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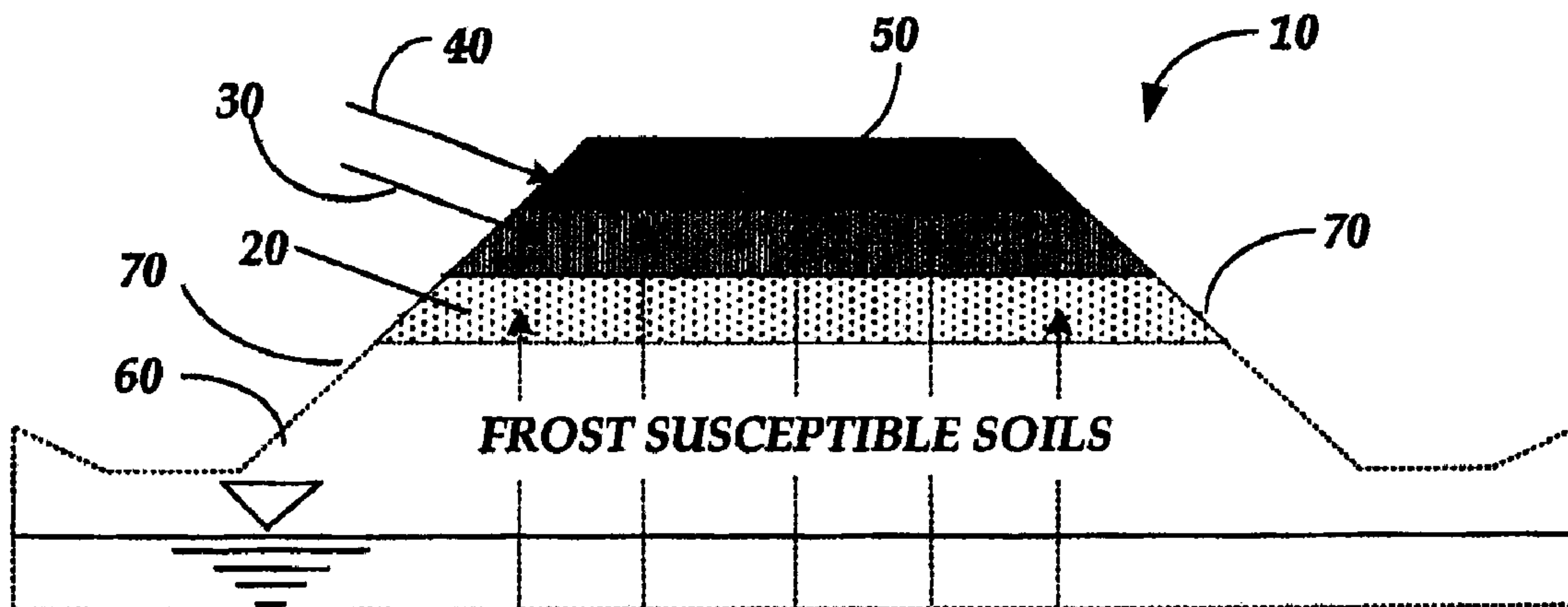
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(54) Titre : TISSU GEOSYNTHETIQUE TISSE AVEC CAPACITE D'IMBIBITION PAR CAPILLARITE DIFFERENTIELLE

(54) Title: WOVEN GEOSYNTHETIC FABRIC WITH DIFFERENTIAL WICKING CAPABILITY



(57) Abrégé/Abstract:

The present invention is directed to a geosynthetic wicking fabric for transporting water from beneath pavement structures to reduce or prevent damaged caused by frost heave and thaw. Further, the present invention is directed to a wicking drainage system employing the wicking fabric.



ABSTRACT

The present invention is directed to a geosynthetic wicking fabric for transporting water from beneath pavement structures to reduce or prevent damaged caused by frost heave and thaw. Further, the present invention is directed to a wicking drainage system employing the wicking
5 fabric.

1 **WOVEN GEOSYNTHETIC FABRIC WITH DIFFERENTIAL WICKING**
2 **CAPABILITY**

3

4 **TECHNICAL FIELD OF THE INVENTION**

5 The present invention is related generally to woven fabrics. More specifically, the
6 present invention is related to geosynthetic wicking fabrics and pavement structures
7 employing same.

8

9 **BACKGROUND OF THE INVENTION**

10 Frost heave and thaw weakening can cause damage to pavement structures,
11 such as parking areas, roadways, airfields, etc., in northern regions. The formation of
12 ice lenses in the pavement structure is a significant contributor to such damage, as
13 illustrated in FIGURE 1. Three elements are necessary for ice lenses, and thus frost
14 heave, to form. These are: (1) frost susceptible soil, (2) subfreezing temperatures, and
15 (3) water. Often, water is available from the groundwater table, infiltration, an aquifer, or
16 held within the voids of fine-grained soil. By removing any of the three elements above,
17 frost heave and thaw weakening can be at least minimized or eliminated altogether.

18 Techniques have been developed to mitigate the damage to pavement structures
19 caused by frost heave and thaw weakening. One such method involves removing the
20 frost susceptible soils and replacing them with non-frost susceptible soils. The non-frost
21 susceptible soil is placed at an adequate thickness to reduce the strain in the frost-
22 susceptible soil layers below to an acceptable level. Other methods include use of
23 insulation to reduce the freeze and thaw depth. In areas where removal of frost
24 susceptible soils and reduction of subfreezing temperature are difficult and expensive,
25 removal of water can lead to savings in construction costs by reducing the formation of
26 ice lenses. By breaking the capillary flow path, frost action can be less severe.

27 A capillary barrier is a layer of coarse-grained soils or geosynthetic in a fine
28 grained soil that (i) reduces upward capillary flow of soil water due to suction gradient
29 generated by evaporation or freezing, and (or) (ii) reduces or prevents water from
30 infiltrating from the overlying fine-pored unsaturated soil into the soil below the capillary
31 barrier. In the latter case, if the capillary barrier is sloped, the infiltrating water flows in
32 the fine soil downwards along the interface with the capillary barrier. Geosynthetic
33 drainage nets (geonets) have been found to serve as capillary barriers because of their
34 large pore sizes. The performance of nonwoven geotextiles as a capillary barrier

1 appears to be compromised by soil intrusion into their interiors, decreasing the pore size
2 and increasing the affinity of the material to water. Further, as reported by Henry (1998),
3 "The use of geosynthetics to mitigate frost heave in soils." Ph.D. dissertation, Civil
4 Engineering Department, University of Washington, Seattle, hydrophobic geotextiles
5 have been more effective in reducing frost heave than hydrophilic geotextiles.

6 The above mentioned capillary barriers attempt to cut off the capillary water flow
7 by generating a horizontal layer with very low unsaturated permeability under suction.
8 The whole structure is permeable for downward rainfall infiltration. This type of capillary
9 barrier requires that the barrier thickness exceed the height of the capillary rise of water
10 in them. In addition, it provides conditions suitable for water vapor flow because of their
11 high porosity and comparatively low equilibrium degrees of saturation.

12 Thus, there remains a need for a woven geosynthetic fabric with differential
13 wicking capability that reduces or eliminates frost heave in soils. Accordingly, it is to
14 solving this and other needs that the present invention is directed.

16 SUMMARY OF THE INVENTION

17 The present invention is directed to a woven geotextile wicking fabric. The
18 wicking fabric comprises a polymeric yarn disposed in one axis of the fabric and a
19 plurality of wicking fibers disposed substantially parallel to one another and woven with
20 the polymeric yarn in another axis of the fabric. The wicking fiber comprises a non-
21 round or non-oval cross-section and has a flux of about 100 cc/g/hr to about 250 cc/g/hr.
22 In one aspect of the present invention, the cross-sectional shape of the wicking fiber is
23 multichannel, trilobal, or pillow.

24 In another aspect of the present invention, a wicking drainage system is
25 disclosed. The wicking drainage system comprises a wicking fabric layer disposed on a
26 layer of frost susceptible soil. A layer of non-frost susceptible soil is disposed on the
27 wicking fabric. Optionally, a base layer for supporting asphalt and/or concrete is
28 disposed on the non-frost susceptible soil. The wicking drainage system can further
29 comprise an impermeable hydrophobic geomembrane disposed below the wicking
30 fabric. Further, the wicking fabric can be tilted with respect to the water table and/or the
31 asphalt and/or concrete layer being supported by the wicking drainage system.

32 Yet, in another aspect of the present invention, a wicking drainage system
33 comprises a wicking fabric layer disposed on a first layer of frost susceptible soil. A
34 second layer of frost susceptible soil is disposed on the wicking fabric layer. Disposed

1 on the second layer of frost susceptible soil is a geotextile layer. A layer of non-frost
2 susceptible soil is disposed on the geotextile layer. Optionally, a base layer for
3 supporting asphalt or concrete is disposed on the non-frost susceptible soil. The
4 geotextile layer can be another wicking fabric layer.

5 It is to be understood that the phraseology and terminology employed herein are
6 for the purpose of description and should not be regarded as limiting. As such, those
7 skilled in the art will appreciate that the conception, upon which this disclosure is based,
8 may readily be utilized as a basis for the designing of other structures, methods, and
9 systems for carrying out the present invention.

10 Other advantages and capabilities of the invention will become apparent from the
11 following description taken in conjunction with the accompanying drawings showing the
12 embodiments and aspects of the present invention.

14 **BRIEF DESCRIPTION OF THE DRAWINGS**

15 The invention will be better understood and the above objects as well as objects
16 other than those set forth above will become apparent when consideration is given to the
17 following detailed description thereof. Such description makes reference to the annexed
18 drawings wherein:

19 FIGURE 1 is an illustration of the formation of ice lenses in a pavement structure;

20 FIGURE 2 is an illustration of wicking fiber cross-sections employed in the
21 present invention;

22 FIGURE 3 is an illustration of a wicking drainage system in accordance with the
23 present invention;

24 FIGURE 4 is an illustration of another aspect of the wicking drainage system in
25 accordance with the present invention;

26 FIGURE 5 is an illustration of yet another aspect of the wicking drainage system
27 in accordance with the present invention;

28 FIGURE 6 is an illustration of still another aspect of the wicking drainage system
29 in accordance with the present invention;

30 FIGURE 7 is a graph illustrating sieve analysis of silt taken from the Cold
31 Regions Research and Engineering Laboratory (CRREL) permafrost tunnel;

32 FIGURE 8 is a graph illustrating sieve analysis of D1 material in Fairbanks;

33 FIGURE 9 is a graph illustrating compaction test results for silts from CRREL
34 permafrost tunnel;

FIGURE 10 is a graph illustrating compaction test results for Fairbanks D1 material with 10% fines; and

FIGURE 11 is comparison of gravimetric water content to matric suction for Fairbanks D1 material.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is directed to a woven, wicking fabric that optimizes capillary tension substantially in a single axis to enhance dewatering around the fabric protected area versus conventional fabrics. For example U.S. Patent No. 6,152,653 describes a geocomposite capillary barrier drain (GCBD) for displacing water from beneath pavement. The GCBD system employs a transport layer, a capillary barrier and a separator layer. Specifically, the GCBD transport layer utilizes the capillary properties of a fiberglass fabric to displace water away from the paved surface. In accordance with the present invention, the novel woven fabric described below can be incorporated into the GCBD system by replacing the fiberglass fabric. Further, the novel woven fabric of the present invention can be employed to replace the GCBD system altogether.

In accordance with the present invention, a geotextile woven, wicking fabric comprises a conventional yarn or a filament in one axis and a wicking fiber woven with the yarn or filament in another axis to form the fabric. For example, the wicking fiber can be woven into the wicking fabric in either the warp or the weft directions. The wicking fiber has a non-round or non-oval cross-section with a surface factor between about 1.5 and about 3.3. In another aspect the wicking fiber has a flux range of about 100 cc/g/hr to about 250 cc/g/hr. Yet, in another aspect the wicking fiber maintains at least about 80 % flux up to 60,000 ft-lb/ft³. Still, in another aspect the wicking fiber maintains unsaturated hydraulic conductivity in environments having saturations between 100 % and 17 %. As indicated above the fabric of the present invention finds utility in civil engineering applications. The polymers described below can be employed to make the conventional yarn or filament.

Wicking Fibers

In one aspect of the present invention, wicking fibers are woven into a wicking fabric substantially parallel to one another. As a result, a fluid, such as water, is transported along the wicking fibers to the periphery of the woven fabric of the present invention. That is, the wicking fibers move the fluid substantially along a single axis.

1 Wicking fibers employed in the present invention have a high surface factor of greater
2 than 1.5 as compared to a round cross-sectional fiber of the same denier having a high
3 surface factor of 1.0. Such wicking fibers generate increased capillary action over round
4 cross-sectional fibers of the same denier. Several types of fibers can be employed in the
5 present invention and are described below.

6 U.S. Patent No. 5,200,248, describes capillary channel polymeric fibers that can
7 be employed in the present invention. Such fibers store and transport liquid and have
8 non-round, cross-section shapes which include relatively long thin portions. The cross-
9 section shapes are substantially the same along the length of the fiber. Further, these
10 capillary channel fibers can be coated with materials that provide an adhesion tension
11 with water of at least 25 dynes/cm.

12 U.S. Patent No. 5,268,229 describes fibers that can be employed in the present
13 invention. These fibers have non-round cross-sectional shapes, specifically "u" and "E"
14 shaped cross-sections with stabilizing legs. Further, these fibers are spontaneously
15 wettable fibers and have cross-sections that are substantially the same along the length
16 of the fiber.

17 U.S. Patent No. 5,977,429 describes fibers having distorted "H" shape, a
18 distorted "Y" shape, a distorted "+" shape, a distorted "U" shape, and a distorted shape
19 of a spun fiber that is referred to as "4DG". Such fibers can be employed in the present
20 invention.

21 U.S. Patent No. 6,103,376 describes a bundle of synthetic fibers for transporting
22 fluids which can be employed in the present invention. The bundle comprises at least
23 two fibers that when acting as individual fibers are poor transporters of fluids, yet when
24 in a bundle the fibers provide a bundle that is an effective transporter of fluids. As
25 described, the bundle has a Specific Volume greater than 4.0 cubic centimeters per
26 gram (cc/gm), an average inter-fiber capillary width of from 25 to 400 microns, and a
27 length greater than one centimeter (cm). At least one of the two fibers has a non-round
28 cross-section, a Single Fiber Bulk Factor greater than 4.0, a Specific Capillary Volume
29 less than 2.0 cc/gm or a Specific Capillary Surface Area less than 2000 cc/gm, and more
30 than 70% of intra-fiber channels having a capillary channel width greater than 300
31 microns.

32 Wicking fibers employed in the present invention are made from the major melt
33 spinnable groups. These groups include polyesters, nylons, polyolefins, and cellulose
34 esters. Fibers from poly(ethylene terephthalate) and polypropylene are useful in the

1 present invention at least because of their manufacturability and wide range of
2 applications. The denier of each fiber is between about 15 and about 250, or between
3 about 30 and about 170.

4 In addition, wicking fibers can be formed from other polymers that shrink
5 significantly when heated, such as polystyrene or foamed polystyrene. The step of
6 shrinking introduces the distortion in the fiber that increases long-range distortion factor
7 (LRDF) and short range distortion factor (SRDF). The relatively large values of LRDF
8 and/or SRDF of the fibers described in U.S. Patent No. 5,977,429 provide their utility in
9 absorbent products. Shrinking occurs for oriented amorphous polymeric fibers when the
10 fibers are heated above their glass transition temperature. The shrinking occurs either
11 prior to or in the absence of substantial crystallization.

12 As indicated above, the wicking fibers of the present invention can be made of
13 any polymeric material that is insoluble in the fluid which is to be contacted with the
14 capillary channel structures. For example, the polymer utilized can be a thermo-plastic
15 polymer, which can be extruded and drawn via an extrusion process to form the final
16 product. Examples of suitable polymeric materials, in addition to polyester, polystyrene
17 and polyolefins such as polyethylene and polypropylene, include polyamides, chemical
18 cellulose-based polymers such as viscose and di- or tri-ace-. Co-, ter-, etc. polymers and
19 grafted polymers can also be used. One type of thermoplastic polymer can be employed
20 in the present invention are polyesters and copolymers of dicarboxylic acids or esters
21 thereof and glycols. The dicarboxylic acid and ester compounds used in the production
22 of polyester copolymers are well known to those of ordinary skill in the art. They include
23 terephthalic acid, isophthalic acid, p,p'-diphenyldicarboxylic acid, p,p'-dicarboxydiphenyl
24 ethane, p,p'-dicarboxydiphenyl hexane, p,p'-dicarboxydiphenyl ether, p,p'-
25 dicarboxyphenoxy ethane, and the like, and the dialkylesters thereof that contain from 1
26 to about 5 carbon atoms in the alkyl groups thereof.

27 Aliphatic glycols useful for the production of polyesters and copolyesters are the
28 acrylic and alicyclic aliphatic glycols having from 2 to 10 carbon atoms, such as ethylene
29 glycol, trimethylene glycol, tetramethylene glycol, pentamethylene glycol, and
30 decamethylene glycol.

31 It is additionally contemplated to utilize copolymers or graft copolymers,
32 terpolymers, chemically modified polymers, and the like, which permanently exhibit high
33 surface hydrophilicity and do not require the use of wetting agents, which may wash
34 away from the structure surface upon contact with fluids. Modified polymers which can

1 exhibit permanent hydrophilicity include chemical cellulose polymers such as cellulose
2 acetates. In addition, one can also include pigments, delusterants or optical brighteners
3 by the known procedures and in the known amounts.

4 A type of polyester which can be employed in the present invention is glycol
5 modified poly(ethylene terephthalate) (pETG) copolyester. Suitable PETG is
6 available from Eastman Chemical Products, Inc. (Kingsport, Tenn., USA), under the
7 name KODAR TM 6763, with a glass transition temperature of about 81 °C.

8 Another factor affecting polymer choice is amenability to chemical modification of
9 its surface for increasing, for example, hydrophilicity. Thus, for capillary channel
10 structures intended for absorbing and/or transporting aqueous based solutions, it can be
11 advantageous to use a polyester-based polymer rather than, for example, a
12 polypropylene. However, this selection option is not meant to thereby limit the scope of
13 the invention. Also, depending upon the intended use of the structures, it can be
14 desirable that the polymer material utilized be flexible at the temperatures at which the
15 structures are intended to be used. Due to the relatively thin walls and bases of the
16 structures hereof, even relatively high modulus polymers can be used to make structures
17 that are both flexible and soft, yet which retain surprisingly high resistance to collapse.
18 Flexibility will depend upon such factors as the thickness and dimensions of the capillary
19 channel walls and base, as well as the modulus of elasticity. Thus, choice of polymer in
20 this regard will be highly subject to the intended use and temperature conditions. Choice
21 of such suitable polymer material is well within the ability of one of ordinary skill in the
22 art.

23 Depending upon the intended use, the capillary channel structures can be made
24 from polymers that are either hydrophilic or oleophilic, or can be treated to be hydrophilic
25 or oleophilic.

26 The surface hydrophilicity of polymers used to make the capillary channel
27 structures of the present invention can be increased to make the capillary channel walls
28 more wettable to water or aqueous solutions by treatment with surfactants or other
29 hydrophilic compounds (hereafter, collectively referred to as "hydrophilizing agents")
30 known to those skilled in the art. Hydrophilizing agents include wetting agents such as
31 polyethylene glycol monolaurates (e.g., PEGOSPERSE.TM. 200ML, a polyethylene
32 glycol 200 monolaurate available from Lonza, Inc., Williamsport, Pa., USA), and
33 ethoxylated oleyl alcohols (e.g., VOLPO.TM.-3, available from Croda, Inc., New York,
34 N.Y., USA). Other types of hydrophilizing agents and techniques can also be used,

1 including those well known to those skilled in the fiber and textile arts for increasing
2 wicking performance, improving soil release properties, etc. These include, for example,
3 surface grafting of polyacrylic acid. Suitable commercially available hydrophilizing
4 agents include ZELCON.TM. soil release agent, a nonionic hydrophile available from
5 DuPont Co., Wilmington, Del. (USA) and Milease T.TM., comfort finish available from ICI
6 Americas, Inc., Wilmington, Del., USA. In addition, IRGASURF™, ceramic microbeads
7 and vinyl pyrrolidone can be employed as hydrophilic or hygroscopic additives.

8 The capillary channel structures of the wicking fibers have an axial base and at
9 least two walls extending from the base, whereby the base and walls define at least one
10 capillary channel. Certain of such fibers have at least five walls and at least four
11 capillary channels. Others can have at least six walls and at least five capillary
12 channels. There is no theoretical maximum number of capillary channels that the
13 structure hereof can have, such maximum number of capillary channels being governed
14 more by need for such structures and practicability of making them. In one aspect of the
15 present invention, the capillary channels are substantially parallel with one another and
16 an open cross-section along at least about 20% of their length, along at least about 50%
17 of their length or and along from at least 90% to 100% of their length.

18 Wicking fibers of the present invention provide flexible, collapse-resistant,
19 capillary channel structures comprising a polymer composition and having at least one
20 intrastructure capillary channel, wherein the structures have an axial base and at least
21 two walls extending from the base, typically (but not necessarily) along substantially the
22 entire length of the base element, whereby the base element and walls define said
23 capillary channel(s). In general, the walls should extend from the base for a distance in
24 the axial direction of the base for at least about 0.2 cm. In another aspect of the present
25 invention, the walls extend from the base for a distance in the axial direction of the base
26 for at least about 1.0 cm. The actual length of the structure is limited only by practical
27 concerns. Although the capillary channel structures hereof can have one capillary
28 channel or a plurality of capillary channels, for convenience the plural form "channels" is
29 used with the intent that it shall refer to a singular "channel" in structures having only one
30 such channel or a plurality of channels in structures having more than one channel. The
31 structures are further characterized in that the capillary channels are open along a
32 substantial length such that fluid can be received from outside of the channel as a result
33 of such open construction. In general, the structures will typically have Specific Capillary
34 Volume (SCV) of at least about 2.0 cc/g, at least about 2.5 cc/g or at least about 4.0

1 cc/g, and a Specific Capillary Surface Area (SCSA) of at least about 2000 cm²/g, at least
2 about 3000 cm²/g or at least about 4000 cm²/g. The procedures to be used for
3 measuring SCV and SCSA are provided in at least one of the patents recited
4 above.

5 The wicking fibers of the present invention have a surface composition that is
6 hydrophilic, which may be inherent due the nature of the material used to make the
7 fibers or may be fabricated by application of surface finishes. Hydrophilic surface
8 finishes provide structures the surfaces of which have large adhesion tension (i.e., that
9 strongly attract) with aqueous liquids and are therefore preferred for applications
10 involving aqueous liquids such as those discussed below for temporary
11 acquisition/distribution structures and permanent storage structures. In one aspect, the
12 hydrophilic surface has an adhesion tension with distilled water greater than 25
13 dynes/cm as measured on a flat surface having the same composition and finish as the
14 surface of the fiber. Some of the finishes/lubricants useful to provide large adhesion
15 tensions to aqueous liquids are described or referenced in U.S. Pat. No. 5,611,981.
16 Surface finishes are well known in the art.

17 As discussed above, the wicking fibers have channels on their surface which
18 may be useful in distributing or storing liquids when the proper surface energetics exist
19 on the surface of the fibers, such as when the fibers satisfy the above equation relating
20 to specific surface forces. The surface energetics determine the adhesion tension
21 between the surface and whatever liquid is in contact with the surface. The larger the
22 adhesion tension, the stronger the force of attraction between the liquid and the surface.
23 The adhesion tension is one factor in the capillary forces acting on the liquid in a
24 channel. Another factor affecting the capillary forces acting on a liquid in a channel is
25 the length of the perimeter of the channel. When the widths of the channels are small,
26 the capillary forces are relatively strong compared to the force of gravity on the liquid,
27 since the force of gravity on the liquid in a channel is proportional to the area of the
28 channel.

29 FIGURE 2 illustrates wicking fiber cross-sections of multichannel, trilobal, and
30 pillow that can be employed in the present invention. However, as indicated in patent
31 discussed above, other shapes can be employed in the present invention. The
32 multichannel is also referred to as the "4DG" shape.

33 In one aspect of the present invention, a wicking fabric made from nylon has high
34 wettability similar to fiberglass. The wicking fabric has a high specific surface area of

1 3650 cm²/g and high permeability of 0.55cm/s (equivalent to a flow rate of 1385
2 l/min/m²).

4 Weaves

5 Weaves which can be employed in the present invention include, but are not
6 limited to, plain, twills, specialty weaves, 3-D's, satins, sateens, honeycombs, lenos,
7 baskets, oxfords, or panamas. Figure 2 is a photomicrograph of a geosynthetic fabric of
8 the present invention.

10 Wicking Drainage System

11 Referring to FIGURE 3, in accordance with the present invention, a wicking
12 drainage system 10 comprises a wicking fabric 20, a non-frost susceptible soil layer 30
13 disposed over the wicking fabric, and a base layer 40, such as an asphalt treated base,
14 disposed on the soil layer 30. Asphalt and/or concrete 50 are disposed on the base
15 layer 40. The wicking fabric 20 is disposed on frost susceptible soil bed 60. The frost
16 susceptible soil bed 60 is raised above the water table to form side drains 70 which
17 facilitate water drainage. The thickness of the frost susceptible soil bed 60 is
18 conventional. For example, soil bed 60 can be 40 inches above the water table. Non-
19 frost susceptible soil layer 30, such as the D1 material with 10% fines content described
20 below, should be of a sufficient thickness as to allow water drainage from the base layer
21 40 to the wicking fabric 20. In one aspect of the present invention, the thickness of the
22 non-frost susceptible soil layer 30 is about 13 inches. However, the thickness can be
23 varied as necessary depending upon soil conditions.

24 In another aspect of the present invention, the wicking drainage system
25 comprises an impermeable hydrophobic geomembrane (not shown) disposed below the
26 wicking fabric 20. The wicking fabric 20 allows water from the overlying soil to pass
27 through the wicking fabric 20 when the overlying soil is saturated and transport water
28 laterally to side drains 70. When the overlying soil is unsaturated, the wicking fabric can
29 absorb water from the overlying unsaturated soil and transport it in the lateral directions.
30 The impermeable hydrophobic geomembrane can repel water and completely cut off the
31 capillary rise of ground water from beneath. In another aspect of the present invention,
32 the geomembrane can be a one-way-valve geotextile.

33 In an alternate design, the wicking drainage system comprises the arrangement
34 as shown in FIGURES 4-6. When installed in the pavement structure, the wicking fabric

1 20 is tilted at a slope from 5–10% so that infiltrating water will flow down dip.
2 Furthermore, there should not be wrinkles of any significance that would cause water to
3 pond on top of impermeable layer. Figure 4 illustrates the wicking drainage system 10 of
4 FIGURE 3 with the tilted arrangement.

5 As illustrated in FIGURE 5, a second layer of wicking fabric 20 is employed in the
6 wicking drainage system 10. Disposed between the respective layers of wicking fabrics
7 20 is a layer of frost susceptible soil. In another aspect of the present invention, as
8 illustrated in Figure 6, the wicking fabric 20 is disposed on a layer of frost susceptible soil
9 60. Further, another layer of frost susceptible soil 60 is disposed on the wicking fabric
10 20. A geotextile separation layer 80 is disposed on the second layer of frost susceptible
11 soil 60, and a layer of non-frost susceptible soil 30 is disposed on the geotextile
12 separation layer 80.

13 The overall effect of the wicking drainage system is to cut off upward capillary
14 water flow and drain most of the infiltrated water out of the pavement structure through
15 the tilted drainage net by the wicking fabric. The driving force for the water flow in the
16 drainage net is gravity and the driving forces for the water flow in the wicking fabric are
17 gravity and suction generated by evaporation and freezing.

18

19 **EXAMPLES**

20 **Example 1: Sieve Analysis and Gradation Curves for Two Typical Soils in Alaska**

21 Two typical soils employed in Alaskan pavements were collected. These soils
22 were Fairbanks silt obtained from the CRREL permafrost tunnel and D1 material
23 obtained from University Ready Mix Company. Silt is a frost-susceptible soil and
24 typically used as subgrade for Alaska pavements. The silt from the CRREL permafrost
25 tunnel was sieved to remove organic material. A sieve analysis was performed on the
26 silt and is shown in FIGURE 7.

27 The D1 material was a typical non-frost susceptible material which is typically
28 employed as base courses in Alaska pavements. To be qualified as a D1 material, the
29 fines content has to be less than 4%. In this example, sieve analysis was made for the
30 Fairbanks D1 material and fines with grain size less than 0.075mm was added to make a
31 new frost susceptible material with 10% fines content. The gradation curves for the
32 original and fabricated D1 materials are shown in FIGURE 8.

33

34 **Example 2: Modified Proctor Compaction Tests**

1 The Fairbanks silt and the D1 material with 10% fines content were compacted in
2 accordance with ASTM D1557 in order to simulate the compaction process in the field.
3 The compaction test results are as shown in FIGURES 9 and 10.
4

5 Example 3: **Soil Water Characteristic Curve**

6 Pressure plate tests in accordance with ASTM D2325-68 were used to obtain the
7 water retention characteristic curve in the range from 0 to 1500kPa. The salt
8 concentration tests were used to measure the soil water characteristic curve for suction
9 values are greater than 1,500kPa. FIGURE 11 shows the test results for Fairbanks D1
10 Material.
11

12 Example 4: **Soil Column Tests**

13 Using the D-1 material with 10% fines and at the optimum moisture content,
14 cylinders were constructed. The cylinders were compacted in five layers, 52 blows to
15 each layer. Geosynthetic materials were placed above the second layer. 13 different
16 cylinders were made testing 5 different geosynthetic materials ((Nylon Wicking Fabric,
17 Glass Fabric, HP570, FW402, and HIPS board). 5 cylinders were made with the
18 geosynthetic material being the same size as the cylinder and 5 cylinders were made
19 with the appropriate geosynthetic material protruding outwards in order to understand
20 the effects and advantages of drainage capabilities for each geosynthetic material. A
21 membrane was placed around each cylinder in order to retain the moisture within the
22 cylinder. Baths were setup to allow for water infiltration from the bottom of the cylinder.
23 The evaporation within the room that the water baths were put in was measured by filling
24 a glass full of water and measuring the weight of the glass of water each day for one
25 week. Water was added to the water baths throughout the week.
26

27 Example 5: **Laboratory Capillary Rise Tests and Soil Water Characteristic Curves** 28 **for Different Geosynthetics**

29 The performance of six different geosynthetics at three different locations of
30 layered pavement systems were tested through two groups of laboratory capillary rise
31 tests. The three locations are in the base course, between the base course and the
32 subgrade, and in the subgrade (Please see Figs. 1 and 2). The D1 material with 10% of
33 fines content and Fairbanks silt was used to represent the base course layer and the
34 subgrade of the pavement structure, respectively. In the first group of tests (Fig.1), all

1 the geosynthetics were wrapped in the membrane, which is referred to as "no drainage"
2 in the later discussion. In the second group of tests, only the top and bottom halves of
3 the soil specimens were wrapped in the membrane while geosynthetics specimens had
4 larger size (about 6 inches in diameter) and exposed partially in the air to increase the
5 evaporation, which is referred to as "with drainage" in the later discussion (Figure 2). Six
6 different geosynthetics were tested and total 36 tests were performed for three different
7 locations. For each location, it included one reference soil tests, six soil columns with
8 geosynthetics inside but no drainage, and six soil columns with geosynthetics inside and
9 with drainage. The purposes of the two groups of tests were (1) to investigate if the
10 geosynthetics can cut off the capillary rise, and (2) to investigate the influence of
11 evaporation on the water content distribution of the pavement structure. The first group
12 of tests was used to simulate the geosynthetic in the center of the pavement structure,
13 while the second group of tests is used to simulate the performance at the shoulder of
14 the pavement structure. For each group of tests, there was also a reference soil column
15 with no geosynthetic inside. The geosynthetic specimens used in the tests, where
16 specimens 1 through 6 were Mirafi® FW402, Mirafi® G-Series Drainage Composites,
17 Glass fabric, Mirafi® HP570, Mirafi Nylon Wicking Fabric, and Imp, respectively.

18 Specimens were compacted in three layers, 25 blows to each layer. A total of
19 twenty six specimens were compacted. Each was 4.5 inches in height. After the
20 specimens were made, a capillary barrier was placed on top of a specimen. Another
21 specimen was placed on top of the capillary barrier. A plastic membrane was placed
22 around each specimen for moisture control. The top of the silt specimens that were
23 placed on top of the capillary barriers were sealed to eliminate evaporation. A total of 13
24 soil columns were made. The soil columns were then placed in a pan and water was
25 periodically poured into the pan to maintain a height of about 0.5 inch to wet the soil from
26 the bottom. After two weeks the specimens were taken out of their water baths in order
27 to measure the moisture content at various heights. The specimens were taken apart
28 and the capillary barrier was removed. A ruler was used to measure the appropriate
29 width of each section. Each section was 1.5 inches in width. Both the top and bottom
30 specimens were cut into three equal sections. A knife was used to cut each section.
31 Once each section was removed, its weight was weighed on a scale the type of capillary
32 barrier and its section height was recorded and the section was placed in a pan that
33 would correspond to that particular specimen. This was done for each specimen.

1 Afterwards, the pans were put in the oven and weighed again 24 hours later in order to
2 obtain the dry weights.

3

4 Example 6: **Salt Concentration Test and Pressure Plate Test**

5 The salt concentration tests were used to measure the soil water characteristic
6 curves for suction values greater than 1,500 kPa. Specimens 2 and 3 show reasonable
7 curves, but the curve for specimen 5 seems a little strange. For this reason, the results
8 are currently being redone. The results may have been construed by a number of
9 things. The first of which is the handling of the materials. Although gloves were used
10 and precautions were taken to prevent moisture from escaping from the capillary barrier,
11 this may have been a source of error. This may account for the extremely low moisture
12 content levels that were found. Another reason may be that the salt concentration levels
13 within the test containers are off. A reason for this may be because the duct tape that
14 was used is not adhering to the glass container as well as one might expect. The results
15 from the next test should prove helpful in determining where the error is coming from.

16 The pressure plate tests in accordance with ASTM D2325-68 were used to
17 obtain the water retention characteristic curve in the range from 0 to 1500 kPa. Data is
18 currently being collected for the pressure plate test. After the data is collected, the
19 specimens need to be dried in order to determine their dry weight which is used to
20 determine the moisture content. Once the moisture contents are determined, the
21 specimens will be saturated and put back into the pressure plate apparatus at a different
22 suction.

23

24 Example 7: **Configuration of pavement section**

25 Preliminary numerical simulations of performance of wicking fabric in expansive
26 soils were performed by assuming material properties of the wicking fabric.

27 In the example, the concrete slab was 0.25 meter (10-in) thick. Those concretes
28 were made with gravel aggregates from Victoria, Texas, 0.45 of water-cementitious ratio

29

(w/cm). The concrete has a Young's Modulus of $E = 2 \times 10^7$ kPa, Poisson's ratio $\nu = 0.15$, and hydraulic conductivity of $K = 1 \times 10^{-12}$ m/s. Due to the symmetry of the pavement structure, a 5-meter (16.4-ft) of width was chosen. The suction at a depth of 6.0 m was constant and assumed to be equal to 10 kPa, which is just above the ground water table.

The suction at the ground surface was assumed to be 1000 kPa for the first approximation. For the left and right sides of the structure, only vertical displacements were allowed due to symmetry.

Example 8: **Simulation of Soil-Structure Interaction**

Coupled thermal-mechanical jointed (contact) elements in ABAQUS/Standard (2002) are used to simulate the interaction at the soil-concrete slab interface. The upper side of the contact element is the bottom surface of the concrete slab and the lower side is the ground surface where the concrete slab is resting. The bottom face of the concrete slab is assigned to be the master surface and the ground surface is assigned to be the slave surface. Namely, the concrete can penetrate into the soil while the soil can not penetrate into the concrete (ABAQUS/Standard 2002).

The "hard" contact relationship in ABAQUS is used to simulate the normal behavior at the soil-slab interface. During the simulation, the program will compute the thickness of the contact elements in the direction normal to the soil-structure interface. When the soil and the slab foundation are in contact (the thickness of the contact element is zero), any compressive load can be transferred from the slab to the soil. When the soil and the foundation are not in contact (the thickness of the contact element is greater than zero), no load can be transferred from the slab to the soil.

The basic Coulomb friction model is used to simulate the tangential behavior in the soil structure interaction in which the two contacting surfaces can carry shear stresses up to a certain magnitude across their interfaces before they start sliding relative to one another.

It is also assumed that no water is allowed to flow through the soil-slab interface. This condition is realized by defining a very low "gap conductance" to the jointed elements. The gap conductance of the contact elements is assumed to be 10^{-30} S^{-1} when the slab and the soil are in contact with each other. The gap conductance of the contact elements is assumed to be 0 when the slab and the soil are separated.

1

2 **Example 9: Discussion of Simulation Results**

3 The wicking fabric was installed at a depth of 1.0 m below the concrete slab. The
4 wicking fabric was assumed to be under high compression with a bulk factor of 1. It had
5 an ability to transport water at a rate of 1.48 gal/hour/yard. This corresponds to an ability
6 of horizontal permeability of 2×10^{-3} m/s (for a wick fabric with a thickness of 1 mm,
7 transmissivity is 2×10^{-6} m²/s). Three different wicking fabrics were considered as
8 follows:

9 1. The ability of the wicking fabric to transport water is limited so that the wicking
10 fabric works as reinforcement only just like geo-textile. This case is referred to as
11 "reinforcement only" in the following discussions;

12 2. The wicking fabric is highly permeable in all directions. This case is referred to
13 as "single layer wicking fabric" in the following discussions; and

14 3. The wicking fabric is highly permeable in the direction towards outside of the
15 pavement only and impermeable in the other two directions. This case is referred to as
16 "wicking fabric with impermeable layer" in the following discussions. It was used to
17 simulate the wicking drainage board proposed in the previous progress report.

18 Two different conditions were considered. One is that the concrete slab is
19 integrated and there is no leakage from the slab to the subgrade, and the other is that
20 there was a leakage at the center of the slab, which caused the suction in the range of
21 1.0 meter below the centerline were equal to 10 kPa (field capacity).

22 In order to investigate the influence of the wicking fabric on the performance of
23 the pavement structure, conditions when there is no inclusion of wicking fabric were also
24 considered. A total of eight simulations were performed as shown in Table 3.

25 Table 3 Summary of the numerical simulation

Case			Max. Von Mises Stress (kPa)	Length of Unsupported Slab (m)
No Leakage	1	No Geosynthetic	2399	1.1
	3	Reinforcement Only	2668	1.1
	5	Single Layer Wicking Fabric	517.6	0.162
	7	Wicking Fabric with Impermeable Layer	517.6	0.162
With Leakage	2	No Geosynthetic	3597	1.4
	4	Reinforcement Only	3600	1.4
	6	Single Layer Wicking Fabric	3527	1.26
	8	Wicking Fabric with Impermeable Layer	1425	0.079

The simulations were performed under steady state conditions. Two parameters were used to evaluate the performance of the pavement structure. The first one was the “length of unsupported slab”, which is length of the slab which was not supported by the subgrade soils. This parameter is related to the differential settlements caused by the expansive soils under certain weather conditions.

The second parameter was the Von Mises stresses. A Von Mises stress is a stress-invariant used in yield criteria. It is calculated independently of the coordinate reference system, does not carry directional stress information such as normal and shear stresses, but carries enough information to identify hot-spots where failure might occur. The larger the Von Mises stresses, the higher possibility of damage there is.

In the simulation of a pavement structure built on expansive soils with no wicking fabric and no leakage, the expansive soils underneath the concrete pavements are covered by the concrete slab so that there is no evaporation of water while the soils outside the concrete slab are subjected to evaporation. As a result, the soils underneath the concrete slab have lower suction values, which correspond to higher moisture contents. While the soils outside of the slab have high suctions and lower water contents (drying). The difference in moisture contents due to the coverage of the concrete slab can cause large differential settlements. The soils at the shoulder of the concrete pavements shrink more than the soils underneath the slab, which cause a

phenomenon called “shoulder rotation” or “edge-drop” case. The differential settlement can be so large that part of the concrete slab loses support from the subgrade soils and make the concrete slab a cantilever. This will cause very large bending moments in the concrete slab, which can result in damage to the slab. The maximum Von Mises Stress for this case is 2399kPa, which is occurring in the center of the slab. The slab and the soils separated at the edge of the slab and the length of the separation is 1.1 m for a 5.0 m concrete slab as shown in Table 3.

Case 2: No Wicking Fabric, With Leakage

In the simulation of pavement structure built on expansive soils with leakage and no wicking fabric, there is a leakage underneath the center of the slab, which makes the soil wetter than the previous case. Outside of the slab, the soils were still dry due to evaporation. As a result, the differential movements are larger than the previous case. The length of unsupported slab is about 1.4m and the maximum Von Mises stress is 3597 kPa, about 50% higher than the previous case. In conclusion, leakage in the pavement structure will make the differential settlements much severe and more likely to result in damage to the pavement structure. Cases 1 and 2 were used as references to demonstrate the influence of wicking fabric on performance of the pavement structure.

Case 3: With Geotextile Reinforcement, No Leakage

In this case, a geotextile was included in the pavement structure at a depth of 1.0 m below the concrete pavement. The geotextile was assumed to have the same permeability as that for the soils because it is relatively thin. Its Young’s modulus was assumed to be 200,000kPa, which is much stronger than the expansive soils. In the simulation of pavement structure built on expansive soils with geotextile reinforcement and no leakage, the inclusion of the geotextile reinforcement had no influence on suction distribution. Although the length of the unsupported slab was 1.1m (the same as that for case 1), the maximum Von Mises Stress was 2668 kPa, 11% higher than that when there is no reinforcement. This case indicates the inclusion of a reinforcement does not cause any benefit for the pavement structure for the differential settlement caused by expansive soils.

1 **Case 4: With Geotextile Reinforcement, With Leakage**

2 In this case, there is a leakage underneath the center of the concrete slab. As a
3 result, the suction was 10 kPa in the range of 1.0 m below the concrete slab. Just like
4 case 2, the leakage significantly increases the differential settlements in the subgrade
5 soils. As a result, the length of unsupported slab is 1.4m and the maximum Von Mises
6 stress is 3600 kPa, which are basically the same as those in case 2. Again, this case
7 indicates that inclusion of a geotextile reinforcement will not reduce the differential
8 settlements caused by expansive soils.

9

10 **Case 5: With a single layer of wicking fabric, no leakage**

11 This case is used to simulate the case when the wicking fabric is installed in a
12 pavement structure. In the simulation of pavement structure built on expansive soils with
13 a single layer of wicking fabric and no leakage, due to the high ability of the wicking
14 fabric to transport water, the wicking fabric significantly increase the suction under the
15 concrete slab and suction distributions in the pavement structure is more uniformly
16 distributed with depth. As a result, the differential settlement in the pavement structure
17 is very small.

18 The length of unsupported slab is only 0.162 m, which is mainly limited at a very
19 small range close to the edge of the slab. Due to the fact that most of the slab is rest on
20 the subgrade soils and suction difference underneath the slab is small, the stress in the
21 slab is small (if the differential settlements are zero, the stress in the slab will be the
22 smallest).

23 The maximum Von Mises stress is only 517.5 kPa, less than 22% of the
24 maximum Von Mises stress for case 1 when there is no wick fabric. This case indicates
25 that inclusion of the wicking fabric can significantly improve the pavement performance
26 and the pavement is much less likely to damage compared with case 1.

27

28 **Case 6: With a single layer of wicking fabric, with leakage**

29 The difference between cases 6 and 5 is that there is a leakage underneath the
30 centerline of the concrete slab. Due to the leakage, the soil underneath the centerline of
31 the slab is very wet with a suction of 10 kPa, while the outside still remains 1000kPa.
32 The difference in suction is large. As a result, the differential settlements are very big.
33 The leakage not only causes swelling for soil above the wicking fabric, it also causes
34 swelling of the soil beneath the wicking fabric. The final length of unsupported slab is

1 1.26 m, and the maximum Von Mises stress is 3527 kPa. Compared with cases 2 and
2 4, inclusion of the wicking fabric only slightly improves the performance of the pavement
3 structure when there is leakage. It is worth noting that case 6 is a steady state
4 simulation in which the leakage is assumed to be lasting for a significant period of time.
5 Under a real situation, a rainfall event only lasts for a short period of time. Therefore, the
6 actual improvement made by including a wicking fabric might be greater than the
7 simulation. This case was performed for comparison purposes only.

9 **Case 7: Wicking Fabric with Impermeable Layer, no leakage**

10 This case simulates the situation in which the wicking drainage board discussed
11 above is installed in a pavement structure. In this simulation of a pavement structure
12 built on expansive soils with the installation of the wicking drainage board and no
13 leakage, the wicking drainage board significantly increases the suction under the
14 concrete slab and suction distributions in the pavement structure is more uniformly
15 distributed with depth as in case 5. The differential settlement in the pavement structure
16 is very small. The length of unsupported slab is only 0.162 m and the maximum Von
17 Mises stress is only 517.5 kPa. The results obtained are like those obtained in case 5.
18 This case indicates that inclusion of wicking drainage board can significantly improve the
19 pavement performance.

20 Different from case 7, in case 8 there is a leakage underneath the centerline of
21 the slab. The leakage causes suction increase underneath the slab, resulting significant
22 difference between the centerline and outside of the slab. However, due to the wicking
23 drainage board is impermeable in the vertical direction, the wetting of the soil is limited
24 between the concrete slab and the wicking drainage board. Also, because the drainage
25 board is permeable on both sides, the bottom side can still drain water out of the
26 pavement structure even when there is leakage on the top. As a result, the soil at the
27 centerline is still drying below the wicking drainage board.

28 The wetting of the soil above the wicking drainage board causes the soil to swell,
29 while the drying of the soil below the wicking drainage board causes the soil to shrink.
30 These two effects counterbalance and reduce the differential settlement even when
31 there is leakage at the center of the slab. In case 8, the slab and the soils are in good
32 contact with a length of unsupported slab of 0.079m. Consequently, the maximum Von
33 Mises stress is 1425 kPa, about 60% and 40% of the maximum Von Mises stresses in
34 cases 1 and 6, respectively. The maximum Von Mises stresses and length of

1 unsupported slab in cases 7 and 8 are much smaller than those under similar situations.
2 It is concluded that inclusion of wicking drainage board can significantly improve the
3 performance of pavement structure.

4 With respect to the above description then, it is to be realized that the optimum
5 dimensional relationships for the parts of the invention, to include variations in size,
6 materials, shape, form, function and manner of operation, assembly and use, are
7 deemed readily apparent and obvious to one skilled in the art, and all equivalent
8 relationships to those illustrated in the drawings and described in the specification are
9 intended to be encompassed by the present invention.

10 Therefore, the foregoing is considered as illustrative only of the principles of the
11 invention. The scope of the claims should not be limited by the preferred embodiments
12 set forth in the examples, but should be given the broadest interpretation consistent with
13 the description as a whole.
14

We Claim:

1. A wicking drainage system comprising:
a woven, wicking fabric layer disposed on a layer of frost susceptible soil, the wicking fabric layer comprising a plurality of wicking fibers disposed substantially parallel to one another and comprising a non-round or non-oval cross-section and having a flux of about 100 cc/g/hr to about 250 cc/g/hr, and
a layer of non-frost susceptible soil disposed on the wicking fabric.
2. The wicking drainage system as claimed in claim 1, further comprising an impermeable hydrophobic geomembrane disposed below the wicking fabric.
3. The wicking drainage system as claimed in claim 1, wherein the wicking fabric is tilted with respect to the water table of the soil upon which the wicking drainage system is disposed.
4. The wicking drainage system as claimed in claim 3, wherein the wicking fabric is tilted at a slope from about 5 to 10%.
5. A wicking drainage system comprising:
a woven, wicking fabric layer disposed on a first layer of frost susceptible soil, the wicking fabric layer comprising a plurality of wicking fibers disposed substantially parallel to one another and comprising a non-round or non-oval cross-section and having a flux of about 100 cc/g/hr to about 250 cc/g/hr,
a second layer of frost susceptible soil disposed on the wicking fabric layer,
a geotextile layer disposed on the second layer of frost susceptible soil; and
a layer of non-frost susceptible soil disposed on the geotextile layer.
6. The wicking drainage system as claimed in claim 5, wherein the geotextile layer is another wicking fabric layer.
7. The wicking drainage system as claimed in claim 1, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.

8. The wicking drainage system as claimed in claim 5, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.
9. A woven geotextile wicking fabric comprising:
 - a polymeric yarn disposed in one axis of the fabric, and
 - a plurality of wicking fibers woven with the polymeric yarn in another axis of the fabric, the wicking fiber having a surface factor greater than about 1.5 and a flux of about 100 cc/g/hr to about 250 cc/g/hr.
10. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber is a polyester, a nylon, a polyolefin, or a cellulose esters.
11. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber is a nylon.
12. The woven geotextile wicking fabric as claimed in claim 11, wherein the wicking fabric has a specific surface area of 3,650 cm²/g.
13. The woven geotextile wicking fabric as claimed in claim 11, wherein the wicking fiber has a permeability of 0.55 cm/s.
14. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber is a polystyrene or a foamed polystyrene.
15. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber is a poly(ethylene terephthalate).
16. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber is a polypropylene.
17. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber is between about 15 and about 250 Denier per filament.

18. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber has a specific capillary volume of at least $2.0 \text{ cm}^3/\text{gm}$.
19. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber has a specific capillary volume of at least $2.5 \text{ cm}^3/\text{gm}$.
20. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber has a specific capillary volume of at least $4.0 \text{ cm}^3/\text{gm}$.
21. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber has a specific capillary surface area of at least $2,000 \text{ cm}^2/\text{gm}$.
22. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber has a specific capillary surface area of at least $3,000 \text{ cm}^2/\text{gm}$.
23. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber has a specific capillary surface area of at least $4,000 \text{ cm}^2/\text{gm}$.
24. The woven geotextile wicking fabric as claimed in claim 9, wherein the wicking fiber maintains unsaturated hydraulic conductivity in environments having saturations between 100% and 17%.
25. A wicking drainage system comprising:
the woven geotextile wicking fabric as claimed in claim 9 disposed on a layer of frost susceptible soil, and
a layer of non-frost susceptible soil disposed on the wicking fabric.
26. The wicking drainage system as claimed in claim 25, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.
27. A wicking drainage system comprising:
the woven geotextile wicking fabric as claimed in claim 9 disposed on a first layer of frost susceptible soil,
a second layer of frost susceptible soil disposed on the wicking fabric layer,

a geotextile layer disposed on the second layer of frost susceptible soil; and
a layer of non-frost susceptible soil disposed on the geotextile layer.

28. The wicking drainage system as claimed in claim 27, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.
29. A woven geotextile wicking fabric comprising:
a polymeric yarn disposed in one axis of the fabric, and
a plurality of wicking fibers woven with the polymeric yarn in another axis of the fabric, the wicking fiber comprising at least one intrastructure capillary channel and a flux of about 100 cc/g/hr to about 250 cc/g/hr, and the wicking fiber maintaining at least about 80% flux up to 60,000 ft-lb/ft³.
30. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber has a surface factor between about 1.5 and about 3.3.
31. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber is a polyester, a nylon, a polyolefin, or a cellulose esters.
32. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber is a nylon.
33. The woven geotextile wicking fabric as claimed in claim 32, wherein the wicking fabric has a specific surface area of 3,650 cm²/g.
34. The woven geotextile wicking fabric as claimed in claim 32, wherein the wicking fiber has a permeability of 0.55 cm/s.
35. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber is a polystyrene or a foamed polystyrene.
36. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber is a poly(ethylene terephthalate).

37. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber is a polypropylene.
38. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber is between about 15 and about 250 Denier per filament.
39. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber has a specific capillary volume of at least $2.0 \text{ cm}^3/\text{gm}$.
40. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber has a specific capillary volume of at least $2.5 \text{ cm}^3/\text{gm}$.
41. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber has a specific capillary volume of at least $4.0 \text{ cm}^3/\text{gm}$.
42. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber has a specific capillary surface area of at least $2,000 \text{ cm}^2/\text{gm}$.
43. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber has a specific capillary surface area of at least $3,000 \text{ cm}^2/\text{gm}$.
44. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber has a specific capillary surface area of at least $4,000 \text{ cm}^2/\text{gm}$.
45. The woven geotextile wicking fabric as claimed in claim 29, wherein the wicking fiber maintains unsaturated hydraulic conductivity in environments having saturations between 100% and 17%.
46. A wicking drainage system comprising:
the woven geotextile wicking fabric as claimed in claim 29 disposed on a layer of frost susceptible soil, and
a layer of non-frost susceptible soil disposed on the wicking fabric.

47. The wicking drainage system as claimed in claim 46, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.
48. A wicking drainage system comprising:
the woven geotextile wicking fabric as claimed in claim 29 disposed on a first layer of frost susceptible soil,
a second layer of frost susceptible soil disposed on the wicking fabric layer,
a geotextile layer disposed on the second layer of frost susceptible soil; and
a layer of non-frost susceptible soil disposed on the geotextile layer.
49. The wicking drainage system as claimed in claim 48, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.
50. A woven geotextile wicking fabric comprising:
a polymeric yarn disposed in one axis of the fabric, and
a plurality of wicking fibers woven with the polymeric yarn in another axis of the fabric, the wicking fiber comprising a bundle of at least two fibers having a specific volume greater than $4.0 \text{ cm}^3/\text{gm}$ and an average inter-fiber capillary width of from 25 to 400 microns; at least one of the at least two fibers having a non-round cross-section, a single fiber bulk factor greater than 4.0, and a specific capillary volume of less than $2.0 \text{ cm}^3/\text{gm}$; and more than 70% of intrafiber channels having a capillary channel width greater than 300 microns.
51. A wicking drainage system comprising:
the woven geotextile wicking fabric as claimed in claim 50 disposed on a layer of frost susceptible soil, and
a layer of non-frost susceptible soil disposed on the wicking fabric.
52. The wicking drainage system as claimed in claim 51, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.
53. A wicking drainage system comprising:
the woven geotextile wicking fabric as claimed in claim 50 disposed on a first layer of frost susceptible soil,
a second layer of frost susceptible soil disposed on the wicking fabric layer,

a geotextile layer disposed on the second layer of frost susceptible soil; and
a layer of non-frost susceptible soil disposed on the geotextile layer.

54. The wicking drainage system as claimed in claim 53, further comprising a base layer for supporting asphalt or concrete disposed on the non-frost susceptible soil.
55. A woven geotextile wicking fabric comprising:
a polymeric yarn disposed in one axis of the fabric, and
a plurality of wicking fibers disposed substantially parallel to one another and woven with the polymeric yarn in another axis of the fabric, the wicking fiber comprising a non-round or non-oval cross-section and having a flux of about 100 cc/g/hr to about 250 cc/g/hr.
56. The wicking fabric of claim 55, wherein the cross-sectional shape of the wicking fiber is multichannel, trilobal, or pillow.
57. The wicking fabric of claim 55, wherein the wicking fiber comprises nylon.
58. The wicking fabric of claim 55, wherein the wicking fabric has a specific surface area of 3650 cm²/g.
59. The wicking fabric of claim 55, wherein the wicking fiber has a permeability of 0.55 cm/s.

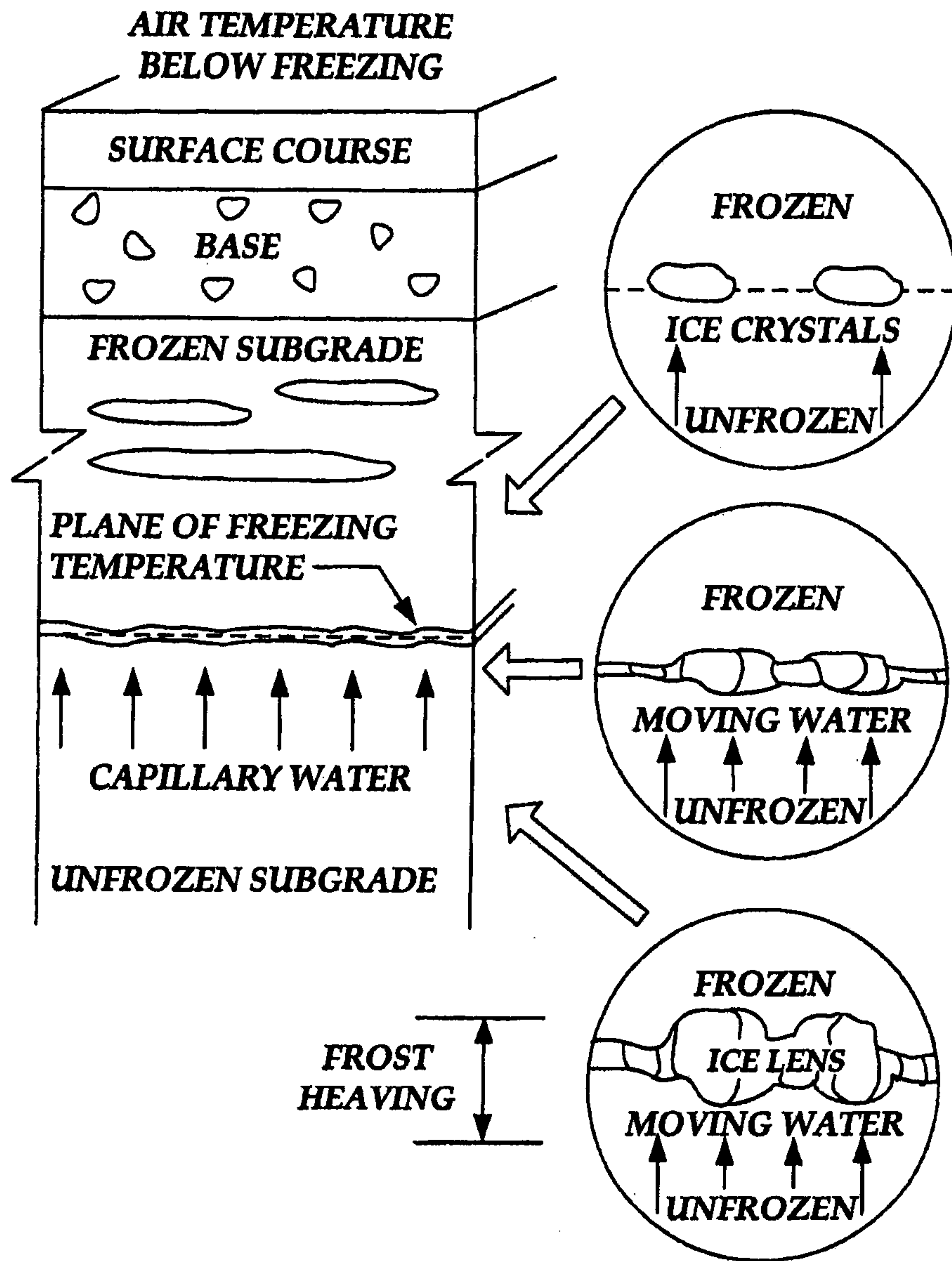


Fig. 1
(PRIOR ART)

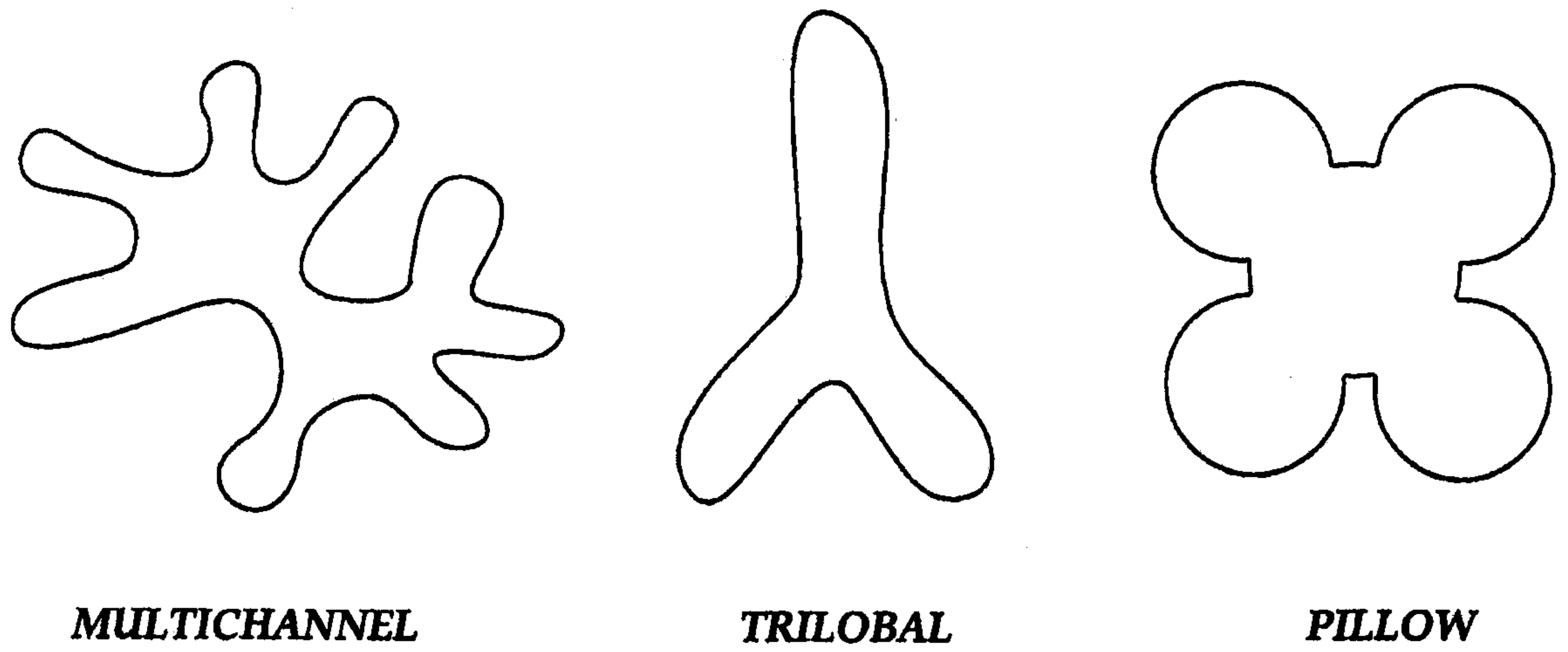


Fig. 2

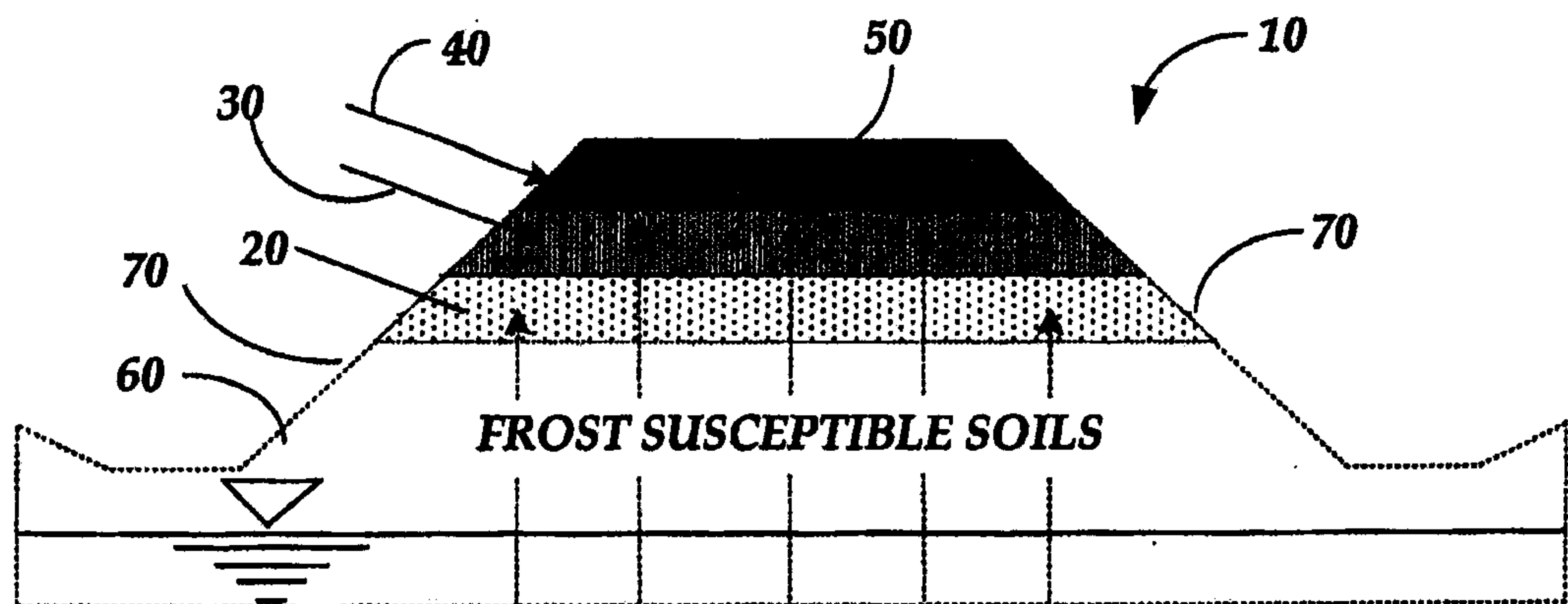
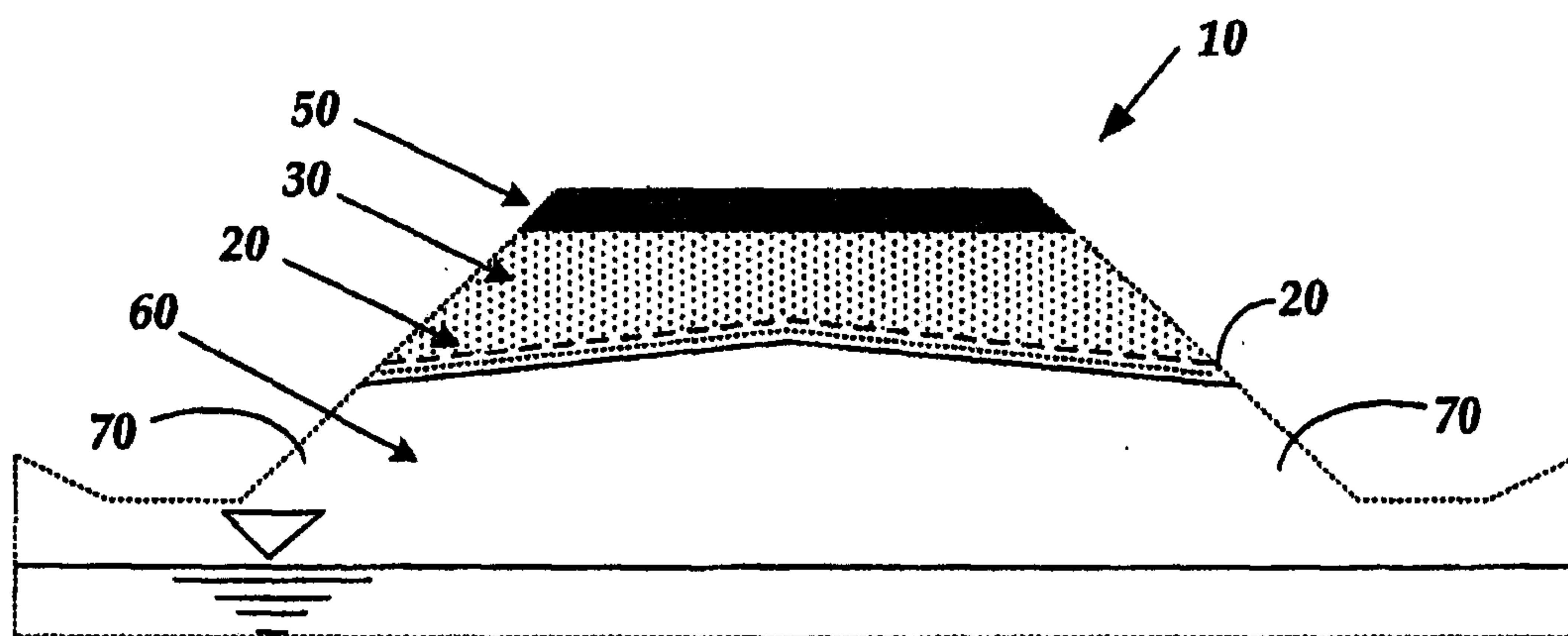
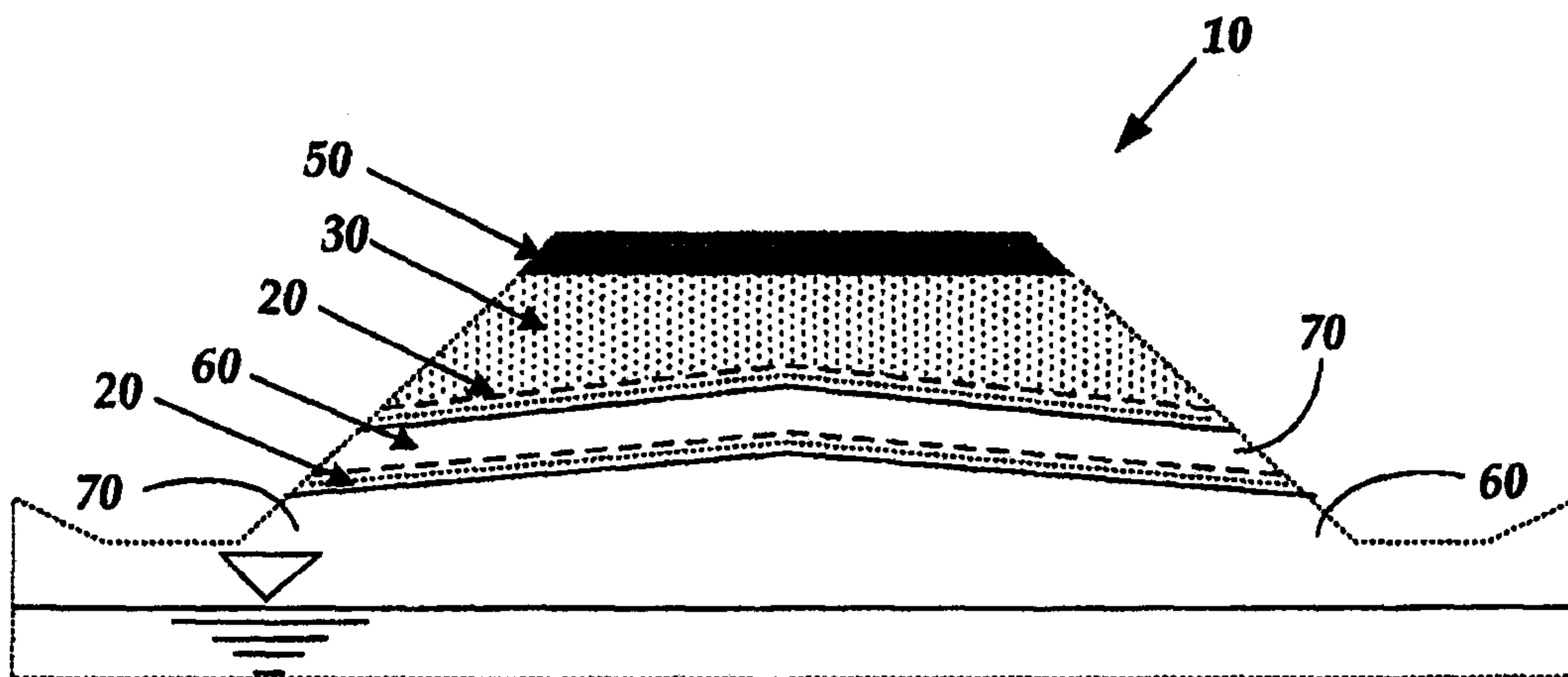
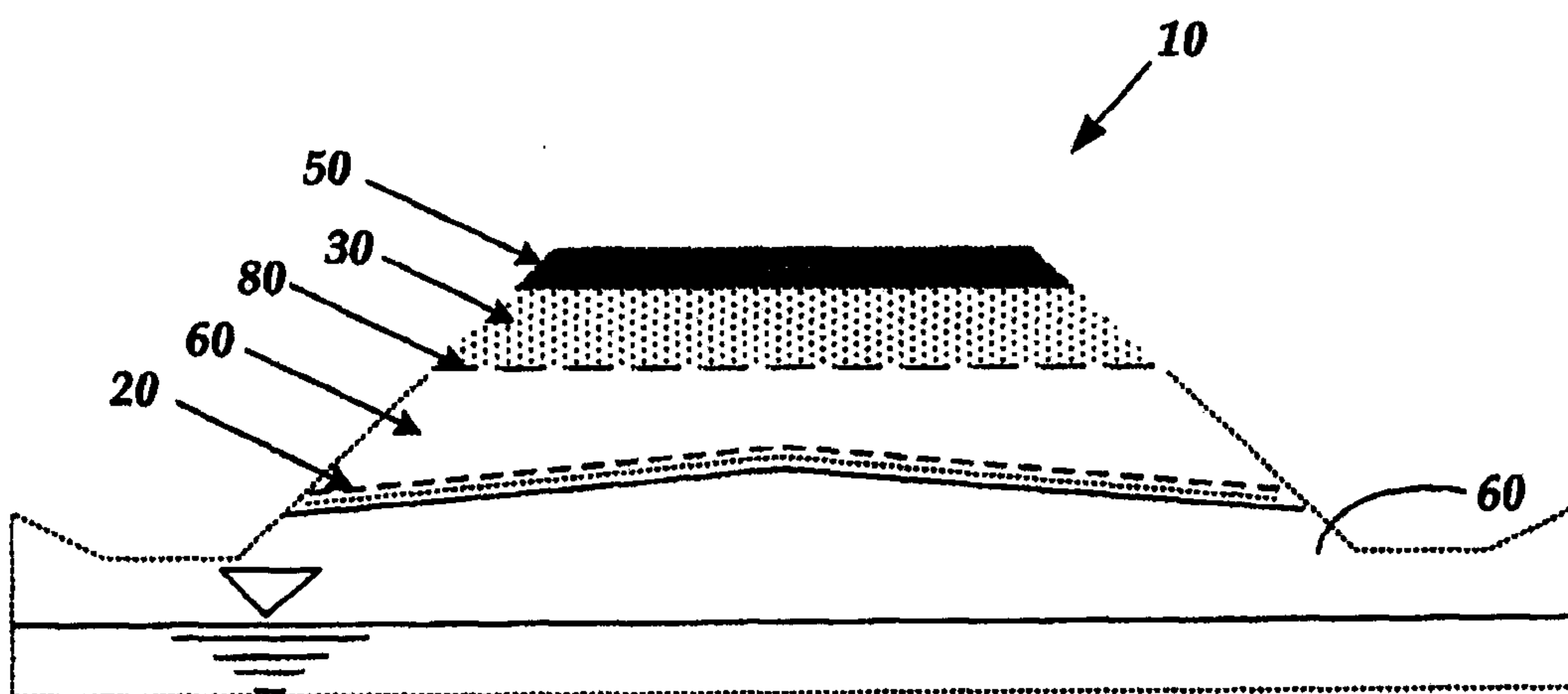


Fig. 3

*Fig. 4**Fig. 5**Fig. 6*

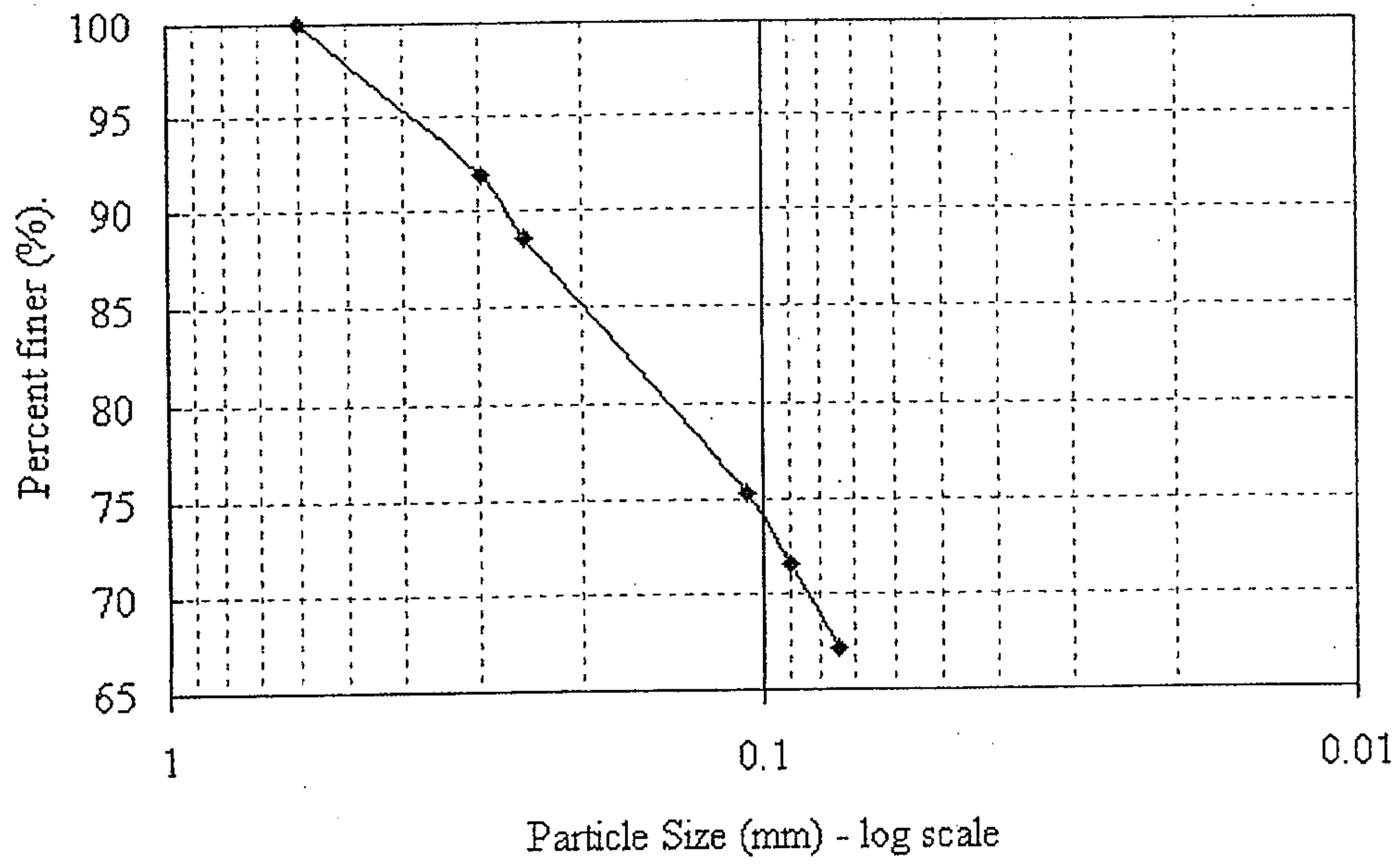


FIGURE 7

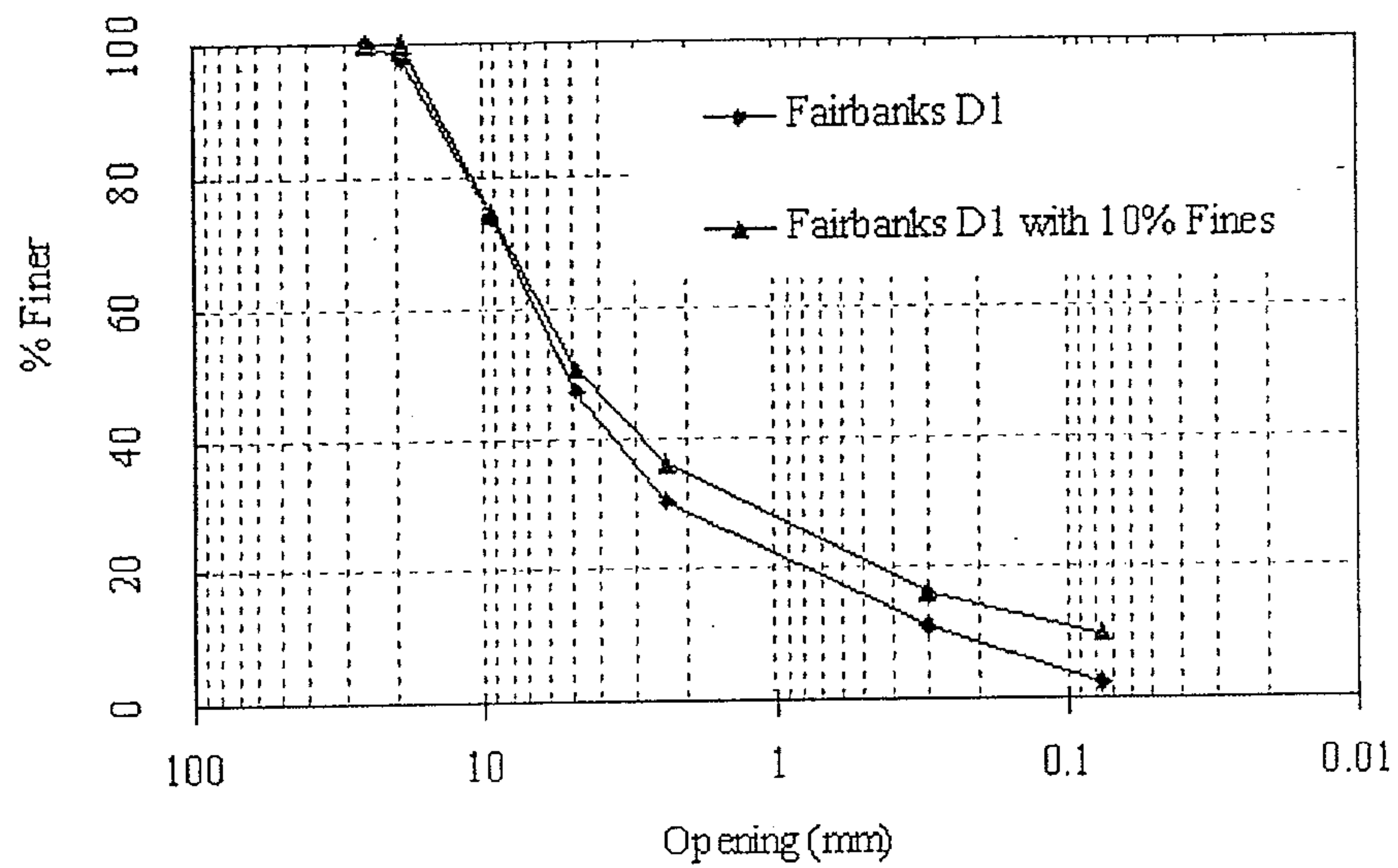


FIGURE 8

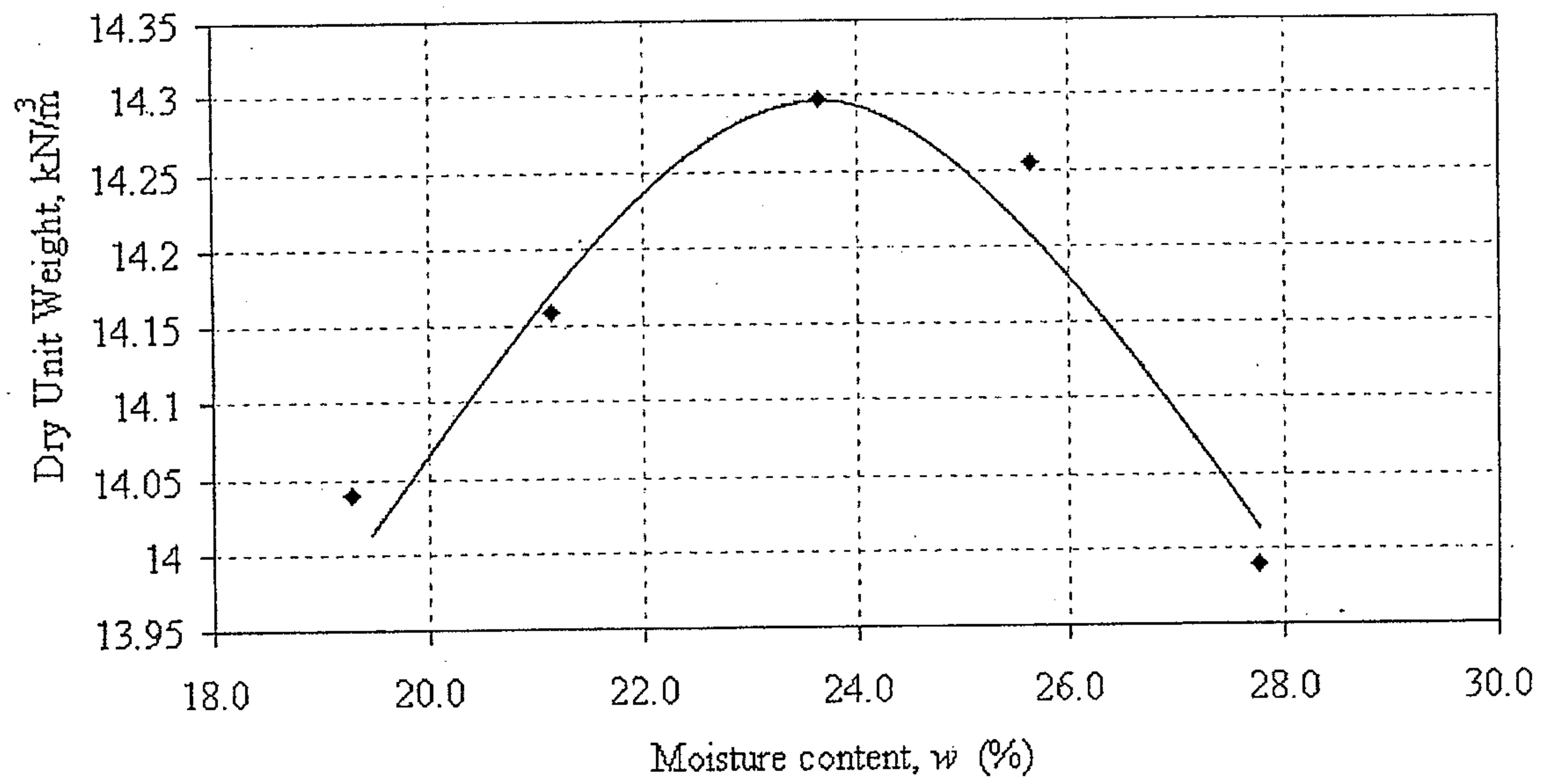


FIGURE 9

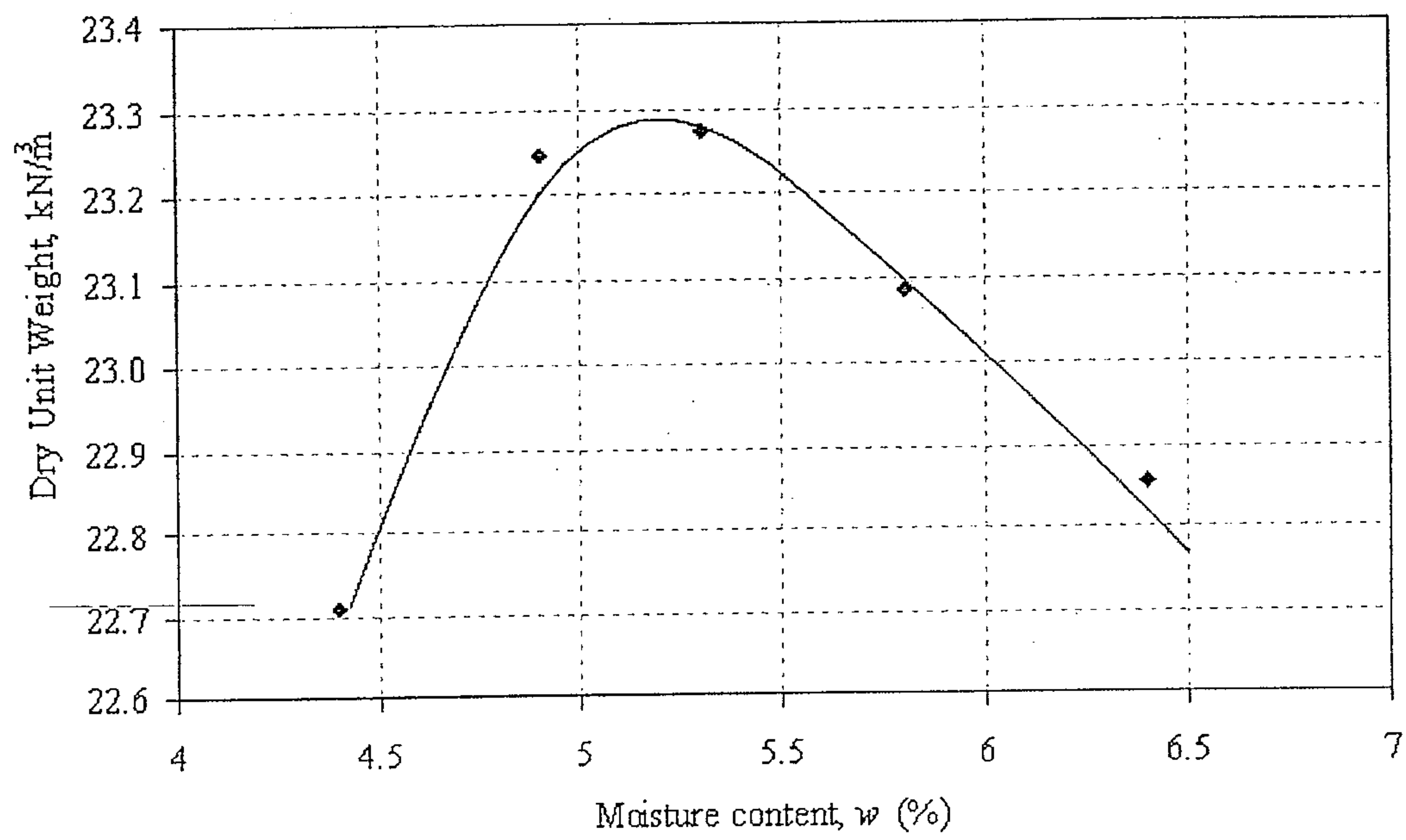


FIGURE 10

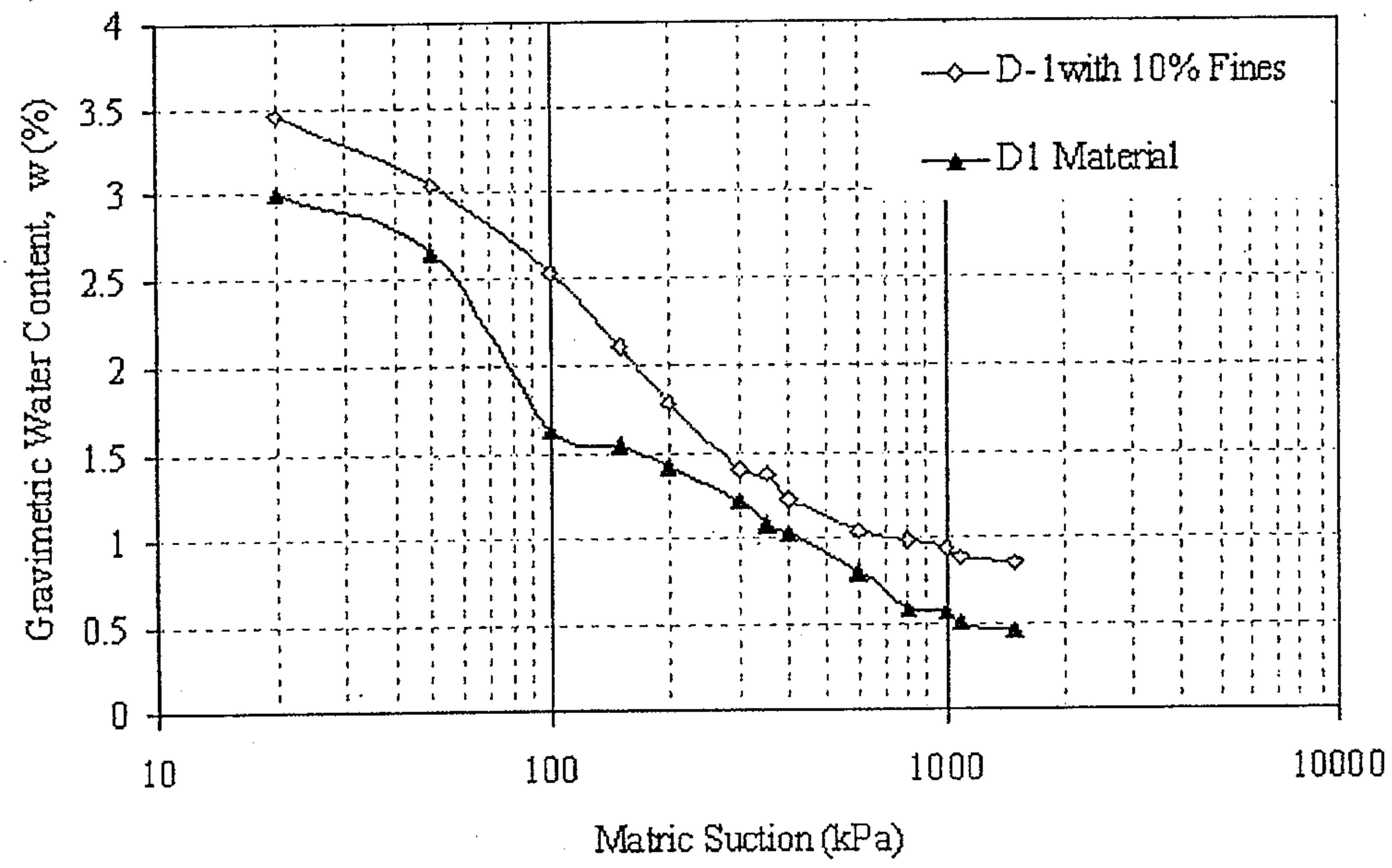


FIGURE 11

