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SUMMARY

- 1) Experiments made by author on a reduced model of anchored bulkheads, buried into the soil to various depths, have proved, that two types of curves are formed, dependent on the flexibility of the sheet piles and the depth at which they are buried in the earth: type I, curves with two convexities and a vertical portion in their lower part, and type II, curves with one convexity, the lower edge of the sheet pile being displaced towards the side of passive earth pressure.
- 2) Real metallic bulkheads and still more such of reinforced concrete are deflected, owing to their stiffness, according to type II, which ever method of computing their depth were applied.
- 3) Theoretical curves computed according to the method of "free earth support" are near those of type II, observed in experiments.
- 4) The method of "fixed earth support" as a consequence of several assumptions made a priori without sufficient theoretical and experimental foundations, leads to quite fortuitous depths of burying bulkheads into the earth.
- 5) As a consequence to the above, anchored sheet piles ought to be computed, pending further investigations, according to the method of "free earth support", however with a coefficient of stability reserve to be determined in each case with regard to given circumstances.

No satisfactory solution has been found as yet for the problem of calculating anchored bulkheads, although there exist two well known methods of computation.

Both methods assume the soil to be a homogeneous mass of ideal sand. They further assume that the distribution of earth pressure on the bulkhead follows a hydrostatic law and that the friction of the soil on both sides of the bulkhead compensates mutually. We adopt the same assumptions for our investigation.

According to the first method the bulkhead is assumed to be a vertical beam supported at the uppermost end by the tying of anchor rods and at the lower end by the passive earth pressure (reaction of the soil), (Krey 1926). This method can be represented by the scheme of Fig. 1, called scheme of free earth support, (Terzaghi, 1944). On the said Fig. 1, the surfaces add_A and $bd_p d$ represent the active and the fully mobilized pressures. The surfaces $bb_1 d_1 d$ or $bb_2 d_2 d$ represent the not fully mobilized passive earth pressure. K_A and K_p are the coefficients of active and passive earth pressure. The other designations are to be seen on the Figure.

The system represented on Fig. 1 is statically determinate, the unknown values being: the depth D at which the sheet piles are driven into the soil and the reaction of the anchor A_p . Those unknown values are determined by two static equations: the sum of horizontal forces (pressures)

$$\sum N = 0$$

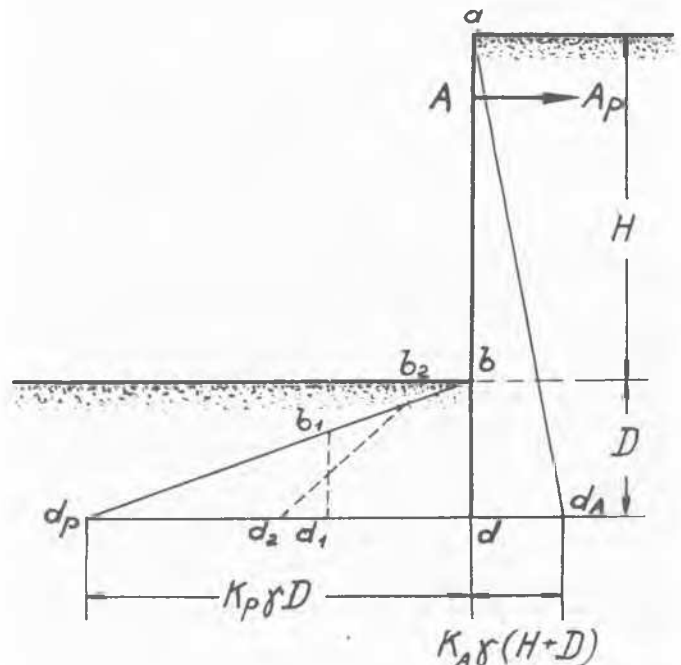
and the sum of moments, f.i. for point A,

$$\sum M = 0.$$

If in this computation you assume the passive earth pressure to be fully mobilized, the coefficient of stability reserve will be, according to Krey, equal to 1. If however the pressure is assumed as being mobilized only partly, the coefficient of stability reserve will be, according to Krey, equal to the rela-

tion of surfaces $\frac{bd_p d}{bb_1 d_1 d}$. In this latter case,

according to the conditions of equilibrium of this system, the depth D will be greater than 1. It has not yet been stated which is the coefficient of reserve guaranting the stability of the bulkhead. It is assumed to range from 1 to 2.

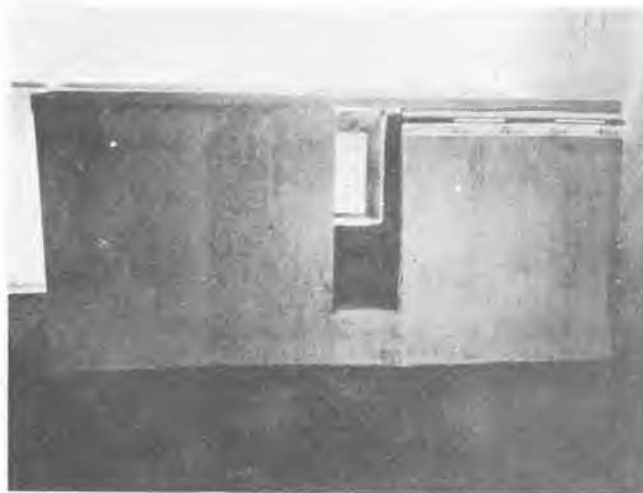


Scheme for computing bulkheads with "free earth support".

FIG.1

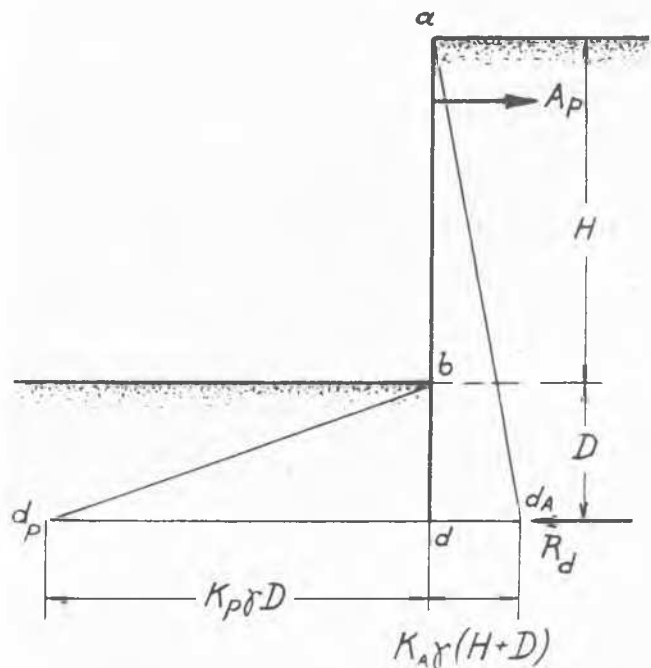
According to the second method of computation, the sheet pile is assumed to be a vertical beam supported at the uppermost and at the tying point of the anchor rods, but at the lower end it is a priori assumed to be fixed in the soil (Lohmeyer, 1930; Blum, 1931). The scheme of computation according to this method, called scheme of fixed earth support, is represented on Fig. 2.

This second scheme differs from the first by the assumption that the passive earth resistance is in every case fully mobilized on the left and the further assumption that on the right there is at the lower edge of the sheet pile a concentrated force R_d . This system is statically indeterminable. The unknown values are: the depth D , the reaction of the anchor A_p and the force R_d . In order to deter-



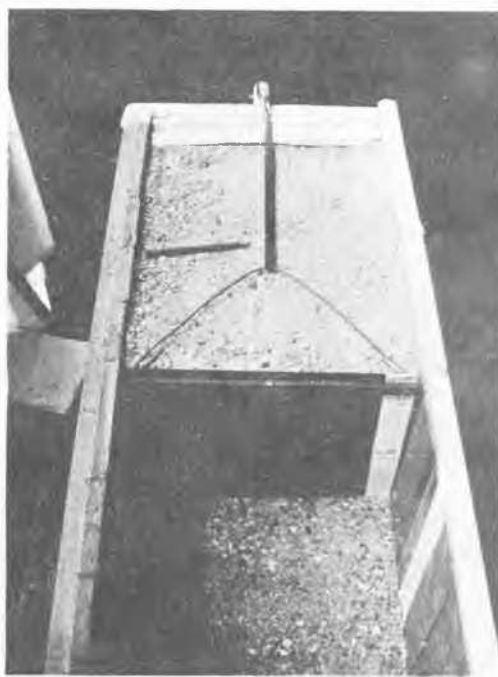
Experimental installation for the observation of bulkhead models, seen from the side.

FIG. 4 a



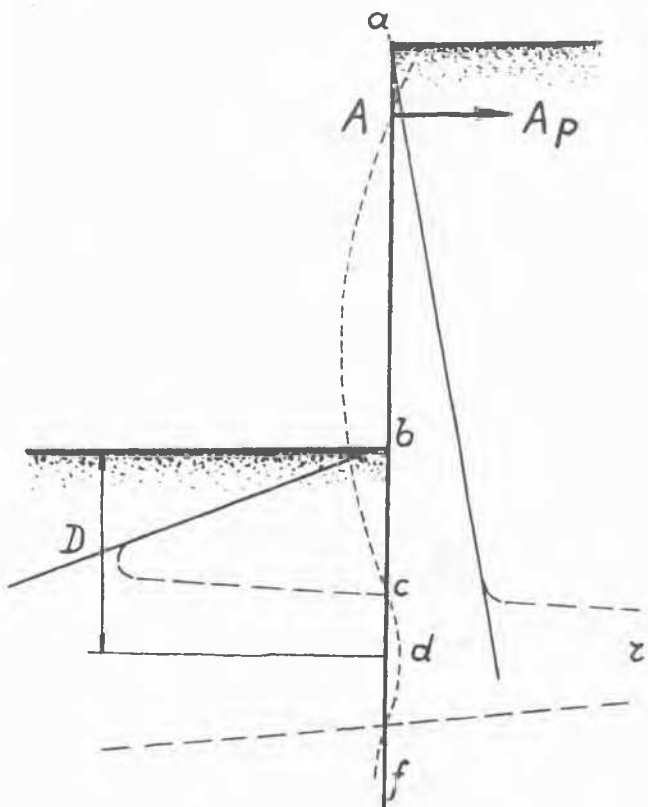
Scheme for computing bulkheads with "fixed earth support".

FIG. 2



Experimental installation for the observation of bulkhead models, as seen from above.

FIG. 4 b



Theoretically assumed elastic line of bulkheads and schema of earth pressures.

FIG. 3

mine the additional unknown of this system, it is assumed that the elastic line of the sheet pile is, like that of the fixed beam, tangent at the point d Fig. 2, to the initial vertical position of the axis of the sheet pile before it was deflected.

The scheme is founded on the following considerations. It is generally assumed that the sheet pile, if sufficiently long, deflects according to the scheme of Fig. 3. On the portion b-c the sheet pile mobilizes the passive earth pressure on the left and owing to the resistance opposed to the deflection by this passive pressure, the sheet pile deflects below point c toward the right and mobilizes on the portion c-f a passive earth pressure on the right.

Thereafter, below the point f, the sheet pile deflects again to the left and so on. The force Rd of the scheme Fig. 2 takes the place of the passive earth pressure d-r on the left and this elastic line in the portion c-d is assumed as tangent to the vertical. In order to simplify the practical use of this method, there have been suggested simplifications of

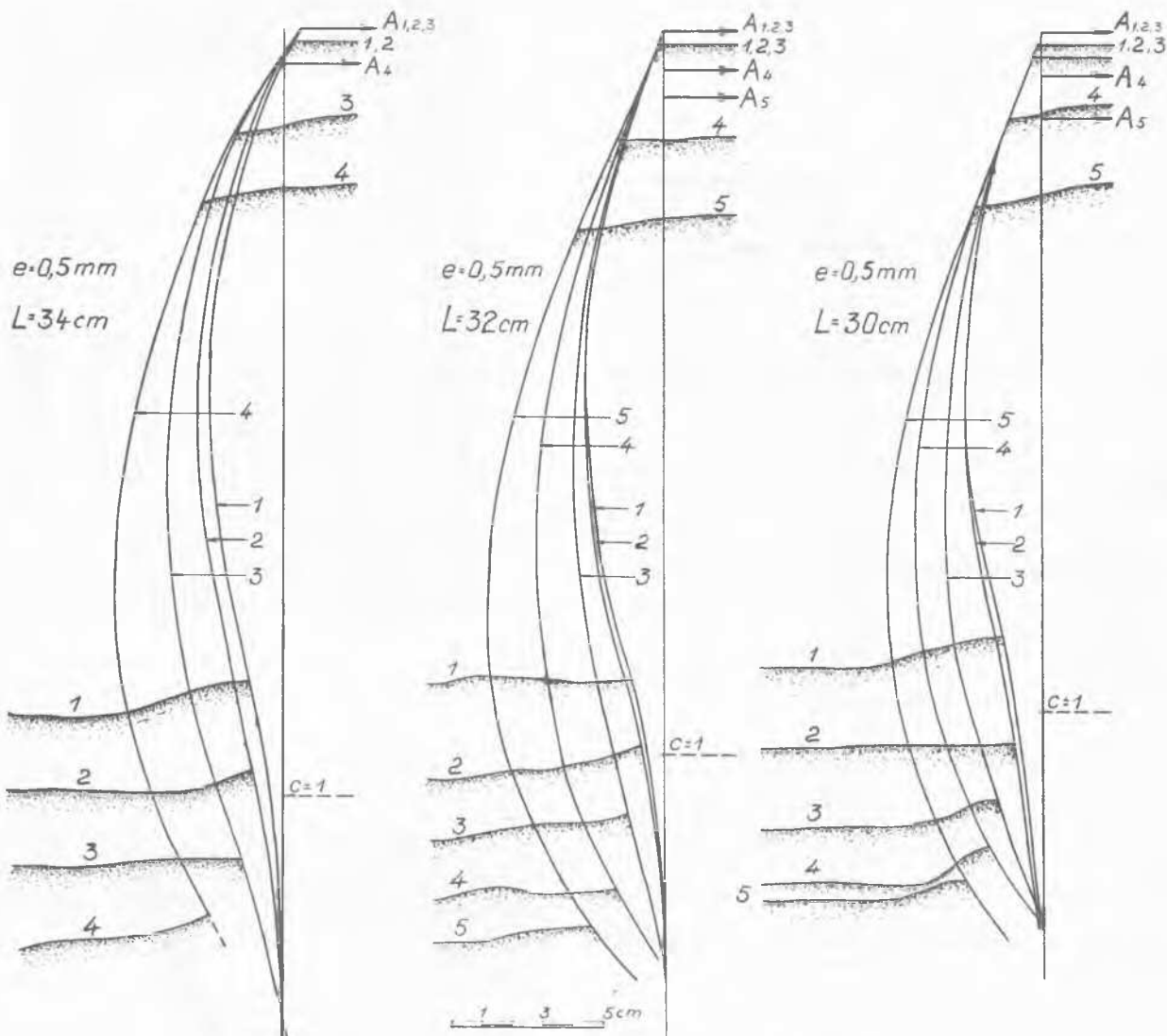
the computation, as f.i. the mode recommended by Blum. The method of fixed earth support has been submitted to a detailed criticism by Dr. sc. techn. R.N. Davidenkoff, 1947.

In the absence of information enabling to form an opinion on the actual working of anchored sheet piles, we found it to be necessary to find out by way of experiments undertaken, on a reduced scale, on a model. We thought it to be important to find out which shape the sheet pile actually takes in the case of various depths of driving into the soil and in which way the flexibility of the sheet pile influences its elastic line. Such experiments could be made with a relatively simple equipment of the experimental installation.

The model we were using consisted of steel sheets of 0,5 to 1,5 mm thickness, 30 cm width and a height which varied from 24 to 36 cm. The soil we were using was river sand with an internal friction coefficient $\tan \phi = 31^\circ$. The experimental installation consisted of a wooden box measuring 105 x 30 x 45 cm with glass panes on both sides for observation purposes, as

shown on photo Fig. 4a and 4b. In order to make the upper rim of the sheet piles sufficiently stiff, we affixed to it with screws a prismatic bar to both ends of which were tied the anchor rods. On the other end the anchor was fastened to the side of the box. The sheet piles were initially set vertically, following the line drawn by a thread stuck to the glass pane. The lower edge of the sheet pile was buried in the sand. Thereafter the sand was filled up equally on both sides up to the point b on the schemes Fig. 1 - 2. From this point on the filling was continued only on the right side, the sand being at the same time condensed, up to the level at which the anchor rods were tied to the sheet pile.

The sand on the left remained non condensed. To the glass pane was thereafter affixed a tracing paper and on it was traced the line of deflection of the sheet piles. Then the sand on the left was taken off by layers and at every change the deflection was traced on the paper. Thus the sand was taken off until the "destruction" of the bulkhead.



Experiment with sheet piles of $e = 0,5$ mm and $L = 34, 32, 30$ cm

FIG.5

FIG.6

FIG.7

Nineteen experiments of this kind were made at all. The most typical lines observed are to be seen on Fig. 5 to 14.

The curves on these figures represent the lines of deflection of the "sheet piles", such as they were traced on the paper seen through the glass panes of the experimental installation. The cipher designating each curve and the ciphers designating the sand layers indicate the curves and the layers corresponding to each others. In those experiments, in which the deflection attained considerable dimensions, the level of the back-fill sagged. The various levels resulting from the sagging are designated with the same ciphers, as the curves to which they correspond.

The initial depth to which the sheet piles were driven in the soil D was computed for the scheme of the fixed earth support (Fig. 2) according to Blum. On the same Figures are indicated by dots the depths to which the sheet piles had to be driven in according to the scheme of free support (Fig. 1) with the coefficient of stability reserve $c = 1$ according to Krey.

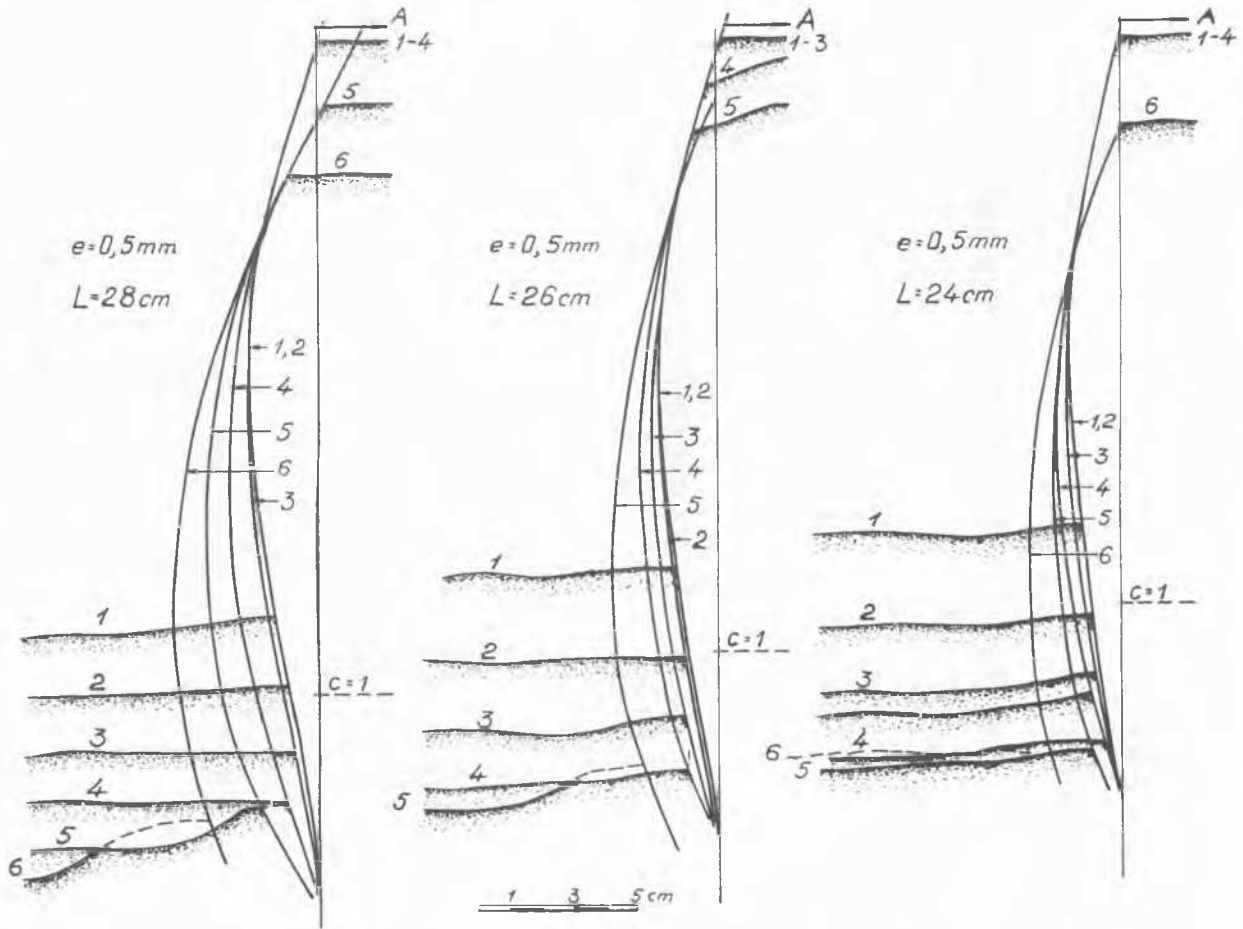
On the drawings are also shown the level corresponding to the displacement of the lower edge preceding the "destruction", as well as those at which the sheet pile was destroyed.

Figures 5 to 10 illustrate experiments undertaken with sheet piles measuring 0,5 mm of thickness e and a length $L = H + D$ (design of

Fig. 1 and 2) equal to 34, 32, 30, 28, 26 and 24 cm.

Figures 11 to 14 represent experiments with sheet piles, of 1,5 mm thickness and lengths, $L = H + D$, equal to 36, 34, 30 and 26 cm.

When comparing on these Figures the elastic lines of the sheet piles as they result from the pressure of the back-fill, we find that there are two types of curves (Fig. 15). Type I has two convexities towards the left, one in the uppermost part and another in the lower part towards the right. As far as the scale of the model permitted to judge, the lower part of the curve does not cross the initial vertical of the sheet pile. Type II has only one deflection, towards the left. The lowest point of these curves was displaced towards the left. In order to state the flexibility of the sheet piles, we computed the values $\lambda = L/r$ in which L represents the total length of the sheet pile as designated above, and r the radius of inertia, equal $r = \sqrt{I/s}$, in which I represents the inertia moment of the sheet pile and s the section through it. On Fig. 16 are indicated the values of the flexibility of experimental sheet piles of various lengths. The formation of curves of type II in the initial stage was observed beginning from Fig. 9, with $e = 0.5$ mm, $L = 26$ cm and $\lambda \approx 1800$. With sheet piles of greater flexibility curves were obtained of type I in



Experiment with sheet piles of $e = 0,5$ mm and $L = 28, 26, 24$ cm

FIG.8

FIG.9

FIG.10

the initial stage, whereas with stiffer sheet piles were obtained curves of type II. On Fig. 16 the line separating the zones of curves, type I and type II, is indicated by dots. Experiments which at first had produced curves of type I proved that with a reduced depth D the curves changed to type II.

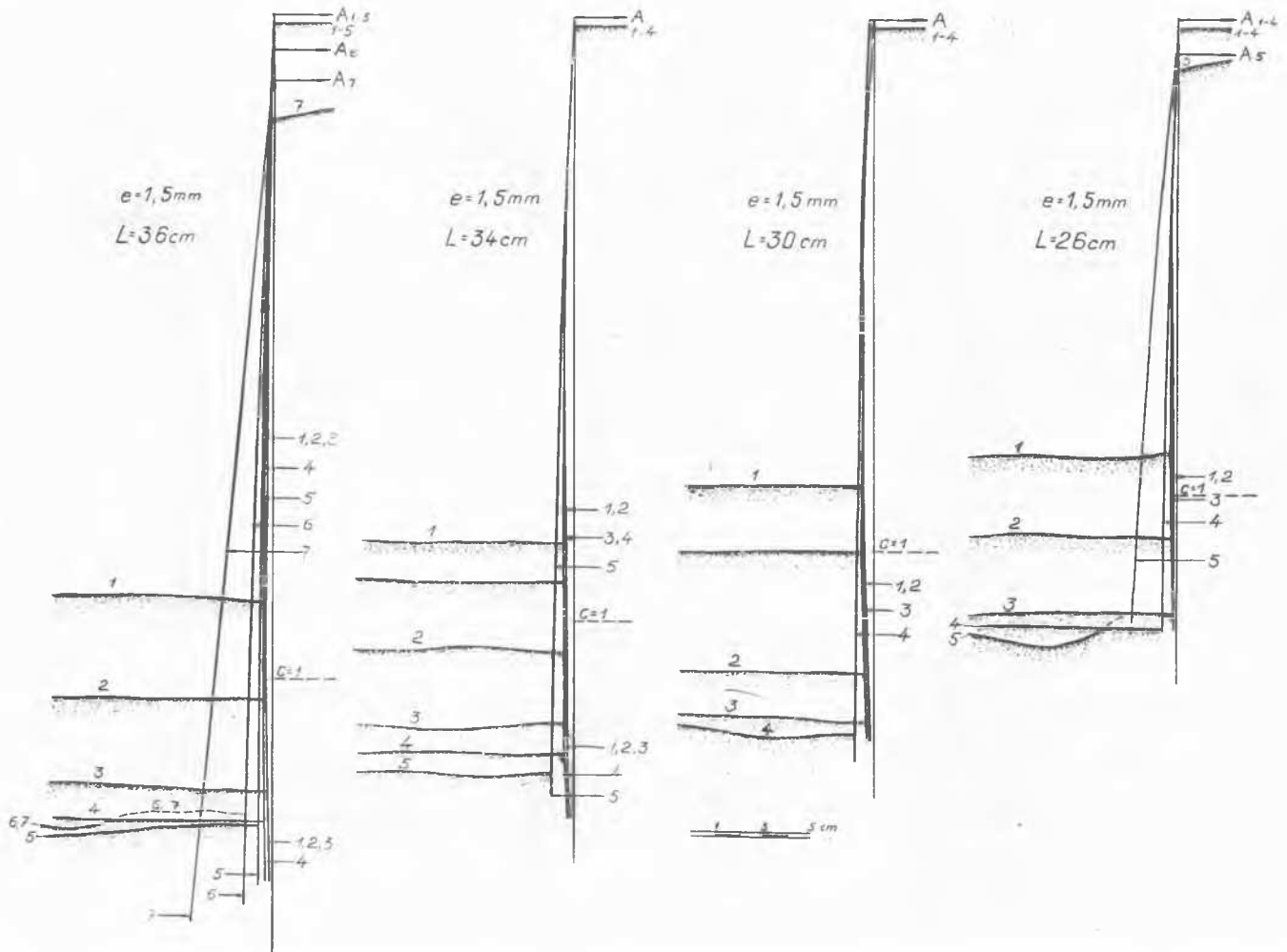
Thus the curve, as resulted from experiments, was dependent on the flexibility of the sheet piles and the depth of driving into the soil. A priori it can be assumed that the type of the curves depends also on the elasticity of the soil. This latter not being invariable, even for the same kind of soils, cannot be characterized by constants and in the present stage of knowledge cannot yet be computed. However the first two factors determining the nature of the curve: the flexibility of the sheet pile and the depth of burying enable, as shown by experiments, to state within the limits of which type of curves will be the elastic line of the real bulkheads. It has to be kept in mind that a certain divergence between real bulkheads and the experimental ones may result from the circumstance that, as the depth of burying is increased, the coefficient of elasticity of the soils increases in real bulkheads in a greater proportion than in the model.

The flexibility of real metallic sheet

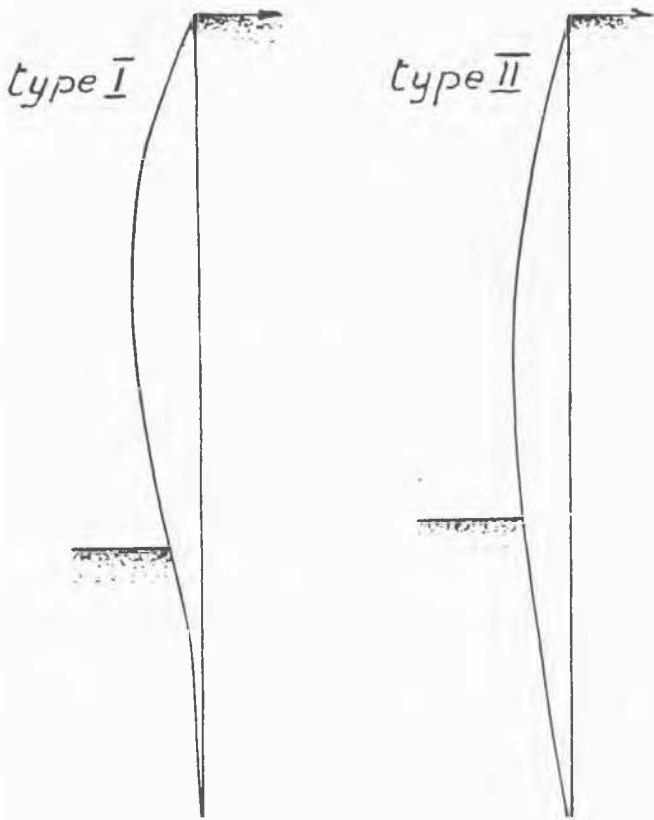
piles of various lengths, computed according to the scheme of free earth support (Fig. 1) in the assumption of various heights H of backfills and of various soils ($\phi = 25^\circ, 30^\circ$ and 35°) are shown in Fig. 17. For their computation were assumed section through sheet piles of various types and various makers, these being indicated in Fig. 17 by conventional signs. By dotted lines are indicated the limits within which vary the values of flexibility for the same length L, as a consequence to using various types of sheet piles.

Comparing on Figures 17 and 16 the flexibility of real sheet piles with the flexibility λ of sheet piles used in experiments, which produced curves of type II, we see (Fig. 16) that the former are situated within the approximate limits of $\lambda = 70$ and 130, whereas the flexibility of the experimental sheet piles which produced curves of type II, is equal approximately to $\lambda = 1800$ (Fig. 16). The curves of resulting for real metallic sheet piles, and still more for reinforced concrete bulkheads are all in the category of type II and far from the limits within which curves of type I are possible.

Although on greater depths the coefficient of the elasticity increases with real sheet piles more than on the model, we consider never-

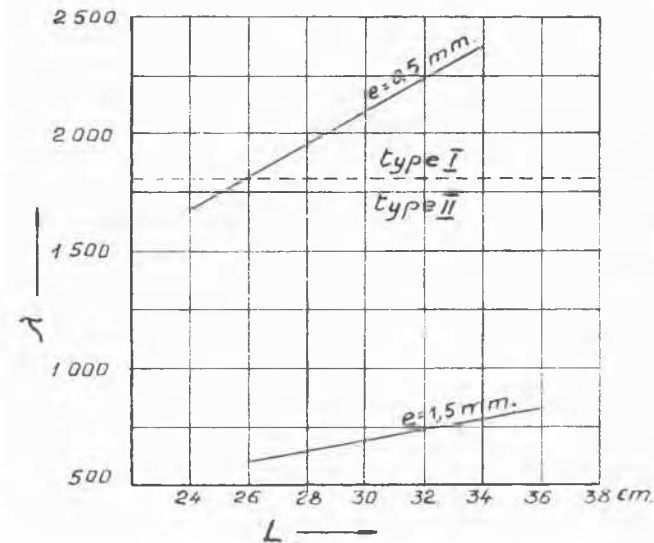


Experiment with sheet piles of $e = 1.5$ mm and $L = 36, 34, 30, 26$ cm
FIG.11 **FIG.12** **FIG.13** **FIG.14**



Types of curves observed.

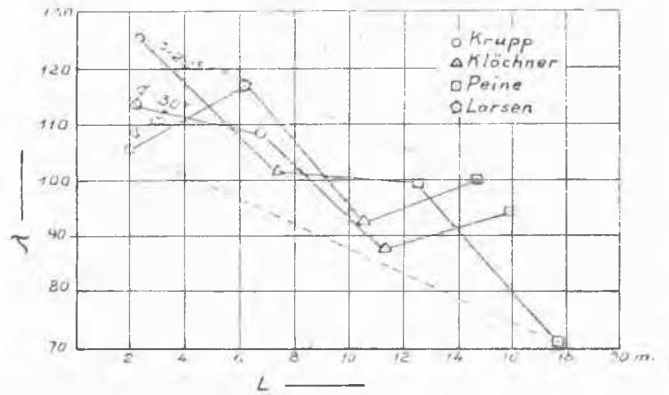
FIG.15



Elasticity λ of experimental sheet piles of various lengths.

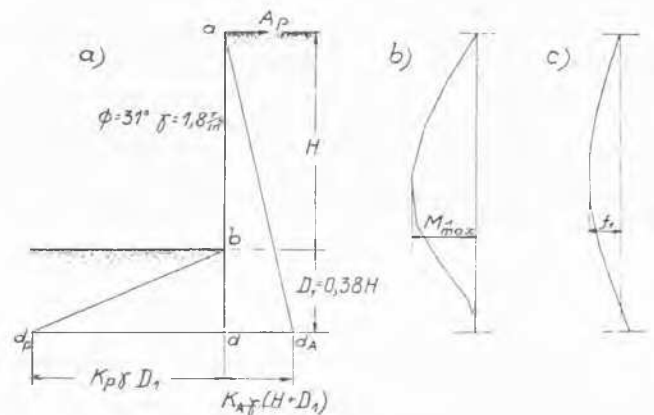
FIG.16

theless that this cannot so much reduce the flexibility of the sheet pile in relation to the compactness of the soil, as to make appear curves of type I at usual depths. It can therefore be stated that in all cases real bulkheads are deflected only towards one side i.e. according type II, to the left and the passive earth pressure is mobilized only on one side, the left on Fig. 2. Accordingly computations applying the method of bulkheads with fixed earth support do not correspond to the real strength of the sheet piles.



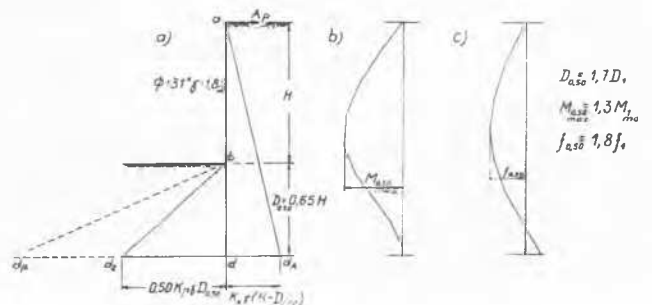
Elasticity λ of real metallic sheet piles of various lengths, types and makers, computed for various soils according to the schema of free earth support.

FIG.17



(a) Schema of pressures, (b) line of moments and (c) theoretical line of elasticity for sheet piles with free earth support under the assumption of full mobilization of passive pressure (for a soil $\phi = 31^\circ$ and $\gamma = 1,8 \text{ T/m}^3$).

FIG.18



(a) Schema of pressures, (b) line of moments and (c) theoretical elasticity line for sheet piles with free earth support under the assumption of 50 p.c. mobilization of passive pressure and comparison of results obtained with those of fig. 18 (D, M_{\max} and f).

FIG.19

The principal errors inherent to the said method are the following. The shape of the deflection of the sheet piles is assumed out of relation with the flexibility of the sheet piles and the elasticity of the soil, whereas in the computation of a statically indeterminate system, such as the scheme of the fixed earth support, these factors must be taken in-

to consideration. There is further no foundation for the assumption that on the left side of the bulkhead the passive earth pressure is fully mobilized. This assumption leads to the necessity of further assuming a concentrated force at the lower edge of the sheet piles, in order to comply with the conditions of equilibrium, of the system, and with the shape of the curves. However the arguments given in favour of the real existence of the said force are not convincing.

It is not the purpose of this paper to investigate all curves. We are limiting ourselves to the curves of type II corresponding to the deflection of real bulkheads.

Assuming the equilibrium of the sheet pile to be that of the scheme of free earth support (Fig. 1), we draw two theoretical curves (Fig. 18 and Fig. 19) of which the first corresponds to fully mobilized passive earth pressure and the second to a passive earth pressure mobilized by 50%, i.e. with a coefficient of stability reserve equal to 2, according to Krey, and with a triangular passive pressure area, such as shown on Fig. 19.

We draw the first curve computing its ordinates according to the general theory of strength.

We draw the second curve, using for the sake of simplicity, the methods of graphic statics. On Figures 12 and 13 are represented under a) the static schemes and under b) the diagrams of bending moments and c) the elastic lines of the sheet pile.

Comparing these theoretical curves with the experimental ones, we see that as regards type II no deflection at the lower edge could be observed. We assume that the deflection at the lower end of the sheet pile must be less important than the displacement of the sheet piles to the left, which is the condition of mobilizing the passive earth resistance.

This explains, to our understanding, why in curves relating to type II the displacement of the lower edge of the sheet piles was towards the left. It results therefore from the above statements that theoretical curves with charges as assumed according to the scheme of free earth support, are not far from the curves type II observed.

As a consequence we arrive at the conclusion that one comes nearer to the truth by computing bulkheads according to the scheme of free earth support, than one would obtain following the method of fixed earth support. It would be highly desirable to undertake further investigation by way of experiments, especially on models of greater size than we could use for our investigation.

LITERATURE.

- H. KREY. Erddruck, Erdwiderstand. Vierte Auflage 1932.
 L. BRENNER und E. LOHMEYER. Der Grundbau, II Band 1930.
 K. TERZAGHI. Theoretical soil mechanics, second print 1944.
 R.N. DAVIDENKOFF. About the calculating of anchored bulkheads, paper, 1947.

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EFFECT OF BOUNDARY CONDITIONS ON LATERAL EARTH PRESSURES.

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SUMMARY.

This paper forms the continuation of the paper "Lateral Earth Pressure as a Problem of Deformation or of Rupture" by Gregory P. Tschebotarioff and Philip P. Brown submitted earlier for publication by the Conference. Further results are presented as obtained in the course of the extensive program of research concerning lateral earth pressures in progress at Princeton University under the sponsorship of the Bureau of Yards and Docks, Navy Department, Washington, D.C.

Data obtained during tests with Model Bulkheads and at high pressures in the Lateral Pressure Meter is reported in graphical form.

A hypothesis is presented which attempts to provide a theoretical explanation of the observed equality of the "at rest" or "consolidated equilibrium" lateral pressures of different types of soils at locations with no adjoining boundaries capable of restraining parallel deformations.

The maximum bending moments and anchor pulls recorded during combined active and passive earth pressure tests with model bulkheads are compared to values obtained from computation by conventional design procedures. The appreciable deviation of pressures near the dredge line boundary from conventional assumptions is made apparent. Its causes are discussed.

Points under further investigation are outlined.

The conventional procedures for the computation of settlements of soft saturated clays usually ignore the effects of shearing resist-

ance to displacements parallel to vertical rigid boundaries in their vicinity and assume that the surface settlements at all times are