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Nakade et al.

[11] **3,783,624**

[45] **Jan. 8, 1974**

[54] **METHOD OF PROVIDING A PILE IN A GROUND FORMATION HAVING A HIGH RESISTANCE TO MOVEMENT**

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[22] Filed: **May 11, 1971**

[21] Appl. No.: **142,377**

Related U.S. Application Data

[62] Division of Ser. No. 808,865, March 20, 1969, Pat. No. 3,623,330.

[30] **Foreign Application Priority Data**

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July 13, 1968 Japan 43/49492
Mar. 21, 1968 Japan 43/18635

[52] **U.S. Cl.** ..... **61/36 R,** 61/53.52, 61/53.64, 61/63

[51] **Int. Cl.** **E02d 3/12,** E02d 3/14

[58] **Field of Search** ..... 61/36 R, 53.62, 53.64, 61/63, 35, 53.52

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Primary Examiner—Mervin Stein
Assistant Examiner—Alex Grosz
Attorney—Edwin E. Greigg

[57] **ABSTRACT**

This invention relates to technique of plugging formations in civil engineering and construction, reinforced underground structure and underground structure required for strengthening the ground thereof, which may be effectively utilized in plugging or in strengthening unstable ground in sealing-off points of water leakage or oil leakage in civil engineering and construction, in preventing gas leaks in soils or in construction, or in increasing bearing capacities of pull-out or push-in piles to be constructed.

Thus, the invention is intended to provide a technique for plugging formations having interstices and a technique for compacting formations by filling interstices with a solidified substance and also provide a reinforced ground structure and an underground structure for reinforcing the ground, characterized in that a fluidal substance, such as an isocyanate compound, which upon coming into contact with water, reacts thereby to produce water-insoluble solidified substance and liberating a gas, is forced to be present in the interstices in formations such as water leakage regions in civil engineering and construction and a ground or weak ground where water leakage or water seepage is expected, so that it reacts with the water and the resulting insoluble solidified substance is allowed to be intimately bonded to the surfaces of the interstices under the pressure of the liberated gas, thereby sealing-off the interstices easily and effectively.

8 Claims, 15 Drawing Figures

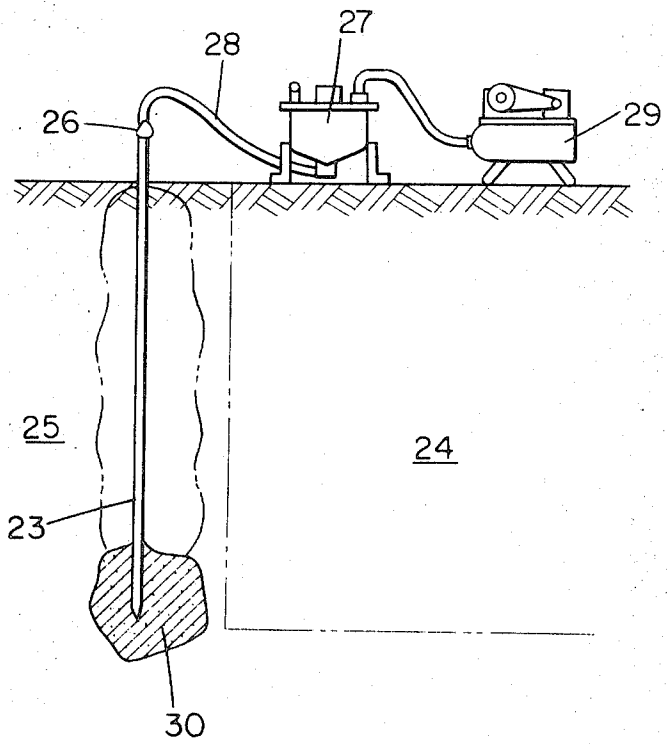


Fig. 1

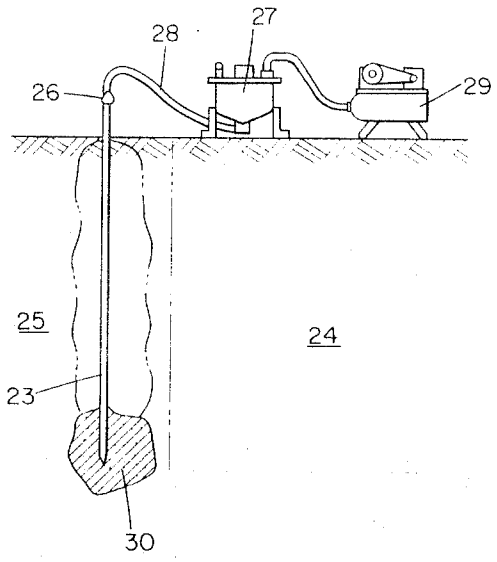


Fig. 2

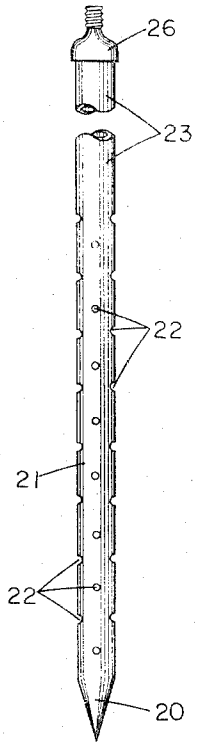


Fig. 3

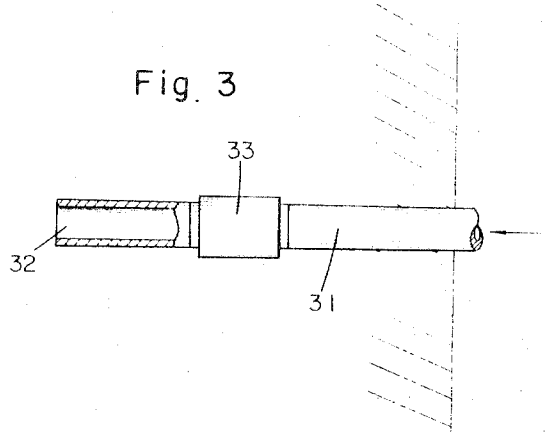


Fig. 4

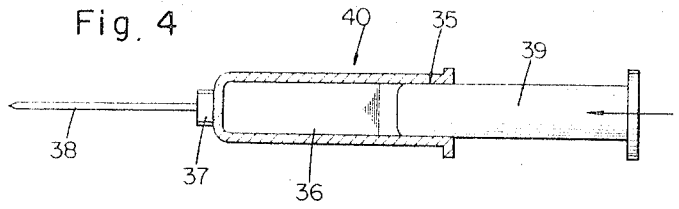


Fig. 5

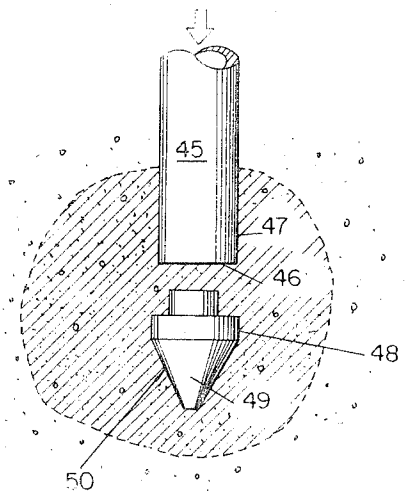


Fig. 6

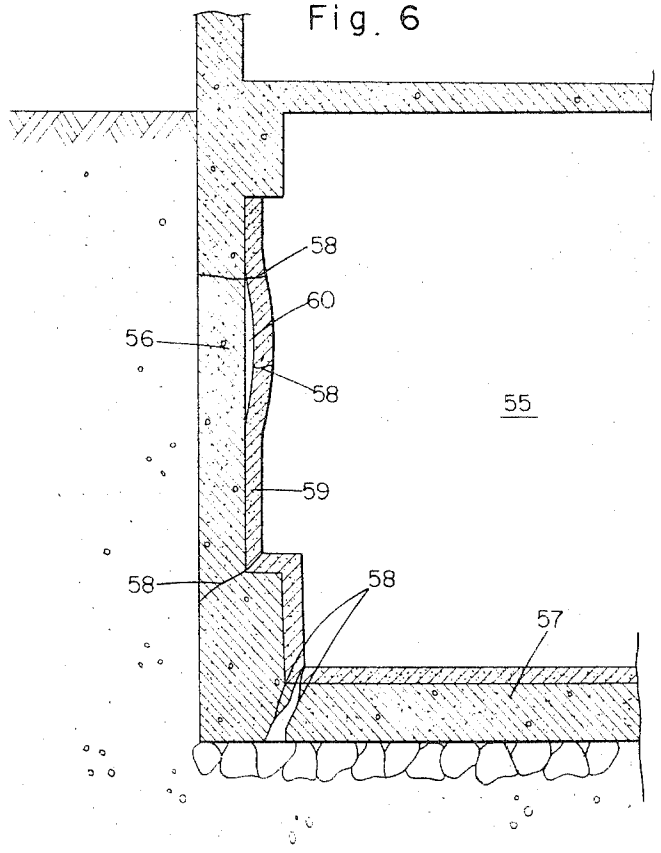


Fig. 7

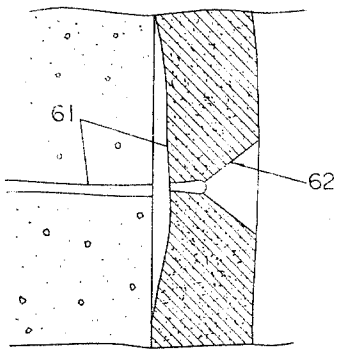


Fig. 8

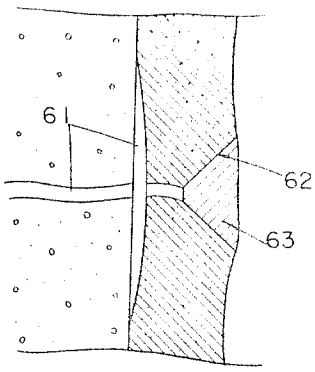


Fig. 9

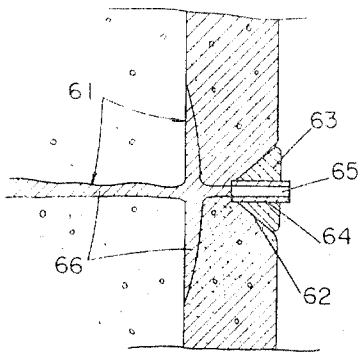


Fig. 10

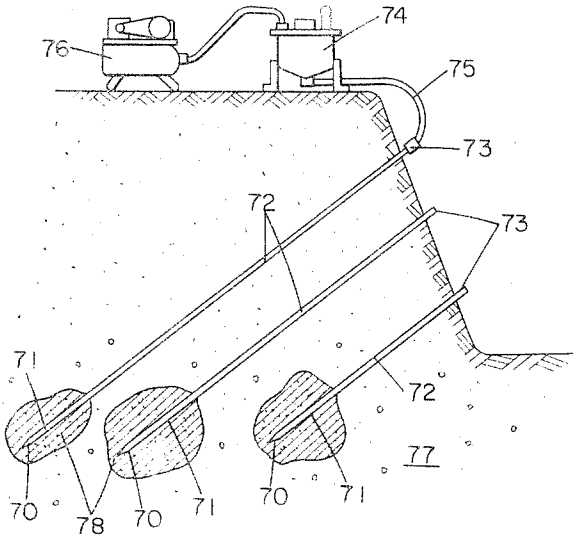


Fig. 11

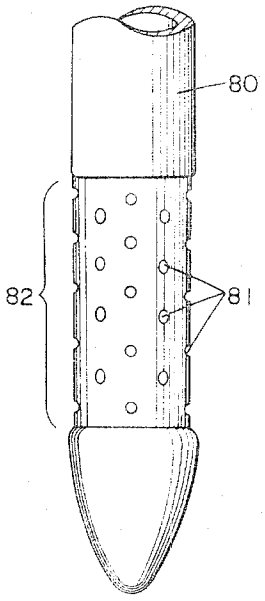


Fig. 12

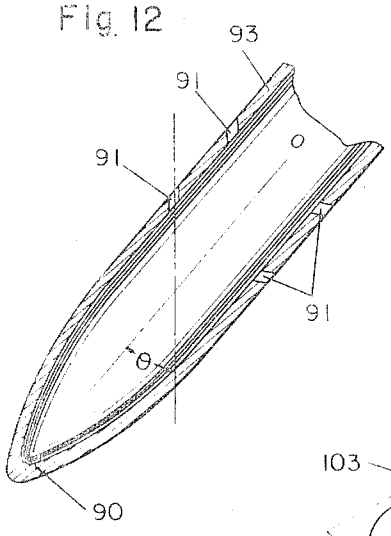


Fig. 14

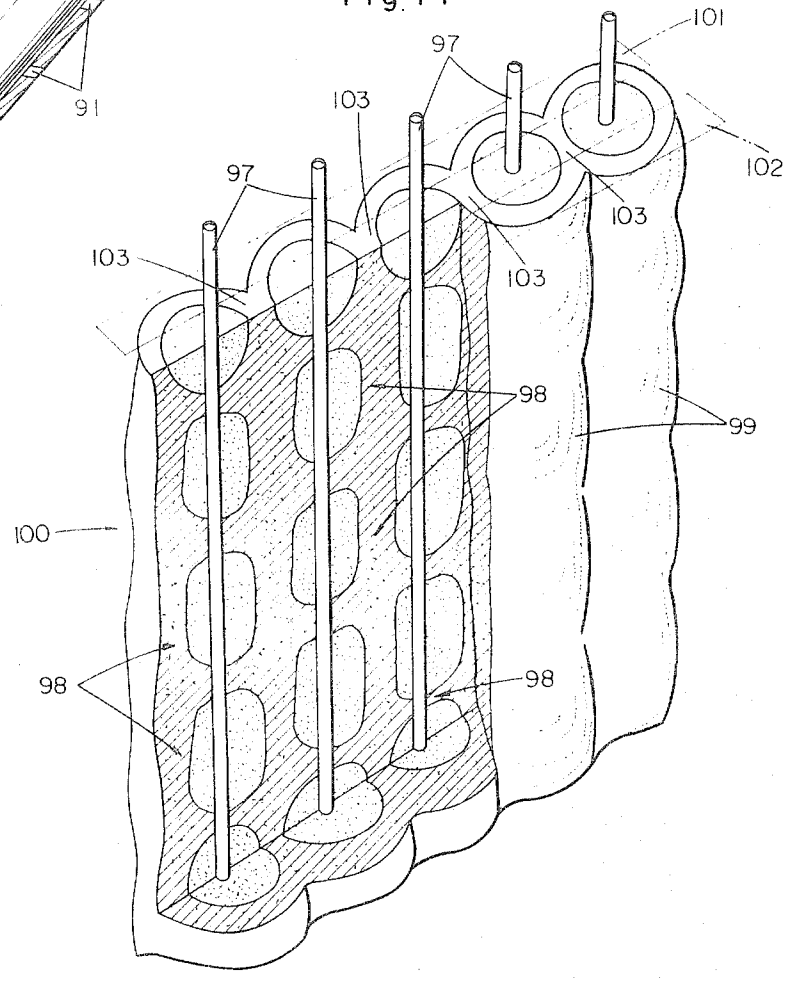


Fig. 15

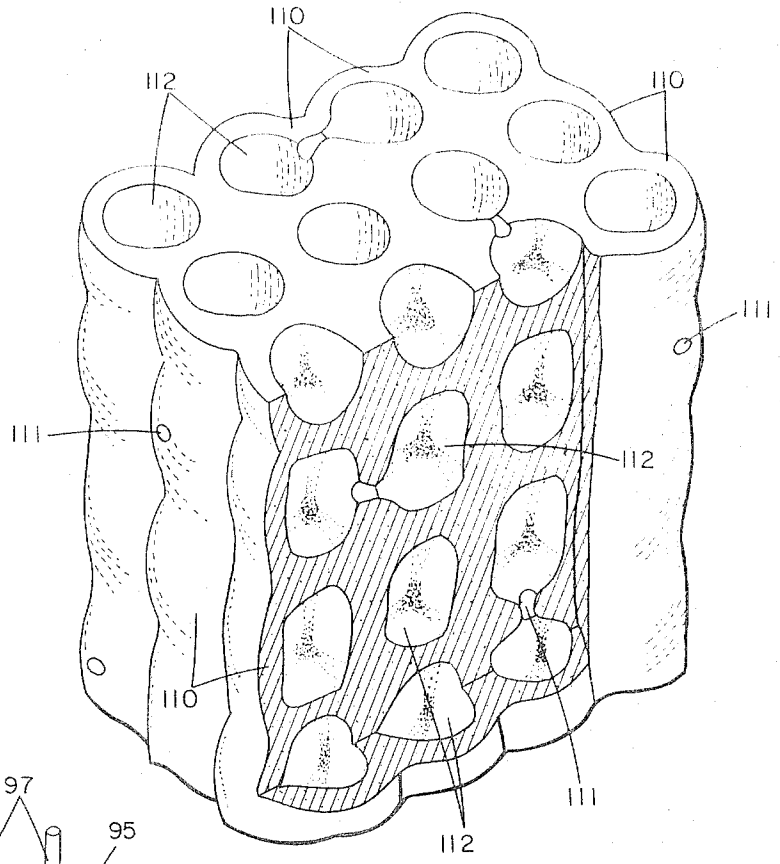
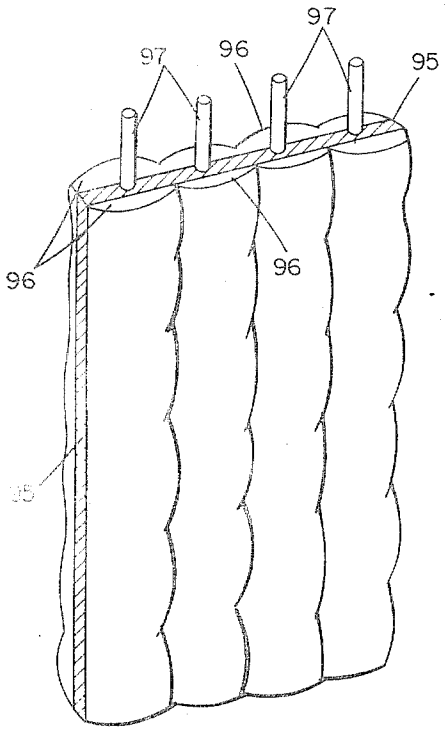


Fig. 13



METHOD OF PROVIDING A PILE IN A GROUND FORMATION HAVING A HIGH RESISTANCE TO MOVEMENT

This application is a divisional application of Ser. No. 808,865, filed Mar. 20, 1969, now U.S. Pat. No. 3,623,330.

BACKGROUND OF THE INVENTION

1. In conventional soil stabilization methods by chemical injection, a chemical liquid obtained by mixing two or more than two reacting chemical components just before injection is injected into the ground, first to replace interstice water in the ground with the chemical mixture, and then, with the inter-reactions between different chemical components, water-insoluble solid substances are formed within the interstices between soil particles for the purpose of shutting-off water or strengthening of soil. However, in such a method each chemical component in the chemical mixture starts a continuous "liquid to solid" transformation at the moment when different chemical components are mixed together, so this solidification takes place with no consideration of time required for the chemical mixture to flow through injection equipment to the expected ground, therefore, in case the speed of solidification of the chemical liquid is high, it is almost impossible to avoid difficulties, due to rapid increase in viscosity, often causing gelation of chemical or plugging near the outlet of injection pipe with reaction product preventing permeation of unreacted liquid, and thus, this method is defective because of the injection being impossible.

On the other hand, in case when solidification is slow, though it is possible to control increase of viscosity in the injection equipment, even after the chemical reaches the expected location within the ground, the fluidity of said liquid still remains and its concentration will be diluted with water contained in the ground, thereby further delaying the solidification, and on occasion, the chemical is carried away from the objective ground location to other places by underground water resulting in the complete failure of the injection purpose.

In other words, the chemical liquid, used in the conventional method, internally comprised two fundamentally contradicting characteristics, one of which is "characteristics requiring maintaining of good fluidity," and the other "that of rapid solidification."

As to this mutual contradiction, the only known controlling method of solidification speed of the chemical liquid was an extremely passive step, that is, to control the speed of chemical reaction along the time-viscosity increasing curve which changes in a specific shape in which the increase of viscosity is kept as low as possible during initial period of injection but will rapidly increase after a certain period of time. However, the speed of chemical reaction is always influenced by surrounding temperature, concentration of chemicals, ratio of chemical components, etc. and to control is not only difficult but the every sort of complication accompanying by an actual performance, such as the necessity of selection of the optimum speed of consolidation due to consideration of ground conditions, capacity of the injection equipment, degrees of workmen's experiences, etc. is the greatest cause of the unstability in the result of injection work.

That is to say, such a complicated method requiring highly technical experiences cannot be considered suitable to everybody. In fact, there were many actual cases which had ended in failure by performing works at invisible locations with accuracy. Further, this method cannot be considered suitable for field works where the working conditions are not perfect in the usual cases.

2. Also, in underground structure, such as basement or tunnels, leakage of ground water may occur through cracks in concrete wall or lining. Conventionally, shutting-off of water at such locations has been performed by sealing-off cracks with chemical liquid similar to those referred to above in similar manner already mentioned. Such methods also had defects similar to these referred to in (1). Supposing that solidification of chemical liquid in cracks was obtained, it would still be impossible to avoid the water between solidified substance and surface of crack, and this remaining water will cause imperfect contact between the solidified substance and the surface of crack, and also the permeation of the said water within the said solidified substance will decrease the strength of it by the softening phenomena thereby making perfect shut-off of water impossible.

3. In the cases where underground anchors are constructed in civil engineering and construction, it is usually done by excavating in advance and constructing concrete anchoring structure, or by boring holes in the ground and putting cement mortar together with anchor rods therein, thereby increasing ground stability; however, excavation or boring require large scale equipments, and in case neighboring structure is very close to such equipments when the job site is limited, such methods become impractical.

Further, excavation or boring require great amount of labor and time, and moreover, concrete or cement mortar require a considerable time before they attain the required strengths, and such methods cannot be employed in cases where a landslide of retaining walls or cut-slope is foreseen and urgent reinforcement is required.

In addition, in cases where the amount of ground water was great, or where underground stream was existing at the site of anchoring structure, not only the construction required great amounts of labor and time, but also it was impossible to obtain the intended strength.

It is possible to offer a method of constructing underground anchor employing a method of chemical injection method which is later described herein, as a method for constructing anchor in the ground solving aforementioned difficulties inexpensively as well as rationally; however, within the scope of conventional chemical injection methods, the application for said purpose was found impossible due to the limited capability of the chemicals thereof.

4. Moreover, in the conventional chemical injection method used for soil stabilization the consolidated lumps of earth formed by the permeation of injected chemical were spherical or cylindrical in shape around the outlet ends of chemical injection pipes and were solid substance homogeneous in cross-section; but they do not necessarily have to be solid homogeneous lumps of earth in cross-section for it will be more rational and economical that they become cells of earth whose peripheral surfaces only are solidified while interiorly un-

solidified. Furthermore, concrete explanation for this will be given later; but in conventional chemical injection methods it was almost impossible to produce a cell-form or shell-form lumps of earth. Supposing it was possible to produce a cell-form or shell-form lumps of earth, their mechanical strength would be so low that they would be of no practical use.

SUMMARY OF THE INVENTION

This invention, as aforementioned, has been developed through a research to improve the fundamental defects of the conventional chemical injection method, and the main technical idea of the invention is very original and is characterized by the use of chemical liquid substance mainly comprising, for example, isocyanate group compound which upon coming into contact with water will start chemical reaction where a water-insoluble solid substance is produced and gas is liberated.

In addition, the present invention may develop the most preferable effectiveness in the easiest-to-use condition in the following manner. Thus, upon coming into contact with water in the interstices present in the texture of the ground or constructions, a mixed fluid consisting of an isocyanate compound and a silane compound is caused to react with said water and the reaction product which is water-insoluble is employed to plug the interstices while utilizing the reaction-produced gas, thereby forming a solid substance in the intended interstices, thus intertexture interstice-plugging, such as water-sealing, gas-sealing and oil-sealing in civil engineering and construction, improvement of the ground, formation of bulbs at the front ends of piles, etc. can be effected in the easiest-to-practice condition and decidedly favorable effectiveness can be obtained.

These may be attributed to the following reasons. In case where an isocyanate compound liquid of relatively high molecular weight is used, the reaction product thereof with water is highly tenacious and a solid of high mechanical strength is obtained, there being no toxic property attributable to the volatile matter. Further, the invention has many advantages associated with the objects thereof, including easiness to obtain a solid having a high content of isocyanate which is an active group, but this isocyanate compound has only one disadvantage that it has relatively high viscosity to the extent that it exerts a high resistance to penetration into intertexture interstices and is rather difficult to inject.

The invention uses a mixed fluidal substance consisting of an isocyanate compound and derivative of silane compound, thus resulting in the remarkable advantage that the silane derivative acts as a solvent for isocyanate compounds and reduces the viscosity, thereby making penetration into interstices easier. Moreover, this silane derivative, though being a more diluent, undergoes hydrolysis as in the isocyanate compound to form a water-insoluble reaction product to assist in plugging the pores and, fortunately, the reaction product from the hydrolysis of the silane derivative, though brittle when alone, is capable of forming a solid having extremely high tenacity and high compression strength when it coexists with the formed gel obtained by the reaction of the silane derivative with water; thus, the invention has made possible the firm sealing of interstices, improvement of the ground, formation of bulbs at the front ends of piles, etc. In addition, in case where a mixed fluid according to the invention is used, the chemical starts a reaction quickly in the manner of a chain reaction upon meeting with water, so that the solid can be conveniently quickly formed without being washed away with torrential underground water. That is to say, the yielding of a reactive hydrogen-containing alcohol easy to combine with the isocyanate compound in the process of the hydrolysis of the silane derivative to form a silicate gel results in the advantage of quickly forming a solid. Details thereof will later be given in embodiment 3. The above is the optimum method of the present invention, but as it is also possible to use an isocyanate compound alone, the basic concept of the invention will be fully described below followed by the description of various modes of the embodiment, function and effectiveness, and other features of the invention.

The points at which this invention fundamentally differs from the conventional method in both theory and practice are as follows.

a. Not only does the chemical itself not produce any solidified substance unless it meets moisture, but also whenever the unreacted substance in the fluidal substance of the invention meets moisture it forms a solidified substance.

b. The most advantageous feature of the invention resides in the use of a fluidal substance which will liberate a gas simultaneously with the formation of a solidified substance. The gas pressure facilitates the automatic advance and penetration of the present chemical into the required position. Further, said solidified substance is caused to firmly bond to part or the whole of the surface defining the interstice, thereby achieving the shutting-off of water and oil and the prevention of gas leakage, and the fluidal substance or solidified substance is urged into the interstices under the gas pressure to effect complete plugging. These are the greatest merits of the invention.

c. And, the fluidal substance which must be solidified by reacting with water in this invention has good fluidity until it encounters with water. Therefore it will easily permeate into voids or interstices of formation of the injected location in the ground.

d. If there is water, it will produce substance without causing difficulty in an imperfect reaction due to dilution by water itself. Liberated gas temporarily expels excessive ground water. An effective area of the solidification in this method is broadly attended by means of the bubble of the gas.

e. Changing into a form which cannot be carried away by water, filling the voids or interstices of the formation assuring the action of shutting-off water or oil, preventing gas leakage and strengthening of ground in good efficiency.

f. Furthermore, the work is very easy for there is no difficulty in controlling of solidification speed.

g. In other words, the fluidal substance employed in this invention automatically reacts at locations where shutting-off of water or where strenghening is required-,i.e. since this chemical automatically selects and reacts at water bearing ground or at the location of water leakage, desired work can be performed inexpensively and rationally without requiring the highly technical experiences which were necessary in conventional methods.

Therefore, it is no exaggeration to say that in this invention the skilled techniques formerly required for chemical injection method is no longer necessary. Also, only a very simple injection equipment is sufficient for the work and nearly no experience in the performance of work is required.

For example, as to the stabilization of a relatively shallow ground where the prevention of water leakage at sheet pile retaining walls in underground excavation, prevention of water leakage in tunnel excavation, prevention of rupture at tunnel facing work, rapid solidification due to mixing with muddy soil, etc. can be achieved, it is possible to stabilize the ground promptly by concentrated injections in selected regions either by the use of a piston-type manual pump or simple injection syringe-type plunger pump or by sprinkling the chemical for mixing.

The invention has the folloiwng objects included in its objects. Further, the advantage that these objects can be achieved is included in the advantages of the invention.

1. This invention does not require the complicated and tiresome controlling of the speed of solidification of the chemical liquid which was necessary in the conventional method; and it is intended to obtain a simple, easy, and sure method in sealing-off voids or interstices in the formations.

2. It is an object of the invention to seal-off water leakage or oil leakage in the ground, to prevent gas leakage through interstices in textures, e.g. gas leakage during the digging of natural gas wells or petroleum gas wells.

3. It is also an object of the invention to provide an effective method for shutting-off water leakage through cracks in structures or interstices in formation.

4. To obtain a reinforced subgrade is also one of the objects of this invention.

5. To construct underground structure with the object of reinforcing the ground is also one of the objects of this invention.

6. Another object of this invention is to provide a pile construction method which can be very effectively utilized without being influenced by the presence of ground water, for instance, as in pile structures such as anchor-rods and bearing piles with pull-out or push-in resistance to the ground.

7. It is also an object of the invention to provide a technique for causing a reaction-produced solidified substance to be firmly bonded to the surface of a substance whose interstices are to be closed, for the purpose of achieving the above-mentioned objects (1), (2) and (3).

8. It is intended to obtain a method for increasing the efficiency of the effective area of the solidification of the fluidal substance injected into the ground or structure by greatly enlarging the region where the fluidal substance used effectively solidifies.

9. It is also an object of the invention to provide a construction work method which can be easily and efficiently applied to obtain an underground water shutting-off wall composed of shell-like consolidated lumps of earth or a ground which is reinforced by shell-like lumps of earth. Other objects and advantages of this invention will become apparent from the following detailed description of the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a simplified side view showing the working method for the case where this invention is utilized as soil stabilization method.

FIG. 2 is a partial sectional side view showing a chemical injection pipe for injection of the chemical into the ground.

FIGS. 3 and 5 are enlarged, partially sectional side views showing chemical injection nozzle parts of other chemical injection equipments, respectively.

FIG. 4 is a partially sectional side view showing a handy chemical injection equipment which can be conveniently used in the injection of the chemical into the ground.

FIG. 6 is a side view drawing of a longitudinal section showing water leakage cracks of a building which can be shut-off by this method.

FIGS. 7–9 are side views of longitudinal sections showing the sequences of work in shutting-off water from leaking cracks.

FIG. 10 is a simplified side view explaining working where the present invention is employed in constructing anchor rods.

FIG. 11 is a side view of outlet ends of a chemical injection pipe suitable for the case especially where chemical injection pipes themselves are used as anchor rods or bearing piles.

FIG. 12 is a side view drawing of the longitudinal section showing outlet ends of another chemical injection pipe especially suitable for the case where the chemical injection pipe itself is used as anchor rod with a great pull-out resistance.

FIG. 13 is a perspective view of an underground water shut-off wall constructed by the conventional method.

FIG. 14 is a partially cut perspective view of an underground fluid-tight wall constructed utilizing the method of this invention.

FIG. 15 is an oblique section in a part, showing only the solids in stabilizing formation.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

EMBODIMENT 1

An example in which this invention is used as ground stabilization method or sealing method is explained in FIGS. 1 and 2; the pipe wall 21 which extends an appropriate distance from the sharply pointed end 20 is perforated with great many chemical outlet holes 22, on the chemical injection pipe 23, which is, for example, as shown in FIG. 1, driven to a certain predetermined depth into the ground which requires a ground stabilizing, such as the ground 25 which is adjacent to the ground 24 which is scheduled for excavation; the head portion 26 of the injection pipe 23 and a chemical tank 27 are pierced through with pipe 28, the liquid substance in the tank 27 is forced into the chemical injection pipe 23 under a static pressure applied with compressed air supplied by an air compressor 29 and thus it is injected into the ground 25 through each outlet hole 22.

As the chemical to be used, the use of a fluidal substance which, upon coming into contact with water, reacts therewith to produce a water-insoluble solidified substance and liberating a gas, makes it possible that a water-insoluble consolidated lump of earth 30 is auto-

matically formed by the moisture in the ground around the part **21** of the injection pipe **23** having the outlet, so that the plugging of formations having interstices takes place, thus reinforcing the ground and, moreover, at the same time with wall sheathing when the excavation-scheduled ground **24** is excavated, water seepage from the excavated surfaces can also be prevented by sealing-off porous formations. In cases where the ground to be stabilized is very wide in up and down direction, then injection outlet holes **22** may be provided on the injection pipe **23** along the length corresponding to the width, or the said chemical injection may be performed by gradually raising or lowering the injection pipe **23.**

By means of the invention, we can obtain a porous sealing wall in the ground as indicated in claim **36** to be later noted.

Further, by means of the invention, we can obtain a porous consolidated soil.

In case the fluid substance to be used is liquid, it can easily penetrate into extremely small interstices, so that the object can be achieved easily and reliably.

The invention can achieve the above-mentioned object by the above-mentioned merit.

An example of the chemical fluid which can be most effectively used in this invention method may be said to be an isocyanate compound which is expressed in the general formula $R-(NCO)n$, or another group of isocyanate compounds obtained by the reaction between said isocyanate compounds and other compounds containing active hydrogen and remaining reactive with water. These compounds can easily polymerize with underground water to form a water-insoluble high polymer substance which liberates carbon dioxide gas.

Where: R is an organic group such as of either an aliphatic or aromatic family or both, *n* is an integer of 2 or more.

So they are polyisocyanates of aliphatic or aromatic family such as: 2.4-tolylene diisocyanate, 2.6-tolylene diisocyanate, mixture of 2.4- and 2.6-tolylene diisocyanate, crude tolylenedisocyanate, diphenylmethane-4,4-diisocyanato, polyallylene polyisocyanate, m-phenylene diisocyanates, hexamethylene -1.6-diisocyanate, o-, m- and p-xylene diisocyanates, methylene-bis-p-phenylene diisocyanate, and polyallylene polyphenyl isocyanate; and prepolymers containing an isocyanate-terminated group produced by the reactions of excess of these polyisocyanates (i.e. those listed at the beginning of this sentence) with compounds containing active hydrogen.

As for the compounds containing active hydrogen employed for the production of said prepolymers, mention may be made of water, alcohols, organic acids, amines, etc.; but as for the alcohols, these dihydric or other polyhydric alcohols are desirable, and such low molecular weight polyhydric alcohols as ethylene glycol, propylene glycol, diethylene glycol, glycerine, trimethylol ethane, trimethylol propane and pentaerythritol, together with castor oil and its derivatives, hydroxyl-group-terminated polyethers and polyesters are also to be included.

The term "water" referred to in this specification includes not only the common water, but also includes the general term "compound containing active hydrogen".

The said hydroxyl-group-terminated polyethers are the addition-polymerization products between the low molecular weight compounds containing active hydrogen and alkylene oxides, and in this case it is desirable to choose low molecular weight compounds containing 2 or more active hydrogen atoms per each molecule. And, as practical examples of such poly-ethers, mention may be made of the reaction products between one or any more members of active-hydrogen-containing low molecular compound group of water, ethylene glycol, propylene glycol, glycerine, trimethylol propane, sorbitol, saccharose, phosphorous acid, orthophosphoric acid, derivatives of phosphoric acid for instance, glycere-phosphoric acid, ammonia, ethylene diamine, diethylene triamine, ethylene amine, etc. and one or more members of alkylene oxide group of ethylene oxide, propylene oxide, 2,3 butylene oxide, tetrahydrofuran, epichlorohydrine, styrene oxide, etc.

Among the hydroxyl group-terminated polyesters, the products obtained by the reaction between organic polybasic acids and an excess of polyhydric alcohols are taken up, in this case, as for the organic polybasic acid, there are oxalic acid, succinic acid, adipic acid, azelaic acid, sebacic acid, maleic acid, fumaric acid, phthalic anhydride, isophthalic acid, terephthalic acid, tetrachlorophthalic acid, trimellitic acid, etc., and as for polyhydric alcohols there are ethylene glycol, propylene glycol, diethylene glycol, dipropylene glycol, 1.3 - butylene glycol, 1.4 - butylene glycol, neopentyl glycol, 1.6 -hexanediol, 1,3,6-hexanetriol, glycerine, trimethylol propane, trimethylol ethane, pentaerythritol, sorbitol and mixtures thereof. The polyesters may be modified by the addition of a small amount of organic monobasic acids and monohydric alcohols. Further, the hydroxyl-group-terminated polyesters produced by the polymerization of oxy-acids and these lactonic compounds are also useful. As to the organic acids, besides all the organic acids which are used for said hydroxyl-group-terminated polyesters, hydroxyl group-terminated polyesters which are produced from said organic acids and for the production of said hydroxyl-group-terminated poly-eithers can also be utilized.

As for the amines, all those containing primary or secondary amines within their molecules are usable. Mention may be made of ammonia, methyl amine, hydrazine, ethylene diamine, diethylene triamine, and amine-terminated polyamides, however, isocyanate-terminated prepolymers which are produced from amines and an excess of polyisocyanate generally lack stability to be stored and so they are not useful.

The isocyanate compound to be used in this invention is preferably to be in a liquid state, however, even if it were a solid in itself which dissolves into solvent to be diluted or changes to liquid state by diffusion under the conditions of employment, then it will serve the purpose just as well. Further, it is possible to adjust the viscosity of said liquid by suitably using solvents according to the condition of the soil to be injected at the site in order to maintain necessary viscosity for the work. Generally, the suitable viscosity is 1 – 2,000 cps, the desirable content of the isocyanate group being 2% or more. The solvents used are those which have no groups reactive with the isocyanate group and which contain no water, including aromatic hydrocarbons, aliphatic hydrocarbons, ketones, esters, others and alkylhalides. As for practical examples thereof, mention may be made of benzene, toluene, xylene, acetone,

methyl-othyl ketone, ethyl acetate, butyl acetate, cellosolve acetate, trichloroethylene, dichloromethane, dichlorobenzene, etc.

When the isocyanate compound reacts with water contained in the ground, for the adjusting of the reaction a suitable amount of catalysts and crosslinking agents may be added. As for the catalysts, any suitable catalyst which accelerates the reaction of known isocyanates with compounds containing active hydrogen may be used. For instance, mention may be made of triethylamine, N-methylmorpholine, N-ethylmorpholine, N-comorpholine, dimethyl-benzyl amine, triethylene diamine, N.N'-dimethyl -2-methylpiperazine, pentamethyl-diethylene triamine etc. of the tertiary amines, or stannous chloride, dibutyl tin dilaurate, dibutyl tin oxide, stannous octate and other organo-tin compounds. These catalysts may be used as mixtures thereof or may be suitable diluted with solvent and allowed to penetrate into sites where the invention is applied, for example, into the ground beforehand. Further, to improve the contact of said isocyanate compounds with water and thereby allowing their reaction to proceed uniformly or to control the stability of the liberated carbon dioxide gas bubbles, surface active agents may be added to the isocyanate compounds beforehand. Particularly useful surface active agents are silicone-type non-ionic ones, which are useful in producing the well-known urethane foam.

When additives such as mentioned above are added to said isocyanate compounds as may be required, and as the said isocyanate compound is injected into the ground, it will start the polymerizing reaction at the instant it comes in contact with ground water to produce water-insoluble gel-form high polymer solid substance within the slits or interstices or between soil particles, without the accompanying defects such as in the conventional method which has been pointed out in (1) through (4) of the foregoing "Background of the Invention" resulting in an instantly effective stabilization of the ground.

The isocyanate compound generally liberates carbon dioxide gas when it comes in contact with water. The carbon dioxide gas thus liberated temporarily expels excessive water in the vicinity of stabilizing parts of the ground during the process, and at the same time it leads to the benefits as described in the "Summary of the Invention" before.

The description of the fruits obtained in the experiments of said invention of chemical injection methods are given below:

EXPERIMENT 1

By preparing a model ground consisting of a sand layer in which the hydraulic gradient can be freely controlled, and therewith comparison were made between the experiments for four kinds of representative grouts of water-soluble chemical fluids available on the market, meeting the conditions shown in the attached Table 1. The isocyanate-type prepolymer used in said experiment consisted of 70 parts in weight of 2 functional urethane prepolymer of polypropylene glycol-tolylene diisocyanate, cut back with 30 parts in weight of xylene solvent, and into which silicone surface active agent of 0.1% in total weight and triethylamine of 0.5% as catalyst were added.

TABLE 1 - CONDITION FOR EXPERIMENT

ITEM	Test 1	Test 2	Test 3
Grain size of soil sample	0.3–0.6mm	0.6–1.2mm	1.2–2.5mm
Porosity of soil sample	40%	33%	37.5%
Hydraulic gradient	1.5	1.5	1.5
Apparent velocity of water flow	0.600 mm/ sec	0.747 mm/ sec	0.800mm/ sec
True velocity of water flow	1.50 mm/ sec	1.965 mm/ sec	2.130 mm/ sec
coefficient of water permeability of soil sample	4.00×10^{-3} cm/sec	4.98×10^{-2} cm/sec	5.83×10^{-2} cm/sec
Quantity of injection grout	300 ml	300 ml	300 ml
Injection pressure	0.5 kg/cm²	0.5 kg/cm²	0.5 kg/cm²
Injection time	20–40 sec	20–40 sec	20–40 sec
Gel time	60±5 sec	60±5 sec	60±5 sec

The results of the experiments are as shown in Tables 2–6 inclusive, and the isocyanate-type prepolymer of this invention showed very effective consolidation results for the model ground with severe underground stream.

TABLE 2 - RESULTS OF TEST 1

Type of grout used	Consolidated volume	Consolidated volume/ injected qty. of grout)× 100	Injection efficiency: (void vol/ injected qty. of grout)×100
	(cm³)	(%)	(%)
Isocyanate-type propolymer	1,887	629.0	251.6
Acrylic amide type	572	124.0	49.6
Water glass type	515	171.7	68.7
Urea-formaldehyde type	402	134.0	53.6
Chrome-lignin type	460	153.3	61.3

TABLE 3 – RESULTS OF THE TEST 2

Type of grout used	Consolidated volume	Consolidated volume/ injected qty. of grout)× 100	Injection efficiency: (void vol/ injected qty. of grout)×100
	(cm³)	(%)	(%)
Isocyanate-type prepolymer	1,860	620.0	235.6
Acrylic amide type	279	93.0	35.0
Water glass type	181	60.3	22.9
Urea-formaldehyde type	86	28.7	10.9
Chrome-lignin type	120	40.0	14.9

TABLE 4 - RESULTS OF THE TEST 3

Type of grout used	Consolidated volume	(Consolidated volume/ injected qty. of grout)× 100	Injection efficiency: (void vol/ injected qty. of grout)×100
	(cm³)	(%)	(%)
isocyanate-type prepolymer	1,560	520.0	197.6
Acrylic amide type	565	183.3	71.6
Water glass type	330	110.0	41.8
Urea-formaldehyde type 295		98.3	37.7
Chrome-lignin type	295	98.3	37.7

EXPERIMENT 2

By preparing a model ground formation of a sandwich-type in which a layer of sieved sand with grain size of 0.6 – 1.2 mm is held between two upper and lower impermeable clay layers, comparative experiments were made therewith for the effect of sealing water at the sand layer for four kinds of representative grout of water-soluble chemical liquids available on the market, meeting the condition of water flow system shown in

the attached Table 5 and those for the isocyanate-type prepolymer of this invention. The isocyanate-type prepolymer used in said experiment consisted of 70 parts in weight of 2 functional urethane prepolymer from tolylene diisocyanate polypropylene glycol, cut back by adding 10 parts in weight of acetone and 20 parts in weight of xylene, into which triethylene diamine of 0.2% of the total weight is added as catalyst.

TABLE 5 - CONDITIONS FOR EXPERIMENT

Porosity of soil sample:	38%
Hydraulic gradient:	3.0
Apparent velocity of water flow:	1.39 mm/sec
True velocity of water flow:	3.66 mm/sec
Injection method: One shot method	
Quantity of injected grout:	600 ml
Injection pressure:	0.5 kg/cm²
Injection time:	15 - 30 sec.
Gel time:	45 sec.

The results of the experiment are as shown in Table 6, and the isocyanate-type prepolymer of this invention especially was the only case where the extent of consolidation showed capability of completely shutting-off flowing water and showing an efficiency of shut-off water of 100%.

TABLE 6.—RESULT OF WATER (SHUT-OFF) EXPERIMENT

Type of grout used	Consolidated volume (cm.³)	Consolidated volume/plus injected qty. of grout ×100 (percent)	Injection efficiency, void vol./injected qty. of grout ×100 (percent)	Efficiency of shut-off water (percent)
Isocyanato-type prepolymer.	4,750	7,017	300.8	100
Acrylic amide type	Flowed away			
Water glass type	Flowed away			
Urea-formaldehyde type.	700	120.7	48.1	7.15
Chrome-lignin type.	555	92.5	35.2	14.7

*Efficiency of shut-off water $=(a-b/a) \times 100$ where:

a: water flow rate before injection

b: water flow rate after injection

If, as the gas-liberating substance, use is made especially of a metal carbide in the form of very fine powder, this is advantageous since the carbide itself forms a water-insoluble substance; such embodiment is shown as follows.

EMBODIMENT 2

The liquid substance which comprises a derivative of silane compound expressed by the general formula $Rn—Si—X_{(4-n)}$ and a small amount of fine metallic carbide suspended in said silane derivative can be applied to this invention, wherein said liquid silane derivative reacts with water to hydrolyze under the normal temperature to produce water-insoluble gel-like silicone compound and said fine metallic carbide liberates hydrocarbon gas in contact with water.

In this case R is an organic group of an alkyl or aryl radical, and X is an alcoxy group or halogen atom.

In general, the less carbon atoms R contains, the faster it hydrolyzes and the more its fluidity increases, therefore, it may be effectively applied to this invention.

In case X is a halogen atom, its usage is confined to the cases in which the corrosive effect in order to liberate hydrogen halide may be ignored.

When X is alcoxy group it is relatively cheap in cost and does not liberate any substance with corrosive property while it generally has a defect which is slow in hydrolysis. It is necessary, therefore, to take into consideration to accelerate the hydrolysis.

It will be effectively accelerated by mixing a small amount of organic acid, or a suitable amount of alcohol in which sodium alcoholate is solved.

Those which are applied to the most practical usage are alcoxy-silane such as tetra-methoxy silane, tetra-ethoxy silane, etc. Those which are crude products containing little remainder of hydrochloric acid are rather cheap and speedy in hydrolysis than the refined products, so they are suitable to practice.

As the fine metallic carbide compounds suspending in the fluid mentioned above, calcium carbide or magnesium carbide, etc., reacting with water to produce acetylene gas, may be used among other metallic carbides.

When much gas foam is desired according to the purpose, it will be achieved by increasing the quantity of these fine metallic carbides suspended in the fluid.

In this case, the addition of carbide which hydrolyzes to produce calcium hydroxide, has an effect to accelerate the hydrolysis of the said silane derivative on account of its alkalinity.

EMBODIMENT 3

A solution prepared by adding a derivative of silane, expressed by the general formula Rn—Si—R′ (4-*n*) (where R′ is other than halogens) described in Embodiment 2 to an isocyanate compound expressed by the general formula R—(NCO)n described in Embodiment 1 or another isocyanate obtained by the reaction of the first-mentioned isocyanate with an active hydrogen-containing compound, may be used as a chemical fluid suitable for the objects of the invention. In this case, since the isocyanate compound and also the silane derivative react with water to form water-insoluble solid gels and possess mutual solubility, it is possible to provide various merits by using the latter as a reactive diluent for the former. For example, an isocyanate prepolymer containing an isocyanate group at the end thereof prepared by the reaction between active hydrogen-containing compound and an excess of polyisocyanate containing an organic radical of aromatic or aliphatic group is advantageous in that it has superior mechanical properties and there is included, no isocyanate compound toxic to the human body, but is disadvantageous in that most of such isocyanate prepolymers are highly viscous so that their penetrability into the interstices in the ground and constructions is inferior. For this reason it is necessary to prepare cut backs with various organic solvents as described in Embodiment 1 in order to reduce the viscosity, but in this case a decrease in the effective component concentration is unavoidable. In such case, if alkoxy silane compounds such as tetraethoxy silane, tetramethoxy silane, dimethoxy silane and dipropoxy silane are used as solvents for cut backs, these solvents will undergo hydrolysis when they come into contact with water to form silicate gels, therefore, they can be employed more effectively as chemical fluids having a high concentration of useful solid component, suited for the objects of the invention. Further, such alkoxy silane compound will yield alcohol upon hydrolysis, resulting in the merit of further promoting the reaction of the chemical fluid into a solid since said alcohol contains active hydrogen and hence reacts with the isocyanate prepolymer. Such

chemical fluid consisting of an isocyanate prepolymer cut back by the alkoxy silane compound which is capable of hydrolysis as described above is low in viscosity and superior in penetrability and yet high in the concentration of the useful solid component and the gel produced by reaction with underground water while it is attended by the formation of gas bubbles comprises inorganic silicate gel present within the polyurethane, so that there is obtained a gel of very high mechanical strength. Further, the use of alkoxy silane less expensive than isocyanate prepolymer will achieve better economy without the performance of the chemical liquid being degraded; rather, it is improved.

If the solvent cut rate by an organic silane compound with respect to the aforesaid isocyanate compound is increased, the effectiveness of gas-bubbling upon reaction with underground water is lowered, but in practice 5 to 80 percent will be effective. Further, for a catalyst for promoting reaction with water in this case, all the tertiary amines or organic metal compounds described in Embodiment 1 can be used.

EMBODIMENT 4

As is shown in FIG.3, the installation of a check valve system **33** at outlet end **32** of an injection pipe **31** to be used for the injection of chemical fluid into the ground, such as already mentioned, is particularly desirable for the following points:

The presence of said check valve prevents the following three accidents at the time of injection:

1. counter flow of the chemical fluid in the injection pipe resulting from back pressure towards the chemical tank by the artesian pressure of underground water,
2. counter flow of chemical fluid due to increase in underground pressure from continuous injection of the fluid chemical, and
3. back pressure of the gas liberated by the said isocyanate compounds injected into the ground.

So, under any condition, smooth and efficient chemical injection can always be performed.

Further, by the gas produced by the injected fluid chemical and with the location of check valve acting as a force resisting point, the injected chemical fluid actively spreads in the ground, with the effective zone of sealing-off of water and of strengthening greatly enlarged.

EMBODIMENT 5

The chemical fluid injection equipment **40** in which a fluid chemical injection pipe **38** is connected and passes through closing cock **37** that is connected to pressure chamber **36** of the manual injection-instrument-type pump **35** as shown in FIG. 4 and manual piston **39** by the operation of which the chemical fluid stored in said pressure chamber **36** can be injected under a suitable static pressure, is useful as a handy equipment for effective performance of emergency works at job sites.

It is also desirable to install an anti-counter-flow system such as described in Embodiment 4.

EMBODIMENT 6

As shown in FIG.5, chemical injection pipe **44** has an open end which in case the said opening becomes the outlet **46**, the peripheral portion **48** which is projecting sidewise beyond said chemical fluid injecting pipe **45** and cap **50** which has a sharply pointed end **49** are installed to said chemical fluid injection outlet **46**; the said injection pipe **45** is then driven into the ground to a depth previously determined, then by pulling out slightly said injection pipe **45**, the projecting peripheral portion **48** of the cap acting as resistance, the said cap **50** will be left at the driven position so that the chemical injection outlet **46** will open. With this system prepared in advance, the plugging of the injection outlet end by earth can be prevented when driving the injection pipe into the ground; and moreover, it will be useful in spreading the injected fluid chemical in the horizontal direction.

Such a cap combined with the anti-counter-flow mechanical system as described in Embodiment 4 will provide a surer and better performance in chemical fluid injection works.

EMBODIMENT 7

The method of this invention can be extensively used not only to stabilize and strengthen the ground, but also to interstices occurring in civil engineering and construction, such as interstices between concrete linings and the earth in tunnels, cracks in exterior walls of the basement, or spaces caused by separation of finishing cement mortar from structural concrete can be sealed to prevent leakage of water through said spaces or sealing-off thereof can be effectively performed; for example, as shown in FIG. **6**, cracks **58** formed in exterior wall concrete **55**, or separated portion **60** between the exterior wall concrete and finish cement mortar **59** that are liable to cause or actually causing ground water leakage from the outside into the interior can be effectively treated.

Again, it can be effectively applied to leaking cracks in tunnel or water tank walls, as to the procedure, for example, as shown in FIG.7, V-cut **6** is made along crack portion **61** which is exposed on front surfaces, and as shown in FIG. **8**, quick setting mortar **63** prepared just beforehand, is grouted into said V-cut, then, as shown in FIG.9, chemical injection holes **64** reaching the interior to cracks are made at suitable locations, and as the required amount of chemical fluid or chemical fluid comprising hydraulic cement or other fine grained solid particles, if necessary, is injected through said injection holes **64** by means of a piston-type manual pump or a simple plunger equipment with nozzle **65** which fit into said injection holes **64**, the chemical fluid, by the inner pressure exerted by the liberated gas, will automatically fill the inside of the cracks from end to end to form sold substance **66**, and thus the purpose of sealing-off or shutting-off of water is accomplished without failure.

Further, in this case if the quick setting mortar **63** is a mortar prepared by mixing the injection chemical itself to be used in the invention with an inert aggregate such as natural sand and crushed sand in the form of powder or fine particles or with an active fine powder such as hydraulic cement and hydraulic plastic, then the results will be more favorable.

Namely, this mortar even with the presence of water at the portion of V-cut **62** will set with no trouble and good bond between the interior surfaces of the V-cut and this mortar can be obtained. Further, due to the gas pressure originated within this mortar, the mortar is forced against the interior side of the V-cut, leaving no unbonded parts resulting in ideal filling. Contrary to this, the presence of water will obstruct the setting of

various conventional mortars and no good effects can be expected for such purposes. Further, the solidified substances produced by the injection chemical fluid will remain not only within the interstices of the structures but also can be extended into the region surrounding the interstices, making more effective the sealing off of water. Also, as for another method of sealing-off of water leakage from cracks in structures, there are cases in which the wall surfaces with cracks are chipped back slightly into which said solidifying substance is applied and finished by trowelling or packing. This method is particularly effective for such locations where cracks in a form of a single line are not clearly visible and for locations of seeping water leakage.

This invention can also be effectively applied to a water shutting-off method such as described as follows:

Namely, the invention may be embodied in such a manner that the present chemical as exemplified in the above, is mixed with sand, glass, powder, carbon powder or other powder or fine particle form of inert substance, or with an active substance such as cement mortar, so as to form a paste-like quick setting mortar, and by utilizing this quick setting mortar, shutting-off of water is completed at the stage shown in FIG.**8.** In this case, by the addition of a slight amount of water to the mixture of said chemical fluid and the solid substances, a good solidification is obtained, in which case the amount of catalyst added may be adjusted to control the setting speed. Again, to have sufficient water on the interior surfaces of the V-cut, it is desirable to spray water beforehand.

In short, for all that has been referred to above and since this invention has characteristics noted in the articles of the "Summary of the Invention," this invention does not contain the defects described in the "Background of the Invention (2)," and perfect speedy sealing of leakage can now be performed.

Further, since it takes more time for the leaking water to react upon the front surface of the fill substance, the proper plasticity for trowelling can be maintained for a sufficiently longer period, so it also has the advantage of allowing more time to finish with ease the built-up surface neatly flush with the existing surrounding surfaces.

Thus, by the addition of aggregate to said chemical fluid, a paste-like mixture as in the use of cement mortar was obtained, as a result, the effect not obtained by the use of cement mortar was bad; that is, whether the packing substance itself kept in a state of optimum state of consistency for handling and packing, or whether it is applied to actual water leakage, it was possible to obtain the effect of stopping the water by the instant solidification of the fill substance.

Particularly, since chemical fluid liberated gas at the time of polymerization is in contact with water, it can be well understood from the foregoing explanation that accurate and effective water sealing can be obtained.

Further, the location of water leakage to which this method can be applied is not limited to those of underground structures only, but also to those of water tank walls, retaining walls, bank surfaces, etc.

This method of sealing off of water will be given in the following experiment:

EXPERIMENT

Three years and 5 months after construction, cracks occurred in the foundation slab of a reinforced concrete building which was located on a sandy-gravel strata 13 meters below the ground water level. The crack was approximately 1 mm in width and approximately 3.5 meters in length and the water leakage was about 150 l/minute. With an experimental purpose of sealing-off this seepage of ground water with great pressure, three holes were bored into the foundation slab along the crack at approximately equal intervals and into each of the bored holes a chemical liquid injection pipe equipped with a cap with pointed end as shown in FIG.**5** and an anti-counter-flow mechanism as shown in FIG.**3** was inserted placing the pointed end of said pipe at a position approximately 20 cm deep in the ground under the slab, and approximately 80 liters of chemical fluid consisting of isocyanate-type prepolymer was injected through each chemical injection pipe.

As the result of the injection, approximately 10% of the total amount of the chemical fluid came out from the crack and flowed over the foundation slab, while most of the remaining chemical fluid filled the crack and the ground below and solidified; and the amount of water leakage through the crack decreased to approximately 2 l/minute.

Further, a partial V-cut was made where sealing-off was imperfect, and as shown in FIG.**9,** chemical fluid injection holes were prepared and at the same time the portions around the V-cut were filled with quick setting mortar; through said chemical fluid injection holes a total amount of 1 liter of the chemical fluid consisting of said isocyanate-type prepolymer was injected with a simple manual injection-type pump as shown in FIG. **4,** stopping completely the leakage of water through the crack. The chemical fluid of isocyanate-type prepolymer used in this case was the same as that used in the Experiment 2 of the Embodiment 1, and the quick setting mortar used in packing consisted of 1 part in weight of this isocyanate-type prepolymer, 3 parts in weight of sieved river sand with an average grain diameter of 0.1 – 0.3 mm and 0.4 part of water, and was used when desirable workability was obtained by mixing the said components together.

EMBODIMENT 8

This invention method can also be applied to the construction of piles with a large pull-out or push-in resistance.

FIG.**10** shows as installation example of earth retaining anchor for cut slope face injection pipe **72,** which has numerous chemical injection outlet holes **71** drilled at fixed points along a designed length of the cone-shaped end **70** as shown in FIG. **2** and driven to a predetermined depth. Connected with hose **75,** chemical tank **74** and head **73** of the injection pipe, the chemical fluid in the chemical tank **74** will, as previously mentioned, upon contact with water, react to produce water-insoluble substance, is forced into the injection pipe **72** under static pressure supplied by the air compressor **76** and is passing through the chemical outlet holes of said pipe, then it is injected into the ground **77** and thereby reacts in contact with water contained in said ground to produce large size, bulb-shaped consolidated lumps of earth **78** around the chemical outlet portion **71** which will sufficiently resist against pull-out or push-in of the pipe **72.**

The number and the diameter of the chemical outlet holes of the chemical injection portion **71** should be determined from the optimum conditions in consideration of the geological conditions of the ground, the

shape and size of the bulb-type consolidated lumps of earth desired, viscosity resistance of the chemical fluid, and allowable stress of the cross-section of the injection pipe.

By making possible the injection from the end of the injection pipe by using the cap as shown in FIG.5, it is possible to produce consolidated lumps of earth which can increase the bearing power; and it is also possible to use the injection pipe as a bearing pile. And in this case the preparation of the injection outlets on the sides will be effective for further increase in bearing force, and it is, of course, possible that the consolidated lumps of earth produced by the side outlets alone can increase the bearing power of the pile.

As mentioned above, when the intention is to fix the pipe in the ground, the pipe with chemical outlet at the end will be driven into the ground; and the chemical fluid producing water-insoluble solidified substance and at the same time liberating gas upon contact with water will be injected, thereby producing bulb-like or cylindrical consolidated lumps of earth without the accompanying conventional defects as described in the "Background of the Invention (3);" anchors with great pull-out resistance, for example, anchors of retaining walls, bridge piers, adjusting of ground reaction for retaining walls etc.; anchors of grate from retaining walls for rock bores, land slide zone, and cut slope faces; anchors to be constructed in stabilizing foundations of structures receiving horizontal forces such as wind pressure or earthquake, or piles with increased bearing force at the end etc.,can easily and quickly be obtained or performed.

In the use of the conventional two-liquid-type injection chemical liquids, chemicals are liable to flow away without concentrating around the pipe and effective formation of bulb-like consolidated lumps of earth cannot be expected; while in the case of this invention the chemical fluid flowing out of the pipe reacts without fail with the interstice water at the side of the said pipe and at the said position where bulb-like consolidated lumps of earth are formed, and by filling the cracks and interstices in the ground around the anchors with the consolidated substance rapidly strengthening the weaker portions of the ground; and, therefore, it is possible to prevent unexpected accidents occurring from the lowering of strength due to unforeseen uneven formations of the ground.

Further, since the pull-out shearing resistance between the anchor-rod and the bulb-like consolidated lumps of earth is created from the following three reasons, the following physicochemical effects which cannot be expected from anchors of the conventional method can be obtained:

1. In the anchors obtained by this invention method, the usual mechanical frictional force governed by the coefficient of friction and the normal pressure due to soil depth is exerted between the bulb-like consolidated lump of earth and the lateral face of the anchor rod.

2. Extremely large physico-chemical bonding force due to the adhesion acting upon the surface of solid substance produced by the chemical injection fluid and that of anchor-rod is developed.

3. Further, since high polymer solid substance is continuously formed, through the injection chemical outlet holes of the injection pipe (or the anchor-rod) between the zones around the injection pipe and the interior of the injection pipe, a riveting effect at the chemical outlet holes can be expected, and so by these effects an extremely great pull-out shearing resistance is produced between the bulb-like consolidated lumps of earth and the anchor rod.

Anchors constructed by this invention method can instantly produce the required strength, so in the case of emergency it can begin to work as anchor immediately since the chemical fluid used reacts at the same time in contact with water to solidify and harden, whereas almost all of the solidified substances produced with the conventional water-soluble injection chemicals such as sodium aluminate, water glass, urea resin, phenol resin, acrylic amide, chrome lignin, etc. have defects of swelling, softening and lowering of strength in the presence of ground water. Compared to these, the chemicals of the present invention have superior advantages of becoming ever stronger in the presence of ground water.

It is of a particular point that the chemicals used in this method in contact with water will liberate gas producing water-insoluble substances. The liberation of gas causes the ground to be forced against the peripheral surface of said pipe normal thereto or so-called radial pressures are created so that the bond between the ground and the pipe is increased and at the same time pressure is increased; and further, together with the increase in the volume of consolidated lumps of earth an extremely great shearing resistance against pulling-off is created. So the construction of a very strong anchor is possible.

According to this invention, a pile with a porous bulb in the ground, as described hereinafter in claim 35, can be obtained.

The description of the experiments in which this invention is performed for the case of pull-off resisting pile, i.e. an anchor, is as follows:

EXPERIMENT 1

Two kinds of sand, one sieved to 0.6 – 1.2 mm, and the other "Toyoura" standard sand meeting JIS (Japanese Industrial Standards) R 5201–1964 were respectively water-compacted in a mould to make 300 $\phi \times$ 500 mm concrete test pieces, a steel pipe 17.3 mm in outer diameter with chemical injection outlet holes of 1 mm in diameter with a pitch of 1.5 cm drilled in portion of the pipe 7.5 cm from the end was driven into each of the compacted sample sand to a depth of 15 cm, and to a prepolymer with a NCO content of 25% produced by the reaction of polypropyleneoxide triol with an OH value of 300 with an 80:20 mixture of 2.4—and 2.6—tolylene diisocyanate, a mixture of 20% (of the prepolymer) xylene and 2% (also of the prepolymer) triethylamine was added. The resultant mixture was injected from the end of each steel pipe;20 hours later they were removed from the mould and subjected to water-immersed curing. At the age of 3 days pull-out tests of steel pipes were made, and the results showed that for the sand of 0.6 – 1.2 mm yielding occurred at 1,012.5 kg,and for Toyoura standard sand at 1,437.8 kg. Thus, very high pull-out shearing resistances of 12.5 kg/cm^2 and 17.75 kg/cm^2, respectively, were obtained.

EXPERIMENT 2

Two 4.8 meter long 1 inch diameter gas pipes were driven sufficiently apart from each other to a depth of 4.5 meters at right angles to a 45° slope cut face, and the prepolymer used in Experiment 1 diluted with 10%

of xylene and mixed with 1% (of the diluted prepolymer) of triethylamine, was injected through each of them. At the chemical injection outlet end (bulb form portion) of each of the injection pipes was a sandy gravel layer containing a large amount of gravels approximately 50 – 100 mm mixed therein. In this case, the chemical outlet portions of the injection pipes were bored with 3 mm diameter outlet holes at a pitch of 5 cm staggered in 2 rows, one pipe over the range of 25 cm in length and the other pipe over the range of 55 cm in length. For pipes with bored lengths of 25 cm, 3 kg and 12 kg of chemicals were injected and for 55 cm type 6 kg and 24 kg of chemicals were injected, and pull-out tests in axial direction of the pipes were made. For comparison purposes pipes with no chemicals injected were also tested. The result of the test showed that the yield points for no chemical injection were below 0.5 tons,while for 3 kg chemical injection was 3 tons, for 6 kg 5.6 tons, for 12 kg 6.0 tons and for 24 kg 8 tons.

It can also be understood from the above experiments, that this invention is extremely excellent.

Further, as to the time of chemical injection, besides injecting after the pipes have been driven into the ground to depth previously intended, the injection may be done while in the process of driving the pipe or may be done while drawing out the pipe to some extent after the completion of driving to the designed depth.

Or else, a spiral projection or grooves prepared on the injection pipe will give a rotating motion to the said pipe making not only the driving of same into the ground easier, but will also become effective by greatly increasing the pull-off resistance. Such a spiral projection or groove can be made on end portions or on intermediate portions of the injection pipe, however, the preparation thereof, particularly on the peripheral surface having chemical outlet holes, will cause better bonding force between the consolidated lumps of earth and said spiral projection or groove obtaining much more desirable results.

EMBODIMENT 9

As shown in FIG.11, if the outer diameter of the portion 82, where the chemical outlet holes 81 of the chemical injection pipe 80 are bored, were made smaller than that of the other portion of said pipe, it will be possible not only to prevent the holes from being plugged with earth and decrease the resistance to the driving of said pipes, but it also will be useful in making the combining force of consolidated lumps of earth with the injection pipe 80 much stronger and this will be effective where, as described in Embodiment 8, the injection pipe itself is utilized as an anchor-rod or as a bearing pile.

EMBODIMENT 10

What is shown in FIG.12 is a modified construction of an injection pipe end, where injection pipe 93, which has a chemical outlet portion 92 with a number of chemical outlet holes 91 drilled at fixed points along a predetermined length of the cone-shaped end part 90 with said chemical outlet holes 91 inclined in such a way that their axial directions toward the interior make acute angle 9 with the driving direction of said injection pipe.

In using this type of injection pipe, even if a certain amount of earth entered said outlet holes, the percussion of the pipe driving will force the earth particles out according to the Law of Inertia, so that the plugging of said holes with earth will be considerably decreased, and discharge of chemicals in both circumferential and axial directions of said pipe within the expected zones being assured, it will be easier to obtain consolidated lumps of earth in initially expected shape and size, and also, when the intention is to use the injection pipe itself as pull-off resistance pile, said modification will be helpful in increasing the pull-off resistance.

Contrary to the above, the conventional type chemical injection pipes to be driven into the ground have chemical injection outlet holes with the hole axis at right angles to that of the injection pipe; so in driving it is difficult to prevent earth from being trapped in said holes and readily plugging up the holes. Occurrence of said plugging not only decreases the number of the chemical outlet holes, but also prevents chemicals from permeating to the expected zones in the stratum so that the initially expected stabilization will become unattainable; or as referred to previously, in the application to such methods where the injection pipe itself is utilized as the bearing pile, the quantity of inside and outside connections of said pipe with solidified substance which is an important functional element in increasing the pull-out or push-in shearing resistance, will be decreased so that it will become difficult to obtain anchors or piles with initially expected pull-out resistance or the bearing power.

The use of the injection pipe as described in this Embodiment 10 is effective in solving the difficulties as mentioned above.

The uses of such injection pipes, as described in Embodiment 9, are, of course, effective in solving said difficulties. However, from the viewpoint of manufacturing injection pipes, the type described in Embodiment 10 is much more practical.

EMBODIMENT 11

This invention may also be applied to the construction of underground structures which can be effectively used as water shut-off walls.

The construction by conventional chemical injection method of a water shut-off wall in the form of a continuous row of piles consisting of consolidated earth as shown in FIG.13, when viewed from the purpose of shutting-off of water, the actually effective zone is that zone 95 which is hatched, and zone 96 without hatching is constructed just as a matter of convenience in the performance and is not functionally necessary. So, the chemicals used in zone 96 were wasted. In order to economize on the amount of chemicals, the spacing of the injection pipes is made closer and at the same time the radius of the pile-form consolidated earth is shorter. However, in this case the number of injection pipes 97 must be increased so that the economical disadvantage cannot be avoided. If the radius of pile-form consolidated earth were made shorter, then in constructing a water shut-off wall with a great depth, there is a tendency for the installed injecting pipe 97 to shift away from the proper position resulting in difficulties in the building of the continuous water shut-off wall.

While by using such injection chemical fluids which in contact with water produce water-insoluble solid substance at the same time liberating gas, it is possible to form cell-like consolidated lumps of earth. In this case injection chemical fluid is first injected into the ground through the injection pipe. Before the chemical gels,resulting from reaction with the interstice water in

the ground, while fluid condition is still maintained, it is well to follow with an injection of suitable amount of water or other liquid through the same injection pipe. By such a two-step injection method, the chemical first injected will be forced out to a distant location from the chemical outlet of the injection pipe by the second injection of the fluid, and as a result it is possible to produce in the ground cell-like consolidated lumps of earth in which the interior is not consolidated. In this case, because the central part of the consolidated lumps of earth has not come in contact with the interstice water in the ground, there is a tendency for the consolidation of said central portion to be delayed. However, if water were used for the liquid which is to be injected later while the outer side of the said cell-like consolidated lumps of earth is in contact with the interstice water contained in the ground, the inner or central portion of said lumps of earth will come in contact with the second injection of water, so when both the inside and outside of said consolidated lumps of earth are in contact with water, there is the advantage of a quick consolidation. If such a catalyst which can accelerate the chemical reaction of the injection chemical fluid is added in a small amount into the water to be used as second injection fluid, then the consolidation from the interior will be accelerated. The reaction between said chemicals and the later injected water will naturally liberate carbon dioxide gas, then under the pressure exerted by the gas, the chemical injected first will be automatically pushed out toward the outside so that with no extra work, the zone of consolidation will be enlarged, and extremely excellent results are obtained.

In general, injection chemical fluid consisting of isocyanate-type compounds compared to commonly used conventional injection chemicals is superior in producing mechanically strong consolidated lumps of earth or in shutting- or sealing-off effect of ground water. By this invention, by making effective use of the characteristics inherent in the isocyanate-type compounds, a path to a rational and economical and inexpensive use will be opened.

FIG. **14** is a partially cut perspective view of an underground fluid-tight wall and shows a staged injection method in which unit injection operations are repeated in vertical direction, thereby forming in turn cell-like consolidated lumps of earth **98** building continuously a pile-form consolidated lumps of earth **99.** Further, by connecting these pile-form, consolidated lumps of earth **99** in horizontal direction, a one body beehive-like construction of wall structure **100** is composed.

As to this fluid-tight wall, in the upper part of FIG.**14,** the zones **101** and **103,** horizontally encircled with dotted line, constitute a double-row wall structure, resulting in a more effective sealing-off of fluid. Further, the front and back continuous fluid-tight walls of zones **101** and **103** are reinforced by mutual connection at zone **103** so it is very strong and can be utilized as an underground fluid-tight wall with high dependability.

Thus, since this is a curved shell-like consolidated lump of earth and the shell-like part thereof contains the soil which is the ground-constituting substance, the amount of solidifying material used can be very small. Nevertheless, even if the ground conditions inside and outside the shell-like part undergo a change after a duration of many years following the construction thereof, the underground structure remains satisfactory in mechanical strength and hence can be maintained in a robust state, since it is a strong underground structure with a great bending moment. Moreover, its construction is very easy and economical, requiring neither excavation nor the driving of ready-made piles which requires an enormous amount of energy. When the chemical which has been pushed and spread begins to solidify, the inside and outside earth pressures are substantially balanced and in this condition, the chemical actually solidifies to form a curved shell-like body so that unlike the case, in which construction is effected by boring a hole and inserting a cylindrical concrete pile into the hole, there is no possbility of the shell-like body receiving a great earth pressure solely from the outside thereof and hence the shell-like body is not required to be designed to resist the normal earth pressure, thus providing the great advantage of effectively utilizing the total strength attained after solidification for the attainment of the intended objects.

With this arrangement, the underground structure according to the invention can also be very effectively utilized in increasing bearing strength of the ground (again both vertical and horizontal loads).

While the method of constructing such underground structures has already been described, it is preferable to use as the fluid which pushes and spreads the chemical, such as will accelerate the solidifying reaction of said chemical. Moreover, even if such fluid is a liquid other than water, it can be conveniently used in such a manner that two additional pipes for separately supplying the chemical and the fluid which is to push and spread the chemical are connected to the injection pipe **97,** said two additional pipes being adapted to alternately communicate with the injection pipe **97** through *n* valve.

EXPERIMENT

In the excavation work of shield with an inner diameter of 3 meters for the installation of sewer culvert under a street, with purpose of stabilizing of cutting face composed of water-containing sandy stratum liable to rupture, an experiment was performed by constructing beehive-type structural ground composed of continuous cell-like consolidated lumps of earth. In this experiment at the ground located in front direction of the shield excavation, chemical injection pipes were driven into the ground at intervals of 80 cm in grating-like pattern, and by using these injection pipes, a multiple-stage injection was in turn repeated and a beehive-form structure was constructed under the ground as if to cover the front side of the cutting face, composed of continuous cell-like consolidated lumps of earth as shown in FIG.**15.** In this case, the pitch of the up-and-down direction at each stage was 1.2 meter, and 40 liters of injection chemical fluid composed of isocyanate-type prepolymer were first injected and directly followed by the injection of 50 liters of water through the same injection pipe to spread while pushing the first injected chemical to a wider zone; and the same operation was repeated for each stage in turn, and the cell-like consolidated lumps of earth were connected in the front-and-back, left-to-right, and in up-and-down directions.

The beehive-form underground structure thus formed stabilized the cutting face, and showed a suitable strength without causing difficulties in excavation and perfect water seal-off effect and made the shield excavation extremely safe and easy. The injection

chemical liquid used for this case was composed of 70 parts in weight of 2 functional modified urethane prepolymer of polypropylene glycol tolylene diisocyanate, modified with hydrocarbon resin, and cut back by adding 30 parts in weight of xylene; the NCO content was 18.8% and viscosity at 20℃ 16.7 CPS. Triethylamine 0.5% of the total amount was added to this as reaction accelerating catalyst. The water injected following the chemical injection was common fresh water to which 0.1% triethylamine was added as hardening accelerator.

EMBODIMENT 12

In Embodiment 11, the solidified structure formed in the ground is described as having a cell-like solidified part in the form of a single cell and such arrangement is effective particularly as a water shutting-off wall in the ground, but in the case of forming a solidified structure, for example, a soil pile having a cell-like solidified part for the purpose of simply strengthening the ground, such cell-like solidified parts may be of the so-called continuous cell type in which each cell is partly connected to adjacent cells or to the outside.

Further, in order to strengthen the ground, the cell-like parts may be formed so as to be three-dimensionally continuous as shown in FIG.15. In FIG. 15, the numeral 110 designates a solidified cell or shell-like part and 111 designates a successive part establishing connection between adjacent unsolidified parts 112 each surrounded with the solidified cell or shell-like part. In reality, they are formed in irregular shapes.

Above described are examples of various applications of the fundamental method of this invention. In short, this invention theoretically completely differs from conventional methods in the solidification function of the chemical fluids used; and therefore it is a new and industrially very valuable invention which can subjugate in one action various difficulties arising from incapabilities in the control of the solidification speed of chemicals and the inaccuracies which were unavoidable in the conventional methods; and because it is, as already stated, not limited only to the strengthening of the ground, it has been developed to be used very effectively as a method of sealing-off of water from water-leaking portions of a building, as a method of constructing piles fixed in the ground such a an anchor or bearing piles, or as a construction method for underground structure, such as fluid-tight walls.

Some of the desirable practical modes of this invention were taken up and especially explained with reference to the accompanying drawings and they are application methods to which many changes can be added, and it must be understood that this invention is not limited only to those practical experiments.

Moreover, the mixtures of said practical examples can be mutually interchanged or can be combined into any combinations unless they are contradicting.

We claim:

1. A method of providing a pile in a ground formation having a high resistance to movement, comprising the steps of:

A. driving a perforated tubular body into the ground formation,

B. injecting a fluid substance including a liquid isocyanate through the perforated tubular body under sufficient force to cause it to pass through the perforations and to enter the soil surrounding the tubular body, the fluid substance which, when coming in contact with water, reacts therewith to produce a water-insoluble solidified substance while liberating gas, a diluent for the fluid substance, and surface active agent, which does not react with the fluid substance and which facilitates the association between the fluid substance and water and serves to improve the stability of foams formed by the fluid substance and the liberated gas,

C. reacting said fluid substance with the water in the ground formation to produce a water insoluble substance and liberate gas, and

D. consolidating the ground surrounding the pile into a first mass.

2. A method of providing a pile in a ground formation as claimed in claim 1, wherein said tubular body is left in the ground to function as the pile which has resistivity against the external force applied in the direction of longitudinal axis thereof.

3. A method of providing a pile in a ground formation as claimed in claim 1, comprising the further steps of withdrawing the tubular body longitudinally of its soil penetration before the initial charge of the fluid substance injected in the ground is consolidated and thereafter introducing secondary charges of the fluid substance sequentially while withdrawing the tubular body to thereby produce a vertically extending consolidated mass.

4. A method of providing a pile in a ground formation as claimed in claim 3, comprising the further step of constructing a wall from a row of interconnected vertically arranged consolidated masses.

5. A method of providing a pile in a ground formation as claimed in claim 1, wherein said tubular body comprises a conical drive portion at one end and open at the other end, a plurality of perforations extending through the wall of said tubular body, said perforations being inclined at an acute angle to the axis of the length of said tubular body and relative to the driving direction of said pipe.

6. A method of providing a pile in a ground formation as claimed in claim 1, wherein said tubular body comprises an open ended hollow tubular member having an inner wall, a solid, conical drive plug provided with a portion complemental to the inner wall of said tubular member, and said plug being arranged to be parted from engagement with one end of the tubular member by pulling back the tubular member, thus making a gap between the open end of the tubular member and the end of the drive plug and introducing the fluid substance under pressure through the gap into the soil.

7. A method of providing a pile in a ground formation as claimed in claim 1, wherein said tubular body has a principal diameter dimension at one end of which is positioned a drive means, said tubular body further including a perforated neck portion of lesser diameter than the principal diameter thereof, said perforated neck portion arranged in proximity to the drive means and its perforations being thereby protected from clogging with soil during the driving operation.

8. A method of providing a pile in a ground formation as claimed in claim 1, wherein the fluid substance further comprises a liquid organic silane derivative and a fine powdered carbide.

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