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Ground Anchorages.

Verankerungen im Baugrund.

Les ancrages dans le sol.

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I. Introduction.

Anchorages are in universal use as a means of resisting tensile forces. The choice of an anchorage is bound up in the first place with the physical properties of the ground, and the most rational type to use can be selected only by an engineer who is familiar with geological structure, qualities and resistance of the ground, aided by careful tests.

Geophysics is as yet so young a science that the resistance of the soil is commonly utilised too little or not at all. Thus the classical type of anchorage foundation is a massive block of concrete, varying in shape in accordance with the design and nature of the ground. This is, of course, a very simple though costly method of anchoring, which when adopted in water-logged ground of little resistance involves the use of a large quantity of concrete, in addition frequently to expensive shuttering and to operations for lowering the ground water level. If such concrete foundations are not to be used, anchorage (in the absence of good rock) can be obtained only by the use of anchor plates or anchor piles, the first of these alternatives being appropriate for horizontal or slightly inclined tensile loads, the latter for vertical or steeply inclined loads.

In the following pages only anchorages by means of piles will be considered.

II. Description of tension piles.

The pre-conditions for the use of tension piles are the following:

1) Exact knowledge of ground conditions. (Positions and qualities of the geological strata.)

2) Knowledge as to how a tensile load will be transmitted from the pile to the ground. (Considerations of equilibrium within the ground.)

Tension piles may be made with either head anchorage or foot anchorage (Fig. 1).

In the case of a true tension pile (Fig. 1 head anchorage and foot anchorage, I and II), the tension is transfered to the ground by friction around the periphery. To make a pile suitable to withstand heavy tensile loads its surface must be as rough as possible, so that piles cast *in situ* are particularly

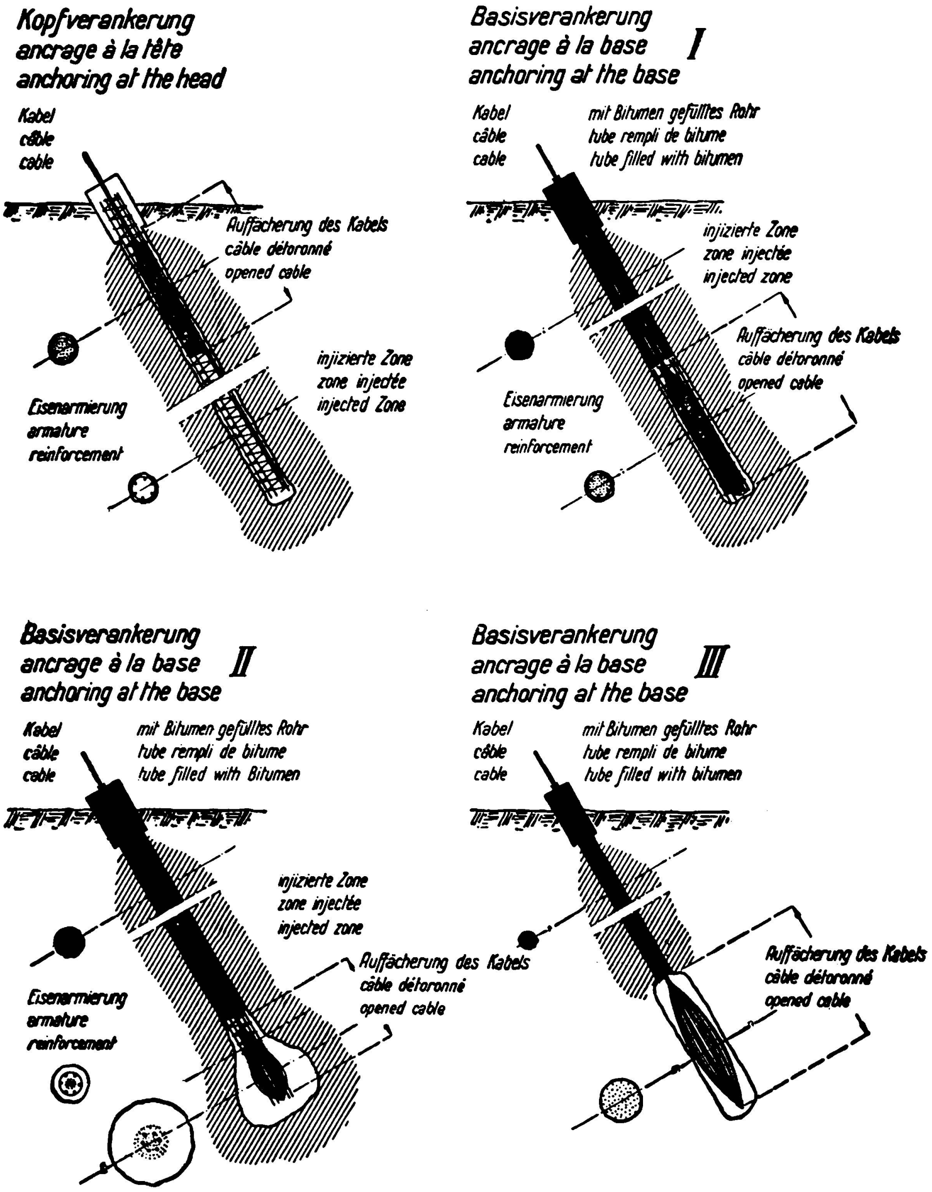

Fig. 1.

Anchoring by boring piles.

effective in this respect, and piles moulded in the ground made by compression or injection offer the following advantages:

1) The operation of boring and removing samples from the ground supplies exact knowledge of the conditions below.

2) The process of compression ensures that the diameter of the pile is larger than its theoretical value, and ensures that the concrete shall penetrate into cavities, thus making a good connection with the ground.

3) The injections result in a complete system of ramifications around the pile which add to the friction against it (Fig. 2).

Fig. 3 shows a hydraulically compressed and injected system of piling known as "Rodio", and it may clearly be observed that the injection at the foot of the pile (which has not been mechanically enlarged) has had the effect of uniting the surrounding gravel and sand with the shaft of the pile to form a single whole; similar enlargements also appear along the pile itself.

Using piles with head anchorage, that is to say with the cable attached to the head of the pile, the reinforcement of the pile must of course be designed to take the full tensile load. The displacements of the pile relative to the surrounding ground are of course, greatest at the head and become smaller towards the foot. In a pile with foot anchorage the reverse is true, the tensile loads being transferred through cables which may, for instance, be enclosed with bitumen in a pipe running down to the bottom of the pile and anchored there in the concrete. No reinforcement of the upper portion of the pile is necessary, since here the whole of the tension is carried by the cable acting independently of the pile. In such a case the largest displacement of the shell of the pile in relation to the surrounding ground occurs at the foot of the pile, and it follows that the action of a pile with foot anchorage is preferable to that of a pile with head anchorage.

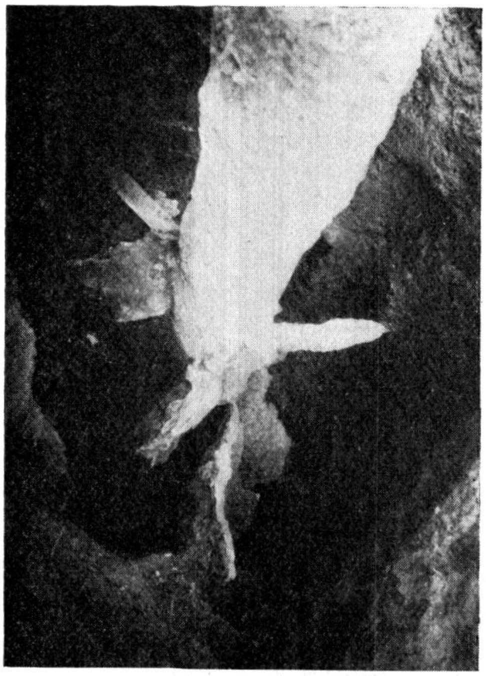

Fig. 2.

"Branches" caused by the injections of cement.

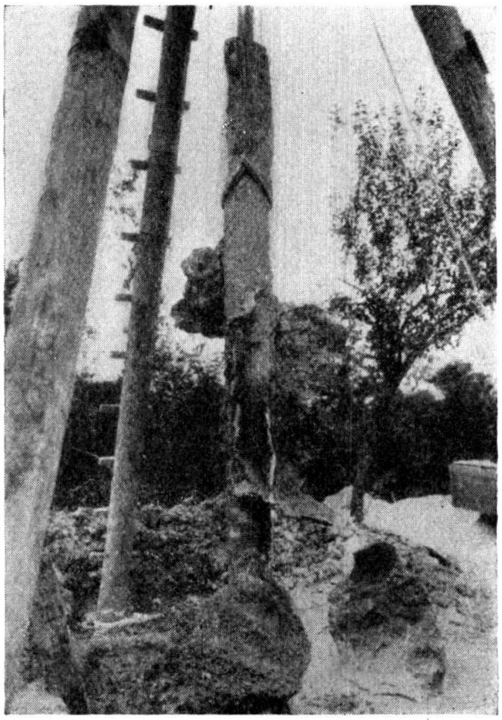

Fig. 3.

The "Rodio" system of hydraulically compressed and injected piles.

III. Experiments.

To determine the resistance of a tension pile accurately by mathematical methods is a very ticklish problem even on the assumption that the ground is homogeneous. When it is remembered that the ground penetrated by the pile consists of different strata, and that the chemical and physical properties may vary even within each stratum, it will be realised that a mathematical solution to a problem indeterminate to so high a degree is practically impossible. Further complication arises through the facts that in the most effective types of pile (the compressed and injected piles), the diameter is a very variable quantity (Fig. 4) and the injection of cement produces a solid connection with the ground, the extent of which cannot be accurately known.

Fig. 4.
Hydraulically compressed and injected pile with variable diameter.

Of the many practical formulae that have been developed from consideration of the equilibrium of the forces acting on the piles, the author proposes to refer only to that of *Dörr*,[1] the results of which agree best with the actual facts indicated by investigations to date. His attempt to estimate the statical resistance of piles with the aid of the *Engesser* theory of soil pressure is, however, known to be incorrect, since he has taken no account of deformation of the ground. The only acceptable method for determining the resistance of a tension pile still consists in test loading, and the author proposes to quote two experiments on tension piles with head anchorage from among the large number of loading tests on piles that have been made by the firm of Sondages, Etanchements, Consolidations "Procédés Rodio" S.A., Paris.

The experiments were made with the aid of a hydraulic press bearing at one end against a central compressive pile, and at the other end against a stiff reinforced concrete construction connecting together two tension piles.

The mutual displacements of the three pile heads brought about by the load imposed in this way were recorded on a selfrecording deflectometer carried on a stiff beam which was supported outside the portion of ground liable to be affected by the load (Fig. 5).

The hydraulic press used in the pile tests at St. Germain allowed of a maximum total load of 220 tons being imposed, or 110 tons for each tension pile, and the result of this was to lift the heads of the piles by respectively 2.85 and 3.15 mm. When the load was removed it was found that a permanent lifting of respectively 0.30 and 0.40 mm remained; in other words seven-eights of the deformation

[1] *H. Dörr:* Die Tragfähigkeit der Pfähle. (W. Ernst & Sohn, Berlin 1922.)

had been of an elastic and only one-eighth of a permanent nature (Fig. 6). On calculating the average sleeve friction due to the imposed tension of 110 tons in accordance with the theoretical diameter of the pile, 42.0 cm, the frictional force worked out at 0.64 kg/cm^2.

Interest also attaches to the piling tests carried out in bad ground at the Quai d'Orsay in Paris. The anchor pile marked D. 18-5 lifted 6.2 mm under a tension of 83.5 tons, and on removing the load the permanent lift was recorded 1.00 mm. On the other hand the pile head marked D. 18-4 showed very pronounced lifting when 50 tons tension was exceeded, this being attributable to

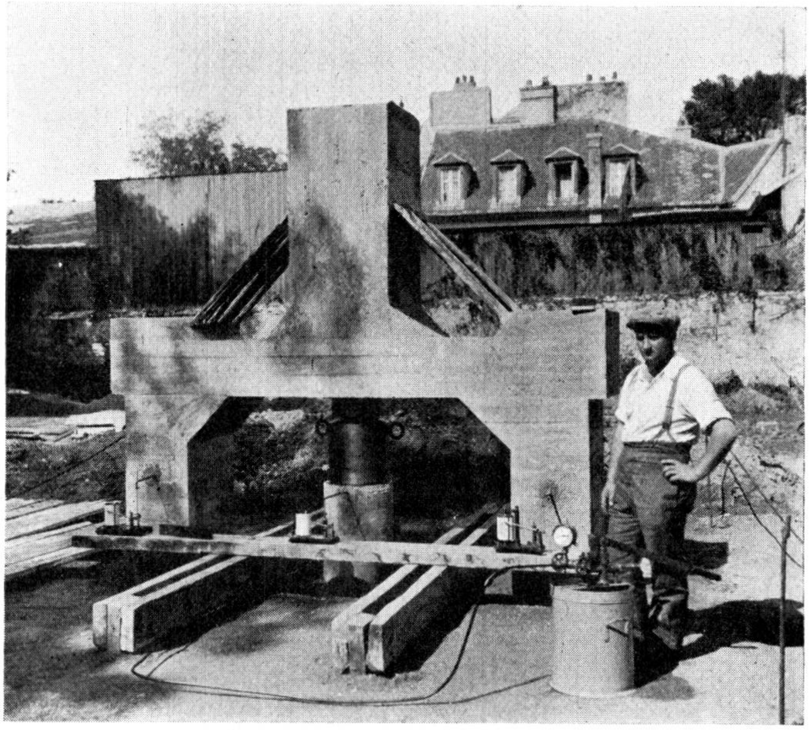

Fig. 5.

Pile tests. Tension piles with head anchoring.
Arrangement of the tests.

the unfavourable effect of a pit existing in its vicinity, causing a reduction in the amount of ground encircling the pile and, therefore, a reduction in the resistance of the latter. It can definitely be stated, however, that this movement rapidly stabilised itself (Fig. 7) — a circumstance which may be accounted for by the enlarged foot of the pile pressing so hard against the ground after the movement had taken place that it was able to take up a notably larger load than had been the case originally.

IV. Uses of Tension Piles.

Anchorages by means of tension piles are now frequently used in the construction of masts and there is a large scope for them in bridge work. In this way simply supported beams may be converted into beams which are rigidly or

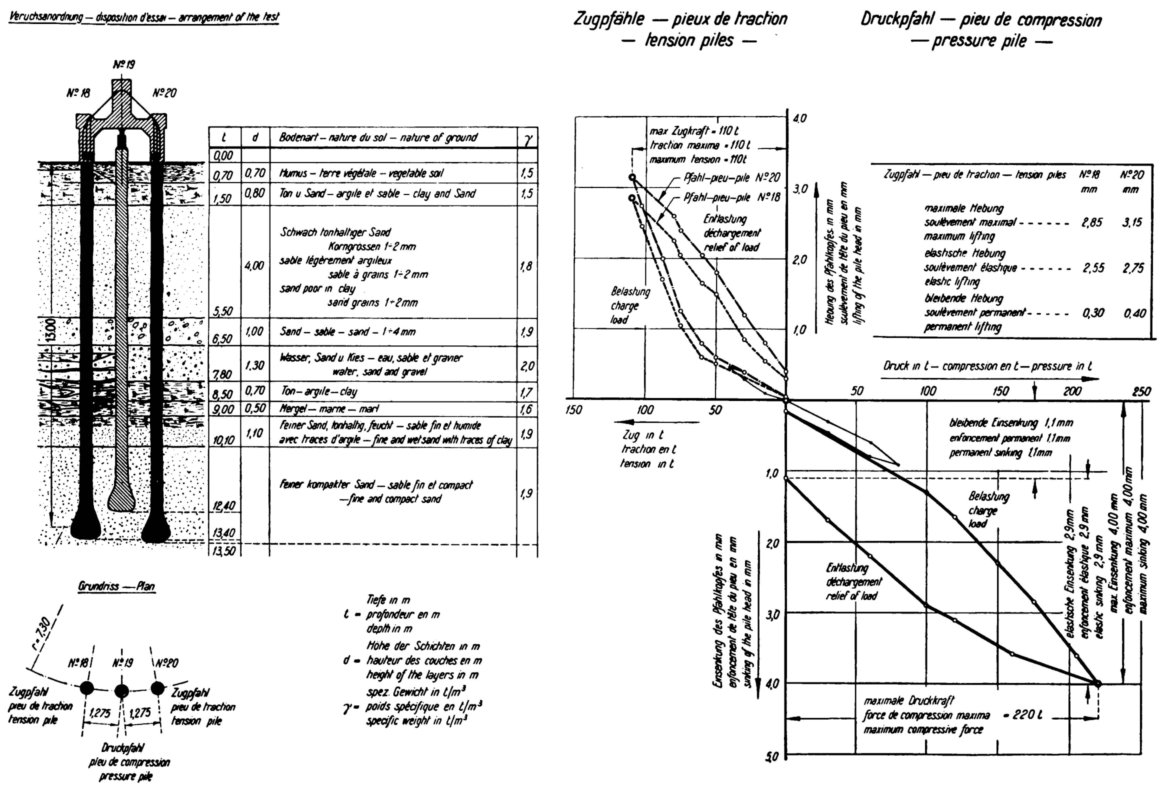

Fig. 6. Results of the pile test at St. Germain.

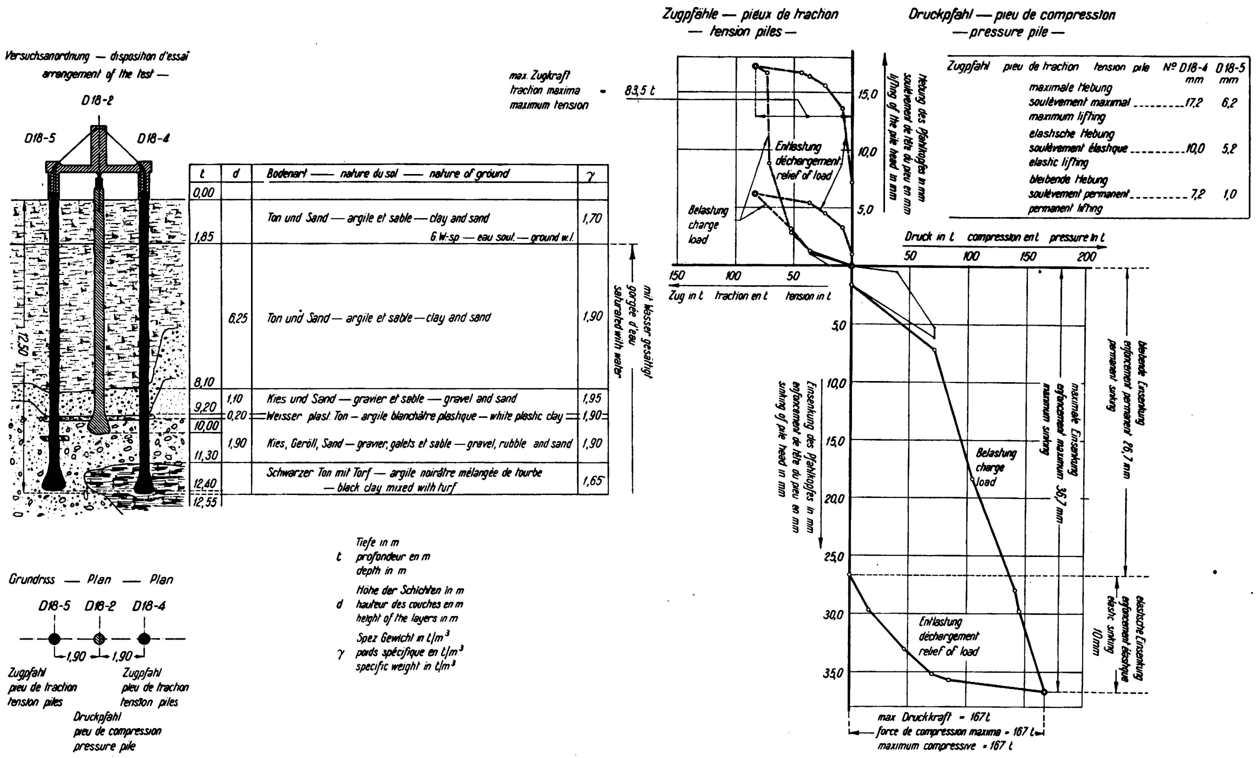

Fig. 7. Results of the pile test, Quai d'Orsay, Paris.

elastically fixed at the ends (Fig. 8), and heavy concrete foundations for suspension bridges may be replaced by clusters of compression and tension piles (Fig. 9).

V. Method of Calculation. Conclusion.

If, even to-day, the adoption of tension piles is viewed with a certain scepticism this is attributable to the fact that the experimental results are too little known, and that no satisfactory mathematical solution has yet been put forward.

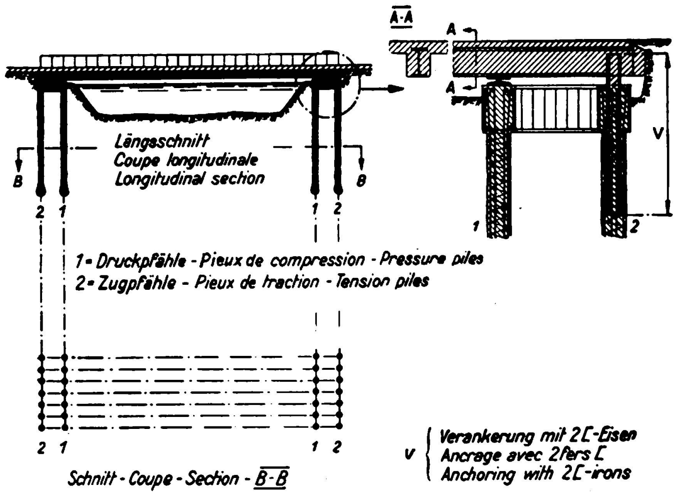

Fig. 8.

Beam Bridge with pressure and tension piles.

Tension piles with foot anchorage (see Fig. 1, Foot Anchorage III) can, however, be calculated by reference to the theories of *Boussinesq*[2] and *Fröhlich*[3] either for elastic isotropes of half or whole space, or for a confined elastic isotropic space, or again for a *confined* space in general, in order to determine the distribution of stress from the conditions of equilibrium and thus fix the length of the tension pile. The space above the ground surface which is not filled with any mass contains imaginary stresses which must in fact be carried by the space below the point of application of the load. On considering the conditions of equilibrium of an imaginary sphere it will be seen that these imaginary compressive stresses are converted into tensile stresses which, in turn, operate to diminish the compressive stresses already existing.

In Fig. 10 this problem, to which the author proposes to revert elsewhere, is shown diagrammatically. Here.

σ_z = vertical compressive stresses,
σ_x = horizontal compressive stresses,
σ_{Ez} = vertical specific earth pressure,
σ_{Ex} = horizontal specific earth pressure.

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[2] *Boussinesq:* Application des potentiels à l'étude de l'équilibre et du mouvement des solides élastiques. Paris 1885.

[3] *Fröhlich:* Druckverteilung im Baugrunde (Julius Springer, Vienna 1934); Elementare Druckverteilung und Verschiebungen im elastisch-isotropen Vollraum. Der Bauingenieur 1934, Nos. 29/30.

Zone A = zone of load transfer.

Zone B = zone of reduction in pressure.

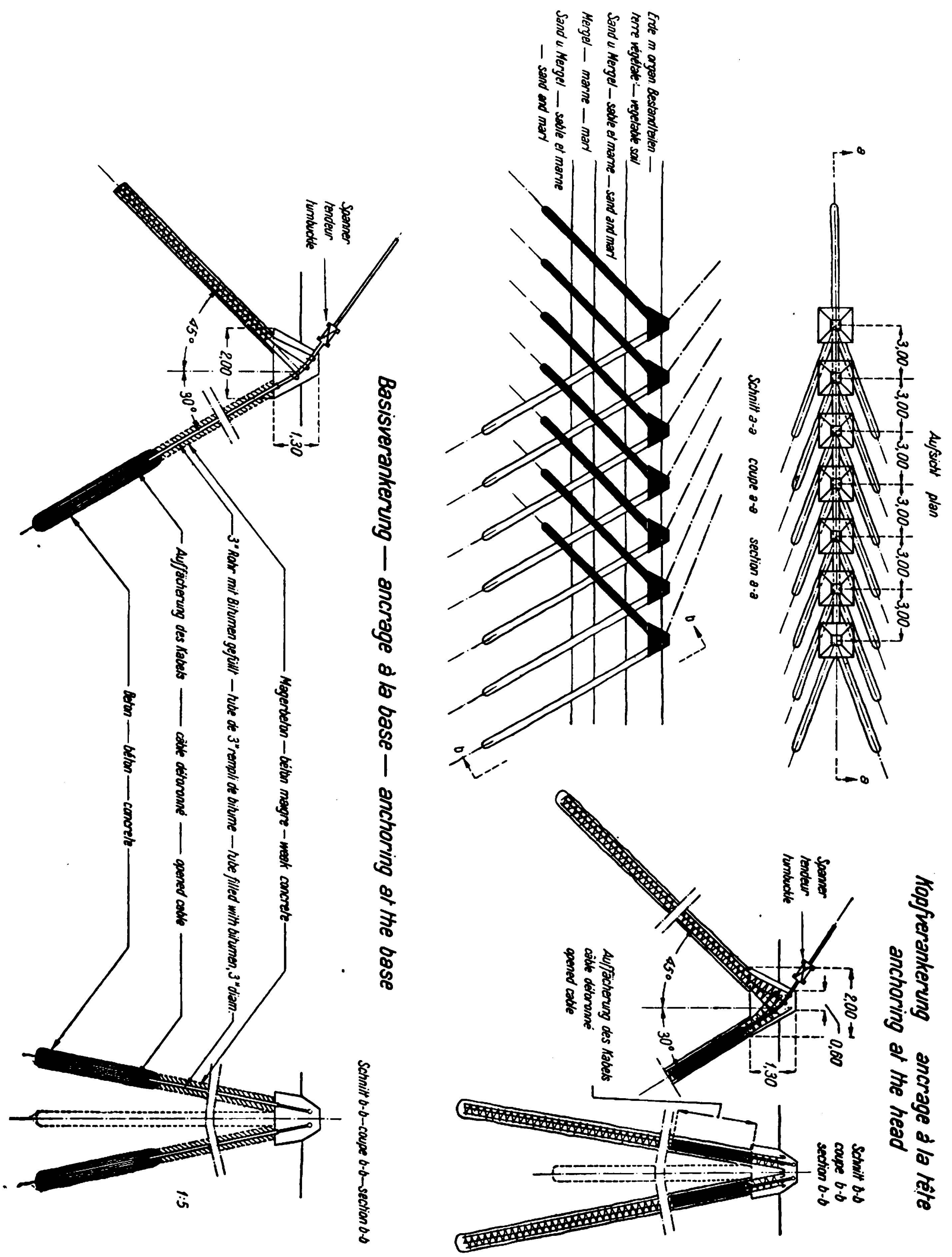

Fig. 9. Scheme for the anchorage of a suspension bridge with pressure and tension piles.

For the purpose of calculating the distribution of pressure, the pull in the cable P may with advantage be resolved into its vertical and horizontal components, P_V and P_H (Fig. 11). By the aid of nomograms (which must be drawn to a sufficiently large scale) a useful picture of the distribution of stress in the ground is readily obtained, even in complicated cases where compression and tension piles are used together.

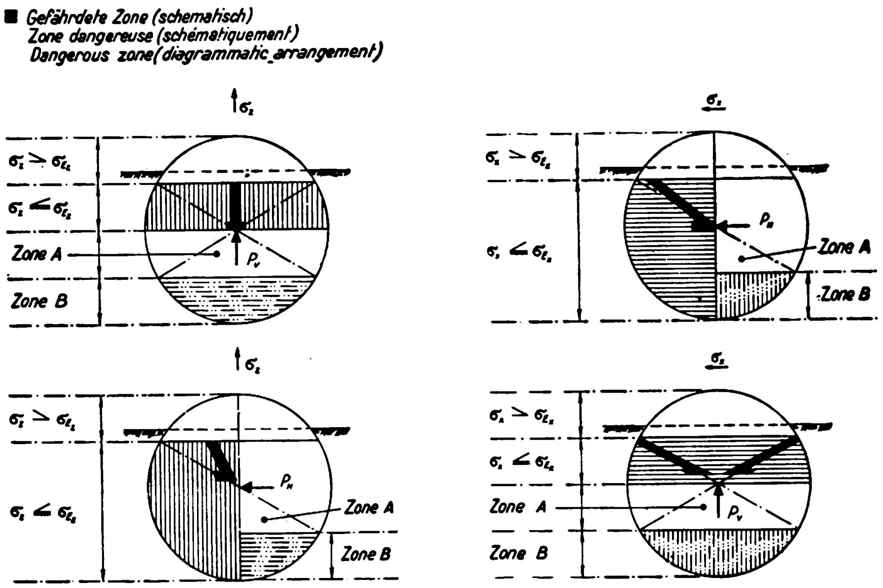

Fig. 10.

Distribution of pressures in the ground. Considerations of equilibrium.

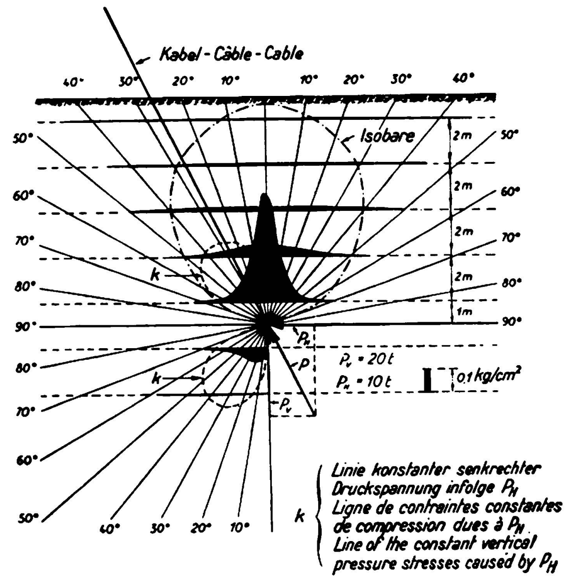

Fig. 11.

Vertical distribution of the pressures caused by the force P of the cable.

Fig. 12 represents such a nomogram for determining the compressive stress σ_z in the half space as a function of P, φ and z. The concentration factor v, is variable between 2 and 6. In order to determine the distribution in pressure in the full space the stresses thus obtained are to be divided by 2.

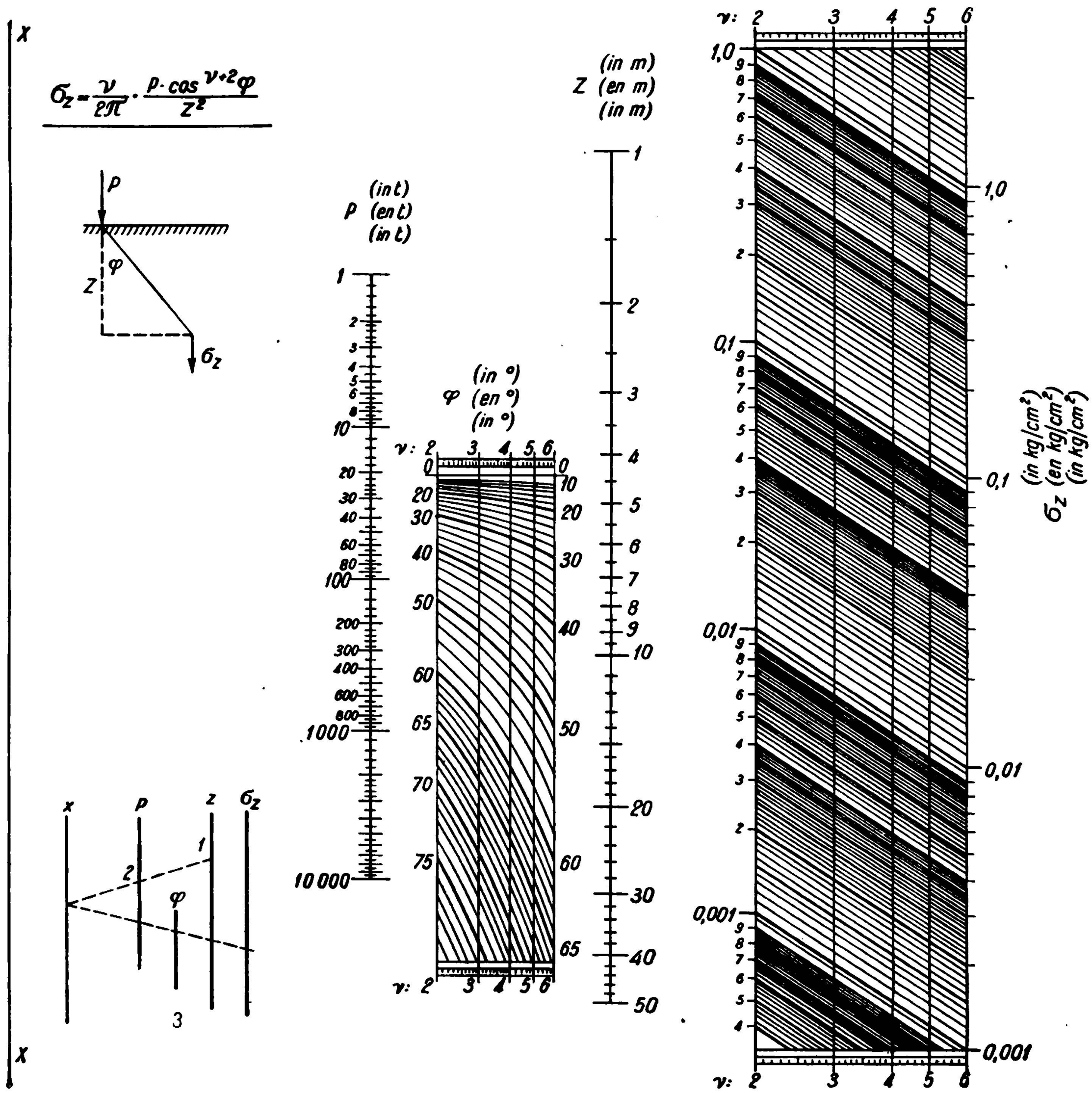

Fig 12.

Nomogram for determining the compressive stresses σ_z.