NEW TECHNOLOGY FOR WEAK ROCK CONSOLIDATION

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ABSTRACT

Shaft sinking in weak rock, especially in water-bearing sand strata, is very difficult. A new type of effective chemical grouting material has been applied for pregrouting in shaft bottom in order to overcome problems of water and sand influx during the course of shaft sinking. This method had been successfully used during the sinking of two vertical shafts at Fengnan Coal Mine in Hebei province by consolidating a six-meter water-bearing sand strata. This paper stresses on the introduction of the characteristics of this new chemical grounting material and the injection technology at shaft bottom.

1. FUROL CHEMICAL GROUTING MATERIAL

1.1 The ingredients of this grouting material

The essential ingredients of this grouting material were furol /A/ and solids /B/. Acid /C/ was used as catalyst and water /D/ as solvent adding also a small amount of other additives.

During preparation, the ingredients /A/, /B/, /C/ and /D/ were mixed into two groups, solution I and II, and were stored separately. These two solutions were carried down to the shaft bottom with two pipelines and injection took place after mixing. Condensation and polymerization occured in sand strata after injection forming a high polymer consolidating the sand and providing the possibility for shaft sinking.

1.2 Factors influencing the time of gelation

The time of gelation is influenced by the following factors: consumption of acid /C/ - catalyst, temperature of grout, ratio of solution I and II /by volume/, and molar ratio of essential ingredients /A/ and /B/ etc. /see Fig. 1, 2, 3, 4/.

As shown in Fig. 1 the time of gelation was shortened with the increasing of acid consumption. Acid consumption should be controlled within 0,3-1,6 % for ordinary engineering practice.

As shown in Fig. 2 reaction accelerated along with increasing of temperature when the temperature of reaction was below 22 °C. But abnormal phenomena appeared when the temperature of reaction was beyond 22 °C. Therefore in practice the temperature of reaction should not be higher than 22 °C.

The influence of ratio of two solutions /by volume/ on time of gelations is illustrated in Fig. 3. This ratio was linear with the time of gelation. In practice this ratio was appropriate to control in about 1:1.

Fig. 4 illustrates that time of gelation was slightly different with various molar ratio of /A/ and /B/. But the price of A was much higher than B, therefore selecting the ratio in the range of 0,55:1.0 - 0.72:1.0 was more appropriate.

1.3 Factors influencing the compressive strength of gel

The compressive strenght of gel was significantly influenced by the following factors: acid consumption, molar ratio of essential ingredients /A:B/ and ratio of solution I and II /by volume/ etc. /see Fig. 5, 6, 7/.

Peak value of compressive strenght appeared associated with acid consumption of 1.5-2.5 %. Because acid was corrosive to equipment and concrete shaft lining the appropriate acid consumption was 1.0-1,5 % considering that it was satisfactory for time of gelation and compressive strength in practice.

Compressive strength could be ranged to 80 kg/cm² when A:B /molar ratio/ was 1:1 /see Fig. 6/. Considering the price of grout and requirement of compressive strength in practice molar ratio was selected as 0.55:1 - 0.72:1 associated with compressive strength of 20-25 kg/cm².

Fig. 7 illustrates that maximum compressive strength occurred when ratio of solution I an II /by volume/ was 0.9:1.0 - 1.2:1.0. Compressive strength was lower when the ratio was higher or lower than the above-mentioned.

1.4 Determination of acid dialysis

Acid as catalyst promoted chemical reaction. But acid dialyzed under water pressure after gelation of grout and was corrosive to shaft lining. Therefore it was necessary to measure acid dialysis ratio and adopt procedure for prevention of corrosion. Fig. 8 shows that most of the acid dialyzed along with not too long a soaking time. After dialysis of acid, it was necessary to adopt appropriate procedure to neutralize it.

1.5 Basic properties of the grout

Viscosity	1.06-1.09 cp.
Specific gravity	1.13-1.16
Capability of injection	0.01 mm /minimum grain size/
Compressive strength of consolidated sand	10-80 kg/cm²
Time of gelation	scores of seconds - some ten minutes /controllable/
Permeability coefficient of consolidated sand	10^{-4} - 10^{-5} cm/sec

2. TECHNOLOGY OF INJECTION IN SHAFT BOTTOM

The main shaft of Fengnan Coal Mine had been designed to sink with water-submerged drop shaft through sand strata. During drop shaft sinking, water and sand flooded in many times. Deviation of shaft lining occured and surface subsidence appeared. At last shaft sinking had to be hung up. Decision was made to apply chemical injection. And with the application of chemical grouting shaft sinking in water-bearing sand strata had been successful.

Technological procedure: concrete mat was first constructed, then drilling of injection boreholes took place, after drilling chemical materials were injected. Grout injected into sand strata through drill rods, distributed, and consolidated sand after chemical reaction. The features of the operation were: limited drilling work, speedy injection process and satisfactory result etc.

2.1 Layout of boreholes and determination of injection length

Owing to the deviation of the drop shaft lining, disturbance of virgin rock strata, existance of pores and inherent unconsolidation of sand strata close-spacing boreholes were adopted. They were drilled in two concentric circles. Diameter of the inner circle was 2.4 m, totally 20 boreholes were drilled with spacing of 0.38 m.

Cementation treatment had been used first in order to fill up the pores, tighten the sand and save on consumption of chemical grouting materials. Diameter of the outer circle was 3.2 m. Totally 40 boreholes were drilled with spacing of 0.25 m. Furol chemical grout was injected through these boreholes. The length of boreholes was 8.4 m /see Fig. 9/.

The shaft had been sunk to a depth of 24.7 m before grouting. The length of injection treatment was designed as 6 m, a zone beginning from the edge of the cutting shoe of the drop shaft to a depth of 30.7 m, 0.3 m into clay strata.

2.2 Injection pattern and material consumption

Drilling of injection boreholes took place at shaft bottom with drilling machine and grouting materials were injected through drill rods.

During cementation treatment displacement injection was applied, more sands were forced out in order to fill up pores in sand strata with cement grout and tighten up the sand to ensure that there would be no excessive loss of chemical grout into the shaft.

In order to carry furol grout into sand strata evenly constant-volume injection pattern was adopted. Injection of stages carried on from top to bottom, and layers in stage inversely /see Fig. 10/. The six-meter injection length was divided into three stages /I, II & III/. The length of each stage was 2 meters. The injection procedure for stages was the top stage first, then the second, and the third one at last. And the two-meter stage itself was divided into six layers with a height of 0.34 m each. The injection procedure of layers was from bottom to the top. After injection of each layer the drill rod was withdrawn upward at a height of 0.34 m until the accomplishment of injection for all six layers.

The consumption of chemical grouting materials was calculated by the diameter and thickness of the diaphragm wall surrounding the shaft. In this case the thickness of the diaphragm wall was 2.9 m calculated by thick walled cylinder theory assuming the allowable compressive strength 20 kg/cm^2 and safety factor 2. The volume of sand strata should be consolidated by grouting materials was 201.3 m^3 and the porosity of sand strata was 38 %. Therefore the total volume of chemical grouting materials needed should be 85 m^3. It was designed that the volume of chemical grouting materials for each hole in stages I and II should be 600 l and for stage III 800 l. According to the abovementioned the total amount for injection should be 80 m^3. In practice the total consumption of chemical grouting materials was 83.2 m^3 including grouting materials for sealing of inspection boreholes. The consumption of raw materials was: /A/ - 23.9 tons, /B/ - 20.8 tons, /C/ - 2.6 tons and other additives.

2.3 Two-solution injection routine operations

The routine operations of injection are showned as Fig.11. The two solutions I and II were prepared separately according to the design and then they were transferred into the measuring buckets 2 and 3. Using membrane pump solutions I and II were carried through two separate pipelines to the shaft bottom via air chamber 5, three-way cock 6, flow meter 7 and pressure meter 8. Then they were prepared into a two-solution grout in mixer 10, transferred through one pipeline, drill rod 11, borehole sealing 14, drill bit 17 and then at last injected into sand strata. In sand strata the grouting materials diffused and distributed forming the fine sand into a gelled solid body 18.

2.4 Excavation of the shaft and results on injection

Probing of the inspection boreholes showed that there was nearly no water in the hole. Decision was made to continue shaft sinking. Before injection water flow had been 18 - 20 m^3/hr in shaft bottom. During excavation firmly consolidated sand was found and the residual water was lowered to 0.2 m^3/hr. The water flow had been reduced by upwards of 99 %.

During excavation the followings were observed: in the shaft bottom zones where cement grout diffused a certain thickness, flaky hard cement consolidated solid body was formed, the sand among flaky cement consolidated bodies had confirmed to a fairly tight specification under pressure. Most of the chamical grout diffused towards the outer part of the shaft forming a dark brown hard watertight diaphragm wall.

3. CONCLUSION

1/ This chemical grout has a low viscosity, high permeability, good injectability and can be used for consolidation of fine sand strata.
2/ Time of gelation can be controlled within the range of scores of seconds to some ten minutes according to the requirement of the project.
3/ The compressive strength of consolidated sand is high. This grout is suitable not only for water sealing but also for consolidation. It can be used for injection in sand strata during shaft sinking and also for consolidation of base in construction of bridge, dam and foundation.
4/The cost of the grout is comparatively low.
5/ Injection shows that the technology applied is reasonable.

LIST OF FIGURES

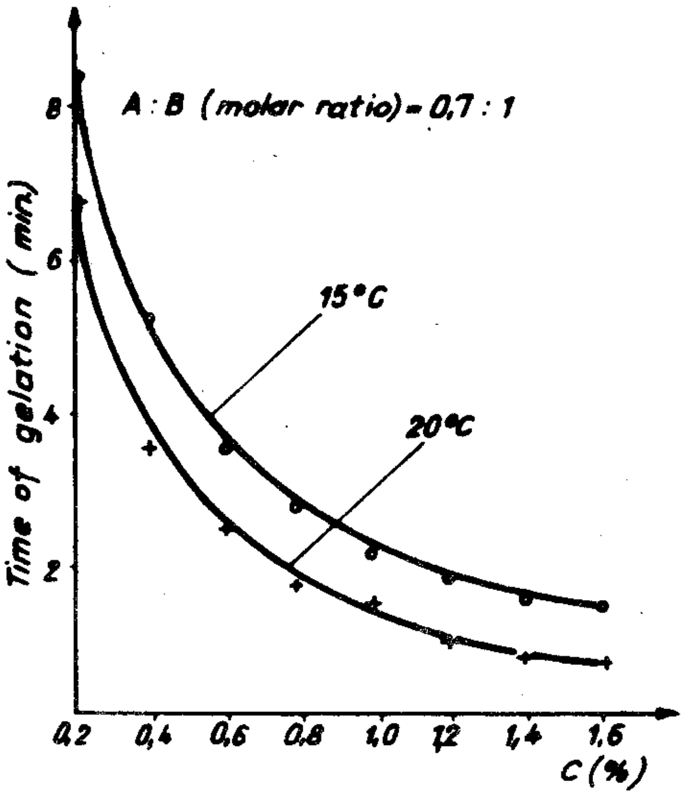

Fig. 1

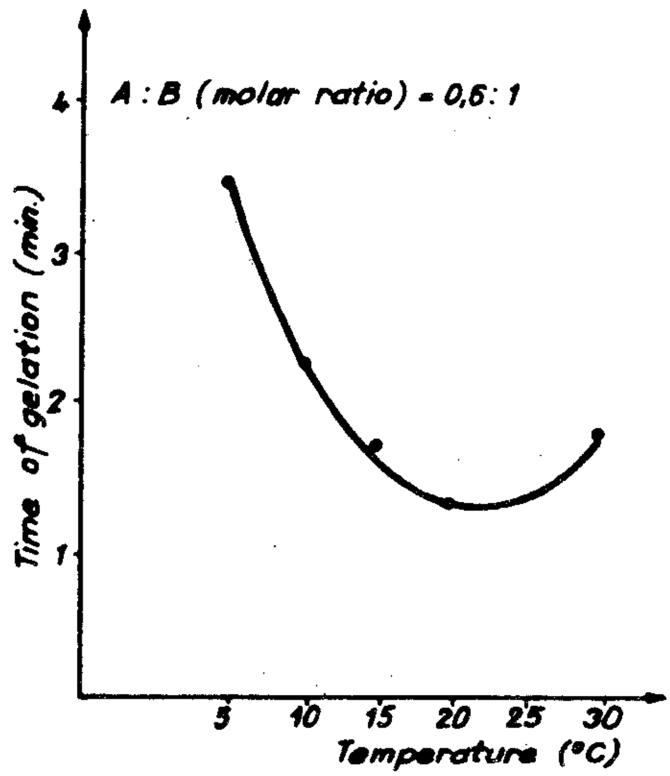

Fig. 2

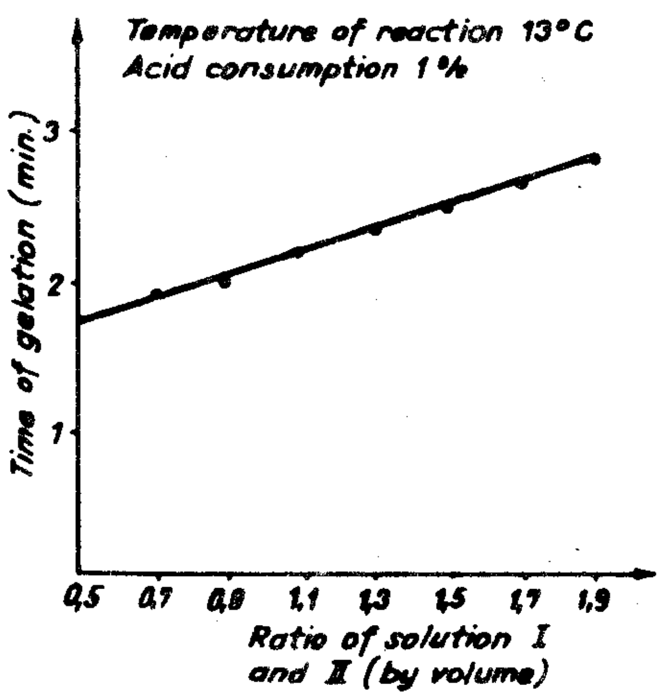

Fig. 3

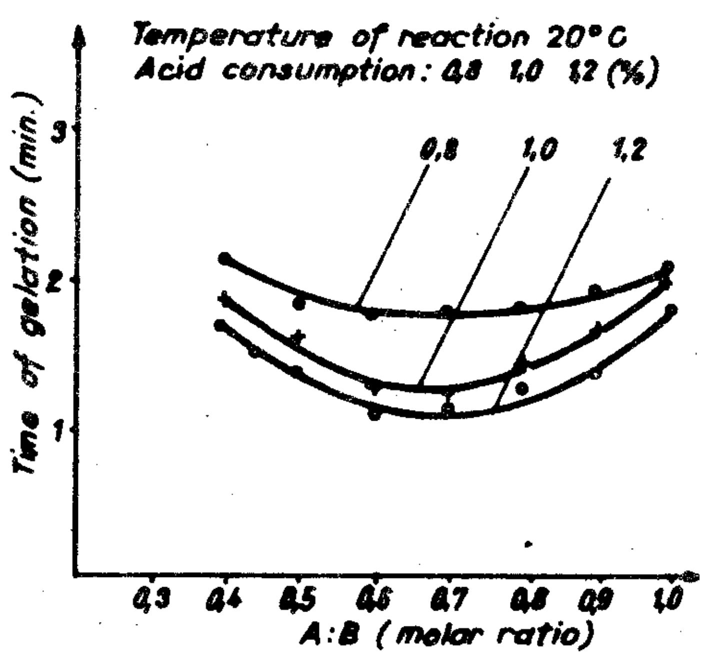

Fig. 4

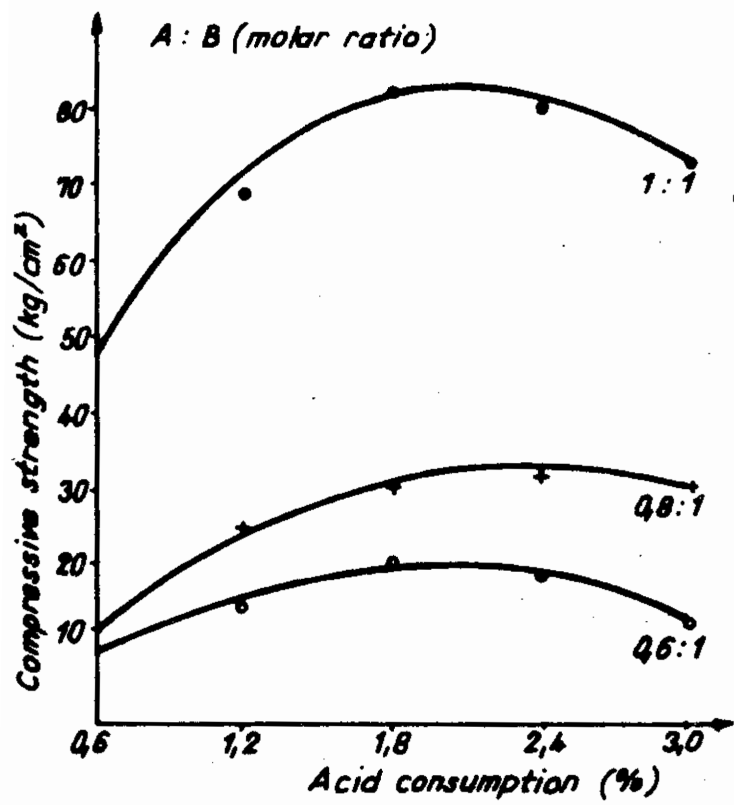

Fig. 5

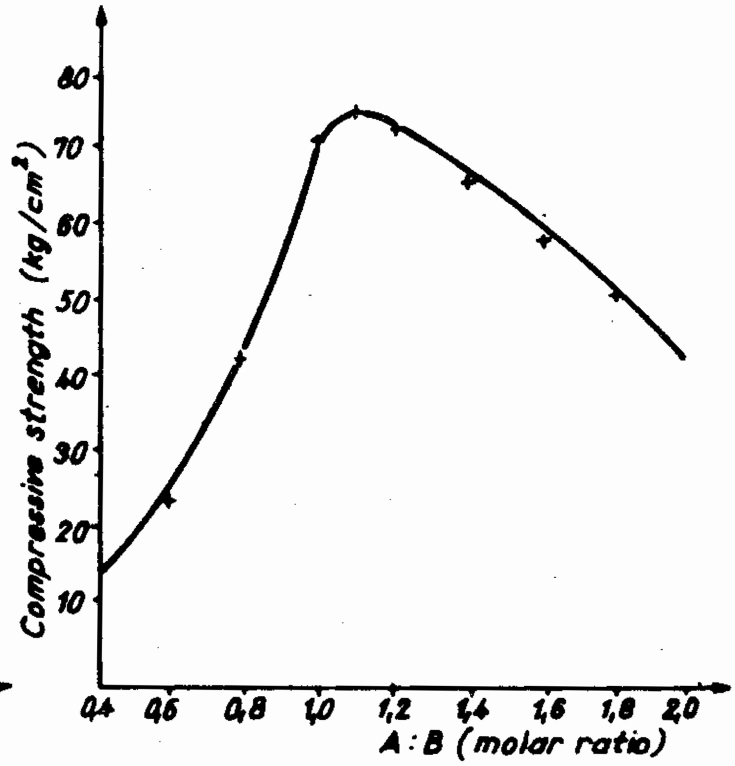

Fig. 6

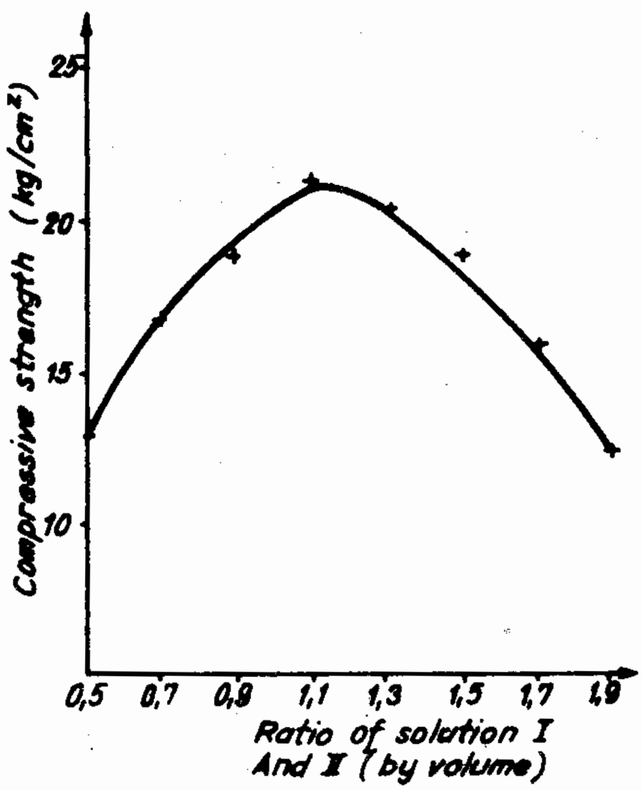

Fig. 7

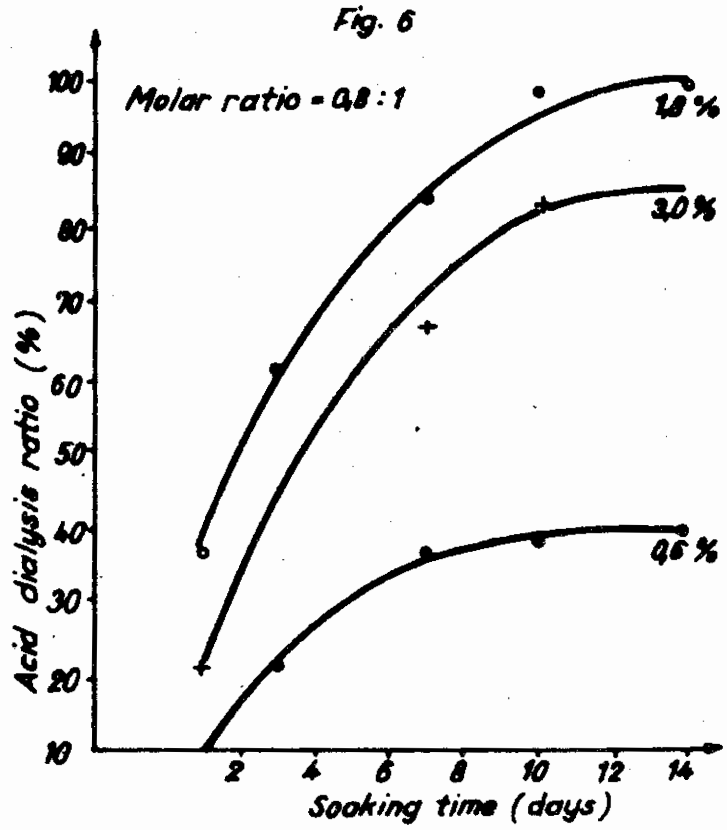

Fig. 8

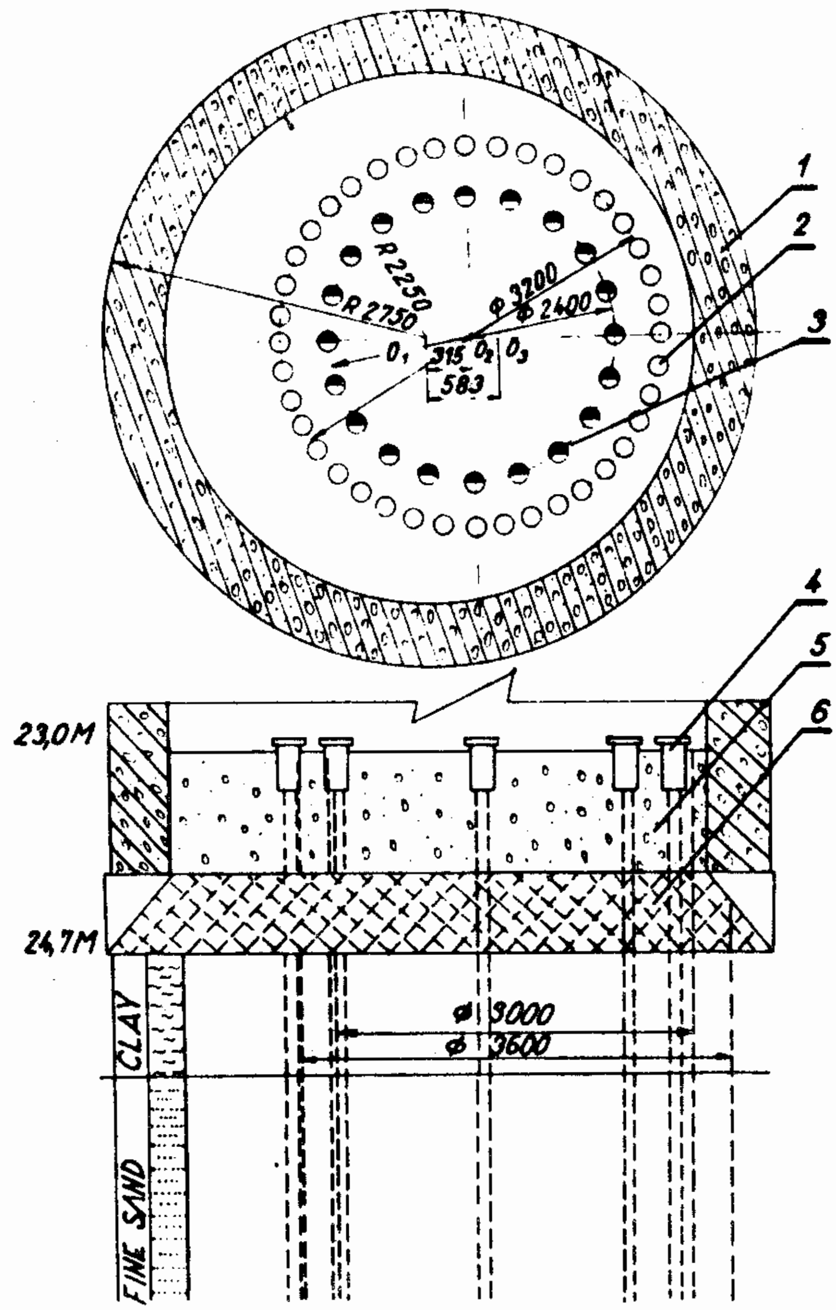
1
2
3
R 2250
R 2750
Φ 3200
Φ 2400
O1
315
O2
O3
583
4
5
6
23,0M
24,7M
CLAY
FINE SAND
Φ 3000
Φ 3600

Fig. 9

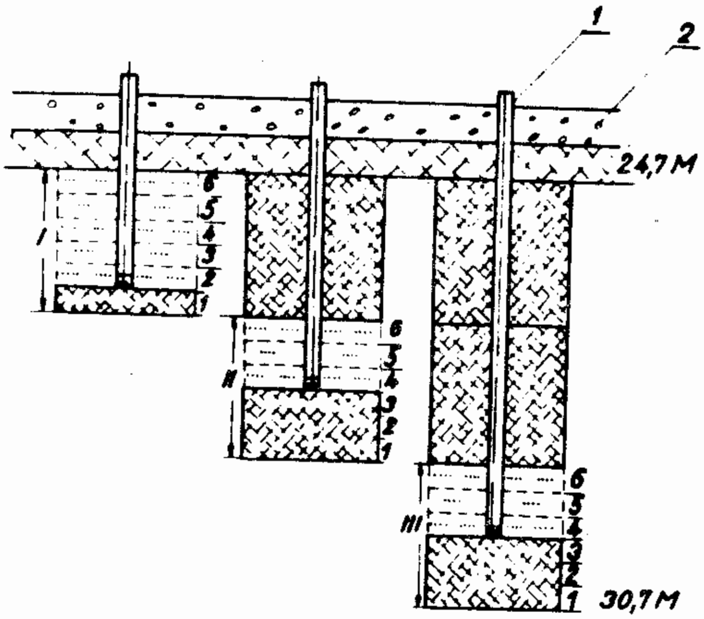

Fig. 10

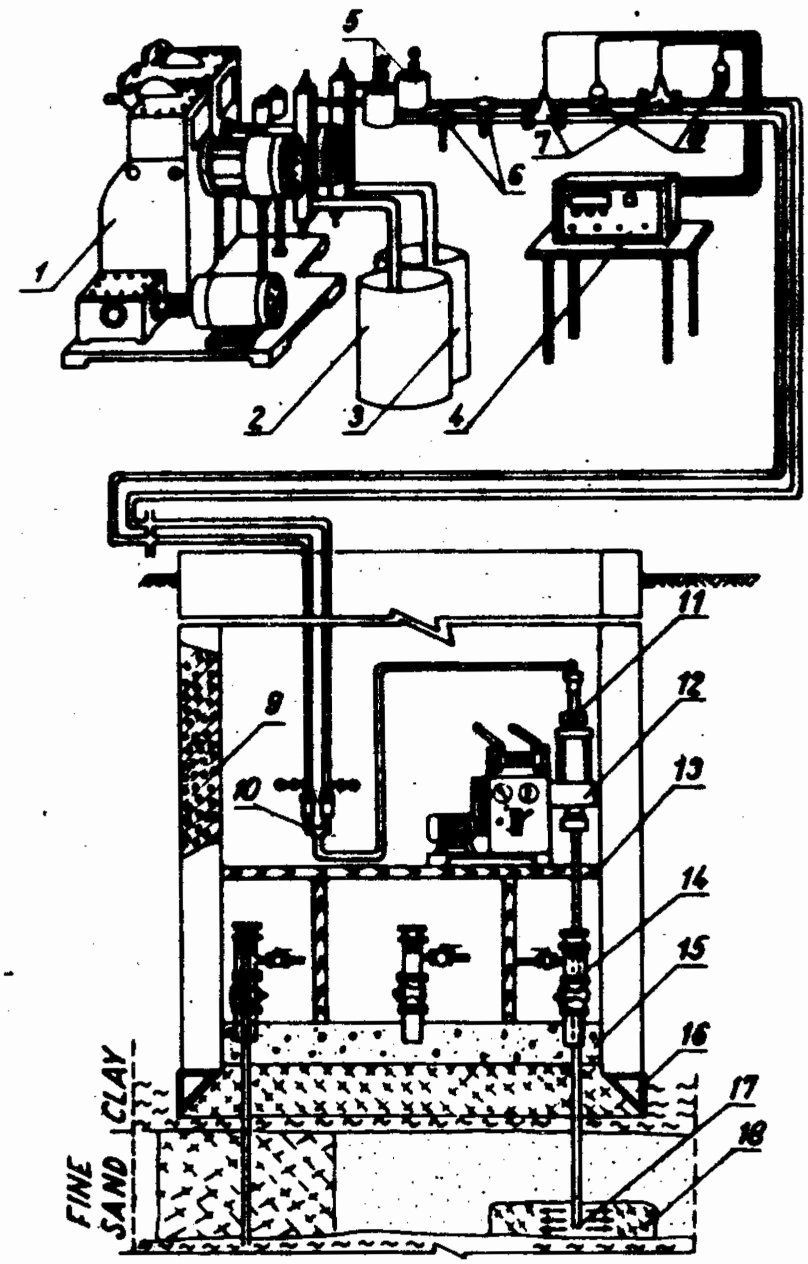

Fig. 11