FIELD STUDY OF AN ANCHORED SHEET PILE BULKHEAD

by

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ABSTRACT

This paper presents the field measuring technique and instrumentation for measuring the amount of shear transfer mobilized across the interlock at the neutral axis of steel arch web sheet piling. Comparisons of tie rod force and positive maximum bending moment by various existing methods together with field measured data are presented.

It is concluded, within the range of applied loads and soil characteristics, that shear transfer takes place across the interlocks. Thus, it is believed that the European practice of assuming that piles act as a unit more closely approximates the given field conditions than the American practice of assuming individual piling action. However, since American practice is based on use of sheet piling in all types of soil, the designer cannot assume that shear transfer always takes place when interlock crimping or welding is not used. For comparisons of tie rod force, it is indicated that there was a trend for the tie rod force to increase as the wall height increases. However, the field results are much smaller than theoretical results. No definite relation could be found between theoretical and field results for the maximum moment. It is thought that much of the scatter may be attributed to composite action between soil and the piling. Further investigation of the soil-structure interaction is necessary in order to more clearly understand the phenomenon.
INTRODUCTION

The section modulus of a structural member is a measure of its ability to resist bending. It is calculated by dividing the area moment of inertia of the member about its axis of bending (the neutral axis) by the distance from that axis to the outermost fiber of the member cross-section. The centroidal axis of an individual arch web sheet piling section is located between the axis of the interlocks and the web (Fig. 1). American design practice is to use this centroidal axis as the neutral axis for evaluating moment resistance. The location of the centroidal axis of a wall composed of several interlocked sheet piling sections is along the line of interlocks (Fig. 1). European design practice is to use this axis, or an intermediate position, as the neutral axis to evaluate the moment resistance. As is evident from Fig. 1, the resistance of an individual section is about one half the resistance of the composite group. Consequently, designs based on the European method are more economical than those based on the American method when using arch web piling.

A review of literature concerning sheet pile structures were made by Fang and Dismuké (1973). The reviews indicated that no information related to the amount of shear transfer across the interlock and the location of the neutral axis of bending for a sheet pile wall were available.

The objective of this study was to evaluate the behavior of interlocked steel sheet piling in an actual field installation. More specifically, the strain distribution across a sheet pile was measured
in order to experimentally locate the neutral axis of bending of the wall. This paper presents a detailed description of the measuring technique and instrumentation used to study shear transfer in a sheet pile wall. In addition, the comparisons of tie rod forces and positive maximum bending moment by various existing methods together with field data are also presented. The existing methods include Blum (1931), free-earth (Anderson, 1956), Tschebotarioff (1951), and Rowe (1952). The results are summarized in graphical form; discussion of test results and further investigation needed are also included.

TEST SITE, INSTRUMENTATION AND MEASURING TECHNIQUES

Test Site

The test site was located at Martins Creek, Pennsylvania. The soil profile was determined from the results of wash borings and from information supplied by the Pennsylvania Power and Light Company. Boring logs recorded the surface conditions, the strata changes and thickness, the standard penetration values for the soils, and the elevation of the groundwater table. Figures 2 and 5 show the results of this soil profile investigation. In general, the test site consisted of a thin layer of sand and silt underlain by a thicker layer of sand, gravel, and boulders.

Instrumentation

The foil-type SR-4 strain gage was chosen as the primary means
of measuring strain in the piling. As strain gages must be protected during and after pile driving operations, an evaluation of the strain gage system was undertaken in the laboratory. Methods for attaching, waterproofing, and protecting the gage were studied. In addition, the behavior of the gage was observed under simulated field conditions.

In the laboratory, a gage was mounted on the outer portion of a 2" x 2" angle to simulate the actual mounting of a gage on the sheet piling and driven into soil. A protective epoxy covering was placed over the gage, but no attempt was made to keep the covering from touching or adhering to the gage.

The soil was composed of equal amounts of coarse sand, obtained directly from the test site, and 3/4" to 1" crushed stone. It was believed that the laboratory soil would be more abrasive to the gage, and its covering, than the soil at the field site. The soil mixture was placed in a 2' diameter cylinder of 4' height. A drain spout was tapped into the bottom and a manometer was attached so that the level of the water table could be controlled and measured. The sand and stone mixture was soaked, vibrated, and allowed to drain. This produced a very compact mixture for the test.

The laboratory testing of the foil-type strain gage proved that the gage could be successfully protected against abrasion under controlled laboratory conditions, and no trouble would arise as long as the epoxy covering remained unbroken and bonded to the steel. Therefore, care was
taken to properly bond the epoxy to the steel in all subsequent gage installations.

After it was shown that the gages could be protected under controlled laboratory conditions, it was decided to test them in the field at a nearby construction project.

Two gages were attached to a sheet piling in the field and driven 20' into a loose, silty sand having a high groundwater table. Both gages were protected by the epoxy covering. One gage was given additional protection by covering it with a steel shoe (Fig. 3) that was welded to the sheet pile (Fig. 4). During and after driving, both gages performed satisfactorily, thereby substantiating the results of the laboratory evaluation.

The field testing of the foil-type strain gage showed that the gage could successfully withstand pile driving forces and the existence of a high groundwater table. It was decided to protect all gages with the steel shoe in order to offer protection against stones that might be encountered at the test site.

The strain gages were installed on the sheet piling at Fritz Laboratory prior to delivering the piling to the test site. The piles were cleaned with high speed grinders to obtain a smooth surface for the gages. The ribbon wire was laid flat and clamped before the gage epoxy was applied. After the wires were in place, the gages were attached and
clamped while the epoxy was setting. Each gage was checked after installation to insure adhesion of the gage to the piling. This was accomplished by a "light bulb test" (Dally and Riley, 1965).

Because of the delicate nature of foil gages, it was necessary to use low temperature solder to install the wires. Terminal tabs were used to allow some play in the wires should they be accidentally pulled. After the wires were installed, gage readings were taken and the protective epoxy covering was applied (Fig. 4).

The strain gages were connected to the arch piles near the interlocks in order to evaluate the shear transfer across the joints. This information would, in turn, lead to the determination of the location of the neutral axis of bending for the sheet pile wall. The layout of the strain gages on the instrumented piling (piling nos. 10, 11, 12, and 13) is shown in Figs. 6 and 10.

After the gages were installed on the piling, they were "zeroed" at Fritz Laboratory with the piling hanging in a vertical position. The initial readings recorded in the laboratory were checked at random at the site before driving was started on each pile. The comparison between the random checks and the laboratory reading was satisfactory.

**Field Test Procedure**

The length of the sheet pile wall was 30 feet which was believed to be long enough to minimize undesirable end effects. The piling was 30 feet long and they were driven 25 feet below ground level. Consequently,
once the arch piles were in place, approximately 5 feet of pile protruded from the ground surface. A standard driving rig with a low energy double action 983 steam hammer was used for the driving operations. A guide frame was used to insure plumbness of the wall. A transit and a six-foot level were used to aid in positioning the piles. The wall was anchored by two tie rods which were held back by H-piles driven vertically 20 feet into the ground. The tie rods were attached to the wall by means of a wale welded to the wall at ground level. The wale and tie rods were located at ground level to facilitate instrumentation and test procedures. The entire test set-up is illustrated in Figs. 5, 6, 7, and 8.

For all piling, the measured out-of-plumbness during the driving never exceeded 1 in. in 30 feet in the X-Y plane (Fig. 5). The deviation from the vertical in the Y-Z plane, however, did increase as the wall was driven (Fig. 6). This attributed to the tendency of sheet piling to close on themselves during driving. The maximum deviation in the Y-Z plane was 5 in. in 30 feet. It should be noted that piles No. 10 and No. 13 met refusal and could not be driven to the required depth. For this reason they protrude 15 in. above the other piles (Figs. 6 and 8).

The soil was excavated in front of the wall in four stages. Each excavation was 5 feet deep as shown in Figs. 5 and 6. The readings were taken, on all strain gages after the excavation and again one week later, just prior to the next excavation sequence. Excavation time for each stage was one day. This sequence of events was repeated until the excavation reached the 20 ft. level. The plan view excavation was approximately 20' x 35' as shown in Figs. 7 and 9. In addition, wall deflections
(measured by transit) were recorded for several wall locations. An initial load of 2000 lbs. was applied to each of the tie rods. Detailed field data is summarized and given by Brewer and Fang (1968).

DISCUSSION OF RESULTS

Figure 11 shows the pertinent data for shear transfer in graphical form. The distribution of vertical strain across the sheet pile interlocks is shown for all gage levels, and at all stages of excavation.

Although there is considerable scatter in the data and a number of the gages failed completely (see Fig. 10), the graphs suggest that shear stress transfer across the interlocks between piles does occur. This is apparent because the vertical strain distribution across the interlocks may be reasonably approximated by a single continuous straight line at all stages of excavation at which there is sufficient data. If there was only partial or no shear stress transfer across the interlocks, the vertical strain distribution across the piles would be shown by two discontinuous straight lines.

Figure 11 shows the vertical strain distribution interlock of joint 1, piles 10 and 11. Other data on piles 11, 12, and 13 are given by Brewer and Fang (1968, 1970).

It is of interest to note from Fig. 11 that the location of the neutral axis of bending for the sheet pile wall, given by the inter-
section of the vertical strain curve with the line of zero strain, does not always lie within the pile cross-section. For discussion purposes, consider the behavior of piling Nos. 10 and 11 at gage level G1 (Fig. 11). It can be seen that just prior to excavation, the neutral axis lies completely outside the piling cross-section toward the fill side of the wall. This could indicate that the piling is in tension due to bending induced during driving, and the compressive bending stresses are carried by the soil behind the piles. Such behavior may be considered composite action, with the wall and the soil acting as a unit, however, there is no further substantiation of this.

Comparisons of tie rod forces versus wall height is shown in Fig. 12. There is a trend that tie rod force increases as wall height increases. However, the field results are much smaller than the theoretical results and are less sensitive. This may be the result of the soil strain conditions. It should be noted that the walls of the excavation did not have to be shored to stand vertically for the full depth of the excavation.

Comparison of the positive maximum bending moment is carried out in a graphical form in Figs. 13 and 14. Bending moment computations are based on strain records. Sheet piles are considered as single acting units. Numerical values of strain were obtained from reading of strain gages which were located near interlocks. It is shown that there is no definite relation between theoretical and experimental results. Possibly, much of the scatter was attributable to composite action between soil and piling.
Other comparisons include theoretical comparisons of tie rod forces, embedment depth, and maximum moment with various existing methods and internal friction angles are given by Lamboj and Fang (1970) together with computation procedures.

**SUMMARY AND CONCLUSIONS**

The analysis of field study of an anchored sheet piling bulkhead can be summarized as follows and conclusions presented considered applicable within the limitations of the assumptions used:

1. Strain gage instrumentation installed on sheet piling prior to driving may be successfully protected against damage during driving.

2. Within the range of applied loads and soil conditions encountered in this investigation, the available data suggests that shear transfer takes place across the interlocks of arch web steel sheet piles.

3. Due to scatter in moment values evaluated from field measurements it is believed that composite action between soil and the piling occurs, however, further investigation of the soil-structure interaction is necessary in order to more clearly understand this phenomenon.

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Fig. 1 Location of Neutral Axis (U. S. and European Practice)
Fig. 2 Soil Profiles and Location Diagram
Fig. 3 Steel Protective Shoe
Fig. 4 A Steel Sheet Pile being Equipped with Strain Rosettes
Fig. 5 Cross-Section of Sheet Pile Wall
Fig. 6 Front of Sheet Pile Wall Showing Location of Strain Gages
Fig. 7 Plan View of Sheet Pile Wall
Fig. 8 Photograph of Field Test in Progress - Tie Rods, Wale, and Strain Indicating Equipment shown.
Fig. 9: Photograph of Excavation at the 10' Level
Fig. 10 Location of Strain Gages

* Denotes Gages That Failed To Balance
Fig. 11 Vertical Strain Distribution Interlock (Joint 1, Piles 10 and 11)
Fig. 12 Comparisons of Tie Rod Force for $\phi = 38^\circ$

Wall Height above Dredge Line, H. ft.
Fig. 13 Comparison of Theoretical Moment Curves with Field Measurements for a wall 20 ft. high
Fig. 14 Comparison of Theoretical Moment Curves with Field Measurements for a wall 15 ft. high
REFERENCES


