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(54) **FORMS AND SUBSURFACE STRUCTURAL ELEMENTS THAT REDIRECT SOIL FORCES**

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(51) **Int. Cl.**

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E02D 27/12	(2006.01)
E04G 13/00	(2006.01)

(52) **U.S. Cl.**

CPC ***E02D 27/08*** (2013.01); ***E02D 27/02*** (2013.01); ***E02D 27/12*** (2013.01); ***E04G 13/00*** (2013.01); *E02D 2200/165* (2013.01); *E02D 2200/1678* (2013.01); *E02D 2250/0007* (2013.01); *E02D 2250/0023* (2013.01); *E02D 2300/002* (2013.01)

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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,090,204	A	5/1963	Upson
4,738,061	A	4/1988	Herndon

(Continued)

FOREIGN PATENT DOCUMENTS

EP	0952258		10/2002
JP	2002309178	A *	10/2002

OTHER PUBLICATIONS

U.S. Appl. No. 16/171,300, filed Oct. 25, 2018, James C. Conner et al.

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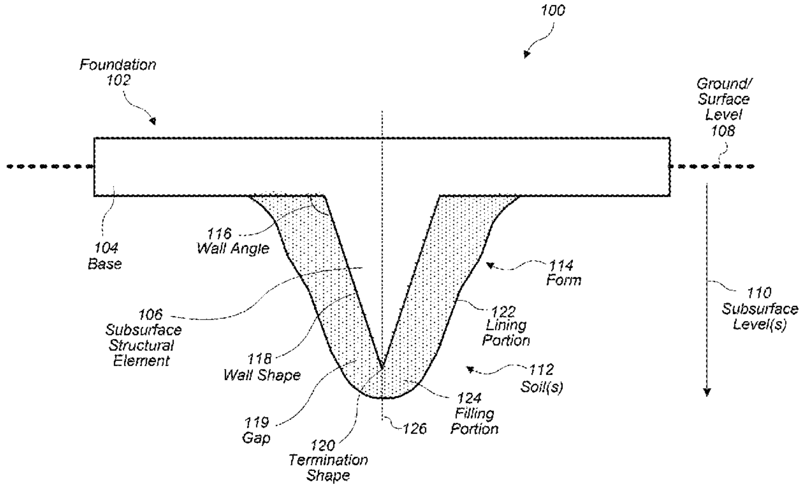
(57) **ABSTRACT**

Embodiments described herein relate to construction of subsurface structural elements that are configured to redirect soil forces. For instance, a form may be used to construct a subsurface structural element such that the subsurface structural element redirects soil forces to vertically displace a foundation rather than have the soil forces crack or otherwise damage the foundation.

20 Claims, 10 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

4,783,935	A *	11/1988	Creager	E04B 1/0007 52/98
4,824,262	A	4/1989	Kamigaito et al.	
5,039,256	A	8/1991	Gagliano	
5,234,290	A	8/1993	Collins	
5,951,207	A	9/1999	Chen	
10,113,289	B2	10/2018	Conner et al.	
10,519,618	B2	12/2019	Conner	
11,118,322	B2	9/2021	Conner et al.	
2001/0010410	A1	8/2001	Meehan et al.	
2009/0173445	A1 *	7/2009	Yeom	H01J 37/321 156/345.48
2011/0002744	A1	1/2011	Tadros	
2013/0313740	A1	11/2013	Gilpin et al.	
2014/0186112	A1	7/2014	Hassan	

* cited by examiner

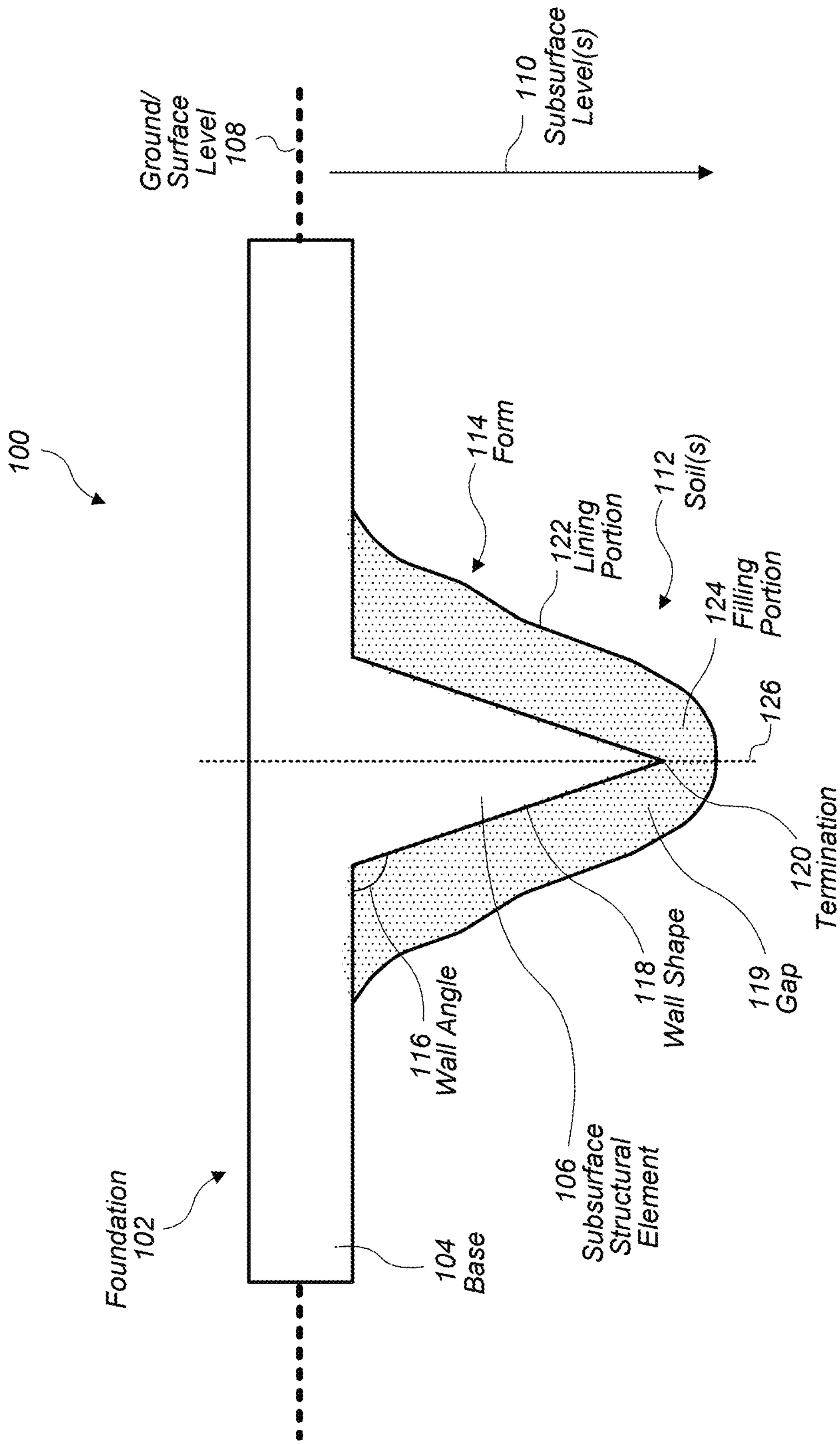
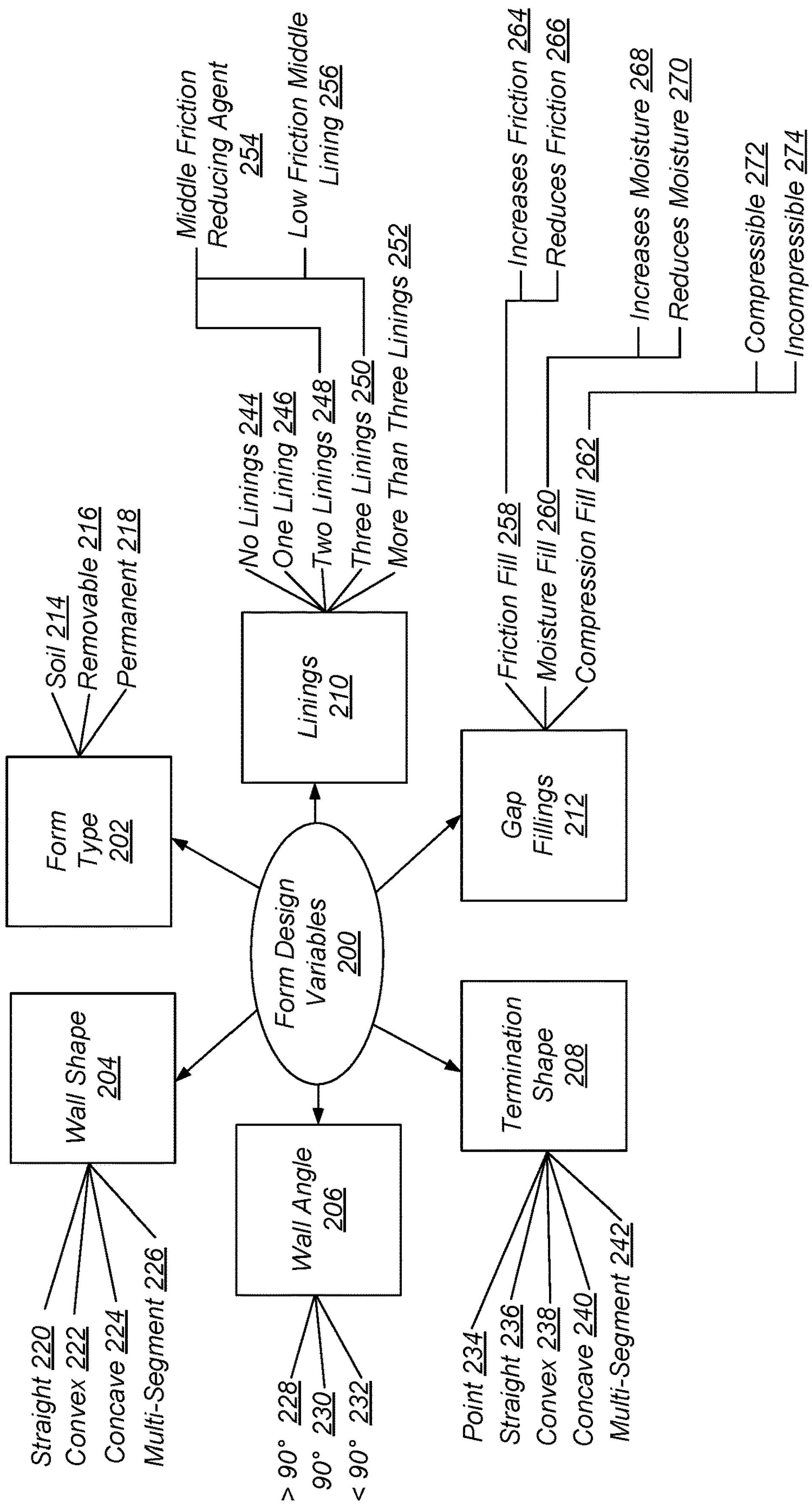

100
Ground/
Surface
Level
108
110
Subsurface
Level(s)
114
Form
112
Soil(s)
122
Lining
Portion
124
Filling
Portion
126
120
Termination
Shape
119
Gap
118
Wall Shape
116
Wall Angle
106
Subsurface
Structural
Element
Foundation
102
104
Base

Fig. 1


Form Design Variables 200
Form Type 202
Wall Shape 204
Wall Angle 206
Termination Shape 208
Linings 210
Gap Fillings 212
Soil 214
Removable 216
Permanent 218
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Convex 222
Concave 224
Multi-Segment 226
> 90° 228
90° 230
< 90° 232
Point 234
Straight 236
Convex 238
Concave 240
Multi-Segment 242
No Linings 244
One Lining 246
Two Linings 248
Three Linings 250
More Than Three Linings 252
Middle Friction Reducing Agent 254
Low Friction Middle Lining 256
Friction Fill 258
Moisture Fill 260
Compression Fill 262
Increases Friction 264
Reduces Friction 266
Increases Moisture 268
Reduces Moisture 270
Compressible 272
Incompressible 274

Fig. 2

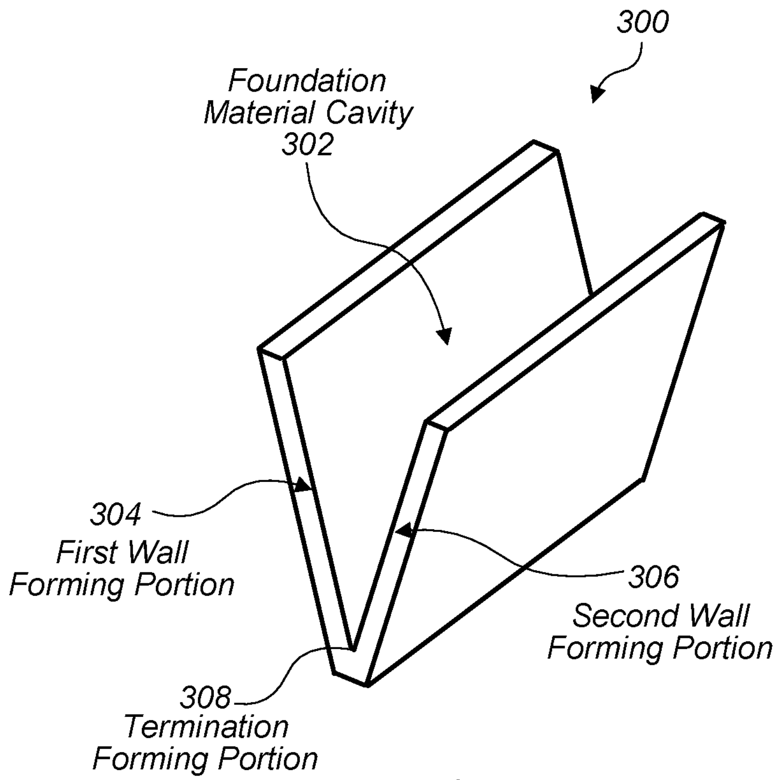
300
Foundation
Material Cavity
302
304
First Wall
Forming Portion
306
Second Wall
Forming Portion
308
Termination
Forming Portion

Fig. 3

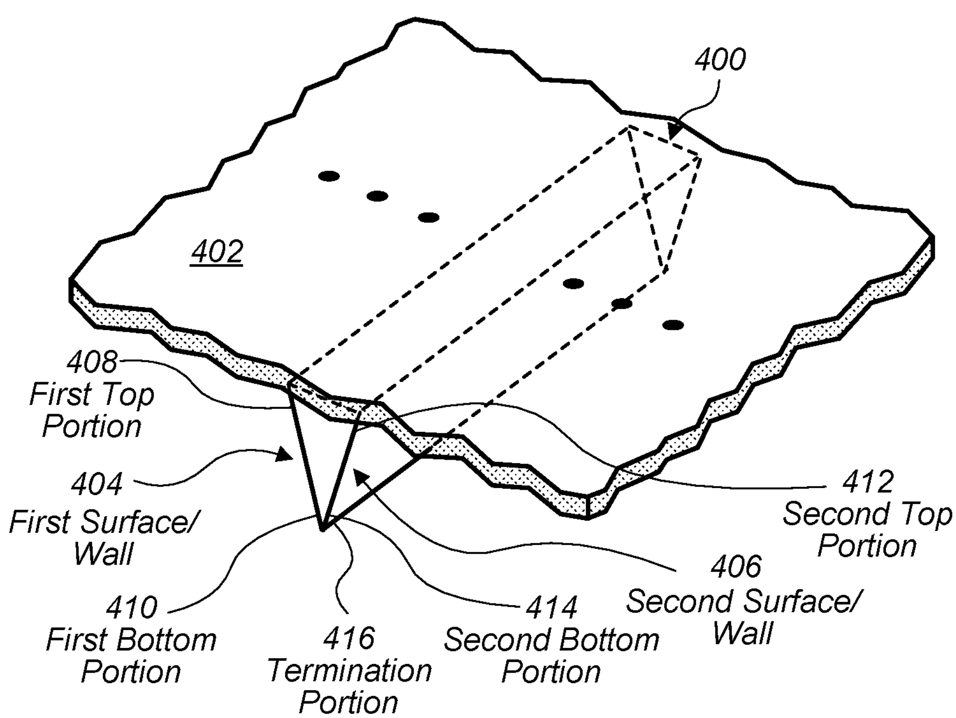
400
402
408
First Top
Portion
404
First Surface/
Wall
410
First Bottom
Portion
416
Termination
Portion
414
Second Bottom
Portion
406
Second Surface/
Wall
412
Second Top
Portion

Fig. 4

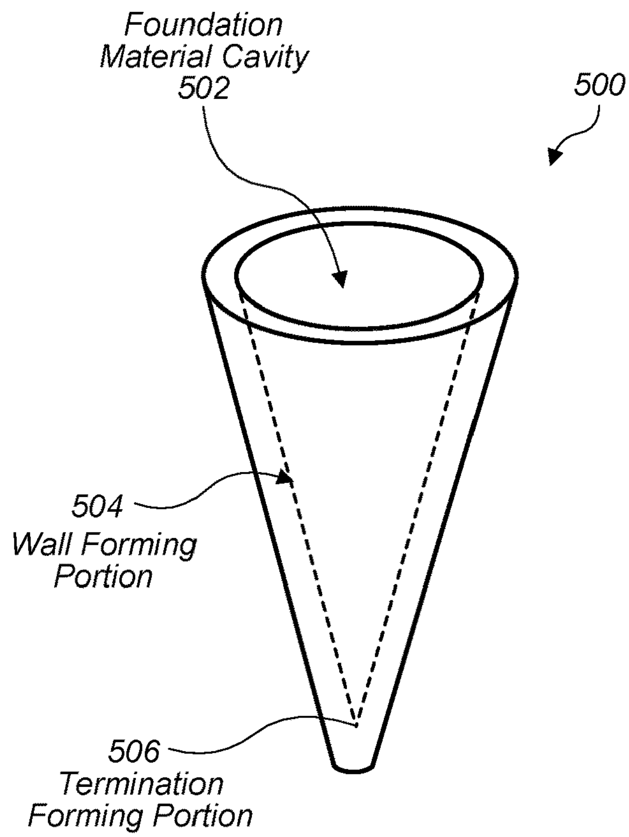
Foundation
Material Cavity
502
500
504
Wall Forming
Portion
506
Termination
Forming Portion

Fig. 5

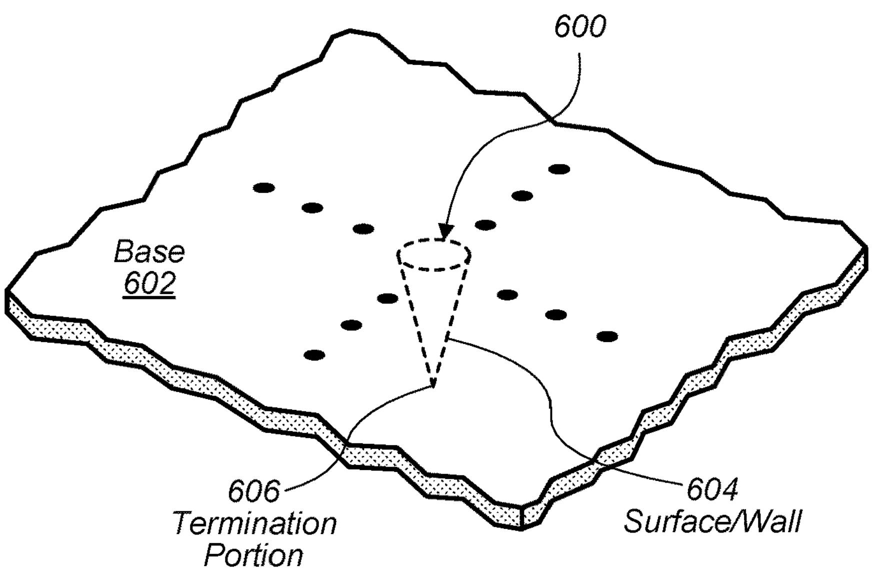
600
Base
602
606
Termination
Portion
604
Surface/Wall

Fig. 6

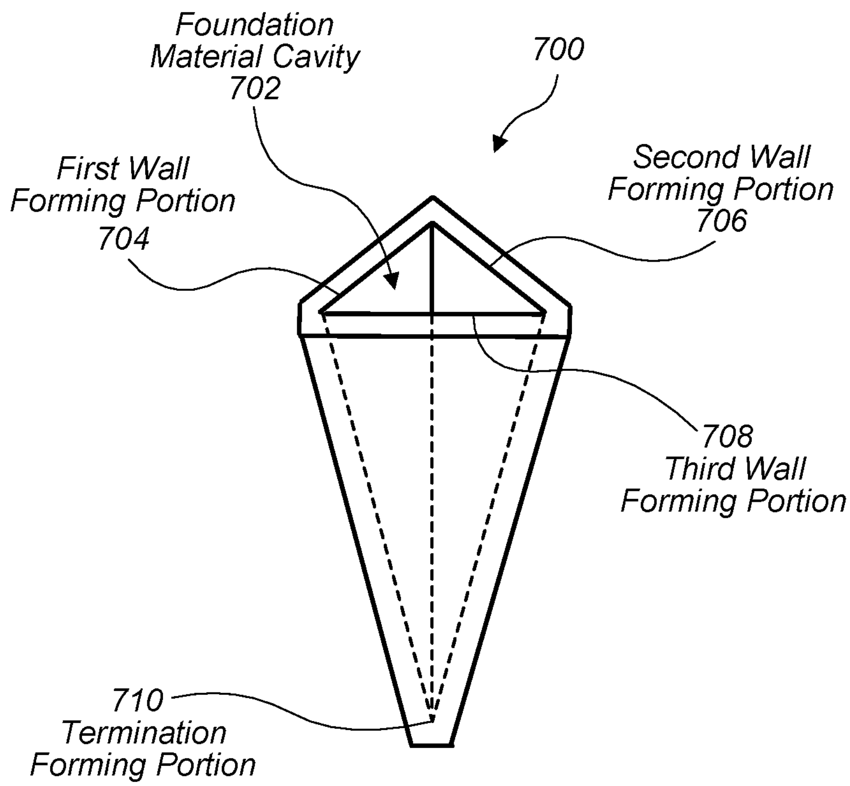
Foundation
Material Cavity
702
700
First Wall
Forming Portion
704
Second Wall
Forming Portion
706
708
Third Wall
Forming Portion
710
Termination
Forming Portion

Fig. 7

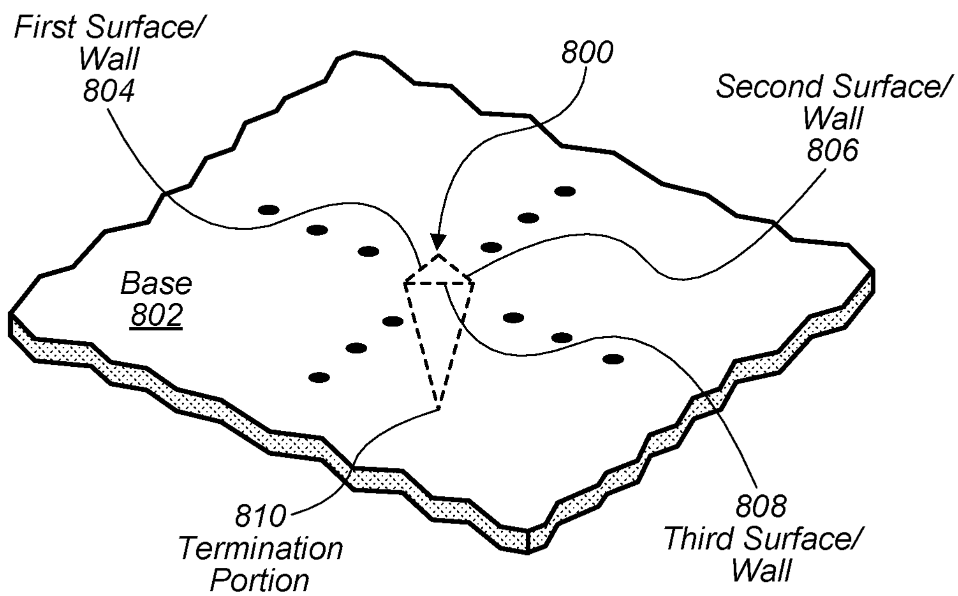
First Surface/
Wall
804
800
Second Surface/
Wall
806
Base
802
810
Termination
Portion
808
Third Surface/
Wall

Fig. 8

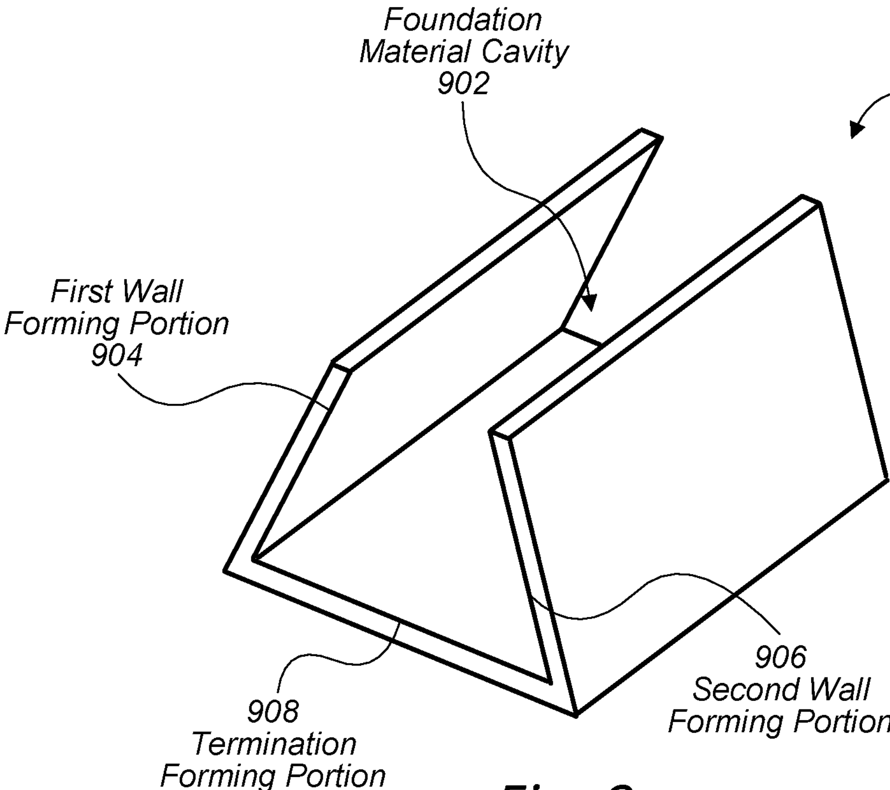
Foundation
Material Cavity
902
900
First Wall
Forming Portion
904
906
Second Wall
Forming Portion
908
Termination
Forming Portion

Fig. 9

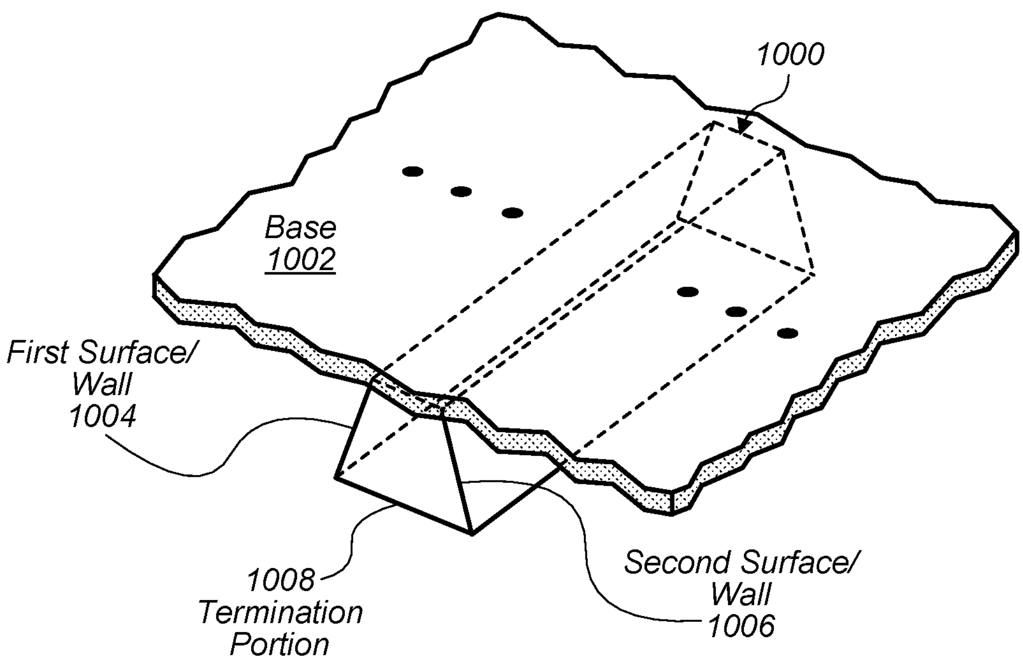
1000
Base
1002
First Surface/
Wall
1004
1008
Termination
Portion
Second Surface/
Wall
1006

Fig. 10

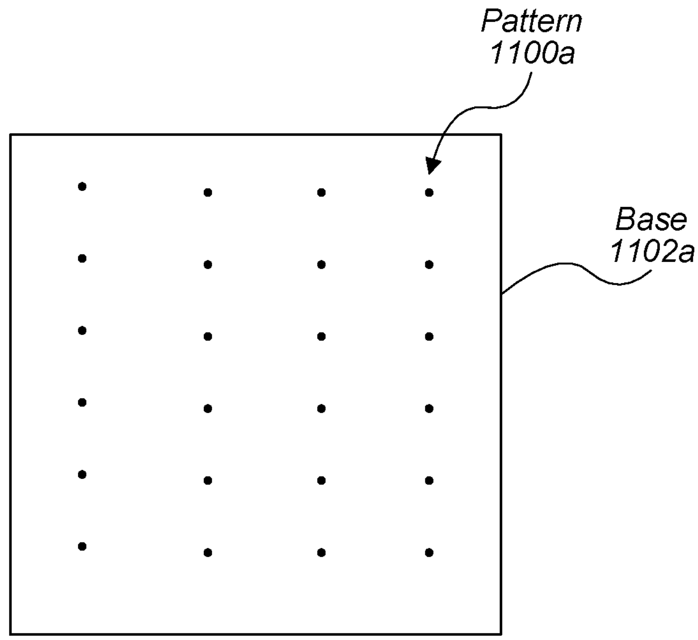

Fig. 11A

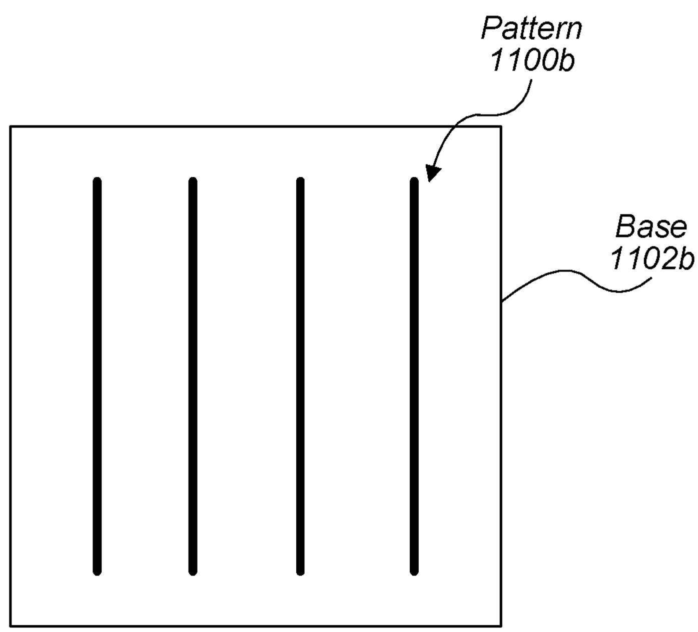

Fig. 11B

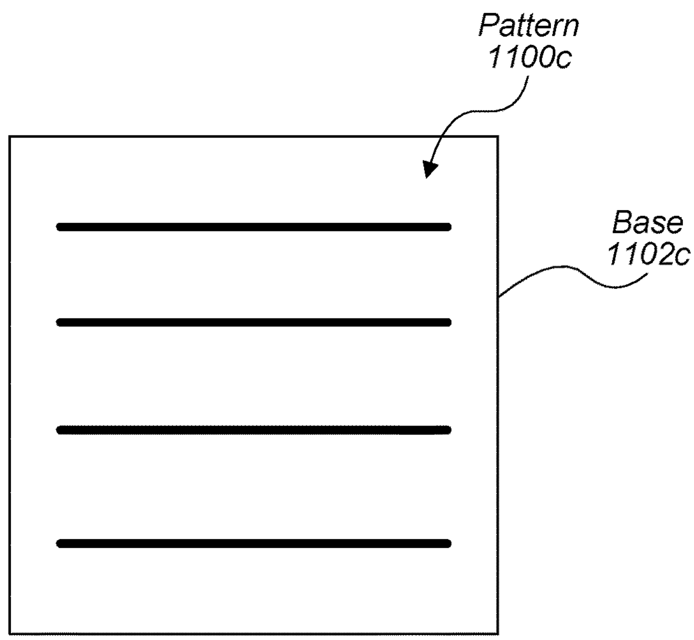

Fig. 11C

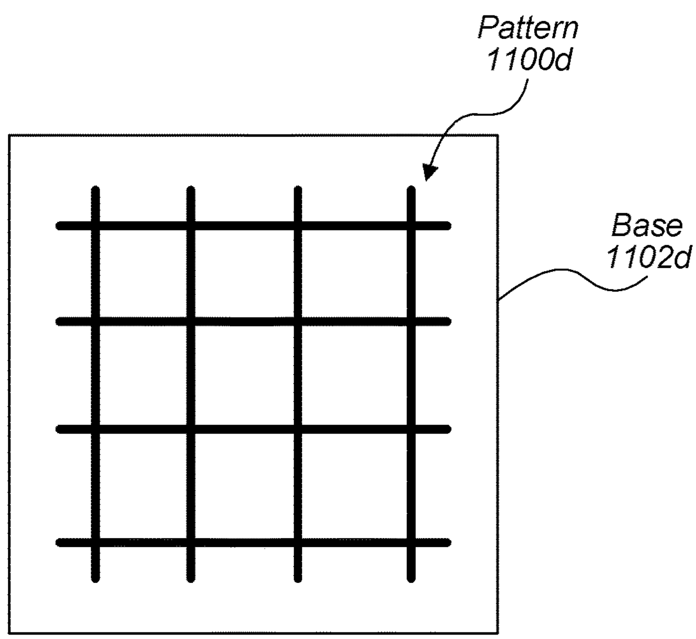

Fig. 11D

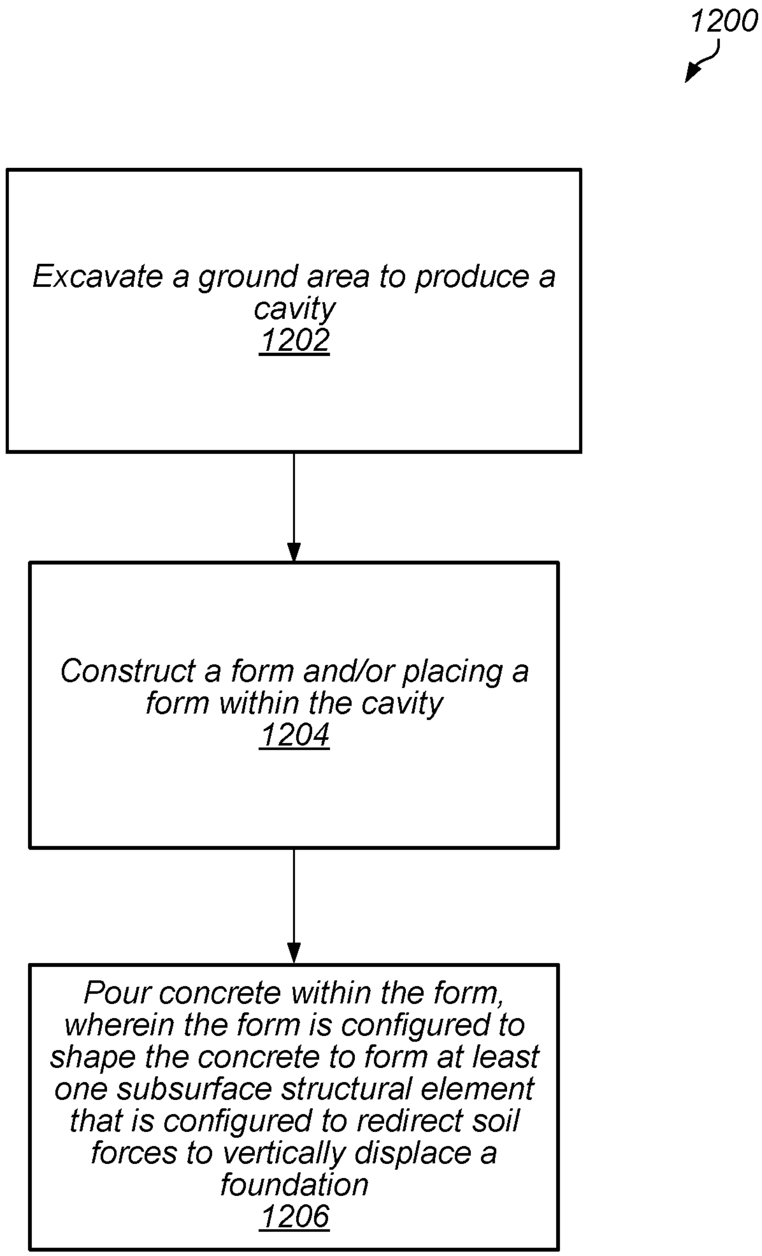
1200
Excavate a ground area to produce a cavity
1202
Construct a form and/or placing a form within the cavity
1204
Pour concrete within the form, wherein the form is configured to shape the concrete to form at least one subsurface structural element that is configured to redirect soil forces to vertically displace a foundation
1206

Fig. 12

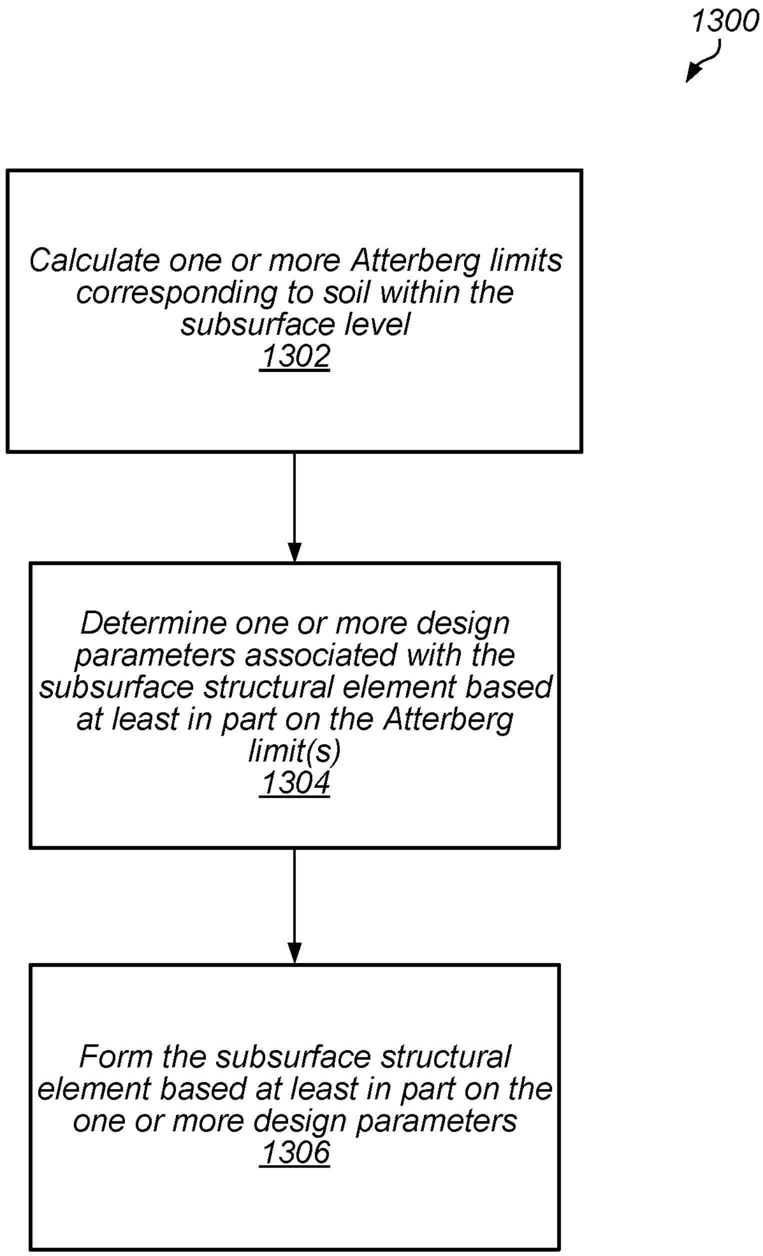
1300
Calculate one or more Atterberg limits corresponding to soil within the subsurface level
1302
Determine one or more design parameters associated with the subsurface structural element based at least in part on the Atterberg limit(s)
1304
Form the subsurface structural element based at least in part on the one or more design parameters
1306

Fig. 13

FORMS AND SUBSURFACE STRUCTURAL ELEMENTS THAT REDIRECT SOIL FORCES

PRIORITY INFORMATION

This application is a continuation of U.S. patent application Ser. No. 17/473,652, filed Sep. 13, 2021, which is a continuation of U.S. patent application Ser. No. 16/723,779, filed Dec. 20, 2019, now U.S. Pat. No. 11,118,322, which is a continuation of U.S. patent application Ser. No. 16/171,300, filed Oct. 25, 2018, now U.S. Pat. No. 10,519,618, which is a continuation of U.S. patent application Ser. No. 15/400,837, filed Jan. 6, 2017, now U.S. Pat. No. 10,113,289, which claims benefit of priority of U.S. Provisional Application Ser. No. 62/276,018, filed Jan. 7, 2016, which are hereby incorporated by reference herein in their entirety.

BACKGROUND

Technical Field

This disclosure relates generally to forms for constructing subsurface structural elements that redirect soil forces.

Description of the Related Art

Foundations typically form the lowest part of an architectural structure and are generally either shallow or deep. Foundations are also sometimes called basework, for example, in the context of large structures. Foundations may be constructed using forms (or formwork). Forms are molds into which concrete (or another material) may be poured to shape the concrete to a desired shape.

SUMMARY OF EMBODIMENTS

Some embodiments may include a form for constructing at least a portion of a structural foundation. The form may include one or more wall forming portions configured to shape a foundation material (e.g., concrete) to form one or more respective walls of at least one subsurface structural element (e.g., a subsurface beam, a subsurface pile, etc.) of the foundation. The form may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element extends from a surface-level base of the foundation to a subsurface level. Furthermore, the form may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element is configured to redirect soil forces to vertically displace the foundation rather than have the soil forces crack or otherwise damage the foundation.

Some embodiments may include a foundation for supporting a structure. For instance, the foundation may include a base (e.g., a surface-level base) and at least one subsurface structural element (e.g., a subsurface beam, a subsurface pile, etc.). The subsurface structural element(s) may extend from the base to a subsurface level. Furthermore, the subsurface structural element may be shaped such that it redirects soil forces to vertically displace the foundation. In some cases, the subsurface structural element(s) may include a triangular cross section and/or a trapezoidal cross section.

Some embodiments may include a method of constructing a foundation. The method may include forming at least one subsurface structural element (e.g., a subsurface beam, a subsurface pile, etc.) that extends from a surface-level base of the foundation to a subsurface level. The subsurface structural element may be configured to redirect soil forces to vertically displace the foundation.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a cross-sectional side view illustrating an example environment in which a form is used to construct a subsurface structural element that redirects soil forces, in accordance with some embodiments.

FIG. **2** is a map providing example design variables that may be considered in the design of a form for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments.

FIG. **3** is a perspective view illustrating an example form for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments.

FIG. **4** is a perspective view illustrating an example subsurface structural element that is configured to redirect soil forces, in accordance with some embodiments.

FIG. **5** is a perspective view illustrating another example form for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments.

FIG. **6** is a perspective view illustrating another example subsurface structural element that is configured to redirect soil forces, in accordance with some embodiments.

FIG. **7** is a perspective view illustrating yet another example form for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments.

FIG. **8** is a perspective view illustrating yet another example subsurface structural element that is configured to redirect soil forces, in accordance with some embodiments.

FIG. **9** is a perspective view illustrating still yet another example form for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments.

FIG. **10** is a perspective view illustrating still yet another example subsurface structural element that is configured to redirect soil forces, in accordance with some embodiments.

FIGS. **11A-11D** illustrate example patterns in which subsurface structural elements may be distributed with respect to a foundation, in accordance with some embodiments.

FIG. **12** is a flowchart of an example method of constructing a foundation that includes a subsurface structural element, in accordance with some embodiments.

FIG. **13** is a flowchart of an example method of forming a subsurface structural element, in accordance with some embodiments.

This specification includes references to "one embodiment" or "an embodiment." The appearances of the phrases "in one embodiment" or "in an embodiment" do not necessarily refer to the same embodiment. Particular features, structures, or characteristics may be combined in any suitable manner consistent with this disclosure.

"Comprising." This term is open-ended. As used in the appended claims, this term does not foreclose additional structure or steps. Consider a claim that recites: "An apparatus comprising one or more processor units . . . ". Such a claim does not foreclose the apparatus from including additional components (e.g., a network interface unit, graphics circuitry, etc.).

"Configured To." Various units, circuits, or other components may be described or claimed as "configured to" perform a task or tasks. In such contexts, "configured to" is used to connote structure by indicating that the units/circuits/components include structure (e.g., circuitry) that performs those task or tasks during operation. As such, the unit/circuit/component can be said to be configured to perform the task even when the specified unit/circuit/component is not currently operational (e.g., is not on). The units/circuits/components used with the "configured to" language include hardware—for example, circuits, memory storing program instructions executable to implement the operation, etc. Reciting that a unit/circuit/component is "configured to" perform one or more tasks is expressly intended not to invoke 35 U.S.C. § 112, sixth paragraph, for that unit/circuit/component. Additionally, "configured to" can include generic structure (e.g., generic circuitry) that is manipulated by software and/or firmware (e.g., an FPGA or a general-purpose processor executing software) to operate in manner that is capable of performing the task(s) at issue. "Configure to" may also include adapting a manufacturing process (e.g., a semiconductor fabrication facility) to fabricate devices (e.g., integrated circuits) that are adapted to implement or perform one or more tasks.

"First," "Second," etc. As used herein, these terms are used as labels for nouns that they precede, and do not imply any type of ordering (e.g., spatial, temporal, logical, etc.). For example, a buffer circuit may be described herein as performing write operations for "first" and "second" values. The terms "first" and "second" do not necessarily imply that the first value must be written before the second value.

"Based On." As used herein, this term is used to describe one or more factors that affect a determination. This term does not foreclose additional factors that may affect a determination. That is, a determination may be solely based on those factors or based, at least in part, on those factors. Consider the phrase "determine A based on B." While in this case, B is a factor that affects the determination of A, such a phrase does not foreclose the determination of A from also being based on C. In other instances, A may be determined based solely on B.

DETAILED DESCRIPTION

Embodiments described herein relate to construction of subsurface structural elements that are configured to redirect soil forces. For instance, a form may be configured to form a subsurface structural element such that the subsurface structural element redirects soil forces to vertically displace a foundation rather than have the soil forces crack or otherwise damage the foundation. The soil forces may include force vectors generated while the soils expand against walls/surfaces of the subsurface structural element. In some embodiments, the soil forces generated by expansive soils while expanding against the sides of the subsurface structural element are less than 90 degrees to the surface of the subsurface structural element, thus creating both a horizontal force vector and a vertical force vector, with the vertical force vector causing the foundation to shift or move vertically.

Some embodiments include a form for constructing at least a portion of a structural foundation (also referred to herein as the "foundation"). As used herein, the term "foundation" may refer to any type of load bearing architectural structure, including but not limited to footings, concrete slabs, concrete slab-on-grade, impact driven piles, drilled shafts, caissons, helical piles, geo-piers, and earth stabilized columns.

The form may include one or more wall forming portions configured to shape a foundation material (e.g., concrete) to form one or more respective walls of at least one subsurface structural element (e.g., a subsurface beam, a subsurface pile, etc.) of the foundation. The form may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element extends from a surface-level base of the foundation to a subsurface level. Furthermore, the form may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element is configured to redirect soil forces to vertically displace the foundation.

In some embodiments, the wall forming portions may include a first wall forming portion and a second wall forming portion. The first wall forming portion may be configured to shape the foundation material to form a first surface (e.g., a planar surface, a concave surface, a convex surface, etc.) of a first wall of the subsurface structural element. The first surface may be formed, via the first wall forming portion, such that it includes a first top portion that meets the surface-level base at a first non-zero angle, and a first bottom portion that is opposite the first top portion. The second wall forming portion may be configured to shape the foundation material to form a second surface (e.g., a planar surface, a concave surface, a convex surface, etc.) of a second wall of the subsurface structural element. The second surface may be formed, via the second wall forming portion, such that it includes a second top portion that meets the surface-level base at the first non-zero angle (or a different angle), and a second bottom portion that is opposite the second top portion. In some examples, the second bottom portion may meet the first bottom portion at a second non-zero angle. The first non-zero angle and the second non-zero angle may be the same in some cases. However, in other cases, the first non-zero angle and the second non-zero angle may be different.

In some examples, the form may include one or more termination forming portions configured to shape the foundation material to form one or more respective termination portions of at least one subsurface structural element. The termination portions may be formed, via the termination forming portions, such that each of the termination portions is adjacent to a bottom portion of at least one of the respective walls.

According to some embodiments, the form may include a lining portion and/or a filling portion. The lining portion may include at least one lining that is adjacent to subsurface soil. The filling portion may include a filling material that at least partially fills a gap between at least one subsurface structural element and the lining portion or the subsurface soil. In some examples, the wall forming portions of the form may include at least part of the filling portion. For instance, the filling portion may define a form boundary that may function, at least in part, as the wall forming portions.

In some embodiments, the lining portion may include multiple linings. For example, the lining portion may include a first lining that is adjacent to the subsurface soil and a second lining. Furthermore, the lining portion may include a third lining and/or a friction reducing agent (e.g., a lubricant). The third lining may be located between the first lining and the second lining. For instance, the third lining may be configured to reduce friction between the first lining and the second lining. Likewise, the friction reducing agent may be disposed between the first lining and the second lining. For instance, the friction reducing agent may be configured to form a friction reducing layer between the first lining and the second lining.

In various embodiments, the form may be a soil form. For instance, soil may be excavated to define a cavity that may be used as a form to receive and shape the foundation material. Additionally, or alternatively, the form may be a removable form that may be removed from the foundation (e.g., after the foundation is constructed using the form) and/or a permanent form that is intended to permanently remain with the foundation.

Some embodiments may include a foundation for supporting a structure. For instance, the foundation may include a base (e.g., a surface-level base) and at least one subsurface structural element (e.g., a subsurface beam, a subsurface pile, etc.). The subsurface structural element(s) may extend from the base to a subsurface level. Furthermore, the subsurface structural element may be shaped such that it redirects soil forces to vertically displace the foundation. In some cases, the subsurface structural element(s) may include a triangular cross section and/or a trapezoidal cross section.

In some examples, at least a portion of the base may extend along a horizontally oriented plane. Additionally, or alternatively, the subsurface structural element may be symmetrical about a vertically oriented plane.

In some embodiments, the subsurface structural element may include a first surface and a second surface, each of which may be planar, concave, convex, etc. The first surface may include a first top portion that meets the base at a first non-zero angle, and a first bottom portion that is opposite the first top portion. The second surface may include a second top portion that meets the base at the first non-zero angle (or a different angle), and a second bottom portion that is opposite the second top portion. In some examples, the second bottom portion may meet the first bottom portion at a second non-zero angle. The first non-zero angle and the second non-zero angle may be the same in some cases. However, in other cases, the first non-zero angle and the second non-zero angle may be different.

In some embodiments, the subsurface structural element may include a third surface (e.g., a planar surface, a concave surface, a convex surface, etc.) that extends from the first bottom portion to the second bottom portion. For instance, the third surface may be included in the subsurface structural element instead of the first bottom portion directly meeting with the second bottom portion. In some instances, the third surface may at least partially define a termination portion of the subsurface structural element.

In some examples, the subsurface structural element(s) may include a beam and/or a pile. For instance, the beam may have a longest dimension that extends substantially parallel to at least a portion of the base. The pile may have a longest dimension that extends substantially perpendicular to at least a portion of the base.

Some embodiments may include a method of constructing a foundation. The method may include forming at least one subsurface structural element (e.g., a subsurface beam, a subsurface pile, etc.) that extends from a surface-level base of the foundation to a subsurface level. The subsurface structural element may be configured to redirect soil forces to vertically displace the foundation.

In various embodiments, the method may include excavating a ground area to produce a cavity that is at least partially defined by subsurface soil. Furthermore, the method may include placing a form within the cavity, and pouring concrete within the form. The form may be configured to shape the concrete to form the subsurface structural element.

In some embodiments, the method may include constructing a form. For instance, construction of the form may include excavating a ground area to produce a cavity that is at least partially defined by surface soil, placing one or more linings within the cavity to form a lining layer, and/or filling a portion of the cavity with a filling material to form a filling layer. In some instances, one or more linings may be placed within the cavity such that at least one of the linings is adjacent to the subsurface soil.

In some implementations, the method may include calculating one or more Atterberg limits (e.g., a shrinkage limit, a plastic limit, and/or a liquid limit) corresponding to soil within the subsurface level. Furthermore, the method may include determining one or more design variables associated with the subsurface structural element based at least in part on the calculated Atterberg limit(s). In some cases, the subsurface structural element may be formed based at least in part on the determined design parameter(s).

FIG. **1** is a cross-sectional side view illustrating an example environment **100** in which a form is used to construct a subsurface structural element (e.g., a subsurface beam, a subsurface pile, etc.) that redirects soil forces, in accordance with some embodiments. As illustrated in FIG. **1**, a foundation **102** may include a base **104** and a subsurface structural element **106**. The base **104** may extend along the ground **108** (also referred to herein as the "surface level"). The subsurface structural element **106** may be configured to extend from the base **104** to a subsurface level **110**. Furthermore, the subsurface structural element **106** may be configured to redirect soil forces to vertically displace the foundation **102**. For instance, the soil forces may include force vectors generated while the soil(s) **112** (e.g., subsurface soil surrounding the subsurface structural element **106**) expand against walls/surfaces of the subsurface structural element **106**.

In various embodiments, a form **114** may be used to construct at least a portion of the foundation **102**. For instance, the form **114** may be used to construct the subsurface structural element **106**. In some examples, the form **114** may be a soil form, a removable form, and/or a permanent form. In some embodiments, the form may be constructed of wood, metal, plastic, fiber glass, and/or resins, etc.

As will be discussed in further detail below with reference to FIG. **2**, the form **114** may be used to shape a foundation material (e.g., concrete) to form a subsurface structural element **114** based on one or more design variables. For example, the design variables may include a wall angle **116**, a wall shape **118**, and/or a termination shape **120**. As illustrated in FIG. **1**, a wall (having the wall shape **118**) of the subsurface structural element **114** may meet the base **104** at a non-zero angle (the wall angle **116**). In a non-limiting example, the wall angle **116** may be greater than 90 degrees and the wall shape **118** may be straight. Furthermore, the termination shape **120** of the subsurface structural element **114** may be a point. In this non-limiting example, the subsurface structural element **114** has a triangular cross section and/or a "v-shaped" cross section. However, as discussed below with reference to FIG. **2**, the wall angle **116**, the wall shape **118**, and/or the termination shape **120** may be different in other embodiments.

As illustrated in FIG. **1**, in some embodiments the form **114** may include a lining portion **122** and/or a filling portion **124**. The lining portion **122** may include at least one lining that is adjacent to subsurface soil **112**. The filling portion **124** may include a filling material (e.g., Gap Fillings **221**, such as but not limited to Friction Fill **258**, Moisture Fill **260**, Compression Fill **262**, illustrated in FIG. **2**, described below) that at least partially fills one or more gaps **119**A, **119**B between the subsurface structural element **106** and the lining portion **122** or the subsurface soil **112**. In some examples, portions of the form **114** that are configured to form walls of the subsurface structural element **106** (also referred to herein as the "wall forming portions" of the form) may include at least part of the filling portion **124**. For instance, the filling portion **124** may define a form boundary that may function, at least in part, as the wall forming portions.

In some embodiments, the lining portion **122** may include multiple linings (e.g., Linings **210**, such as but not limited to One Lining **246**, Two Linings, Three Linings **250**, etc., illustrated in FIG. **2**, described below). For example, the lining portion **122** may include a first lining (e.g., One Lining **246**) that is adjacent to the subsurface soil **112** and a second lining (e.g., Two Linings **248**). Furthermore, the lining portion **122** may include a third lining (e.g., Three Linings) and/or a friction reducing agent **266** (e.g., a lubricant). The third lining may be located between the first lining and the second lining. For instance, the third lining may be configured to reduce friction between the first lining and the second lining. Likewise, the friction reducing agent may be disposed between the first lining and the second lining. For instance, the friction reducing agent may be configured to form a friction reducing layer between the first lining and the second lining.

In some examples, at least a portion of the base **104** may extend along a horizontally oriented plane (e.g., a plane that is orthogonal to the page of FIG. **1** and coincident with the broken line corresponding to the surface level **108**). Additionally, or alternatively, the subsurface structural element **106** may be symmetrical about a vertically oriented plane (e.g., a plane that is orthogonal to the page of FIG. **1** and coincident with broke line **126**).

FIG. **2** is a map providing example design variables **200** that may be considered in the design of a form for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments. For instance, one or more of the design variables **200** may be considered in the design of the forms described with reference to FIGS. **1**, **3-10**, **12**, and **13**. In the following discussion regarding the design variables **200**, reference will be made to both FIGS. **1** and **2** for illustrative purposes.

The design variables **200** may be adjusted based on the desired performance of the subsurface structural element **106** and/or the foundation **102** that is to be constructed. For instance, the design variables **200** may be adjusted to improve performance of the subsurface structural element **106** and/or the foundation **102** in expansive soils and clays. In various embodiments, the design variables **200** may include form type **202**, wall shape **204**, wall angle **206**, termination shape **208**, linings **210**, and/or gap fillings **212**.

In some embodiments, the form type **202** design variables may include a soil form **214**, a removable form **216**, and/or a permanent form **218**. With a soil form **214**, the soil **112** itself may be shaped such that the soil **112** serves as a form **114**. For instance, soil may be excavated to define a cavity that may be used as a form to receive and shape the foundation material. A removable form **216** may be a form **114** configured to be removed from the subsurface structural element **106** and/or the foundation **102** after construction of the subsurface structural element **106** and/or the foundation **102**. A permanent form **218** may be a form **114** that is configured to remain with the subsurface structural element **106** and/or the foundation **102** after construction of the subsurface structural element **106** and/or the foundation **102**.

In some examples, the wall shape **204** design variables may include a straight wall **220**, a convex wall **222**, a concave wall **224**, and/or a multi-segment wall **226**. For instance, the form **114** may include one or more wall forming portions having straight walls **220**. The straight walls **220** may be configured to shape a foundation material to form corresponding straight walls of the subsurface structural element **106**. Additionally, or alternatively, the form **114** may include one or more wall forming portions having convex walls **222**. The convex walls **222** may be configured to shape the foundation material to form corresponding convex walls of the subsurface structural element **106**. Additionally, or alternatively, the form **114** may include one or more wall forming portions having concave walls **224**. The concave walls **224** may be configured to shape the foundation material to form corresponding concave walls of the subsurface structural element **106**.

In some embodiments, the form **114** may include one or more wall forming portions having multi-segment walls **226**. The multi-segment walls **226** may include multiple segments of straight walls **220**, convex walls **222**, concave walls **224**, or combinations thereof.

In various embodiments, the wall angle **206** design variables may include a greater than 90 degrees wall angle **228**, a 90 degrees wall angle **230**, and/or a less than 90 degrees wall angle **232**. The wall angle **206** design variables may refer to the angle at which a wall forming portion of the form **114** meets the base **104** of the foundation **102** or a base forming portion of the form **114**. Additionally, or alternatively, the wall angle **206** design variables may refer to the angle at which a wall of the resulting subsurface structural element **106** (i.e., the subsurface structural element **106** that is to be formed using the form **114**) is to meet the base **104** of the foundation **102**. In FIG. **1**, the wall angle **116** is depicted as a greater than 90 degrees wall angle **228**. However, in some embodiments, the wall angle **116** may be a 90 degree wall angle **230** or a less than 90 degree wall angle **232**.

In some embodiments, the termination shape **208** design variables may include a point termination shape **234**, a straight termination shape **236**, a convex termination shape **238**, a concave termination shape **240**, and/or a multi-segment termination shape **242**. The termination shape **208** design variables may refer to a shape of a termination forming portion of the form **114**. Additionally, or alternatively, the termination shape **208** design variables may refer to a shape of a termination portion of the resulting subsurface structural element **106** (i.e., the subsurface structural element **106** that is to be formed using the form **114**). In some examples, the form **114** may include one or more termination forming portions configured to shape the foundation material to form one or more respective termination portions of the subsurface structural element. In some cases, each of the termination portions may be adjacent to a bottom portion of a wall of the subsurface structural element **106**.

In FIG. **1**, the termination shape **120** is depicted as a point termination shape **234**. Opposing walls of the form **114** may each have a respective bottom portion, and the bottom portions may meet at a point, forming a V-shape. Correspondingly, opposing walls of the subsurface structural element **106** may each have a respective bottom portion, and the bottom portions may meet at a point, forming a V-shape. However, in some embodiments, the termination shape **120** may be a convex termination shape **238**, a concave termination shape **240**, and/or a multi-segment termination shape **242**.

In various examples, the linings **210** design variables may include no linings **244**, one lining **246**, two linings **248**, three linings **250**, and/or more than three linings **252**.. As discussed above with reference to FIG. **1**, in some embodiments the form **114** may include a lining portion **122**. The lining portion **122** may include at least one lining that is adjacent to subsurface soil **112**. In a particular non-limiting example, the lining portion **122** may include two linings **248** and a middle friction reducing agent **254** disposed between the two linings **248**. The middle friction reducing agent **254** may be configured to reduce friction between the two linings **248**. For instance, the middle friction reducing agent **254** may be a lubricant.

According to another particular non-limiting example, the lining portion **122** may include three linings **250**. For instance, a low friction middle lining **256** may be disposed between two other linings to ease movement between the two other linings. The low friction middle lining **256** may have a low coefficient of friction to reduce friction between the two other linings. In some cases, a middle friction reducing agent **254** may function as a low friction middle lining **256**.

Additionally, or alternatively, a middle friction increasing agent and/or a high friction middle lining may be disposed between two linings to increase friction between the two linings.

In some embodiments, the gap fillings **212** design variables may include a friction fill **258**, a moisture fill **260**, and/or a compression fill **262**. As discussed above with reference to FIG. **1**, in some embodiments the form **114** may include a filling portion **124**. The filling portion **124** may include a filling material that at least partially fills a gap between the subsurface structural element **106** and the lining portion **122** or the subsurface soil **112**. In some examples, wall forming portions of the form **114** may include at least part of the filling portion **124**. For instance, the filling portion **124** may define a form boundary that may function, at least in part, as the wall forming portions.

In some examples, the filling material may comprise a friction fill material **258**. In some embodiments, the friction fill material **258** may be configured to increase friction **264** between the soil **112** and the subsurface structural element **106**. In other embodiments, the friction fill material **258** may be configured to reduce friction between the soil **112** and the subsurface structural element **106**.

Additionally, or alternatively, the filling material may comprise a moisture fill material **260**. In some embodiments, the moisture fill material **260** may be configured to increase moisture **268** of the soil **112** around the subsurface structural element **106**. In other embodiments, the moisture fill material **260** may be configured to reduce moisture **270** of the soil **112** around the subsurface structural element **106**.

Additionally, or alternatively, the filling material may comprise a compression fill material **262**. In some embodiments, the compression fill material **262** may be compressible **272** to absorb soil forces before they reach the subsurface structural element **106**. In other embodiments, the compression fill material **262** may be incompressible **274**, or substantially incompressible, such that the compression fill material **262** transmits soil forces directly to the subsurface structural element **106** with little or no loss of force.

It should be understood that the filling material may have one or more of the properties described above with reference to the friction fill material **258**, moisture fill material **260**, and the compression fill material **262**. For instance, a filling material may both reduce friction **266** and be incompressible **274**, such as smooth, round rocks.

In some embodiments, no filling material may be used to fill the gap(s) **119**A, **119**B between the subsurface structural element **106** and the lining portion **122** or the subsurface soil **112**. That is, one or more of the gap(s) **119**A, **119**B may comprise an unfilled void or empty space between the soil **112** (or the lining portion **122**) and the subsurface structural element **106**.

FIG. **3** is a perspective view illustrating an example form **300** for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments. The subsurface structural element may be part of a foundation. For instance, the foundation may include a base at a surface level, and the subsurface structural element may extend from the surface-level base to a subsurface level. In various embodiments, the form **300** may include a foundation material cavity **302** configured to receive a foundation material (e.g., concrete) to form a V-shaped subsurface structural element, such as the subsurface structural element **400** discussed below with reference to FIG. **4**. Furthermore, the form **300** may include features, materials, and/or properties of embodiments of forms described herein with reference to FIGS. **1**, **2**, and **11**A-**13**.

In some examples, the form **300** may include one or more wall forming portions configured to shape the foundation material to form one or more respective walls of the subsurface structural element. The form **300** may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element extends from the surface-level base of the foundation to a subsurface level. Furthermore, the form **300** may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element is configured to redirect soil forces to vertically displace the foundation.

In some embodiments, the wall forming portions may include a first wall forming portion **304** and a second wall forming portion **306**. The first wall forming portion **304** may be configured to shape the foundation material to form a first surface of a first wall of the subsurface structural element. The first surface may be formed, via the first wall forming portion **304**, such that it includes a first top portion that meets the surface-level base at a first non-zero angle, and a first bottom portion that is opposite the first top portion. The second wall forming portion **306** may be configured to shape the foundation material to form a second surface of a second wall of the subsurface structural element. The second surface may be formed, via the second wall forming portion, such that it includes a second top portion that meets the surface-level base at the first non-zero angle (or a different angle), and a second bottom portion that is opposite the second top portion. In some examples, the second bottom portion may meet the first bottom portion at a second non-zero angle. The first non-zero angle and the second non-zero angle may be the same in some cases. However, in other cases, the first non-zero angle and the second non-zero angle may be different.

In some examples, the form **300** may include a termination forming portion **308** configured to shape the foundation material to form a corresponding termination portion of the subsurface structural element. As illustrated in FIG. **3**, the termination forming portion **308** may be configured to shape the foundation material to form a termination portion of the subsurface structural element that has a point termination shape.

In various embodiments, the form **300** may be used to construct a subsurface structural element that is V-shaped and/or a subsurface structural element that has a triangular cross-section. In some examples, the form **300** may be used to construct a subsurface beam.

FIG. **4** is a perspective view illustrating an example subsurface structural element **400** that is configured to redirect soil forces, in accordance with some embodiments. For instance, the subsurface structural element **400** may be constructed using the form **300** discussed above with reference to FIG. **3**. The subsurface structural element **400** may be part of a foundation. For example, the foundation may include a base **402** at a surface level, and the subsurface structural element **400** may extend from the surface-level base to a subsurface level. Furthermore, the subsurface structural element **400** may be shaped such that it redirects soil forces to vertically displace the foundation. The subsurface structural element **400** may include features, materials, and/or properties of embodiments of subsurface structural elements described herein with reference to FIGS. **1**, **2**, and **11A-13**.

In some embodiments, the subsurface structural element **400** may include a first surface **404** and a second surface **406**. The first surface **404** may include a first top portion **408** that meets the base **402** at a first non-zero angle, and a first bottom portion **410** that is opposite the first top portion **408**. For instance, as illustrated in FIG. **4**, the first non-zero angle at which the first top portion **408** meets the base **402** may be greater than 90 degrees. The second surface **406** may include a second top portion **412** that meets the base **402** at the first non-zero angle (or a different angle), and a second bottom portion **414** that is opposite the second top portion **412**. In some examples, the second bottom portion **414** may meet the first bottom portion **410** at a second non-zero angle, e.g., to form a termination portion that has a point termination shape as illustrated in FIG. **4**. The first non-zero angle and the second non-zero angle may be the same in some cases. However, in other cases, the first non-zero angle and the second non-zero angle may be different.

In various embodiments, the subsurface structural element **400** may be V-shaped and/or have a triangular cross-section such that it is capable of redirecting soil forces to vertically displace the foundation. In some examples, the subsurface structural element **400** may be a beam that has a longest dimension that extends substantially parallel to at least a portion of the base **402**.

FIG. **5** is a perspective view illustrating another example form **500** for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments. The subsurface structural element may be part of a foundation. For instance, the foundation may include a base at a surface level, and the subsurface structural element may extend from the surface-level base to a subsurface level. In various embodiments, the form **500** may include a foundation material cavity **502** configured to receive a foundation material (e.g., concrete) to form a conical subsurface structural element, such as the subsurface structural element **600** discussed below with reference to FIG. **6**. Furthermore, the form **500** may include features, materials, and/or properties of embodiments of forms described herein with reference to FIGS. **1**, **2**, and **11A-13**.

In some examples, the form **500** may include a wall forming portion **504** configured to shape the foundation material to form a conical wall of the subsurface structural element. The form **500** may be configured to shape, based at least in part on the wall forming portion **504**, the subsurface structural element such that the subsurface structural element extends from the surface-level base of the foundation to a subsurface level. Furthermore, the form **500** may be configured to shape, based at least in part on the wall forming portion **504**, the subsurface structural element such that the subsurface structural element is configured to redirect soil forces to vertically displace the foundation.

In some examples, the form **500** may include a termination forming portion **506** configured to shape the foundation material to form a corresponding termination portion of the subsurface structural element. As illustrated in FIG. **5**, the termination forming portion **506** may be configured to shape the foundation material to form a termination portion of the subsurface structural element that has a point termination shape.

In various embodiments, the form **500** may be used to construct a subsurface structural element that is conical and/or a subsurface structural element that has a triangular cross-section. In some examples, the form **500** may be used to construct a subsurface conical pile.

FIG. **6** is a perspective view illustrating another example subsurface structural element **600** that is configured to redirect soil forces, in accordance with some embodiments. For instance, the subsurface structural element **600** may be constructed using the form **500** discussed above with reference to FIG. **5**. The subsurface structural element **600** may be part of a foundation. For example, the foundation may include a base **602** at a surface level, and the subsurface structural element **600** may extend from the surface-level base to a subsurface level. Furthermore, the subsurface structural element **600** may be shaped such that it redirects soil forces to vertically displace the foundation. The subsurface structural element **600** may include features, materials, and/or properties of embodiments of subsurface structural elements described herein with reference to FIGS. **1**, **2**, and **11A-13**.

In some embodiments, the subsurface structural element **600** may include a conical surface **604**. The surface may include a top portion that meets the base **602** at a non-zero angle, and a bottom portion that is opposite the top portion. For instance, as illustrated in FIG. **6**, the non-zero angle at which the top portion meets the base **602** may be greater than 90 degrees. The bottom portion may form a termination portion **606**. For instance, termination portion **606** may have a point termination shape.

In various embodiments, the subsurface structural element **600** may be conical and/or have a triangular cross-section such that it is capable of redirecting soil forces to vertically displace the foundation. In some examples, the subsurface structural element **600** may be a pile that has a longest dimension that extends substantially perpendicular to at least a portion of the base **602**.

FIG. **7** is a perspective view illustrating yet another example form **700** for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments. The subsurface structural element may be part of a foundation. For instance, the foundation may include a base at a surface level, and the subsurface structural element may extend from the surface-level base to a subsurface level. In various embodiments, the form **700** may include a foundation material cavity **702** configured to receive a foundation material (e.g., concrete) to form a pyramidal subsurface structural element, such as the subsurface structural element **800** discussed below with reference to FIG. **8**. Furthermore, the form **700** may include features, materials, and/or properties of embodiments of forms described herein with reference to FIGS. **1**, **2**, and **11A-13**.

In some examples, the form **700** may include one or more wall forming portions configured to shape the foundation material to form one or more respective walls of the subsurface structural element. The form **700** may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element extends from the surface-level base of the foundation to a subsurface level. Furthermore, the form **700** may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element is configured to redirect soil forces to vertically displace the foundation.

In some embodiments, the wall forming portions may include a first wall forming portion **704**, a second wall forming portion **706**, and a third wall forming portion **706**. The first wall forming portion **704** may be configured to shape the foundation material to form a first surface of a first wall of the subsurface structural element. The second wall forming portion **706** may be configured to shape the foundation material to form a second surface of a second wall of the subsurface structural element. The third wall forming portion **708** may be configured to shape the foundation material to form a third surface of a third wall of the subsurface structural element. As illustrated in FIG. **7**, the wall forming portions **704**, **706**, and **708** may converge at a termination forming portion **710** having a point termination shape to correspondingly shape the foundation material to form a termination portion of the subsurface structural element that has a point termination shape. Furthermore, the wall forming portions **704**, **706**, and **708** may be configured to shape the foundation material such that the corresponding surfaces/walls of the subsurface structural element meet the base of the foundation at one or more non-zero angles.

In various embodiments, the form **700** may be used to construct a subsurface structural element that is pyramidal and/or a subsurface structural element that has a triangular cross-section. In some examples, the form **700** may be used to construct a subsurface pyramidal pile.

FIG. **8** is a perspective view illustrating yet another example subsurface structural element **800** that is configured to redirect soil forces, in accordance with some embodiments. For instance, the subsurface structural element **800** may be constructed using the form **700** discussed above with reference to FIG. **7**. The subsurface structural element **800** may be part of a foundation. For example, the foundation may include a base **802** at a surface level, and the subsurface structural element **800** may extend from the surface-level base to a subsurface level. Furthermore, the subsurface structural element **800** may be shaped such that it redirects soil forces to vertically displace the foundation. The subsurface structural element **800** may include features, materials, and/or properties of embodiments of subsurface structural elements described herein with reference to FIGS. **1**, **2**, and **11A-13**.

In some embodiments, the subsurface structural element **800** may include a first surface **804**, a second surface **806**, and a third surface **808**. The first surface **804** may include a first top portion that meets the base **802** at a non-zero angle, and a first bottom portion that is opposite the first top portion. For instance, as illustrated in FIG. **8**, the non-zero angle at which the first top portion meets the base **802** may be greater than 90 degrees. The second surface **806** may include a second top portion that meets the base **802** at the non-zero angle (or a different angle), and a second bottom portion that is opposite the second top portion. The third surface **808** may include a third top portion that meets the base **802** at the non-zero angle (or a different angle), and a third bottom portion that is opposite the third top portion.

In various embodiments, the subsurface structural element **800** may be pyramidal and/or have a triangular cross-section such that it is capable of redirecting soil forces to vertically displace the foundation. In some examples, the subsurface structural element **800** may be a pile that has a longest dimension that extends substantially perpendicular to at least a portion of the base **802**.

FIG. **9** is a perspective view illustrating still yet another example form **900** for constructing a subsurface structural element that redirects soil forces, in accordance with some embodiments. The subsurface structural element may be part of a foundation. For instance, the foundation may include a base at a surface level, and the subsurface structural element may extend from the surface-level base to a subsurface level. In various embodiments, the form **900** may include a foundation material cavity **902** configured to receive a foundation material (e.g., concrete) to form a tapered subsurface structural element, such as the subsurface structural element **1000** discussed below with reference to FIG. **10**. Furthermore, the form **900** may include features, materials, and/or properties of embodiments of forms described herein with reference to FIGS. **1**, **2**, and **11A-13**.

In some examples, the form **900** may include one or more wall forming portions configured to shape the foundation material to form one or more respective walls of the subsurface structural element. The form **900** may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element extends from the surface-level base of the foundation to a subsurface level. Furthermore, the form **900** may be configured to shape, based at least in part on the wall forming portions, the subsurface structural element such that the subsurface structural element is configured to redirect soil forces to vertically displace the foundation.

In some embodiments, the wall forming portions may include a first wall forming portion **904** and a second wall forming portion **906**. The first wall forming portion **904** may be configured to shape the foundation material to form a first surface of a first wall of the subsurface structural element. The second wall forming portion **906** may be configured to shape the foundation material to form a second surface of a second wall of the subsurface structural element. As illustrated in FIG. **9**, the wall forming portions **904** and **906** may diverge from a top portion of the form **900** to a termination forming portion **908** having a straight termination shape to correspondingly shape the foundation material to form a termination portion of the subsurface structural element that has a straight termination shape. Furthermore, the wall forming portions **904** and **906** may be configured to shape the foundation material such that the corresponding surfaces/walls of the subsurface structural element meet the base of the foundation at one or more non-zero angles.

In various embodiments, the form **900** may be used to construct a subsurface structural element that is tapered and/or a subsurface structural element that has a trapezoidal cross-section. In some examples, the form **900** may be used to construct a subsurface trapezoidal beam.

FIG. **10** is a perspective view illustrating still yet another example subsurface structural element **1000** that is configured to redirect soil forces, in accordance with some embodiments. For instance, the subsurface structural element **1000** may be constructed using the form **900** discussed above with reference to FIG. **9**. The subsurface structural element **1000** may be part of a foundation. For example, the foundation may include a base **1002** at a surface level, and the subsurface structural element **1000** may extend from the surface-level base to a subsurface level. Furthermore, the subsurface structural element **1000** may be shaped such that it redirects soil forces to vertically displace the foundation. The subsurface structural element **1000** may include features, materials, and/or properties of embodiments of subsurface structural elements described herein with reference to FIGS. **1**, **2**, and **11**A-**13**.

In some embodiments, the subsurface structural element **1000** may include a first surface **1004** and a second surface **1006**. The first surface **1004** may include a first top portion that meets the base **1002** at a non-zero angle, and a first bottom portion that is opposite the first top portion. For instance, as illustrated in FIG. **10**, the non-zero angle at which the first top portion meets the base **1002** may be less than 90 degrees. The second surface **1006** may include a second top portion that meets the base **1002** at the non-zero angle (or a different angle), and a second bottom portion that is opposite the second top portion.

In some embodiments, the subsurface structural element may include a third surface that extends from the first bottom portion to the second bottom portion. For instance, the third surface may at least partially define a termination portion **1008** of the subsurface structural element that has a straight termination shape.

In various embodiments, the subsurface structural element **1000** may be tapered and/or have a trapezoidal cross-section such that it is capable of redirecting soil forces to vertically displace the foundation. In some examples, the subsurface structural element **1000** may be a trapezoidal beam that has a longest dimension that extends substantially parallel to at least a portion of the base **1002**. Furthermore, the subsurface structural element **1000** may include "locking taper" wall angles that are less than 90 degrees, which may cause expansive soils to grip the subsurface structural element **1000** tightly.

FIGS. **11**A-**11**D illustrate example patterns in which subsurface structural elements may be distributed with respect to a foundation and/or a base of a foundation, in accordance with some embodiments. In FIG. **11**A, the dots of pattern **1100***a* may represent, for example, subsurface piles (e.g., the subsurface conical pile and/or the subsurface pyramidal pile discussed above with reference to FIGS. **6** and **8**, respectively). The subsurface piles may be distributed relative to a base **1102***a* of a foundation as indicated by pattern **1100***a*.

In FIG. **11**B, the vertical lines of pattern **1100***b* may represent, for example, subsurface beams (e.g., the subsurface V-shaped beam and/or the subsurface tapered beam discussed above with reference to FIGS. **3** and **9**, respectively). The subsurface beams may be distributed relative to a base **1102***b* of a foundation as indicated by pattern **1100***b*.

In FIG. **11**C, the horizontal lines of pattern **1100***c* may represent, for example, subsurface beams (e.g., the subsurface V-shaped beam and/or the subsurface tapered beam discussed above with reference to FIGS. **3** and **9**, respectively). The subsurface beams may be distributed relative to a base **1102***c* of a foundation as indicated by pattern **1100***c*.

In FIG. **11**D, the vertical and horizontal lines of pattern **1100***d* may represent, for example, subsurface beams (e.g., the subsurface V-shaped beam and/or the subsurface tapered beam discussed above with reference to FIGS. **3** and **9**, respectively). The subsurface beams may be distributed relative to a base **1102***d* of a foundation as indicated by pattern **1100***d*.

FIG. **12** is a flowchart of an example method **1200** of constructing a foundation that includes a subsurface structural element, in accordance with some embodiments. For instance, the method **1200** may be used to construct subsurface structural elements in accordance with one or more embodiments described above with reference to FIGS. **1**-**11**. At **1202**, the method **1200** may include excavating a ground area to produce a cavity. At **1204**, the method **1200** may include constructing a form and/or placing a form within the cavity. In some embodiments, constructing the form may include forming a lining layer by placing one or more linings within the cavity such that the linings are adjacent to the subsurface soil. Additionally, or alternatively, constructing the form may include filling a portion of the cavity with a filling material to form a filling layer **117**. At **1206**, the method **1200** may include pouring concrete within the form. The form may shape the concrete to the desired shape of the subsurface structural element.

FIG. **13** is a flowchart of an example method **1300** of forming a subsurface structural element, in accordance with some embodiments. At **1302**, the method **1300** may include calculating one or more Atterberg limits (and/or a measure of water content of soils) corresponding to soil within the subsurface level. The Atterberg limits are a measure of water contents of soils. Dry, clayey soil changes in behavior and consistency as it takes on increasing amounts of water. Depending on the soil's water content, the soil may appear in a solid state, a semi-solid state, a plastic state, or a liquid state. The consistency and behavior of the soil is different in each of these states. The Atterberg limits can be used to distinguish between different types of soils (e.g., between silt and clay, between different types of silts, between different types of clays, etc.).

At **1304**, the method **1300** may include determining one or more design variables associated with the subsurface structural element. In various embodiments, the design variables may include one or more of the design variables discussed above with reference to FIG. **2**. At **1306**, the method **1300** may include forming the subsurface structural element based at least in part on the determined design variables.

In some examples, the design variables may be determined based at least in part on the calculated Atterberg limits. The Atterberg limits may include a shrinkage limit, a plastic limit, and/or a liquid limit.

The shrinkage limit (SL) may be the water content of a soil at which further loss of moisture will not result in any more volume reduction. In some embodiments, the shrinkage limit may be calculated using ASTM International D4943.

The plastic limit (PL) may be calculated using ASTM Standard D4318, which includes rolling out a thread of a fine portion of a soil on a flat, non-porous surface. The thread will retain its shape down to a narrow diameter if the moisture content of the soil is at a level where the soil behavior is plastic. The plastic limit may be the moisture content at which the thread breaks apart at a diameter of 3.2 mm. If the thread cannot be rolled out to a diameter of 3.2 mm, then the soil may be considered non-plastic.

The liquid limit (LL) may be the water content of a soil at which the behavior of a soil (e.g., a clayey soil) changes from plastic to liquid. In some embodiments, the liquid limit may be calculated using the ASTM standard test method D4318, the Casagrande test, and/or the fall cone test (also called the cone penetrometer test).

The calculated values of the Atterberg limits may have a close relationship between properties of a soil, e.g., compressibility, permeability, and strength. Accordingly, the Atterberg limits may provide an indication of the subsurface soil forces that a subsurface structural element may incur.

Other engineering properties of a soil may also be strongly correlated with indices that may be derived using the Atterberg limits. For instance, the indices may include a plasticity index (PI), a liquidity index (LI), and/or a consistency index (CI).

The plasticity index may be a measure of the plasticity of a soil. The plasticity index may calculated as the difference between the liquid limit and the plastic limit: PI=LL−PL. Low plasticity index soils tend to be silt, while high plasticity index soils tend to be clay. Soils with a plasticity index of zero (non-plastic) tend to have little or no silt or clay.

The liquidity index may be a used for scaling the natural water content of a soil sample to the limits. For instance, the liquidity index may be calculated as a ratio between (1) the difference between natural water content and plastic limit and (2) the difference between liquid limit and plastic limit: LI=(W−PL)/(LL−PL), where W is the natural water content.

The consistency index may indicate the firmness (or consistency) of a soil. For instance, the consistency index may be calculated as a ratio between (1) the difference between liquid limit and natural water content and (2) the difference between liquid limit and plastic limit: CI=(LL−W)/(LL−PL), where W is the natural water content.

Furthermore, the activity (A) of a soil may be the plasticity index divided by the percent of clay-sized particles (e.g., particles that are less than 2 micrometers in size) present. The dominant clay type that is present in a soil may be determined based on the activity of the soil. With a high activity soil, the soil may experience a large volume change when wetted and large shrinkage when dried.

In some embodiments, the design variables may be determined based at least in part on the plasticity index, the liquidity index, the consistency index, and/or the activity of a soil.

The order of the blocks of the methods may be changed, and various elements may be added, reordered, combined, omitted, modified, etc. Various modifications and changes may be made as would be obvious to a person skilled in the art having the benefit of this disclosure. The various embodiments described herein are meant to be illustrative and not limiting. Many variations, modifications, additions, and improvements are possible. Accordingly, plural instances may be provided for components described herein as a single instance. Boundaries between various components and operations are somewhat arbitrary, and particular operations are illustrated in the context of specific illustrative configurations. Other allocations of functionality are envisioned and may fall within the scope of claims that follow. Finally, structures and functionality presented as discrete components in the example configurations may be implemented as a combined structure or component. These and other variations, modifications, additions, and improvements may fall within the scope of embodiments as defined in the claims that follow.

What is claimed is:

1. A foundation, comprising:

a horizontal base, extending in a horizontal direction;

one or more vertically-oriented beams extending below the base, into a subsurface level, wherein the one or more vertically-oriented beams narrow along at least some portion of a downward extension of the respective vertically-oriented beam from the horizontal base in a vertical direction orthogonal to the horizontal direction of the base; and

a filling material, form, or liner, configured to form respective unfilled voids between the one or more vertically-oriented beams and the filling material, form or liner, at the subsurface level, wherein the unfilled voids are distinct from filling material.

2. The foundation of claim **1**, wherein the respective unfilled voids are formed at least partially by ground material.

3. The foundation of claim **1**, wherein the unfilled voids are partially filled with a filling material comprising one or more of:

a friction fill material,

a moisture fill material, or

a compression fill material.

4. The foundation of claim **1**, further comprising one or more forms, between the vertically-oriented beams and the subsurface level, wherein the forms comprise one or more wall forming portions configured to shape foundation material into the vertically-oriented beams such that the vertically-oriented beams narrow along at least some portion of the downward extensions of the respective vertically-oriented beam.

5. The foundation of claim **1**, wherein the filling material, form, or liner, configured to form respective unfilled voids comprises one or more forms including:

a lining portion adjacent to subsurface soil, and/or

a filling portion including filling material partially filling larger unfilled voids than said unfilled voids proximate the vertically-oriented beams at the subsurface level, between the vertically-oriented beams and the lining portion or the subsurface soil, wherein the filling portion defines a form boundary that functions, at least in part, to form one or more walls of the vertically-oriented beams.

6. The foundation of claim **1**, wherein:

the one or more vertically-oriented beams each attach to the horizontal base at respective uppermost extents of the respective vertically-oriented beams and terminate at respective lowermost extents of the respective vertically-oriented beam; and

the filling material, form, or liner, configured to form respective unfilled voids is located proximate the lowermost extent of the respective vertically-oriented beams.

7. The foundation of claim **1**, wherein the one or more vertically-oriented beams extending below the base form a pattern under an interior portion of the horizontal base.

8. The foundation of claim **1**, wherein the filling material, form, or liner, configured to form respective unfilled voids comprises at least one of:

a soil form;

a removable form; or

a permanent form.

9. A method of constructing a foundation, comprising a horizontal base and a plurality of vertically-oriented beams at a subsurface level, the method comprising:

excavating to produce one or more cavities for the vertically-oriented beams of the foundation, the cavities at least partially defined by subsurface soil;

forming respective volumetrics spaces for the plurality of vertically-oriented beams at the subsurface level, comprising, for individual ones of the vertically-oriented beams:

forming, via a combination of one or more of excavating ground material, filling a portion of a cavity with filling material, forming one or more forms, or placing one or more liners within a cavity, a volumetric space for the vertically-oriented beam, wherein the volumetric space for the vertically-oriented beam narrows along at least some portion of a downward extension of the volumetric space in a vertical direction, and wherein the remaining ground material, filling material, one or more forms, or one or more liners is configured to form one or more unfilled voids, between the vertically-oriented beam and the remaining ground material, filling material, one or more forms or one or more liners at the subsurface level, wherein the unfilled voids are distinct from ground material and filling material; and

pouring concrete on the filling material, one or more forms, or one or more liners that are configured to form one or more unfilled voids proximate the one or more vertically-oriented beams at the subsurface level to form a vertically-oriented beam that narrows in accordance with the corresponding volumetric space that narrows along at least some portion of a downward extension of the vertically oriented beam; and

forming a horizontal base above the plurality of vertically-oriented beams.

10. The method of claim **9**, wherein, subsequent to pouring the concrete, the unfilled voids comprise respective unfilled voids formed at least partially by ground material.

11. The method of claim **9**, further comprising:

filling the unfilled voids partially with a filling material comprising one or more of:

a friction fill material,

a moisture fill material, or

a compression fill material.

12. The method of claim **9**, wherein said forming respective volumetric spaces for the vertically-oriented beams comprises constructing or placing one or more permanent forms for forming the vertically-oriented beams.

13. The method of claim **9**, further comprising:

placing one or more linings within the cavity such that at least one of the one or more linings is adjacent to the subsurface soil, wherein the placing the one or more linings forms a lining layer; and

filling a portion of the cavity with a filling material to form a filling layer above the lining layer.

14. The method of claim **13**, wherein the one or more linings comprise:

a first lining adjacent to the subsurface soil;

a second lining; and

at least one of:

a third lining between the first lining and the second lining, wherein the third lining is configured to reduce friction between the first lining and the second lining; or

a friction reducing agent between the first lining and the second lining.

15. A system, the system comprising:

a structure; and

a foundation configured to support the structure, wherein the foundation comprises:

a horizontal base, extending in a horizontal direction;

one or more vertically-oriented beams extending below the base, into a subsurface level, wherein the one or more vertically-oriented beams narrow along at least some portion of a downward extension of the respective beam from the horizontal base in a vertical direction orthogonal to the horizontal direction of the base; and

a filling material, form, or liner, configured to form respective unfilled voids, comprising unfilled voids, between the one or more vertically-oriented beams and the filling material, form or liner, at the subsurface level, wherein the unfilled voids are distinct from filling material.

16. The system of claim **15**, wherein the respective unfilled voids are formed at least partially by soil.

17. The system of claim **15**, wherein the unfilled voids are partially filled with a filling material comprising one or more of:

a friction fill material,

a moisture fill material, or

a compression fill material.

18. The system of claim **15**, further comprising one or more forms, between the vertically-oriented beams and the subsurface level, wherein the forms comprise one or more wall forming portions configured to shape foundation material into the vertically-oriented beams such that the vertically-oriented beams narrow along at least some portion of the downward extension of the respective vertically-oriented beams.

19. The system of claim **15**, wherein the filling material, form, or liner, configured to form respective unfilled voids comprises one or more forms including:

a lining portion adjacent to subsurface soil, and/or

a filling portion including filling material partially filling larger unfilled voids than said unfilled voids proximate the vertically-oriented beams at the subsurface level, between the vertically-oriented beams and the lining portion or the subsurface soil, wherein the filling portion defines a form boundary that functions, at least in part, to form one or more walls of the vertically-oriented beams.

20. The system of claim **15**, wherein the filling material, form, or liner, configured to form respective unfilled voids proximate the one or more vertically-oriented beams at the subsurface level comprises at least one of:

a soil form;

a removable form; or

a permanent form.

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