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GEOLOGIC CONTROL OF SAND BOILS ALONG MISSISSIPPI RIVER LEVEES

Charles R. Kolb

Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

August 1975

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GEOLOGIC CONTROL OF SAND BOILS ALONG MISSISSIPPI RIVER LEVEES

by

Charles R. Kolb

Soils and Pavements Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

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A common problem during floods along the lower Mississippi River is the formation of sand boils on the landward sides of levees. If the hydrostatic pressure in the pervious substratum landward of a levee becomes greater than the submerged weight of the topstratum, the uplift pressure may cause heaving and rupture at weak spots with a resulting concentration of seepage flow in the form of sand boils. This, in turn, can lead to piping and instability of the
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PREFACE

This paper by Dr. Charles R. Kolb was presented at the Annual Meeting of the Geological Society of America held 3 November 1973 in Dallas, Texas. Dr. Kolb as Chairman of the River Engineering Committee of the Society was in charge of papers being presented on engineering geologic problems associated with rivers. Dr. Kolb (now retired) was formerly Chief, Engineering and Geology Division, Soils and Pavements Laboratory (S&PL), at the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi.

COL G. H. Hilt, CE, is the Director of the WES, and Mr. F. R. Brown is Technical Director. Mr. J. P. Sale is Chief, S&PL.

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GEOLOGIC CONTROL OF SAND BOILS ALONG MISSISSIPPI RIVER LEVEES

Charles R. Kolb (Ret.)*, 3314 Highland Drive, Vicksburg, Miss. 39180

ABSTRACT

A common problem during floods along the lower Mississippi River is the formation of sand boils on the landward sides of levees. If the hydrostatic pressure in the pervious substratum landward of a levee becomes greater than the submerged weight of the topstratum, the uplift pressure may cause heaving and rupture at weak spots with a resulting concentration of seepage flow in the form of sand boils. This, in turn, can lead to piping and instability of the levees during critical high-water periods. The disposition of pervious versus impervious floodplain deposits beneath the levee and the angle at which such bodies are crossed by the overlying levees are controlling factors in the localization of sand boils. Thus recognition of alluvial landforms forming the riverbanks, the types of soils associated with them, and their detailed mapping in plan and profile are important factors in levee design. Corrective design involves (a) detailed delineation of the surface and subsurface geology, (b) careful selection of borrow pits to avoid stripping critically thin topstratum deposits, and (c) the use of riverside or landside berms or blankets, and/or the installation of relief wells.

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* Former Chief of Engineering Geology Division, U. S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

INTRODUCTION

A common and potentially hazardous phenomenon associated with a flooding Mississippi River is seepage beneath the levees and the formation of sand boils. Sand boils consist of sand carried to the surface on the landward side of levees by seepage forces which often deposit these granular materials in the form of conical mounds (Fig. 1) with water issuing from the top of the mound. Although limited underseepage and through-seepage of the levees are generally acceptable, seepage beneath levees in the form of sand boils indicates active piping and poses a threat to levee safety.

The U. S. Army Corps of Engineers has observed and recorded seepage phenomena during floods along Mississippi River levees in some detail since the early 30's, and in the early 50's the first comprehensive studies were made of the phenomena of underseepage and sand boils (Mansur, Kaufman, and Schultz, 1956). The purpose of this paper is to review and reevaluate some of the findings and conclusions reached in this earlier study concerning the effect of geologic factors on underseepage; to discuss underseepage data collected along a randomly selected 40-mile reach of the river during the 1973 flood (USAE District, Vicksburg, 1974); and to relate such data to geologic mapping completed in the late 1950's (Kolb et al., 1958).

THE SETTING

Approximately 2000 miles of levees flank the Mississippi River in the Lower Mississippi Alluvial Valley. These massive earth embankments are from 30 to 40 ft high and effectively confine flood flows throughout most of the Lower Valley. The distance between levees on either side of the river varies widely. Overbank flood flows range from 15 miles wide between some of these embankments to less than 2 miles wide in some reaches. Figure 2 shows a typical surface profile along an east bank levee at levee station (LS) 2860 or approximately at river mile 563. Flood heights against this levee during the floods of 1937, 1950, and 1973 are shown in this figure. The height of the project flood (the maximum flood expected in the valley) is also shown. Note that overbank flood heights contained by the levee in this reach were moderate during the 1973 flood. Underseepage was correspondingly moderate.

In fact, few sand boils of consequence were reported by the various teams who surveyed underseepage along the levees during the maximum height of the 1973 flood (USAE District, Vicksburg, 1974). Many pin boils were reported. These are springs or upwellings of water on the landward side of the levee which carry almost no material to the surface and with no buildup of sediment around their mouths. As flood heights increase and the head difference on either side of the levee increases, however, pin boils may become sand boils which pipe material to the surface.

Figure 3 summarizes the underseepage data collected during the 1973 flood in a 40-mile reach of the river which includes Arkansas City, Arkansas. The river reach was more or less randomly selected. Levees are shown in this figure with an appropriate symbol. Levee stations are shown at 20,000-ft intervals. Landside areas where moderate to heavy, heavy, and very heavy seepage occurred are symbolized in Figure 3 and notes taken by the survey parties along such seepage areas are summarized. Areas of light and moderate seepage recorded by the survey parties are not shown. An asterisk is used to indicate areas where pin boils were reported.

Every attempt was made to make the adjectival classifications of heavy, medium, and light seepage as meaningful as possible. Moist areas on the landside levee, on the berm, or in the field landside of the levee were classified as "light" seepage. The designation "heavy" seepage was reserved for areas where water was visibly flowing, often from pin boils or small sand boils. "Medium" seepage was reserved as an intermediate classification. The river crested for the first time in this reach of the river on 18 April and a field survey was scheduled to correspond with this high river stage. However, rain (see Table 1) interfered considerably with the judgments used in classifying underseepage. Another survey was made during a subsequent crest near the middle of May. Sunny weather prevailed before and during this latter survey. Thus, the judgments of underseepage made during the 10-13 May time span were given more weight in arriving at adjectival underseepage ratings plotted in Figure 3.

Seepage values corresponding to the three classifications of light, moderate, and heavy are approximate at best. Mansur, Kaufman, and Schultz (1956) classified "heavy" seepage as more than 10 gpm per 100 ft of levee, "medium" seepage as between 5 and 10 gpm per 100 ft of levee, and "light" as less than 5 gpm per 100 ft of levee.

DEVELOPMENT OF UNDERSEEPAGE

A convenient distinction in the Mississippi Valley as in other alluvial valleys is that between a more or less impervious, fine-grained topstratum and an underlying substratum of sand. Figure 4 schematically depicts the topstratum-substratum relationship at right angles to a typical levee, the irregular thickness of the topstratum, and the depth to the generally impermeable Tertiary horizon (to be discussed more fully in the following section). Note the generalized seepage pattern as flood flows rise against the levee, the zone where seepage typically occurs on the landward side of the levee, and the effect of borrow pits which often penetrate substratum sands on the riverside of the levee and form an effective and troublesome avenue for seepage.

The first sign of underseepage is usually a dampening of the topstratum soil at the levee landside toe, along drainage ditches landside of the levee, or up through the ubiquitous crayfish holes that often decorate low-lying areas by the tens of thousands (Fig. 5). As overbank flood flows rise against the levees, hydrostatic pressure in the pervious substratum landward of the levee becomes greater than the submerged weight of the topstratum. Pitcher pumps sunk into the substratum sands, at dwellings and in cow pastures and often miles from the river, begin to flow. Uplift pressures seeking relief along paths of least resistance carry seepage to the surface through root holes, shrinkage cracks, minute fissures, and along man-made and natural depressions and drainage channels. As underseepage increases, springs begin to flow from thousands of pin boils. Some of these eventually develop into sand boils as sand and silt are carried to the surface from the substratum. A common method for combatting boils is to surround the features with rings of sandbags. Impounding water within such rings to a height equal to the effective hydraulic head stops seepage and sand boil activity at a given point, but subsurface pressures continue to seek avenues for relief by welling through countless other openings. As the flood continues to rise and hydraulic pressures in the substratum increase, seepage keeps pace until the landward sides of the levees are often covered by broad sheets of water with springs and sometimes the more ominous sand boils welling up to heights slightly above the surface of the impounded water (Fig. 6). Although such impounded water makes many of the roads impassable in and near the levees, preempts farming, and covers vast areas with quagmires, a serious situation arises only where sand boils form and piping beneath the levee becomes a possibility.

Topstratum landward of the levees can be classified into three categories (Mansur, Kaufman, and Schultz, 1956): (a) no significant topstratum; (b) topstratum of insufficient thickness to withstand the hydrostatic pressures that tend to develop; and (c) topstratum of sufficient thickness to withstand any hydrostatic pressure that may develop during the maximum design flood.

The situation in (a) above occurs only at the extreme northern part of the valley or where topstratum has been removed. Seepage under such conditions can be heavy as uplift pressures are readily dissipated, but piping and the formation of sand boils are rare. Where large seepage volumes cause problems, drainage sumps and pumps can be used to keep critical areas reasonably dry. Other methods, such as the installation of berms riverward or landward of the levees, the installation of sublevees or cutoffs, etc., have proven effective. Such measures will be discussed more fully later.

Category (c) above presents no underseepage problems except at localized spots where the landside topstratum has been removed or partially removed. An interesting case in point is where a soils boring has been made to the underlying substratum and left open or backfilled with pervious material.

Potentially dangerous underseepage most frequently encountered along the levees is category (b) above. In this case the resistance to seepage flow through the topstratum is so great in comparison with the low resistance to seepage flow through the substratum sands that appreciable artesian pressures are built up beneath the topstratum landward of the levee toe. During high water such artesian pressures range from 25 to 75 percent of the net head on the levee and may extend appreciable distances landward of the levee.

The amount of underseepage and uplift hydrostatic pressure which develops landward of the levee is related to the location of the point where seepage enters the substratum on the riverside of the levee and the configuration, thickness, and distribution of the relatively impervious topstratum on the landward side of the levee. One of the most useful tools for determining these important factors and the general distribution and configuration of the topstratum and substratum deposits is a knowledge of the geology of the Lower Mississippi Valley and the alluvial morphology of the floodplain. The use of air photo interpretive methods to subdivide alluvial landforms into such basic types as point bars, abandoned channel fillings, natural levees, backswamp deposits, etc., is an important first step in determining where and what kinds of underseepage should be expected along a given reach of levee.

ALLUVIAL VALLEY GEOLOGY AND ITS EFFECT ON UNDERSEEPAGE

The Alluvial Valley of the Lower Mississippi is a broad flatland about 500 miles long and averaging 50 miles wide. It begins at the confluence of the Mississippi and the Ohio Rivers at Cairo, Ill., and extends southward to the vicinity of Baton Rouge, La., where it merges with the Deltaic Plain. The configuration of the valley between Memphis, Tenn., and Baton Rouge, La. is shown on the inset map in Figure 3.

The shape of the floodplain--its outline where it joins the hill lands--is the culmination of erosional and depositional processes during waxing and waning stages of Late Wisconsin glaciation. Glacial meltwaters flowing to the Gulf, then some 450 ft lower than today, during the glacial maximum scoured an entrenched valley into underlying Tertiary and older deposits to depths

100 to 400 ft below the level of the present floodplain. As sea level began to rise about 17,000 years ago remnant sands and gravels within the entrenched valley were covered by additional sands and gravels and at higher levels by sand alone. As a result, a variable thickness of sand and gravel lies above an irregularly eroded and relatively impermeable basement of Tertiary and pre-Tertiary deposits (Fig. 4).

Beginning about 10,000 years ago a topstratum of clay, silt, and sandy mixtures of clay and silt was deposited above the sandy substratum, first in the lower part of the valley and then in the northern portions. At the southern end, deltas were built and abandoned. Northward, within the Alluvial Valley itself, the Mississippi River changed from a shallow, braided, anastomosing stream to a deep, sinuous, meandering one. Meander belts were built and courses were abandoned about as frequently as were the deltas to the south. The result of this alluvial activity is the deposition of a topstratum sequence that is highly variable in thickness, often increasing from a superficial cover less than 2 ft thick to a massive clay 100 ft thick within a horizontal distance of 200 ft.

Point Bar Deposits

Point bar or accretion deposits underlie perhaps 60 percent of the Mississippi River levees. They form on the insides or the convex sides of bends as the bends meander and enlarge. Topographically, the point bar consists of low ridges of silty sand or sand with intervening arcuate lows called swales. Swales, filled with silt and clay, mark quiescent stages in growth of the bend, their directions paralleling the former active river channel. Because of downstream migration of meanders, however, successive ridges and swales tend to overlap in a complex fashion. As individual bends grow, central portions of the bend and those portions most distant from the active channel are covered with vegetation which traps additional fine-grained soils, so that, even though the ridge-and-swale topography is preserved, the entire sequence is buried eventually beneath a thin cover of finer grained material. The result is a soil sequence in the ridge areas which tends to grade downward from sandy silt into silty sand and eventually into the clean pervious sand of the substratum. The thickness varies with latitude but can range from inches to as much as 25 ft in the southern part of the valley. The swales, on the other hand, consist of essentially impervious materials, generally varying in depth from 10 to 50 ft. Some are unusually shallow, their depth often depending on effectiveness of scour in the swale during flood flows.

Figure 7 shows the effect of these elongate clay bodies on underseepage, particularly where they pass beneath a levee at an acute angle. Seepage is often heaviest and boil formation most marked within the acute angle. The clay body tends to concentrate seepage in the pervious ridge areas where the geometry of the levee vis-a-vis the trend of the swales resembles that shown in Figure 7. Note that boils also tend to form adjacent to the swale within the obtuse angle formed by the swale and the levee. However, such seepage is generally less pronounced. Figure 8 illustrates the distribution of boils where swales cross beneath levees at roughly right angles. Boils still concentrate in the ridge soils next to the clay swales, but their distribution is more random than in the case shown in Figure 7.

Point bar deposits are generally the only deposits along the river thin enough or permeable enough to pose underseepage problems beneath the levees. Note that in the 40-mile reach of the river shown in Figure 3, significant underseepage during the 1973 flood was confined almost entirely to areas where these deposits underlie the levee. What could not be shown in Figure 3, because of the scale of mapping, are the numerous swales which cross beneath the levees within this reach, and although underseepage data in most instances were insufficiently detailed to pinpoint the influence and effect of such minor clay bodies, their effect has been amply demonstrated in previous studies (Mansur, Kaufman, and Schultz, 1956).

An important and often critical factor illustrated in Figure 7 is the effect of borrow pits on the riverside of the levee in initiating or increasing underseepage. Borrow for the levee, particularly during the early years of levee construction, was often taken directly riverside of the levees. Such pits often expose impervious underlying sand and silty sand and provide ready access for seepage of floodwaters beneath the levee. An important underseepage preventive measure has been to locate such borrow areas only where they do not expose underlying pervious strata. Where critical underseepage conditions are caused by borrow areas the areas are often filled with impermeable riverside blanket. No attempt has been made in Figure 3 to delineate borrow pits which may affect the localization of underseepage.

Natural Levee Deposits

It was stated above that underseepage is generally confined to areas of point bar deposition. An exception to this is where the levee is built on semipervious natural levee deposits.

Natural levees were formed along the migrating Mississippi River channel before the construction of artificial levees. Each year the river topped its banks during floods, the coarsest materials in suspension in the floodwaters were dropped near its banks, and the fines were carried into the low-lying adjacent bankswamp areas. With time, well defined low ridges averaging 10 to

15 ft high were formed, particularly on the outside of bends and along many straight reaches of the river. Continued migration of the river left natural levee segments complexly distributed over the floodplain surface, and in many instances, the artificial levees were built on soils readily identifiable as natural levees. Where these deposits overlie point bar deposits they generally add to the weight of the underlying point bar topstratum and thereby help resist lifting of the topstratum by excessive substratum pressures in the underlying clean sands. In other instances, however, such as in the situation shown in detail along section A-A' in Figure 7, such semipervious strata form ready paths for seepage. Here natural levee deposits overlie impermeable backswamp clays and access of water from the borrow pit permits seepage, particularly where the sloping natural levee surface joins the backswamp. The most critical situation occurs where old crevasse channels have been scoured through the natural levee by ancient floods and backfilled with materials even more permeable than the bordering natural levee. Such backfilled crevasse channels provide ready seepage paths and are sometimes the sites for restricted boil formation.

Backswamp Deposits

As briefly mentioned above, backswamp deposits consist chiefly of clay left in suspension in floodwaters as the floods top riverbanks and spread out in the lowlands adjoining the natural levees. Strata ranging from paper-thin to several inches thick gradually accumulate in these low-lying areas, and thicknesses of from 30 to 80 ft of impervious clay are not uncommon. As a rule, backswamp deposits, because of their imperviousness and fairly broad lateral extent, are least troublesome of all the alluvial environments from the standpoint of underseepage. Only in the situation discussed above, where the backswamp forms an impermeable floor for an overlying semipervious natural levee deposit, do moderate underseepage problems develop.

Figure 3 nicely illustrates the effect of backswamp clays on underseepage where such clays underlie the levee. From approximately LS 300 to 1200 on the west bank of the river, the levee is built on backswamp clays. Significant underseepage in this extensive levee reach occurred only from LS 280 to 290, and at Arkansas City between LS 745 and 770. In both instances the levee is so aligned that it extends over small portions of point bar deposits. Note also the extensive borrow pit in the levee setback opposite river mile 570. This illustrates location of riverside borrow pits in deposits, which, because of their thickness and impermeability, have no effect on underseepage.

Channel-Fill Deposits

The thickest and generally the most impervious of the deposits bordering the river are channel-fill deposits which fill abandoned meander loops of the river. When cutoff of the meander occurs the upper and lower entrances to the loop are often plugged with sandy sediments and the abandoned channel is left as an oxbow lake in the alluvial plain. As the river migrates away from the point of cutoff, the oxbow lake becomes isolated, often a score or more miles from the active stream, and only the finest of the sediments in overbank flows reach the lake. Eventually the lakes are completely filled with fine sediment and as a result significant bodies of clay known as "clay plugs" are found throughout the alluvial plain. These bodies are as deep and as wide as the former cutoff channel, with depths varying from about 100 to 130 ft and with widths averaging about 3000 ft. Hundreds of clay plugs which preserve the entire abandoned loop, and literally thousands of clay plugs which have been partially destroyed by subsequent river meandering, have been mapped in the alluvial plain. These significant clay bodies have a marked effect on river meandering, channel stability, and, where they lie beneath the levees, on underseepage.

Figure 9 shows the effect of one such abandoned channel fill on seepage. In this instance we are dealing with a split abandoned channel, one which once contained an island in the cutoff loop--a fairly common occurrence in the Mississippi Valley. Because of the geometry of the clay plug and the angle at which it is crossed by the levee, seepage and sand boils are particularly troublesome in the cul-de-sac represented by that part of the former river island just landward of the levee. Boils are also common where the clay plug or channel fill forms an acute angle with the levee. This is similar to the situation previously described where the smaller clay swales cross beneath the levee at acute angles.

Figure 10 shows a similar situation. In this instance a borrow pit flanks the riverside of the levee and a drainage ditch penetrates fairly permeable material some distance from the landside toe of the levee. Boils and seepage are found in the acute angle made by the channel filling with the levee, but the most pronounced drainage and boil development are in that portion of the drainage ditch which has partially penetrated the clay and silty topstratum.

Because the drainage ditch is at some considerable distance from the levee toe, boils are frequent but movement of subsurface material to the surface and the danger of piping are negligible.

Figure 8, introduced previously, illustrates a situation somewhat analogous to the seepage problem occasioned by a riverside borrow pit. In this instance the seepage source, however, is a partially filled abandoned channel, an oxbow lake, occurring close to the riverside of the levee. Such partially filled channels permit ready access for seepage beneath the levee and when point bar deposits flank the landward side of the levee, boils and underseepage are common. Cases in point are seepage reaches 1 through 8 in Figure 3 where oxbow lakes Beulah and Caulk Point lie just riverward of the levee and furnish a source for underseepage through the levee.

Note that seepage through the clay channel fillings is rare in Figure 3. However, significant seepage was recorded through the lower arm of the clay plug at seepage reach 11. This is probably due to a thick sand filling in this lower arm of the clay plug at the time of cutoff. Seepage reach 12, between levee stations 3330 and 3340, also occurs in a mapped clay plug. More detailed mapping and a boring or two might clarify what appears to be an anomalous situation.

UNDERSEEPAGE AND LEVEE DESIGN

That the localization of boils and underseepage is due largely to the thickness and distribution of the semipervious and impervious units in the topstratum has been amply demonstrated. The key to the delineation of such units in plan and profile is the geologic environment of deposition. Careful studies involving air photo interpretation of these environments have proved extremely useful in design for levee underseepage in the Lower Mississippi Valley. Soil borings placed so as to prove out and refine these interpretations are a second important step in levee design. Once the distribution of the topstratum units has been determined, engineers base their design of underseepage control measures on a variety of parameters. Thicknesses of the substratum sands are determined from available geologic maps or by borings, and permeabilities are determined by field pumping tests or by correlations between the D_{10}, or effective grain size, and permeability. Seepage flow and hydrostatic heads landward of the levee are determined for the project flood. These parameters are based on seepage formulas and/or piezometric data.

Mansur, Kaufman, and Schultz (1956) in summarizing underseepage control measures list riverside blankets, relief wells, landside seepage berms, drainage blankets or trenches, cutoffs, and sublevees, but state that only the first three methods are considered generally applicable for Mississippi River levees. Sublevees and drainage blankets or trenches are cited as being applicable in certain special situations.

Impervious riverside blankets are soil blankets sealing thin topstratum areas or seepage into a borrow pit which has uncovered permeable strata. The blanket should be the width of the borrow pit, or from 1000 to 1500 ft wide. The thickness of the blanket should be from 3 to 5 ft. The permeability of the blanket should be on the order of 0.01 to 0.1 × 10^{-4} cm/sec. Such blankets reduce both landward substratum pressure and seepage.

Relief well systems are wells spaced from 75 to 300 ft apart on the landward sides of levees to relieve uplift pressures. Mansur, et al., recommend wells to depths of 60 to 120 ft with screens 40 to 80 ft in length. Such wells reduce substratum pressure and intercept seepage but increase the total seepage approximately 20 to 40 percent depending on conditions. Disadvantages of relief wells are that they require periodic inspection and maintenance, must be protected from backflooding, and they increase the total quantity of seepage about 20 to 40 percent depending on conditions. These disadvantages can be partially overcome by providing the wells with suitable guards, check valves, and standpipes to prevent flow during low flood stages.

Landside berms control seepage by increasing the thickness of the landward topstratum so that the weight of the berm and topstratum is sufficient to resist uplift pressures. A berm also lengthens the path of seepage flow, thereby reducing the tendency of failure by piping. The berm should be wide enough so that the head at the berm toe is no longer critical. Thicknesses of these berms at the toe of the levee range from 3 to 10 ft, the width of the berm from 100 to 400 ft. Berms can be used to control seepage efficiently where the landside topstratum is relatively thin and uniform, or where no topstratum is present, but they are not efficient where the topstratum is relatively thick and high uplift pressures develop. Berms may vary in type from impervious to completely free draining. The selection of the type of berm to use should be based on availability of borrow materials and relative cost of each type.

For details on the design of these and other underseepage control measures, see the comprehensive work by Mansur, Kaufman, and Schultz (1956).

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Table 1

1973 Stage and Rainfall Data Pertinent to Underseepage Inspection of Levees Shown in Figure 3 (from USAE District, Vicksburg, 1974)

Date	Arkansas City River Stage, ft	Rainfall in.
16 Apr	43.9	1.65
17 Apr	43.7	
18 Apr	43.8	3.32
10 May	47.5	
11 May	47.6*	
12 May	47.6	
13 May	47.6	
14 May	47.5	
15 May	47.4	
Gage zero	96.7 msl	

* Maximum stage during 1973 flood. West bank levees were inspected for underseepage on 18 Apr and on 14 and 15 May. East bank levees were inspected on 17 and 18 Apr and on 10 and 11 May.

Figure 1. Sand boils rising above the water level of a sack sublevee near Friars Point, Miss., 1937 high wate~.

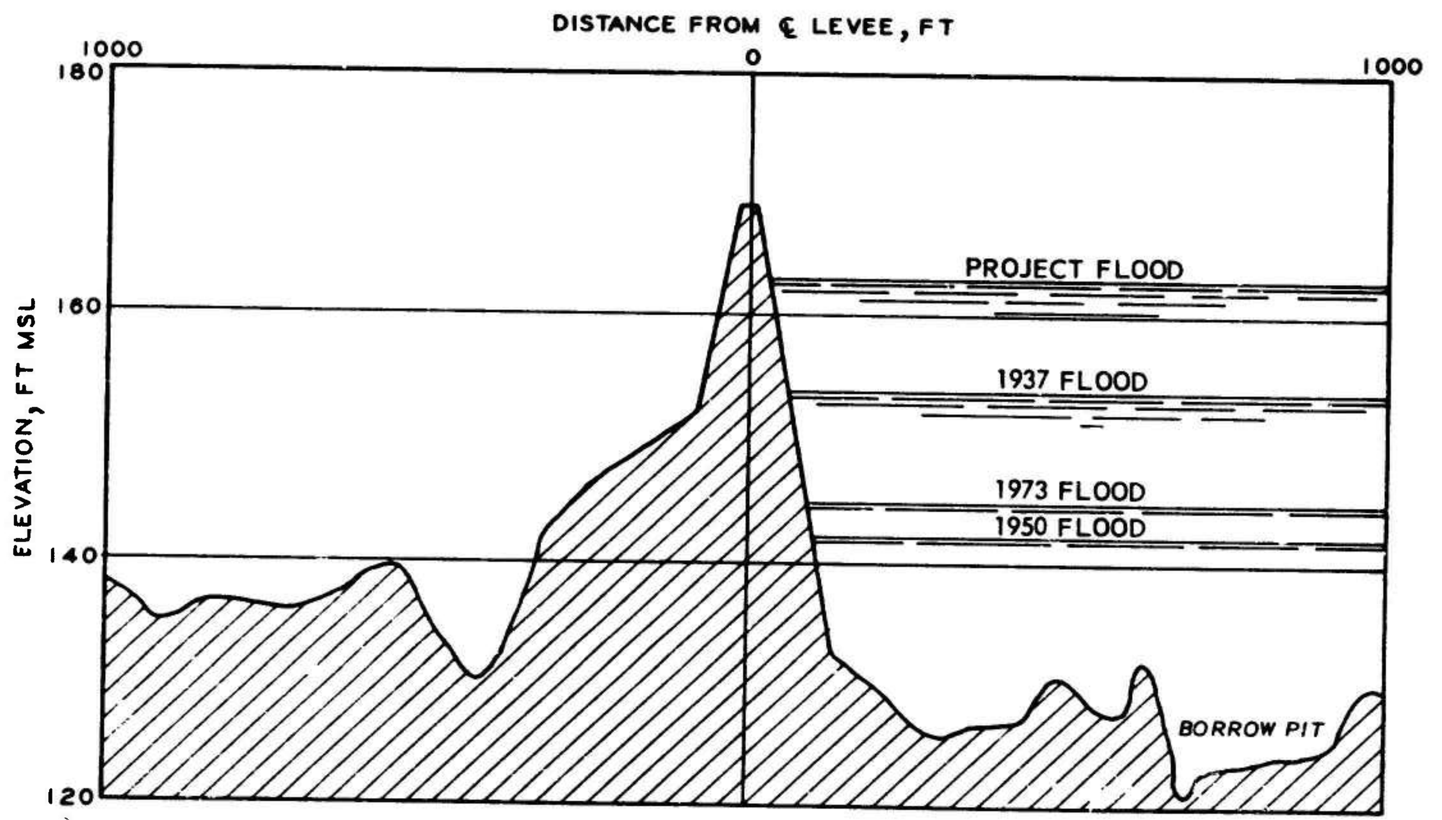

Figure 2. Surface profile along a typical levee showing crest heights of three major floods and of the project flood. Profile taken on east bank of river at levee station 2860.

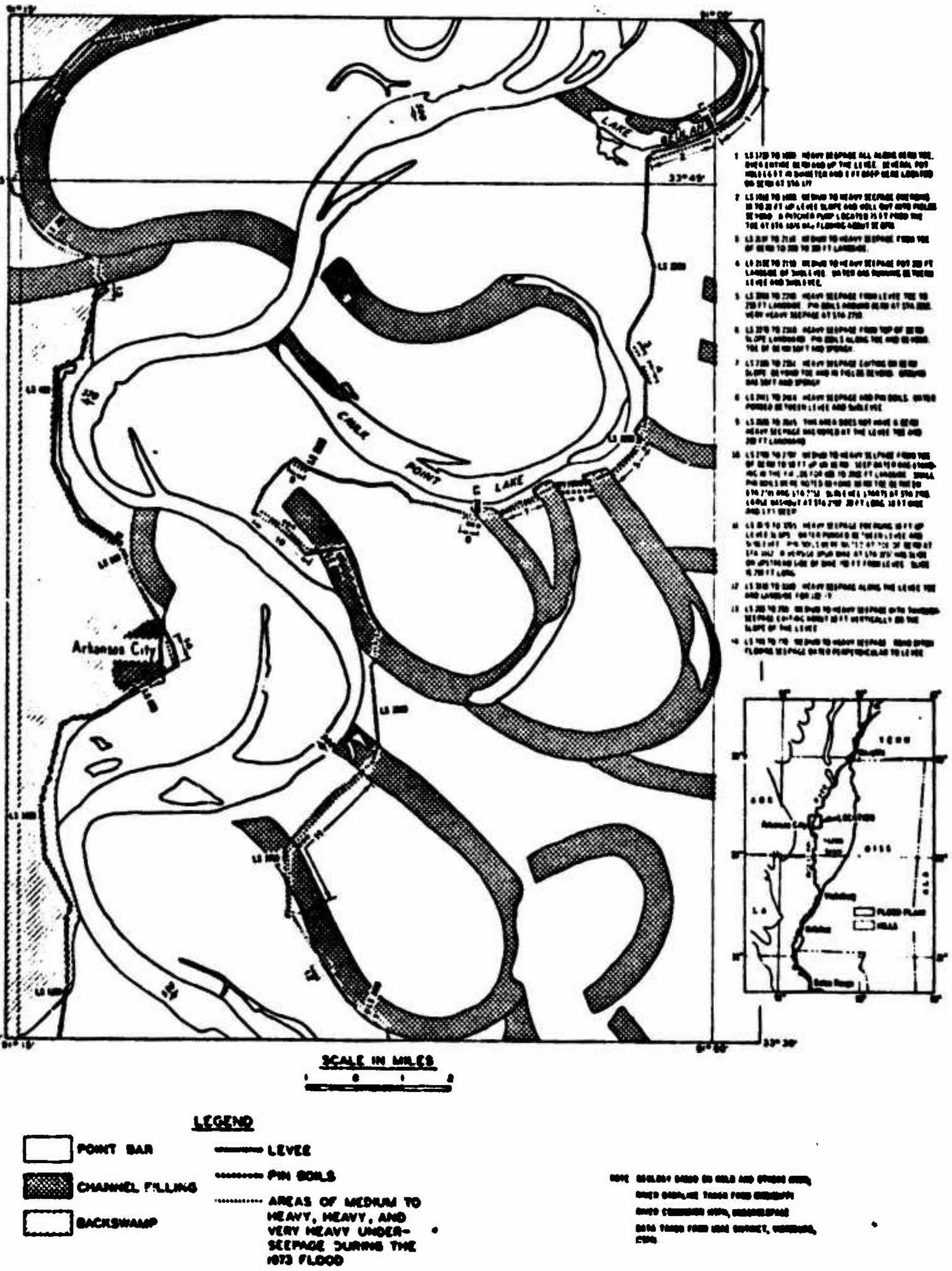

Figure 3. Geologic environments of deposition along a typical reach of the Mississippi River. Areas of significant seepage and of pin boil development during the 1973 flood are shown.

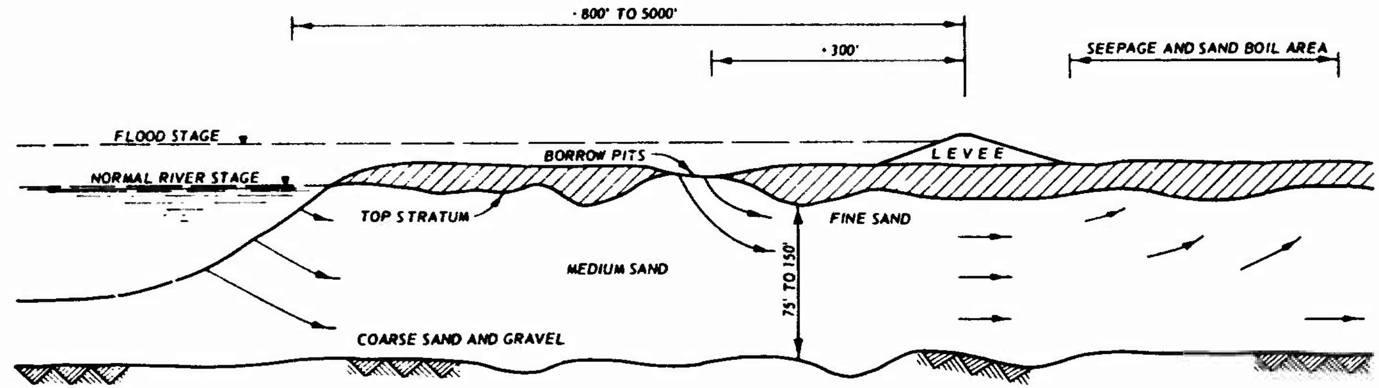

Figure 4. Generalized geologic cross section beneath levees in the Arkansas City area. Relatively impervious topstratum is underlain by pervious substratum, which is, in turn, underlain by Tertiary clay.

Figure 5. Clay encircling typical crayfish hole in topstratum deposits. These holes are often paths for seepage and eventual sand boil development.

Figure 6. Sand boils and seepage water on mainline Mississippi River levee near Greenville during 1973 flood. Notice floodwater elevation on riverside of levee. Most of the boils are ringed with sandbags.

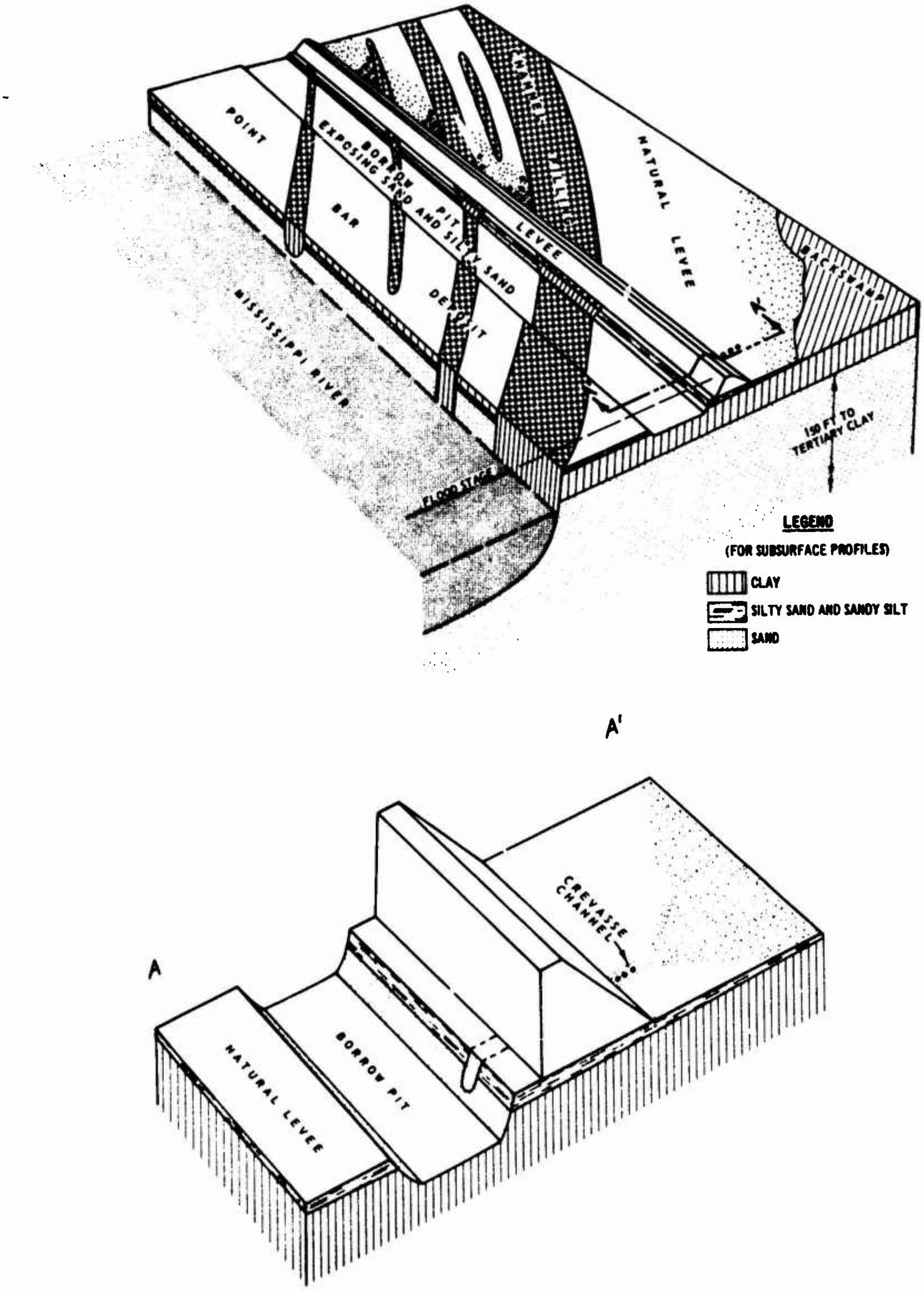

Figure 7. Clay channel fillings and swales crossing beneath levees at an angle. Boils tend to form in point bar deposits within the acute angle between the levee and the clay body. Boils (shown with asterisks) and seepage (shown with a dot pattern) are generally absent in backswamp deposits. A special case is illustrated in the expanded section shown along A-A'. Here a well developed, semipervious natural levee deposit lies between the backswamp clays and the artificial levee. In such instances seepage may occur in the extreme landward portions of the natural levee and in old natural levee crevasses backfilled with sand.

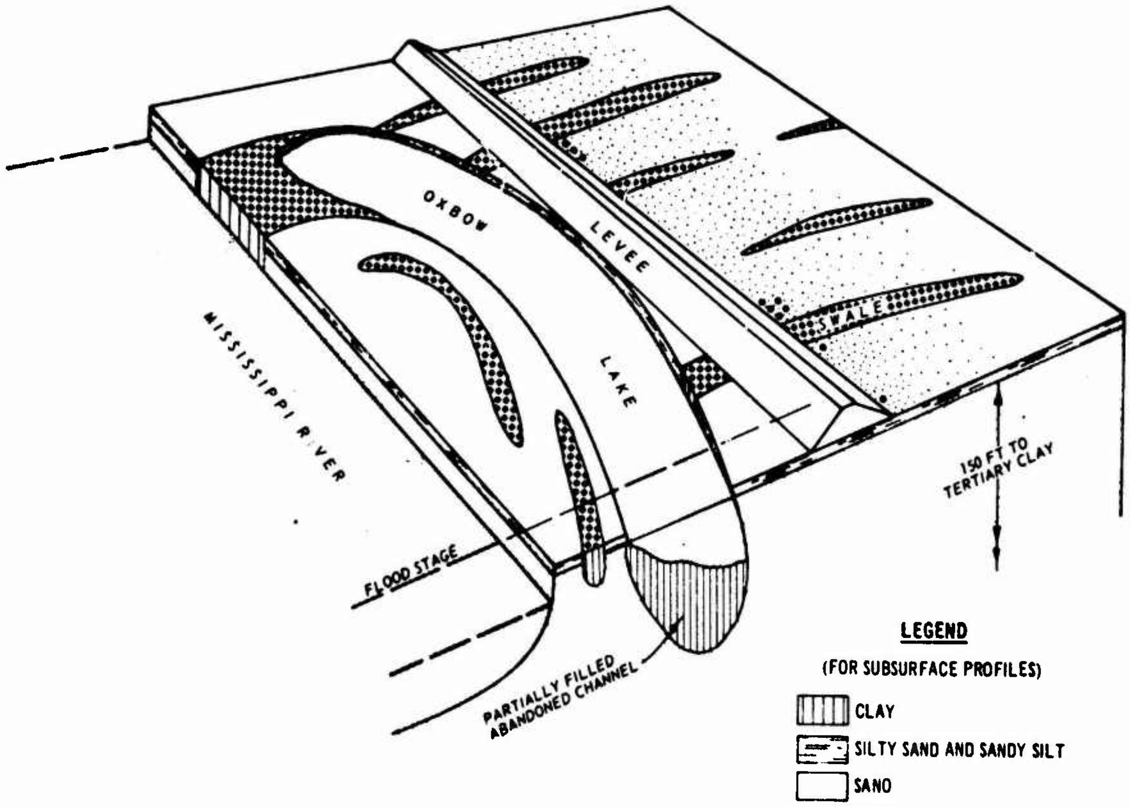

Figure 8. Where swales and channel-fill clays cross beneath the levees at more or less right angles, boils are fairly randomly dispersed and not as frequent or severe as when an acute angle is formed between the levee and the clay bodies. In this case an oxbow lake partially filling an abandoned channel is a serious source for seepage of floodwaters beneath the levee.

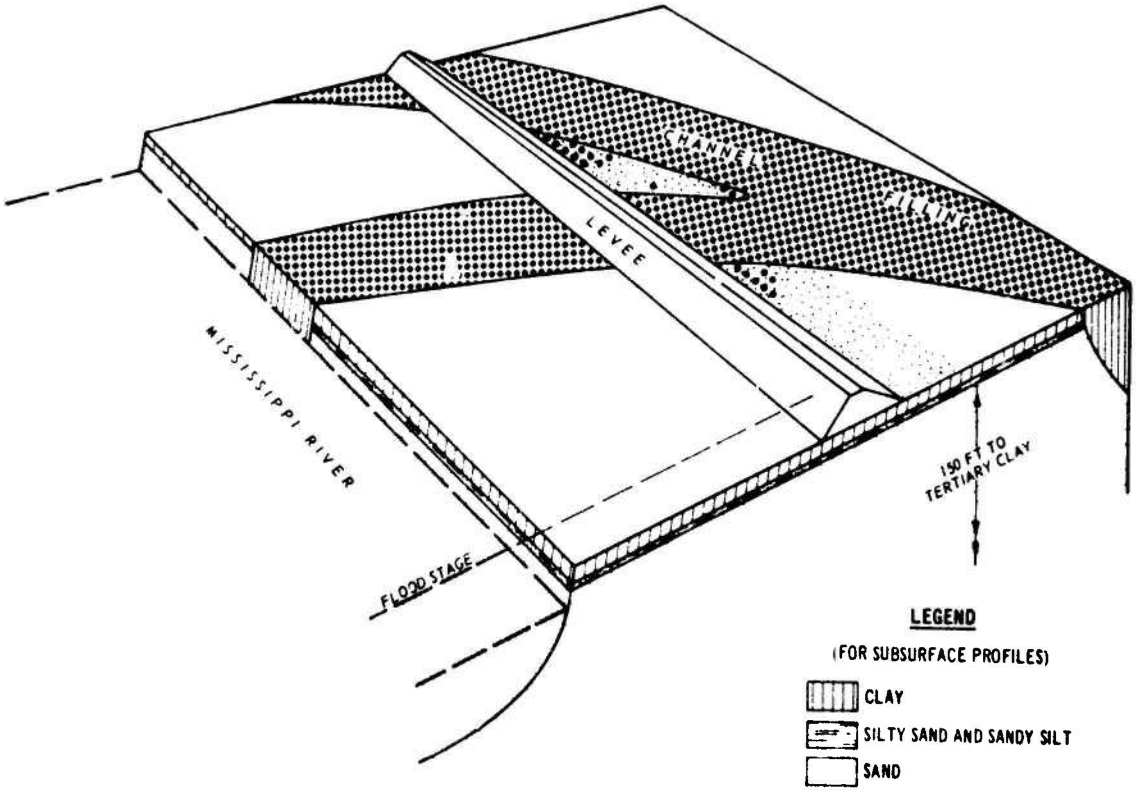

Figure 9. Effect of a split channel filling on localizing seepage and sand boil formation.

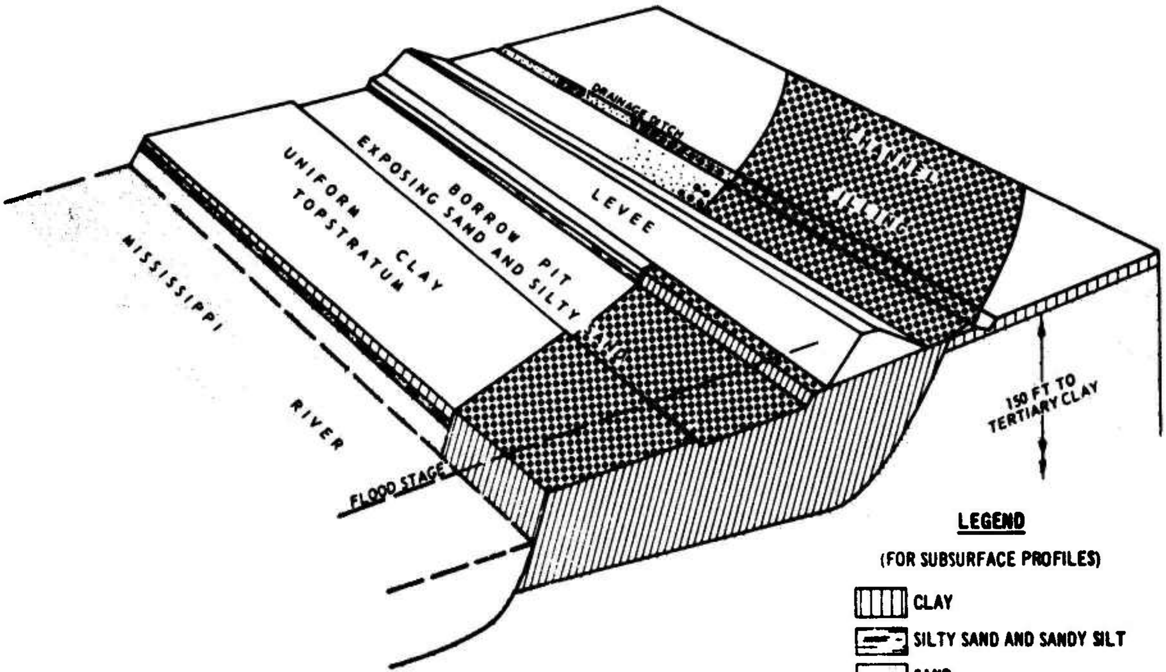

Figure 10. Drainage ditches penetrating fairly permeable materials on the landside of the levees are usually the sites for heavy seepage and boil formation. Borrow pits on the riverside of the levee, which have removed impervious topstratum, greatly accentuate the problem.

In accordance with ER 70-2-3, paragraph 6c(1)(b), dated 15 February 1973, a facsimile catalog card in Library of Congress format is reproduced below.

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