International Conference on Case Histories in Geotechnical Engineering

(1984) - First International Conference on Case Histories in Geotechnical Engineering

11 May 1984, 8:00 am - 10:30 am

# Foundation Movement Monitoring of Heavy Structures – A Case History

M. R. Lewis
*Bechtel Civil & Minerals, Inc., Gaithersburg, Maryland*

A. Sanver
*Bechtel Civil & Minerals, Inc., Gaithersburg, Maryland*

# Foundation Movement Monitoring of Heavy Structures - A Case History

**M. R. Lewis**

**Engineering Supervisor, Geotechnical Services, Bechtel Civil & Minerals, Inc., Gaithersburg, MD**

**A. Sanver**

**Manager, Geotechnical Services, Bechtel Civil & Minerals, Inc., Gaithersburg, MD**

SYNOPSIS Accurate monitoring of settlement beneath the main structures of a nuclear power plant not only demonstrates the stability of the structures, but also confirms predicted settlements, thereby verifying the geotechnical parameters used in the design. At the Grand Gulf Nuclear Station near Port Gibson, Mississippi, rebound and settlement monitoring has been continuous since the start of site excavation in 1974. As a result, actual settlements have been shown to be close to the predicted levels. This paper discusses the planning, installation and monitoring of the settlement instrumentation and reviews the factors that were important to the choice of instrumentation.

## INTRODUCTION

It is rare that settlement performance of heavy structures is monitored for long periods of time (many years) starting very early into construction and continuing well after the final settlements are reached. For some nuclear power plants, this is done in order to provide the public a high degree of assurance with respect to stable foundations and to verify that the design geotechnical parameters for the foundation medium are representative. Such was the case for Mississippi Power & Light Company's Grand Gulf Nuclear Station. The generating station consists of two adjacent 1250 MWe units, each with separate Reactor Containment, Auxiliary, Turbine, Emergency Diesel Generator, and Standby Service Water Basin (SSWB) structures. Control and Radwaste Buildings are shared. Although other significant structures exist at the site and were monitored, this paper will confine itself to the power block structures that are listed above and shown on Figure 1. This paper discusses the program used to monitor the performance of the bearing stratum prior to, during, and after construction. Specifically, the paper details the planning, installation, and monitoring of the heave and settlement and briefly discusses factors considered in the choice of monitoring methods. Included were considerations of ruggedness versus sophistication, the degree of redundancy required, the location of the instrumentation and bench marks, frequency of monitoring, and the accuracy of measurements at locations where construction activities are constantly affecting the monitoring program.

## SITE AND SUBSURFACE CONDITIONS

The Grand Gulf Nuclear Station is located near the east bank of the Mississippi River in Claiborne County, Mississippi, about 25 miles south of Vicksburg and 37 miles northeast of Natchez. The community of Grand Gulf is about

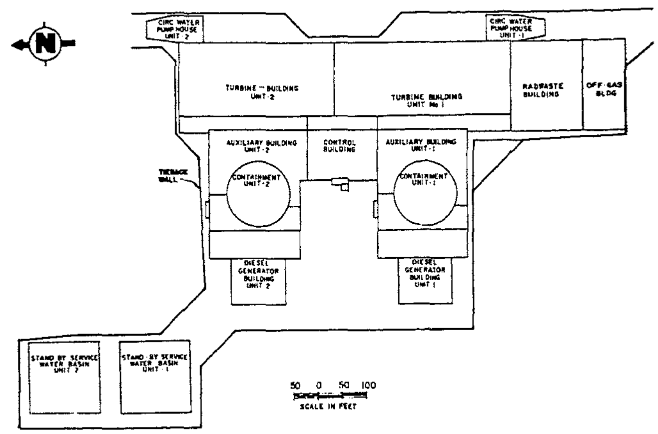


Fig. 1. Power Block Structure Location Plan

1½ miles to the north and Port Gibson is about 6 miles to the southeast.

The site area is about 2300 acres and is located in the Gulf Coastal Plain physiographic province. The western half of the site is in the Mississippi Alluvial Valley and the eastern half is in the Loess or Bluff Hills.

The higher elevations of the site (the Bluff area) consist of an Upper Pleistocene age silt deposit (loess), ranging from approximately elevation 206 feet to elevation 120 feet. This deposit overlies a pre-Pleistocene age formation referred to as the Terrace Deposits, which is made up of layers of clay, silt, sand, and gravel. The interface of the loess and the terrace deposits is approximately elevation 130 feet. Beneath the terrace deposits is the Miocene age Catahoula Formation, which is over 300 feet thick and consists of a hard to very hard, gray to green, indurated silty to sandy clay with interbedded lenticular beds of indurated or cemented silt, clay, and sand.

The principal water table lies within the terrace deposits throughout most of the eastern portion of the site. However, in the general vicinity of the power block, the principal water table intersects the Catahoula Formation and is at approximately elevation 78 feet. Perched water tables were encountered in observation wells at various depths, typically at approximately elevation 103 feet. A plant design ground water level of elevation 109 feet has been selected to reflect the perched water ("bathtub") effect which occurs in the power block area after the placement of the granular compacted backfill. The top of the Catahoula Formation ranges from approximately elevation 95 feet to elevation 75 feet, and is the foundation bearing stratum for the major power block structures, except the Diesel Generator Building, which is founded on compacted structural fill. The typical subsurface profile is shown on Figure 2 and the engineering properties of the Catahoula and backfill sand are given in Table I.

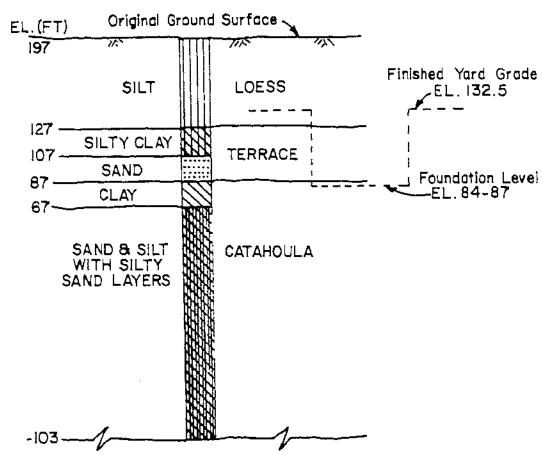


Fig. 2. Typical Subsurface Profile

TABLE I. Engineering Properties

Catahoula Bearing Stratum-Nominal Top El. 87 Ft.

Unit Weight - 120 pounds per cubic foot (pcf)
Friction Angle - 16 degrees
Cohesion - 4 kips per square foot (ksf)
Poisson's Ratio - 0.47
Modulus of Elasticity
0 to 50-foot depth - 6,000 ksf
50 to 100-foot depth - 15,000 ksf
Below 100-foot depth - 20,000 ksf

Structural Backfill - 95% ASTM D 1557

Unit Weight - 125 pcf
Friction Angle - 35 degrees
Cohesion - 0 ksf
Poisson's Ratio - 0.4
Modulus of Elasticity - 1800 ksf

In the power block area, excavation to reach the Catahoula bearing stratum resulted in the removal of approximately 11 ksf of overburden. The excavation was carried out in two stages. The first stage consisted of a general excavation of the area down to elevation 132.5 feet.

The second stage consisted of an excavation down to foundation subgrade, elevation 84 feet to 87 feet, utilizing a vertical tieback wall consisting of driven steel H-piles, timber lagging, and earth tiebacks.

## HEAVE/SETTLEMENT PREDICTIONS

The Catahoula Formation is a very dense and hard granular-cohesive, over-consolidated, and stratified deposit. Recovery of representative undisturbed samples was, at best, a very difficult process. Laboratory tests on relatively undisturbed samples that could be recovered indicated both rebound and recompression would occur quickly. It was, therefore, concluded that the response of the Catahoula would be essentially elastic.

The prediction of heave was based on two approaches:

1. Recompression index obtained from laboratory consolidation tests, and

2. Published observations relating heave to depth of excavation (Moorehouse, 1972).

From the above, the amount of heave at the subgrade level was estimated to be approximately 3 to 4 inches.

Settlement for each structure was computed using two methods. The first method modeled the Catahoula Formation as a homogeneous, isotropic, elastic half-space. For this method, an equation based on elastic theory (Bowles, J. E., 1968), and an average modulus of elasticity, were used. The second method modeled the Catahoula Formation as consisting of three 50-foot-thick layers, each lower layer stiffer than the layer above, and resting on a rigid base. The basis for this model was the rebound extensometer data itself, which indicated the modulus of elasticity increased with depth. The average modulus of elasticity and the average stress within each layer were used to compute the elastic shortening of each layer. A 2 vertical to 1 horizontal stress distribution was used to determine the stress within each layer. The cumulative elastic settlement of each structure is the upper bound value of the results determined from these two models.

Two ground water levels were considered in the analyses: the normal level of elevation 78 feet and the maximum design level of elevation 109 feet. Each structure was analyzed for bearing capacity and settlement. The minimum ultimate bearing capacity of the Catahoula Formation is approximately 45 tons per square foot (tsf). The maximum static bearing pressure is approximately 6 tsf for the Auxiliary Building mat foundation. The maximum total settlement was estimated to be approximately 1 inch for the Auxiliary Building. Settlement was expected to be negligible after construction. Structural loading, maximum predicted and measured settlement, and the foundation analyses for each structure are given in Table II.

TABLE II. Foundation Analyses

| Structure-Unit | Foundation Type (Thickness) | Plan Dimension | Loading DL+LL* (ksf) | Ult. Bearing Capacity (ksf) | Total Settlement | | Percent of DL Completed |
|---|---|---|---|---|---|---|---|
| | | | | | Predicted (in.) | Measured (in.) | |
| Containment-1 | Mat-9.5' | 134' Dia. | 8.7 | 104 | 0.8 | 1.1 | 100 |
| Containment-2 | Mat-9.5' | 134' Dia. | 8.7 | 104 | 0.8 | 1.0 | 50 |
| Aux. Bldg.-1 | Mat-6.0' | 180'x249' | 12.2 | 88 | 1.0 | 1.1 | 100 |
| Aux. Bldg.-2 | Mat-6.0' | 180'x249' | 12.2 | 88 | 1.0 | 0.6 | 70 |
| Radwaste Bldg. | Mat-6.0' | 171'x194' | 6.9 | 102 | 0.8 | 0.8 | 100 |
| Control Bldg. | Mat-7.0' | 96'x142' | 6.1 | 93 | 0.5 | 0.9 | 100 |
| SSWB-1 | Mat-4.0' | 150'x150' | 7.1 | 108 | 0.7 | 0.6 | 100 |
| SSWB-2 | Mat-4.0' | 150'x150' | 7.1 | 108 | 0.7 | 0.5 | 100 |
| DG Bldg.-1** | Mat-5.0' | 94'x121' | 2.1 | 127 | 0.8 | 0.4 | 100 |
| Turbine Bldg.-1 | Mat-6.0' | 170'x355' | 3.0 | 97 | 0.4 | 0.7 | 100 |
| Turbine Bldg.-2 | Mat-6.0' | 170'x355' | 3.0 | 97 | 0.4 | 0.5 | 85 |

* DL = Dead Load
LL = Live Load

** DG Bldg. = Diesel Generator Bldg.

## FOUNDATION MONITORING PROGRAM

It was recognized that the rebound of the excavation bottom (Catahoula Formation) may be significant due to the relatively high overburden load to be removed (about 11 ksf) from the top of the Catahoula Formation. Based on field and laboratory investigations, the amount of rebound was very roughly estimated to be about 3 to 4 inches. Due to the layered and variable nature of the Catahoula Formation, it was recognized that unless the rebound of the Catahoula was measured during excavation, one would not know how much rebound occurred and further, if the subsequent settlement would be simply the recompression settlement. The rebound measurements were expected to monitor elastic and any inelastic magnitude and rate of movement. An added value of the rebound program would be a check on the modulus of elasticity of the foundation material in its gross (mass) behavior.

With this in mind, the following basic guidelines were established for the development of the foundation monitoring program:

- The type and amount of instrumentation and monitoring methods should be selected with practical goals in mind, and since the foundation stability was otherwise well demonstrated, the monitoring program should not be directed towards any "research" effort.
- The instrumentation must possess a sensitivity and range adequate for the probable magnitude and nature of the measurements to be taken.
- The instrumentation must be reliable and relatively simple to install and not unduly sensitive to damage during reasonably careful installation practice.
- Since the jobsite environment will be moderately severe for mechanical damage and will also be wet, the instrumentation must be survivable under conditions of operation for extended periods of time in which maintenance will be impractical or impossible.
- Most instrument locations will be inaccessible; consequently, the instruments must be monitored remotely (requiring electronic devices).
- The monitoring of the instrumentation should be expected to be done, at some stages of the construction, by individuals who may not be instrumentation specialists, but semiexperienced or inexperienced engineering or construction personnel.
- The type and amount of instrumentation and monitoring methods should be selected such that there will be minimal disruption of the construction schedule or normal construction practices.
- The cost of purchasing, installing and monitoring of the instrumentation should be commensurate with the benefits to be derived.

Based on the above guidelines and a review of the available instrumentation at the time (1973), it was decided to utilize the following to monitor the foundation heave and settlement:

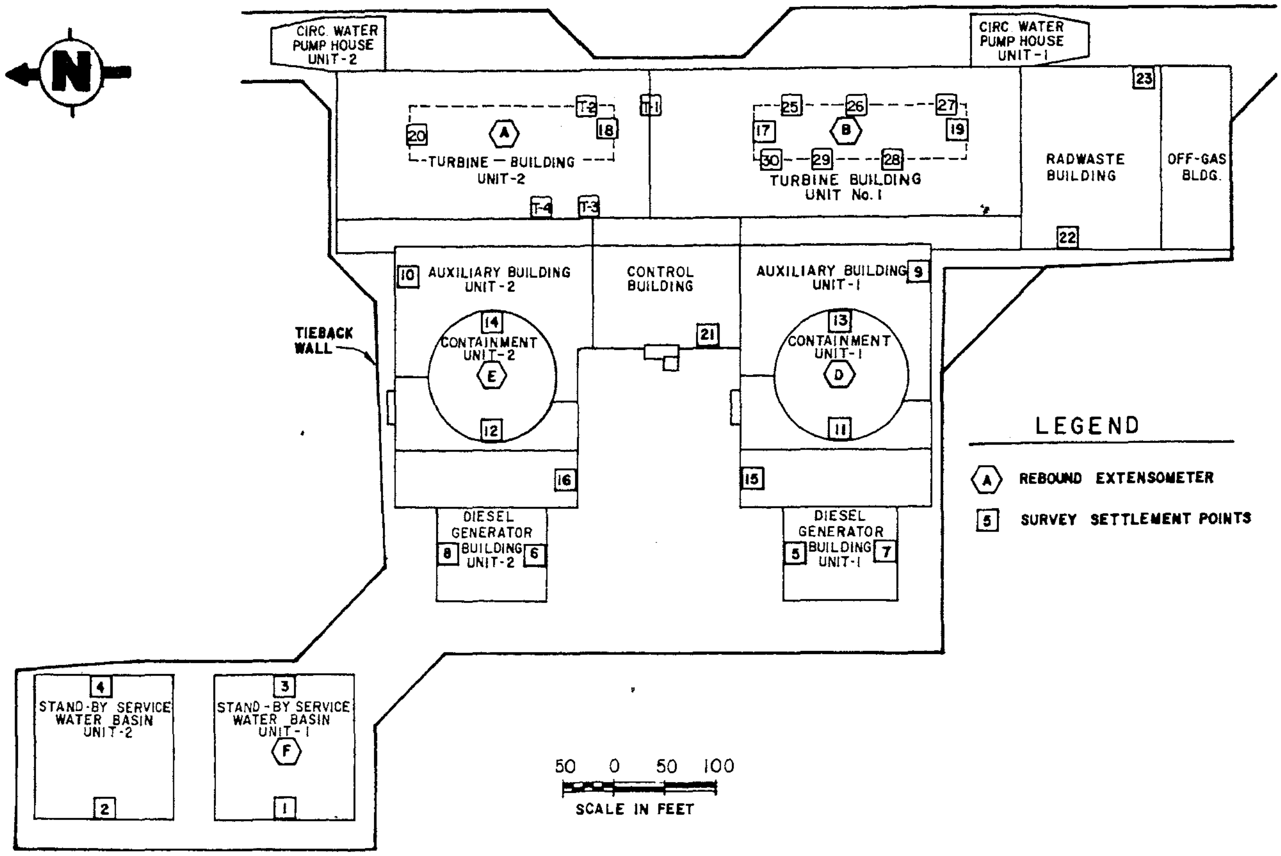


Fig. 3. Instrumentation Locations

1. Multiple Position Borehole extensometers (rebound extensometers) to monitor heave during overburden removal and subsequent settlement as the structures are constructed.

2. Conventional surveying of settlement markers to monitor settlement after the start of building construction.

Following is a discussion of each item.

REBOUND EXTENSOMETERS

Five locations were selected for installation of the rebound extensometers. This included the Containment and Turbine Buildings and one Standby Service Water Basin. The locations of the instruments and structures are shown on Figure 3. The extensometers were supplied and installed by Terrametrics, Inc. of Golden, Colorado, soon after site excavation work started. The model 3-CSLT(R) extensometer, a three-element rod-type instrument, was selected for use. The extensometer is composed of a common anchor grouted in place at the bottom of the drilled hole, 150 feet below the final excavation level. Three intermediate sensors were grouted in position at approximately 3, 50, and 100 feet below the final excavation level. Rebound, and subsequent recompression in the subgrade, were measured by spring-loaded rod elements and the measurements converted into electrical signals by integral electronic transducers. The extensometer signal cable extended up the drilled hole and was protected by polyethelene tubing encased in grout. As the excavation was deepened, the grout material was removed, the polyethelene tubing shortened, and the signal cable shortened or coiled, as required. The 3-CSLT(R) had a range of 6 inches for the top elements and 4 inches for the two deeper elements.

The extensometers were read using a Teledyne Terrametrics Model DC-7 Digital Extensometer Readout unit, which is a portable multiple-range indicator.

After the foundation bearing elevations were reached, the remote readout wires were extended to assemble locations under the working mats. Monitoring was continued until the indicated movements stopped or until the elements stopped functioning.

The installation of the five sets of rebound extensometers was started on April 1, 1974, and completed on May 7, 1974. The installation effort took 22 working days for the 5 rebound extensometers, including 3 days of rain delay. The total subcontract cost for installation of the extensometers was about $50,000. Additional description and details of the rebound extensometer design and installation are available (Blendy and Boisen, 1978).

As manufactured, installed, and maintained, the rebound extensometers were not found to be durable enough to survive the site conditions and the normal construction activities for the long period of time involved (several years). It was clear that if similar devices are expected to function for long periods of time under complex heavy construction conditions, the normal construction practices will need to be impacted with resultant cost and schedule penalties. The following summary gives the survival record for the rebound extensometers:

Of the 5 extensometer locations and 15 elements:

1. One sensor was damaged and was inoperative during installation.
2. A total of six sensors had failed by the end of the first year of operation.
3. A total of seven sensors had failed by the end of the second year of operation.
4. A total of four sensors were still operable in 1981.

## SETTLEMENT MARKERS

Three permanent bench marks were established early in the project for use during construction and for subsequent plant operation. One bench mark was located within the power block area, a minimum of 300 feet from the nearest major structure and the other two were located in a remote area of the site away from any construction activities. Each bench mark is referenced to the nearest USGS datum and was checked against the USGS datum at maximum six-month intervals. Further, each bench mark was checked against the others every other month. These bench marks were used as the reference for the settlement survey, which was done on a monthly basis during construction.

The settlement markers themselves were established on the structures as soon as practicable. In some cases, this meant there was some delay between pouring the foundation basemat and establishing a particular settlement marker for a structure. Location of the settlement markers is shown on Figure 3.

The actual field survey, including data reduction, took two days per unit utilizing a four-man crew. This amounted to about $1300/month or $15,600/year for the survey crew. The survey was always a closed traverse, second order survey, although the crew worked to a 5/1000 allowable closing error, which is more stringent than the specified second order survey. All surveying was optical except in portions of the Turbine Building where a tape was used.

The survey equipment consisted of a "Philadelphia (invar) Rod" graduated to 0.01 foot and a Wild NA-2 self-leveling level. The combination of the rod and level allowed the surveyor to interpolate to 0.001 foot. However, experience indicated the optical survey was most probably accurate to ±1/8 inch (0.01 foot). All instruments were calibrated periodically.

## RESULTS

The rebound extensometers did not have the reliability that was hoped for. This was due primarily to construction activities and difficulties in maintenance. However, very valuable information was gained from the rebound extensometers that did function. Figure 4 is a plot for the Unit 1 Turbine Building, which shows the unloading and loading of the bearing stratum and heave and settlement of the bearing stratum versus time. The information obtained from the rebound portion of the curve enabled a good estimate of the modulus of elasticity of the bearing stratum and thus a reliable prediction of the final settlements to be expected for the structures.

The fluctuation in the optical settlement monitoring is attributed to survey accuracy. As expected, the settlement of the Turbine Building is on the order of 40 percent of the measured heave based on the ratio of the final structural loading (DL+LL) to the load removed during excavation. This implies the Catahoula bearing stratum behaved as an elastic medium as originally assumed.

## CONCLUSIONS

Heavy construction that results in buildings with relatively high foundation loads generally consists of very complex and congested activities for significant lengths of time, which increases the chances of damage to monitoring instruments, markers, bench marks, etc. The construction activity planning results in a constant state of change in priorities and sequencing. Under those circumstances, any heave/settlement monitoring that sets goals of high accuracy and durability of instrumentation will require very significant cost and schedule impacts on the projects. A program of conventional surveying methods still appears to be the best approach to balancing need and cost unless the durability and reliability of electronic instrumentation are improved.

At the Grand Gulf Nuclear Station, due to congestion in the buildings' construction activity and permanent installation of equipment, etc., the accuracy of surveying was probably ±1/8 inch, which should be considered the best possible accuracy. If greater accuracy is required, an impact on construction activities will result. Whether the latter is justified should be dependent on the needs of a specific site and project.

The following practical difficulties were encountered in the heave/settlement monitoring. These may be important for planning purposes on other projects:

1. The measured heave of the foundation bearing stratum was found to be about half of that estimated. It is likely that if the anchor point had been deeper, the predicted heave would have been more comparable to the measured heave.
2. The surveying methods have a practical accuracy of ±1/8 inch.

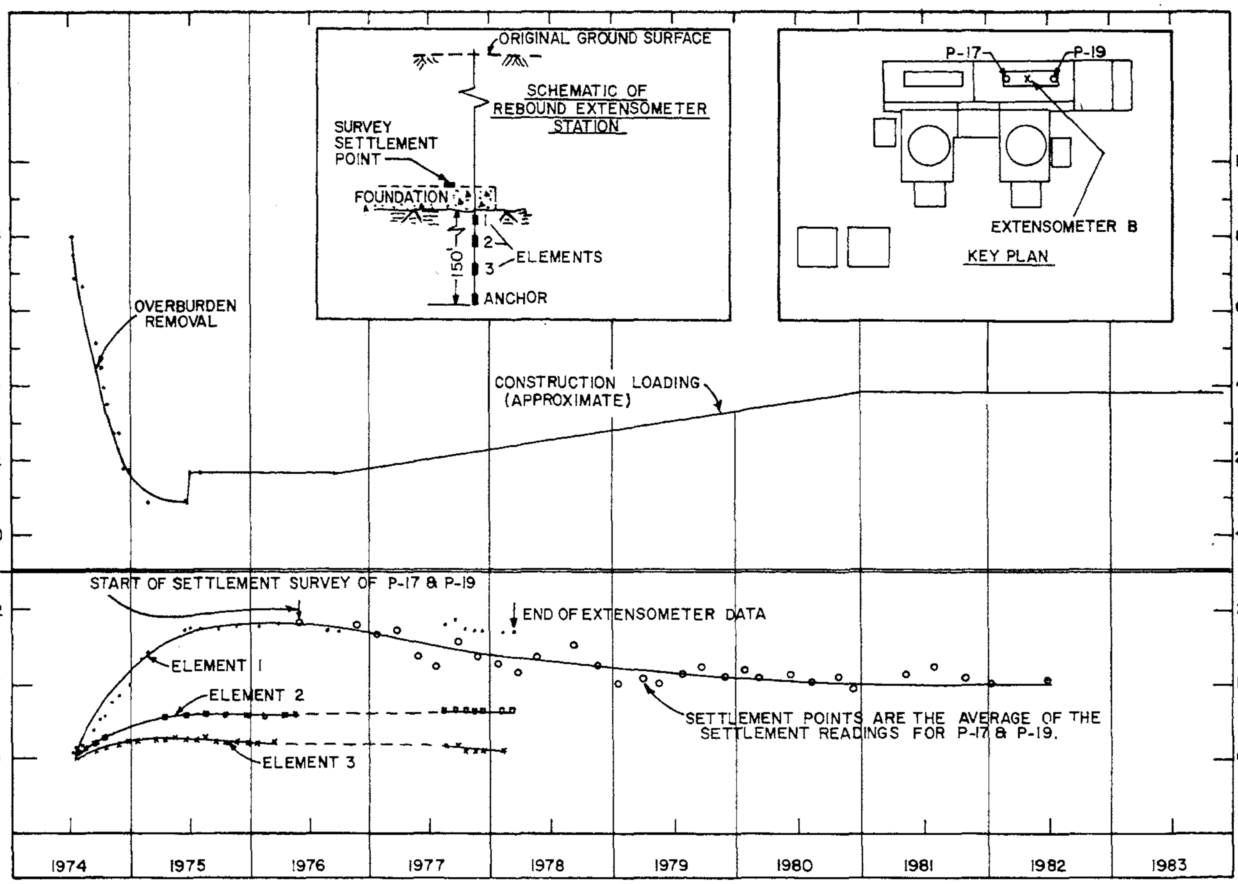


Fig. 4. Heave and Settlement Monitoring, Turbine Building Unit 1

3. The surveying method and the rebound extensometer measurements could not be correlated for the settlement portion of the monitoring program for all of the instrumentation locations.

4. Heavy construction activities result in a sequence of construction that is necessarily variable and very difficult to predict. Thus, it is impossible to estimate or predict the starting point and the rate of loading the bearing stratum. Therefore, the verification of the physical parameters for the bearing stratum will always have its limitations.

The main purpose of the heave/recompression monitoring program was to demonstrate the stability of the power plant foundations without a major impact on the project cost and schedule. This purpose has been fully met. On the secondary purpose of verification of subsurface parameters, the measured settlements were generally close to the estimated values for the structures, which tends to confirm the validity of the assumed subsurface parameters.

## ACKNOWLEDGEMENTS

The writers gratefully acknowledge the Owners, Mid-South Utilities and Mississippi Power & Light Company; and the Architect-Engineer and Constructor, Bechtel Power Corporation, Gaithersburg, Maryland; for permission to publish this case history. The invaluable help of J. N. Koch and L. E. Slayden for typing and editing of the transcript and preparing the figures, respectively, are also acknowledged.

## REFERENCES

Blendy, M. M. and B. P. Boisen (1978), Deep Foundation Rebound at the Grand Gulf Nuclear Power Station. Proc. 19th U.S. Symposium on Rock Mechanics, Stateline, Nevada, Vol. 2, 95-100.

Bowles, J. E. (1968), Foundation Analysis and Design, 85-87 pp., McGraw Hill, New York, New York.

Moorehouse, D. C. (1972), Shallow Foundations. Proc. of the Specialty Conference on Performance of Earth and Earth-Supported Structures, Lafayette, Indiana, Vol. II, 71-109.

Final Safety Analysis Report, Grand Gulf Nuclear Station Units 1 and 2, Middle South Utilities System.