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(54) **BI-STABLE MATERIAL TO DEVELOP
STOWABLE HIGH STRENGTH COLUMN**

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

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A stowable, load-bearing apparatus is disclosed having at least two bi-stable strips. Each of the bi-stable strips is alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature and a coiled conformation having longitudinal curvature and lateral linearity. The two bi-stable strips are intercoiled when in the coiled conformation, have opposing lateral curvature relative to one another when in the extended conformation, and when extended are directed into a load-bearing alignment by a structural alignment member.

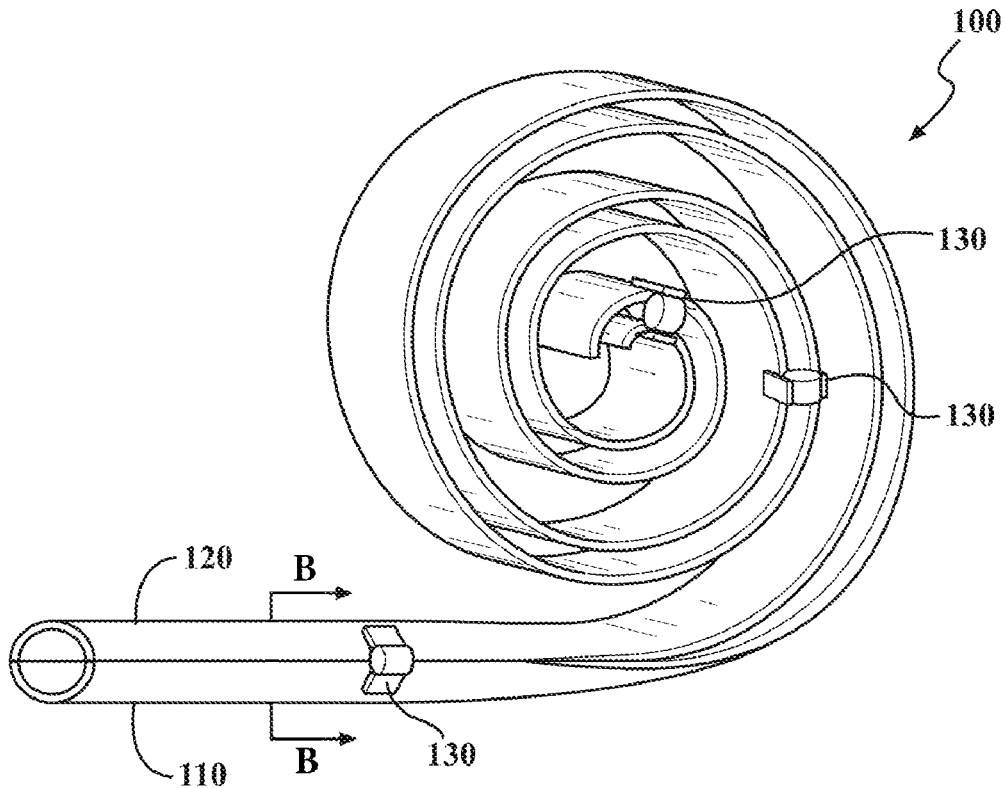


FIG. 1A

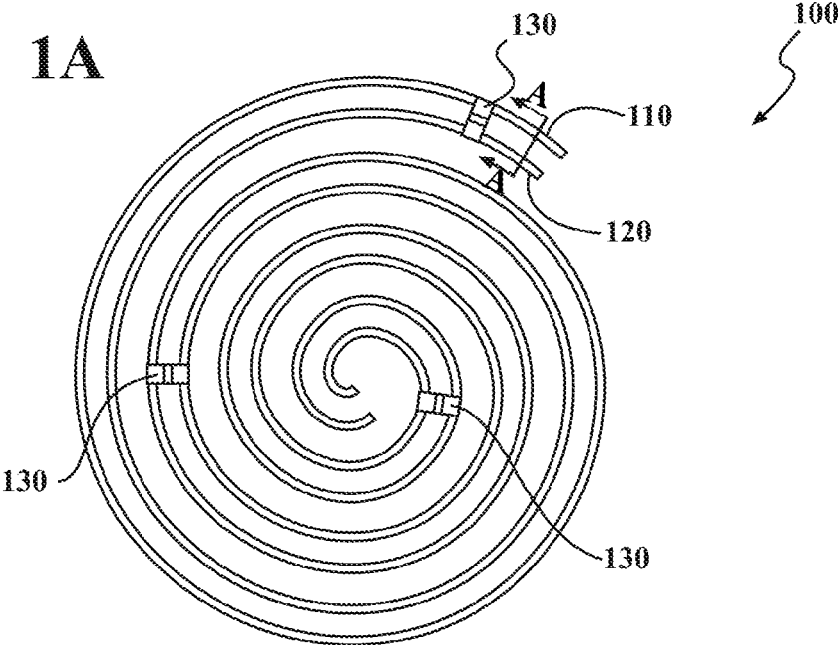
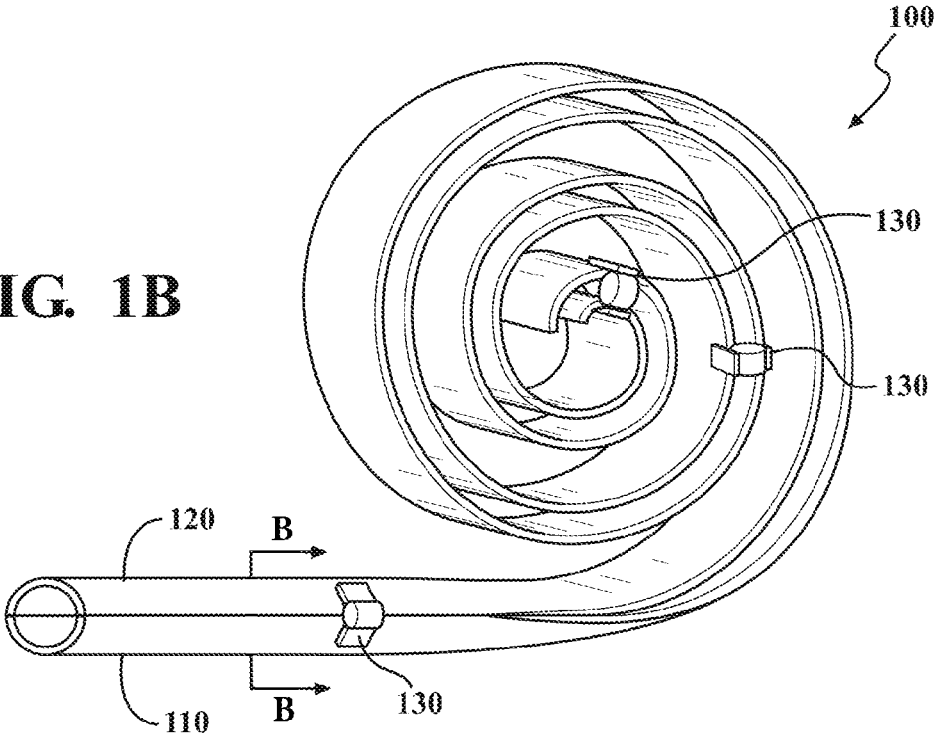


FIG. 1B



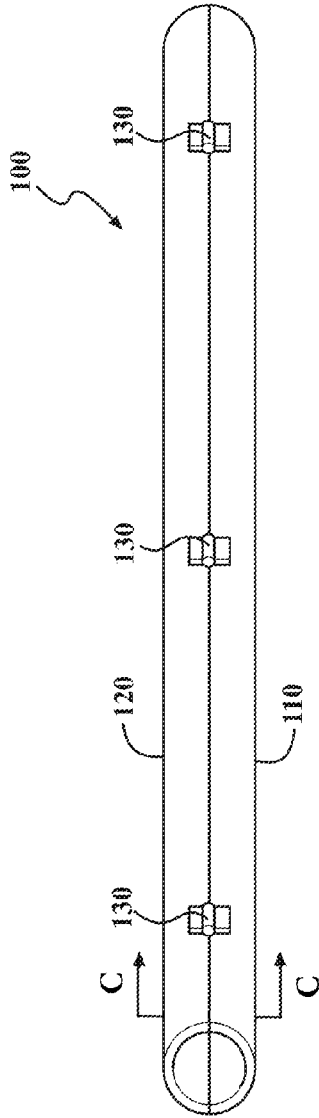


FIG. 1C

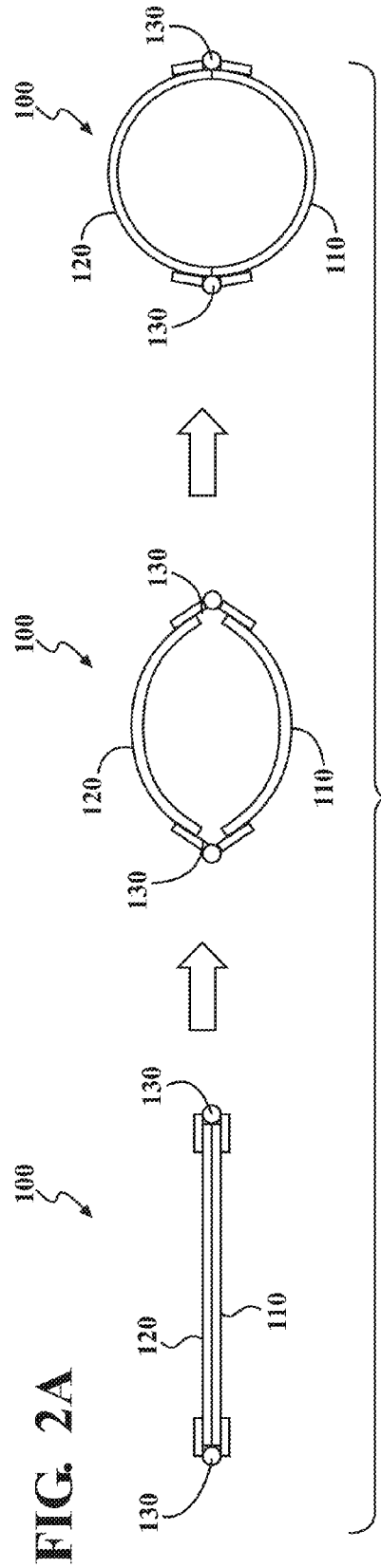
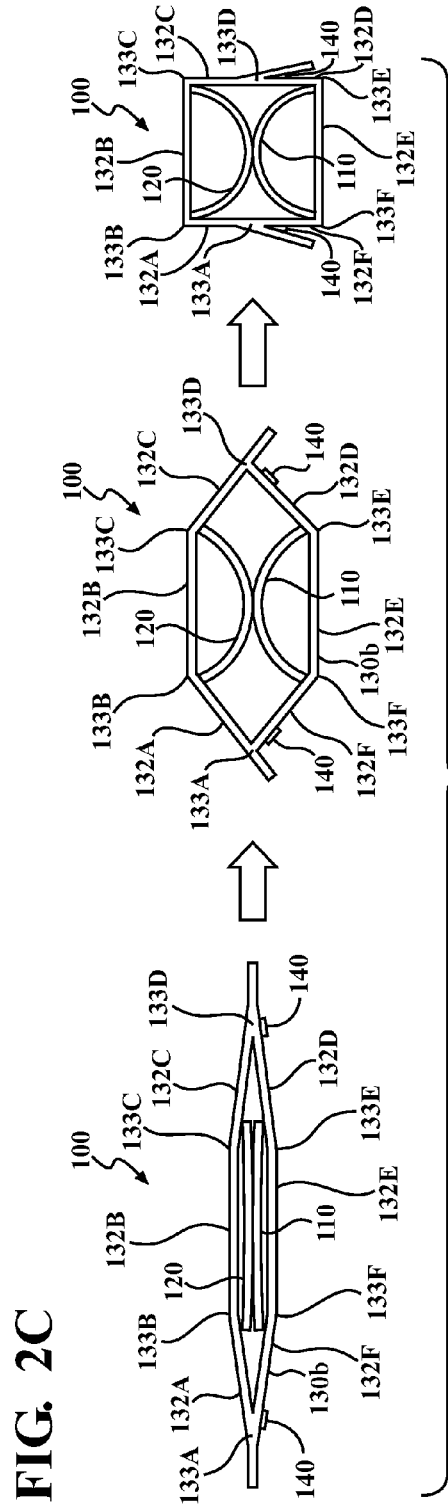
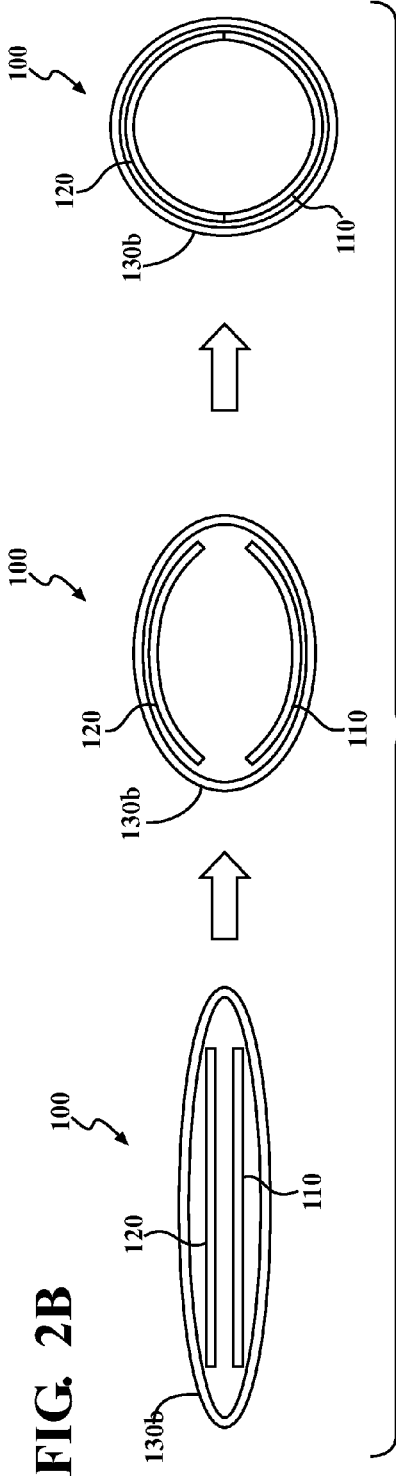


FIG. 2A



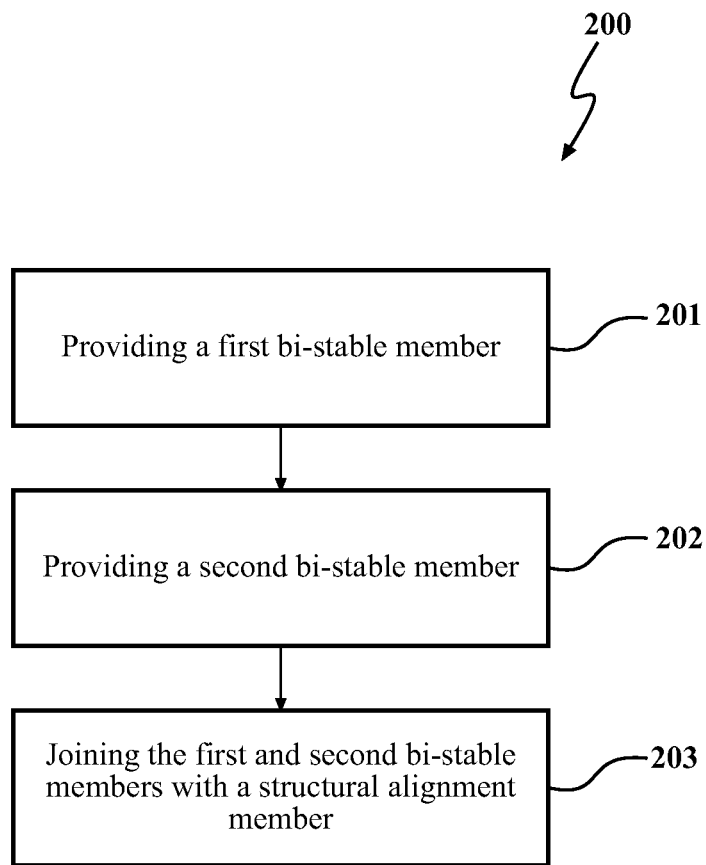


FIG. 3

BI-STABLE MATERIAL TO DEVELOP STOWABLE HIGH STRENGTH COLUMN

TECHNICAL FIELD

[0001] The present disclosure relates to a high-strength, extended support column which is collapsible for convenient storage.

BACKGROUND

[0002] Bi-stable materials, and structures or devices derived therefrom, can be present in either of two stable conformations, but are structurally unstable in any other conformations. In an example, bi-stable strips which are deployable in either a coiled conformation having longitudinal curvature and lateral linearity, or an extended conformation having longitudinal linearity and lateral curvature, are known in the art.

[0003] Structural support members based on bi-stable materials utilize this property to enable convenient reversibility between a retracted, stowable form and an extended, column-like, load-bearing form. The design of such structures however typically leads to formation in the extended form of a column which is either incomplete, having a gap, or otherwise not cross-sectionally affixed. This in turn leads to less than optimal load bearing strength.

SUMMARY

[0004] A stowable support apparatus, reversibly configurable in a stowable conformation and a column-like conformation, is disclosed. The stowable support apparatus includes a first bi-stable member, a second bi-stable member, and at least one structural alignment member. Each of the first bi-stable member and the second bi-stable member is alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity. The structural alignment member is configured to direct the stowable support apparatus into a load bearing conformation when the first and second bi-stable members are present in the extended conformation. The first and second bi-stable members can have an opposing lateral curvature relationship relative to one another when in the extended conformation.

[0005] In another implementation, a method for making a stowable support apparatus is disclosed. The method includes a step of providing a first bi-stable member and another step of providing a second bi-stable member. The first and second bi-stable members are alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity. The method additionally includes a step of joining the first and second bi-stable members with at least one structural alignment member. The structural alignment member is configured to direct the stowable support apparatus into a load bearing conformation when the first and second bi-stable members are present in the extended conformation.

BRIEF DESCRIPTION OF THE DRAWINGS

[0006] FIG. 1A is a side cross-sectional view of a stowable support apparatus including first and second bi-stable materials, the first and second bi-stable materials present in a coiled conformation;

[0007] FIG. 1B is a perspective view of the stowable support apparatus of FIG. 1A with the first and second bi-stable materials present in a partially extended conformation;

[0008] FIG. 1C is a perspective view of the stowable support apparatus of FIG. 1A with the first and second bi-stable materials present in a fully extended conformation;

[0009] FIG. 2A is a series of cross sectional views of the apparatus of FIG. 1A-1C viewed along lines A, B, and C;

[0010] FIG. 2B is a series of cross sectional views of an apparatus of the type shown in FIG. 1A modified to have an encapsulating structural alignment member, and viewed along lines analogous to A, B, and C;

[0011] FIG. 2C is a series of cross sectional views of an apparatus of the type shown in FIG. 1A modified to have another type of encapsulating structural alignment member, and viewed along lines analogous to A, B, and C; and

[0012] FIG. 3 is a flow diagram of a method for making a stowable support apparatus.

DETAILED DESCRIPTION

[0013] The present disclosure provides variations of a reversibly retractable/extendible support apparatus. The disclosed stowable support apparatuses are conformationally stable in either a retracted or stowable state, which is useful for storage, transport, or the like, or in an extended or deployed state which is useful for supporting a load. In general, when in the deployed state, the apparatus resembles a column-like structure amenable to a wide variety of uses. The unique design features of the apparatus confer superior load-bearing performance in comparison to competing structures.

[0014] Apparatuses of the present disclosure include at least two bi-stable strips. Each bi-stable strip is easily and reversibly transformable between an extended conformation and a coiled conformation. Further, each bi-stable strip is affixed to another bi-stable strip by one or more fastening members. As will be more clearly illustrated below, this combination of features allows the apparatus, when deployed, to form a fully-enclosed column in contrast to a single bi-stable strip apparatus which forms an open column.

[0015] With reference to FIGS. 1A-2C, a stowable support apparatus 100 may include a first bi-stable member 110, a second bi-stable member 120, and at least one structural alignment member 130. The first and second bi-stable members 110, 120 are configured to alternate between a compact form suitable for storage, and an extended form suitable for load support when the first and second bi-stable members 110, 120 are properly aligned. The at least one structural alignment member 130 is configured to maintain the first and second bi-stable members 110, 120 in contact or close proximity with one another, and to guide the first and second bi-stable members into proper alignment relative to one another for load support upon extension.

[0016] Each of the first and second bi-stable members 110, 120 (referred to collectively as “the bi-stable members 110, 120”) comprises a bi-stable strip having a longitudinal axis and a lateral axis. Each of the bi-stable members 110, 120 is characterized by at least semi-rigid structural stability in either of a coiled conformation and an extended conformation, and relative structural instability in other conformations. Thus, each of the bi-stable members 110, 120 can be relatively easily transformed, with a proper application of pressure, from the coiled conformation to the extended conformation, and vice-versa.

[0017] The coiled conformation of the bi-stable members **110**, **120** is characterized by a linear lateral axis and a curved longitudinal axis. Conversely, the extended conformation of the bi-stable members **110**, **120** is characterized by a linear longitudinal axis and a curved lateral axis. In many variations, the coiled conformation of the first bi-stable member **110** and the coiled conformation of the second bi-stable member **120** will be substantially identical to one another. However, the extended conformation of the first bi-stable member **110** and the extended conformation of the second bi-stable member **120** will typically be different, having opposite curvature, as discussed in greater detail below.

[0018] Referring now to FIG. 1A, an example of the apparatus **100** is shown in a coiled conformation, i.e. with both the first bi-stable member **110** and the second bi-stable member **120** present in the coiled conformation. It is to be noted that the first and second bi-stable members **110**, **120**, when in the coiled conformation, are intercoiled or coiled around one another. For clarity only, the first and second bi-stable members **110**, **120** are shown relatively loosely coiled and substantially spaced apart. More typically in actual practice, the first and second bi-stable members **110**, **120** would be more tightly intercoiled.

[0019] The structural alignment member **130** of FIG. 1A comprises a plurality of flexible fasteners, in this instance a plurality of hinged fasteners, each affixed to adjacent lateral edges of the first and second bi-stable members. FIGS. 1B and 1C show the apparatus of FIG. 1A partially and completely transformed, respectively, from the coiled conformation to the extended conformation. It can be seen that the hinge portion of each of the plurality of flexible fasteners provides flexibility which allows each of the hinged, dual ended fasteners to maintain contact with the first and second bi-stable members when in either the coiled conformation or the extended conformation. In addition, the plurality of flexible fasteners direct the first and second bi-stable members **110**, **120** into the desired structural alignment upon elongation, forming a laterally enclosed tube as shown in FIG. 1C.

[0020] FIG. 2A shows a series of cross-sectional views of the apparatus of FIGS. 1A-C, highlighting the lateral curvature, or lack thereof, of the first and second bi-stable members **110**, **120** when in the coiled form (left), an intermediate form (middle), and the extended form (right). The three cross-sectional views of FIG. 2A are viewed along the lines A-A, B-B and C-C of FIGS. 1A-C, respectively. The cross-sectional views of FIG. 2A further illustrate how the structural alignment member **130** directs the first and second bi-stable members **110**, **120** into an alignment suitable to support a load as the apparatus **100** transitions from a coiled form to an extended form.

[0021] While the apparatus **100** of FIGS. 1A-1C has a plurality of hinged fasteners, any other suitable flexible fastener can be used. For example, suitable structural alignment members **130** of the flexible fastener type can include multiple flaps formed of flexible material and affixed to adjacent lateral edges of the first and second bi-stable members **110**, **120**. Such flexible material can include a flexible fabric, flexible membrane, or any other flexible material. In other instances, the structural alignment member **130** can comprise a single flexible fastener affixed to adjacent lateral edges of the first and second bi-stable members **110**, **120**, along the entirety or a substantial portion of the length of the adjacent lateral edges. In yet other instances, the structural alignment member **130** can include one or more flexible fasteners that

are integrally formed with either or both of the first and second bi-stable members, rather than being affixed thereto.

[0022] In general, the first and second bi-stable members **110**, **120** will have opposing lateral curvature relationship when in the extended conformation, relative to their longitudinal curvature when in the coiled conformation. Referring again to the example of FIG. 1B, the extended portion of the first bi-stable member **110** has a concave surface facing in the direction of the coiled portion and a convex surface facing away from the direction of the coiled portion. This can be termed a “positive curvature relationship”, and materials having this property are known in the art. In contrast, the extended portion of the second bi-stable member **120** has a convex surface facing in the direction of the coiled portion and a concave surface facing away from the direction of the coiled portion. This can be referred to as a “negative curvature relationship”. While the particular opposing lateral curvature relationship between the first and second bi-stable members **110**, **120** of FIG. 1A results in a cylindrical structure with concave surfaces facing one another in the example of FIG. 1B, it is to be understood that the lateral curvature of each of the first and second bi-stable members **110**, **120** can be reversed so that convex surfaces face one another when the stowable support apparatus **100** is deployed.

[0023] Methods for fabricating the bi-stable member **110** or **120** having a positive curvature relationship typically involve fabrication of a bi-layered or multi-layered, composite material having a positive Poisson ratio such that extension in the longitudinal direction results in retraction in the lateral direction, and vice-versa. This positive Poisson ratio results in the positive curvature relationship of the first bi-stable member of FIGS. 1B, 1C. The second bi-stable member having a negative lateral curvature relationship can be similarly designed of bi-layered or multi-layered, composite materials, at least one of which comprises an auxetic material having a negative Poisson ratio wherein extension in the longitudinal direction leads to expansion in the lateral direction, and vice-versa. This negative Poisson ratio results in the negative lateral curvature relationship of the second bi-stable member **120** in the example of FIGS. 1B, 1C. A non-limiting example of such an auxetic material includes a composite material wherein structural fibers form a periodic, inverted polygonal cell structure.

[0024] Referring now to FIGS. 2B and 2C, the structural alignment member **130** can alternatively be a flexible encapsulator **130b** such as a carbon fiber or epoxy comprising membrane. The cross-sectional views of FIGS. 2B and 2C are of an apparatus **100** analogous to that of FIGS. 1A-1C, in which the flexible fastener type of structural alignment members **130** are replaced with a flexible encapsulator **130b**, and the three views in each of FIG. 2B and 2C are along similar lines to those of lines A-A, B-B and C-C of FIGS. 1A-1C. A flexible encapsulator **130b** is a variety of structural alignment member which surrounds or encapsulates at least a portion of the first and second bi-stable members **110**, **120**. A flexible encapsulator **130b** can be a membrane, fabric, or other flexible material having a sock-like or sleeve-like shape. In some variations, a flexible encapsulator **130b** type of structural alignment member will be co-coiled with the first and second bi-stable members **110**, **120** when the first and second bi-stable members **110**, **120** are in the coiled conformation.

[0025] Referring again to FIG. 2B, the left panel shows the bi-stable members **110**, **120** in the coiled conformation, in the right panel they are in the extended conformation, and in the

middle panel they are in an intermediate state. As the apparatus **100** transitions from the stowed configuration to the deployed configuration, the flexible encapsulator **130b** variety of structural alignment member **130** forces the first and second bi-stable members **110**, **120** in to the tube shape that is the required alignment for maximum load bearing in this example. In this tube-like alignment, the cross-sectional view of the first and second bi-stable members **110**, **120** appears as two 180° arcs held together at their end points to form a circle.

[0026] A similar scenario is depicted in FIG. 2C, however the lateral curvature relationships of the first and second bi-stable members **110**, **120** when in the extended conformation are reversed. In this example, the flexible encapsulator **130b** type of structural alignment member **130** is capable of adopting a shape with a square longitudinal edge section. Optionally in this example, the structural alignment member **130** is not uniformly flexible, but instead has rigid walls with longitudinal pivot lines. In this example, the structural alignment member has six rigid walls **132A**, **1320B**, **132C**, **132D**, **132E**, and **132F** and six longitudinal pivot lines **133A**, **133B**, **133C**, **133D**, **133E**, and **133F** (the longitudinal pivot lines **133A-133F** appearing as pivot points in the end cross-sectional view of FIG. 2C) enabling the structural alignment member to alternate between a longitudinal edge section that is hexagonal when the apparatus **100** is stowed and a longitudinal edge section that is square when the apparatus **100** is deployed. Because of the reversed polarities of the curvature relationships of the first and second bi-stable members **110**, **120** as well as the properties of the square flexible encapsulator **130b**, the first and second bi-stable members are forced into a structure having a longitudinal edge cross sectional shape of two opposing arcs symmetrically conjoined at their midpoints. The apparatus **100** as a whole has the shape of a rectangular prism when deployed. The example of FIG. 2C also includes optional longitudinal flaps (appearing as lateral flaps in the end cross-sectional view of FIG. 2C) affixable with fasteners **140**. When the longitudinal flaps are affixed to the fasteners **140** as in the right panel of FIG. 2C, this can help to maintain the apparatus **100** in the deployed configuration.

[0027] Also disclosed, and with reference to FIG. 3, is a method **200** for making a stowable support apparatus. The method **200** includes a step **201** of providing a first bi-stable member **110**. The method also includes a step **202** of providing a second bi-stable member **120**. The first bi-stable member **110** and second bi-stable member **120** provided in the providing steps **201** and **202** are as described above. In particular, each is alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity. In addition, the first bi-stable member **110** provided in step **201** and the second bi-stable member **120** provided in step **202** will generally have opposing lateral curvature relationship relative to one another, as defined above.

[0028] The method **200** also includes a step **203** of joining the first and second bi-stable members with at least one structural alignment member **130**. The structural alignment member **130** which is employed in the joining step **203** is as described above with reference to the stowable support apparatus **100**. Thus, the structural alignment member **130** as employed in the method **200** is configured to direct the stowable support apparatus **100** into a load bearing conformation when the first and second bi-stable members **110**, **120** are present in the extended conformation. Likewise, non-limiting

examples of a structural alignment member **130** suitable for use in the method **200** include various forms of flexible fastener and/or flexible encapsulator **130b**, as discussed above.

[0029] The method **200** can additionally include a step of intercoiling the first and second bi-stable members **110**, **120**. The intercoiling step can either precede or follow the joining step. For example, if the structural alignment member **130** is a flexible encapsulator **130b**, such as a sleeve-shaped fabric, the flexible encapsulator **130b** sleeve can be slid over the first and second bi-stable members **110**, **120** while they are in the extended conformation and they can then subsequently be intercoiled. Such an approach can result in the co-coiling of the flexible encapsulator **130b** with the first and second bi-stable members **110**, **120** as mentioned above.

[0030] In an example in which the intercoiling step can precede the joining step **203**, the first and second bi-stable members can be intercoiled and one or more flexible structural alignment members **130** of the flexible fastener type can subsequently be affixed to adjacent lateral edges of the first and second bi-stable members **110**, **120**.

[0031] The foregoing description relates to what are presently considered to be the most practical embodiments. It is to be understood, however, that the disclosure is not to be limited to these embodiments but, on the contrary, is intended to cover various modifications and equivalent arrangements included within the spirit and scope of the appended claims, which scope is to be accorded the broadest interpretation so as to encompass all such modifications and equivalent structures as is permitted under the law.

What is claimed is:

1. A stowable support apparatus, comprising:

- a first bi-stable member, the first bi-stable member being alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity;
- a second bi-stable member, the second bi-stable member being alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity; and
- at least one flexible fastener affixed to adjacent lateral edges of the first and second bi-stable members in both the extended conformation and the coiled conformation.

2. The stowable support apparatus of claim 1, wherein the at least one flexible fastener is configured to guide the first and second bi-stable members into proper alignment relative to one another for load support upon extension.

3. The stowable support apparatus of claim 1, wherein the first bi-stable member and the second bi-stable member have an opposing lateral curvature relationship relative to one another.

4. The stowable support apparatus of claim 1, wherein either of the first and second bi-stable members comprises an auxetic material.

5. The stowable support apparatus of claim 4, wherein the at least one flexible fastener comprises at least one of a hinge and a flexible membrane.

6. The stowable support apparatus of claim 1, wherein the first and second bi-stable members alternate between the extended and coiled conformation in tandem, and are intercoiled when in the coiled conformation.

7. A method for making a stowable support apparatus, the method comprising:

providing a first bi-stable member, the first bi-stable member being alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity;

providing a second bi-stable member, the second bi-stable member being alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity;

joining the first and second bi-stable members with at least one structural alignment member configured to join the first and second bi-stable members when they are in either the extended conformation or the coiled conformation.

8. The method of claim 7, wherein providing the second bi-stable member is further characterized in that the second bi-stable member has an opposing lateral curvature relationship relative to the first bi-stable member.

9. The method of claim 8, wherein providing the first bi-stable member is further characterized in that the first bi-stable member comprises an auxetic material, or providing the second bi-stable member is further characterized in that the second bi-stable member comprises an auxetic material.

10. The method of claim 7, wherein the joining step comprises engaging a flexible encapsulator about the first and second bi-stable members while the first and second bi-stable members are in the extended conformation.

11. The method of claim 7, further including a step of intercoiling the first and second bi-stable members.

12. The method of claim 7, wherein the joining step comprises affixing a flexible fastener to adjacent lateral edges of the first and second bi-stable members while the first and second bi-stable members are in either of the extended conformation or the coiled conformation.

13. A stowable support apparatus, comprising:

a first bi-stable member, the first bi-stable member being alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity;

a second bi-stable member, the second bi-stable member being alternatable between a stable, extended conformation having longitudinal linearity and lateral curvature, and a stable, coiled conformation having longitudinal curvature and lateral linearity; and

at least one flexible encapsulator surrounding or encapsulating at least a portion of the first and second bi-stable members in both the extended conformation and the coiled conformation.

14. The stowable support apparatus of claim 13, wherein the flexible encapsulator directs the apparatus into a load bearing conformation when the first and second bi-stable members are present in the extended conformation.

15. The stowable support apparatus of claim 13, wherein the first bi-stable member and the second bi-stable member have an opposing lateral curvature relationship relative to one another.

16. The stowable support apparatus of claim 15, wherein either of the first and second bi-stable members comprises an auxetic material.

17. The stowable support apparatus of claim 13, wherein the flexible encapsulator surrounds or encapsulates at least a portion of the first and second bi-stable members.

18. The stowable support apparatus of claim 13, wherein the first and second bi-stable members alternate between the extended and coiled conformation in tandem, and are intercoiled when in the coiled conformation.

19. The stowable support apparatus of claim 18, wherein the flexible encapsulator is co-coiled with the first and second bi-stable members when the first and second bi-stable members are present in the coiled conformation.

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