c Within First 100 ft from Levee Toe						
Bay Island	C	12.0	X(165)			X
Bay Island	D	7.4	X(215)			X
Iowa River	A	15.8	X(343)		X(167)	
Sny Island	B	17.9	X(332)		X(54)	
Sny Island	H	14.1	X(251)		X(76)	
Muscatine Island	MA	6.0		X		X
Muscatine Island	MB	9.0	X(781)		X(407)	
Green Bay	GBA	7.9		X		X
Green Bay	GBB	16.8		X		X
Fabius River	FA	8.1	X(133)			X
South Quincy	SQ	6.9	X(233)		X(86)	
South River	SRA	9.7	X(92)			X
South River	SRB	16.3		X		X
South River	SRC	14.7	X(45)			X
Sny Island	SC	4.8		X		X
Sny Island	SD	10.6	X(102)			X
Total			11	5	5	11
Worst Observed Performance: Category 3a to 4c Within First 100 ft from Levee Toe						
Muscatine Island	A	9.9	X(242)		X(25)	
Green Bay	A	7.3		X		X
Hunt	B	6.3		X	X(20)	
Fabius River	A	7.9	X(211)			X
South Quincy	A	16.9	X(521)		X(179)	
Sny Island	A	7.8		X		X
Sny Island	F	11.8		X		X
Sny Island	G	9.7		X		X
Sny Island	I	4.0		X		X
Muscatine Island	MC	14.6	X(516)		X(152)	
Fabius River	FB	16.1	X(59)		X(6)	
Sny Island	SA	17.0	X(193)			X
Sny Island	SB	16.5	X(266)		X(117)	
Total			7	6	6	7

Table 79

Summary of Berm Requirements Using Creep Ratio Criteria at Old and New Piezometer Range Sites

Levee District and Range		Design Head H ft	Levee Width L_2 ft	Foundation Top-stratum	Worst Perf. First 100 ft	Creep Ratio c	Req'd Creep Length L_c	Berm Width Req'd x_b
Observed Performance: Category 1b to 2c Within First 100 ft from Levee Toe								
Bay Island	C	13.9	133	OL	1d	15	209	76
Bay Island	D	15.4	138	OL	1e	15	231	93
Iowa River	A	15.6	153	CL	2a	15	234	81
Sny Island	B	16.8	228	CL	1d	15	252	24
Sny Island	H	19.4	192	CL	1d	15	291	99
Muscatine Island	MA	10.8	123	SP	1b	15	162	39
Muscatine Island	MB	18.5	235	SP	2b	15	278	43
Green Bay	GBA	13.5	89	SP	2b	15	203	114
Green Bay	GBB	13.5	130	SP	1e	15	203	73
Fabius River	FA	14.8	205	CL	1d	15	222	17
South Quincy	SQ	15.7	198	CL	1e	15	236	38
South River	SRA	13.6	140	CL	1e	15	204	64
South River	SRB	12.2	103	SC	1d	15	183	80
South River	SRC	12.7	143	CL	1d	15	191	48
Sny Island	SC	13.0	139	CL	1d	15	195	56
Sny Island	SD	14.5	184	CL	1c	15	218	34
Observed Performance: Category 3a to 4c Within First 100 ft from Levee Toe								
Muscatine Island	A	18.2	203	SP	4c	15	273	70
Green Bay	A	12.8	177	SP	4a	15	192	15
Hunt	B	14.8	139	ML	3a	18	266	127
Fabius River	A	14.8	198	CL	4a	15	222	24
South Quincy	A	16.6	172	CL	3b	15	249	77
Sny Island	A	13.4	129	CL	4a	15	201	72
Sny Island	F	13.8	215	CL	4a	15	207	0
Sny Island	G	15.5	144	CL	3a	15	233	89
Sny Island	I	13.3	115	CL	4a	15	200	85
Muscatine Island	MC	18.7	193	CL	3b	15	281	88
Fabius River	FB	20.5	200	CL	4b	15	308	108
Sny Island	SA	17.5	332	CL	4c	15	263	0
Sny Island	SB	19.3	153	CL	4b	15	290	137

APPENDIX A: TIME-LAG ANALYSIS, SNY ISLAND, RANGES A AND B

Basic Data

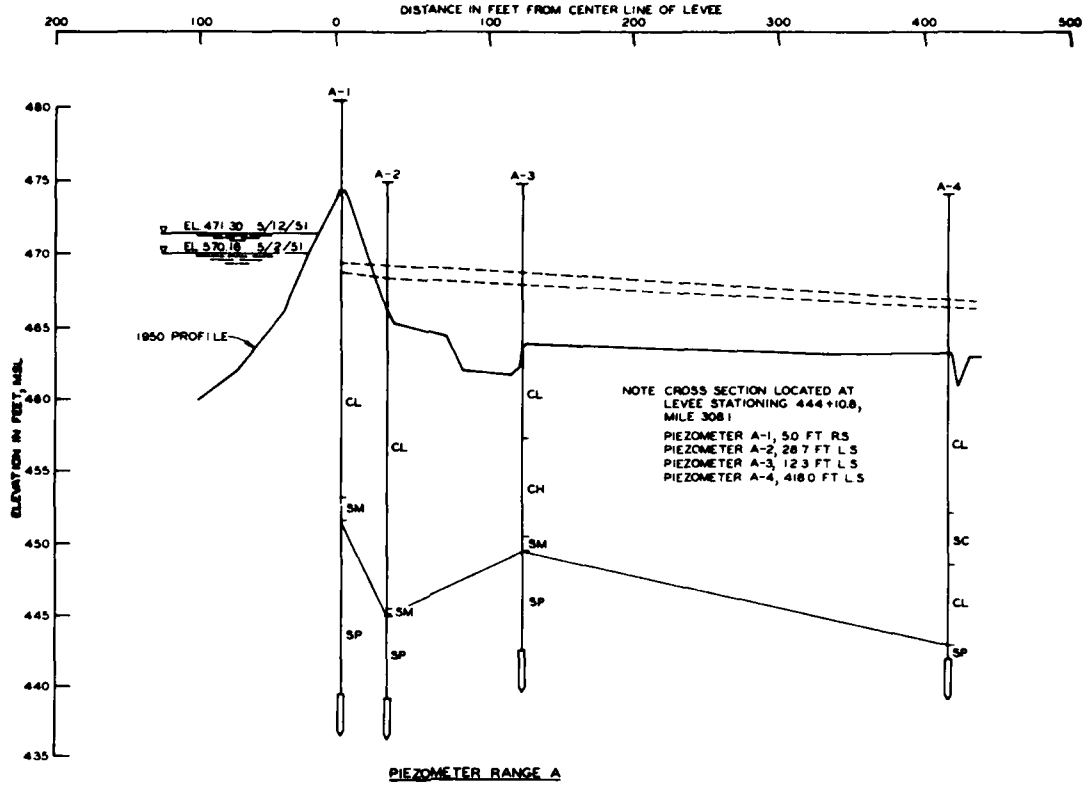
1. From time to time, questions have been asked regarding the time required for the groundwater pressure landside of levees to fully respond to changes in the river stage. During the flood of May 1951, daily and sometimes twice daily readings were obtained from the Sny Island Levee Drainage District, Piezometer Ranges A and B. Figure A1 shows the cross sections for these ranges. Figure A2 presents a plot of river stage and piezometer data for 1-15 May 1951 as listed in Table A1.

Discussion

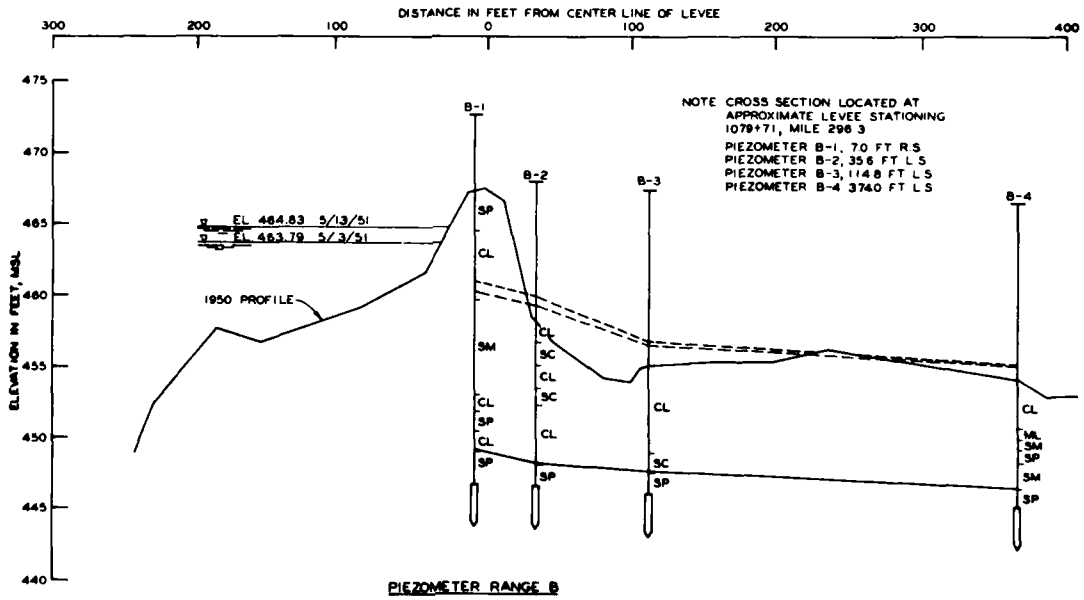
2. It is to be noted that on 1 May the river stage is already 4 to 10 ft above the ground elevation of the landside piezometers and that all piezometers are indicating groundwater pressure 1 to 6 ft above the natural ground elevation. Because of this excess groundwater pressure, it is reasonable to assume that the pervious substratum is saturated.

3. An examination of Figure A2 indicates that changes in piezometric pressure generally reflect immediately changes in the river stage, i.e., when the river stage increased, the piezometric pressure generally increased; when the river stage decreased, the piezometric pressure generally decreased; and when the river stage crested or bottomed, the groundwater pressure did likewise. This generally immediate response of the groundwater pressure is best seen with the 13 May data when the river crested and all the piezometer data likewise crested at essentially the same time. One exception was the data obtained from Piezometer A-4 where readings for 12 May and the morning of 13 May appear to be in gross error, and a dashed line has been drawn to indicate what may be a reasonable correction.

4. Although the groundwater pressure generally reflects comparable



PIEZOMETER RANGE A



PIEZOMETER RANGE B

Figure A1. Sny Island cross sections for Piezometer Ranges A and B, with selected 1951 piezometric data

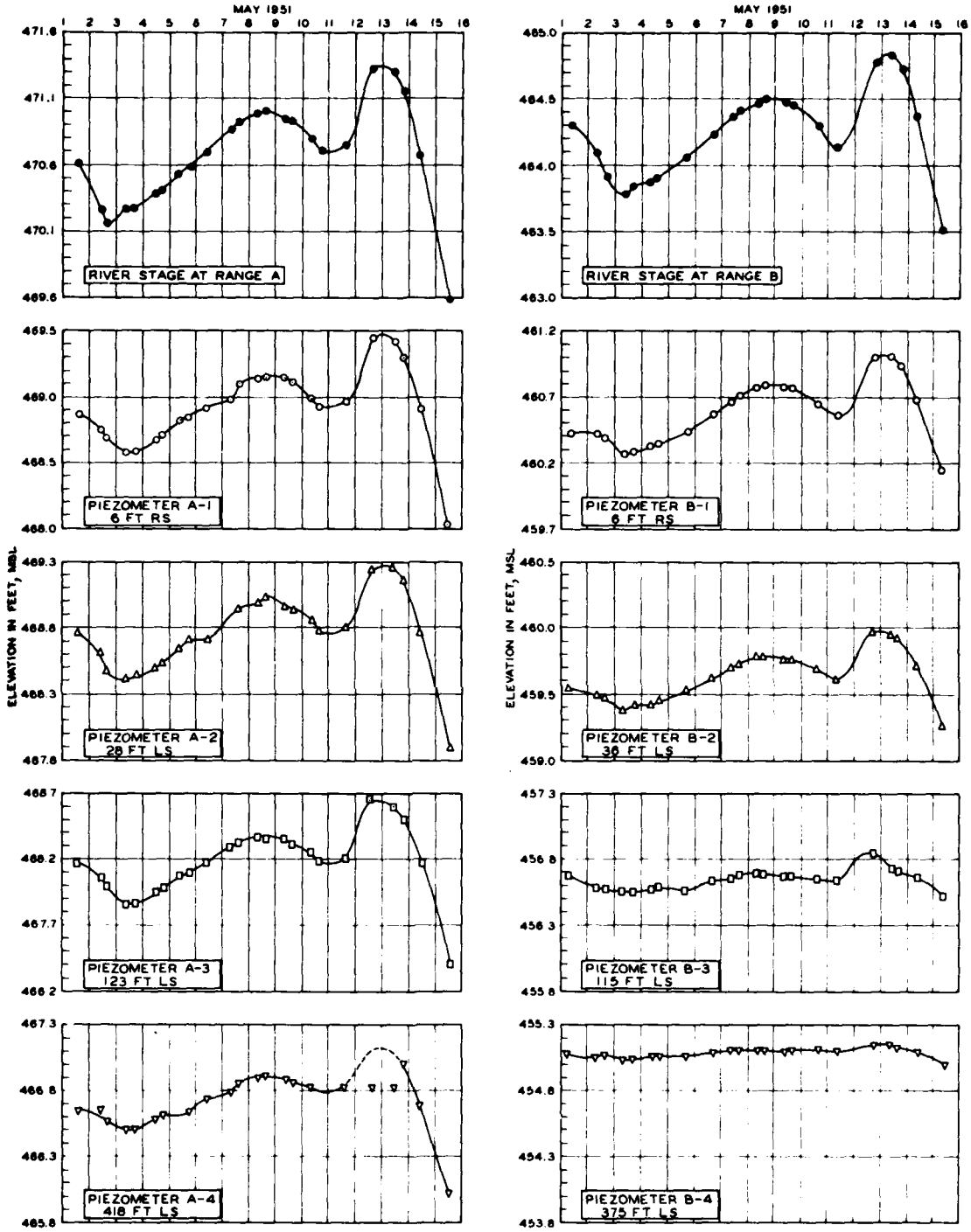


Figure A2. Sny Island river stage and piezometric elevations for Ranges A and B, 1-15 May 1951

changes in the river stage immediately, some irregularities can be noted. For instance, from 2 to 3 May an intermediate low for the river stage seems to precede the comparable low for Piezometers A-1, A-3, and B-3 by about one day, but for the other piezometers, the time difference does not appear to be significant. Also, some of the piezometer readings, particularly those for Piezometers A-1, A-2, and A-4 from 3 to 10 May, seem to have moved in an irregular fashion. Some of the irregularity can probably be attributed to difficulty in making accurate soundings, and some can be attributed to the impossibility of making the river stage and piezometer readings at the same instance of time. To determine how much of these irregularities can be attributed to these minor inaccuracies of the data, two additional types of plots have been prepared.

River Head Versus Piezometric Head

5. The first type is a plot of river head versus piezometric head relative to the natural ground elevation. Data for these plots of Piezometers A-2, A-3, and A-4 in Figure A3 and B-2, B-3, and B-4 in Figure A4 are listed in Tables A2 and A3, respectively. If there were no time lag or other irregularities in the piezometer readings, the plotted points should fall on a single line for both rising and falling river stages. If there were a time lag, the plotted points should form inclined elliptical loops with the points tracking in a clockwise direction. For the data that have been examined, three periods of falling stages and two periods of rising stages are included; therefore, two complete loops and one partial loop should be evident if there were a systematic time lag. However, such is not the case. One partial loop does appear for Piezometers A-2, A-3, and A-4, but that is all. Therefore, this type of plot indicates that there was neither a consistent nor a significant time lag in the groundwater pressure at these piezometer locations.

6. One other interesting point, however, is the notable decrease in the piezometric pressure at Piezometers B-2 and B-3 from 12 to 13 May

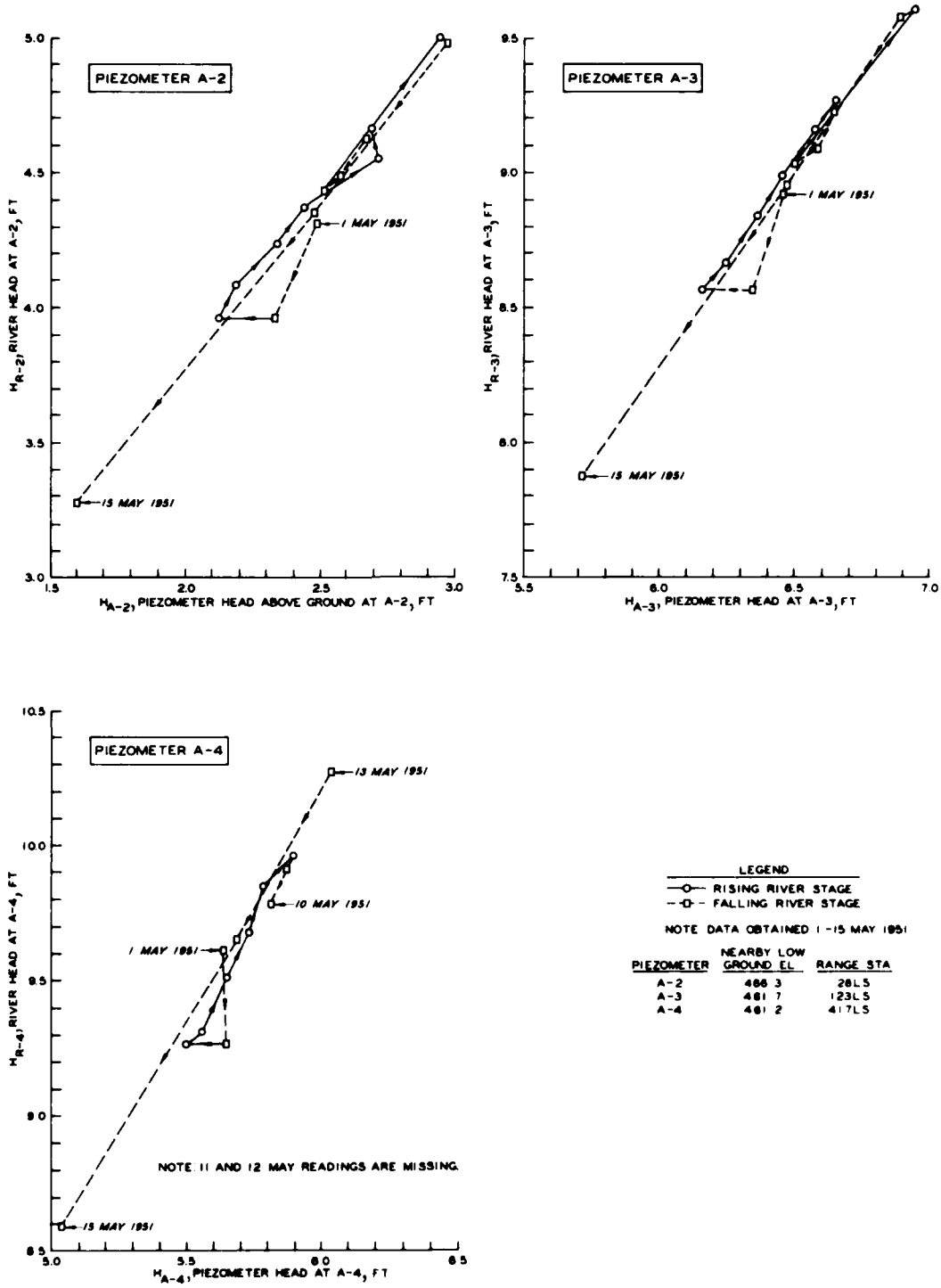


Figure A3. Sny Island, Range A, river head versus piezometric head, 1-15 May 1951

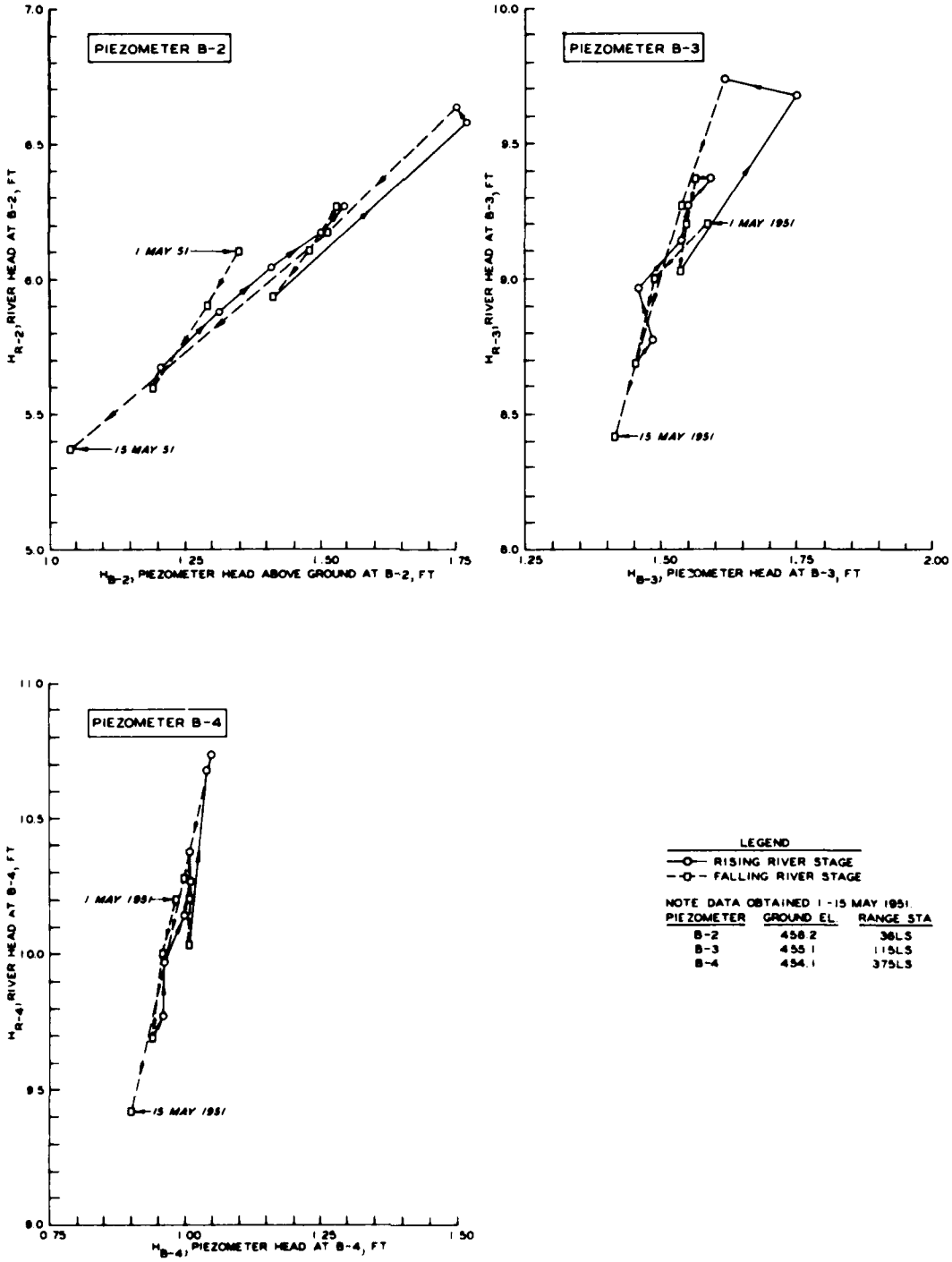


Figure A4. Sny Island, Range B, river head versus piezometric head, 1-15 May 1951

even though the river continued to rise. This pressure relief could be explained by a nearby rupture in the top stratum, which occurred sometime between the readings of 12 and 13 May. Thus, it must be recognized that some irregularities in the piezometric pressure response can also be caused by initiation or sudden opening of seepage paths through the top stratum as the pressure tends to increase during rising river stages. Likewise, the closing or healing of seepage paths could also explain apparent irregularities, such as an increase or no change in the piezometric pressure during falling stages of the river.

Daily Change in River Stage Versus Daily Change in Piezometric Reading

7. The second type of supplementary plot prepared shows daily change in river stage versus daily change in piezometer readings. Data for these plots of Range A in Figure A5 and Range B in Figure A6 are listed in Tables A4 and A5, respectively. If there were no time lag or other irregularities, the plotted points should fall on a single line for each piezometer, the slope of the lines should be the same for both rising and falling river stages, and all lines should pass through the origin. If there were significant time lag, there should be a plus piezometric change at zero river change for a river crest; whereas at a river stage bottom, there should be a negative piezometric pressure change for a zero river change, and the plotted data should have the form of an inclined ellipse with the plotted points tracking in a counterclockwise fashion.

8. An inspection of Figures A5 and A6 indicates that there was no systematic counterclockwise pattern for the plotted points and that, in general, the lines connecting the data points pass through zero. There are three notable exceptions to the general pattern. The first is for all piezometers for Range A from 1 to 3 May where none of the data points falls into the anticipated linear pattern. A possible explanation for this occurrence is that the river stage which was falling may have been read earlier than the piezometers on 1 May and later than

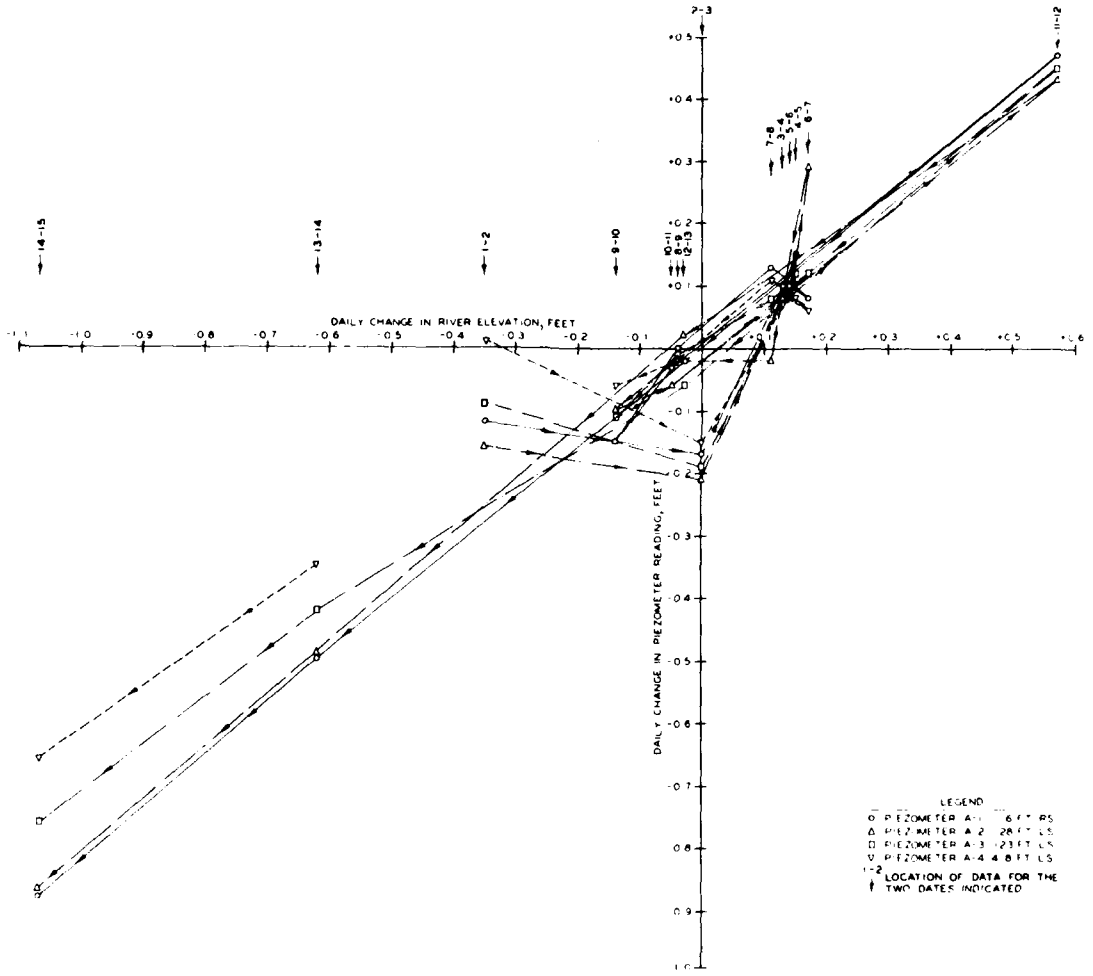


Figure A5. Sny Island, Range A, daily change in river stage versus daily change in piezometric elevation head, 1-15 May 1951

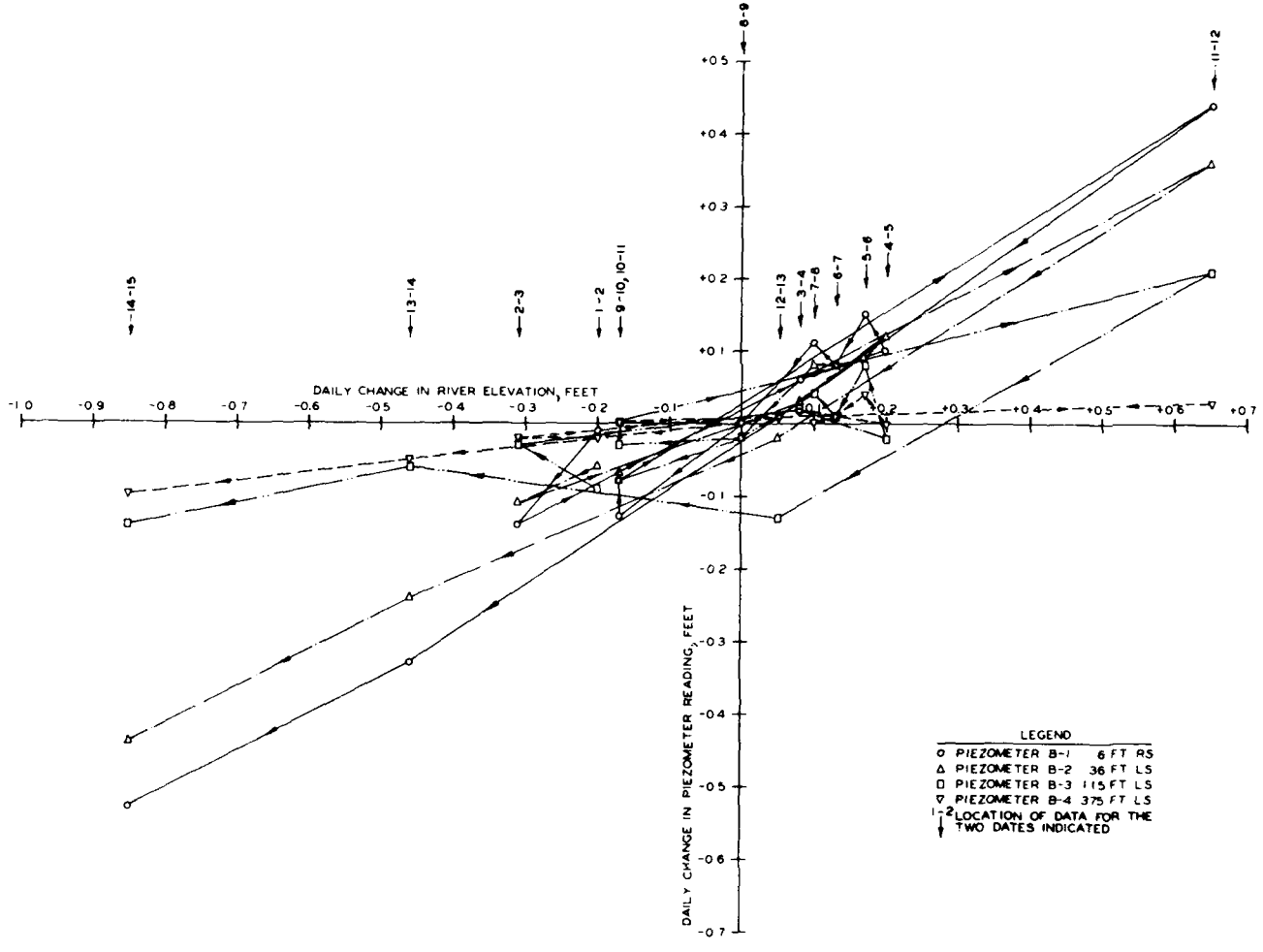


Figure A6. Sny Island, Range B, daily change in river stage versus daily change in piezometric elevation head, 1-15 May 1951

the piezometers on 2 and 3 May when the river stage bottomed out and began to rise.

9. The second exception to the general pattern is for Piezometer A-2 from 6 to 8 May. These two irregular data points can best be explained as simply an erroneous reading most likely for 7 May when the piezometric pressure probably was recorded about 0.1 to 0.2 ft too high. However, it is also possible that something could have happened to reduce the underseepage and natural pressure relief in the vicinity of Piezometer A-2 at this time, thus causing the pressure to increase sharply. This restriction could then have gradually dissipated so that by 9 May the situation had returned to normal.

10. The third exception to the general pattern is for Piezometer B-3 from 12 to 13 May. This irregular data point indicates that there was a significant decrease in the piezometric pressure at this time even though the river was continuing to rise. As mentioned in paragraph 6 of this appendix, this situation more than likely can be explained by the opening of a new seepage path in the near vicinity of Piezometer B-3.

Summary of Time-Lag Consideration

11. The reader must be careful to recognize that data presented here for the analysis of time lag for the piezometer response are for a time when the substratum is most likely fully saturated. As has been previously noted, all piezometers on the first day of this set of data indicate groundwater pressure 1 to 6 ft above the ground surface; thus, it is reasonable to assume that the substratum was saturated. If the substratum were not saturated, significant time lag should have been anticipated.

12. The reader also is cautioned to note that any conclusion regarding time lag based on the data analyzed here is strictly applicable only to the 1950 piezometers installed in the pervious substratum at Sny Island, Ranges A and B. If the piezometer tips should be installed in a relatively impervious stratum or if installation procedures should

result in the clogging of the well screen, significant time lags should be expected. As a matter of fact, at least some of the RID 1977 piezometers experienced significant time lag during the 1979 high-water season, perhaps because well screens may have been partially clogged during installation or perhaps for other reasons. Falling head and/or other field tests can and should be conducted on these piezometers to determine if they are now free draining.

13. Although it is possible for any piezometer to become clogged during or subsequent to installation, for the 1951 data analyzed, there was apparently no significant or systematic time lag for the piezometer response to changes in the river stage. All three types of plots, (a) river stage and piezometric head versus time, (b) river head versus piezometric head, and (c) daily change in river stage versus daily change in piezometric head, indicate that, in general, there was no significant time lag. In isolated cases where there may have been some time lag, the situation can be explained by differences in time for recording river stage and piezometer levels, the sudden initiation or decrease in underseepage nearby, or simply errors in piezometer readings.

Comparative Response at Ranges A and B

14. It should be noted that depending on distance from the center line of the levee and ground conditions, some piezometers have a large response to changes in the river stage, and others have a relatively small response. Piezometers closest to the levee generally have a larger response than those farthest from the levee. This can be illustrated by examination of the data in Figures A5 and A6. Data in Figure A5 for Range A indicate that the piezometer response (ratio of change in piezometric pressure to change in river head) ranged from 0.8 for the piezometers nearest the levee to about 0.6 for the piezometer 418 ft from the center line of the levee. At Range A, the top stratum is about 12 to 20 ft thick. However, at Range B where the top stratum is only about 6 to 8 ft thick and the opportunity for underseepage and

natural pressure relief is greater, the 1951 piezometric response shown in Figure A6 was quite different. For Piezometers B-1 and B-2 located on or at the levee, the response averaged about 0.6. For Piezometers B-3 and B-4 located from 115 to 375 ft landside from the center line of the levee, the response averaged about 0.2 ft of piezometric pressure per foot of river head. Thus, while there was no significant time lag in piezometer response, there was a significant difference in the amount of response, caused by a difference in ground conditions and the pressure relief afforded by the natural underseepage in the area.

Table A1

River Stages and Piezometric Elevations for May 1951, Sny Island, Ranges A and B

Range A							Range B						
Day May 1951	Time	Miss. River Stage el	Piezometer A-1	A-2	A-3	A-4	Day May 1951	Time	Miss. River Stage el	Piezometer B-1	B-2	B-3	B-4
1	1300	470.61	468.86	468.78	468.16	466.64	1	1045	464.3	460.42	459.55	456.68	455.08
2	1030	470.26	468.74	468.62	468.05	466.65	2	0830	464.1	460.41	459.49	456.59	455.06
2	1530	470.16	468.69	468.47	467.99	466.57	2	1400	463.9	460.39	459.47	456.58	455.08
3	0900	470.26	468.57	468.41	467.86	466.50	3	1030	463.79	460.27	459.38	456.56	455.04
3	1530	470.27	468.57	468.45	467.86	466.51	3	1400	463.84	460.29	459.41	456.56	455.04
4	1145	470.39	468.67	468.49	467.95	466.57	4	0900	463.87	460.33	459.41	456.58	455.06
4	1530	470.42	468.69	468.53	467.97	466.61	4	1330	463.90	460.35	459.45	456.59	455.06
5	0800	470.54	468.82	468.64	468.07	466.65							
5	1630	470.59	468.84	468.70	468.09	466.63	5	1545	464.07	560.43	459.53	456.56	455.06
6	0850	470.68	468.92	468.72	468.16	466.73	6	1700	464.24	460.58	459.62	456.64	455.10
7	0800	470.85	469.00	469.01	468.28	466.79	7	0930	464.37	460.66	459.70	456.65	455.11
7	1445	470.90	469.10	468.97	468.32	466.86	7	1600	464.41	460.71	459.73	456.67	455.11
8	0900	470.96	469.13	468.99	468.36	466.90	8	1015	464.47	460.77	459.78	456.69	455.11
8	1415	470.98	469.13	469.04	468.35	466.90	8	1530	464.50	460.79	459.78	456.69	455.11
9	0830	470.92	469.13	468.97	468.35	466.88	9	0940	464.47	460.77	459.76	456.67	455.11
9	1330	470.90	469.10	468.95	468.32	466.86	9	1500	464.46	460.77	459.76	456.67	455.11
10	0815	470.78	468.98	468.87	468.24	466.82							
10	1515	470.68	468.92	468.78	468.18	466.82*	10	1415	464.30	460.64	459.68	456.64	455.11
11	1410	470.73	468.95	468.81	468.20	466.82*	11	0930	464.13	460.56	459.61	456.64	455.11
12	1420	471.30	469.42	469.24	468.65	466.82*	12	1755	464.78	461.00	459.97	456.85	455.14
13	1000	471.27	469.40	469.26	468.59	467.04	13	0845	464.83	461.01	459.95	456.72	455.15
13	1700	471.13	469.28	469.16	468.51	467.00	13	1600	464.73	460.94	459.92	456.71	455.12
14	0930	470.65	468.90	468.77	468.17	466.69	14	0830	464.37	460.68	459.71	456.66	455.10
15	1130	469.58	468.02	467.90	467.41	466.03	15	0840	463.52	460.15	459.27	456.52	455.00

* Data appear to be in error.

Table A2

River Head and Piezometric Head at Piezometer Locations for Time-Lag Analysis, May 1951 Piezometer Data, Sny Island, Range A

Day May 1951	Miss. River Stage el	Piezometer: A-2 Ground El 466.2 River Head	A-2 Piezometric el	A-2 Piezometric Head	A-3 Nearby Low Ground El 461.7 River Head	A-3 Piezometric el	A-3 Piezometric Head	A-4 Nearby Low Ground El 461.0 River Head	A-4 Piezometric el	A-4 Piezometric Head
1	470.61	4.31	468.78	2.48	8.91	468.16	6.46	9.61	466.64	5.64
2	470.26	3.96	468.62	2.32	8.56	468.05	6.35	9.26	466.65	5.05
3	470.26	3.96	468.41	2.11	8.56	467.86	6.16	9.26	466.50	5.50
4	470.39	4.09	468.49	2.19	8.66	467.95	6.25	9.31	466.51	5.51
5	470.54	4.24	468.64	2.34	8.84	468.07	6.37	9.54	466.65	5.65
6	470.68	4.38	468.72	2.42	8.98	468.16	6.46	9.68	466.73	5.73
7	470.85	4.55	469.01	2.71	9.15	468.28	6.58	9.85	466.79	5.79
8	470.96	4.66	468.99	2.69	9.26	468.36	6.66	9.96	466.90	5.90
9	470.92	4.62	468.97	2.67	9.22	468.35	6.65	9.92	466.88	5.88
10	470.78	4.48	468.87	2.57	9.08	468.24	6.54	9.78	466.82	5.82
11	470.73	4.43	468.81	2.51	9.03	468.20	6.50	9.73	(Missing)	
12	471.30	5.00	469.24	2.94	9.60	468.65	6.95	10.30	(Missing)	
13	471.27	4.97	469.26	2.96	9.57	468.59	6.89	10.27	467.04	6.04
14	470.65	4.35	468.77	2.47	8.95	468.17	6.47	9.65	466.69	5.69
15	469.58	3.28	467.90	1.60	7.88	467.41	5.71	8.58	466.03	5.03

Table A3

River Head and Piezometric Head at Piezometer Locations for Time-Lag Analysis, May 1951 Piezometer Data, Sny Island, Range B

Day May 1951	Miss. River Stage el	Piezometer B-2 Ground El 458.2 River Head	Piezometer B-2 Piezometric el	Piezometer B-2 Piezometric Head	Piezometer B-3 Ground El 455.1 River Head	Piezometer B-3 Piezometric el	Piezometer B-3 Piezometric Head	Piezometer B-4 Ground El 454.1 River Head	Piezometer B-4 Piezometric el	Piezometer B-4 Piezometric Head
1	464.3	6.10	459.55	1.35	9.20	456.68	1.58	10.20	455.08	0.98
2	464.1	5.90	459.49	1.29	9.00	456.59	1.49	10.00	455.06	0.96
3	463.79	5.59	459.38	1.18	8.69	456.56	1.46	9.69	455.04	0.94
4	463.87	5.67	459.41	1.21	8.77	456.58	1.48	9.77	455.06	0.96
5	464.07	5.87	459.53	1.33	8.97	456.56	1.46	9.97	455.06	0.96
6	464.24	6.04	459.62	1.42	9.14	456.64	1.54	10.14	455.10	1.00
7	464.37	6.17	459.70	1.50	9.27	456.65	1.55	10.27	455.11	1.01
8	464.47	6.27	459.78	1.58	9.37	456.69	1.59	10.37	455.11	1.01
9	464.47	6.27	459.76	1.56	9.37	456.67	1.57	10.37	455.11	1.01
10	464.30	6.10	459.68	1.48	9.20	456.64	1.54	10.20	455.11	1.01
11	464.13	5.93	459.61	1.41	9.03	456.64	1.54	10.03	455.11	1.01
12	464.78	6.58	459.97	1.77	9.68	456.85	1.75	10.68	455.14	1.04
13	464.83	6.63	459.95	1.75	9.73	456.72	1.62	10.73	455.15	1.05
14	464.37	6.17	459.71	1.51	9.27	456.66	1.56	10.27	455.10	1.00
15	463.52	5.32	459.27	1.07	8.42	456.52	1.42	9.42	455.00	0.90

Table A4

Daily Change in River Stage and Piezometric Elevation Head for Time-Lag Analysis, May 1951 Piezometer Data, Sny Island, Range A

Day May 1951	Mississippi River Stage el	Mississippi River Daily Change	Piezometer A-1 el	Piezometer A-1 Daily Change	Piezometer A-2 el	Piezometer A-2 Daily Change	Piezometer A-3 el	Piezometer A-3 Daily Change	Piezometer A-4 el	Piezometer A-4 Daily Change
1	470.61		468.86		468.78		468.16		466.64	
		-0.35		-0.12		-0.16		-0.09		+0.01
2	470.26		468.74		468.62		468.05		466.65	
		+0.00		-0.17		-0.21		-0.19		-0.15
3	470.26		468.57		468.41		467.86		466.50	
		+0.13		+0.10		+0.08		+0.09		+0.07
4	470.39		468.67		468.49		467.95		466.57	
		+0.15		+0.15		+0.15		+0.12		+0.08
5	470.54		468.82		468.64		468.07		466.65	
		+0.14		+0.10		+0.08		+0.09		+0.08
6	470.68		468.92		468.72		468.16		466.73	
		+0.17		+0.08		+0.29		+0.12		+0.06
7	470.85		469.00		469.01		468.28		466.79	
		+0.11		+0.13		-0.02		+0.08		+0.11
8	470.96		469.13		468.99		468.36		466.90	
		-0.04		0.00		-0.02		-0.01		-0.02
9	470.92		469.13		468.97		468.35		466.88	
		-0.14		-0.15		-0.10		-0.11		-0.06
10	470.78		468.98		468.87		468.24		466.82	
		-0.05		-0.03		-0.06		-0.04		-
11	470.73		468.95		468.81		468.20		-	
		+0.57		+0.47		+0.43		+0.45		-
12	471.30		469.42		469.24		468.65		-	
		-0.03		-0.02		+0.02		-0.06		-
13	471.27		469.40		469.26		468.59		467.04	
		-0.62		-0.50		-0.49		-0.42		-0.35
14	470.65		468.90		468.77		468.17		466.69	
		-1.07		-0.88		-0.87		-0.76		-0.66
15	469.58		468.02		467.90		467.41		466.03	

Table A5

Daily Change in River Stage and Piezometric Elevation Head for Time-Lag Analysis, May 1951 Piezometer Data, Sny Island, Range B

Day May 1951	Mississippi River Stage el	Mississippi River Daily Change	Piezometer B-1 el	Piezometer B-1 Daily Change	Piezometer B-2 el	Piezometer B-2 Daily Change	Piezometer B-3 el	Piezometer B-3 Daily Change	Piezometer B-4 el	Piezometer B-4 Daily Change
1	464.3		460.42		459.55		456.68		455.08	
		-0.20		-0.01		-0.06		-0.09		-0.02
2	464.1		460.41		459.49		456.59		455.06	
		-0.31		-0.14		-0.11		-0.03		-0.02
3	463.79		460.27		459.38		456.56		455.04	
		+0.08		+0.06		+0.03		+0.02		+0.02
4	463.87		460.33		459.41		456.58		455.06	
		+0.20		+0.10		+0.12		-0.02		0.00
5	464.07		460.43		459.53		456.56		455.06	
		+0.17		+0.15		+0.09		+0.08		+0.04
6	464.24		460.58		459.62		456.64		455.10	
		+0.13		+0.08		+0.08		+0.01		+0.01
7	464.37		460.66		459.70		456.65		455.11	
		+0.10		+0.11		+0.08		+0.04		0.00
8	464.47		460.77		459.78		456.69		455.11	
		0.00		0.00		-0.02		-0.02		0.00
9	464.47		460.77		459.76		456.67		455.11	
		-0.17		-0.13		-0.08		-0.03		0.00
10	464.30		460.64		459.68		456.64		455.11	
		-0.17		-0.08		-0.07		0.00		0.00
11	464.13		460.56		459.61		456.64		455.11	
		+0.65		+0.44		+0.36		+0.21		+0.03
12	464.78		461.00		459.97		456.85		455.14	
		+0.05		+0.01		-0.02		-0.13		+0.01
13	464.83		461.01		459.95		456.72		455.15	
		-0.46		-0.33		-0.24		-0.06		-0.05
14	464.37		460.68		459.71		456.66		455.10	
		-0.85		-0.53		-0.44		-0.14		-0.10
15	463.52		460.15		459.27		456.52		455.00	

APPENDIX B: NOTATION*

c	A constant for natural top stratum where $c = 1/\sqrt{(k_f/k_b)(z_b)(d)}$; creep ratio
d	Effective thickness of pervious substratum
F	Factor of safety against uplift
Δh	Difference in piezometer readings
h_a	Allowable head at berm toe
h_c	Critical head at which the force of the net head equals the submerged weight of the top stratum
h_o	Head at landside levee toe
h_x	Hydrostatic head beneath top stratum
h_1, h_2	Substratum heads at two piezometers on a line perpendicular to the levee at distances ℓ_1 and ℓ_2 , respectively, from landside levee toe
H	Net head on levee
i	Gradient through top stratum
i_c	Critical gradient for landside top stratum
i_1	Upward gradient at landside berm toe
i_o	Upward gradient at landside levee toe
k	Coefficient of permeability
k_b	Coefficient of permeability of top stratum
$k_{b\ell}$	Permeability of landside top stratum
k_{br}	Permeability of riverside top stratum
k_f	Average horizontal coefficient of permeability of pervious substratum
ℓ	Horizontal distance between piezometers
ℓ_1, ℓ_2	Respective distances from landwide levee toe to the piezometers installed on a line perpendicular to the levee
L_c	Required creep length
L_1	Distance from riverside levee toe to river
L_2	Base width of levee and berm
L_3	Length of top stratum landward of levee toe

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* Essentially consistent with the notations in TM 3-424 and EM 1110-2-1913 (see footnotes on pages 6 and 8, respectively).

M	Slope of hydraulic grade line, at middepth of pervious stratum, beneath the levee
s	Distance from the landwide levee toe to the point of effective seepage entry
t	Thickness of berm
x	Distance from levee toe
x_b	Berm width based on creep ratio formula
X_{sp}	Semipervious berm width based on uplift formula
x_1	Effective length of riverside blanket
x_3	Distance from landside levee toe to effective seepage exit
z_b	Effective thickness of top stratum
$z_{b\ell}$	Effective thickness of landside top stratum
z_{br}	Effective thickness of riverside top stratum
z_t	Critical thickness of top stratum
γ_t	Wet unit weight of soil
γ_w	Unit weight of water
γ'	Submerged or buoyant unit weight of soil

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Cunny, Robert W
Documentation and analysis of Rock Island underseepage data / by Robert W. Cunny. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. ; available from National Technical Information Service, 1980.
205, [129] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; GL-80-3)
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