United States Patent Application Publication	20250262778
Kind Code	A1
Publication Date	August 21, 2025
Inventor(s)	Graham; Howard

STRUCTURAL WAVE FRAMEWORKS WITH NEUTRAL AXIS AND BEND LIMITERS

Abstract

Flexible Frameworks with Neutral Axis and Bend limiters may be provided by a framework, including a plurality of flexible components, each flexible component having a plurality of structural components, including a first annular member; a second annular member; a first axial member, a second axial member, diametrically opposite from where the first axial member is connected to the first annular member and the second annular member; a first undulating member, having an annular profile and a waveform defined about a circumference thereof, which intersects the first annular member twice, intersects the first axial member once, and intersects the second axial member once; and a second undulating member, having an annular profile and a waveform defined about a circumference thereof, which intersects the second annular member twice, intersects the first axial member once, and intersects the second axial member once.

Inventors: **Graham; Howard (Temecula, CA)**

Applicant: **Graham; Howard** (Temecula, CA)

Family ID: **1000008487572**

Appl. No.: **19/053883**

Filed: **February 14, 2025**

Related U.S. Application Data

us-provisional-application US 63553864 20240215

Publication Classification

Int. Cl.: **B25J18/06** (20060101); **A61M25/01** (20060101)

U.S. Cl.:

CPC **B25J18/06** (20130101); A61M25/0138 (20130101); A61M25/0147 (20130101)

Background/Summary

CROSS-REFERENCES TO RELATED APPLICATIONS [0001] The present disclosure claims benefit and priority to U.S. Provisional Patent Application 63/553,864, entitled “STRUCTURAL WAVE FRAMEWORKS WITH NEUTRAL AXIS AND DEFLECTION CONSTRAINTS” and filed on 2024 Feb. 15, which is incorporated herein by reference in its entirety.

BACKGROUND
[0002] When an element in bending begins to deflect, portions of the element experience compressive strain, and other portions experience tensile strain. The neutral axis is the axis, or plane, in the cross section of the element in bending where there are no compressive or tensile strains. In uniform elements, the neutral axis typically bisects the element perpendicularly to the direction of the applied bending force.
SUMMARY
[0003] The present disclosure provides structural wave frameworks with neutral axis and bend limiters.
[0004] A provided flexible framework includes a plurality of flexible components, each flexible component of the plurality of flexible components having a plurality of structural components, including a first annular member; a second annular member; a first axial member, connected on opposing ends to the first annular member and the second annular member, respectively; and a second axial member, connected on opposing ends to the first annular member and the second annular member, respectively, in some embodiments diametrically opposite from where the first axial member is connected to the first annular member and the second annular member. The flexible framework further includes a first undulating member, having an annular profile and a waveform defined about a circumference thereof, which intersects the first annular member twice, intersects the first axial member once, and intersects the second axial member once; and a second undulating member, having an annular profile and a waveform defined about a circumference thereof, which intersects the second annular member twice, intersects the first axial member once, and intersects the second axial member once.
[0005] Additional features and advantages of the disclosed method and apparatus are described in, and will be apparent from, the following Detailed Description and the Figures. The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the figures and description. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and not to limit the scope of the inventive subject matter.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0006] FIG. **1** is prior art, demonstrating mechanical concepts relevant to the contents of the present disclosure.
[0007] FIG. **2** is prior art, demonstrating mechanical concepts relevant to the contents of the present disclosure.
[0008] FIG. **3** illustrates a flexible framework component, according to embodiments of the present disclosure.

[0009] FIG. **4** illustrates a flexible framework component with dependent bend limiters, according to embodiments of the present disclosure.
[0010] FIG. **5** illustrates a flexible framework component with independent bend limiters, according to embodiments of the present disclosure.
[0011] FIG. **6** illustrates a flexible framework component with wave-matched bend limiters, according to embodiments of the present disclosure.
[0012] FIG. **7**A illustrates a flexible framework component with internal wire guides, according to embodiments of the present disclosure.
[0013] FIG. **7**B illustrates a flexible framework component with external wire guides, according to embodiments of the present disclosure.
[0014] FIGS. **8**A-**8**B illustrate flexible framework components with compliant axial members, according to embodiments of the present disclosure.
[0015] FIG. **9** illustrates a flexible framework component with compliant axial members and variable-height spacing between paired bend limiters, according to embodiments of the present disclosure.
[0016] FIG. **10** illustrates a flexible framework component with an alternating neutral axis, according to embodiments of the present disclosure.
[0017] FIG. **11** illustrates a flexible framework component with axially offset undulating members, according to embodiments of the present disclosure.
[0018] FIGS. **12**A-**12**C illustrate disks with circumferential holes for use in constructing a flexible framework, according to embodiments of the present disclosure.
[0019] FIGS. **13**A-**13**B illustrate flexible frameworks composed of the flexible framework components discussed herein, according to embodiments of the present disclosure.
[0020] FIG. **14**A illustrates a flexible framework in bending, composed of the flexible framework components, according to embodiments of the present disclosure.
[0021] FIG. **14**B illustrates an alternate perspective of a flexible framework in bending, composed of the flexible framework components, according to embodiments of the present disclosure.
[0022] FIG. **15** illustrates an isometric view of a flexible framework in bending where flexible framework components are rotationally offset from one another, according to embodiments of the present disclosure.
[0023] FIG. **16** illustrates a wire-guided flexible framework, according to embodiments of the present disclosure.
[0024] FIG. **17**A illustrates a wire guided flexible framework with a jacket, according to embodiments of the present disclosure.
[0025] FIG. **17**B illustrates a wire guided flexible framework with a liner, according to embodiments of the present disclosure.
[0026] FIG. **18**A-**18**D illustrate example wire guide elements with wires guides in various locations, according to embodiments of the present disclosure.

DETAILED DESCRIPTION

[0027] The present disclosure provides flexible frameworks with neutral axis and bend limiters, in which structural wave frameworks can be used for the construction of flexible structures. The integration of a neutral axis structural members within a framework of a flexible structure defines the structure's axis of bending. Neutral axis structural members also define the axial arc length of a flexible structure in bending, and ensure the dimensional repeatability of the arc length during use. Bend limiters can be integrated into the design of the singular structural wave framework to prevent the structure being subjected to overstressed conditions. When bend limiters are fully engaged, the bend limiters define the radius of curvature for a flexible structure. Dimensions of the constraints can be designed not only to prevent overstressed conditions but also to establish a specific radius of curvature based on a specific design requirement.
[0028] In some of the figures of the present disclosure, a shared coordinate system is used (as

indicated with the compasses in individual figures) with X, Y, and Z directions to aid in understanding. Although a user may orient the described devices in various positions, various dimensions may be referred to as a width, a height, or a depth, which represent measurements on the X axis, Y axis, and Z axis, respectively. The term vertical is understood to correspond to an orientation relative to the Y axis, and horizontal is understood to correspond to an orientation relative to the X axis. Furthermore, discussion of forces and moments may include directional identifiers that correspond to the same shared coordinate system and it is understood that the directional identifiers are included only to aid in understanding, and not to limit the subject matter of this disclosure.

[0029] FIG. **1** is prior art, and demonstrates certain properties of elements subjected to bending stresses. FIG. **1** illustrates a cantilevered beam **100** subjected to a vertical force **120**. Also illustrated are axis of bending **160** (in the Z-direction) and the tensile strains **130** and compressive strains **140** that result within the beam **100**. The plane at which there are no compressive strains **140** or tensile strains **130** is the neutral axis **150**, which in some cases may be referred to as the neutral surface. It has been known to establish the flexible structure wave in bending to have a radial thickness to be greater than the axial height to minimize the stress in bending. However, design-dependent sections can have both characteristics.

[0030] FIG. **2** is prior art and shows the cantilevered beam **100** of FIG. **1** where the vertical force **120** has induced bending in the cantilevered beam **100**. The neutral axis **150** experiences deflection along with the beam **111**, but does not experience tensile strain **130** or compressive strain **140**. The plane perpendicular to the axis of bending **160** is the plane of deflection, which is an X-Y plane in the illustrated embodiment.

[0031] FIG. **3** shows a flexible framework component **300**, having two annular members **310**A-B (generally or collectively, annular members **310**), two undulating members **320**A-B (generally or collectively, undulating members **320**), and two axial members **330**A-B (generally or collectively, axial members **330**), according to embodiments of the present disclosure. The annular members **310** form vertical bounds for the flexible component, and the distance between the annular members **310** is defined by the height of the axial members **330**. The axial members **330** are substantially rectangular prisms, and each axial member **330** is oriented vertically (along the Y-direction), connecting on each end to opposite annular members **310**. The axial members **330** form a neutral axis of deflection for the flexible framework component **300**.

[0032] Although illustrated with a first axial member **330**A and a second axial member **330**B that are each connected to the first annular member and the second annular member diametrically opposite to one another (e.g., 180 degrees apart), the present disclosure contemplates that an uneven separation (e.g., of less than 180 degrees in one direction and more than 180 degrees in the opposing direction) is also possible. With an even (e.g., 180 degree) opposition between the axial members **330**, the degree of permitted bending or deflection is equal in each direction (e.g., positive Z-ward and negative Z-ward). In the case where the axial members **330** are separated unevenly, the degree of permitted deflection will be greater in the direction of bending in which the separation is greater than 180 degrees compared to the direction of bending in which the separation is less than 180 degrees. Designs are possible with other spacing less than 180 degrees, thereby allowing a greater degree of deflection of each single cell flexible structure in the direction where the neutral axes are greater than 180 degrees. A combination of variable neutral axis locations can be used to create an overall structure of complex curves.

[0033] The undulating members **320** have an annular profile in the X-Z plane (matched with the annular members **310**), and have a sinusoidal waveform defined about the circumference of the annular profile. Each undulating member **320** includes two or more full waveforms around the circumference of the undulating member **320**, and may also be understood as including various arms **325**A-H (generally or collectively, arms **325**). The undulating members **320** are disposed between the annular members **310**, and are mirrored about an X-Z plane that bisects the axial members **330**. The undulating members **320** are further configured such that the waveform intersects the axial members **330** at a point where the waveform is furthest from the nearest annular member **310**. In other words, the “lower” undulating member **320** intersects the axial members **330** at the apexes of the waveform, and the “upper” undulating member **320** intersects the axial members at the nadirs of the waveform. The undulating members **320** tangentially intersect the annular members **310** at points on the annular members **310** that are 90 degrees (where the Y axis is the axis of rotation) removed from the points at which the annular members **310** intersect the axial members **330**.

[0034] In some examples, the undulating members **320** intersect one another at the same point that the undulating members **320** intersect the axial members **330**, and in yet other examples, the undulating members **320** intersect the axial members **330** at respectively distinct points. The circumferential free length of the undulating member **320** affects the stiffness of the structure in bending. The undulating member **320** that intersects the axial member **330** and connects to the annular member **310** at a point circumferentially at 90 degrees will have greater flexibility than if connected to an annular member **310** at a point less than 90 degrees. The distance between the intersection of a first undulating member **320** and a second undulating member **320** on a given axial member **330** corresponds to the deflection stiffness of the flexible framework component **300**. As the distance between intersection points is reduced, the deflection stiffness of the flexible framework component **300** increases. Adjusting the distance between the intersections of a first undulating member **320** and a second undulating member **320** on a given axial member **330** can be achieved by either changing the length of the axial members **330**, and as a result, the height of the flexible framework component **300**; or, by adjusting the amplitude of the waveform of the undulating members **320**. An increased amplitude of the waveform of the undulating member **320** results in closer undulating-axial intersections, and thus an increased deflection stiffness.

[0035] Both the undulating members **320** and the axial members **330** are defined within the profile of the annular members in the X-Z plane. Stated differently, the flexible framework component **300** forms a skeleton of a hollow cylinder.

[0036] The flexible framework component **300** is configured to deflect in a predictable and dimensionally repeatable manner when various stresses are applied. The axial members **330** contain neutral axes, and define the axis of bending of the flexible framework component **300**. For example, when a force is applied to the flexible framework component **300** in the Y-direction, the resulting bending occurs about the X-axis rotation. Any force acting on the flexible framework component **300** having components in the Y-direction (with the exception of forces coaxial with the neutral axis) will result in deflection where the axis of bending is in the X-direction. In other words, the placement of the neutral axis defines the axis of rotation of the flexible framework component.

[0037] In addition to providing neutral axes, the axial members **330** provide resistance to axial forces, and prevent the flexible framework component **300** from compressing or extending in length when subjected to an axial load. The compression resistance provided by the axial members **330** also ensures a constant axial arc length of the flexible framework component **300** when in bending.

[0038] According to some embodiments, flexible framework components **300** are constructed by additive manufacturing, using methods such as 3-D printing. In such embodiments, flexible framework components **300** are constructed of thermoplastics, resins, polymers, or metals.

[0039] According to some embodiments, flexible framework components **300** are constructed by removing material from an existing hollow cylinder, such as a section of pipe or tubing. In such embodiments, flexible framework components **300** are constructed of plastics, polymers, metals, and the like. The present disclosure further contemplates embodiments formed by chemical etching, laser etching, and laser cutting.

[0040] FIG. **4** shows an isometric view of a flexible framework component **300** with dependent bend limiters **420**, according to embodiments of the present disclosure. The flexible framework component **300** with dependent bend limiters **420** has two annular members **310**, two undulating members **320**, and two axial members **330**; and further includes four dependent bend limiters **420**A-D (generally or collectively, dependent bend limiters **420**). The dependent bend limiters **420** are protrusions that emanate from the annular members **310** towards one another along the Y-direction, and are 90 degrees removed from the axial members **330**, at the tangential intersection of the undulating members **320** and annular members **310**. The illustrated flexible framework component **300** has four dependent bend limiters **420** divided into two pairs, where each dependent bend limiter **420** is directed towards the dependent bend limiter **420** protruding from the opposite annular member **310**.

[0041] The dependent bend limiters **420** are disposed within the plane of deflection of the flexible framework component **300** with dependent bend limiters **420**, and are configured such that when bending occurs (axis of bending in the Z-direction) the dependent bend limiters **420** will contact one another and prevent further deflection. In some examples, dependent bend limiters **420** prevent plastic deformation of the material from which the flexible framework component **300** is constructed. The dependent bend limiters **420** can be configured to prevent permanent deformation and overstressing of the flexible framework component **300** when included thereon.

[0042] The dependent bend limiters **420** can be described as bending stops, which contact one another when a certain amount of deflection occurs. By varying the length of the dependent bend limiters **420**, the user can tune the maximum deflection of a given flexible framework component **300** with dependent bend limiters **420**. By increasing the length of each dependent bend limiter **420**, contact occurs after less deflection, resulting in a decreased maximum deflection, and by decreasing the length of each bend limiter **420**, contact occurs after more deflection, resulting in an increased maximum deflection. In other words, the length of the dependent bend limiters **420** is inversely related to the maximum deflection of the flexible framework component **300** with dependent bend limiters **420**.

[0043] Although illustrated with four dependent bend limiters **420** in FIG. **4**, the present disclosure contemplates that a flexible framework component **300** may have three dependent bend limiters (e.g., **420**A-C), two opposing dependent bend limiters (**420**A-B), two un-opposing bend limiters emitting from the same annular member (e.g., **420**A and **420**C from **310**A), two un-opposing bend limiters emitting from the different annular members (e.g., **420**A from **310**A and **420**D from **310**B), or one bend limiter (e.g., **420**A). Additionally, although illustrated as substantially uniform to one another, the present disclosure contemplates that the relative sizes of the dependent bend limiters **420** may differ from one another to affect different flexing properties in a given flexible framework component **300**.

[0044] FIG. **5** shows a flexible framework component **300** with independent bend limiters **520**A-D (collectively or generally, independent bend limiters **520**), according to embodiments of the present disclosure. As in previously described examples, flexible framework components **300** with independent bend limiters **520** include two annular members **310**, two undulating members **320**, and two axial members **330**. A flexible framework component **300** with independent bend limiters **520** and further includes third annular member **310**C, disposed between the undulating members **320**. The independent bend limiters **520** emanate from the third annular member **310**C, above and below in the Y-direction, towards the first two annular members **310**A-B. The independent bend limiters **520** function much the same as the dependent bend limiters **420**, excepting that as deflection occurs in the flexible framework component **300**, the independent bend limiters **520** contact the annular members **310**, preventing further deflection.

[0045] Although illustrated with four dependent bend limiters **520** in FIG. **5**, the present disclosure contemplates that a flexible framework component **300** may have three dependent bend limiters (e.g., **520**A-C), two opposing dependent bend limiters (**520**A-B), two un-opposing bend limiters emitting from the same side of the third annular member (e.g., **420**A and **420**C from **510**), two un-opposing bend limiters emitting from the different side of the third annular member (e.g., **520**A and **520**D from **510**), or one bend limiter (e.g., **520**A). Additionally, although illustrated as substantially uniform to one another, the present disclosure contemplates that the relative sizes of the dependent bend limiters **520** may differ from one another to affect different flexing properties in a given flexible framework component **300**.

[0046] FIG. **6** illustrates a flexible framework component **300** with a wave-matched bend limiter **610**, according to embodiments of the present disclosure. The wave matched bend limiter **610** is an annular component disposed between the undulating members **320**, and intersects the axial members **330**. The wave-matched bend limiter matches the curvature of the waveform of the undulating component, such that when the flexible framework component deflects, the undulating components contact the wave-matched bend limiter to prevent further deflection. The wave-matched form of the wave-matched bend limiter allows for a greater surface area of the contact area between an undulating component and the wave matched bend limiter, as the contact occurs over a larger edge of the wave matched bend limiter **610** and undulating member **320**. The larger contact area serves to distribute force over a larger volume of the bend limiter, allowing for greater compressive forces which may incur deformation in, a comparable smaller, dependent bend limiter **420** or an independent bend limiter **520**.

[0047] In some embodiments, such as the illustrated embodiment, the wave-matched bend limiter **610** incudes a cut-out sections **615**A-B (generally or collectively, cut-out sections **615**) proximate to the plane of deflection. The cut-out sections **615** provide the wave-matched bend limiters **610** with compressibility, allowing for deflection after contact between the wave-matched bend limiters **610** and the undulating members **320**, albeit at an increased resistance, relative to the deflection resistance prior to the contact.

[0048] In some embodiments, the wave-matched bend limiter does not include cut-out sections **615**, and deflection of the flexible framework component is ceased after contact between the wave-matched bend limiter **610** and the undulating members **320**.

[0049] FIG. **7**A illustrates a flexible framework component **300** with guide holes **720**A-B (generally or collectively, wire guide holes **720**) disposed on the interior of the annular member **310**, according to embodiments of the present disclosure. In some examples, the flexible framework component **300** includes protrusions **710** on the outer circumference of the annular members **310**, each of which defines a corresponding guide hole **720**A-D. The protrusions **710**, and guide holes **720** are 90 degrees removed from the axial members **330** and protrude in the Z-direction, towards the center of the annular member **310**. Guide holes can be round, square, rectangular, or any other appropriate shape as needed per the design.

[0050] FIG. **7**B illustrates a flexible framework component **300** with guide holes **720**A-D disposed on the exterior of the annular members **310**, according to embodiments of the present disclosure. The flexible framework component **300** includes protrusions **710**A-D on the outer circumference of the annular members **310**, each of which defines a corresponding guide hole **720**A-D. The protrusions **710**, and guide holes **720** are 90 degrees removed from the axial members **330** and protrude in the Z-direction, towards the center of the annular member **310**.

[0051] Although illustrated with four protrusions **710** and guide holes **720** in FIGS. **7**A-B, the present disclosure contemplates that a flexible framework component **300** may have one protrusion **710**A, two protrusions **710**A-B, three protrusions **710**A-C, or four protrusions **710**A-D, each having one or more guide hole **720**. Additionally, although illustrated as substantially uniform to one another, the present disclosure contemplates that the relative sizes of the protrusions **710** and guide holes **715** may differ from one another to affect different joining and attachment properties in a given flexible framework component **300**.

[0052] In some embodiments, the Y-directional height of a protrusion is not greater than the Y-directional height of an annular member **310**, and in some embodiments, the Y-directional height of a protrusion **710** is equal to the Y-directional height of an annular member **310**.

[0053] In some embodiments, the protrusions **710** and guide holes **720** are configured to accommodate guide wires, which, when tensioned and secured, can provide the forces required to induce bending and deflection in flexible framework component **300** with guide holes **720**. Further discussion of guide wires and related systems can be found in FIGS. **16** and **17**A-**17**B and the associated description.

[0054] In some examples the protrusions **710** and guide holes **720** are configured to accommodate fasteners or adhesives, which can be used to secure multiple flexible framework components **300** with guide holes **715** together. Such fasteners may include bolts, screws, rivets, pins and the like. In other examples, the protrusions **710** do not include guide holes **720** and simply provide surface area by which to adhere multiple flexible framework components **300** together. Such processes may include the use of welding, heat bonding, brazing, and chemical adhesives.

[0055] FIGS. **8**A-**8**B illustrate flexible framework components **300** with compliant axial members **330**, according to embodiments of the present disclosure. Axial members **330** may be generally in-line with the longitudinal axis of a flexible framework (e.g., substantially aligned with the Y-axis of the flexible framework component **300** when in an un-bent configuration) as illustrated in FIGS. **3**-**11**, or may include two or more compliant structures **810**A-L (generally or collectively, compliant structures **810**) that can provide greater structural flexibility in bending compared to in-line axial members **330** by absorbing some of the stress from the structural wave. Indeed, the integration of a compliant axial members **330** within a framework has been found to reduce the restriction in bending in the axis 90 degrees to the primary axis of bending, while being sufficiently supportive to influence the primary axis of bending. By including compliant structures **810**, the axial members **330** thereby allow a flexible framework design to exhibit further movement or progression of the flexible framework through a vessel or pathway than an otherwise similar design using in-line axial members **330**.

[0056] The compliant structures **810** define an undulating pathway between two connection points within a given flexible framework component **300**, such as an annular member **310** or the intersection of the undulating members **320**. Generally, the connection points for the compliant structures **810** remain in-line with one another on a given side of the flexible framework component **300**, with each axial member **330** being disposed about 180 degrees apart from each other relative to the connection points. As illustrated, each compliant structure **810** is defined with curves in the same direction as corresponding compliant structure **810** at the same height (e.g., along the Y-axis), such that the bottommost undulation in the first axial member **330**A and the bottommost undulation in the second axial member **330**B are both defined with a counterclockwise curve, and similarly the second-bottommost undulation in the first axial member **330**A and the second-bottommost undulation in the second axial member **330**B are both defined with a clockwise curve. The present disclosure contemplates that the curves as the same heights in opposing compliant structures may instead be counter-curved so that, for example, for each clockwise curve in a first axial member **330**A, an opposing counterclockwise curve is defined at the same height in the second axial member **330**B.

[0057] Although illustrated with generally evenly sized S-shaped compliant structures **810**, the present disclosure contemplates that compliant structures **810** can take other shapes and be provided in various numbers and orientations. For example, FIG. **8**A illustrates an embodiment with four compliant structures **810**A-D (two per axial member **330**), while FIG. **8**B illustrates an embodiment with twelve compliant structures **810**A-L (six per axial member **330**). In another example, the compliant structures **810** can define uneven S-shapes, with one end or undulation of a compliant structure **810** larger than the other. Similarly, although illustrated in FIGS. **8**A-**9**B with substantially semi-circular undulations in a compliant structure **810**, the undulations may be have different arcuate shapes, or generally define a Z-like shape. In another example, although illustrated with two undulations per compliant structure **810** (one curved clockwise and one curved counterclockwise), a compliant structure **810** may be defined by one undulation or by more than two undulations in the plane defined by the outer circumference of the annular members **310** such that the compliant structure **810** defines one or more gaps in material (e.g., air gaps) along a straight-line path between the annular members **310** in the height direction (e.g., the Y-axis).

[0058] FIG. **9** illustrates a flexible framework component **300** with compliant axial members **330** (e.g., including compliant structures **810**) and variable-height spacing between paired bend limiters, according to embodiments of the present disclosure. The paired bend limiters include positive protrusions **910**A-F (generally or collectively, positive protrusions **910**) and negative protrusions **920**A-F (generally or collectively, negative protrusions **920**) that are located and shaped to form a corresponding pair to contact one another when the flexible framework component **300** is bent to thereby control a degree of bending permitted by the flexible framework component **300**. Each of the protrusions (positive and negative) is defined with respect to an annular member, approximately 90 degrees from the axial members **330** on either side. The positive protrusions **910** project from the annular members **310** (e.g., upward or downward in the Y-direction) and the negative protrusions **920** are defined in the material of the annular members **310** to define an accommodating space for the positive protrusions to seat into when the flexible framework component **300** bends, to thereby control an extent of bending permitted. Although illustrated with four annular members **310**A-D with associated spacing, the present disclosure contemplated that variable-height spacing may be achieved in flexible framework components **300** having fewer than or more than four annular members **310**A-D.

[0059] The size and shape of the paired bend limiters are varied in the current example, such that a first height H**1** between the first pair (**910**A/**920**A) is different from the second height H**2** between the second pair (**910**A/**920**A), and different from the third height H**3** between the third pair (**910**C/**920**C) (e.g., H**1**≠H**2**≠H**3**), despite the height between each pair of neighboring annular members **310** being the same (e.g., an inter-annular height HA). In some examples, a subset of the spacings between the paired bend limiters on a given side of the flexible framework component **300** are the same height (e.g., H**1**=H**2**≠H**3**). In some examples, one or more (but not all) of the spacings between the paired bend limiters on a given side of the flexible framework component **300** are the same height as the inter-annular height HA (e.g., H**2**=HA≠H**1**).

[0060] Although the illustrated example is shown with three pairs of bend limiters on either side of the flexible framework component **300** with equivalently sized heights between opposing pairs of bend limiters at the same height (on the Y axis) of the flexible framework component **300**, the present disclosure contemplates that other relationships are possible. For example, as illustrated, the first height H**1** between the first pair (**910**A/**920**A) is the same as the fourth height H**4** between the fourth pair (**910**D/**920**D), the second height H**2** between the second pair (**910**B/**920**B) is the same as the fifth height H**5** between the fifth pair (**910**E/**920**E), and the third height H**3** between the third pair (**910**C/**920**C) is the same as the sixth height H**6** between the sixth pair (**910**E/**920**E). However, the opposing heights in some embodiments are non-equivalent in the opposing pair of bend limiters, to thereby affect a non-uniform extent of permitted bending for the flexible framework component **300**. In some examples, the heights are mirrored along the Y-axis (e.g., H**1**=H**6**, H**2**=H**5**, H**3**=H**4**, where H**1**≠H**3**). In some examples, the bend limiters are omitted from one side of the flexible framework component **300** (e.g., H**4**=H**5**=H**6**=HA).

[0061] The present disclosure contemplates that the individual heights may define different equivalences to one another from the illustrated example, and that one or more of the heights between a pair of bend limiters may be equal to the height between the annular members **310** (e.g., H**1**=HA, H**2**=HA, etc.).

[0062] Each of the heights discussed herein shall be understood to refer to the distance in the Y-direction (e.g., the longitudinal axis) of the flexible framework component **300** when in an un-bent state. When referring to the distance between two bend limiters, the distance shall be understood to be measured from the location of maximal projection away from (or into, in the case of a negative protrusion **920**) the respective annular member **310**.

[0063] Bend limiters can be integrated into the design of the singular structural wave framework to prevent the structure from being subjected to overstressed conditions. When bend limiters are fully engaged, the bend limiters define the radius of curvature for a flexible structure. Dimensions of the constraints can be designed not only to prevent overstressed conditions, but also to establish a specific radius of curvature based on a specific design requirement.

[0064] Bend limiters integrated into the design with equal heights will form a geometric shape of a circle (a given radius and circumferential length) based on the number of equal length wave cells. The integration of bend limiters of variable heights along the length of the structure provides a way of creating other radial geometric shapes being parabolic and hyperbolic when fully engaged. The present disclosure contemplates that a designer can integrate bend limiters with a mix of variable heights and fixed heights to design complex geometric shapes in a single plane.

[0065] Additionally, flexible structures during use may be subjected to torsional loads during use—seeking to bend or twist the structure in a direction other than the intended axis for bending. The bend limiters as a result of this torsional loading may be displaced and lose the compressive contact possibly resulting in an overstressed condition. However, when using paired positive and negative bend limiters with conformal shapes, the design offers a locking engagement between the pair, in which the locking bend limiters, when engaged, prevent or reduce the bend limiter (and thereby the structure) from being displaced by torsional loading. The locking bend limiters also provide a structural axis alignment feature. When a flexible structure is in bending the alignment of the bend limiter can be influenced by outside forces or loading deflecting the axis of bending. The nesting characteristic of the locking bend limiters provides a way to achieve axial alignment when outside forces cause the axis to bend out of plane.

[0066] FIG. **10** illustrates a flexible framework component **300** with an alternating neutral axis, according to embodiments of the present disclosure. The illustrated flexible framework component **300** includes five annular members **310**A-E, two undulating members **320**A-B, eight axial members **330**A-H, in which the axial members **330** do not extend for the entire height (e.g., in the Y-direction), but instead define a plurality of neutral axis gaps **1010**A-H (generally or collectively, neutral axis gaps **1010**) in which material is omitted. The neutral axis gaps **1010** permit (constrained) bending in a direction other than the main direction of bending (e.g., from the Y-axis towards the X-axis in addition to from the Y-axis towards the Z-axis), and provide additional ease of bending in the main direction of bending by reducing the amount of material to bend when bending the flexible framework component **300**.

[0067] FIG. **11** illustrates a flexible framework component **300** with axially offset undulating members **320**, according to embodiments of the present disclosure. The illustrated flexible framework component **300** includes a two annular members **310**A-B, two undulating members **320**A-B, two axial members **330**A-B, and a plurality of protrusions **710**A-H on the outer circumference of the annular members **310**, each of which defines a corresponding guide hole **720**A-H (protrusion **710**H and guide hole **720**H being obscured in the view of FIG. **11**), although a greater number of components may be incorporated into a flexible framework component **300** using the various features discussed in the present disclosure. As illustrated, a first subset of the protrusions **710** (**710**A, **710**C, **710**E, **710**G) are circumferentially aligned with the axial members **330** of the flexible framework component **300**, while a second subset of the protrusions are aligned 90 degrees offset from the neutral axis defined by the axial members **330**, and are instead circumferentially aligned with axial offsets **1110**A-D (generally or collectively, axial offsets **1110**) associated with the undulating members **320**.

[0068] The axial offsets **1110**, when included in the design of a flexible framework component **300**, connect between an annular member **310** and an undulating member **320**, which extend in a direction equivalent to the axial members **330** (e.g., the Y direction), albeit at a rotational offset (e.g., 90 degrees) from the neutral axis defined by the axial members **330**. The vertical offset from the annular members **320** imparted by the axial offsets **1110** to the undulating members **320** imparts additional flexibility to the flexible structural component **300**; allowing for easier (e.g., with a lower applied force) or greater ability to bend (e.g., from the Y-axis towards the Z-axis) than designs that do not axial offsets **1110**.

[0069] The present disclosure contemplates that, all else being equal, that designs with "taller" axial offsets **1110** generally offer a greater increase in flexibility that designs with "shorter" axial offsets **1110**, and that a designer can tune the total height of the axial offsets to affect the flexibility of the component **300**. However, the benefits of added flexibly begin to decrease when the total height of the axial offsets **1110** occupy more than 50% of the total distance between the annular members. Accordingly, the height of a given axial offset **1110** is generally recommended to be between 1% and 20% of the distance between the associated annular members **310**. The present disclosure contemplates that the axial offsets **1110** may extend from the annular members **310** for a same distance as one another, or may extend from the annular members **310** for variable distances (e.g., axial offset **1110**A and axial offset **1110**B extend for a first distance versus axial offset **1110**C and axial offset **1110**D, which extend for a second distance).

[0070] Although illustrated with axial offsets included on both an upper and lower annular member **310**, the present disclosure contemplates that one annular member **310** may include, and one annular member **310** may omit axial offsets **1110**, with the undulating members **320** directly connected to the annular member **310**. For example, the second annular member **310**B may omit the third axial offset **1110**C and the fourth axial offset **1110**D, while the first annular member **310**A includes the first axial offset **1110**A and the second axial offset **1110**B.

[0071] FIGS. **12**A-**12**C illustrate disks **1200**, which may be integrated into a structure using flexible framework components **300** to accept various guidewires, flexible electrical wires, flexible optical strands, conductors, conduits, specific pathways, or the like, according to embodiments of the present disclosure.

[0072] FIG. **12**A illustrates a disk **1200** having circumferential holes **1210** the center points of which are located proximately to the edge of the disk **1200**, and a central hole **1220**, having a shared center point with the disk **1200**. The disk **1200** is a rigid circular plate, having the same radial dimensions as that of the flexible framework component **300**. The illustrated embodiment is a disk **1200** containing sixteen circumferential holes **1210**, but the present disclosure further contemplates embodiments having no circumferential holes **1210** in addition to embodiments having about more or fewer circumferential holes **1210** than illustrated (e.g., about five, ten, twenty, or fifty circumferential holes **1210**). The diameters of the circumferential holes **1210** are illustrated as equivalent, but embodiments having variably distinct diameters of circumferential holes **1210** are contemplated.

[0073] Similarly, FIG. **12**B illustrates disk **1200** having circumferential holes **1210** the center points of which are located proximately to the edge of the disk **1200**, but omits a central hole **1220**. Although illustrated in FIGS. **12**A and **12**B as separate elements from a flexible framework components **300**, which a manufacturer can secure between two neighboring flexible framework components **300** in a structure, the present disclosure contemplates that one or more of the ring members **310** of a flexible framework component **300** may incorporate a disk **1200** as an integral element.

[0074] According to some embodiments, some of the circumferential holes **1210** are configured to align with the guide holes **715** of flexible framework components **300** with guide holes **720**. In some embodiments, a disk **1200** is disposed in between two flexible framework components **300** in order to form a flexible framework, or integrally manufactured with one or more flexible framework components in the flexible framework.

[0075] FIG. **12**C illustrates a flexible framework that incorporated disks **1200***a-h* into the design, according to embodiments of the present disclosure. According to some embodiments, one or more of the circumferential holes **1210** and the central hole **1220** are configured to accommodate various flexible conduits **1230**, which may include guidewires, flexible electrical wires, flexible optical fibers, conductors, tubes, conduits, specific pathways, or the like, and insulative or protective elements therefor. In such an embodiment, when multiple disks **1200** are integrated into a flexible framework, a flexible conduit **1230** can be inserted through the central holes **1220** of multiple disks **1200** and a fluid, electrical, or optical transportation system can be implemented within the flexible framework.

[0076] In various embodiments, one or more disks **1200** are placed between flexible framework components **300** to act as washers or friction-reducing members, provide an adhesion point between neighboring flexible framework components, or provide additional mounting points or guides via the circumferential holes **1210** for various accessories or guidewires. In some embodiments, a disk **1200** is mounted at the end or between neighboring flexible framework components **300** to provide a cap or a stop to reduce fluid flow, or define a continuous pathway through the entire length of the structure while in bending, or improve sterility of the device while in use.

[0077] FIGS. **13**A-**13**B illustrate flexible frameworks **1300**, composed of flexible framework components **300** (e.g., two or more of any flexible framework component **300** as shown in FIGS. **3-11** and the variations thereof discussed in relation to the associated Figures). The illustrated embodiment includes seven flexible framework components **300**, but a flexible framework **1300** may include any number of flexible framework components **300**, in order to meet the demands of a desired usage. Flexible frameworks **1300** may include about five, ten, twenty, fifty, one hundred, or five hundred flexible framework components **300**, in various embodiments, although more or fewer may be included.

[0078] The individual framework components **300** may be any one of the flexible framework components **300** shown in FIGS. **3-11**. Flexible Frameworks **1300** may also include embodiments of flexible framework components having some or all of the discussed variants of dependent bend limiters **420**, independent bend limiters **520**, wave-matched bend limiters **610**, and protrusions **710** with guide holes **725**. Furthermore, a single flexible framework **1300** may also include multiple embodiments of flexible framework components, such as those listed above. Stated differently, any successive flexible framework component **300** in a flexible framework **1300** may have any quantity of guide holes **715**, a different points of intersection of two components, or a height that is different from a respective quantity of through holes, a point of intersection of two components, or a height than a neighboring flexible framework component **300**. In various embodiments, the framework **1300** can be 3-D printed or laser cut from tubing, and can be made out of polymer, metal, etc.

[0079] In some embodiments the flexible framework components **300** in a flexible framework **1300** are connected by means of fasteners, which may include bolts, screws, rivets, pins and the like. In some embodiments, the flexible framework components **300** in a flexible framework **1300** are connected by heat bonding, welding, brazing or one of various adhesives. In some embodiments, the flexible framework components **300** in a flexible framework **1300** are connected by integrated manufacture.

[0080] In some examples, a flexible framework **1300** includes a protective coating that coats each individual flexible framework component of the flexible framework. This coating may be a protective sealant, or an applied layer of finish.

[0081] FIG. **14**A illustrates a flexible framework **1300** in bending. The axial members **330** of each flexible framework component **300** collectively define a neutral axis for the entire flexible framework **1300**. In the illustrated embodiment, the axial members **330** of each flexible framework component **300** are axially aligned, and the flexible framework **1300** has a uniform axis of bending in the Z-direction. The axial members **330** of each individual flexible framework component **300** ensure that the axial arc length of the deflected flexible framework **1300** is equal to that of the height of the non-deflected flexible framework **1300**.

[0082] FIG. **14**B illustrates a planar X-Y view of a flexible framework **1300** in bending.

[0083] FIG. **15** shows a planar Y-Z view of a flexible framework **1300** where each flexible framework component **300** is rotationally offset from one another. By rotationally offsetting each flexible framework component **300**, the axial curve of the flexible framework **1300** in bending is no longer two-dimensional. When the flexible framework components **300** are no longer rotationally aligned, the neutral axes of each flexible framework component **300** are no longer axially aligned. This results in each flexible framework component **300** deflecting in a different direction relative to a first flexible framework component, and irregular curves and unique formations of the flexible framework **1300** can be created.

[0084] FIG. **16** illustrates a wire guided flexible framework **1600**. In some embodiments, a wire guided flexible framework **1500** includes flexible framework components **300** with guide holes **720** and a wire **1610** disposed within the guide holes **720**. The wire **1610** is installed through each axially aligned guide hole **720** in a wire guided flexible framework **1600**, parallel to the axial members **330**. The wire **1610** is secured to the final flexible framework component and passes through the guide holes **720** of the other flexible framework components. The unattached end of the wire **1610** may be attached to an actuator, or operated manually. When tension is introduced to the wire **1610** by retraction, the attached end of the wire **1610** transfers a compressive force to the final flexible framework component. As the tension is increased and the wire **1610** is shortened, the flexible components of the wire guided flexible framework **1600** deflect towards the side of the framework in which the wire **1610** is disposed. In embodiments where the neutral axes of each flexible framework component are aligned, the wire guided flexible framework **1600** deflects as illustrated in FIGS. **14**A-**14**B. In alternate terms, shortening the wire **1610** provides the compressive force required for the wire guided flexible framework **1600** to deflect.

[0085] According to some embodiments, wire guided flexible frameworks **1600** are configured to have a tube disposed within the framework, for the purposes of fluid transport from one end of the framework to the other. In some such embodiments, the tube is disposed in the empty space inside each flexible framework component (See FIG. **17**B). In other such embodiments, the tube is disposed within the central holes **720** of disks **700** disposed between each successive flexible framework component **300**.

[0086] According to some embodiments, wire guided flexible frameworks **1500** do not include flexible framework components **300** with guide holes **715**. Alternatively, the wire **1610** is disposed in circumferential holes **1210** of disks, wherein a disk is disposed in between each flexible component of the wire guided flexible framework **1500**.

[0087] FIG. **17**A shows a wire guided flexible framework **1600** disposed within a flexible tube **1710** (e.g., a jacket). According to some embodiments, the tube is a catheter. In such embodiments, the flexible framework may be a wire guided flexible framework **1600**, such that the catheter is operable to be guided during use. In some examples, the tube is a mesh tube, a textile tube, or a polymer tube disposed about an outer circumference of the flexible framework. In some embodiments the tube can be a jacket that is installed over the tube, where the jacket is a section of mesh or textile that is secured about the framework.

[0088] FIG. **17**B illustrates a wire guided flexible framework **1600** disposed within an external flexible tube **1710**, and having an internal flexible tube **1720** (e.g., a liner) disposed within the empty space inside the wire guided flexible framework **1600**. The internal tube may be used for fluid transport, such as in a cathing process. In the illustrated embodiments, the wire guided flexible framework **1600** includes external protrusions **710** and guide holes **720** through which the wire **1610** passes. In some embodiments, the wire guided flexible framework **1600** may include wire guide holes **720** not aligned with the bending plane of the individual flexible framework components **300**. Together, the embodiments shown in FIGS. **17**A and **17**B form a catheter, although the two maybe be used separately in different devices.

[0089] For effective multi-directional deflection with rotationally offset flexible framework components **300**, some wires **1610** must traverse sections of the wire guided flexible framework **1600** in which another wire **1610** is responsible for the bending. According to some embodiments, additional protrusions **710** and guide holes **720** on given flexible framework component **300** may serve as retaining points for a wire **1610** that does not induce deflection in the given flexible framework component **300**, but induces deflection in other flexible framework components **300** in the wire guided flexible framework **1600**. These additional protrusions **710** and guide holes **720**, may be located at any point about an annular member **310** of a given flexible framework component **300**, in order to serve the need of the wire guided flexible framework **1600**.

[0090] FIG. **18**A-**18**D illustrate example wire guide elements **1800** with wires guides **1810** in various locations, according to embodiments of the present disclosure. The present disclosure contemplates that various wire guide elements **1800** may be used as integrated elements of the flexible framework components **300** or as separate elements secured to one or more flexible framework components **300**. For example, FIGS. **7**A and **7**B show internal and external wire guides as a single piece, whereas FIGS. **14**A through **16** show wire guides that are individual pieces that are disposed between the individual framework components **300**. FIGS. **18**A-**18**B show that a variety of number and positions of wire guides **1810** may be included in a wire guide element **1800**, and that different numbers and orientations of wire guides **1810** can be included at different locations within a single wire guided flexible framework **1600** or on opposing ends (integrated or separately attached) of a single flexible framework component **300**.

[0091] Certain terms are used throughout the description and claims to refer to particular features or components. As one skilled in the art will appreciate, different persons may refer to the same feature or component by different names. This document does not intend to distinguish between components or features that differ in name but not function.

[0092] As used herein, “about,” “approximately” and “substantially” are understood to refer to numbers in a range of the referenced number, for example the range of −10% to +10% of the referenced number, preferably −5% to +5% of the referenced number, more preferably −1% to +1% of the referenced number, most preferably −0.1% to +0.1% of the referenced number.

[0093] Furthermore, all numerical ranges herein should be understood to include all integers, whole numbers, or fractions, within the range. Moreover, these numerical ranges should be construed as providing support for a claim directed to any number or subset of numbers in that range. For example, a disclosure of from 1 to 10 should be construed as supporting a range of from 1 to 8, from 3 to 7, from 1 to 9, from 3.6 to 4.6, from 3.5 to 9.9, and so forth.

[0094] As used in the present disclosure, a phrase referring to “at least one of” a list of items refers to any set of those items, including sets with a single member, and every potential combination thereof. For example, when referencing “at least one of A, B, or C” or “at least one of A, B, and C”, the phrase is intended to cover the sets of: A, B, C, A-B, B-C, A-C, and A-B-C, where the sets may include one or multiple instances of a given member (e.g., A-A, A-A-A, A-A-B, A-A-B-B-C-C-C, etc.) and any ordering thereof. For avoidance of doubt, the phrase “at least one of A, B, and C” shall not be interpreted to mean “at least one of A, at least one of B, and at least one of C”.

[0095] As used in the present disclosure, the term “determining” encompasses a variety of actions that may include calculating, computing, processing, deriving, investigating, looking up (e.g., via a table, database, or other data structure), ascertaining, receiving (e.g., receiving information), accessing (e.g., accessing data in a memory), retrieving, resolving, selecting, choosing, establishing, and the like.

[0096] Without further elaboration, it is believed that one skilled in the art can use the preceding description to use the claimed inventions to their fullest extent. The examples and aspects disclosed herein are to be construed as merely illustrative and not a limitation of the scope of the present disclosure in any way. It will be apparent to those having skill in the art that changes may be made to the details of the above-described examples without departing from the underlying principles discussed. In other words, various modifications and improvements of the examples specifically disclosed in the description above are within the scope of the appended claims. For instance, any suitable combination of features of the various examples described is contemplated.

[0097] Within the claims, reference to an element in the singular is not intended to mean “one and only one” unless specifically stated as such, but rather as “one or more” or “at least one”. Unless specifically stated otherwise, the term “some” refers to one or more. No claim element is to be construed under the provision of 35 U.S.C. § 112 (f) unless the element is expressly recited using the phrase “means for” or “step for”. All structural and functional equivalents to the elements of the various embodiments described in the present disclosure that are known or come later to be known to those of ordinary skill in the relevant art are expressly incorporated herein by reference and are intended to be encompassed by the claims. Moreover, nothing disclosed in the present disclosure is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims

Claims

1. A flexible framework, comprising a plurality of flexible components, each flexible component of the plurality of flexible components having a plurality of structural members, including: a first annular member; a second annular member; a first axial member, connected on opposing ends to the first annular member and the second annular member, respectively; a second axial member, connected on opposing ends to the first annular member and the second annular member, respectively; a first undulating member, having an annular profile and a first waveform defined about a circumference thereof, which connects to the first annular member twice, connects to the first axial member once, and connects to the second axial member once; and a second undulating member, having an annular profile and a second waveform defined about a circumference thereof, which connects to the second annular member twice, connects to the first axial member once, and connects to the second axial member once.
2. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: the first undulating member and the second undulating member intersect the first axial member at a shared point on the first axial member; and the first undulating member and the second undulating member intersect the second axial member at a shared point on the second axial member.
3. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: the first undulating member and the second undulating member intersect the first axial member at respectively distinct points on the first axial member; and the first undulating member and the second undulating member intersect the second axial member at respectively distinct points on the second axial member.
4. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: the given flexible component further comprises a protrusion on an inner circumference of the first annular member, wherein the protrusion defines a through hole.
5. The flexible framework of claim 1, further comprising a plurality of disks having a plurality of through holes defined therein, wherein each disk is disposed between two flexible components.
6. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components, the given flexible component further comprises a bend limiter, disposed within a plane of deflection, configured to limit an extent of deflection of the given flexible component.
7. The flexible framework of claim 6, wherein the bend limiter comprises one of: a first dependent bend limiter projecting from the first annular member and paired with a second dependent bend limiter projecting from the second annular member; an independent bend limiter projecting from the first annular member and not paired with a corresponding bend limiters projection from the second annular member; a wave-matched bend limiter defined in a third annular member, disposed between the first annular member and the second annular member, and having a shape matched to the first waveform and the second waveform; and a positive protrusion projecting from the first

annular member and paired with a negative protrusion defined within the second annular member.

8. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components, the given flexible component is formed by removing material from a section of pipe or tubing.

9. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components, the given flexible component is formed by additive manufacturing.

10. The flexible framework of claim 1, wherein a first flexible component is connected to a second flexible component via one or more of welding, brazing, use of an adhesive, integrated manufacture, and fasteners.

11. The flexible framework of claim 1, wherein at least one of a height, a quantity of through holes, or a point of intersection of two structural components of a first flexible component is different from a corresponding one of a height, a quantity of through holes, or a point of intersection of two structural components of a second flexible component.

12. The flexible framework of claim 1, wherein a neutral axis of a first flexible component is rotationally offset from a neutral axis of a second flexible component, such that when the flexible framework is subjected to a bending force, the flexible framework deflects into an irregular curve.

13. The flexible framework of claim 1, wherein the flexible framework includes a coating, comprising one of a sealant, a finish, and a protective layer that coats each flexible component of the plurality of flexible components.

14. The flexible framework of claim 1, wherein the flexible framework includes a jacket, comprising one of a polymer tube, a textile tube, and a mesh tube disposed around an outer circumference of the flexible framework.

15. The flexible framework of claim 1, wherein a tube is disposed within the flexible framework in a space defined within respective first annular members and second annular members of each flexible component of the plurality of flexible components.

16. The flexible framework of claim 1, further comprising a wire, configured such that the wire passes through a through hole in each of the flexible components, and when a tension is induced in the wire, bending is induced in the flexible framework.

17. The flexible framework of claim 1, wherein the first axial member and the second axial member each comprise compliant structures that comprise undulations that define one or more gaps of material along straight-line paths defined between the first annular member and the second annular member.

18. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: a third annular member is disposed between the first annular member and the second annular member, wherein a first height between the first annular member and the third annular member is different from a second height between the second annular member and the third annular member.

19. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: a third annular member is disposed between the first annular member and the second annular member, wherein inter-annular heights between the first annular member and the third annular member and between the second annular member and the third annular member are substantially equivalent; the first annular member defines a first positive protrusion; the third annular member defines a first negative protrusion disposed corresponding to the first positive protrusion and defines a second positive protrusion; the second annular member defines a second negative protrusion disposed corresponding to the second positive protrusion, wherein a first height defined between the first positive protrusion and the first negative protrusion is different from a second height defined between the second positive protrusion and the second negative protrusion.

20. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: wherein the first undulating member is connected to the first annular member via a first axial offset and a second axial offset, wherein the first axial offset and the second axial

offset extend from the first annular member towards the second annular member.
21. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: the second axial member is connected to the first annular member and the second annular member diametrically opposite to where the first axial member is connected to the first annular member and the second annular member.
22. The flexible framework of claim 1, wherein for a given flexible component of the plurality of flexible components: the second axial member is connected to the first annular member and the second annular member unevenly about circumferences to where the first axial member is connected to the first annular member and the second annular member, wherein the given flexible component exhibits a greater degree of flexible in a first direction in which the first axial member is located further from the second axial member along the circumference than in a second direction in which the first axial member is closer further from the second axial member along the circumferences.
23. A flexible component, comprising: a first annular member; a second annular member; a first axial member, connected on opposing ends to the first annular member and the second annular member, respectively; a second axial member, connected on opposing ends to the first annular member and the second annular member, respectively, diametrically opposite from where the first axial member is connected to the first annular member and the second annular member; a first undulating member, having an annular profile and a waveform defined about a circumference thereof, which intersects the first annular member twice, intersects the first axial member once, and intersects the second axial member once; and a second undulating member, having an annular profile and a waveform defined about a circumference thereof, which intersects the second annular member twice, intersects the first axial member once, and intersects the second axial member once.
24. The flexible component of claim 23, further comprising: a plurality protrusions on an inner circumference of the first annular member or the second annular member, each protrusion having a though-hole disposed therein.
25. The flexible component of claim 23, wherein the first axial member and the second axial member control a direction of deflection by forming neutral axes when the flexible component is subject to a bending stress.
26. The flexible component of claim 23, wherein the first axial member and the second axial member each comprise compliant structures that comprise undulations that define one or more gaps of material along straight-line paths defined between the first annular member and the second annular member.
27. The flexible component of claim 23, further comprising a bend limiter that includes one of: a first dependent bend limiter projecting from the first annular member and paired with a second dependent bend limiter projecting from the second annular member; an independent bend limiter projecting from the first annular member and not paired with a corresponding bend limiters projection from the second annular member; a wave-matched bend limiter defined in a third annular member, disposed between the first annular member and the second annular member, and having a shape matched to the first waveform and the second waveform; and a positive protrusion projecting from the first annular member and paired with a negative protrusion defined within the second annular member.
28. The flexible component of claim 23, further comprising a third annular member disposed between the first annular member and the second annular member, wherein inter-annular heights between the first annular member and the third annular member and between the second annular member and the third annular member are substantially equivalent; the first annular member defines a first positive protrusion; the third annular member defines a first negative protrusion disposed corresponding to the first positive protrusion and defines a second positive protrusion; the second annular member defines a second negative protrusion disposed corresponding to the second positive protrusion, wherein a first height defined between the first positive protrusion and the first

negative protrusion is different from a second height defined between the second positive protrusion and the second negative protrusion.

29. A wire-guidable flexible framework comprising a plurality of flexible framework components and a plurality of wires, wherein: each flexible framework component comprises a neutral axis component, a waveform component, and an annular structural component having a protrusion containing a though hole; and the plurality of flexible components are secured together into the flexible framework, and configured such that a wire of the plurality of wires passes through a through hole in each of the flexible components, and when a tension is induced in the wire, bending is induced in the flexible framework.

30. The wire-guidable flexible framework of claim 29, wherein a given protrusion on a given flexible framework component is disposed 90 degrees about a given annular structural component from an intersection of the neutral axis component on the given annular structural component.

31. The wire-guidable flexible framework of claim 29, wherein a neutral axis component comprises compliant structures that comprise undulations that define one or more gaps of material along straight-line paths defined between neighboring annular structural components.

32. The wire-guidable flexible framework of claim 29, the annular structural component further comprising a bend limiter that includes one of: a first dependent bend limiter projecting from the annular structural component and paired with a second dependent bend limiter projecting from a second annular structural component; an independent bend limiter projecting from the annular structural component and not paired with a corresponding bend limiters projecting from the second annular structural component; a wave-matched bend limiter defined in a third annular structural component, disposed between the annular structural component and the second annular structural component, and having a shape matched to a shape of the waveform component; and a positive protrusion projecting from the annular structural component and paired with a negative protrusion defined within the second annular structural component.

33. The wire-guidable flexible framework of claim 29, further comprising a third annular structural component disposed between the annular structural component and a second annular structural component, wherein inter-annular heights between the annular structural component and the third annular structural component and between the second annular structural component and the third annular structural component are substantially equivalent; the annular structural component defines a first positive protrusion; the third annular structural component defines a first negative protrusion disposed corresponding to the first positive protrusion and defines a second positive protrusion; the second annular structural component defines a second negative protrusion disposed corresponding to the second positive protrusion, wherein a first height defined between the first positive protrusion and the first negative protrusion is different from a second height defined between the second positive protrusion and the second negative protrusion.

34. The wire-guidable flexible framework of claim 29, wherein a neutral axis component comprises an axial member connected on a first end to the annular structural component and on a second end to the waveform component, wherein a neutral axis gap is defined between the waveform component and a second annular member of the flexible framework component.