

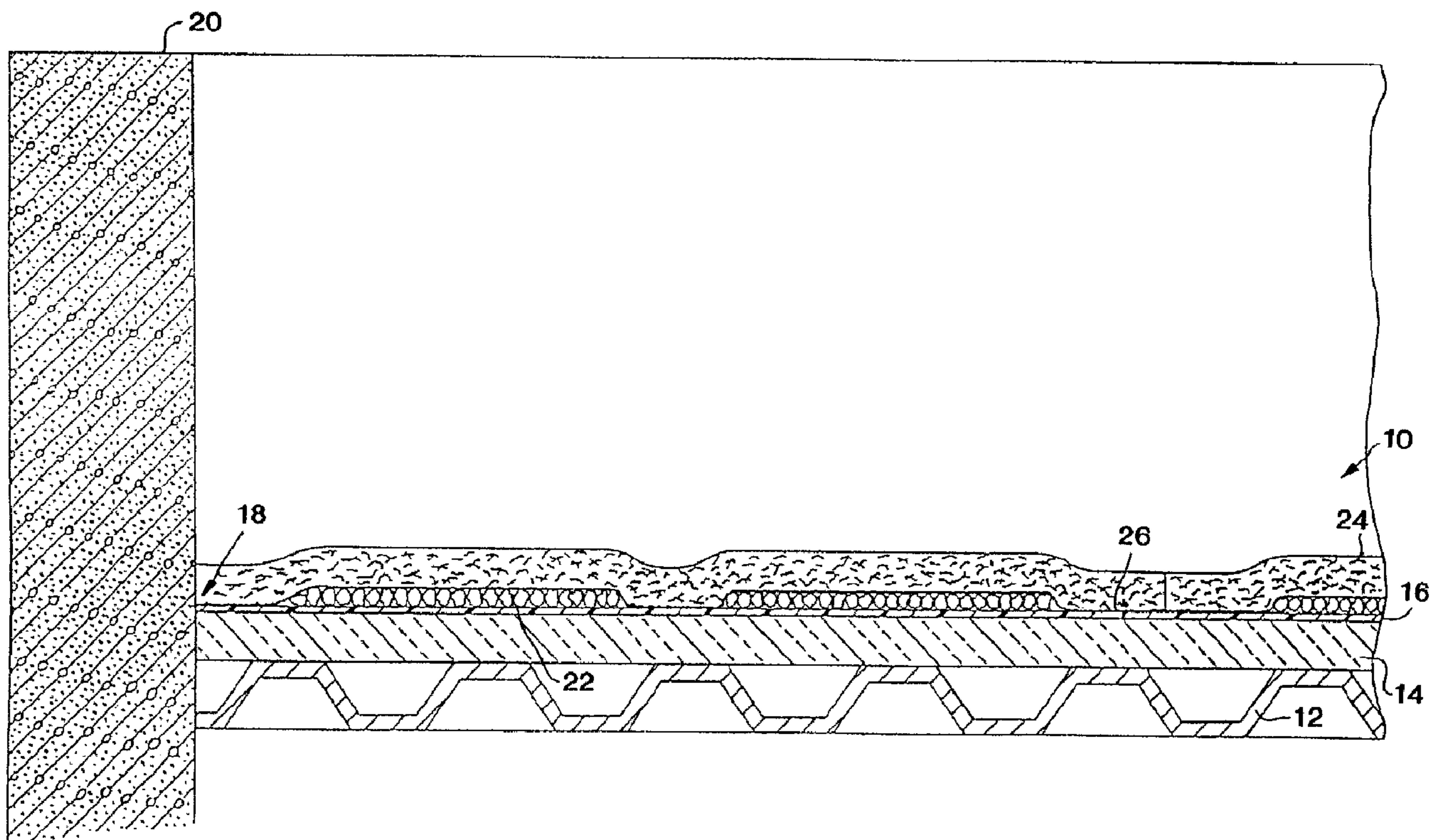


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(54) Title: STRUCTURE AND METHOD OF REDUCING UPLIFT OF AND SCOURING ON MEMBRANE ROOFS



(57) Abrégé/Abstract:

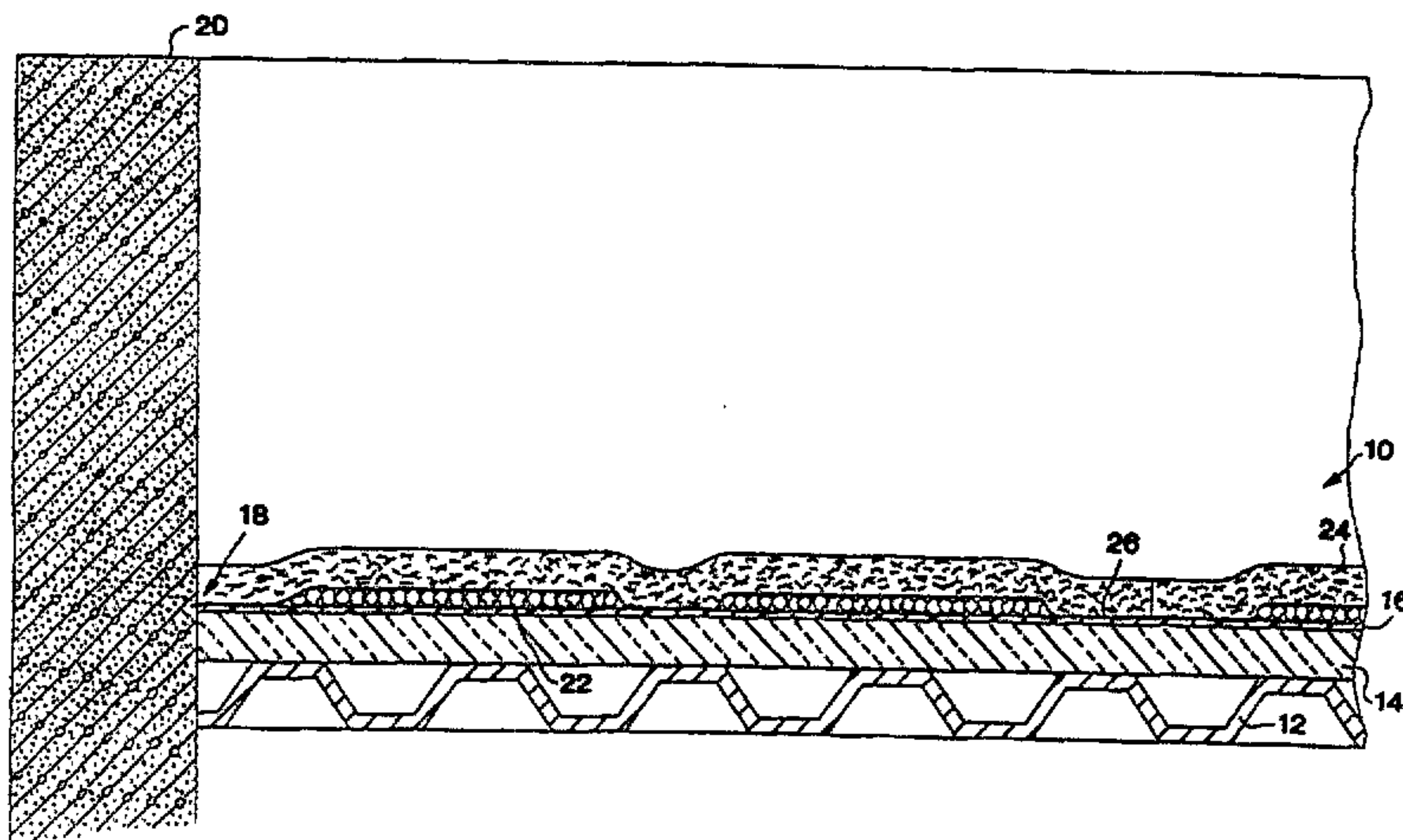
A roof structure (10) and method for reducing uplift on a roof resulting from a wind blowing over the roof at a rooftop wind speed. The roof has a membrane (16) overlying a deck (12). An air permeable and resilient mat (24) is installed over the membrane (16). The mat (24) has openings of a size to reduce the wind velocity passing through it to the membrane (16) while the openings being of a size that the mat (24) is not lifted by a pressure differential therein reducing uplift on the membrane (16).



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(54) Title: STRUCTURE AND METHOD OF REDUCING UPLIFT OF AND SCOURING ON MEMBRANE ROOFS



(57) Abstract

A roof structure (10) and method for reducing uplift on a roof resulting from a wind blowing over the roof at a rooftop wind speed. The roof has a membrane (16) overlying a deck (12). An air permeable and resilient mat (24) is installed over the membrane (16). The mat (24) has openings of a size to reduce the wind velocity passing through it to the membrane (16) while the openings being of a size that the mat (24) is not lifted by a pressure differential therein reducing uplift on the membrane (16).

STRUCTURE AND METHOD OF REDUCING UPLIFT OF AND SCOURING ON MEMBRANE ROOFS

Field of the Invention

5 This invention is related to the general field of membrane roofs, commonly referred to as flat or low-sloped roofs, and more particularly is related to a structure and method of distributing and reducing the uplift forces across the roof which are caused by wind velocity, and the reducing of scouring of any aggregate layer on the membrane caused by wind forces.

Background of the Invention

10 A common roof style for commercial and industrial buildings, apartment complexes and row homes is the flat or low-sloped roof. Although nominally flat, this roof style usually has a slight slope or pitch to cause and direct drainage. For purposes of brevity, the term "flat roof" will be used
15 hereafter to describe roofs of this style.

A flat roof comprises at a minimum a deck and a waterproof membrane. An insulation layer can be, and frequently is, installed between the deck and the membrane.

20 There are two basic categories of flat roof construction. In the built-up roof system (BUR), felt and bitumen are layered to form the waterproof membrane, and a layer of gravel or a coating is placed on top to protect the membrane from ultraviolet radiation. In the single-ply roofing system (SPM), a single elastomeric sheet overlies the deck.

25 The primary purpose of any roof is to separate the exterior atmosphere from the interior of the building, and maintain the integrity of that separation during all weather including expected extremes of ambient weather

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conditions throughout a reasonable lifetime. This requirement involves several design factors, which include the consideration of: (1) external and internal temperatures; (2) external moisture, air moisture, rain, snow, sleet and hail; (3) wind uplift of the membrane; (4) impact resistance to weather and other effects such as dropped tools and walking; (5) the esthetics of the roof; and (6) influence of solar radiation and ultraviolet rays.

For flat roofs, the ability to withstand uplift forces caused by wind across the roof surface is one of the more critical design factors. The roof is a major portion of the surface area in building structures, accounting for as much as 40% of the surface area. Wind across the roof produces uplift forces at the roof surface, which may cause detachment and billowing of the membrane, scattering of ballast, and even catastrophic roof failure in extreme situations. Consequently, the flat roof design normally incorporates one or more features to counter the wind uplift forces, as described below.

In a single-ply roof, one of the most common methods of countering uplift forces is the use of stone ballast. The waterproofing membrane is completely covered with a uniform layer of stone aggregate (usually #4 river rock or equivalent, $\frac{3}{4}$ " to $2\frac{1}{2}$ " diameter), at layer depth sufficient to produce a down-load pressure of approximately 10 pounds per square foot. The substantial weight of this aggregate is an added load to the roof and support structure which must be factored into the design of the building.

However, a major problem with stone ballast is that strong winds often cause the ballast stones to shift position, clustering in some areas and uncovering the membrane in other areas. This phenomena is referred to as scouring. Where the migration of the aggregate results in areas that are clear of ballast, the exposed membrane can billow upward from the aerodynamic lift of the wind, resulting in the membrane becoming damaged or disengaged. The membrane uplift and billowing accelerates the migration of ballast. Therefore, the exposed membrane has increased exposure to UV rays.

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Another counter to uplift forces in single-ply roofing systems involves mechanically affixing the waterproofing membrane and any underlying insulation to the deck with fasteners, which anchor the membrane and transfer the uplift load to the deck. In a majority of commercial and industrial buildings, the deck is formed of corrugated steel of 18 to 22 gauge thickness. Decks may also be formed from wood, concrete, gypsum and other suitable materials. The fasteners experience lateral and vertical loads, including uplift on the membrane, the oscillating loads of membrane billowing, and deck flutter, which may over time cause the fasteners to become disengaged, ultimately backing out and leaving the membrane unsecured. A backed-out fastener may puncture the waterproofing membrane, and membrane billowing can increase the forces acting on the membrane seams, therein resulting in seam failure.

Another alternative is to fully adhere the waterproofing membrane to the top surface of a subcomponent sheet, which has in turn been mechanically affixed to the roof deck. The adhesive bond between waterproofing membrane and subcomponent's top surface is subjected to uplift forces from the passage of wind over the membrane. The adhesive bond between waterproofing membrane and subcomponent top surface is subjected to shear forces as a result of expansion and contraction of the membrane. Both the subcomponent material and the adhesives are usually sensitive to moisture and condensation, which over time cause adhesive bond failure. Subsequent membrane failure occurs as oscillating and billowing causes the membrane to peel from the substrate.

The built-up roof must also counter the effect of uplift forces, in that the built-up layers of felt and bitumen can delaminate, and chunks of asphalt/felt can be blown off the roof. The built-up roof system also experiences scouring problems when loose gravel is used as the top layer to protect the membrane from ultraviolet radiation. In fact, the smaller sized gravel migrates even more easily than the larger ballast stone used with single-ply roofs.

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Consequently, there has been a continuing need for better methods and structures to counter the effects of uplift forces, or to counter the uplift forces directly.

One method of countering uplift, in the type of roof where insulation panels are installed on top of the membrane, is disclosed in U.S. Patent 4,583,337, which teaches installing corrugated cover members overlying insulation panels along the periphery of the roof. The wind flowing around the corrugated cover members is purported to create a vacuum under the cover members, so that the differential pressure pulls the cover members downward against the insulation to counter the uplift on the insulation, and thus retain the insulation.

U.S. Patent No. 4,926,596 discloses an apertured overlay that is stretched over the membrane. The apertured overlay is secured at the periphery of the roof, and allows wind to pass through to the membrane. The overlay physically restrains the waterproof membrane from billowing.

Both of these methods counter the uplift by creating an opposing force on the membrane, and in that sense are related in concept and approach to the older methods of ballast, mechanical fasteners, and adhesives. It is an object of the present invention to counter the uplift in different manner, in which the uplift force itself is reduced, and the uplift force is more uniform across the roof surface.

In addition to its efficacy in reducing and evenly distributing uplift forces, another major advantage of the present invention is that it can be used alone or in conjunction with other uplift countering methods, such as ballast, affixed or adhered membrane, and built-up roofs, and in fact makes these other methods even more effective than they would be if used alone. For example, the elimination of scouring permits the use of a smaller-size aggregate for ballast, and the reduction of uplift force permits the use of less total weight of ballast. The reduction and more even distribution of uplift forces reduces the frequency and likelihood of fastener or adhesive bond failure, or delamination

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of built-up roofs. Further, the invention itself provides a resilient cover to the roof therein protecting from physical damage and reduces the ultraviolet rays reaching the membrane.

Summary of the Invention

5 This invention relates to a roof structure for and method of reducing and distributing uplift forces resulting from wind blowing across a flat roof and retaining ballast in position where present. The roof structure includes a waterproof membrane overlying a deck, and is characterized by an air permeable and resilient mat which is installed over the membrane. The mat has
10 a random convoluted mesh of a size which breaks up the laminar flow of wind passing over the membrane, slows and defuses the wind velocity directly above the membrane, and permits pressure equalization within the mat, so that the mat is not lifted away from the membrane.

 One object, feature and advantage resides in the air permeable
15 and resilient mat overlying the ballast, if provided, to prevent scouring of the ballast.

 Another object, feature and advantage resides in the air permeable and resilient mat being adhered in a grid pattern to retain ballast, if provided, in the ballast respective grid.

20 In a preferred embodiment, the waterproof membrane overlays a decking and is secured at the periphery of the roof. A layer of ballast overlies the membrane and is cleared in section to secure the air permeable and resilient mat by an adhesive. The mat reduces uplift on the membrane.

 In the preferred embodiment, the mat is constructed of synthetic
25 fibers randomly aligned into a web and bonded together at their intersections, forming a relatively rigid mat having significant porous area between the random fibers to disrupt and diffuse the wind over the membrane.

 Further objects, features and advantages of the present invention will become more apparent to those skilled in the art as the nature of the inven-

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tion is better understood from the accompanying drawings and detailed description.

According to one aspect of the present invention, there is provided a method of constructing a roof structure which will reduce uplift comprising: providing a roof having a membrane; installing a ballast layer comprising loose aggregate prior to installing an air permeable and resilient mat; and installing the air permeable and resilient mat constructed of randomly aligned fibers which are joined by a binding agent, over the membrane, and overlying the aggregate, the mat having openings of a size to reduce the wind velocity over the membrane from that of rooftop wind speed reducing the scouring of the aggregate across the roof while the openings being of a size that the mat is not lifted by the pressure differential therein reducing uplift on the membrane.

According to another aspect of the present invention, there is provided a method of constructing a roof structure which will reduce uplift comprising: providing a roof having a membrane; installing a ballast layer having a loose aggregate; clearing away the aggregate from the membrane in specific segments; and securing an air permeable and resilient mat to the specific segments using an adhesive means, the mat having openings of a size to reduce the wind velocity over the membrane from that of rooftop wind speed while the openings being of a size that the mat is not lifted by the pressure differential therein reducing uplift on the membrane.

According to still another aspect of the present invention, there is provide a roof structure comprising: a roof decking; a membrane; means for securing the membrane to the roof decking; and an air permeable and resilient mat

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constructed of randomly aligned fibers overlying the membrane, the mat having openings of a size to reduce the wind velocity over the membrane while the openings being of such a size that the mat is not lifted, the fiber content by
5 area of the mat less than 45 percent of the mat.

According to yet another aspect of the present invention, there is provided a roof structure comprising: a roof decking; a single-ply membrane; aggregate overlying the membrane for securing the membrane to the roof decking; and
10 an air permeable and resilient mat overlying the membrane and the aggregate, the aggregate loosely retained between the membrane and the mat, the mat having openings of a size to reduce the wind velocity over the membrane while the openings being of such a size that the mat is not lifted.

15 According to a further aspect of the present invention, there is provided a method of constructing a roof structure which will reduce scouring comprising: providing a membrane roof over a deck, the roof having a layer of aggregate loosely placed on the membrane; installing an air
20 permeable and resilient mat over the aggregate for reducing the wind velocity over the aggregate and applying a force to the aggregate.

According to yet a further aspect of the present invention, there is provided a method of constructing a roof
25 structure which will reduce scouring comprising: providing a membrane roof over a deck, the roof having a layer of aggregate; clearing the aggregate from the membrane in a specific pattern; installing an air permeable and resilient mat over the aggregate by an adhesive to the cleared
30 specific pattern on the membrane for reducing the wind velocity over the aggregate and retaining the aggregate with the specific pattern.

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Brief Description of the Drawings

For the purpose of illustrating the invention, the drawings show a form which is presently preferred. However, this invention is not intended to be limited, nor is it limited, to the precise arrangement and instrumentalities shown. The scope of the invention is determined by the claims found at the end of this description.

Figure 1 is a cross-sectional view of a single-ply stone-ballasted roof according to the invention;

10 Figure 2 is a top view of the roof of Figure 1 with portions of the mat broken away;

Figure 3 is a graphical presentation of the external pressure distribution above a corner of a flat roof which does not incorporate the invention;

15 Figure 4 is a schematic representation of small-scale roof model for wind tunnel testing, with the locations of pressure sensors identified.

Figure 5A and 5B are graphical representation of the mean coefficient of pressure across the roof model of Figure 4 without (Figure 5A) and with (Figure 5B) the invention, generated by data smoothing of the readings of the pressure sensors in wind tunnel testing.

25 Figures 6A and 6B are graphical representation of the minimum coefficient of pressure across the roof model of Figure 4 without (Figure 6A) and with (Figure 6B) the invention, generated by data smoothing of the readings of the pressure sensors in wind tunnel testing.

Figures 7A and 7B are graphical representation of the root mean square values of coefficient of pressure

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across the roof model of Figure 4 without (Figure 7A) and with (Figure 7B) the invention, generated by data smoothing of the readings of the pressure sensors in wind tunnel testing.

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Figure 8 is a cross-sectional view of a roof of an alternative embodiment of a mechanical affixed single-ply roof;

Figure 9 is a cross-sectional view of a roof of an alternative embodiment of a built-up roof system; and

5 Figure 10 is a cross-sectional view of a roof of an alternative embodiment of a roof system called an "upside-down" roof.

When referring to the drawings in the description which follows, like numerals indicate like elements, and primes (' and ") indicate counterparts of such elements.

10

Detailed Description of the Invention

Figure 1 illustrates an embodiment of a roof structure 10 according to the invention. The structure includes a roof decking 12 and an insulation layer 14 laid on and overlying the decking. In a preferred
15 embodiment, the roof has a single-ply waterproof membrane 16 secured at the periphery 18 of the roof deck in proximity to the roof parapet 20 by conventional methods. The single-ply membrane is not secured except at the roof periphery and simply overlies the insulation. The single-ply membrane 16 is formed in sheets which are bonded together by heat welding, solvent welding
20 or adhesives, to form a larger sheet as required to cover the entire roof.

Overlying the single-ply membrane 16 is a layer of gravel aggregate 22 used as ballast. The size of the aggregate 22 is $\frac{3}{8}$ of an inch nominal diameter gravel. This is considerably finer than the stone aggregate of prior ballasted single-ply roofs which require #4 river rock (2" to 2½" diameter).
25 The rate application per square is less than a typical rate of 10 pounds per square for conventional construction. (A square is 100 square feet, a common term in roofing.)

An air permeable and resilient mat 24 overlies the aggregate 22. The mat preferred is a nonwoven air permeable and resilient mat made of
30 synthetic fibers (usually nylon, PVC or polyester) which are opened and

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blended, then randomly aligned into a web by air flow. The web is treated with binding agents of water based phenolics and latexes. The treated web is then oven cured to bind the fabrics into relatively rigid mat having significant porous area between the random fibers. (The machinery used to produce this material is sometimes called a "Rando-Webber").

U.S. Patent No. 5,167,579 describes an air permeable and resilient mat being used in conjunction with a ridge vent of a sloped roof.

10 In a preferred embodiment, the mat material has a thickness of $\frac{3}{8}$ of an inch and comes in rolls 78 inches wide and 60 yards long. The material weighs 11.11 pounds per square (1.8 oz./ft²) and has a percent open area of 65%.

The aggregate can be laid in an even coverage layer over the roof, and then after shoveling out a row or grid pattern and sweeping the open grid lines clean, the air permeable and resilient mat 24 is laid over the aggregate and secured to the membrane at the bare grid lines by adhesive, as shown in Figure 2, where a 3-inch strip adhesive region 28 is shown in hidden line. The mat 24 is secured to the membrane 16 to prevent the mat 24 from being pushed across the roof 10. An adhesive 26 such as COBRA[®] Venom sold by GAF Building Materials Corp, or a neoprene cement, or a tape may be used to secure the mat 24 to the membrane 16. Small gaps are positioned in the adhesive to allow water to drain properly.

The mat 24 retains the aggregate ballast 22 in the grid pattern, thus preventing the phenomena of scouring, which would otherwise occur with such small aggregate. In

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addition, as discussed below, the mat reduces the wind speed across the ballast 22.

Theory behind wind uplifts

In the designing of a roof, the pressure differential on the membrane has to be determined. However, in the design of the roofs, not only average day basic wind speed has to be considered, but winds associated with hurricanes and thunderstorms and Foehnlike winds need also to be considered.

5 Therefore, tables, charts and equations are required to determine the maximum uplift force on the membrane. One of the items that has to be determined is the basic wind speed (V_o). The speed of the wind is constantly changing. Therefore, the basic wind speed (V_o) is the average wind speed over time.

10 The speed of the wind at the roof top (V_R) is calculated as a function of the basic wind speed (V_o), the height above the ground the roof is located (basic wind speed (V_o) is typically measured at 32.8 feet (10m)), and the type of terrain in the area. There are numerous theories on how to determine roof top wind speed (V_R) including methods from the Uniform Building Code, ANSI Standards, and Factory Mutual Standards, Standard Building Code.

15 These theories each achieve different results but the underlying equation is the same and is $V_R = AV_o^m H^n$. The constant "A" and exponent "n" are functions of ground roughness. The exponent "m" is a power constant and typically about 1.0. H represents the building height.

20 Typically, the wind speed on the roof surface (V_s) is greater than the roof top wind speed (V_R). The roof top wind speed is determined by the local wind speed as described above. Roof top wind speed (V_R) is the speed of the wind at that height of the roof and does not include the change of wind speed because of the interaction with the roof.

Using Bernoulli's equation

25
$$P_R/\gamma + V_R^2/2g = P_s/\gamma + V_s^2/2g$$

where P_R is the air pressure roof top level and P_s is the air pressure on the roof's surface, the equation is rearranged to achieve a dimensionless coefficient of pressure

$$C_p = \Delta p(2g)/\gamma V_R^2.$$

Therefore, substituting C_p into the equation results in $V_s = V_R(1-C_p)^{0.5}$. It is this pressure differential that exerts a force on the membrane causing the membrane to lift. Since the volume of wind having to pass over the roof includes a portion of the wind that would have typically passed through the space occupied by the building, the velocity over the roof (V_s) must be greater than the roof top wind speed (V_R). Therefore, C_p must be negative.

It has been recognized that the maximum coefficient of C_p occurs when the wind impinges at 45° relative to the roof as shown in Figure 3. The maximum coefficient of pressure is about -3 to -3.3 for a roof without parapets.

Parapets lower the maximum coefficient of pressure (e.g., maximum -2.5). However, while the coefficient of pressure is lowered, the area influenced by the new maximum pressure is increased. The force on the membrane could be actually higher for a roof with parapets. Factors included in determining the force are the height of the parapets and the surface area of the roof.

Critical pressure points on a membrane roof

Typical pressures in four areas have to be determined before determining the pressure differential acting on the membrane 16. The pressures that need to be identified are the external pressure (P_R) associated with roof top wind speed (V_R), the pressure in the interior of the building structure 10 (P_I) underlying the membrane 16, the roof surface pressure (P_S) associated with the roof surface wind speed (V_S), and the pressure on top of the membrane (P_M). The pressure on top of the membrane (P_M) would equal the roof top surface pressure (P_S) if the membrane did not have an intervening layer such as ballast 22 or the air permeable and resilient mat 24.

The pressure on the interior of the structure 10 (P_I) would be equal to the roof top level pressure (P_R) if the structure was completely open. If this was the case, the differential pressure would be equal to zero. However, structures 10 are not completely open and more closely resemble an unvented

case. In this situation, the internal pressures (P_I) equals the roof top flowable air pressure (P_R) when there is no wind or before the wind begins to blow. The internal pressure can, in addition, be influenced by the air handling and conditioning system in the building. Air handling system usually places a positive pressure in the structure resulting in a greater pressure differential. If the roof decking 12 were sealed such that no air could penetrate, a vacuum could be created under the membrane 16. This vacuum would contract the uplift. However, due to normal cracks and openings in the deck, the pressure below the membrane 16 is assumed to be equal to the pressure inside the building (P_I).

In comparing the pressure at the roof surface (P_S) to that at the top of the membrane (P_M), Bernoulli's equation can be used. As indicated previously, the wind speed of the roof surface (V_S) is larger than the wind speed at the membrane. Therefore, the relationship may be written as

$$V_S = KV_M$$

where K is a constant that is less than 1. Therefore, the pressure of the membrane equals the

$$P_M = P_S + V_R^2(1-C_p)(1-K^2)\gamma/2g$$

In field test, the constant for the air permeable and resilient mat 24 has been determined to be approximately 0.1. The air permeable and resilient mat reduces the wind velocity passing over the membrane 16 to one-tenth the speed of roof top wind speed (V_S).

Theory on Why Air Permeable and Resilient Mat Succeed

While not wishing to be bound by theory, it is thought that the air permeable and resilient mat is successful in reducing uplift of the membrane because: 1) the mat reduces the wind velocity over the membrane, 2) the mat is porous so that any lateral forces generated by the wind are compensated by the static coefficient of friction of the mat with the roof, 3) the surface of the

mat creates turbulence over the roof therein disrupting uplift and 4) if there is ballast, the mat limits scouring of the ballast.

Reduce wind velocity over the membrane

5 In order for the wind to pass over the membrane, the wind must pass through the mat. The mat is comprised of synthetic fibers randomly aligned into a web having significant porous area to allow the wind to pass through the mat. However, the wind as it flows past the fibers are subject to boundary-layer effects resulting in the flow engaging the fibers being zero. The fibers are sufficiently close (35 % of the mat is fiber) that while the wind flows
10 through the mat, the speed of the wind passing through the mat is greatly reduced.

By reducing the wind uplift forces acting on the roof surface, the mat reduces the load required for the uplift forces on the building structural components, reducing construction costs.

15 No uplift on mat

As indicated above, the uplift of the membrane is created by the change of pressure (Δp) across the membrane resulting because the velocity under the membrane is substantially zero. The mat having significant porous area between the fibers has essentially the same pressure above and below the
20 mat. Wind gusts are not constant, and therefore, the mat can dissipate the pressure differential over time, when the velocity of the wind approaches zero.

Turbulence

The mat having a porous surface and wind blowing through and across the mat create turbulence. The laminar flow of the wind is converted to
25 turbulent flow. Whereas the laminar flow has a primary vectorial direction which transfers the energy of the wind into reducing the pressure and creating uplift, the turbulent flow has wind vectors in 4π steradians. The resulting average of all the vectors is a net velocity in any given direction that is less than that found in the laminar flow.

Limit scouring

In conventional ballasted single-ply roofs, the roof surface wind speed (V_s) engages the ballast on primarily one surface. The wind exerts a force on the ballast pushing it in a windward direction. The mat overlying the ballast reduces the wind speed on the ballast which is equal to the roof surface wind speed (V_s). In addition, the mat exerts a downward force on the ballast therein creating a larger force (weight) that the wind must move. Moreover, the contact of the mat with the ballast increases the static coefficient of surface friction and increases the critical velocity. In addition, the mat adhered to the membrane defines grids which contain the ballast. Therefore, the size of the ballast can be reduced without concern of scouring of the ballast.

Wind Tunnel Test

A wind tunnel test was conducted to measure the coefficient of pressure (C_p) on the membrane, and is related to the pressure on top of the membrane (P_m). The model of the building had a roof area of 30 cm. x 30 cm. Twenty three pressure taps were located on the model roof to determine the pressure at various locations across the membrane. Figure 4 is a schematic representation of the small scale roof model that was wind tunnel tested with the pressure taps, pressure sensors, identified.

Tests were conducted with the wind flow both normal to one of the walls of the roof and diagonal such that the wind impinged at 45° relative to the roof as shown in Figure 4. In addition, the roof was tested with the initially flow both being a smooth flow and a turbulent flow wind. While the tests were done in non-boundary layer wind and therefore absolute values of the pressure coefficients could not be extrapolated to full scale, the wind tunnel test clearly showed the benefit of the air permeable and resilient mat 34.

The data for the worse cause situation for both uplift and scouring (i.e, smooth flow impinging at a diagonal) is listed in following table. In

analyzing the data, two zones of effect were found. The approximate demarcation of the two zones is shown in Figure 4.

ZONE I						
Tap No.	Cp(mean)		Cp(min)		Cp(rms)	
	with mat	w/o mat	with mat	w/o mat	with mat	w/o mat
11	-1.03	-1.06	-1.12	-1.23	0.026	0.099
15	-1.05	-1.47	-1.13	-1.60	0.025	0.070
18	-1.09	-2.11	-1.17	-2.23	0.025	0.086
19	-1.07	-2.04	-1.18	-2.53	0.025	0.127
20	-1.12	-3.13	-1.20	-3.82	0.023	0.348
21	-1.11	-3.93	-1.19	-4.20	0.028	0.110
22	-1.14	-2.94	-1.25	-3.43	0.028	0.185
23	-1.10	-2.19	-1.18	-2.66	0.026	0.179
ZONE II						
5	-1.02	-0.67	-1.11	-0.72	0.023	0.015
6	-1.02	-0.63	-1.13	-0.69	0.026	0.019
7	-1.01	-0.78	-1.12	-0.91	0.027	0.045
8	-1.09	-0.75	-1.18	-0.80	0.020	0.011
9	-1.07	-0.69	-1.16	-0.73	0.027	0.014
10	-1.05	-0.68	-1.13	-0.86	0.026	0.051
12	-1.09	-0.79	-1.18	-0.85	0.029	0.012
13	-1.09	-0.73	-1.16	-0.80	0.023	0.015
14	-1.07	-0.92	-1.19	-1.23	0.028	0.126
16	-1.12	-0.99	-1.20	-1.05	0.021	0.013
17	-1.11	-0.86	-1.23	-1.16	0.025	0.041

Figure 5A, 5B, 6A, 6B, 7A and 7B are graphical representations of the data both interpolated and extrapolated.

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Figure 5A shows the mean value of the coefficient of pressure of the membrane without the air permeable and resilient mat. Figure 5B shows the mean value of the coefficient pressure (C_p) of the top of the membrane with the air permeable and resilient mat located on top of the membrane. The data is both interpolated and extrapolated from the data in the above table. The mean value of the coefficient pressure (C_p) is associated with the average load. The coefficient of pressure (C_p) decreased from above -3.50 to generally around -1.10 in zone I. It increased from about -.70 to generally around -1.05 in zone II. It is applicant's belief that the increase in zone II was the result of the test parameters and would not exist in actually field use.

Figure 6A shows the minimum coefficient of pressure without the air permeable and resilient mat. Figure 6B shows the minimum coefficient of pressure with the air permeable and resilient mat. The minimum value of the coefficient of pressure is associated with maximum uplift. Wherein without the air permeable and resilient mat, portions of the roof membrane experienced uplift forces associated with a C_p of -4.20 (See tap 21). While the membrane without the mat had a minimum maximum uplift associated with a C_p of -.70 (see taps 5, 6, 9), with the air permeable and resilient mat overlaying the membrane, the minimum maximum uplift was related to a coefficient of pressure of approximately -1.10. (See taps 5, 6, 7, 11, 15). Therefore, the mat made certain areas have a larger maximum uplift. However, the maximum uplift experienced by any portion of the membrane with the mat was that associated with a coefficient of pressures (C_p) of -1.25. Therefore, while the maximum load in certain areas increased, the maximum load for any portion of the roof decreased drastically.

Figures 7A and 7B show the root mean square (RMS) of the coefficient of pressure which could be considered to be associated with the energy transferred to the roof membrane by the wind. Figure 6A shows the RMS of the coefficient of pressure of the membrane without the mat and varies

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from 0.1 to 0.348. However, the entire membrane which is covered by the mat, has a coefficient of pressure RMS of approximately 0.025.

Therefore, the wind tunnel verifies that the air permeable and resilient mat reduces the maximum uplift experienced by the membrane and in addition creates a more uniform distribution of uplift on the roof. The more uniform uplift on the roof results in less stress to the membrane in that various portions of the membrane are not pulled by contrasting different levels of suction by the wind.

Other benefits of invention

In addition to protecting from wind uplift and preventing the aggregate ballast from scouring, the air permeable mat has additional benefits. As indicated previously, two other design factors that are considered are 1) impact resistance, and 2) the influence of solar radiation and ultraviolet rays. Moreover, the air permeable and resilient mat can reduce the overall load on the roof and is easy to install.

The mat is resilient and relatively rigid. These attributes of the mat result in the mat being able to be walked on and returning to its shape without damage to the underlying membrane. In addition, if a person working on the roof drops a tool such as a wrench, hammer, the impact of the tool will not damage the underlying membrane. Likewise, a sharp object such as a knife or a screw driver will not make contact with the membrane and possible puncture the membrane.

Weather-related damage that have been a concern for flat roofs include items such as wind blow debris including sheet metal, such as from ventilators and air conditioner units, and tree branches blowing across the roof and puncturing the membrane. Another weather-related concern for a membrane roof is hail hitting the membrane puncturing the membrane weakening the adhesive bonds between the membrane and the substrate. In addition in the case of certain rigid insulation, the hail damages the insulation underlying the membrane by permanently compressing the insulating cells. The

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mat protects the membrane from both kinds of weather related damage discussed, along with other weather-related damage.

5 The membrane when exposed to ultra-violet rays of the sun deteriorates molecularly. One of the primary purposes of the gravel on the built-up roof is to prevent the ultra-violet rays from hitting the felt and bitumens of the built-up roof. The mat achieves a similar benefit, however not to the same extent.

10 The mat also can be colored to provide radiation benefits by reducing heat load. In addition, if the roof is visible, the mat can be colored for aesthetic purposes.

The mat does add weight (load) to the roof that must be accounted for in the design of the roof. However, as indicated previously, in a single-ply ballasted roof, the size of aggregate can be reduced. Therefore, the total load added to the roof with the mat is less than that with
15 conventional ballasted single-ply roof.

In that the wind generate forces are compensated by the static coefficient of friction, therefore the air permeable and resilient mat will not blow on the roof while the adhesive is setting. Therefore, an installer will have an easy time installing the mat.

20

Other preferred embodiments

An alternative embodiment of a single-ply roof mechanically affixed is shown in Figure 8. The roof structure 10' has a roof deck 12', an insulation layer 14' overlying the roof deck 12'. The roof structure 10' has a
25 single-ply membrane 16' overlying the insulation 14'. The membrane 16' is secured at the periphery 18' in proximity to a parapet 20'. In addition, the membrane 16' is secured to the decking 12' by a plurality of fasteners 30 at designated points to secure the insulation 14' and membrane 16' to the decking 12'. The fastener 30 is secured to the underside of the membrane 16'. Typical-
30 ly the fastener 30 is located at a joint location 30 where the single-ply mem-

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brane 16' is formed by joining two sheets together. The sheets are bonded together by heat welding, solvent welding or adhesives to form a larger sheet if required to cover the entire roof. The fastener 30 penetrates through an underlying sheet 32 and adheres to an overlying sheet 34. The sheets 32 and 34 are welded or adhered together at joint 36 such that the fastener 30 is underlying the continuous single-ply membrane 16'. The above construction is conventional and well known.

The roof 10' of the preferred embodiment has an air permeable and resilient member 24' overlying the membrane 16'. The air permeable and resilient member 24', similar to the first embodiment, is a non-woven air permeable and resilient mat made of synthetic fibers (usually nylon, PVC, or polyester) which are open and blended, then randomly aligned into a web by air flow. The web is treated with binding agents of water based phenolics and latexes. The treated web is then oven cured to bind the fabric into relative rigid mats having sufficient porous areas between the random fibers. In the preferred embodiment, the mat 24' has a thickness of $\frac{3}{8}$ of an inch. The mat 24' comes in rolls 78 inches wide and 20 yards long. The mat 24' weighs 11.11 - 13.89 pounds per square and has a fiber percentage of between 35 and 45 percent.

The air permeable and resilient mat 24' is secured to the roof 10' by placing an adhesive or neoprene cement or other comparable adhesive 26' in a 3 inch strip around the periphery of the mat and a 3 inch strip down the center line of the length of the mat 24'. The mat 24 is secured to the membrane 16' to prevent the mat 24' from being pushed across the roof 10.

Another preferred embodiment having a built-up roof 10" without a parapet is shown in Figure 9. The roof structure 10" has a roof decking 12". The roof structure 10" has an insulation layer 14" or plurality of insulation layers. The insulation layer 14" overlies the roofing deck 12" and is laid on the decking 12" and is secured by mechanical fasteners. The roof structure 10" has a built-up membrane 46" comprising layers of roofing felt interposed with bituminous (roofing asphalt). The top layer of bitumen may or may not receive

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a layer of gravel aggregate 22" at a ratio of 200 pounds to 60 pounds square asphalt. The roof structure 10", in addition, may have 200 pounds per square of gravel of $\frac{1}{4}$ to $\frac{3}{8}$ of an inch diameter on top. The above construction is conventional and well known.

5 The roof 10" has an air permeable and resilient mat 24" overlying the aggregate 22" or roof membrane 46". The air permeable and resilient mat 24" in the preferred embodiment is a non-woven air permeable and resilient mat made of synthetic fibers (usually nylon, PVC or polyester) which are open and blended, then randomly aligned into a web by air flow. The web is treated
10 with binding agents or water based phenolics and latexes. The treated web is then oven cured to bind the fabric into relatively rigid mats having a significant porous area between the random fibers. The mat 24" has a thickness of $\frac{3}{4}$ of an inch and comes in rolls 78 inches wide and 34 yards long. The mat 24" weighs 31.25 pounds per square and has a percent open area of 71.43.

15 The air permeable and resilient mat 24" is secured to the roof 10" using a suitable adhesive in the same method described in the first embodiment or being hot mopped into place. An alternative method is to place a plurality of pavers 48 on the roof 10" underlying the mat 24" and secure the mat 24" to the pavers 48.

20 Figure 10 shows an alternative embodiment of an "upside-down" roof 10'', a roof where the insulation layer is on top of the membrane 16''. The roof structure 10'' has a roof decking 12''. Figure 6 shows the roof decking 12'' formed of concrete; the roof decking 12'' can also be formed of wood, corrugated steel, gypsum and other suitable materials. The roof structure
25 10'' has a single-ply membrane 16'' overlies the roof decking 12''. The single-ply membrane 16'' is secured at the periphery of the roof deck 12'', not shown. The single-ply membrane 16'' is not secured except at the periphery 18 and simply overlies the roof deck 12''. The single-ply membrane 16'' is formed in sheets. The sheets are bonded together by heat welding, solvent
30 welding or adhesives, to form a larger sheet if required to cover the entire roof.

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Overlying the membrane 16''' is an insulation layer 14'', or plurality of insulation layers. The insulation layer 14'' is secured by an adhesive fastener to the underlying membrane 16''. The above construction is conventional and well known.

5 The roof 10''' has an air permeable and resilient mat 24''' overlying the insulation layer 24''. The air permeable and resilient mat 24''' is similar to those described in the other embodiments. The air permeable and resilient mat 24'' is secured to the roof 10'' using neoprene or another suitable adhesive to the insulation layer 24''. An alternative method is to place a
10 plurality of pavers on the roof 10'' underlying the mat 24'' and secure the mat 24'' to the pavers.

The present invention may be embodied in other specific forms without departing from the spirit or central attributes thereof and, accordingly, reference should be made to the dependent claims, rather than to the foregoing
15 specification, as indicating the scope of the invention

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CLAIMS:

1. A method of constructing a roof structure which will reduce uplift comprising:

providing a roof having a membrane;

5 installing a ballast layer comprising loose aggregate prior to installing an air permeable and resilient mat; and

installing the air permeable and resilient mat constructed of randomly aligned fibers which are joined by a
10 binding agent, over the membrane, and overlying the aggregate, the mat having openings of a size to reduce the wind velocity over the membrane from that of rooftop wind speed reducing the scouring of the aggregate across the roof while the openings being of a size that the mat is not
15 lifted by the pressure differential therein reducing uplift on the membrane.

2. A method of constructing a roof structure which will reduce uplift comprising:

providing a roof having a membrane;

20 installing a ballast layer having a loose aggregate;

clearing away the aggregate from the membrane in specific segments; and securing an air permeable and resilient mat to the specific segments using an adhesive
25 means, the mat having openings of a size to reduce the wind velocity over the membrane from that of rooftop wind speed while the openings being of a size that the mat is not lifted by the pressure differential therein reducing uplift on the membrane.

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3. A method as in claim 1 or 2 wherein the air permeable and resilient mat is constructed of randomly aligned synthetic fibers which are open and blended, randomly aligned into a web by an airflow, joined by phenolic and latex binding agents and heat cured to produce a varying mesh.

4. A roof structure comprising:

a roof decking;

a membrane;

10 means for securing the membrane to the roof decking; and

an air permeable and resilient mat constructed of randomly aligned fibers overlying the membrane, the mat having openings of a size to reduce the wind velocity over the membrane while the openings being of such a size that the mat is not lifted, the fiber content by area of the mat less than 45 percent of the mat.

5. A roof structure as in claim 4 wherein the membrane is a single-ply membrane.

20 6. A roof structure as in claim 4 wherein the membrane is a multi-ply built-up roof.

7. A roof structure comprising:

a roof decking;

a single-ply membrane;

25 aggregate overlying the membrane for securing the membrane to the roof decking; and

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an air permeable and resilient mat overlying the membrane and the aggregate, the aggregate loosely retained between the membrane and the mat, the mat having openings of a size to reduce the wind velocity over the membrane while
5 the openings being of such a size that the mat is not lifted.

8. A roof structure as in claims 4, 5, 6 or 7 further comprising an insulation between the roof decking and the membrane.

10 9. A method of constructing a roof structure which will reduce scouring comprising:

providing a membrane roof over a deck, the roof having a layer of aggregate loosely placed on the membrane;

15 installing an air permeable and resilient mat over the aggregate for reducing the wind velocity over the aggregate and applying a force to the aggregate.

10. A method as in claim 9 wherein the membrane is a single-ply and the aggregate is a ballast.

11. A method as in claim 9 wherein the membrane is a
20 multi-ply built-up layer and the aggregate is a gravel.

12. A method of constructing a roof structure which will reduce scouring comprising:

providing a membrane roof over a deck, the roof having a layer of aggregate;

25 clearing the aggregate from the membrane in a specific pattern;

installing an air permeable and resilient mat over the aggregate by an adhesive to the cleared specific pattern

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on the membrane for reducing the wind velocity over the aggregate and retaining the aggregate with the specific pattern.

13. A method as in claim 12 wherein the step of
5 clearing the aggregate further comprises the step of:

clearing a grid of aggregate from the membrane the size of the air permeable and resilient mat and clearing a center line of aggregate from the membrane running the long direction of the mat.

10 14. A method as in claim 9 wherein the air permeable and resilient mat has a fiber content of approximately 35 percent.

SMART & BIGGAR

PATENT AGENTS

OTTAWA, CANADA

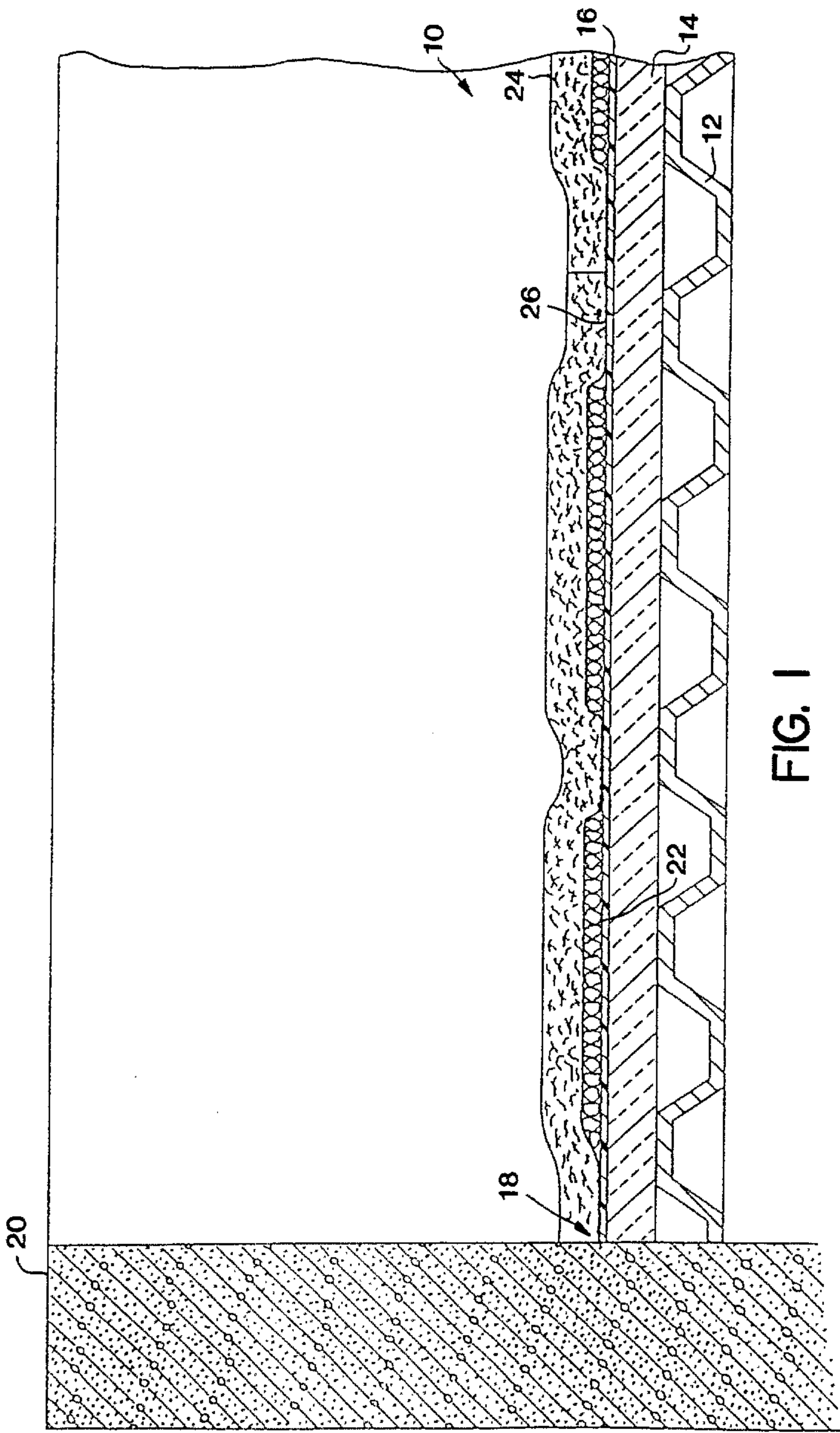


FIG. 1

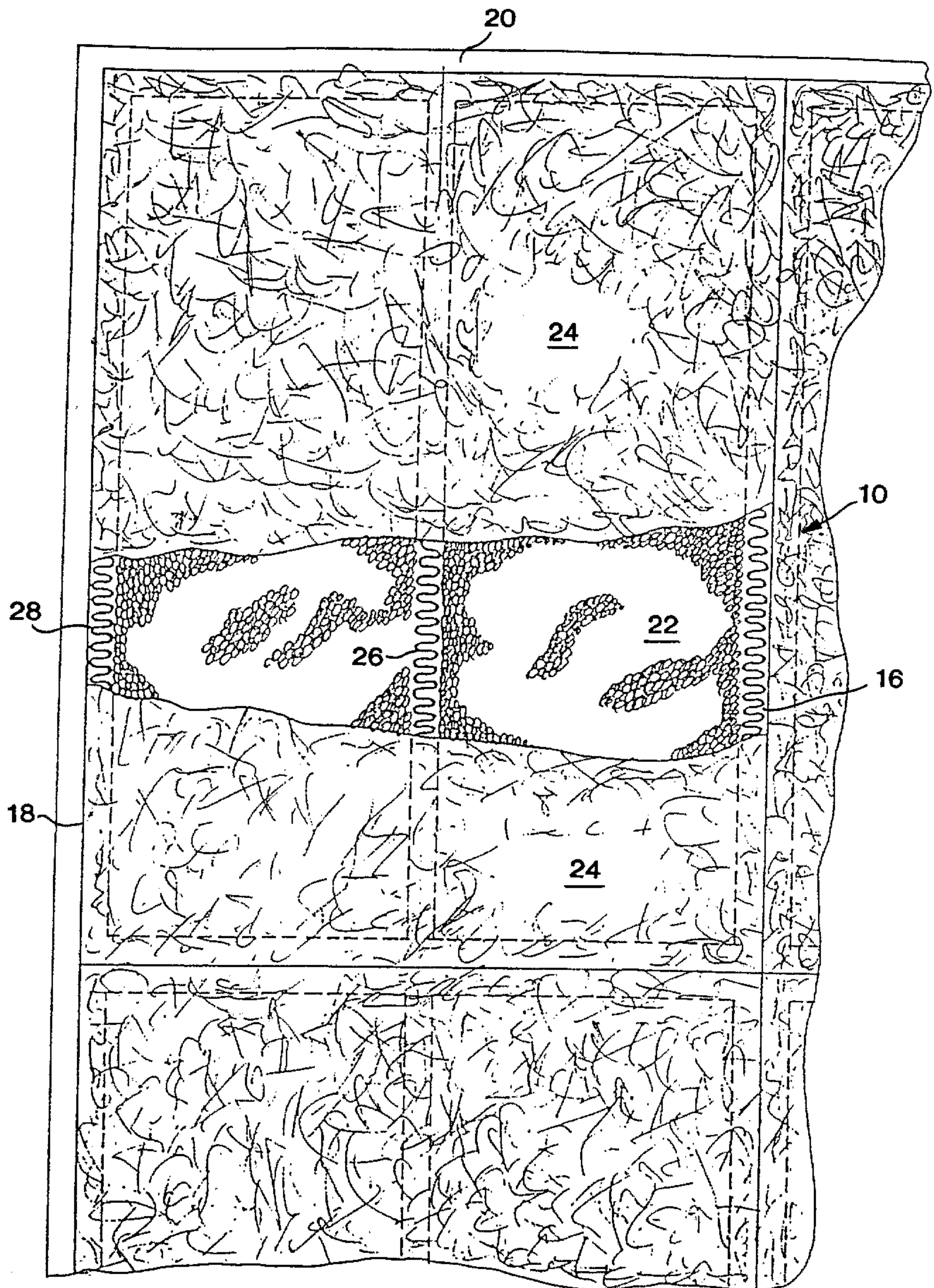


FIG. 2

SUBSTITUTE SHEET (RULE 26)

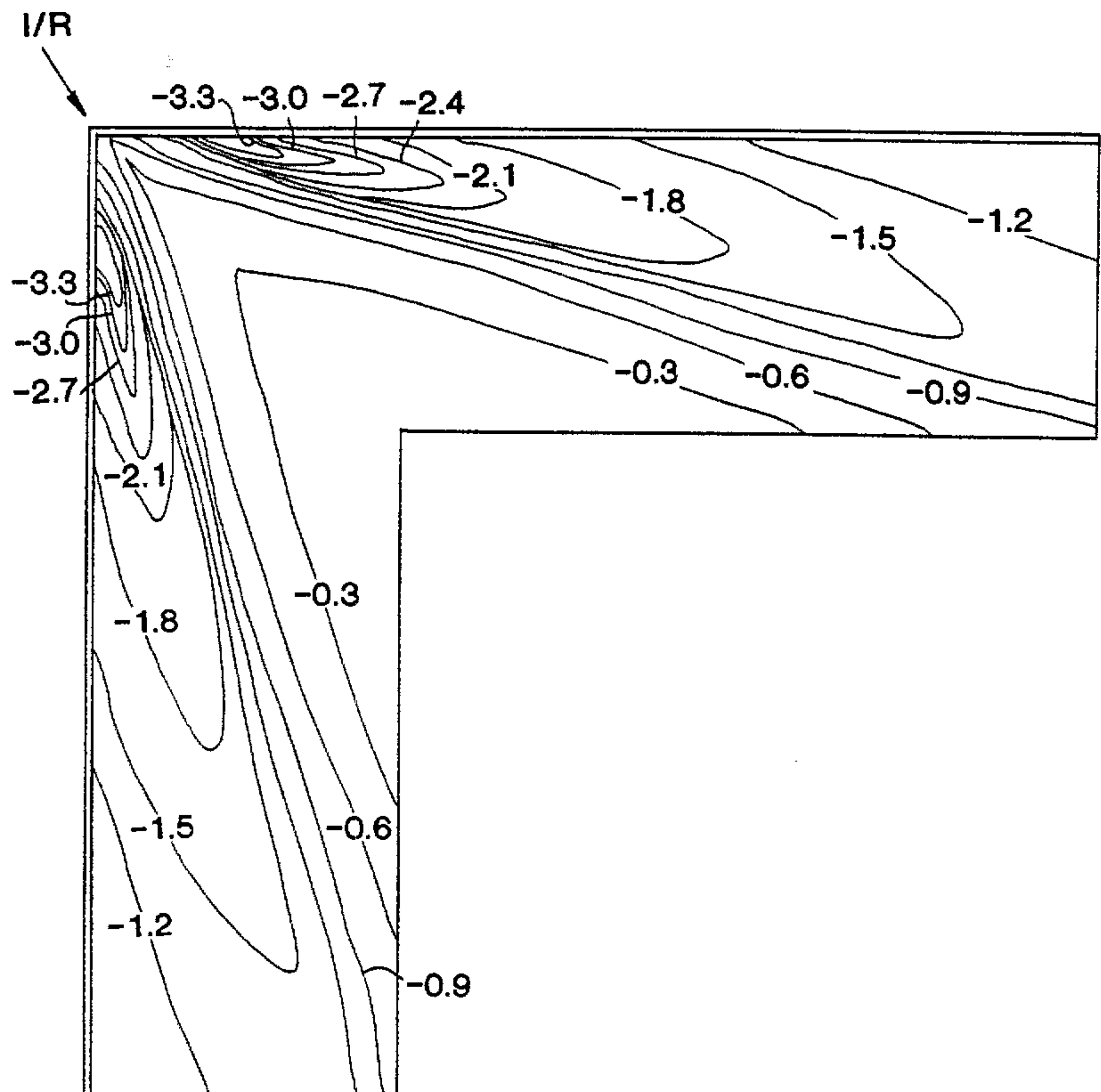


FIG. 3

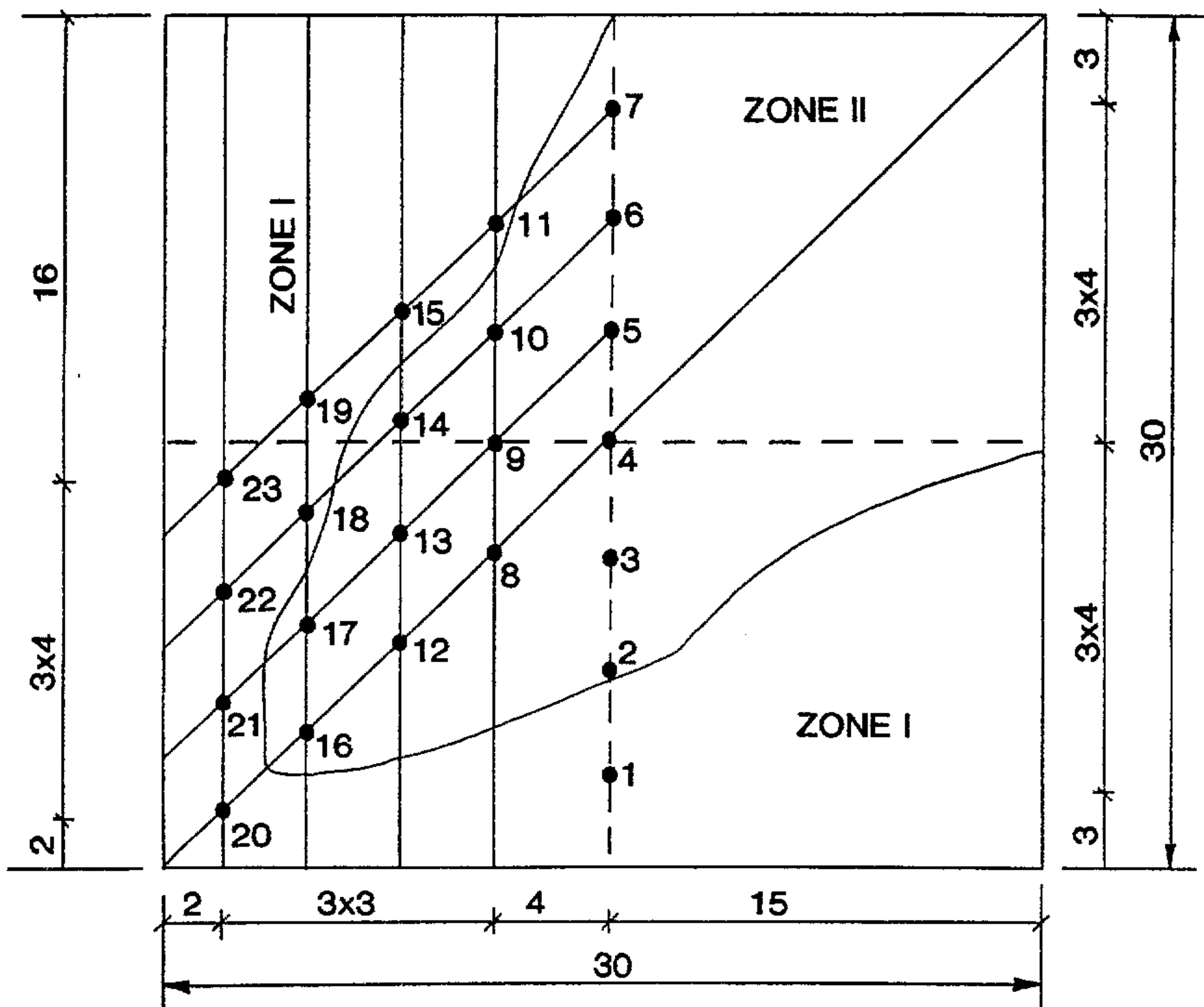


FIG. 4

FIG. 5A

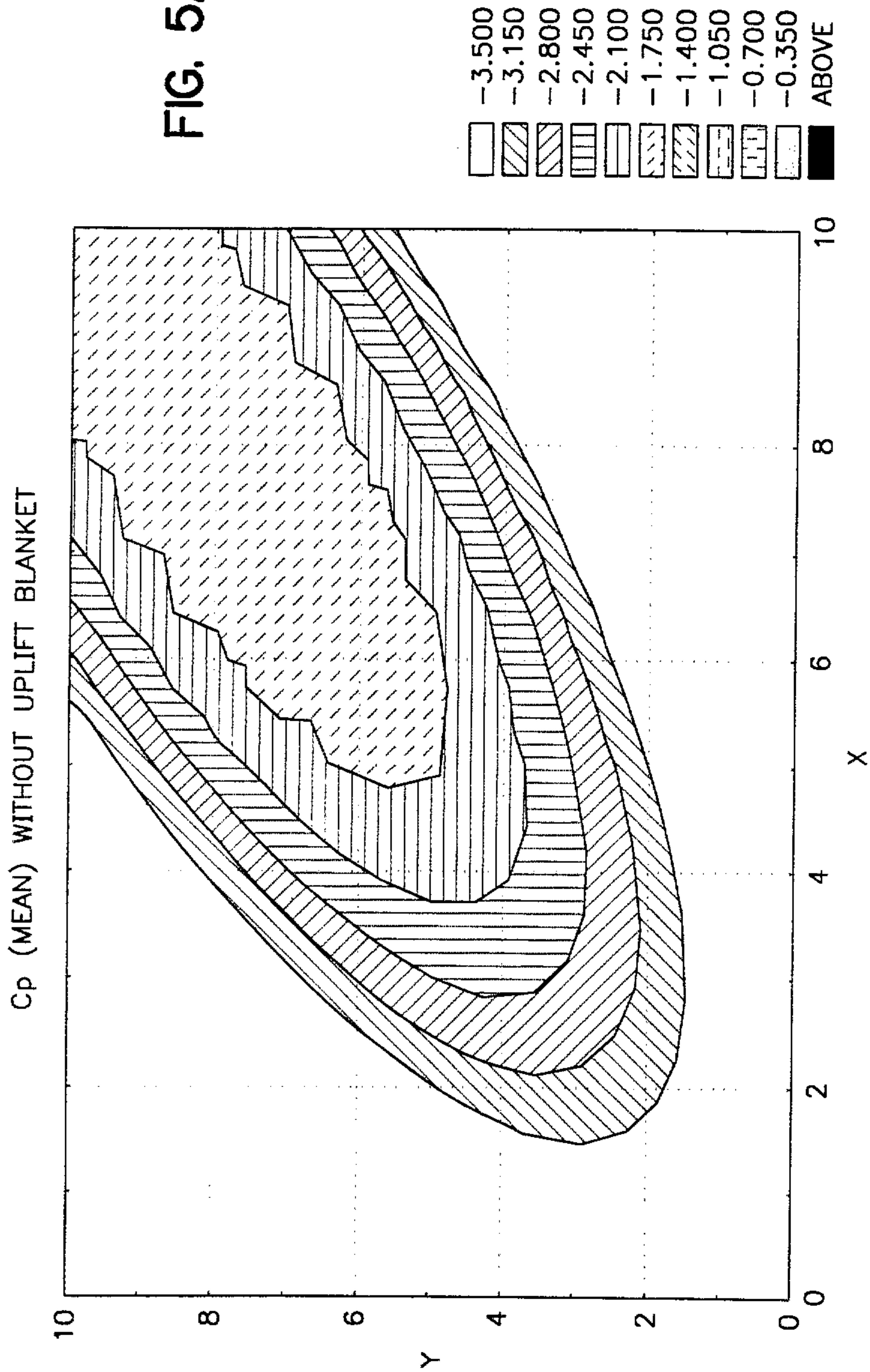


FIG. 5B

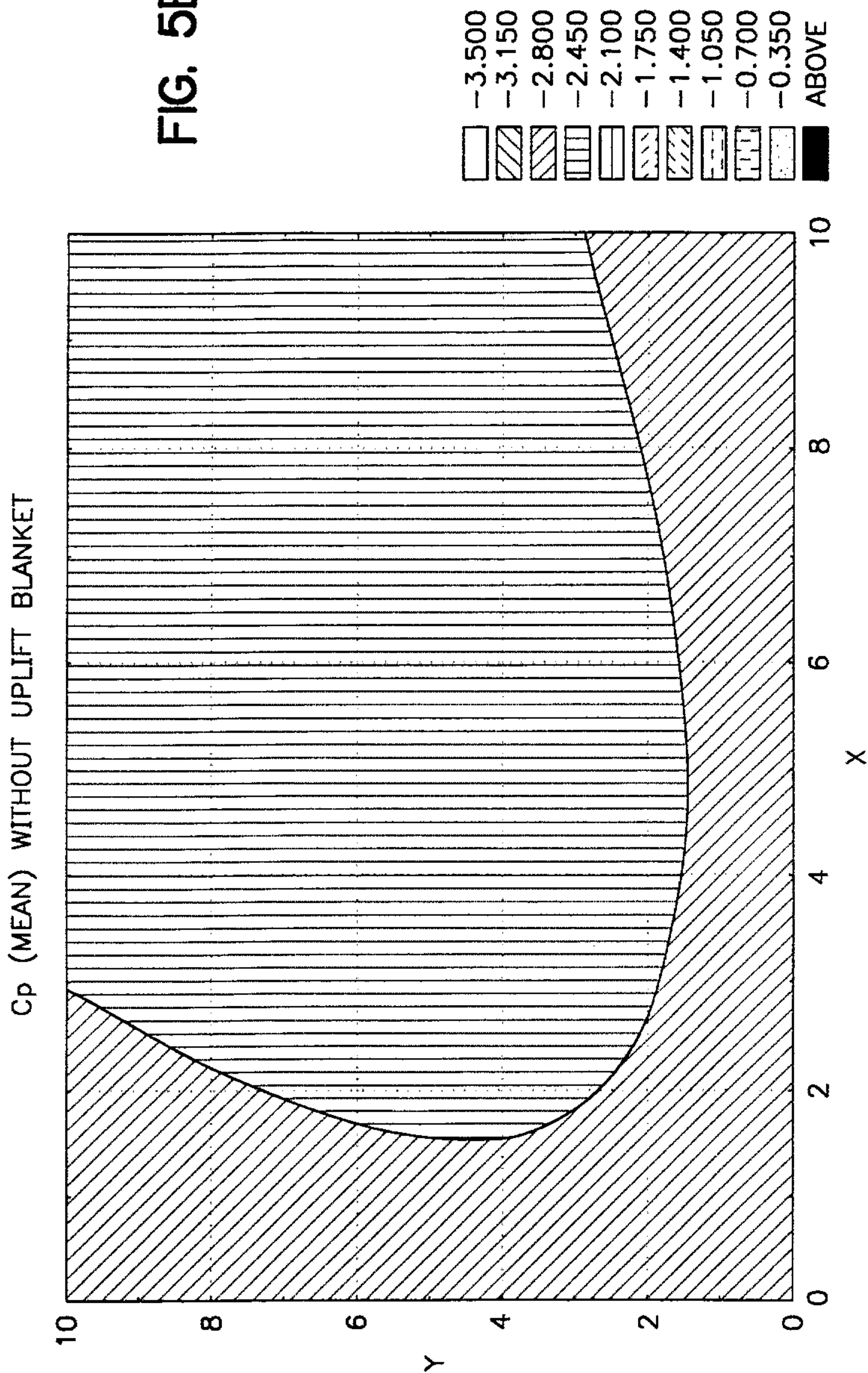


FIG. 6A

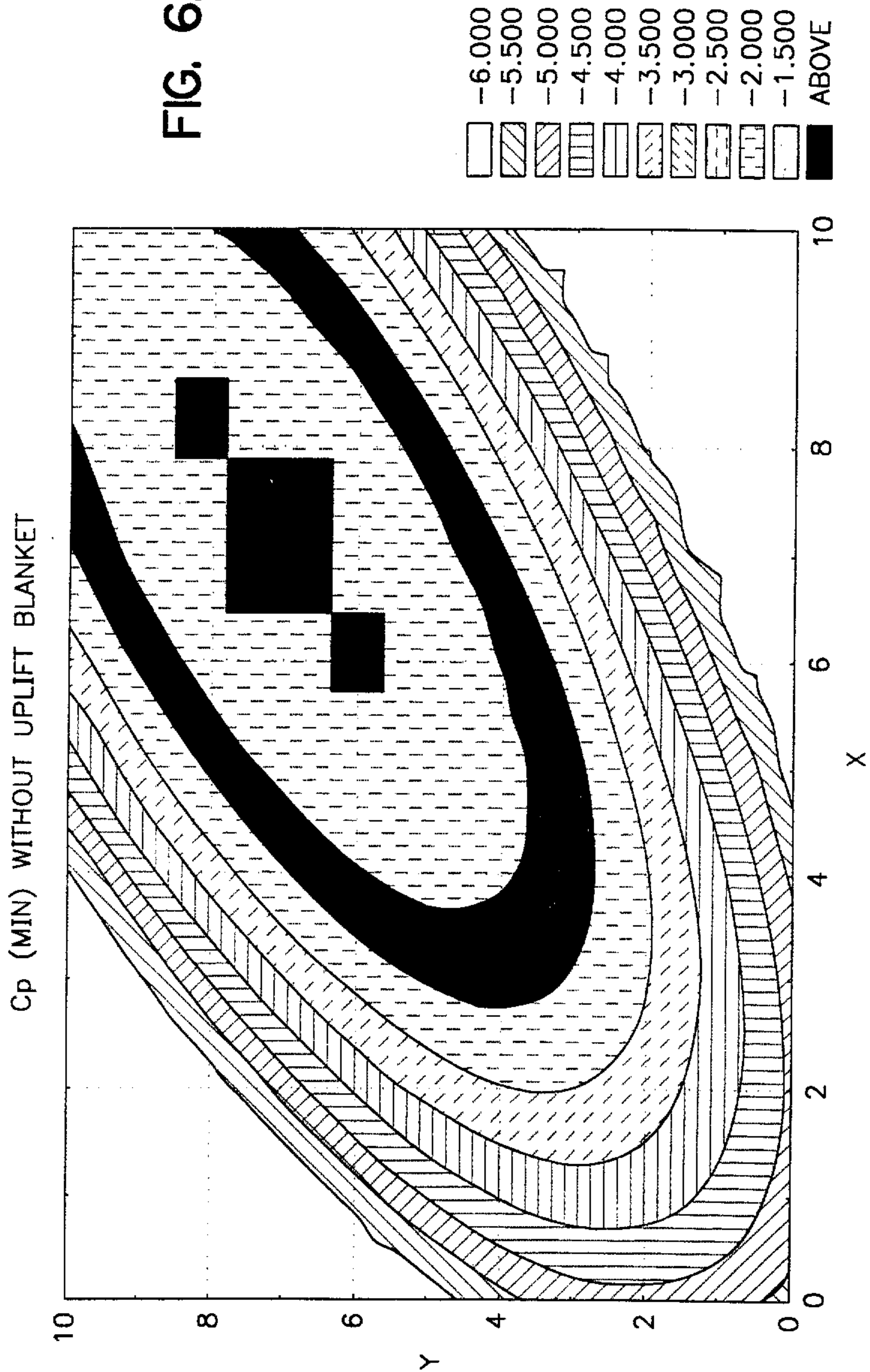


FIG. 6B

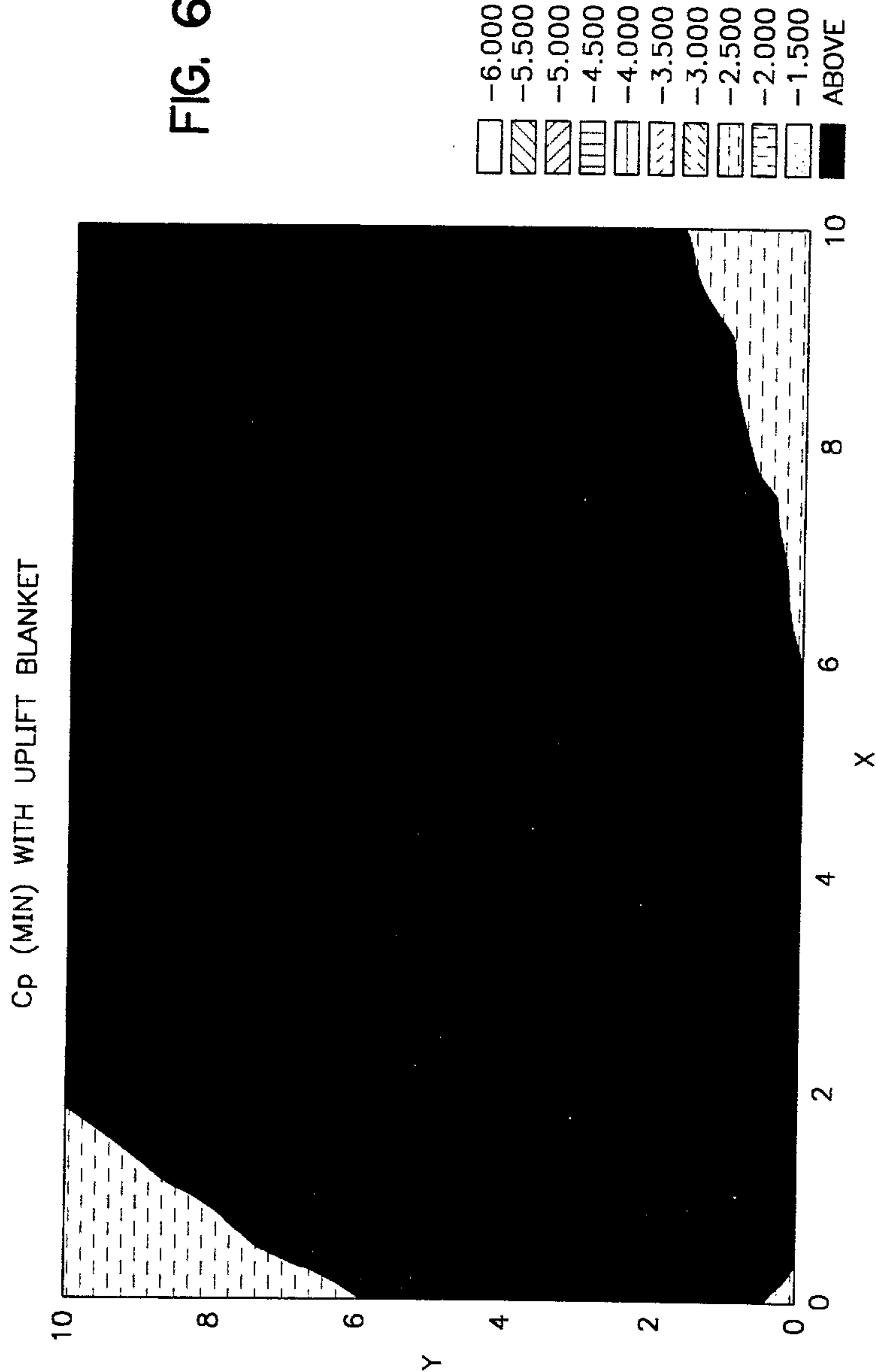


FIG. 7A

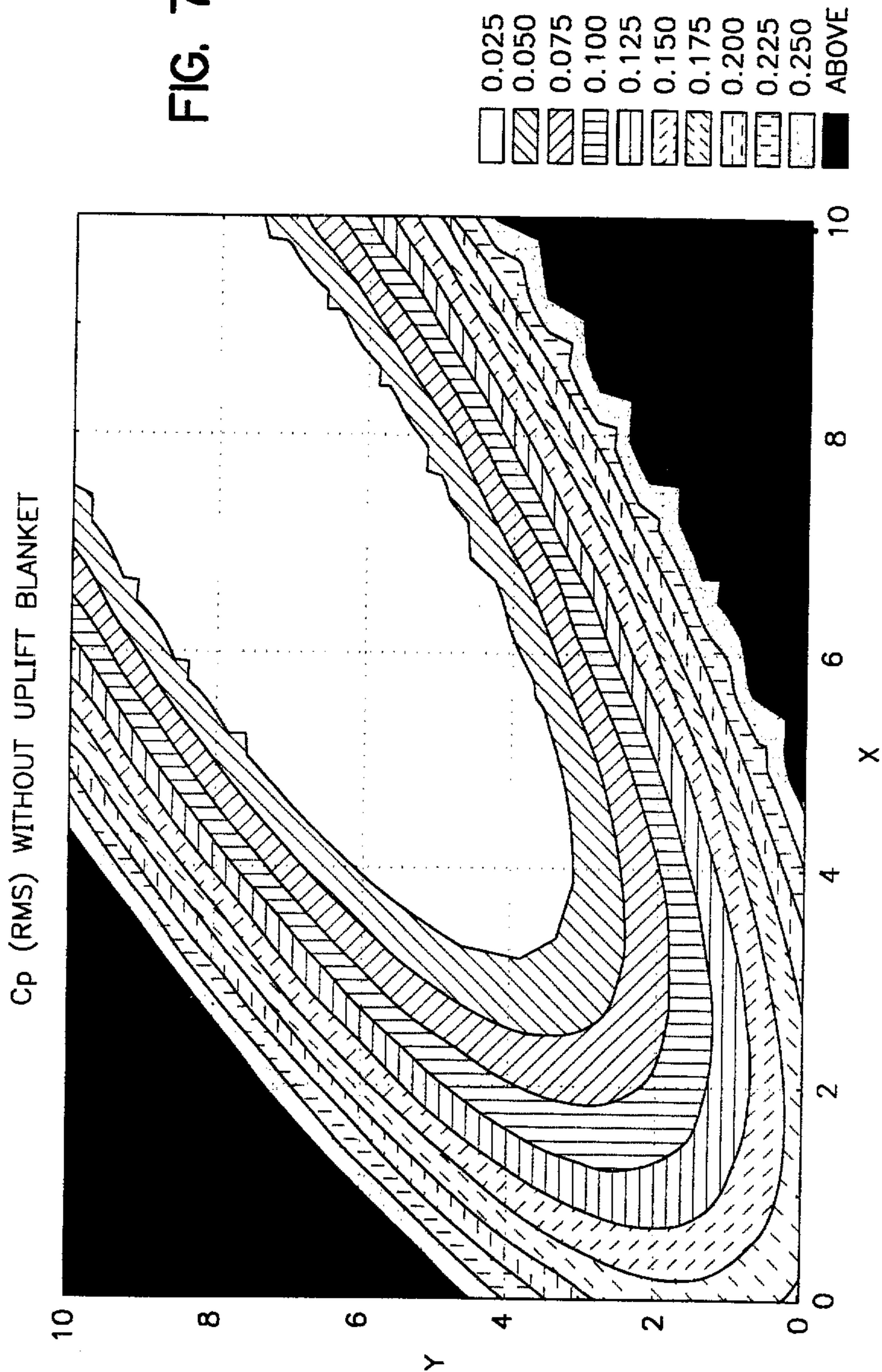
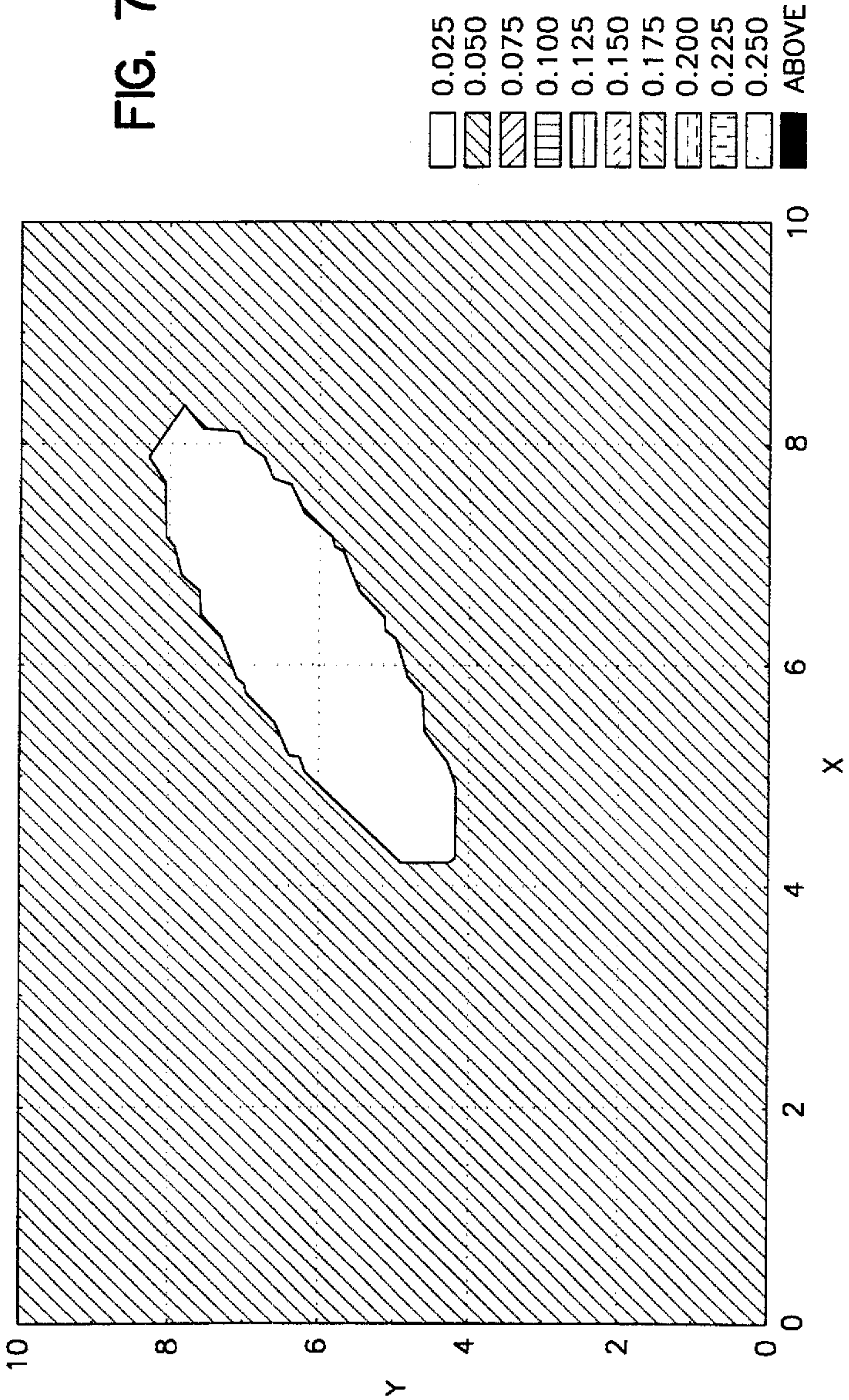


FIG. 7B

Cp (RMS) WITH UPLIFT BLANKET



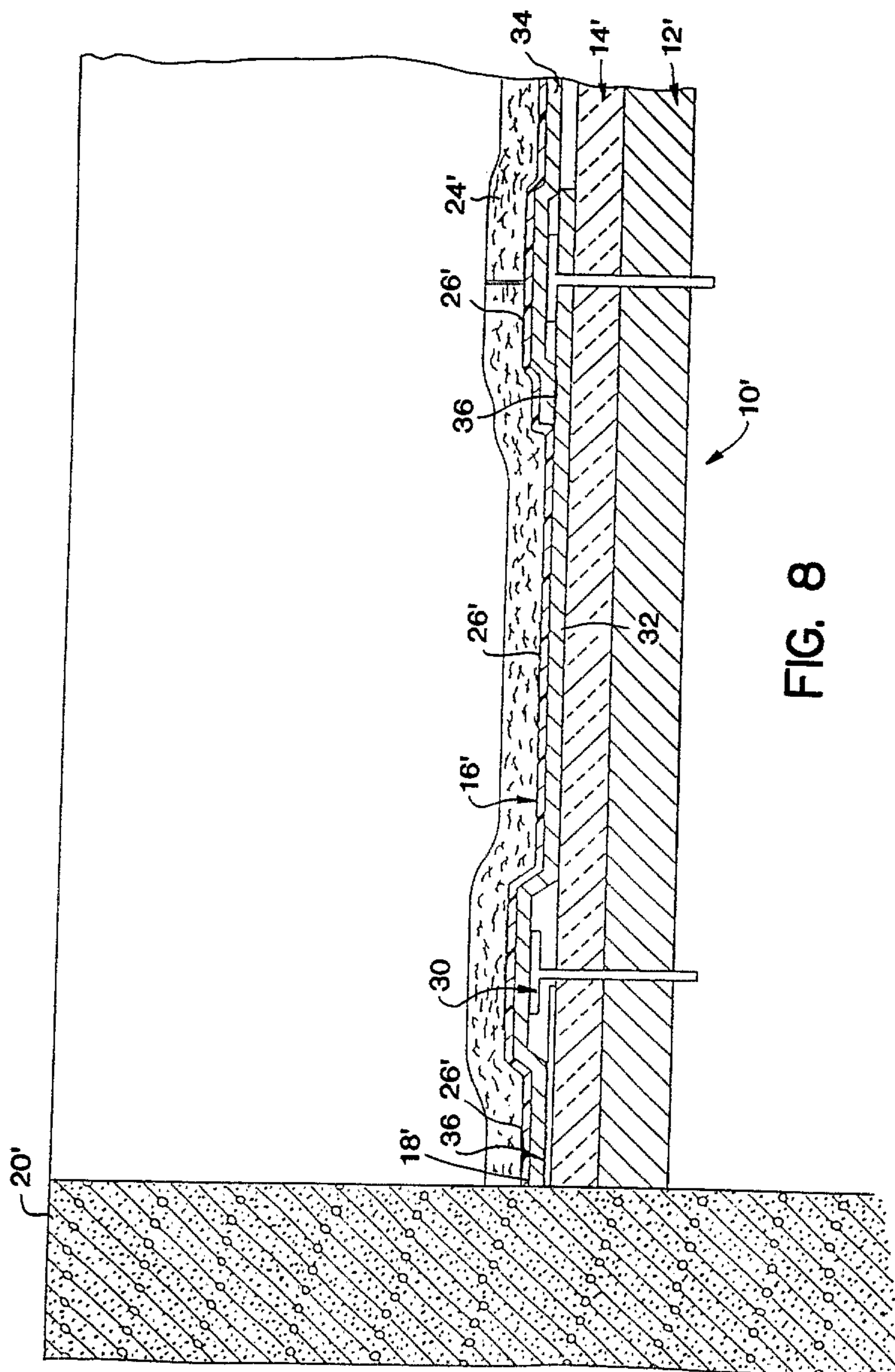


Fig. 8

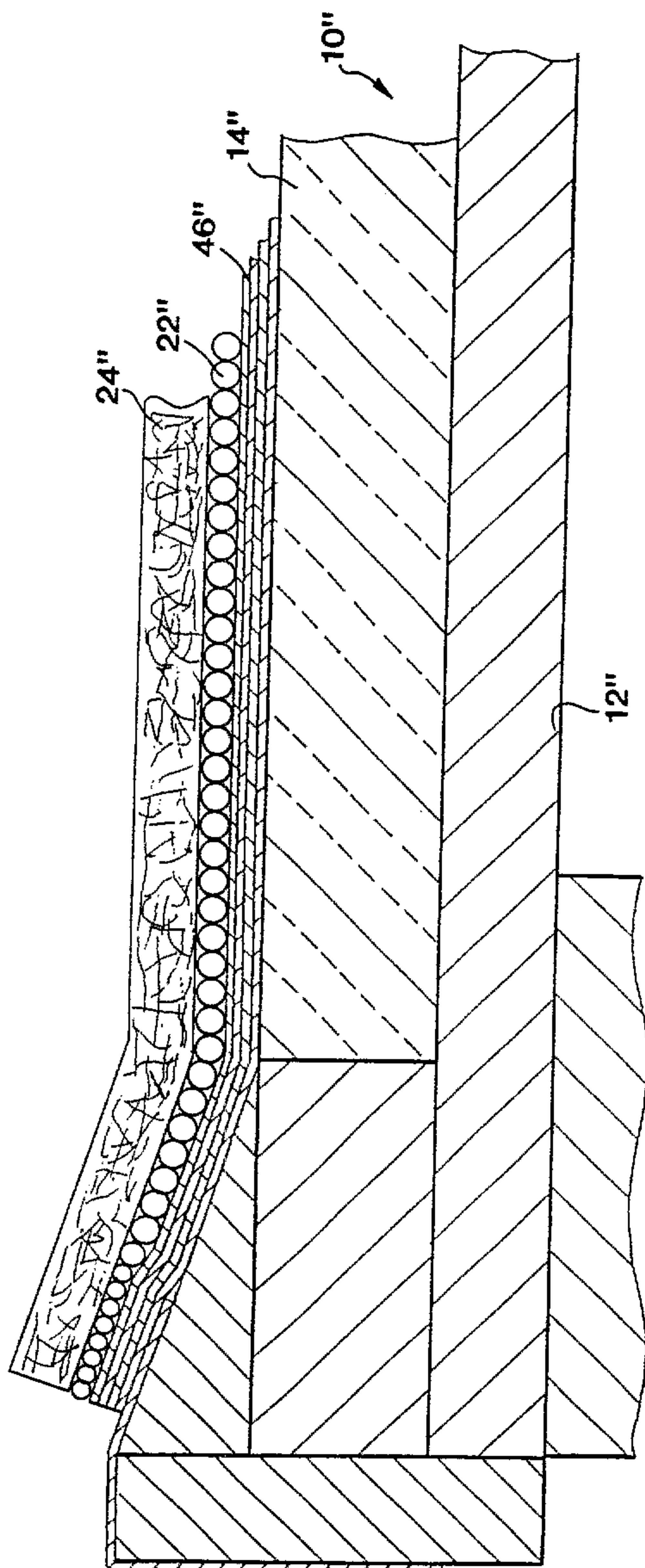


FIG. 9

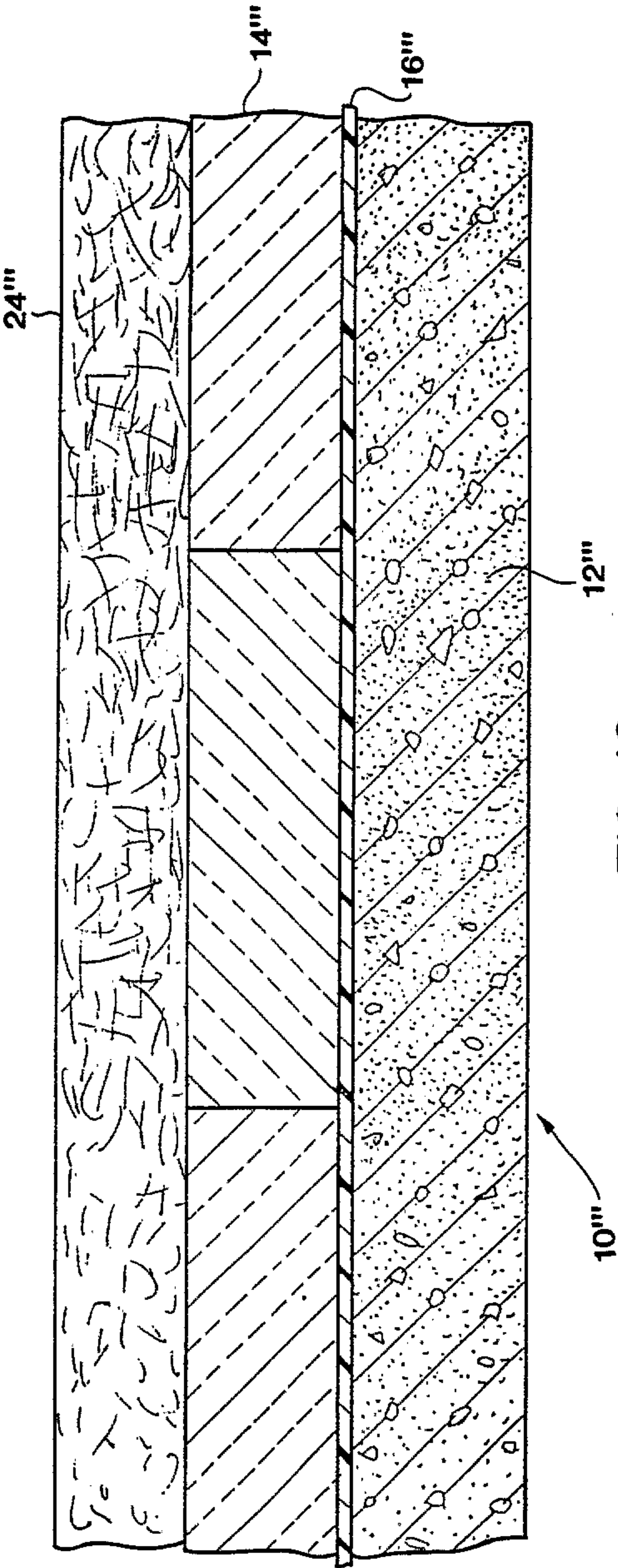


FIG. 10

