Dec. 14, 1971 E. J. MONAHAN 3,626,702

FLOATING FOUNDATION AND PROCESS THEREFOR

Filed Feb. 12, 1970

FIG. 1

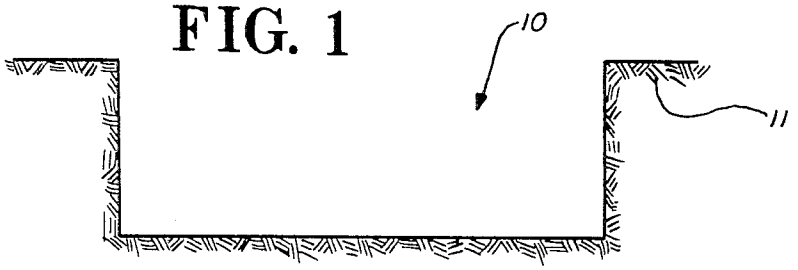


FIG. 2

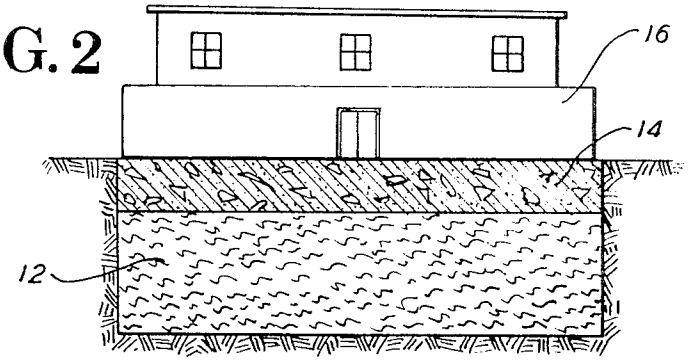


FIG. 3

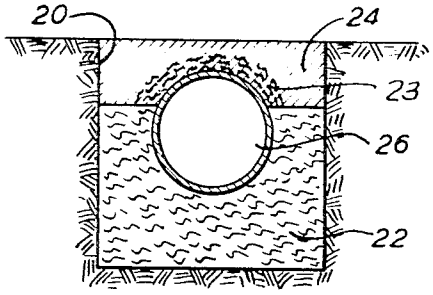
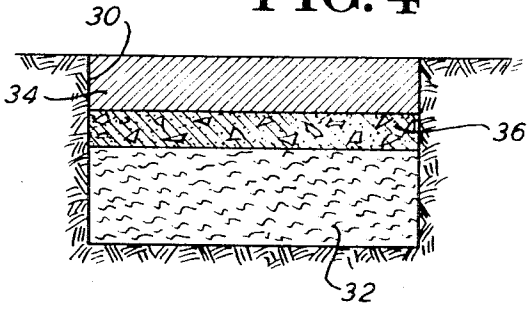


FIG. 4



INVENTOR.
EDWARD J. MONAHAN

BY

Cifelli & Behr
ATTORNEYS

United States Patent Office 3,626,702
Patented Dec. 14, 1971

3,626,702

FLOATING FOUNDATION AND PROCESS THEREFOR

Edward J. Monahan, 381 Broad St., Apt. A913, Newark, N.J. 07104

Filed Feb. 12, 1970, Ser. No. 10,843
Int. Cl. E02d 3/12, 27/36, 27/46
U.S. Cl. 61—50 13 Claims

ABSTRACT OF THE DISCLOSURE

There is provided a novel form of floating subfoundation and a method of producing the same. The novel subfoundation comprises a layer of moderately rigid, synthetic, polymeric foam placed in the excavation for a structure. A customary rigid fundation, suitably of reinforced concrete is placed over the subfoundation and the structure erected upon the rigid foundation. The novel subfoundation makes possible greatly increased structural loads on soils which are unstable and not normally considered capable of supporting high loads.

THE FIELD OF INVENTION

Novel structural foundations.

DESCRIPTION OF THE PRIOR ART

The problem of erecting structures on unstable soils is well recognized in the architectural arts and many methods have been developed to solve this problem.

Excluding the expensive alternatives of deep foundations such as piles or caissons, three different approaches have been conventionally taken to solve this problem. The approaches may be summarized as excavation, soil stabilization and flotation.

The first method is perhaps the simplest and involves excavation of the building site through the unstable soil layer down to the bedrock or to a structurally stable subsoil, with (typically) subsequent placement of compacted granular fill. This particular approach can be extremely expensive and moreover is not always practical even where the stable sub-soil is not too far from the surface. This approach is particularly impractical where the stable sub-soil or bedrock is covered with a marshy layer since in addition to the ordinary expenses of excavation, problems of pumping and drainage must be met in order to cope with seepage into the excavation.

The second approach is to attempt to stabilize the natural soil by compaction (e.g. vibroflotation for loose granular soils), surcharging (preconsolidation of compressible soils), or by injection (e.g. chemical stabilization, grouting). Generally speaking, these methods require stabilization of an area somewhat in excess of the specific area upon which the structure is to be erected, thus adding to the cost without necessarily benefiting solely the area of the building.

Classical examples of such stabilization are to be found on the island of Venice which is built upon sand islands stabilized by wooden pilings driven into the subsoil. Another classical example, which is still used today in Holland, is the placement of woven wooden matting upon the marshy soil and building upon such matting. This latter method finds a modern equivalent in the various forms of steel mats used for the construction of temporary air strips in forward military areas.

A modern variation of the soil stabilization technique is to be found in the disclosure of Jorczak et al. U.S. Pat. 3,367,892. This method contemplates the injection of a urethane prepolymer into the soil in the presence of a curing agent, a blowing agent, and a blowing delay agent. The purpose of the curing agent is to set the prepolymer into a polyurethane polymer. The purpose of the blowing agent is to cause the polymer to foam thus injecting itself into all the interstices between the soil particles and at the same time providing a structural link between them thus enhancing stabilization. Since, under normal circumstances, the heat produced by the curing step causes simultaneous blowing of the polymer, the blowing delay agent permits the mixture to penetrate into the soil before the blow stage commences.

The flotation method is utilized not only in soft, generally unstable soils, but also in areas subject to earthquake shock which would rupture conventional rigidly embedded foundations. It is customary to build such floating buildings upon a rigid concrete platform. The theoretical basis of this approach is that regardless of the specific supportive strength of the soil, any area of land will support a structure equivalent in weight to the weight of soil excavated from that area. Thus since the building would, even under the most unstable conditions, displace an amount of soil equal to or less in weight than its own weight such a building would tend to float in the soil. Unfortunately, it is not possible to cast a stable foundation platform directly onto an unstable sub-soil particularly where the unstable sub-soil is below the level of the surrounding water table. Hence, in addition to the excavation required to reduce the pressure on the area of land to be built upon in order to achieve the flotation effect, still further excavation is required followed by backfill with stable, substantially high density material, such as sand, gravel and the like. Such stabilization of course often tends to subtract from the "loss of pressure" effect obtained by the primary excavation.

It is to be understood, however, that the theory of flotation discussed above is an extreme case. That is to say, it assumes no supportive power by the soil whatsoever. In practice, of course, this is never entirely the case since even the most unstable soils usually have a certain measure of supportive power. Thus it is often possible to float low buildings on a rigid platform on unstable soils with substantially no excavation for relief of pressure.

However, if it were possible to substantially reduce the weight of stabilizing material reintroduced into the excavation, that is to say, the backfill used to stabilize the area immediately under the rigid platform foundation, it would be possible to float substantially higher buildings upon unstable soils thus giving rise to a far more efficient use of land in areas having such unstale soils.

SUMMARY OF THE INVENTION

It has been discovcered that the stabilizing influence provided by conventional backfill materials such as sand, gravel and the like can be provided by synthetic polymeric foams, suitably rigid synthetic polymeric foams, which possess sufficient compressive strength to support substantial structures while at the same time having a density far less than that of these conventional materials. The weight credit which is thus obtained by using such foams in place of conventional backfill materials may then be used in constructing structures of greater weight, presumably higher structure, on a given area of land than was heretofore possible.

Many different foams are known in the polymer art which can be used for the provision of such subfoundations. There may be mentioned polyurethane foams, polystyrene foams, epoxy foams, phenolic foams, urea formaldehyde foams and syntactic polyvinyl chloride foams, although the scope of the present invention is in no way considered as limited to these named foams. Urethane foams are the foams of choice since these foams are comparatively inexpensive, can be formulated into composi-

tions of very substantial compressive strength using formulations which are well known in the art and these foams may be readily prepared by a variety of methods.

The present invention is readily distinguished from the Jorczak (supra) method in that Jorczak seeks to stabilize an unstable soil by providing structural links between the soil particles, while the present method contemplates the total removal of a precalculated amount of soil and its replacement by a polymer foam to provide a weight credit.

The foams, in particular the urethane foams, may either be manufactured in situ to fit the specific dimensions of the foundations, or the subfoundation may be constructed from slabs of prefabricated foam having the necessary mechanical qualities which are shipped to the site of the building ready made. Both modes are to be considered to be within the scope of the present invention.

Since the art foam production is extremely voluminous, no useful purpose would be served by detailing all the modes for the production of such foams. Reference is made, however, to T. H. Ferrigno, Rigid Plastic Foams, 2nd Edition, Reinholdt Publishing Corporation, New York 1967, J. H. Saunders and C. K. Frisch, Polyurethane, Part 2, Chemistry and Technology, Interscience Publishers, New York, 1964; S. M. Kujawa, High Density Urethane Foam Prepared by the One-Shot Technique, Journal of Cellular Plastics, vol. 1, page 400, 1965, and Cear et al., SPE Technical Papers, Reports of the Technical Conference (Buffalo), Plastic Foams, paper 76 (Oct. 5, 1961).

It is further within the scope of the present inveniton that the novel subfoundations of the present invention be used in areas of construction other than the construction of the floating buildings. Specifically included within the scope of the invention are the foundations for pipelines, such as sewer and water pipelines, transcontinental oil or gas pipelines, highways, airport runways, and the like as well as backfill for foundation footings of the conventional type.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional view of an excavation for a building;

FIG. 2 is a cross-sectional elevation of the excavation of FIG. 1 showing the placement of backfill, foundation and building;

FIG. 3 is a cross-sectional view of a buried pipeline; and

FIG. 4 is a cross-sectional view of a roadbed or airport runway.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the process of the present inveniton, the area upon which a building, roadbed, runway, pipeline, or the like is to be constructed, is excavated to provide a predetermined amount of pressure release from the sub-soil on which the proposed structure will rest. In FIG. 1, the subsoil **11** is excavated to give excavation **10**.

A substantial portion of the excavation **10** is filled with a rigid polymeric foam **12**. While it is permissible to use any foam with sufficient compressive strength and resistance to water, it is especially preferred to use a rigid urethane foam which may be either cast at the site of the excavation or shipped in, in the form of precast slabs.

Urethane foams are preferred principally for reasons of cost but also since their properties may be readily varied to suit the desired conditions by means and formulations well known in the art. The urethane foams utilized in the practice of the present invention are designated as rigid urethane foams. While it is understood that the relationship between the compressive strength of a foam and its density may be varied in accordance with the formulation selected, it has been found that the most suitable range of foams are those having a compressive strength of 70 p.s.i. and a density of 4 lb. per cubic foot through those having a compressive strength of 1000 p.s.i. and a density of 20 lb. per cubic foot. This range should be in no way considered as limiting upon the invention, since foams having a compressive strength of at least 30 lb. per square inch and a density of 3 lb. per cubic foot may also be utilized in the invention, and foams having even lower compressive strengths and densities may be found useful.

The selection of a foam having a particular density must be made after taking into consideration all the circumstances of the individual case. Thus high density foams are clearly more expensive than the lower density foams due to increased cost of materials. This increase in cost must be measured against increase in compressive strength in what is substantially an exponential relationship. Furthermore, particularly when on-site production of the foam is contemplated, it should be recognized that the production of high density foams of uniform properties becomes more difficult as the density increases. This factor is due to the decreasing heat conductivity of the foams with increase in density since considerable amounts of heat are generated during the actual polymerization step and such considerations must be taken into account. However, methods for assuring satisfactory distribution of compressive strength are well known in the art.

The preferred technique for preparing the high density polyurethane foams used as backfill in the present invention is the so-called one shot technique. In this technique two carefully metered streams are brought together, one stream containing a polyhydroxy compound such as Heterofoam® (produced by Hooker Chemical Corporation) and a prepolymer or polyisocyanate stream. Optionally, the polyhydroxy stream may contain a catalyst, or when water is to be the blowing agent, the water component. The isocyanate stream contains the halocarbon blowing agent. Since the halocarbon blowing agent, suitably a polyhalohydrocarbon such as a polyfluorohydrocarbon is not reactive either with the isocyanate or the polyol, it may be also carried in the polyol stream. However, water being reactive with isocyanate cannot be carried in the isocyanate stream.

Thus it will be seen that both halocarbon and water may be utilized as the blowing agent.

Generally speaking it has been found that where foams having a density in excess of 6 lb. per cubic foot are to be produced, it is not necessary to employ a catalyst since the use of such a catalyst would cause too rapid a rise in the internal temperature of the foam during the polymerization step.

If desired a cell controller of the type known in the art may be utilized to control excessive size of the bubbles arising from the blowing agent system. It has been found, however, that where the foams projected are in the 10 to 20 lb. per cubic foot range such cell controllers are not necessary.

In the production of subfoundations in accordance with the present invention, conventional polyurethane components such as those discussed above are mixed in conventional one-shot machinery and injected into the excavation to form layer **12** as shown in FIG. 2. In dealing with high density urethane foams care must be taken that each layer of foam deposited be not excessively thick in order to avoid scorching and cracking of the foam in the process of formation. While not to be taken as limiting conditions, nevertheless it is advisable where foams of 6 lb. per cubic foot density are to be utilized each layer be not in excess of 14 inches in thickness or if a density as high as 24 lb. per cubic foot is required, the layer thickness should not be in excess of 5 inches. These depths of course can be well controlled by means familiar to those skilled in the art. Thus where the subfoundations are precast, the slabs should not exceed those dimensions. Similarly where in situ casting is employed, the foundations are cast in layers corresponding to those thicknesses. Conventional engineering techniques may be employed to prevent the sliding of layers over each other.

It should be noted that the insulating and impact protecting qualities of foams can be readily utilized in this technique. For example, where a pipeline **26** is to be laid in unstable ground, the foam **22** is injected into the excavation trench, the pipeline is laid over the partially filled trench and said pipeline **26** is then further embedded in more foam. Optionally the foam may cover the entire circumference of the pipeline prior to being covered by the surface layer of soil **24**, the optional layer being designated **23**.

In the construction of roads or runways for aircraft an excavation **30** is similarly filled with the layer of foam **32** which is then covered with the substantially rigid layer **36** which may comprise concrete, low mesh asphalt, or the like and a surface layer **34** which may be concrete or high mesh asphalts. If desired, intermediate layer **36** may be omitted.

As examples of the formulation and production conditions for formation of certain foams within the scope of the present invention, the following may be mentioned. However, these examples are given for purposes of exemplification only and not for the purposes of limitation.

Example 1.—Conditions for producing 20 PCF foam—6" bun

Formulation:
- Heterofoam [1] polyol—100 pts. (polyol steam)
- Polyphenyl isocyanate—84 pts.
- Halocarbon blowing agent—3 pts. (isocyanate steam)
- Cell controller—0.5

Machine conditions:
- Polyol/isocyanate steam—114.3/100
- Dispense rate, p.p.m.—28.6
- Mixer speed, r.p.m.—5000 plus
- Polvol temperature, ° F.—112
- Isocyanate steam temp., ° F.—70
- N_2 pad on reservoirs, p.s.i.g.—15

[1] Registered trademark, Hooker Chemical Corp.

Example 2.—Conditions for producing 4 PCF foam—12" bun

Formulation:
- Heterofoam polyol—100 pts. (polyol steam)
- Polyphenyl isocyanate—84 pts.
- Halocarbon blowing agent—12 pts. (isocyanate steam)
- Cell controller—1 pt.

Machine conditions:
- Polyol/isocyanate steam—103.1/100
- Dispense rate, p.p.m.—28.6
- Mixer speed, r.p.m.—5000 plus
- Polyol temperature, ° F.—130
- Isocyanate temp., ° F.—70
- N_2 pad on reservoirs, p.s.i.g.—15

Example 3.—Conditions for high rise 8 PCF panel

Formulation:
- Heterofoam polyol—100 pts. (Propyl Steam)
- Triethylamine catalyst—0.1 pt.
- Polyphenyl isocyanate—84 pts. (Isocyanate Steam)
- Halocarbon blowing agent—9 pts.
- Cell controller—1 pt.

Machine Conditions:
- Polyol/isocyanate steam—108/100
- Mixer speed, r.p.m.—5000 plus
- Dispense rate, p.p.m.—39.6
- Polyol temp., ° F.—104
- Isocyanate temp., ° F.—70
- N_2 pad on reservoirs, p.s.i.g.—15
- Substrate temp., ° F.—150

ILLUSTRATION OF WEIGHT CREDIT

Material—Density of soil 100 lb. per cubic foot.
Size of excavation—15 ft. depth by 10 by 10 ft.
Density of foam—5 lb. per cubic foot
Compressive strength of foam—30 lb. per square inch

The total weight of soil removed is 150,000 lb. thus the pressure relief at the base of the 15 ft. excavation is 1,500 lb. per square foot. Thus since the total weight of foam inserted as backfill is 7,500 lb., the added pressure is only 75 lb. per square foot. Thus there is a credit available for building pressure of 1,425 lb. per square foot.

This represents an advantage over present methods of 925 lb. per square foot since conventionally unstable marginal layers having a water table at or substantially at the surface are permitted to sustain a building pressure of 500 lb. per square foot.

The foam plastic has a strength of 30 lb. per square inch. A building pressure of 1425 lb. per square foot is equivalent to approximately 10 lb. per square inch. Thus such a building load allows a considerable safety factor with respect to the strength of the plastic foam.

The foregoing illustration may be summarized mathematically as follows:

Where P_B is the downward pressure of the structure over the foundation area

L is the load bearing pressure of the unstable soil
D*e* is the density of the soil
D*p* is the density of the plastic used
Z is the depth of the excavation and
C is the compressability of the foam, then

$$L+[De-Dp]Z>P_B<C$$

It will be clear to those skilled in the art that D*p*, Z and C can be varied to provide the desired safety factor and P_B can be decreased by providing a rigid platform foundation thus increasing the area over which the building presence is applied.

I claim as my invention:

1. A subfoundation for a structure exerting a downward pressure in excess of the building pressure sustainable by an unstable soil which comprises a layer of rigid foam plastic placed below the structure, said foam layer replacing soil originally present wherein P_B is the downward pressure of the structure over the foundation area,
L is the load bearing pressure of the unstable soil
D*e* is the density of the soil
D*p* is the density of the plastic used
Z is the depth of the excavation, and
C is the compressability of the foam, then

$$L+[De-Dp]Z>P_B<C$$

2. A subfoundation according to claim **1** additionally comprising a rigid platform located between the bottom of the structure and top of the foam layer wherein P_B is the pressure exerted on the foam over the area of the platform by the combined weight of the structure and the platform.

3. A foundation according to claim **1** wherein the foam comprises a foam selected from the group consisting of polyurethane, polystyrene, phenolic epoxy, urea formaldehyde, and syntactic polyvinyl chloride foams, and combinations thereof.

4. A foundation according to claim **3** wherein said foam has a density of between 3 and 20 lb. per cubic foot and a compressive strength of between 30 and 1000 lb. per square inch.

5. A foundation according to claim **3** wherein the foam is polyurethane foam having a density of at least 3 lb. per cubic foot and a compressive strength of at least 30 lb. per square inch.

6. A formulation according to claim **1** wherein the structure is a subterranean pipe and the foam subfoundation is located under the partially encompassing outer circumference of the pipeline.

7. A foundation according to claim **6** additionally comprising a layer of said foam encompassing the remaining portion of the circumference of said pipeline.

8. A process for providing a structural subfoundation according to claim 1 which comprises the steps of

(a) excavating the soil of said foundation

(b) partially filling said foundation with a rigid polymeric foam.

9. A process according to claim 8 wherein the polymeric foam is produced in the site of the excavation.

10. A process according to claim 8 wherein the foam layer is produced by casting thin layers of foam on top of each other.

11. A process according to claim 8 wherein the polymeric foam is precast and subsequently installed in the foundation in slab form.

12. A process according to claim 8 wherein the polymeric foam is foam selected from a group consisting of polyurethane, polystyrene, epoxy, phenolic urea formaldehyde, and syntactic polyvinyl chloride foams.

13. A process according to claim 8 wherein the foam is polyurethane foam having a density of at least 3 lb. per cubic foot and a compressive strength of at least 30 lbs. per square inch.

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JACOB SHAPIRO, Primary Examiner

U.S. Cl. X.R.

52—169; 61—72.1; 94—7; 138—105