Engineering Geology of the Paducah West and Metropolis Quadrangles in Kentucky

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By WARREN I. FINCH

CONTRIBUTIONS TO ENGINEERING GEOLOGY

Prepared in cooperation with the Kentucky Geological Survey

A field and laboratory study of engineering behavior of earth materials in an urban area

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

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ENGINEERING GEOLOGY OF THE PADUCAH WEST AND METROPOLIS QUADRANGLES IN KENTUCKY

By Warren I. Finch

ABSTRACT

Surficial deposits in the Paducah West and Metropolis quadrangles in McCracken County, Ky., consist chiefly of unconsolidated silt and clay of alluvial, lacustrine, and loessal origin, and underlying poorly consolidated, sandy, clayey gravel. These surficial deposits cover the bedrock formations except in places where erosion has removed them along creeks and steep slopes of the uplands. Surficial silt and clay cover the largest part of the mapped area. Bedrock formations consist of poorly to moderately consolidated sand, lean to plastic clay, and mixtures of interlayers of silt, sand, and clay.

On the basis of laboratory and field tests, the surficial silty and clayey materials in their natural state will commonly swell and compact differentially under load, particularly if the moisture content changes. They compact well, have low compressibility, and are suitable for fill if the slopes do not exceed 2 to 1 and if compacted to maximum density at optimum moisture content. They are susceptible to rapid erosion unless protected, are characterized by slow to moderately slow percolation of surface and ground waters, and have moderate shear strength when dry but rapidly decreasing strength as moisture content increases. They are unsatisfactory for road subgrade and base. The surficial gravel deposits are good to excellent for fill, building foundations, and road subgrade and base. Precautions ought to be taken to prevent failure of roads and other structures built across the contacts of permeable gravel and sand with underlying impermeable clay. The bedrock materials range from poor to good for various engineering uses.

Ohio River flood crests at altitudes of 325–335 feet are common; the highest recorded was about 347 feet in 1937.

Paducah is in an area that has a long history of seismic activity, and structures should be earthquake resistant, conforming to a building code such as the National Building Code.

INTRODUCTION

This report discusses the engineering properties and behavior of unconsolidated surficial deposits and poorly to moderately consolidated sedimentary rocks in the Paducah West and Metropolis quad-

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rangles, McCracken County, Ky.; it is based largely on field and laboratory tests made on samples of these materials. Need and demand for engineering geology studies are growing in areas of residential and industrial development to insure the best use of land and design of stable foundations for buildings, roads, and other structures. Quantitative data on the physical properties of the materials and the interpretation of such data are used by public agencies and private organizations in planning urban development. This report presents information on the general engineering properties of the different rock units and can be used as a guide in planning more detailed engineering studies needed for specific road and building sites.

The fieldwork was done in 1963–64, concurrently with geologic mapping of the Paducah West and Metropolis quadrangles and with a similar engineering-geology study of the Paducah East quadrangle by T. C. Nichols, Jr. (1968), whose guidance in the study presented here is gratefully acknowledged. Samples collected from near the surface by hand shovel and from greater depths by power auger were analyzed by T. C. Nichols, Jr., and G. S. Erickson, U.S. Geological Survey. Fred M. Wreck operated the power auger and assisted with the field tests. This study is part of the cooperative program of geologic mapping of Kentucky being conducted by the Kentucky Geological Survey and the U.S. Geological Survey.

To promote the industrial development of the Paducah area, the Paducah Chamber of Commerce and the Kentucky Department of Commerce made a study of the area's industrial resources and published (1964) a summary of their findings. Three of six industrial sites described are wholly or partly in the Paducah West and Metropolis quadrangles.

ENGINEERING GEOLOGIC MAP UNITS

The map (pl. 1) is a modification of the geologic map of the Paducah West and Metropolis quadrangles (Finch, 1966). Insofar as practical, parts or all of the geological units composed of the same type of rock having similar engineering properties are combined and shown on the map by the same color pattern. Correlation between the map units and the geologic units is shown in the stratigraphic column on the left of the map. For brevity, the engineering map units are designated throughout most of the report by letter symbols. The poorly to moderately consolidated bedrock materials consist of sand (S), lean (low- to medium-plastic) clay (Cl), clayey sand and sandy clay (CS), plastic clay (Cp), and interlayered sand, clay, and silt (SCM, where S=sand, C=clay, M=silt). Of these, SCM is not exposed but occurs beneath surficial materials and at places beneath the Ohio

River in the northern part of the mapped area. The unconsolidated surficial materials, which are geologically much younger than the bedrock materials, consist of silty and clayey sand (Smc), gravel (G), silt and clay (MC), and sandy, clayey gravel (Gsc). The most extensive map unit is MC, and with few exceptions the bottommost surficial material is Gsc. The surficial materials lie on an uneven erosional surface cut into the geologically older bedrock materials (pl. 1, section A–A'). Contours drawn on the top of this erosional surface are shown on the map. These contours can be used to determine the thickness of surficial materials. For example, at a point where a subsurface (red) contour line crosses a surface topographic (brown) contour line, the thickness of surficial materials is the numerical difference between the altitudes indicated by the two contour lines.

Colluvial material—debris accumulated by slope wash and creep—covers large parts of many areas shown as Gsc, S, Cl, CS, and Cp. It is generally an irregular blankletlike deposit that ranges from a few inches to as much as 10 feet in thickness and consists of a mixture chiefly of loessal silt from the MC unit and subordinately of pebbles and sand. Because of its high silt content, engineering properties of the colluvial material are similar to those of MC.

LABORATORY AND FIELD TESTS

Quantitative data determined by laboratory and field tests are summarized in table 1. The methods of testing are briefly described in the footnotes of table 1 and are described in greater detail by Nichols (1968). The numerical data are meaningful to the engineer and architect and are significant here because they determine in part the interpretations of the engineering properties and behavior of the materials listed in table 2.

Grain size and grading,[1] mineralogic composition, degree of induration and consolidation,[2] and moisture content of a material determine for the most part its engineering behavior. In a general way, the finer grained, poorer graded, less indurated and consolidated, and wetter a material is, the less strength it has to support loads. The mineral content, particularly clay minerals, may contribute to a material's relative weakness and instability. Fine-grained materials, such as silt and clay, under certain conditions can produce hazards unfavorable

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[1] Engineers commonly use the term grading instead of sorting, which geologists use. Poorly graded material contains almost all one grain size; such material is termed "well sorted" by a geologist. Conversely, well-graded material represents a mixture of almost equal amounts of each grain size and is poorly sorted.

[2] Induration—the process of hardening sediments through cementation, pressure, heat, or other cause. Consolidation—the process through which loose and soft sediments become firm and coherent. Consolidated material is relatively easy to loosen at the excavation site; indurated material is more difficult and commonly requires blasting.

to structures. Many engineering tests are designed specifically for such materials and are not applicable to the coarse-grained materials.

The grain size of fine materials, determined by mechanical analyses and grading, is illustrated by cumulative curves shown in figures 1 through 6. These curves are made by (1) successively adding the percentages by weight in increasing grain sizes, (2) plotting these cumulative percentages against each grain size, and (3) drawing a smooth curve through the points. For poorly graded material the cumulative curve is very steep through a narrow range of grain size (curve 7, fig. 3), whereas for well-graded material the curve is slanted through a fairly wide range of grain sizes (curve 3, fig. 5). The offset in the curves at the point of change from sieve to hydrometer analysis probably indicates the presence of soluble salts, according to G. S. Erickson (written commun., 1964). Testing samples in the field with dilute hydrochloric acid disclosed no carbonate. The coarse-sand- and granule-size fractions shown on curves for MC, particularly for lacustrine deposits (figs. 2, 3) and loess (fig. 4), consist mostly of iron oxide(?) concretions. A good indication of the general fineness of a material is the median grain size (at the 50th percentile). The range of median grain size in samples of fine-grained materials tested is as follows: Smc, 137 microns (one sample); MC, $<$1–215 microns; CS, 9.1–73 microns; Cp, 2.7 microns (one sample); and SCM, 9.3–29.0 microns (table 1). In contrast, the median grain size of the coarse-grained materials from analyses reported by Pree, Walker, and MacCary (1957, p. 22) is as follows (assignment to map units based on their lithologic descriptions of samples): S, approximately 250–900 microns; and SCM, approximately 200–260 microns.

The dominant minerals of the materials tested are quartz and various clay minerals (table 1). Quartz is a resistant and stable mineral which contributes to the strength and stability qualities of a material. Clay minerals, however, are relatively weak, compressible, and unstable. Montmorillonite swells moderately to greatly when wet and is detrimental to the engineering properties of materials containing it. Calcium montmorillonite, however, swells much less than sodium montmorillonite. The most abundant clay mineral of Cp (Porters Creek Clay) is calcium montmorillonite, and it contributes to the undesirable qualities for use of Cp as fill and foundation materials in places where it is exposed to the atmosphere. (Table 2, see: "Slope stability" and "Suitability for foundations.") The most abundant clay mineral of the MC material is a mixed-layer clay mineral of variable composition, which consists predominantly of aluminum-interlayered vermiculite, montmorillonite (calcium montmorillonite noted in some samples), and kaolinite (table 1). The presence of

FIGURE 1.—Cumulative curves for samples from alluvium (MC).

FIGURE 2.—Cumulative curves for hand-dug samples from lacustrine deposits (MO).

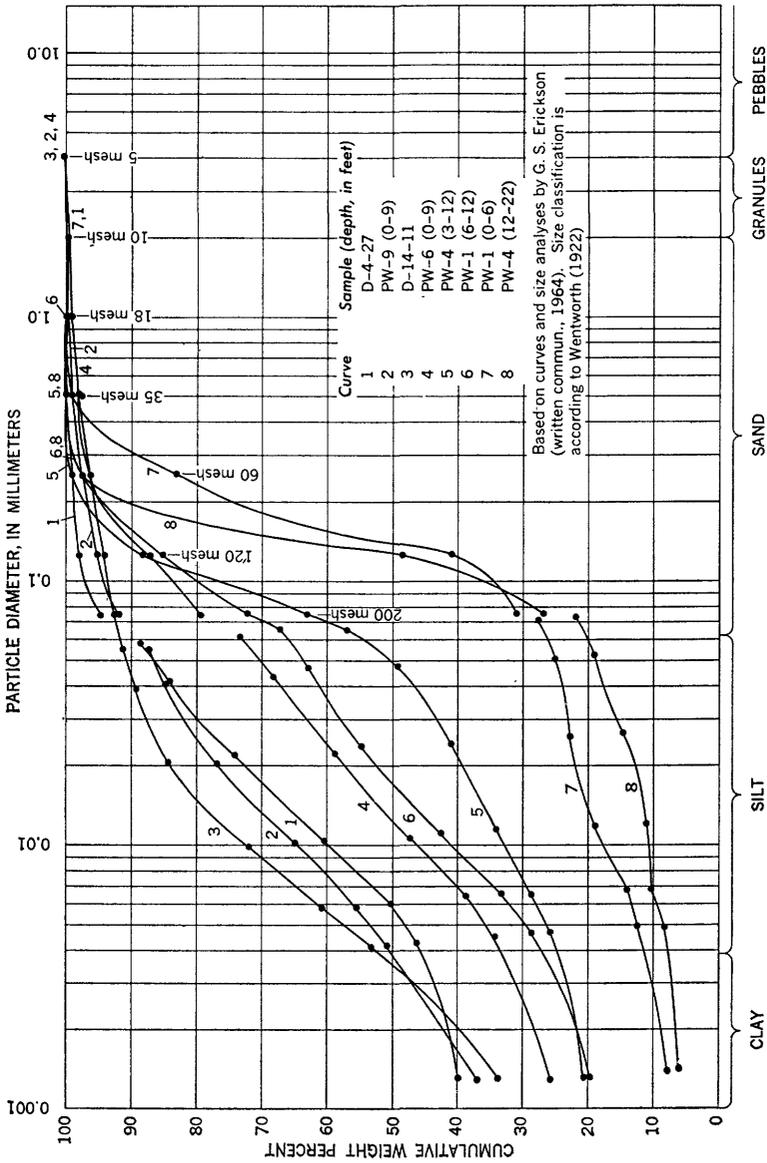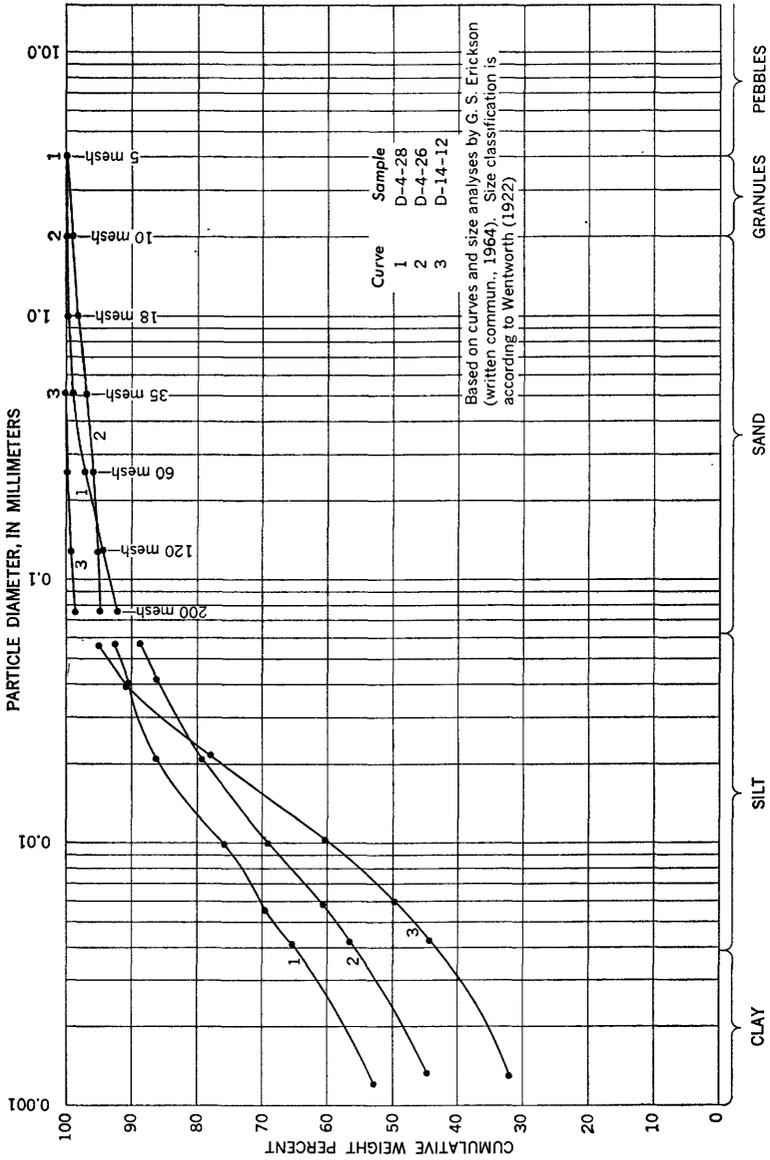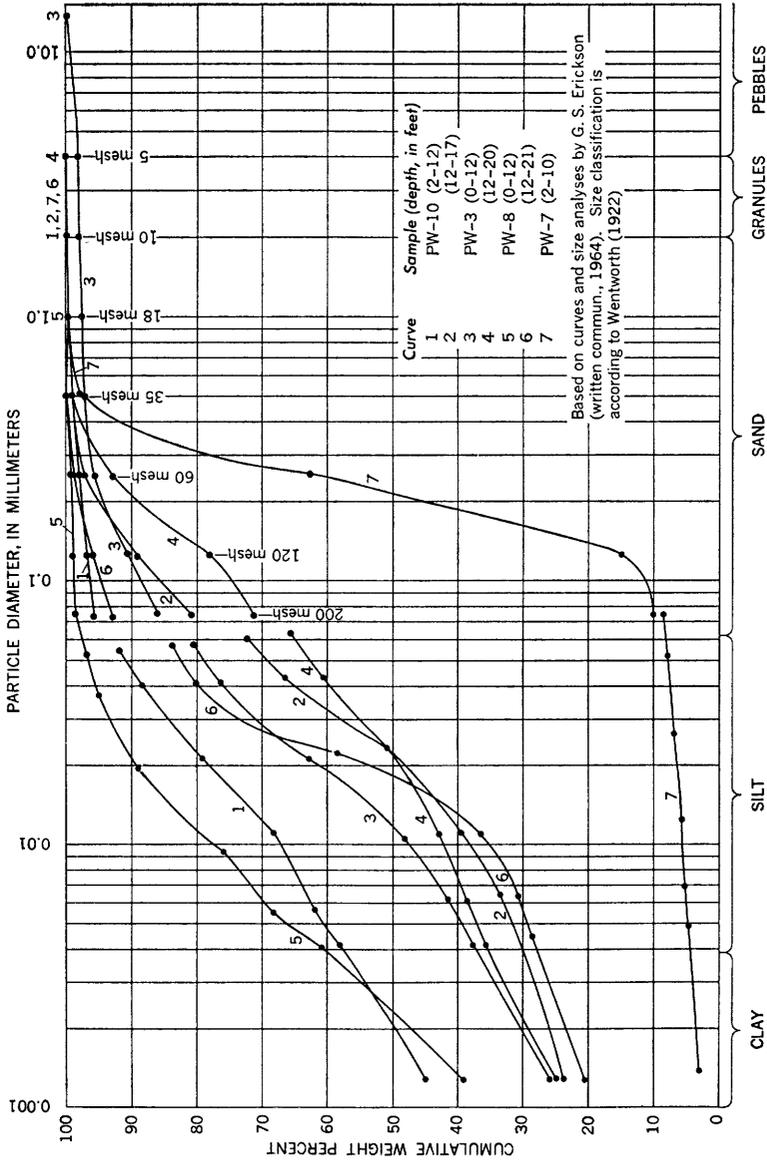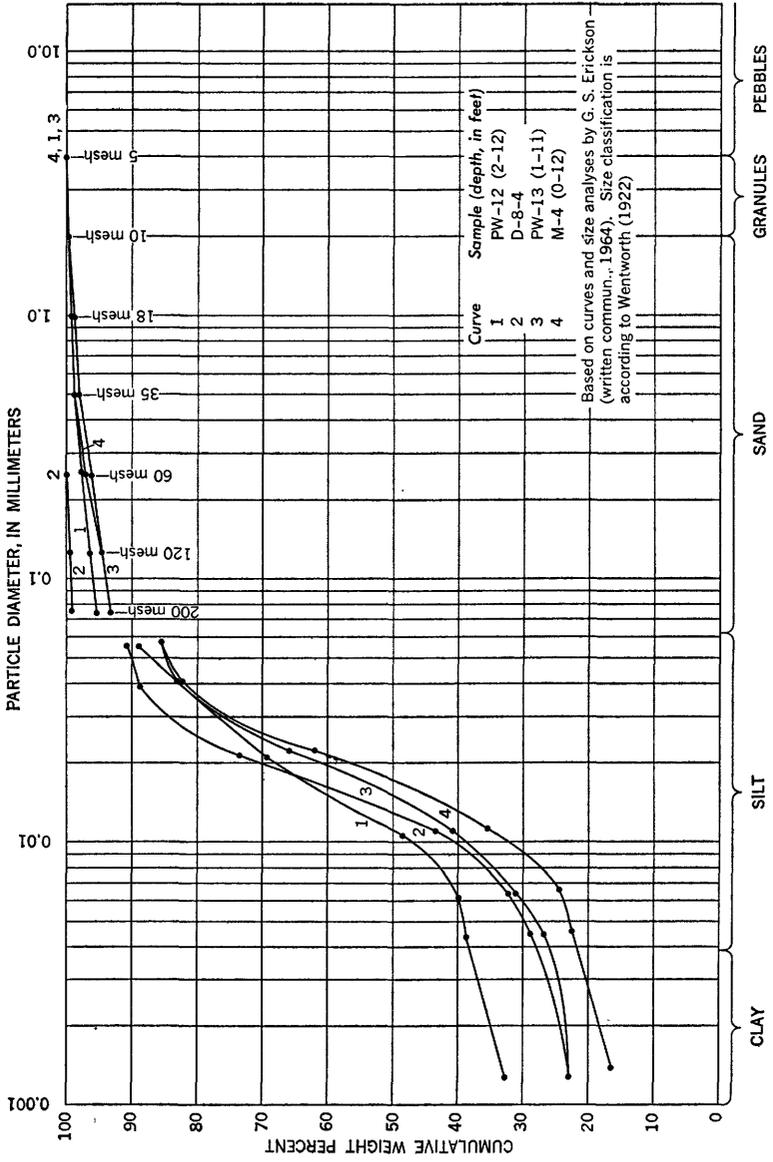FIGURE 3.—Cumulative curves for drill-hole samples from lacustrine deposits (MC).

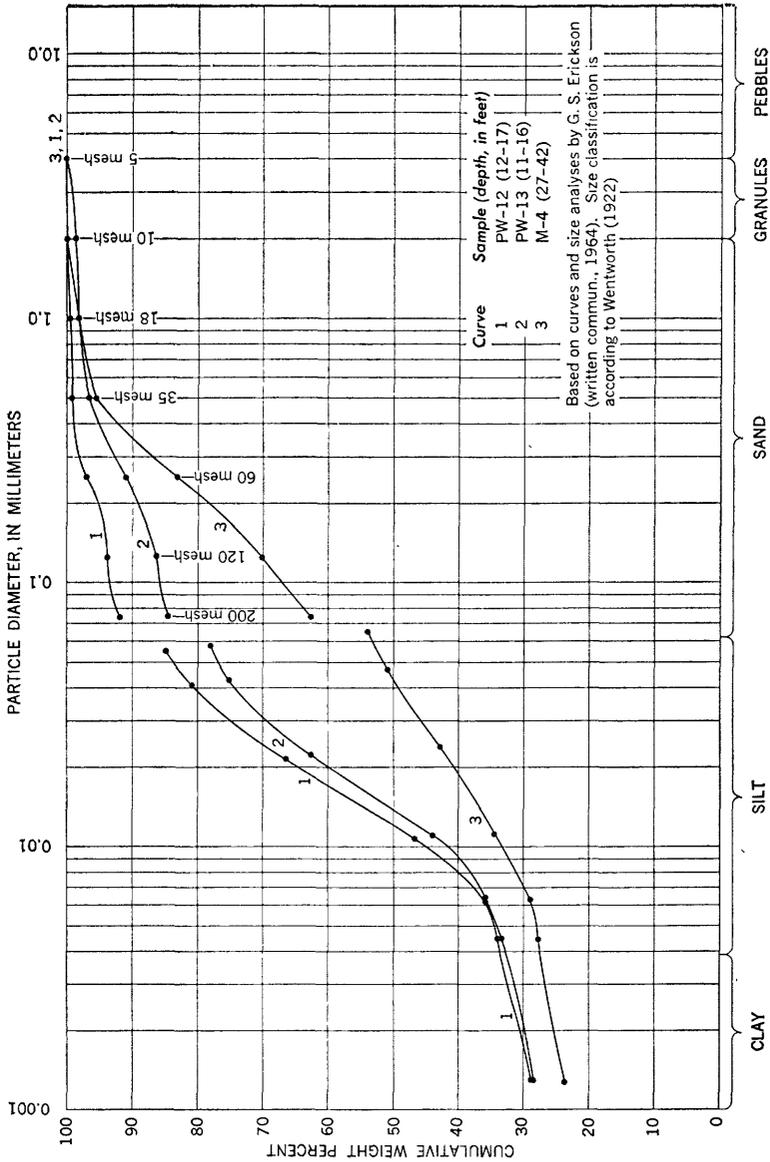FIGURE 4.—Cumulative curves for samples from loess (MC).

FIGURE 5.—Cumulative curves for samples from silt and sand deposits (MC).
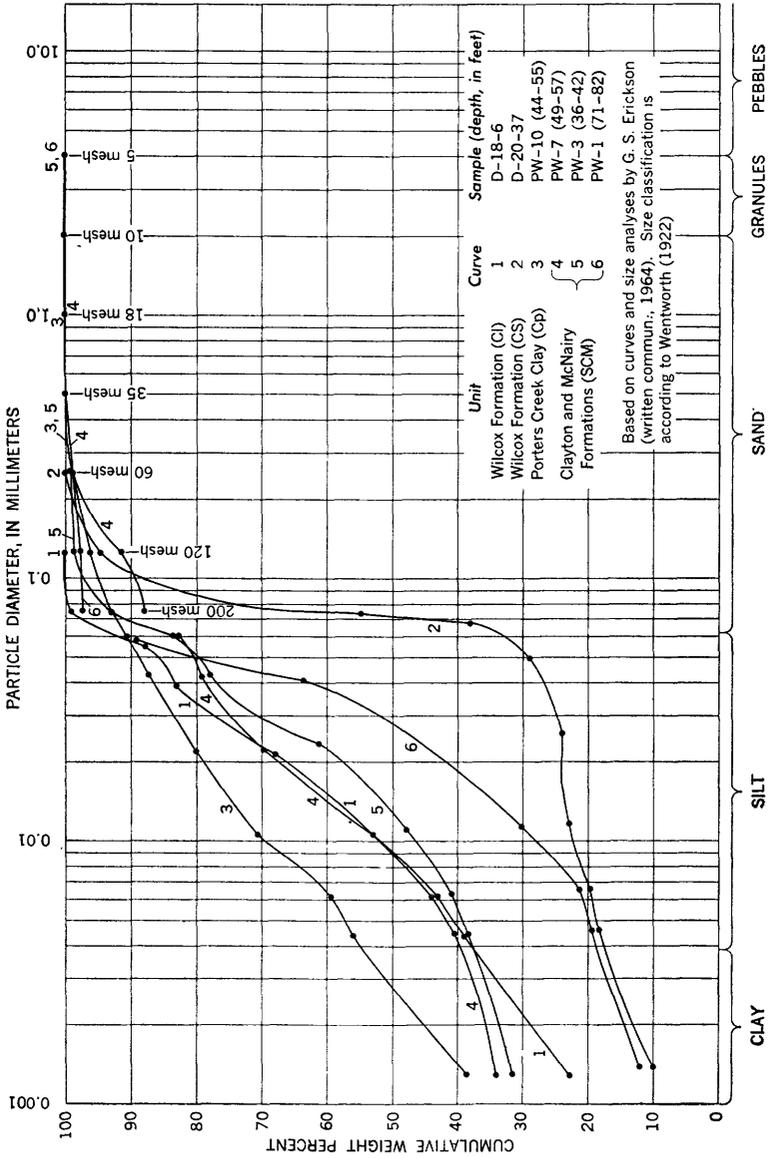
FIGURE 6.—Cumulative curves for samples from the Clayton and McNairy Formations, Porters Creek Clay, and Wilcox Formation.

variable amounts of montmorillonite in these mixed-layer clays is the probable indirect cause of differential swelling and consolidation under load.

The acidity and alkalinity of the materials are shown by the pH values given in table 1. These values are variable, and where the materials are moderately (pH 6) to very strongly (pH 4.5 and below) acidic, precautions need to be taken to prevent direct chemical corrosion and corrosion by electrolytic (galvanic) action of steel pipelines.

Physical properties such as specific gravity, porosity, bulk density of disturbed material, dry density of material in place, and moisture content of the samples of the materials in their natural state are given in table 1. These values indicate to the engineer what may be needed to make the natural materials stronger and more stable to support loads. The bulk density, which is the density of the natural material, and the moisture content values were used to approximate the natural conditions in samples tested in the laboratory.

The moisture-density test was made only on the hand-dug samples. It indicates the moisture content needed to achieve the maximum density of the material, which is almost essential information in order to use the material for fill.

The consolidation test made on the hand-dug samples indicates the percent consolidation that would take place upon wetting compacted material at natural moisture content under a load. The consolidation coefficient, c_v, can be used by engineers to estimate the amount of settlement over a given length of time for a given load resting on the material tested (Peck and others, 1953, p. 83).

The Atterberg limits measure the moisture contents at which materials begin to behave as liquids and plastics (semisolid and solid states not considered here) and the range in moisture content through which the material remains plastic (table 1, footnote 9). Comparison of the plastic limit with the natural moisture content indicates that many of the materials may be unstable under natural conditions. A material loses all strength if the moisture content equals or exceeds the liquid limit.

The plastic limits of Cp (Porters Creek Clay) in the disturbed state are high (table 1; also see Nichols, 1968). In the natural or undisturbed state, however, this clay appears to be lean (low to medium plastic). Thus, the plastic limit and other test data for disturbed and remolded Cp shown in table 1 are believed to be considerably different from those for undisturbed Cp. In general, undisturbed Cp is a relatively stable clay for certain types of structures and ought to be considered for pile foundations.

From the grain-size analyses and Atterberg limits, soils can be classified into groups according to the Unified Soil Classification System (U.S. Federal Housing Admin., Architectural Standards Div., 1961). Each group of soils has relative desirabilities for various uses. Most of the material in the MC map unit falls into the ML and CL soil groups (table 1, footnote 10), which are characterized by being susceptible to frost action, by being fair as foundation material for low buildings (CL, expansion very dangerous if hard and dry), by probably requiring percolation tests to determine desirability for sewage disposal, and by being good (especially CL) for reservoir sites.

The compressive strength of remolded MC material tends to be less than that tested in the field (table 1). Based on these compressive strength values, the shear strength of MC material is low.

Swell pressures as indicated by the potential volume control (PVC) test are considerably greater for remolded dry samples (table 1; see also Nichols, 1968, table 1) than for undisturbed samples cut from a fresh exposure with natural moisture content (Nichols, 1968, table 1). This difference is due mostly to the moisture in the undisturbed samples and partly to the reorientation of particles in the remolded samples. The swell-pressure values for MC material range from noncritical to critical, which reflects the variations in amount of montmorillonite in the mixed-layer clays, and which gives rise to differential consolidation.

GENERAL ENGINEERING PROPERTIES AND BEHAVIOR OF THE MATERIALS

The general engineering properties and behavior of each engineering unit are described in table 2. Certain problems common to Paducah and adjacent areas with similar geologic conditions and materials are emphasized by describing them in greater detail below.

The largest part of the mapped area is underlain by material designated on the map as MC, which consists chiefly of loess or of loessal material. Most engineering problems common to loess (Gibbs and Holland, 1960) are also common to the MC material.

The surface drainage on the MC unit in low or flat areas is poor because of low permeability, as demonstrated by the infiltration tests (table 1), and such surfaces become inundated unless artificially drained.

The water table in the low areas, particularly below altitudes of 350 feet, is within a few feet of the surface in the wet season, and basements in such areas need a properly designed pumping system to prevent flooding and to drain sewers. In upland areas the MC material is rarely water saturated.

The MC material may be used for fill having a slope ratio of as much as 2 to 1 (horizontal to vertical) if compacted to maximum density at optimum moisture content. Changes in moisture content, however, will cause either swelling or settling, and normal rainfall will cause gullying. To prevent these actions, the sides of the fill need to be covered with retaining walls or at least well sodded, and the upper surface provided with good drainage. Where these precautions have not been taken, roadways are uneven, and settling is common along the sides and at the junction of the fill with bridge abutments.

Differential settling is the chief problem with foundations in the MC unit. Under load the MC material tends to consolidate differentially, particularly with changes in moisture content, causing the building to settle and walls to crack. Structures on MC material require foundations designed for low-stress concentrations. Tall structures on MC material may require pile supports bottomed in the underlying Gsc, Cp, or SCM materials. Site testing is strongly recommended.

Frost action is the most common cause of failures in roadways built on MC material. The maximum frost penetration in the Paducah area is about 11 inches, the average being about 5 inches (Johnson, 1952, p. 126–127). A freeze-thaw test (table 2) showed that frost action is more severe after a thaw than after a single freeze and that the soil-moisture content increases and the load-carrying capacity decreases after several cycles of freezing and thawing. During winter in the Paducah area, many freeze-thaw cycles occur. In flat, poorly drained areas, roadway surfaces underlain by MC material break up because of frost heave. To minimize frost heave, the road base or subbase should be made of gravel, and for heavily travelled roads it should be dense-graded crushed aggregate.

The Gsc materials have little or no frost susceptibility and are excellent for foundations and road base or subbase. In the upland areas, where the MC unit is less than 10 feet thick, some roadway cuts could be either deepened or planned deeper to utilize to an advantage the underlying gravel for the road subbase. Where practical, footings for structures should be extended to Gsc.

The poorly to moderately consolidated bedrock units (S, Cl, CS, Cp, and SCM) form a small part of the land surface in the mapped area, and few structures other than those related to roads are built on them. Springs and seeps are common at the contact of Cp, Cl, and CS with the overlying units Gsc and S. Improperly drained roads commonly settle and break up where they cross these contacts. The Cp unit is exposed in a cut in the Hinkleville Road about 1½ miles west of Noble Park, and part of the material used in the fill at the adjacent railroad overpass was, apparently, Cp. Slides occurred in both the cut

and the fill shortly after two extremely heavy rains about a week apart in March 1964.

Most of the materials in the area are easily moved with hand and power equipment. Sporadic sandstone boulders and blocks as much as 15 feet across occur near the base of Gsc (continental gravel deposits) and on the slopes of Cp (Porters Creek Clay) beneath the contact with Gsc; those more than 3 feet across that were discovered during geologic mapping are indicated on the map. Some sand (S) and gravel (Gsc) beds are indurated, particularly east and southeast of Lone Oak. These indurated beds and some large boulders may require blasting to remove.

Two bridges and a navigation dam cross the Ohio River within the mapped area. Subsurface data obtained in connection with their construction have been published (Modjeski, 1919; U.S. Army Corps Engineers, 1929–30a, 1929–30b; Walker, 1957, pl. 6, section 13; Pree and others, 1957, pl. 9, sec. $A-A'$). These data and their interpretation differ considerably. Recent mapping (Finch, 1966, see note for sec. $B-B'$, $C-C'$, and $D-D'$) shows the base of surficial materials (alluvium) to be considerably higher across the Ohio than is indicated in the previously published reports.

FLOODING

Flooding below altitudes of about 340 feet is a source of engineering problems in the Paducah area. High flood crests occurred in February 1884 at 340.16 feet above sea level (river stage 54.2 ft), April 1913 at 340.26 feet (river stage 54.3 ft), and February 1937 at 346.56 feet (river stage 60.60 ft). The high-water line of the 1884 flood is shown on a map at a scale of 1:24,000 by the U.S. Army Corps of Engineers (1929–30b). The 1937 flood "was of sufficiently unusual magnitude to surpass in extent within the area * * * all other floods of which any geologic or other record could be found" (Mansfield, 1938, p. 731). Since 1937, flood-control measures such as Kentucky Dam make the recurrence of another flood of that magnitude less likely. The city of Paducah is now protected by a floodwall, which rises to an altitude of about 350 feet. Records show that since 1945, when Kentucky Lake was impounded, flood crests 325–335 feet in altitude are common (table 3). Flood stage is at a river stage of 39 feet (324.96 ft above sea level).

EARTHQUAKES

The mapped area is in the northern part of the Mississippi embayment area, which has a long history of seismic activity. Potential earthquakes, therefore, are a basic consideration for certain types of construction, particularly tall buildings and bridges. The New Madrid

TABLE 3.—*River crests, 1945–64, Paducah Station (foot of Jefferson Street), Ky.*

[From records of the U.S. Geol. Survey District Office, Louisville, Ky.]

Date	River stage (in feet)	Altitude, above sea level (in feet, 1929 adjustment)	Date	River stage (in feet)	Altitude, above sea level (in feet, 1929 adjustment)
1945, Mar. 10	50.39	336.35	1953, Mar. 9	33.88	319.84
1946, Jan. 19	45.87	331.83	1954, Jan. 27	30.25	316.21
Feb. 20	41.77	327.73	1955, Mar. 29	47.47	333.43
1947, Jan. 28	39.20	325.16	1956, Feb. 26	42.94	328.90
1948, Feb. 22	45.58	331.54	1957, Feb. 10	45.05	331.01
Apr. 25	43.60	329.56	Apr. 18	39.71	325.67
1949, Jan. 13	41.94	327.90	1958, May 18	40.25	326.21
Feb. 4	46.13	332.09	1959, Feb. 2	36.75	322.71
Feb. 25	42.85	328.81	1960, Apr. 8	35.32	321.28
1950, Feb. 13	53.31	339.27	1961, Mar. 11	45.72	331.68
1951, Jan. 17	39.83	325.79	May 18	46.94	332.90
Feb. 11	39.96	325.92	1962, Apr. 1	40.76	326.72
Feb. 26	42.78	328.74	1963, Mar. 19	49.95	335.91
1952, Jan. 14	39.73	325.69	1964, Mar. 21	47.73	333.69
Feb. 8	44.04	330.00			
Mar. 17	39.84	325.80			
Mar. 27	43.86	329.82			

earthquake of 1811–12, one of the strongest on record in the United States and centered about 50 miles southwest of Paducah, was the only major earthquake in historic times in this area. As the population was then sparse, the earthquake caused only a few deaths and minor property damage (Fuller, 1912). It was felt over a large area and toppled chimneys in Cincinnati, Ohio, 350 miles away. Fuller (1912, p. 12) presented evidence to show that earlier shocks equal in intensity to the 1811–12 earthquake probably occurred during historic and prehistoric times. Although earthquakes have been rather frequent, destructive ones have been infrequent. Judging from the history of other seismically active areas, it is reasonable to assume that more major earthquakes will occur in the future. Earthquakes felt in the Paducah area since 1811 are listed in table 4. Only a few minor shocks have been centered beneath or near Paducah.

TABLE 4.—*Recorded earthquake shocks felt in Paducah, Ky.*

Date	Rating [1]	Remarks	Reference
1811, Dec. 16	XII	New Madrid earthquake [2]	Moneymaker, 1954.
1812, Jan. 23	XII	do	Do.
Feb. 7	XII	do	Do.
1843, Jan. 4 [3]	IX–X	Centered near New Madrid	Do.
1856, Nov. 9	IV–V	Felt elsewhere	Moneymaker, 1955.
1872, Mar. 26	III	Not recorded elsewhere	Do.
1878, Nov. 18 [3]	VI–VIII	Affected 150,000 sq mi	Do.
1882, Sept. 27 [3]	VI–VII	Affected 40,000 sq mi	Do.
Oct. 14–15 [3]	V	do	Do.
1883, Jan. 11 [3]	V	Affected 80,000 sq mi	Do.
1887, Feb. 6 [3]	V	Affected 75,000 sq mi	Do.
1895, Oct. 31 [3]	IX	Epicenter Charleston, Mo., affected about 1 million sq mi.	Do.
1899, Apr. 29 [3]	VI	Affected 40,000 sq mi	Do.
1903, Feb. 8 [3]	VI	Affected 70,000 sq mi	Moneymaker, 1957.
Nov. 4 [3]	VI	do	Do.
Nov. 27	III–IV	Near maximum intensity at Paducah; affected 70,000 sq mi.	Do

See footnotes at end of table.

TABLE 4.—*Recorded earthquake shocks felt in Paducah, Ky.*—Continued

Date	Rating [1]	Remarks	Reference
1909, Oct. 23 [3]	V–VI	Affected 40,000 sq mi	Moneymaker, 1957.
1917, Apr. 9 [3]	VI	Affected 200,000 sq mi	Do.
1922, Mar. 23	V	Centered somewhere in western Kentucky.	Do.
1924, Apr. 2	IV	Also felt at points in southern Illinois.	Do.
1925, May 13		Felt elsewhere in western Kentucky and southern Illinois.	Do.
1927, May 7 [3]	VII	Affected 130,000 sq mi	Moneymaker, 1958.
1934, Apr. 19	III	Centered at Rodney, Mo	B. C. Moneymaker, written commun., 1965.
1940, May 31	IV–V	Maximum intensity at Paducah; felt from Henderson, Ky., to Cairo, Ill.	Moneymaker, 1958.
1945, Nov. 13 [3]	IV	Centered near Cairo, Ill	Do.
1949, Jan. 13 [3]	V	Affected 7,000 sq mi	Do.
1952, Feb. 20	IV	Epicenter between Tiptonville, Tenn., and Hickman, Ky.	B.C. Moneymaker written commun., 1965.
1955, Jan. 25	IV	Epicenter near Finley, Tenn	Do.
1957, Mar. 26	III–IV	Not felt elsewhere	Do.
1958, Jan. 27	V	Affected about 300 sq mi	Do.
Nov. 7	VI	Affected 33,000 sq mi	Do.
1962, Feb. 16		Felt from 21st and Harrison Street to New Concord School.	Recorded by W. I. Finch.
1963, Mar. 3		Low rumble, slight shock lasted 2–3 sec.	B. C. Moneymaker, written commun., 1965.
Aug. 8		Sharp shock in western Kentucky and southern Illinois.	Do.

[1] Maximum degree of intensity within the area noted assessed by B. C. Moneymaker in terms of a modified Mercalli scale (Wood and Neumann, 1931). Ratings I–IV, no damage; V, broken dishes and cracked windows; VI–VII, cracked plaster and slight damage to poorly built buildings; VIII, damage negligible in buildings of good design and construction, slight to considerable in ordinary buildings, considerable in poorly built and designed buildings; IX, damage considerable to great in well-designed and well-built buildings; X, severe damage to well-built wooden and masonry buildings, to bridges, and to dams; occurrence of landslides, cracked ground, and broken pipelines; XI, few if any (masonry) structures remain standing, disturbances in ground many and widespread; XII, total damage.

[2] Moneymaker (1954, p. 228) estimated that 2,000–3,000 shocks were felt in Tennessee during 1811 and 1812. Only those of rating XII are listed here.

[3] Paducah not named, but description indicates Paducah was affected.

Schlicker, Deacon, and Twelker (1964) described five different ways geologic formations may react to earthquake vibrations:

Elastic reaction to vibrations occurs in a bedrock formation or other extremely competent non-bedrock material, in which damping does not play an important part, and in which the component particles maintain the same relative position. As far as we now know, structures founded on an elastic-responding medium are subject only to vertical and lateral forces of acceleration. Elastic-reacting foundation materials constitute the "good ground" of any urban area.

Fluid reacting formations are those which undergo a total loss of strength upon repeated application of forces. * * * Soils which are capable of a fluid response range in texture from clay to coarse sand and gravel. Ordinarily a fluid response involves some degree of saturation of the soil unit involved; however, disastrous flow slides occurred in deep loess beds in Kansu Province of western China during the two great earthquakes of 1920 and 1927. Ground motion disrupted the fragile bonds of the soil formation, allowing a mixture of soil and air to flow some 5 or 6 miles with great speed. * * *

Brittle response of geologic formations under earthquake stresses occurs principally where relatively competent units occupy precarious positions on hillsides, or mountain tops. * * *

Viscous or visco-elastic response to earthquake loading is that which is undergone by a mass of "plastic" clay or similar cohesive material having the following general properties: (1) low mobility of pore water, (2) ability to deform plastically under shear stresses of low to moderate order, (3) incapable of sudden (that is, within the period of duration of an earthquake) changes in volume, and (4) a "rubber-like" response to dynamic loads. * * *

Fine-grained alluvial deposits or lacustrine clays are the most important of the materials having a viscous or visco-elastic response to ground vibrations. The rubber-like behavior of these materials causes an amplification of ground motion, which may justify the term "bad ground," at least for certain types of building construction. On the other hand, this material (like rubber) absorbs energy internally when undergoing repeated stress reversals. Therefore, while soft, fine-grained alluvial deposits will have a tendency to magnify the motion of small or moderate ground motion, more severe ground motion tends to be damped out by this same material. * * *

Granular response to earthquake loadings involves principally the tendency of thick beds of loose, cohesionless materials to densify under vibratory loadings, resulting in differential settlements of structures which may be founded thereon. * * *

Earthquake reaction characteristics for each map unit are given in table 2. Materials with a tendency to elastic reaction from earthquake shocks and thereby constituting "good ground" include the map units G in part, Gsc, Cl, S in part, CS, Cp, and SCM. Material of the MC unit would have a viscous or visco-elastic response and would be susceptible to differential compaction and landslides under certain conditions and to groundwave motion from distant earthquakes such as at New Madrid. Over much of the area shown as MC, materials having good earthquake stability lie a few feet to no more than 35 feet below MC (section *A–A'*). Footings could be extended down to these materials to good advantage. Earthquake-resistant construction should conform to available building codes such as the Uniform Building Code (International Conference of Building Officials, 1964) and the National Building Code (Natl. Board Fire Underwriters, 1955, p. 265–268).

Faults, movement along which causes earthquakes, are probably more numerous in the area than indicated on the map. Ross (1963, 1964) showed several major faults in southern Illinois that trend toward the Paducah area, but mapping in Kentucky disclosed scant evidence for the continuation of only one of them. None of the faults is known to have been active in geologically recent time.

CONSTRUCTION MATERIALS

An important aspect of the industrial development of any area is the availability of construction materials. In the mapped area the reserves of sand and gravel are large, and about 25 miles to the east, in the Kentucky Dam area, large quantities of limestone aggregate are available. Sand has been mined for subfoundation fill from pits in the

S unit southeast of Lone Oak and in the Smc unit west of the Irvin S. Cobb Bridge.

Gravel has been mined for road metal in large quantities from pits in the Gsc unit and in small quantities from pits in the ridgelike deposits of the G unit. Sand and gravel for portland cement and bituminous concrete are obtained from the Ohio River bed, chiefly in the Paducah East quadrangle.

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