July 12, 1966 H. LORENZ 3,260,054

PROCESS FOR PRODUCING EXCAVATIONS IN WATER-BEARING GROUND

Filed April 5, 1963 3 Sheets-Sheet 1

FIG. 1a

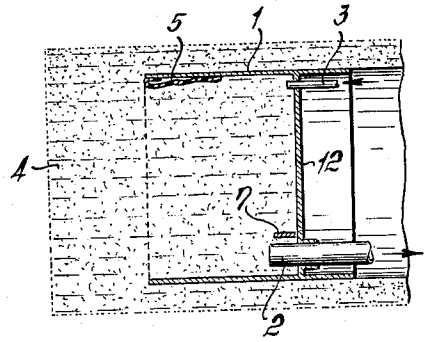


FIG. 1b

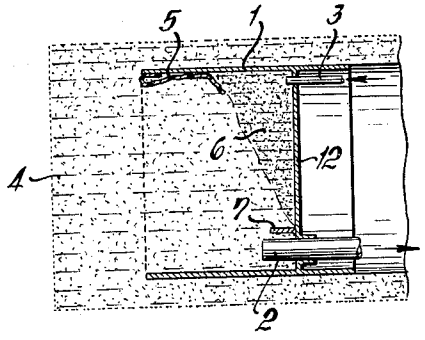


FIG. 1c

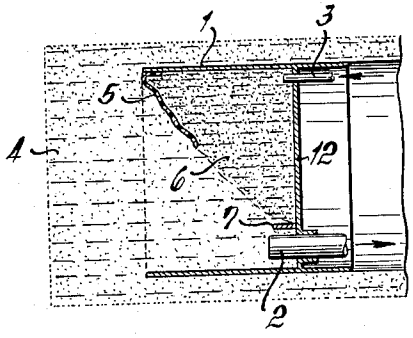


FIG. 1d

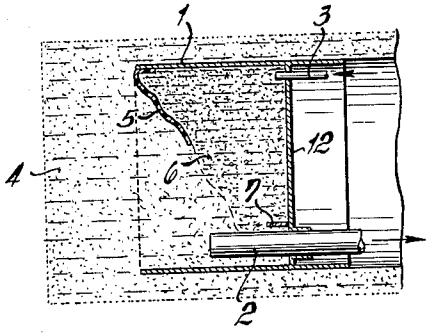
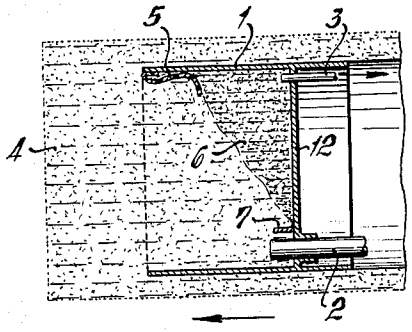


FIG. 1e



INVENTOR
Hans LORENZ

July 12, 1966 H. LORENZ 3,260,054

PROCESS FOR PRODUCING EXCAVATIONS IN WATER-BEARING GROUND

Filed April 5, 1963 3 Sheets-Sheet 2

FIG. 2

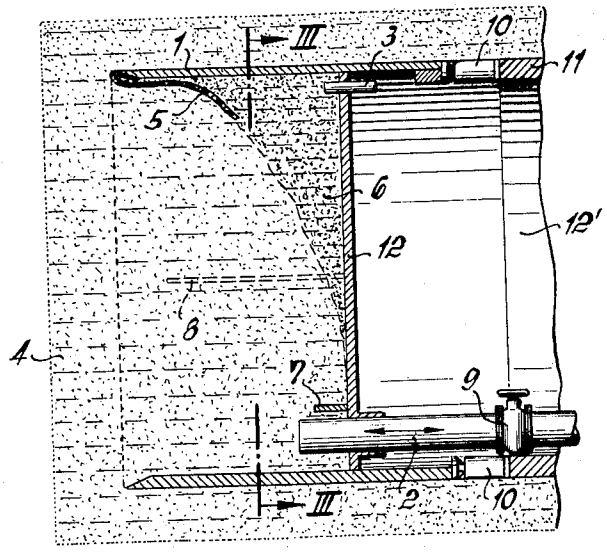
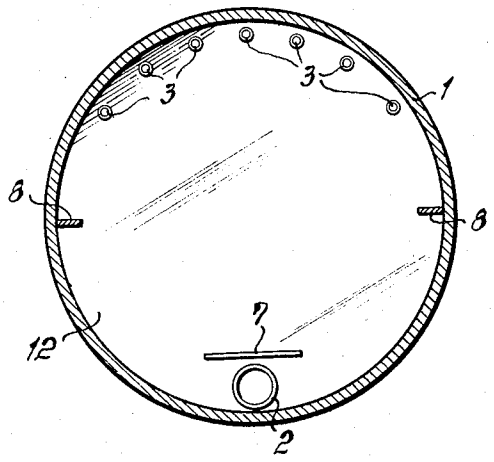


FIG. 3



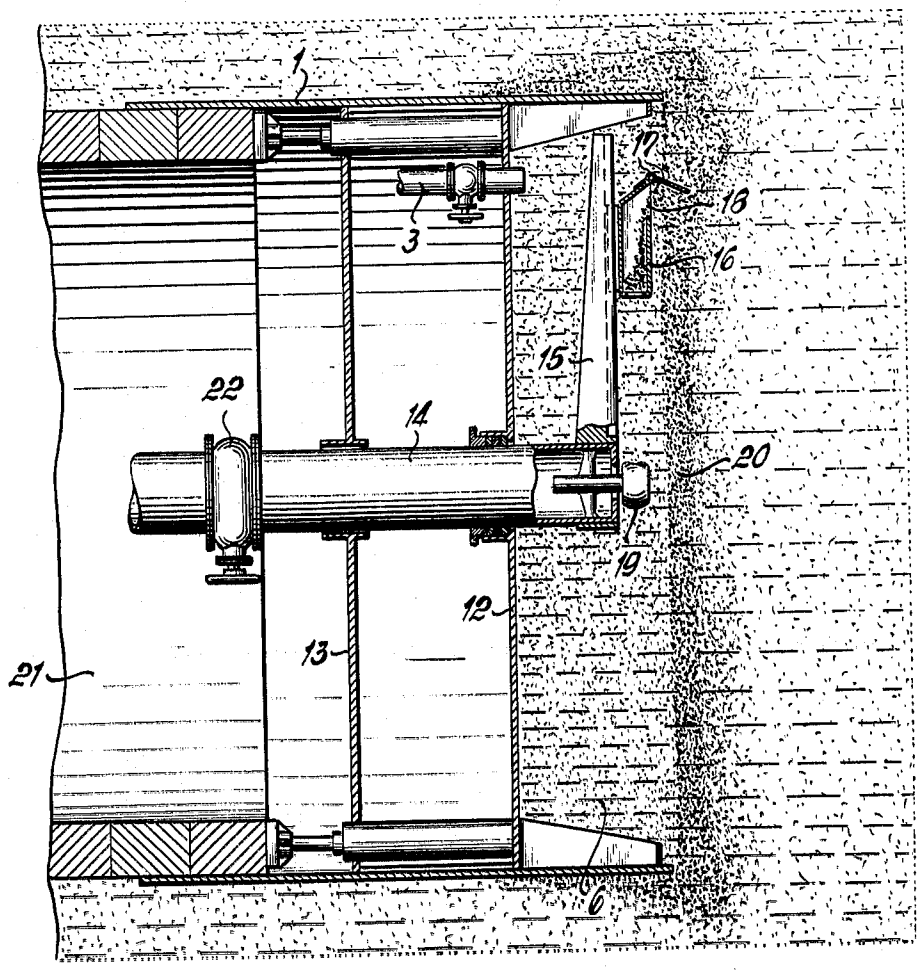
INVENTOR
Hans LORENZ

July 12, 1966 H. LORENZ 3,260,054

PROCESS FOR PRODUCING EXCAVATIONS IN WATER-BEARING GROUND

Filed April 5, 1963 3 Sheets-Sheet 3

FIG. 4



INVENTOR
Hans LORENZ

United States Patent Office 3,260,054 Patented July 12, 1966

3,260,054

PROCESS FOR PRODUCING EXCAVATIONS IN WATER-BEARING GROUND

Hans Lorenz, Berlin-Charlottenburg, Germany, assignor of one-third each to Entreprises Leon Chagnaud & Fils, Paris, France, and Entreprises Joya-Chabert, Villeurbanne, Rhone, France

Filed Apr. 5, 1963, Ser. No. 270,958
Claims priority, application Germany, Apr. 12, 1962, L 41,737; July 13, 1962, L 42,452
8 Claims. (Cl. 61—42)

This invention relates to processes for producing excavations in water-bearing ground by means, for example, of a caisson.

It is well-known, in the construction of tunnels and galleries to produce excavations in non-stable rock or ground by means of a caisson which contains in its front portion a work chamber in which the ground is loosened either manually or mechanically. When a sufficiently large hollow space has been created in the work chamber, the caisson is driven forward a corresponding extent. The completion of the resulting excavation takes place at the rear end of the caisson as the operation progresses. In water-bearing ground, the caisson is mostly driven forward by the use of compressed air which is introduced into the work chamber and which expels the water from said chamber and from the in-situ ground at the face of the excavation. However, the use of compressed air makes the operation substantially more expensive and slower, since the work chamber is accessible only by way of air-locks which, together with the material locks which are also necessary, requires a special development of the caisson and slows down the operation. Depending on the operating depth, very long locking or sluicing times may be required for conveying persons back and forth. In addition, first, the method of working with compressed air is permissible only to certain operating depths at which the operating pressure to be used will not be injurious to the health of the persons working in the chamber. Secondly, this method of working requires a substantial covering of the upper edge of the caisson with ground in order to prevent the compressed air from being blown out.

In some cases, the caisson may also be driven forward in water-bearing ground by the use of a subsoil drainage. However, this method of construction is limited to certain maximum working depths because of the delivery capacity of the pumps and may involve substantial expenditures.

It is an object of the present invention to provide a process which makes it possible to carry out, simply and dependably, excavations for tunnels, galleries or similar structures in water-bearing ground, even at great working depths, without the use of compressed air or subsoil drainage.

To solve this problem, the invention starts with the premise that it is known in soil mechanics to use thixotropic liquids for stabilizing and sealing purposes in the ground because they offer sufficient resistance to the earth and water pressure by their hydrostatic pressure and their film-forming properties. Thixotropic liquids are used both in the lowering of open and closed caissons, and in the so-called method of slitting construction where it is important to stabilize a prismatic cavity in the ground permanently or temporarily until the cavity is filled, for example, by a supporting wall. As shown for example in U.S. Pat. 2,678,540 a thixotropic liquid is one which contains certain colloidal suspensions which enables it to pass suddenly from the liquid aggregate condition into the solid aggregate condition. Such liquids do not penetrate into porous structure, such as coarse grained soil, even under high external pressure. There is formed on the

surface of contact of the liquid with the soil, a water-impermeable film which prevents further penetration of material similarly to a rubber membrane. Such a liquid may be produced, for example, by a suspension of pure bentonite in water. Experiments have shown that the thixotropic action of such a suspension collapses at a concentration of about 100 grams of bentonite per litre of water. The concentration of bentonite which will be employed depends on the type of soil and the quality of the bentonite.

The present invention combines the use of thixotropic liquids with the known caisson method of construction in a novel and advantageous manner and solves the above-described problem in that a cushion of thixotropic liquid is constantly maintained in the front end of the caisson between the facing of the excavation and a transverse wall of the caisson or shield and in that the ground at the facing or front of the excavation, while continuously secured by the thixotropic liquid and under utilization of the water pressure prevailing in front of the cushion, is loosened or detached either by self-circulation alone or by tools working ahead of the thixotropic liquid and is conveyed, via passages in the thixotropic cushion and in the transverse wall, into the pressureless caisson space at the back of the transverse wall.

In a process having these features, the soil and water pressure at the facing of the excavation is continually absorbed by the thixotropic liquid and by the transverse wall of the caisson bounding the thixotropic cushion at the back, without it being necessary to make said caisson especially strong nor have it especially tightly connected to the caisson case or jacket. Owing to the sealing effect of the thixotropic liquid, any inflow of water from the facing of the excavation is dependably avoided. In addition, the caisson case is relieved from radially acting crushing or compressive stresses in the region of the thixotropic liquid, since said stresses are aborbed by the thixotropic liquid. More particularly when comparing a work chamber which is not filled by a thixotropic cushion with one according to the present invention which is, it is seen that in the latter the earth pressures acting radially from without are absorbed by the incompressible fluid. This is especially useful and advantageous because axial knife-edge forces come into existence in addition to said earth pressures when driving the caisson forward, said forces causing an inwardly directed deformation of the casing of the shield. Without the resistance of the thixotropic fluid, said forces could only be kept within permissible limits by very strong stiffening and reinforcement, that is to say by additional means, namely additional pressure compensating means. Thereby the thixotropic fluid which is used in the present invention serves, so to speak, as an additional reinforcement for the casing of the shield. Thereby a relief of the driving shield is obtained by the ability of the thixotropic fluid to absorb pressures, so that a simpler construction of the shield is possible. If the in-situ soil contains a high amount of water and is friable or non-cohesive, any expenditure for detaching and conveying the soil into the pressureless caisson space can be dispensed with, since, according to the invention, the pressure ahead of the thixotropic cushion is utilized for the purpose of circulating or flushing the soil into one or more pipes which are preferably arranged at the lowest zone in the caisson, and for conveying the soil through said pipes into the pressureless zone in the caisson at the back of the transverse wall. One or several of such conveying pipes or conveyors may preferably be positioned to be displaceable longitudinally in the transverse wall of the caisson, in order to make it possible to influence the boundary surface between soil and thixotropic liquid at will. The sealing of such a longitudinally displaceable

positioning offers no difficulties, since the thixotropic liquid will dependably take care of such sealing.

However, if necessary, the loosening of the ground may be assisted by tools working ahead of the thixotropic liquid, for example, mechanical tools, such as worms with cutting heads. Such tools may rotate in a conveying pipe and are arranged in such a manner that, for example, the cutting head conveys only earth and water. In such a case, just as in the case of using conveying pipes used merely for self-circulation, the thixotropic liquid can be utilized for the purpose of supporting the conveying pipes within the thixotropic liquid in any position desired. There thus exists the possibility of positioning such conveying pipes articulately, possibly even also longitudinally displaceably, at the transverse wall of the caisson, while connecting them articulately to the rearwardly following pipe, for example, in such a manner that the front opening of a conveying pipe or a cutting head mounted thereon can be moved to form a cup-shaped excavation face. Owing to its high density, the thixotropic liquid will hold such a movable conveying pipe in any position so that special supports for such pipes are unnecessary. Further, it is not necessary to make the joints especially strong or tight, since no load is placed on them by the overhanging conveying pipe and they are sealed off by the thixotropic liquid.

The pipes may be provided, in the pressureless caisson space at the back of the transverse wall, with slides or slide valves or similar closures for shutting and opening them.

For forming and maintaining the cushion, the thixotropic liquid is pressed in through one or more pipes which are perferably arranged at or on the upper edge of the transverse wall of the caisson. When the loosening and conveying of the soil through the pipe or pipes has created sufficient space for pressing the caisson forward, said pressing forward is effected with withdrawal of the excess thixotropic liquid to a specific minimum content of the cushion. In order to regulate the feed and removal of the thixotropic liquid, the pipe may be provided with appropriate valves, slides or the like.

It has been found to be particularly expedient to loosen the soil in radial strips by tools extending in radial directions over the excavation face with simultaneous stabilization by the thixotropic liquid pressing on the cutting surfaces and, depending on whether the tools operate entirely ahead of the cushion of thixotropic liquid or at the boundary between same and in-situ soil, to feed the soil, either mixed with water or as rock pile or aggregate enveloped by thixotropic liquid, to one or more pipes serving as passages through the thixotropic liquid and through the transverse wall.

A particularly expedient embodiment of a caisson for carrying out the process in this manner is obtained by arranging, in front of the front transverse wall of the caisson, at least one radial guide arm, preferably rotatable in plane prependicular to the longitudinal axis of the caisson, for a scraping or cutting device radially reciprocable on said arm and developed approximately in the manner of a pan scraper or scoop grader and having a lateral inlet opening facing the excavation face.

The invention will next be explained in conjunction with the accompanying drawing in which:

FIGS. 1*a*, 1*b*, 1*c*, 1*d*, and 1*e* show diagrammatic longitudinal sections at an excavation face for different, successive stages of a process of the invention;

FIG. 2 shows a longitudinal section through the caisson of a first embodiment, enlarged in relation to FIGS. 1*a*–1*e*;

FIG. 3 shows a cross section taken along line III—III of FIG. 2 without showing the ground and the thixotropic liquid, and

FIG. 4 shows a longitudinal section through the caisson of a modified embodiment.

FIG. 1*a* shows the position of the caisson at the beginning of the driving operation. The soil **4** fills fully the caisson space ahead of the transverse wall **12** formed by a breast shield known per se. As is apparent from FIGS. 2 and 3, a pipe **2** is passed through the transverse wall **12** at approximately its lowest point. Pipe **2** serves to remove soil loosened in the caisson **1**. The pipe **2** is preferably longitudinally movable, within certain limits, in said transverse wall **12**; so that it can be displaced with its front end, for example, from the position shown in FIG. 1*a* to the position shown in FIG. 1*d*. Instead of using one pipe **2**, several such conveying pipes may be employed.

Arranged at the upper edge of the transverse wall **12** is a pipe **3** which serves to pass thixotropic liquid into the caisson space ahead of the transverse wall **12**. In the embodiment shown in the drawing, the pipe **3** also serves for the return of thixotropic liquid from said space into the pressureless caisson space or chamber **12'** when the caisson **1** is pressed forward. Alternatively, a special pipe may be arranged for returning the thixotropic liquid. Also, as shown in FIG. 3, a plurality of pipes **3** for the movement of said liquid in either direction may be arranged at the upper edge of the transverse wall **12** or at other parts of the transverse wall.

All pipes **2** and **3** are provided with slides or slide valves (not shown) for shutting-off or opening the pipes.

A method of working with the above-described caisson is the following:

When the caisson **1** is in the position shown in FIG. 1*a*, the operation is started in that thixotropic liquid is forced through the pipe **3** into the caisson space in front of the transverse wall **12**. Said liquid gradually fills the space **6**, in the manner shown in FIGS. 1*b*, 1*c*, and 1*d* and forms a cushion whereby the soil, which is displaced by the thixotropic liquid and which, due to its being water-bearing, either flows spontaneously ("is self-flowing") or is loosened by means of special tools rotating in the pipe **2** or in one or more other pipes (not shown) or which, by the pressure of the forced-in thixotropic liquid, is forced out through the pipes **2** into the pressureless caisson space **12'** (FIG. 2) owing to the excess pressure prevailing ahead of the thixotropic liquid. From said space **12'**, it may be pumped out or conveyed further by workmen working under normal pressure conditions, i.e., without any excess pressure, or mechanically loaded onto other conveying devices and removed. While the thixotropic liquid is being forced in, it is prevented from penetrating into the pipe **2**, which opens in front of the transverse wall **12**, by a blocking plate **7** or the like fixed on the transverse wall **12** above the opening of the pipe **2**.

In the condition shown in FIG. 1*c*, the space **6** filled with thixotropic liquid is as large as it can get by the earth-static conditions (slope line). In this state, a special effect is obtained by a protective strip **5**, which is made of plastic or of another elastic or possibly even rigid material and which serves the purpose of preventing the thixotropic liquid from escaping from the space **6** of the caisson **1** at the upper (cutting) edge of the caisson. In the state shown in FIG. 1*a*, said protective strip **5** closely engages the inner surface of the caisson owing to the pressing-in of the latter and is subsequently pressed against the face of the excavation by the thixotropic liquid under the constructional conditions shown in FIGS. 1*b*, 1*c*, etc. In the following state, it may be advisable to push the pipe **2** somewhat farther into the front caisson space, in order somewhat to increase the space **6** filled with the thixotropic liquid at the bottom. This is apparent from FIG. 1*d* which illustrates the final stage of the excavating phase. When this phase is reached, the withdrawal of soil from the pipe **2** is stopped by means of a slide valve. The slide valve may also be operated in the earlier states of construction in order to prevent that the amount of soil removed is greater than the amount of thixotropic liquid fed through the pipe **3**, for the thixotropic liquid must always act with a small excess pressure over the hydrostatic pressure.

FIG. 1*e* shows how the caisson is then pressed forward whereby the space **6** filled with thixotropic liquid or the cushion of thixotropic liquid occupying said space is reduced, while the excess thixotropic liquid is withdrawn inwardly from the cushion through the pipe **3** and possibly through additional pipes. However, the cushion always maintains the minimum size shown in FIG. 1*e* and the excavation face is always covered with thixotropic liquid, so that the former is always stabilized by the latter. After the installation of stiffening rings at the rear end of the caisson or the development of the excavation has been advanced by the insertion of the caisson and the presses (not shown) have been returned to starting position, the operations of FIGS. 1*b* to 1*d* are repeated.

FIGS. 2 and 3 are more detailed sectional views of the caisson and show, in addition to the above-explained development, welded-on plates **8** approximately in the center of the caisson **1**, the purpose of said plates consisting of avoiding that the thixotropic liquid advances at the inner surface of the caisson casing transversely to the longitudinal axis thereof instead of exerting a surface pressure on the ground at the excavation face and of conveying said soil into the discharge pipe. FIG. 2 also shows a slide valve **9** in the pipe **2**, as well as presses **10** which cause the advance of the caisson. FIG. 2 also shows the last installed stiffening ring **11**.

In the caisson shown in FIG. 4, a second transverse wall **13** is arranged at some distance at the back of transverse wall **12**, and a central pipe **14** is longitudinally displaceably positioned in the two walls, said pipe **14** being provided at its front end facing the excavation face **20** with a radial guide arm **15** capable of rotating within the cushion **6** of thixotropic liquid. The guide arm **15** may, for this purpose, be arranged rotatably on the pipe **14** or else, the pipe **14** may be rotatable together with the radial guide arm **15**.

Reciprocally arranged on the guide arm **15** in the longitudinal direction thereof is a bucket-shaped or scoop-shaped scraping device **16** which is provided with one or more scraping or cutting flaps **17**. The latter are operative only when the scraping bucket **16** moves from the circumference of the caisson **1** toward the pipe **14** and are, for this purpose, articulately fixed at the outer edge of a lateral opening **18** of the bucket **16** facing the excavation face in such a manner that they can be folded-out toward the excavation face **20** and that they are kept in this position by the resistance of the soil when the bucket moves from the outside to the inside, i.e., toward the pipe **14**.

Upon the reverse motion of the bucket **16** from the pipe **14** toward the caisson casing, on the other hand, the scraping or cutting flap **17** folds down and engages the side wall of the bucket **16**. The bucket **16** is closed at its outer end facing the caisson casing. It comprises a discharge opening toward the pipe **14**; said opening may be open continually, but may also be closable.

The mode of operation of the scraping bucket **16** is such that, with each work stroke, i.e., with each motion toward the guide arm **15** from the outside to the inside toward the pipe **14** or the caisson casing, it cuts a radial strip out of the in-situ ground at the excavation face **20**, whereby the soil not gripped by the bucket is stabilized by thixotropic liquid from the cushion **6** immediately upon being exposed. The soil scraped off by the cutting or scraping flap **17** is discharged through the bottom opening of the bucket **16** toward the pipe **14**. After each work stroke, the cutting or scraping flap **17** engages the scraping bucket **16** which is guided back to the caisson casing in order to be able to carry out a new work stroke. During, or else after, this return motion, the arm **15** can be rotated further through an angular extent required for a new work stroke so that the scraping bucket **16** is gradually able to work the entire surface of the excavation face.

During this operation, the longitudinally displaceable central pipe **14** may serve, within an unchanged driving (drive-on) position of the caisson **1**, for advancing the excavation by a certain extent in that it is, for example, advanced within said extent after all radial cuts have been carried out. It is also possible, by corresponding axial displacement of the pipe **14**, to regulate the scraping or cutting depth of the scraping or cutting flap **17** by adjusting the axial distance of the rotating arm **15** from the transverse wall **12** so that the scraping or cutting flap **17** grips, during the work stroke, only soil or, in the boundary region, both soil and thixotropic liquid, in which case the proportion of the two materials collected can be selected by appropriate axial adjustment of the pipe **14**.

If the adjustment is such that the cutting flap **17** operates only in the ground, the loosened soil can be conveyed, possibly with the water it contains, to the pipe **14** with the discharge opening of the bucket closed and without contact with the thixotropic liquid and can then be emptied directly into said pipe so that only soil, possibly mixed with water, is conveyed. But if the cutting flap **17** operates in the boundary region of the thixotropic liquid and the ground, the latter will be fed to the pipe **14** as rock pile or aggregate enveloped by thixotropic liquid.

This coarse mixture is fed to a crushing and mixing device **19** which is arranged in the center of the caisson and which serves to loosen the mixture and to produce a readily conveyable, intimate mixture of the soil material and the thixotropic liquid. Said mixture is delivered from the mixing device **19** to the pipe **14** in which is arranged a mechanical, hydraulic or pneumatic conveying device (not shown) through which the mixture is conveyed into the caisson space **21** at the back of the transverse walls **12, 13**. The amount to be removed can be set by means of the valve **22**.

In the caisson space **21**, the mixture may be fed to a separating device (such as a centrifuge), which separates the soil from the thixotropic liquid. The thixotropic liquid purified in this manner can be fed again through the pipe **3** to the cushion **6** in front of the transverse wall **12**.

Instead of using the central pipe **14** for conveying or removing the mixture consisting of soil material and thixotropic liquid, it is also possible to arrange one or more conveying pipes at another position in the caisson. Moreover, instead of one rotating arm, there may be two or more rotating arms each having a scraping bucket.

The reciprocable arrangement of the scraping or cutting device **16** on the radial guide arm **15**, in conjunction with the longitudinally displaceable arrangement of the pipe **14**, offers the possibility of developing the excavation face, seen in longitudinal section, in any manner desired in that, for example, during the radial motion of the scraping bucket **16** forming the scraping or cutting device, the pipe **14** may be simultaneously moved axially forward toward the excavation face. Depending on the ratio of the velocities of the axial feed and of the radial motion, the tunnel face receives, in longitudinal section, the form of an arc of a circle, of an elliptical arc or of any other curve. If the radial motion of the scraping bucket **16** is stopped and only the pipe **14** is moved forwardly in axial direction, the tunnel face, in longitudinal section, may also be given the form of a polygon.

In the process according to the present invention, the conditions of the ground, of water and pressure can be determined by advancing mechanically acting sounding apparatus (soil penetrometers) or by using geophysical methods or by density (hydrostatic) measurements by means of radio-active isotopes. On the basis of the results of the measurements, the operations and, more particularly, the pressure and the amount of the thixotropic liquid forming the cushion may be adapted to the conditions prevailing in each particular instance.

What is claimed is:

1. A process for producing excavations in water-bearing ground by means of a caisson having a determinable driving direction including a transverse wall defining a rearwardly disposed pressureless chamber, said process comprising forming and maintaining a cushion of thixotropic liquid at the front end of the caisson between the excavation face and the transverse wall of the caisson, loosening the ground at the excavation face which is stabilized by the thixotropic liquid and conveying the thusly loosened ground into the pressureless chamber via a passage in the cushion and transverse wall.

2. A process according to claim 1 comprising increasing the cushion of thixotropic liquid while maintaining the caisson stationary and withdrawing the thusly displaced ground through the cushion and the transverse wall of the caisson, and subsequently driving the caisson forward while returning the excess thixotropic liquid to the pressureless space.

3. A process according to claim 1 wherein the cushion of thixotropic liquid is kept continually under a small excess pressure relative to the hydrostatic pressure.

4. A process according to claim 1 wherein the escape of thixotropic liquid from the cushion adjacent the upper region of the caisson is prevented by a strip advanced with the caisson upon each advance of the latter and which are applied against the excavation face during loosening and removal of ground.

5. A process according to claim 1 wherein the soil is loosened in radial strips at the face of the excavation, the strips being instantaneously stabilized by the thixotropic liquid.

6. A process according to claim 5 wherein the ground enveloped by thixotropic liquid, prior to being removed, is further loosened and processed, together with the thixotropic liquid, to a readily conveyable fine mixture.

7. A process according to claim 6 wherein the mixture is passed into the pressureless space and the thixotropic liquid is separated and fed to the excavation space ahead of the transverse wall of the caisson.

8. A process according to claim 1 wherein the excavation face is formed and the caisson is driven forward and the pressure and amount of thixotropic liquid forming the cushion are controlled according to measuring results obtained in advance of the caisson.

References Cited by the Examiner

UNITED STATES PATENTS

168,146	9/1875	Dowd	61—84
300,469	6/1884	Haskin	61—42
438,509	10/1890	Vering	61—84
2,055,876	9/1936	Newman	61—42

CHARLES E. O'CONNELL, *Primary Examiner.*

EARL J. WITMER, *Examiner.*

R. A. STENZEL, *Assistant Examiner.*