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State University of New York at Buffalo

SUBSURFACE CONDITIONS OF
MEMPHIS AND SHELBY COUNTY

by

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Center for Earthquake Research and Information

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Memphis, Tennessee 38152

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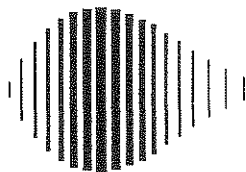
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K.W. Ng¹, T-S. Chang² and H-H.M. Hwang³

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PREFACE

The National Center for Earthquake Engineering Research (NCEER) is devoted to the expansion and dissemination of knowledge about earthquakes, the improvement of earthquake-resistant design, and the implementation of seismic hazard mitigation procedures to minimize loss of lives and property. The emphasis is on structures and lifelines that are found in zones of moderate to high seismicity throughout the United States.

NCEER's research is being carried out in an integrated and coordinated manner following a structured program. The current research program comprises four main areas:

- Existing and New Structures
- Secondary and Protective Systems
- Lifeline Systems
- Disaster Research and Planning

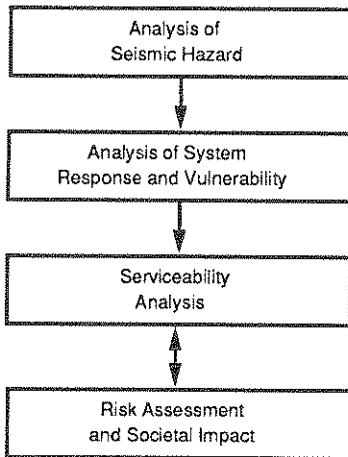
This technical report pertains to Program 3, Lifeline Systems, and more specifically to water delivery systems.

The safe and serviceable operation of lifeline systems such as gas, electricity, oil, water, communication and transportation networks, immediately after a severe earthquake, is of crucial importance to the welfare of the general public, and to the mitigation of seismic hazards upon society at large. The long-term goals of the lifeline study are to evaluate the seismic performance of lifeline systems in general, and to recommend measures for mitigating the societal risk arising from their failures.

From this point of view, Center researchers are concentrating on the study of specific existing lifeline systems, such as water delivery and crude oil transmission systems. The water delivery system study consists of two parts. The first studies the seismic performance of water delivery systems on the west coast, while the second addresses itself to the seismic performance of the water delivery system in Memphis, Tennessee. For both systems, post-earthquake fire fighting capabilities will be considered as a measure of seismic performance.

The components of the water delivery system study are shown in the accompanying figure.

Program Elements:



Tasks:

Wave Propagation, Fault Crossing
Liquefaction and Large Deformation
Above- and Under-ground Structure Interaction
Spatial Variability of Ground Motion

Soil-Structure Interaction, Pipe Response Analysis
Statistics of Repair/Damage
Post-Earthquake Data Gathering Procedure
Leakage Tests, Centrifuge Tests for Pipes

Post-Earthquake Firefighting Capability
System Reliability
Computer Code Development and Upgrading
Verification of Analytical Results

Mathematical Modeling
Socio-Economic Impact

This report presents the subsurface conditions of Memphis and Shelby County based upon existing geotechnical data consisting of 8,500 boring logs collected from government agencies and private geotechnical companies, and of other water-well logs, soil surveys and technical publications. The subsurface conditions are presented in the format of representative soil logs to facilitate the evaluation of the soil amplification and liquefaction potential in Memphis and Shelby County due to earthquakes. In addition, these soil logs are also very useful for land use planning.

NOTICE

The actual soil logs, intended to be Appendix A of this report, are too lengthy to include in this printing. The appendix, which contains 679 pages of data, is available under separate cover, and can be obtained by writing to NCEER's Publications Department.

ABSTRACT

This report presents the subsurface conditions of Memphis and Shelby County based upon existing geotechnical data. For this study, about 8,500 boring logs have been collected from government agencies and private geotechnical companies. Supplementary geotechnical data were also gathered from water-well logs, soil surveys, and technical publications. These data have been compiled and analyzed to establish the subsurface conditions of Memphis and Shelby County. The subsurface conditions are presented in the format of representative soil logs. These soil logs can be used to evaluate the soil amplification and liquefaction potential in Memphis and Shelby County due to earthquakes. In addition, these soil logs are also very useful for land use planning.

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SECTION 1

INTRODUCTION

The New Madrid seismic zone is regarded by seismologists and engineers as the most hazardous seismic zone in the eastern United States. The City of Memphis and Shelby County, Tennessee are situated less than 100 miles from the epicenters of the 1811-1812 New Madrid earthquakes. These earthquakes are the largest historical earthquakes ever known to have occurred in the North America. The New Madrid seismic zone is still seismically active where small earthquakes have been routinely recorded by regional seismic networks as shown in Fig. 1-1. Thus, a significant potential of seismic hazard exists in Memphis and Shelby County.

Numerous studies [1,3,4,10,13,15,16,17,21,22] have demonstrated that soil conditions have profound effects on ground motions due to earthquakes. The bedrock motions can be greatly modified, both in amplitude and frequency characteristics, as the seismic waves are transmitted through the overlying soil deposits. The effects of soil conditions on earthquake ground motions have been well demonstrated by many actual earthquakes such as the Niigata earthquake of 1964, the Caracas earthquake of 1967, and the Mexico earthquake of 1985. Memphis and Shelby County are located in the Mississippi Embayment which is composed of relatively unconsolidated soils up to about 3,000 feet thick. A recent study by Hwang et al. [5] has shown that the soil conditions in the Memphis area have significant effects on the amplification of strong earthquake acceleration.

Having recognized the significant influence of soil conditions on the earthquake ground response and the high seismic hazard potential in Memphis and Shelby County, an effort is made to investigate the subsurface conditions of Memphis and Shelby County. The understanding of subsurface conditions is essential for seismic risk studies such as the Seismic Risk Assessment of Memphis Water Delivery System project. Based upon the geotechnical data gathered from existing boring logs, water-well logs, soil surveys, and technical publications, this report presents the subsurface conditions of Memphis and Shelby County.

New Madrid Seismic Zone : 1974 - 1988

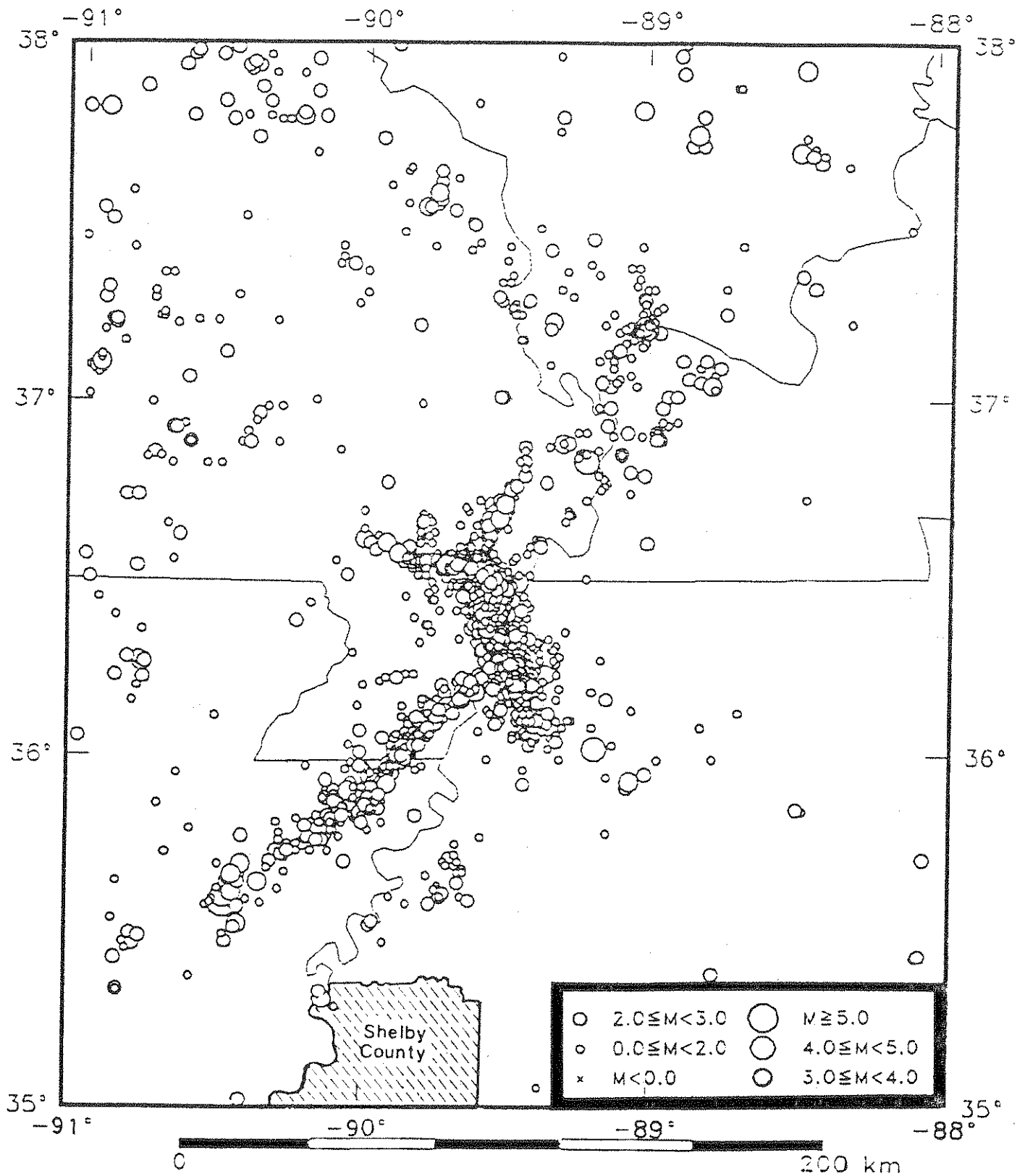


Fig. 1-1 Epicenter Map of the New Madrid Seismic Zone.

SECTION 2

GEOGRAPHY AND GEOLOGY

2.1 Geography

Memphis and Shelby County are located in the southwestern corner of Tennessee (Fig. 2-1). The study area is bounded by the longitudes of 35°25'N on the north and 34°59'N on the south; and the latitudes of 90°19'W on the west and 89°38'W on the east. It comprises an area of about 751 square miles. The principal stream in this area is the Mississippi River and its major tributaries are the Loosahatchie River, Wolf River, and Nonconnah Creek.

Physiographically, Memphis and Shelby County are situated in two major provinces: the Gulf Coastal Plain and the Mississippi Alluvial Plain as illustrated in Fig. 2-2. The Gulf Coastal Plain in this area is characterized by gently rolling to hilly topography and is dissected at many places by rivers and creeks. The Mississippi Alluvial Plain in this area is flat-lying and is characterized by fluvial deposition features such as point bars, abandoned channels, back swamps, and natural levees.

The altitude of Memphis and Shelby County ranges from 430 feet above mean sea level on the highest hills and ridges to 185 feet above mean sea level on the floodplains of the Mississippi River. The average altitude is about 300 feet above mean sea level. The most prominent topographic feature in this area is the bluffs that rise abruptly up to 100 feet above the eastern limit of the Mississippi Alluvial Plain. The detailed topography of the area can be found in the topographic quadrangle maps published by the U.S. Geological Survey (USGS) [19].

2.2 Geology

As depicted in Fig. 2-3 and Fig. 2-4, Memphis and Shelby County are in the central part of the Mississippi Embayment, a syncline or a trough-like depression that plunges southward along an axis which approximates the course of the

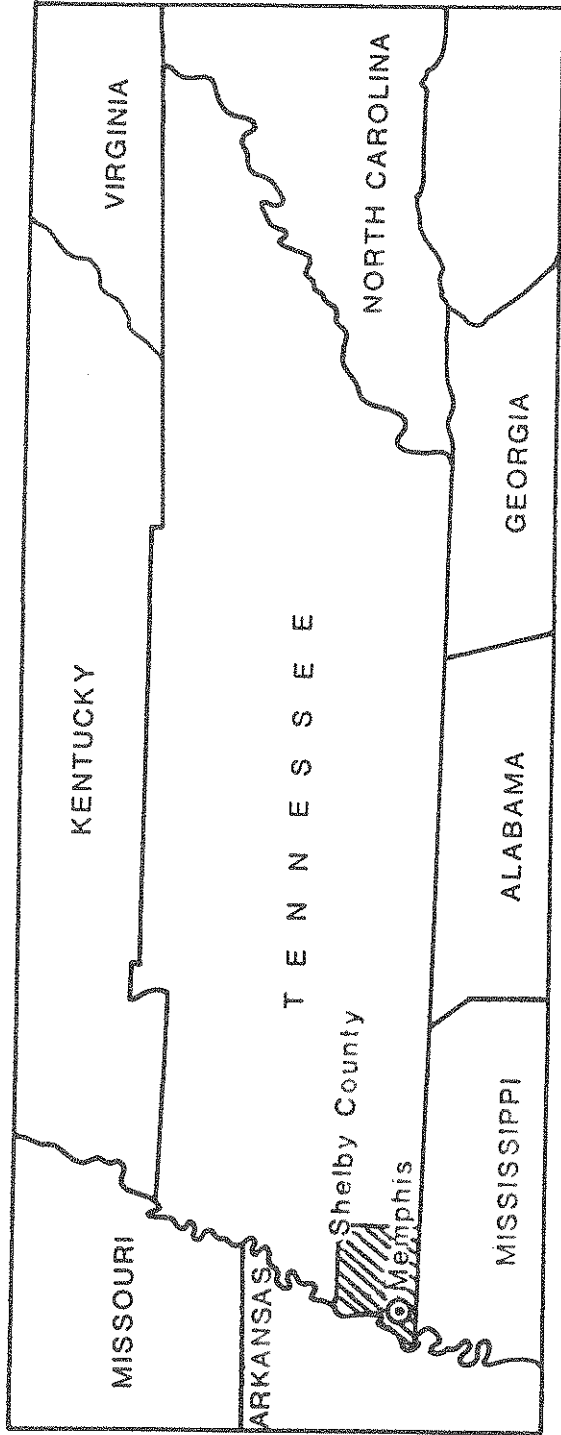


Fig. 2-1 Location of Memphis and Shelby County

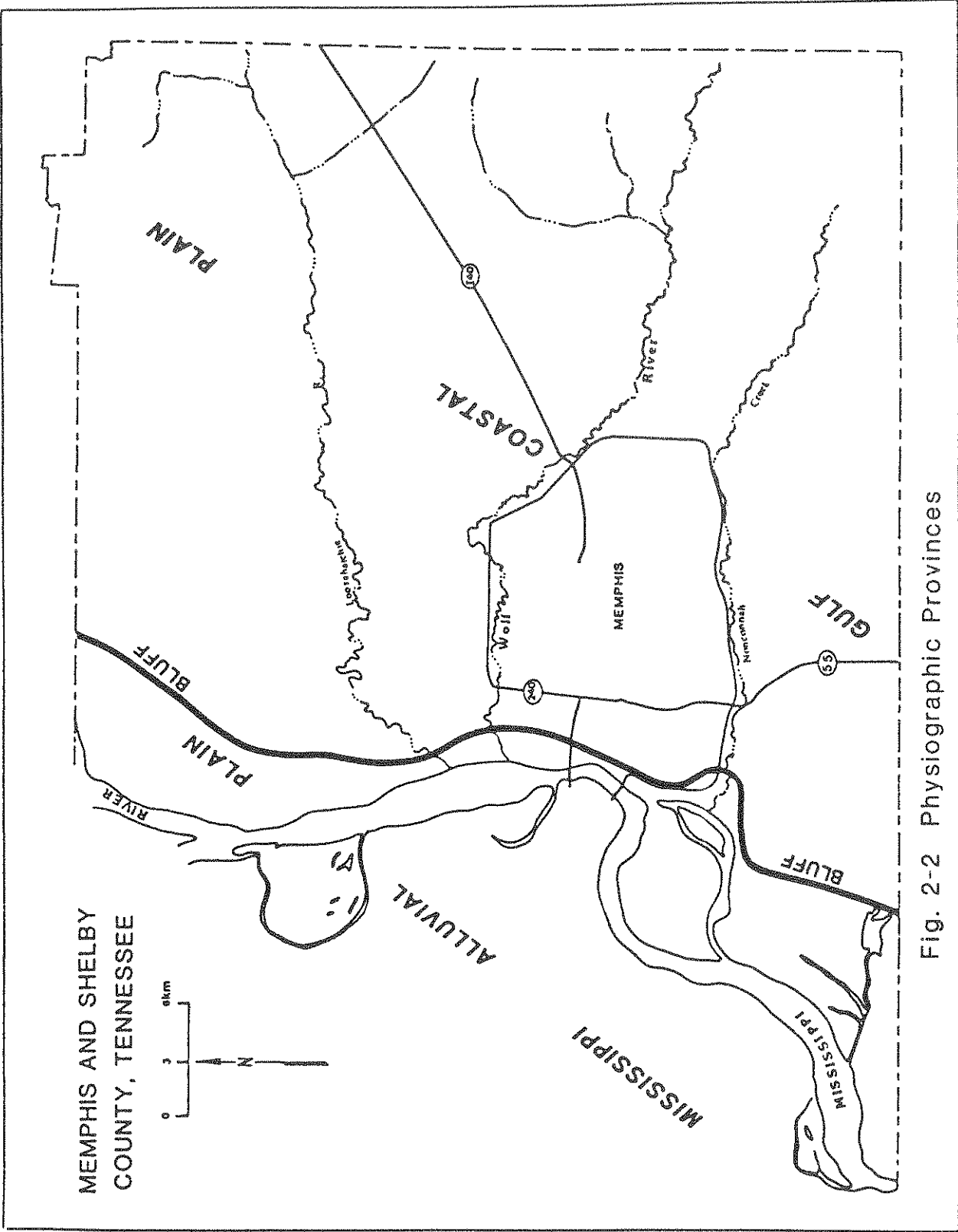


Fig. 2-2 Physiographic Provinces

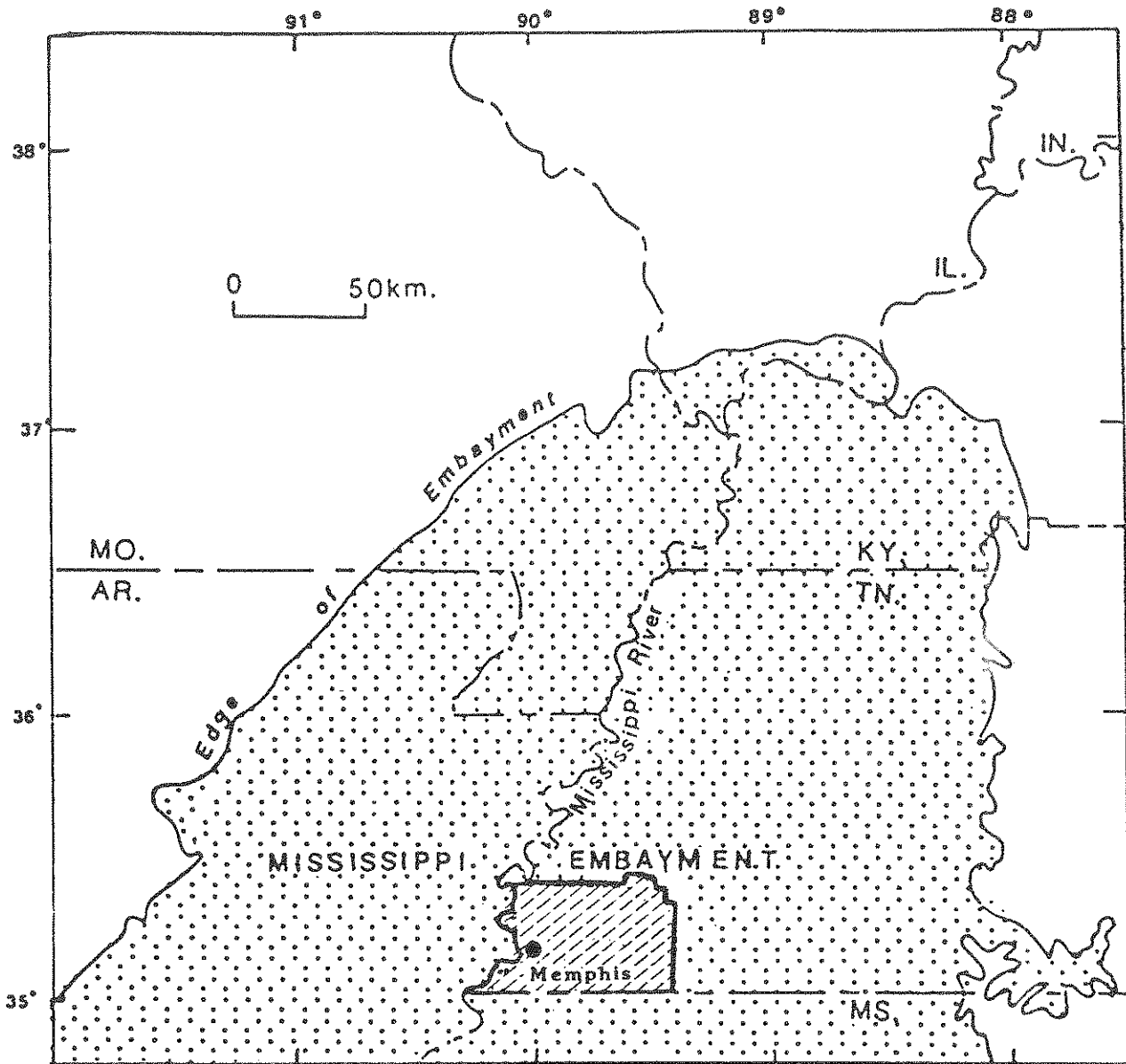
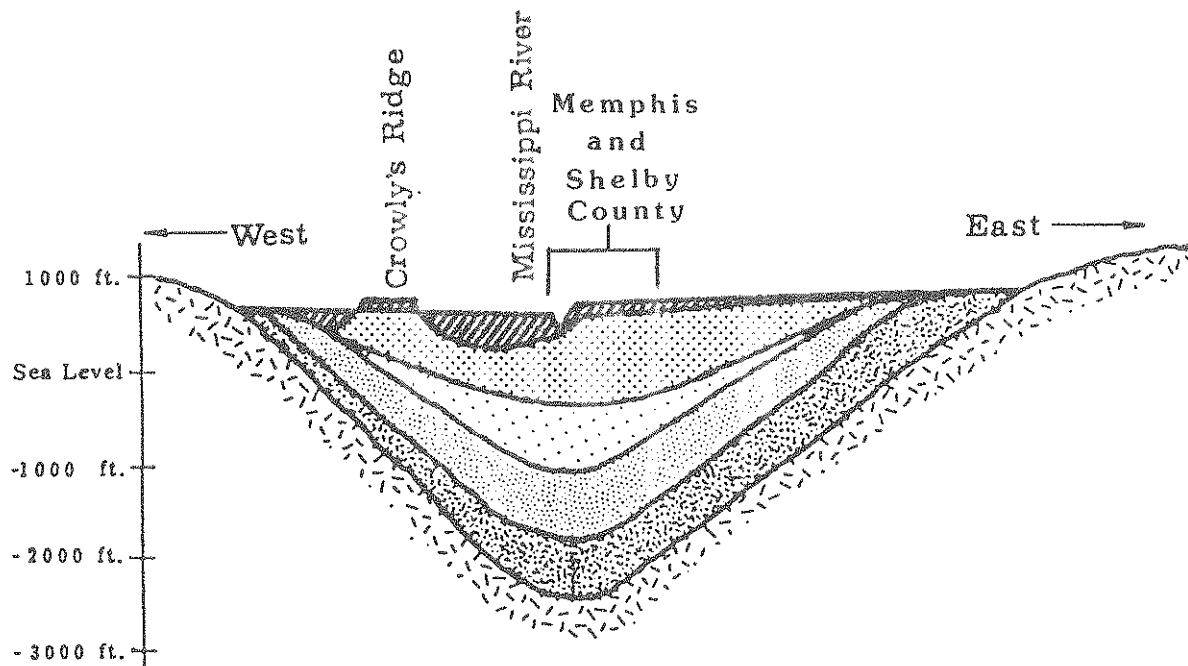


Fig. 2-3 Mississippi Embayment



LEGEND


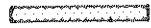
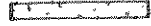
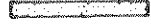
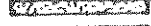
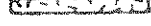
-  : Recent and Plio-Pleistocene 0-10 Million years
-  : Middle and Upper Eocene 40-50 Million years
-  : Lower Eocene 50-60 Million years
-  : Paleocene 60-70 Million years
-  : Cretaceous 70-100 Million years
-  : Paleozoic Rock 300-600 Million years



Fig. 2-4 Cross Section of Mississippi Embayment
(Ref. 20)

Mississippi River. The Paleozoic rock that forms the bedrock floor of the Mississippi Embayment is located about 3,000 feet below Memphis and Shelby County. The embayment is filled with sediments of clay, silt, sand, gravel, chalk and lignite ranging in age from Cretaceous to Recent [2,11]. There is no well-consolidated rock above the Paleozoic rock, except some local beds of ferruginous and Calcareous sandstone and limestone [11]. The geologic formations underlying the study area are shown in Fig. 2-5. Since the site response during earthquakes is usually controlled by the upper unconsolidated soils layers [8,16,17]; therefore only the Jackson and younger geologic formations are discussed in this report.

The Jackson Formation is composed of hard blue, gray, or brown clays and interbedded with very dense white fine sands and some seams of lignite [2,8]. It overlies and confines the Memphis Sand, an aquifer which supplies most of the public and industrial water used in Shelby County. The Jackson sediments were deposited during the last incursion of the sea into the embayment [8]. The thickness of the Jackson Formation in this area ranges from 0 to 350 feet. It crops out in many places along the bluffs east of the Mississippi River.

Overlying the Jackson Formation is a discontinuous series of fluvial deposits that occur along the Mississippi River and the larger streams in the area. These deposits, also referred as terrace deposits, thin gradually eastward and are absent in many places as a result of erosion or non-deposition. The fluvial deposits are composed mostly of coarse-grained quartz sand, fine-grained iron-stained quartz and chert gravel. Lenses of yellowish-brown clay are frequently present locally in the lower part of the deposits. The fluvial deposits are basically red or brown, dense and well-graded. They can be distinguished easily from the underlying Jackson Formation by the color and grain size distribution. The thickness of the fluvial deposits ranges from 0 to 200 feet. They generally occur 35 to 50 feet below the ground surface.

The surface geology of Memphis and Shelby County comprises loess and alluvium except for a narrow strip of Jackson Formation that outcrops along the bluffs. The generalized surface geology is shown in Fig. 2-6.

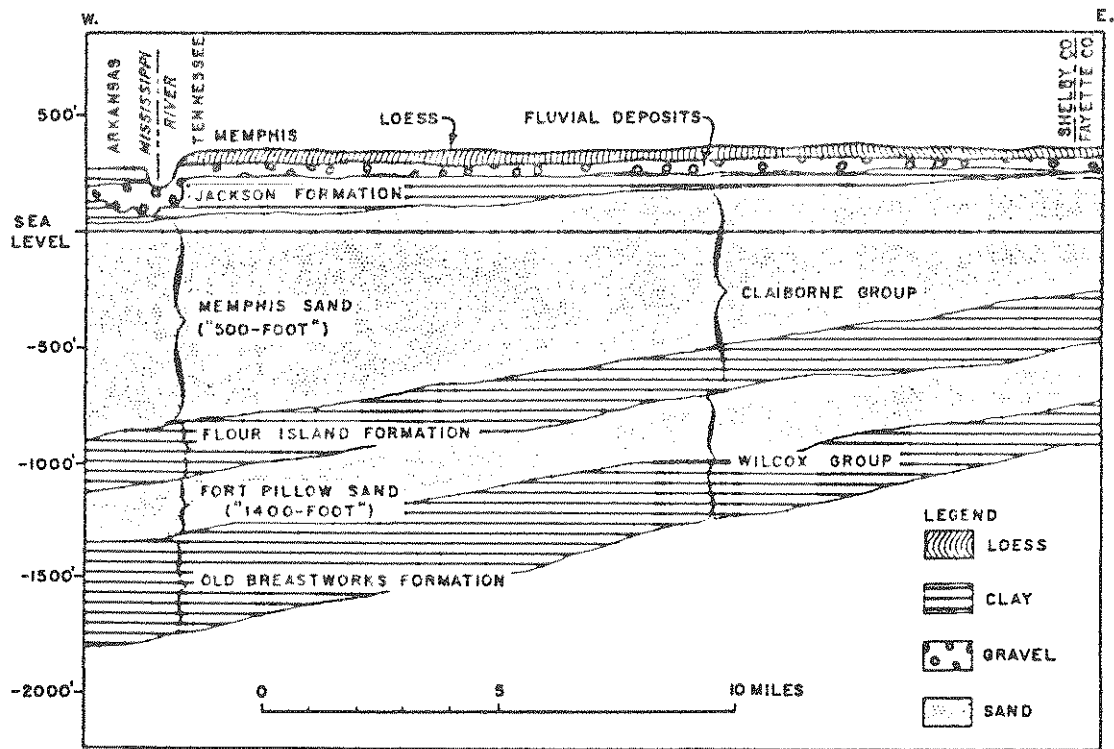


Fig. 2-5 Geologic Formations Underlying Memphis and Shelby County (Ref. 20)

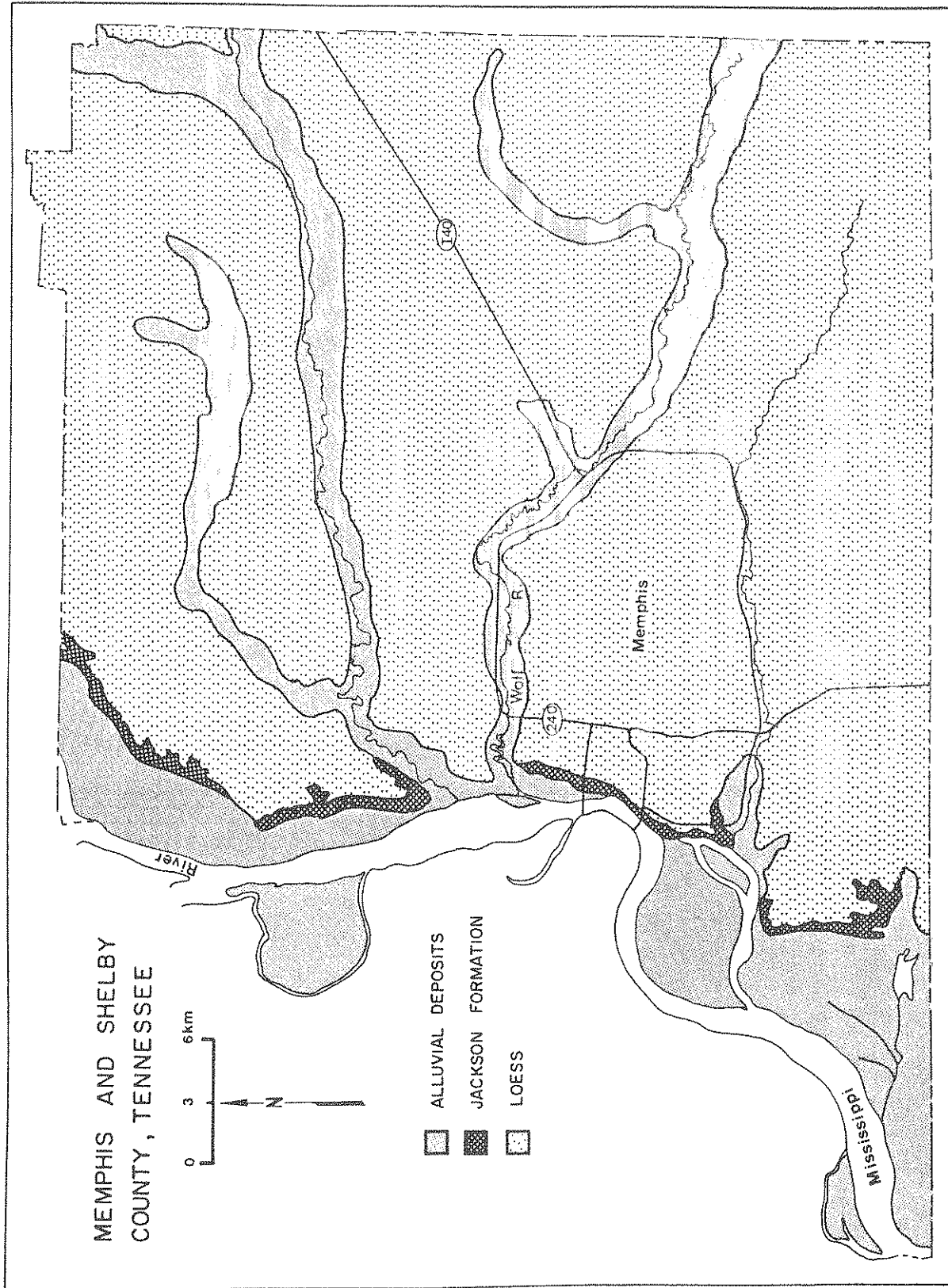


Fig. 2-6 Generalized Surface Geology (Ref. 20)

Loess is a windblown deposit that covers most of the Shelby County. It is composed of silt and clayey silt. It is generally buff colored and uniform in texture. Loess is highly cohesive when dry, but loses all its cohesion when wet. Loess is capable of standing on vertical slopes so long as the top of the slopes are protected from water softening such as by vegetation. Vertical root holes are commonly present in the loess and provide rapid vertical drainage that keeps the loess dry and cohesive. The maximum thickness of loess in this area is about 65 feet on the bluffs and thins gradually toward east.

Alluvium is the sediments laid down by streams along the channels and upon the floodplains during flood periods. It is composed of sand, clay, silt, and gravel. The alluvium in this area is generally confined to narrow strips along the Mississippi River and its tributaries and is frequently subjected to flooding and reworking. The coarsest material is usually found in the lower level of the alluvium and the finest in the upper level. Lignite, peat and carbonaceous materials are distributed irregularly throughout the upper level. Alluvial sands are usually white or gray, loose to medium dense, and poorly-graded. The loose and poorly-graded alluvial sands are prone to liquefaction when subjected to earthquakes or prolonged vibrations.

SECTION 3

DATA COLLECTION, COMPILATION AND ANALYSIS

The subsurface conditions may be determined by using existing geotechnical data or by performing new subsurface explorations. Due to the size of the Shelby County and the high cost of subsurface exploration, it is beyond the scope of this study to perform any soil boring; thus the subsurface conditions of Memphis and Shelby County are established based upon existing geotechnical data.

3.1 Data Collection

Through an extensive search for existing geotechnical data from various sources, approximately 8,500 boring logs at various locations in the Shelby County have been collected. Most of the boring logs were obtained from soil investigation reports by local geotechnical consulting firms and the U.S. Army Corps of Engineers. In addition, geotechnical data were also gathered from water-well logs, soil surveys, and technical publications.

3.2 Data Compilation

Since the data are collected from various sources, considerable time and effort have been spent on compiling these data. For this study, the data are compiled according to their locations; therefore an appropriate map is needed. The map of Shelby County published by the Shelby County Engineering Department is selected as the basemap. In addition, a set of topographic quadrangle maps of Shelby County by the USGS and the Official Map of Memphis by the Memphis City Department of Engineering are also used as supplementary maps.

For the purpose of data classification, a grid system consists of rectangular cells with equal size of 30 seconds in both latitude and longitude is selected. Each cell is approximately 2,500 feet by 3,000 feet in the east-west and north-south directions, respectively; and represents an area of approximately 172 acres in the Shelby County. The vertical grid co-ordinates are designated by alphabets while the horizontal grid co-ordinates are designated by Arabic numerals. Each cell is

identified by a cell code (mesh number); e.g. F7, C11, SS25, M(-4), etc. Each cell is considered as a basic unit of the map. A map of Memphis and Shelby County with the proposed grid system is shown in Fig. 3-1. The latitude and longitude coordinates are also given in the map for reference.

In the compilation process, all boring logs and supplementary geotechnical data are grouped, classified and organized by the cell code. The product of the compilation process is a systematic geotechnical data base. Fig. 3-2 shows the distribution of the collected boring data. The number indicated in a cell refers to the total number of data available in that cell. It is noticed that the collected boring data for Memphis and urban areas in Shelby County are reasonably well-distributed. The areas lacking data are usually agricultural lands, forests, state parks, and sparsely populated rural areas.

3.3 Data Analysis

The data in each cell are reviewed and analyzed to produce a representative soil log that delineates the subsurface conditions in the cell. The data analysis procedure consists of the following major steps:

1. Draw all the available boring logs in a cell on a working drawing and record the geotechnical data on the drawing.
2. Create a representative soil profile by connecting the boundaries of the soil strata with approximately the same soil characteristics in terms of soil classification, depth, and soil properties; then determine the strata boundaries of the representative soil profile.
3. Compute the average values of soil properties such as SPT N-values, natural soil density, and unconfined compressive strength.
4. Determine the ground surface elevation of the representative soil log by averaging the elevations recorded in the boring logs or reading from the USGS topographic maps.

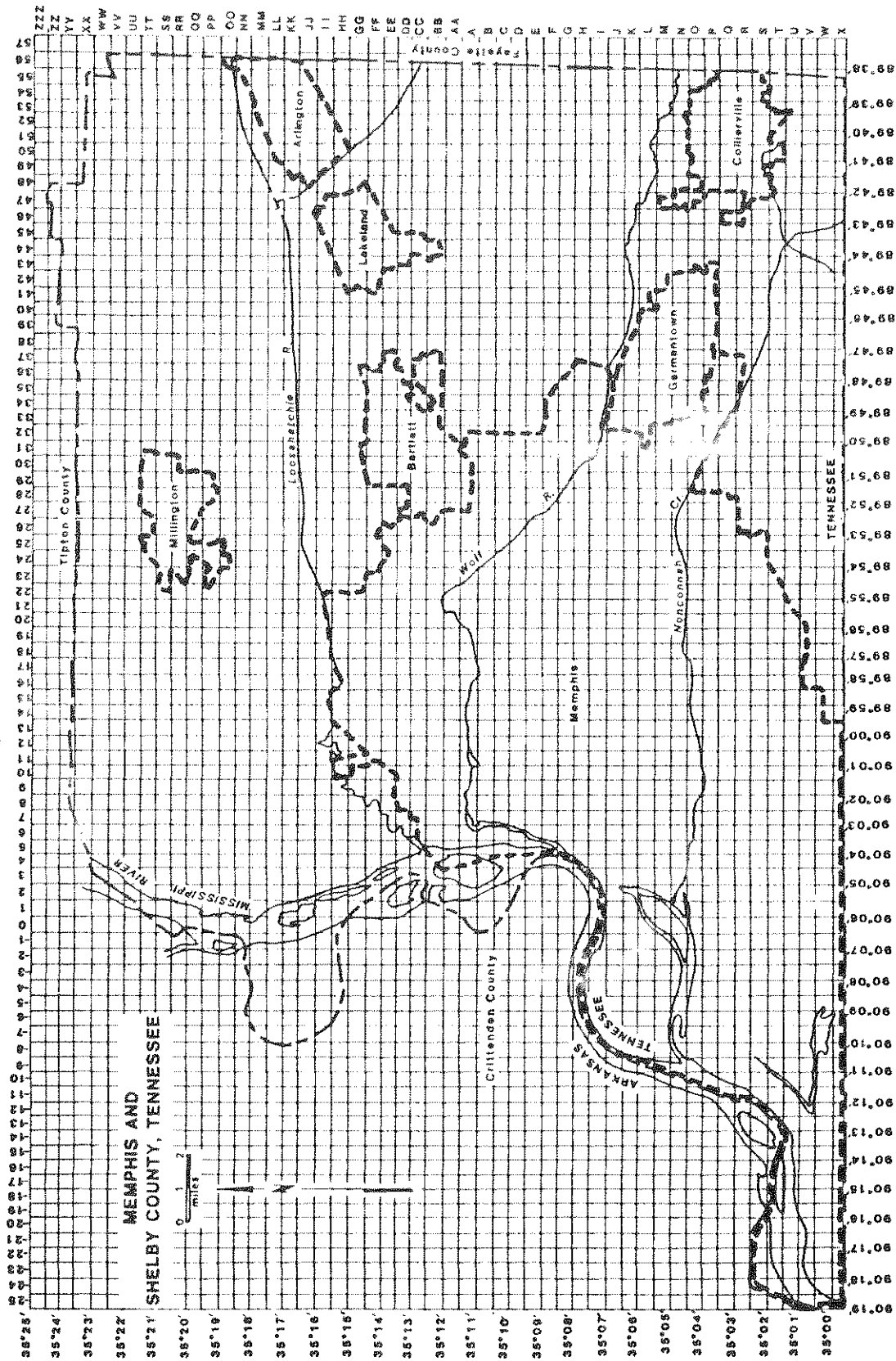


Fig. 3-1 Map of Memphis and Shelby County

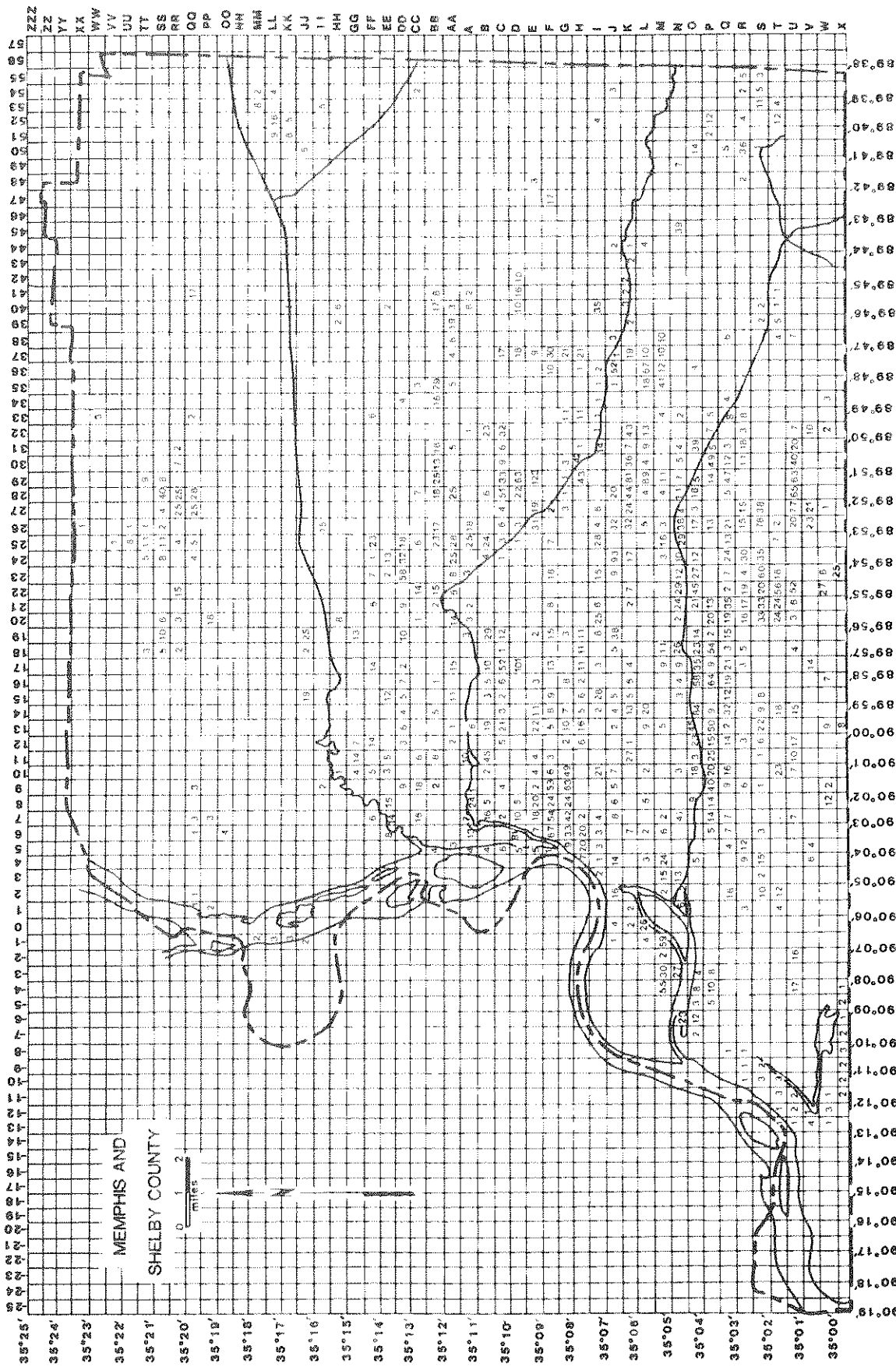


Fig. 3-2 Boring Data Distribution Map

5. Estimate the groundwater level of the representative soil log from the available groundwater data. Record the static groundwater level, if available.
6. Plot a representative soil log based upon the results obtained from steps 2 through 5.

The following example is used to demonstrate the procedure of data analysis. In this example, there are 6 boring logs available for cell F10. First, all the 6 boring logs are drawn on a drawing as shown in Fig. 3-3. The groundwater level and soil properties for each boring are also recorded in the drawing. Based upon the information in the drawing, a representative soil profile is established by connecting the boundaries of the soil strata with approximately same soil characteristics in terms of soil classification, depth, and soil properties. The strata boundaries of the representative soil profile for cell F10 are shown in Fig. 3-3 by using dash lines.

In this example, the uppermost stratum can be easily determined. The uppermost 33 feet is composed of loose to medium dense silt and sandy silt which are both classified as ML according to the Unified Soil Classification System. Underneath the ML stratum is a layer of very stiff sandy clay (CL) and/or medium dense clayey sand (SC) that ranges in thickness from 4 to 11 feet with an average of 7 feet thick. The average is used to represent the thickness of the representative stratum. Underlying the (CL-SC) stratum is predominantly dense to very dense sand (SP) and/or clayey sand (SC) with occasional layers of silty sand (SM) and sandy silt (ML). Since the borings were terminated at the depth of 51 feet or less, the subsurface conditions below 51 feet are basically unknown; therefore the soil profile is terminated at this depth. Next, the groundwater levels recorded in borings B-1, B-2, B-4, and B-6 are averaged. The average value, i.e., 20 feet below the ground surface, is used as the representative groundwater level. In addition, the average values of SPT N-values (N), unconfined compressive strength (Q_u) and natural soil density (γ) are also computed and shown in Fig. 3-3.

The ground surface elevation of the boring site are usually recorded in the boring logs. The average value of these recorded elevations is used as the representative

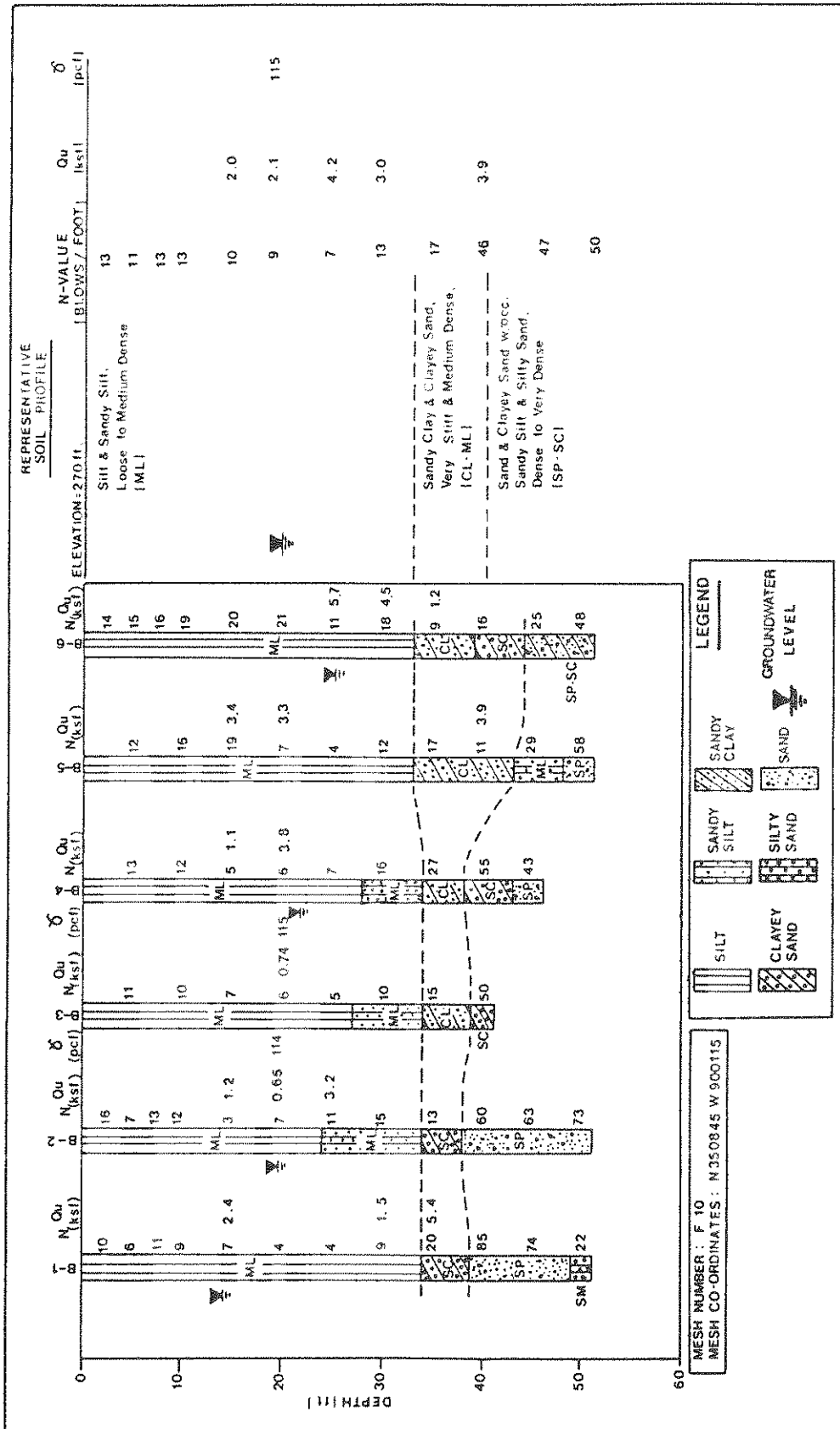


Fig. 3-3 Illustration of Data Analysis Procedure

ground surface elevation for the cell. In case the ground surface elevations are not recorded in boring logs, an approximate elevation can be read from the USGS topographic maps. For example, due to the absence of elevations from the boring logs in cell F10, an elevation of 270 feet is read from the USGS topographic maps and used as the representative ground surface elevation. Finally, based upon the results of the above analysis, a representative soil log as shown in Fig. 3-4 is created to delineate the subsurface conditions underlying the area defined by the cell. It is noticed that the undrained shear strengths (S_u) are reported in the soil logs instead of the unconfined compressive strengths (Q_u) because most engineering applications require the input of undrained shear strength rather than unconfined compressive strength. The undrained shear strength for cohesive soils is usually taken as one-half of the unconfined compressive strength. A soil log has been produced for each cell using the procedure mentioned above. The Appendix A contains all the representative soil logs for Memphis and Shelby County.

JOB LOCATION: MEMPHIS, TN
 OWNER: CER I

DATE: 3-28-89
 HESH NUMBER: F10

SHEET: 1/1
 BORING N350845W900115

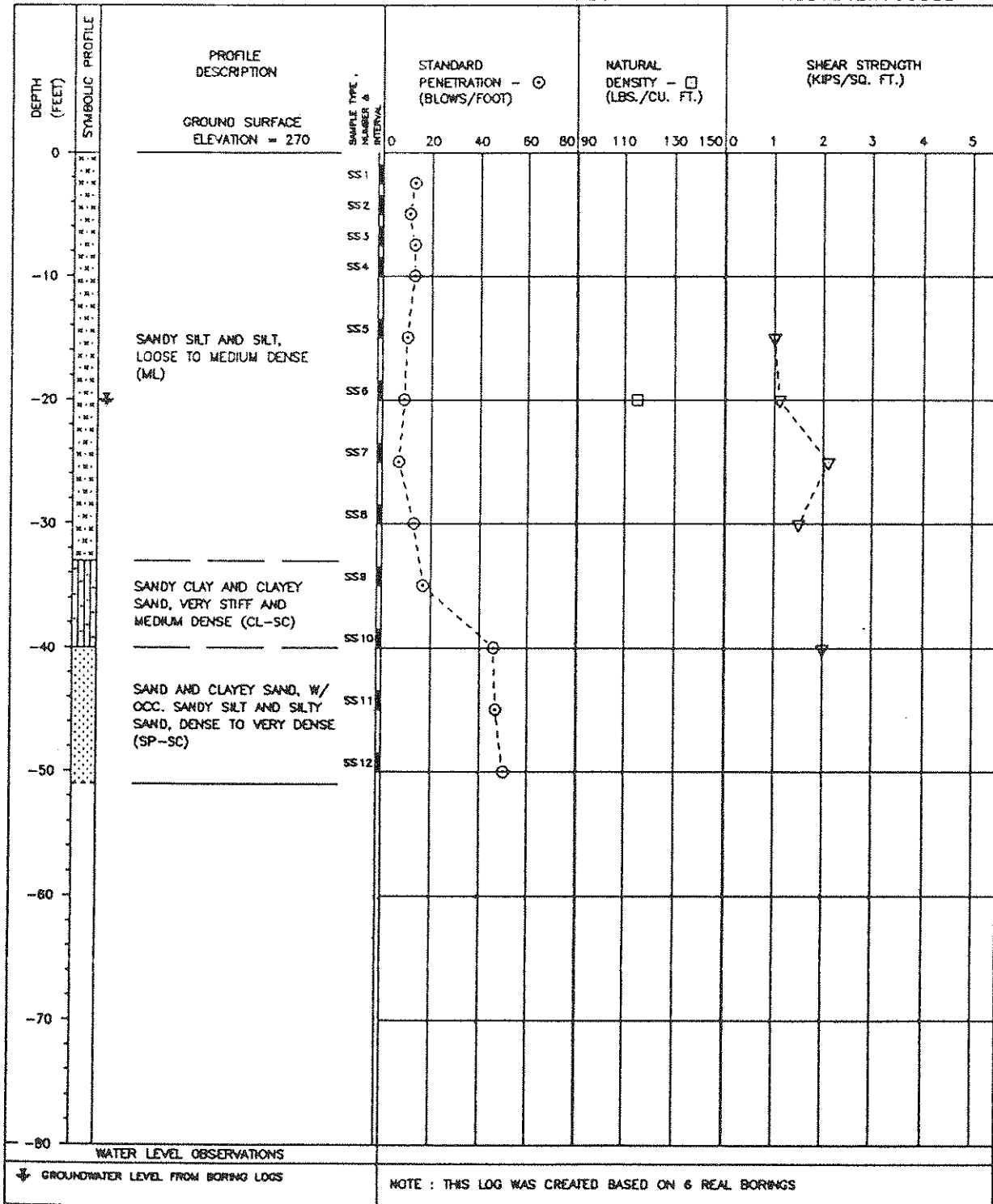


Fig. 3-4 Example of Representative Soil Log

SECTION 4

SUMMARY AND CONCLUDING REMARKS

This report presents the subsurface conditions of Memphis and Shelby County based upon existing geotechnical data. About 8,500 boring logs at various locations in Shelby County have been collected from government agencies and private geotechnical companies. In addition, geotechnical data have been gathered from water-well logs, soil survey and technical publications. A grid system consists of rectangular cells with equal size of 30 seconds in both latitude and longitude is applied to the study area. Each cell represents an area of about 172 acres. The collected geotechnical data are compiled and organized according to the cell designations. The data in each cell are then reviewed and analyzed. It is noticed that the subsurface information revealed by the boring logs are reasonably consistent and generally conform to the geologic information discussed in Section 2.

The results of the analysis are presented in the form of soil logs that delineate the representative subsurface conditions in the cell. The soil logs produced in this study can provide an engineering basis for the evaluation of soil amplification and liquefaction potential in Memphis and Shelby County due to earthquakes. In addition, these soil logs can also be utilized for land use planning for Memphis and Shelby County.

The users of the soil logs should realize that these soil logs only represent the average soil conditions and engineering soil properties within the cells. In reality, soils are heterogeneous and anisotropic materials; hence the subsurface conditions can be extremely complex and subject to changes with time. For these reasons, the representative soil logs should not be used to substitute any subsurface exploratory program for construction projects.

The quality of the soil logs are influenced by the following factors : the quantity and quality of the available geotechnical data, the depth of the borings, and the methods of subsurface explorations. The total number of boring logs utilized to create a soil log is recorded in the representative soil log; thus this number can be

used as an indicator for the quality of that soil log. The soil logs can be updated and improved if more data are available in future as the urban development of Memphis and Shelby County progresses.

SECTION 5

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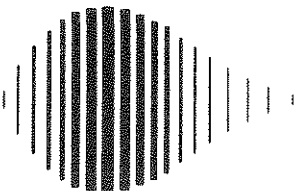
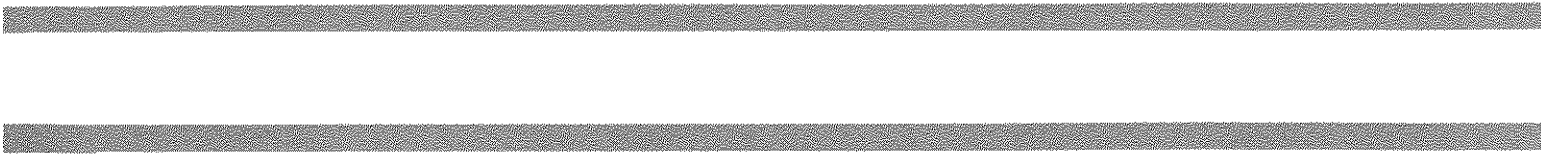
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