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(54) **A PYROTECHNIC METHOD FOR THE STABILISATION OF LOW BEARING CAPACITY SUBSOIL**
PYROTECHNISCHES VERFAHREN ZUR STABILISIERUNG VON UNTERGRUND MIT GERINGER
TRAGFÄHIGKEIT
PROCEDE PYROTECHNIQUE POUR LA STABILISATION DE SOUS-SOL A FAIBLE CAPACITE DE
SUPPORT

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Description

[0001] The subject of the invention is a pyrotechnic method for the stabilisation of low bearing capacity subsoil, also called weak soil. This method is used in civil and harbour engineering, and during the construction of motorways, roads, airports, railway lines etc.

[0002] Pyrotechnic methods use the energy of shock waves resulting from the explosion of charges. The method for the consolidation of saturated non-cohesive soil, set out in Polish patent description no. 151405, consists of the use of charges with a length of at least a quarter of the thickness of the soil layer to be consolidated, and with a mass $g = k \times H^{1/2}$ kg/running metre, where H is the thickness of the consolidated soil layer and k is an empirical factor which depends on the particle size distribution and compaction of the soil, and is selected from the range of 0.3 to 1.0 kg/m². Charges are placed in non-tabulated shot holes, in at least three parallel layers. In each layer the charges are placed at the vertexes of a grid of equilateral triangles. The length of the sides of these triangles is a quarter of the radius of effective action of the shock wave. The layers are arranged such that the vertexes of the triangles of one layer are shifted in relation to the vertexes of the triangles of the next layer, by half the length of a triangle side. The distance between layers is such that the ends of the charges of one layer are on the plane which bisects lengthways the charges of the next layer. The shot holes, the diameters of which vary from 15 to 30 cm, are drilled with a bentonite suspension. The use of charges with a diameter of 5 to 6 cm is recommended.

[0003] Another method for the consolidation of cohesive soil lying under a layer of saturated non-cohesive soil, is set out in the Polish patent description no. 145208. This involves the use of explosive charges fired in three series. The first series of oblong charges are placed in the cohesive soil in the shot holes, which should reach down to load bearing soil. The charges are arranged at an equal distance of four times the radius of the effective impact of the explosion of the charges, which distance depends on the weight of the explosive in the charges. For the subsequent series of explosions the arrangement of the charges is different. A method according to the preamble of claim 1 can be found in NL-A-770 39 35.

[0004] For the technological process of construction works it is very important that soil consolidation immediately follows subsoil stabilization works. In that way, soil settlement during the construction works prevents later settlement resulting from service loads that could exceed permissible limits.

[0005] The invention proposes a pyrotechnic method of soil stabilisation characterised by shot holes with a diameter from 0.02 to 1.5 m and a depth of up to 50 m, drilled with a water flush or a mud or clay suspension, at a spacing of 3 to 25 m, this spacing distance being inversely proportional to the thickness of the layer of soil that is to be stabilised. The charges, the total length of

which cannot exceed the thickness of the layer to be consolidated, are composed of several small "sub-charges", spaced at distances from 1 to 10 m down the shot hole. The bottom end of each charge is blocked with a rod the diameter of which is greater than that of the shot hole. The sub-charges are fired successively from the top one to the bottom one, with a delay of between 0.05 to 10 milliseconds. The sequence of firing starts at one end of the area of soil to be consolidated. The charges are fired individually or in small groups at time intervals.

[0006] As a result of the firing of the charges, soil stabilisation progresses linearly across the area to be stabilised. After each explosion the vertical shot holes are filled with loose ground gravitationally, manually, or mechanically so as to make piles. During the firing of neighbouring charges these piles function as vertical drains that allow water to flow out. The impact of the subsequent firings consolidates the saturated soil in the piles.

[0007] For cohesive, non-loose ground, such as peaty ground, it is recommended that before the drilling of the shot holes, a layer of loose soil, or better, sand, is deposited on the area to be stabilised. The thickness of this layer should vary from 0.5 to 20 m. In particular geodesic conditions the thicker layer of 20 m is favourable. In, for instance, the case of stabilisation works made from an embankment like a silted up pier. In the case of harbour engineering, the thickness of silt often exceeds 20 m. After the explosions the non-cohesive sand or soil fills the shot holes which then function as vertical drains.

[0008] It is also recommended, that the sub-charges are vertically fastened with distance making wood, plastic or metal rods.

[0009] The invented method presented above produces compacted subsoil with a structure that enables rapid soil consolidation, the degree of consolidation being $S_k > 0.9$ which guarantees that the service settlement will be lower than the maximum acceptable, as determined by building standards.

[0010] The following two descriptions of subsoil stabilisation projects will help to fully explain this invention.

Example 1

[0011] During the construction of the approaches to a new river bridge, the stabilisation of subsoil, composed of peat and sediments, with a plasticity degree I_L between 0.60 and 0.80, was carried out. The thickness of the subsoil to be stabilised varied from 6 to 16 m, with the roof of the weak soil layer from 1 m below ground level and the floor up to 16 m below that. Before stabilisation the area was covered with a layer of poured sand 1 m thick, which facilitated the movement of machines and guaranteed spontaneous filling of shot holes. This limited the need for dozers or manual filling. The shot holes, with diameters varying from 0.05 to 0.25 m, right down to the floor of the layer to be stabilised, were drilled by a self-propelled drilling machine. Drillings were flushed with water, without a drilling fluid. The spacing of the shot holes,

drilled at the intersection points of a square grid, depended on the depth of the hole: where thickness of the soil layer to be stabilised was from 13 to 16 m - the square side R equalled 4 m. Where it was from 9 to 13 m - R=6 m. From 6 to 9 m - R=6 m. The diameter of the sub-charges varied from 2.5 to 10 cm, and the distance between them, determined by wooden distance rods, was less than 2 m. The total weight of dynamite or dynamonite in a charge did not exceed 4.0 kg. The firing was done in one series of explosions. The sub-charges were fired successively from the top one to the bottom one, with a delay of from 0.05 to 5 milliseconds. The bottom end of each charge was blocked with a wooden rod with a diameter greater than that of the shot hole, thus containing the explosion in the shot hole. The charges were fired one after another, beginning from one end of the stabilised subsoil area. Stabilisation of the subsoil layer was the result of superposition of separate stabilisations achieved at a distance of $0.75 \times R$ between the charges. Four and a half months after the stabilisation works, soil consolidation of degree $S_k = 0.92$ was obtained.

Example 2

[0012] During the construction of a motorway the stabilisation of subsoil composed of weak dusty clay, sediments, and weak, fine grained-sand with a degree of plasticity IL from 0.55 to 0.85 and a degree of compaction ID from 0.25 to 0.40 was carried out. The thickness of the subsoil layer to be stabilised varied from 5 to 6 m. The roof of the weak soil layer was from 1 m to 1.5 m below ground level and the floor of the weak soil layer about 5 to 6 m deeper. The diameter of the charges was from 1.5 cm to 5 cm, and their length equalled the thickness of the stabilised subsoil. The shot holes were drilled with steel boring rods. The total weight of dynamite, dynamonite or ammonite in a charge did not exceed 2.5 kg. Each charge was fired in such a way that the upper sub-charge had a fuse with a delay of 1 millisecond, the middle one had a fuse with a delay of 3 milliseconds, and the bottom one a fuse with a delay of 5 milliseconds. The charges were spaced $R=5$ m, on a grid of equilateral triangles. It was assumed that that the stabilised subsoil area equalled $0.6 R$ from the axis of the charge. The charges were fired one by one. Twenty-one days after the subsoil stabilisation was carried out the average settlement of the ground was 0.27 cm. Later measurements proved the effectiveness of the method - the subsoil settlement was lower than that allowed by building standards.

Claims

1. A pyrotechnic method for stabilisation of low bearing capacity subsoil that consists of determination of the parameters of the layer of soil to be stabilised, drilling non-tabulated, vertical shot-holes at the intersection

points of a square or equilateral triangle grid, selection, preparation and firing the oblong charges, **characterised by** the fact that the shot-holes with a diameter from 0.02 to 1.5 m and a depth of up to 50 m, are drilled with a water flush or a mud or clay suspension, at a spacing of 3 to 25 m inversely proportional to the thickness of the layer of soil that is to be stabilised and the charges, the total length of which cannot exceed the thickness of the layer to be consolidated are composed of several small "sub-charges", spaced at distances from 1 to 10 m down the shot hole, with the bottom end of each charge blocked with a rod the diameter of which is greater than that of the shot hole and sub-charges are fired successively from the top one to the bottom one, with a delay of between 0.05 to 10 milliseconds in one series starting at one end of the area of soil to be consolidated, successively individually or in small groups at time intervals.

2. Method according to claim 1, **characterised by** the fact that before the drilling of the shot holes a layer of loose soil, the thickness of which should vary from 0.5 to 20 m and which fills the shot holes after the explosions, is deposited on the area to be stabilised.
3. Method according to claim 1, **characterised by** the fact that the "sub-charges" are vertically fastened in the shot holes with wood, plastic or metal distance making rods.

Patentansprüche

1. Ein pyrotechnisches Verfahren zur Stabilisierung von Untergrund mit geringer Tragfähigkeit, das auf der Bestimmung der Bodenparameter der zu stabilisierenden Schicht, der Anbringung vertikaler, unberührter Sprenglöcher an den Schnittstellen eines quadratischen oder gleichseitig dreieckigen Gitternetzes der Auswahl, Vorbereitung und Zündung länglicher Sprengladungen, die **dadurch gekennzeichnet ist, dass** die Sprenglöcher mit einem Durchmesser von 0,02 bis 1,5 m und einer Tiefe von bis zu 50 m unter Einsatz einer Wasserbohrspülung oder einer Lehm- oder Tonsuspension in Abständen von 3 bis 25 m, die umgekehrt proportional zur Mächtigkeit des zu stabilisierenden Untergrundes zu wählen sind, eingebohrt werden und die Sprengsätze, deren Gesamtlänge die Mächtigkeit des zu stabilisierenden Untergrundes nicht überschreiten darf, aus mehreren kleinen Untersprengsätzen zusammengesetzt sind, die in Abständen von 1 bis 10 m in den Sprenglöchern versenkt werden, und deren untere Enden mit Stäben blockiert sind, deren Durchmesser größer ist als der Durchmesser des Sprenglochs, wobei die Zündung der Sprengsätze sukzessiv von oben nach unten erfolgt mit einer Verzögerung von

0,05 bis 10 msec in einer Serie, beginnend an einem Ende des zu stabilisierenden Geländes, danach der Reihe nach einzeln oder in kleinen Gruppen in Zeitintervallen vorgehend.

des barres de distance en bois, plastique ou métal.

2. Das Verfahren nach Patentanspruch 1 ist **dadurch gekennzeichnet, dass** vor der Anbringung der Sprenglöcher, eine Schicht mit losem Grund, dessen Mächtigkeit von 0,5 bis 20 m variieren kann, und der nach der Sprengung die Sprenglöcher ausfüllt, auf dem zu stabilisierenden Gelände aufgeschüttet wird. 5 10
3. Das Verfahren nach Patentanspruch 1 ist **dadurch gekennzeichnet, dass** die "Untersprengsätze" in den Sprenglöchern vertikal mit Hilfe von Holz-, Kunststoff-, oder Metallstäben zur Gewährleistung der entsprechenden Abstände befestigt werden. 15

Revendications 20

1. Le renforcement des bases de construction d'une capacité basse de charge à l'aide de la méthode pyrotechnique consistant à préciser les paramètres du sol de la couche renforcée, à faire des trous de mine sans tubage, verticaux, disposés dans le plan selon les points d'intersection de la grille des mailles carrées ou en forme d'un triangle équilatéral, ainsi qu'à choisir, préparer et tirer les charges d'explosif allongées. Cette méthode se **caractérise par le fait que** les trous de mine des diamètres de 0,02 à 1,5 m et de la profondeur jusqu'à 50 m sont percés avec une boue à base d'eau, une boue d'argile ou d'aluminium, dans l'écartement de 3 à 25 m choisi de manière inversement proportionnelle à la puissance de la couche, et la charge d'une longueur totale pas plus grande que la puissance de la couche renforcée est faite à l'aide de petites charges composantes situées à distance de 1 à 10 m et avec le bout inférieur de la charge bloqué par une barre d'un diamètre plus grand que le trou de mine; chaque charge est, cependant, tirée avec un délai des charges composantes de 0,05 à 10 msec, de la charge supérieure jusqu'à la charge inférieure, en commençant par une série d'un bout du plan de la base renforcée, et ensuite individuellement ou en groupes par quelques charges et à intervalles de temps. 25 30 35 40 45
2. La méthode selon la restriction 1 **se caractérisant par le fait qu'**avant de percer les trous de mine, on fait un remblai du sol incohérent de l'épaisseur de la couche de 0,5 à 20 m sur la base renforcée, dans lequel, après avoir tiré les charges, on remplit les trous créés par l'explosion. 50
3. La méthode selon la restriction 1 **se caractérisant par le fait que** les charges composantes sont situées verticalement dans les trous de mine à l'aide 55

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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