Oct. 31, 1967 C. PAYNE 3,349,525

INTERACTING LAMINAR SHELL STRUCTURAL COMPONENT

Filed Jan. 14, 1966 2 Sheets-Sheet 1

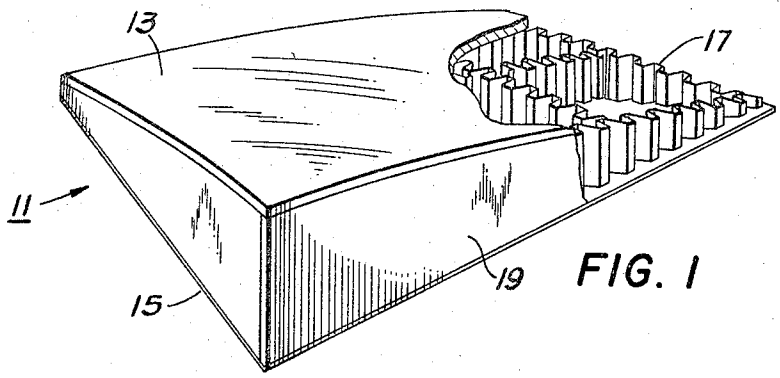


FIG. 1

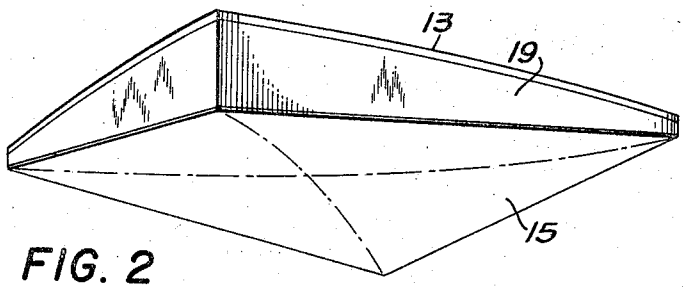


FIG. 2

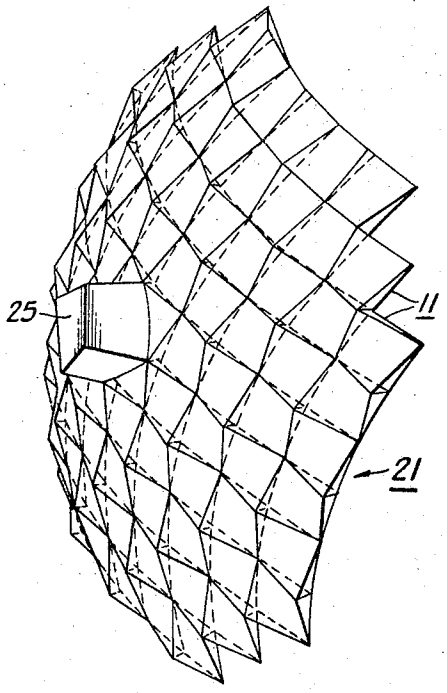


FIG. 4

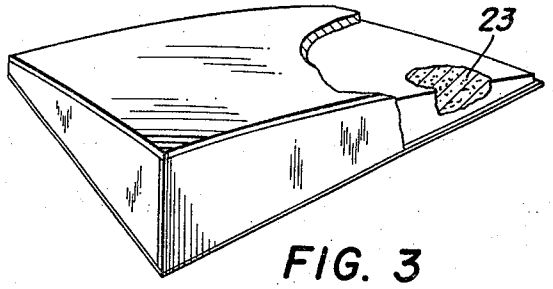


FIG. 3

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INTERACTING LAMINAR SHELL STRUCTURAL COMPONENT

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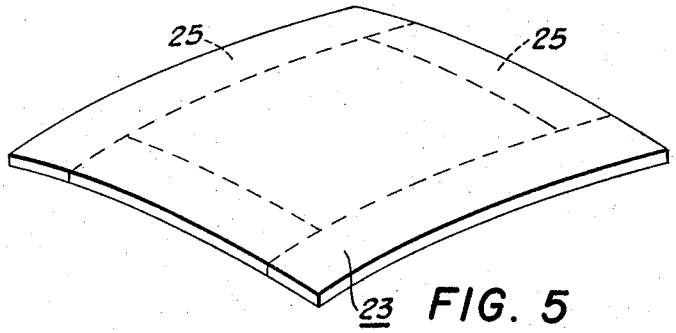


FIG. 5

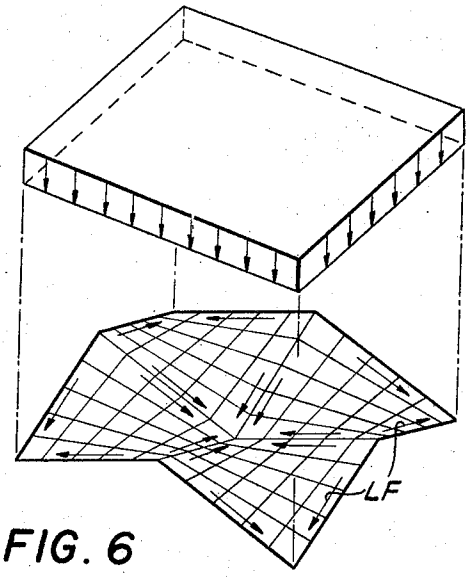


FIG. 6

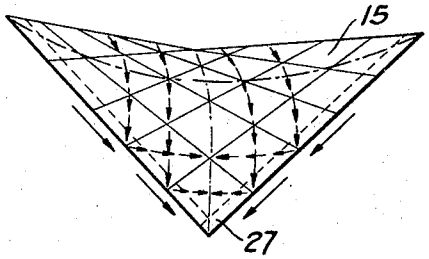


FIG. 7

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INTERACTING LAMINAR SHELL STRUCTURAL COMPONENT

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7 Claims. (Cl. 52—80)

This invention relates to structural members and more particularly to an interacting laminar shell type of structural component in the form of a panel.

The structural advantage of a curved thin plate or laminar membrane has not heretofore been completely and fully developed in the building arts for the reason that such curved membranes tend to buckle at relatively low compressive loads and thus lose their structural effectiveness before they can be of any significant use. The problem becomes more acute, as the compressive loads on the curved membranes increases. In the case of a double-curved membrane structure, particularly, it has not been possible to realize the full advantage of this type of membrane because of premature buckling due to elastic instability at the threshhold of the elasto-plastic range where the elastic modulus falls off. Heretofore, there has been no simple, satisfactory way to effectively utilize the potential full structural capacity of a thin laminar member.

The present invention, however, discloses a solution to the problem and includes a laminar structural component in the form of a panel having a primary or principal membrane, a secondary or back-up membrane which is thinner than the primary membrane, and an intermediary core which is bonded to both the primary and the secondary membranes. The primary membrane is a portion of a synclastic surface, but it may also be a portion of an anticlastic surface, and the secondary membrane is generally an anticlastic surface.

For a further understanding of the present invention and for further advantages and features thereof, reference may be made to the following description taken in conjunction with the accompanying drawing which shows, for the purpose of exemplification, a preferred embodiment of the invention.

In the drawing:

FIG. 1 is a schematic perspective view looking downward at the top of an interacting laminar shell structural component partly in section, in accordance with the invention;

FIG. 2 is a schematic perspective view looking upward at the bottom of the laminar shell component of FIG. 1;

FIG. 3 is a schematic perspective view of a modification of the embodiment of FIG. 1;

FIG. 4 is a schematic perspective of a typical structure incorporating the laminar structural component of FIG. 1;

FIG. 5 is a schematic perspective view of the top laminar shell in another embodiment of the invention;

FIG. 6 is a schematic perspective view of hyperbolic paraboloidal surfaces subjected to a superimposed loading showing the forces acting between interacting hyperbolic paraboloidal surfaces; and

FIG. 7 is a schematic view of the forces acting in one such surface.

As used herein, a laminar membrane may be considered as a thin plate having a small thickness in relation to its other dimensions. As used hereinafter, a synclastic surface curves away from, in all directions, a plane tangent to the surface at a point of tangency. A typical synclastic surface is a spherical surface. An anticlastic surface curves in one direction convexly along a longitudinal planar section and concavely in another direction along a transversely planar section substantially perpendicular to the longitudinal plane. A typical anticlastic surface is the surface of the seat portion of the riding saddle.

The interacting laminar shell structure **11** of FIG. 1 includes a top or synclastic primary membrane **13**, a secondary or anticlastic back-up membrane **15** spaced apart from the primary membrane **13**, and a core **17** which is bonded to both the primary and the second membranes. The peripheral edges of both the primary and the secondary membranes **13**, **15** may be, as illustrated herein, connected together by means of plate-like web members **19**, which are generally trapezoidal in shape, as may be noticed from FIGS. 1 and 2.

In any particular application, such as for example, the portion of an antenna reflector **21** shown in FIG. 4, the reflector surface is made up of a plurality of edge abutting panels or prisms each of which would have the form of the interacting laminar shell structure **11**.

The primary membrane **13** may be either a single plate, as shown in FIGS. 1 and 2, or it may be a structural sandwich type panel comprised of adhesively secured layers, or a composite panel that is itself comprised of inner and outer membranes fixedly connected to a preferred type of core reinforcement between the inner and outer membranes. It should be understood that the several interacting laminar shell structures **11** comprising the structure shown in FIG. 4 may be fastened together in any suitable manner such as by welding—if a weldable metal is used—or by bolts, or other type of fastener means well known in the art.

In a typical interacting laminar shell structure **11**, the primary membrane **13** may be a segment of the surface of: a paraboloid, a sphere, an ellipsoid, a cylinder, or any other like surface of revolution, whereas the secondary membrane **15** may be generally an anticlastic surface, such as a segment of a hyperbolic paraboloidal surface. As mentioned previously, the primary membrane **13** may be also anticlastic if preferred or desired.

In any particular interacting laminar shell structure, the secondary membrane **15** is considerably less stiff than the primary membrane **13**, and is generally thinner than the primary membrane. Therefore, the secondary membrane acts as an elastic foundation for the primary membrane. Furthermore, the secondary membrane acts to support only the buckling forces that develop in the primary membrane, and in so doing, the secondary membrane stabilizes the primary membrane so that the primary membrane can accept loads and stresses which approach, and in some cases exceed, the yield strength of the material of the primary membrane. For example, whenever the material of the primary membrane is a ductile material, the stress in the ductile primary membrane may be in the plasto-elastic range, where stresses will exceed the yield strength of the material.

It is a feature of the present invention that the primary membrane **13** is stabilized by the secondary membrane acting through some form of core medium **17**. Buckling forces which develop in the primary membrane because of dimensional instability, or for any other reason, are transmitted to the secondary membrane through the core system. The core system may be a series of interconnected webs disposed in a cellular arrangement as shown in FIG. 1, or a honeycomb arrangement, or a solid core **23** of the type suggested in FIG. 3. A typical solid core synthetic product which is suitable for the purpose described herein includes a low-density concrete binder phase of hydraulic cement, a surface active additive, and an aggregative phase of expanded polystyrene particles, which is marketed under the trademark Dycon. In any event, whatever type of core medium is utilized, it must be bonded to both the primary membrane and the secondary membrane for effectiveness.

It is also a feature of the present invention that the

secondary membrane **15** when loaded transversely by buckling forces transmitted thereinto, acts to direct such forces along the edges of the secondary membrane end through the points of connection into the main structural support, such as the support **25** shown in FIG. 5, for the interacting laminar shell structures.

It should then be evident to those skilled in the art, that the novel structural panel component of the invention possesses numerous features and advantages not heretofore available in the art. That such a structural panel is adaptable to various types of buildings is evident, and to those structures the present invention contributes a significant reduction in weight, economy of construction, and a more efficient utilization of materials in the panels.

FIG. 5 illustrates another embodiment of a synclastic primary membrane **23** in accordance with the invention wherein edge bands **25** are employed around the periphery of the laminar membrane. Such edge bands **25** may, of course, be employed around the periphery of all prism panels or laminar shell structures **11** and the edge bands **25**, when used on the laminar shell structures **11** forming the typical structure **21** of FIG. 4, become interlocked at the joints between four adjacent panels and substantially strengthen the entire structure **21**.

The action of the edge band system may be multitudinous and redundant while the principal shell operates in the elastic range, depending primarily upon the conditions of support provided to the complete structure. However, the action of the structure may be readily envisioned. It must be remembered that as the primary membrane **13** (FIG. 1) is permitted to flow, it generates lateral buckling forces which become transferred to the undulating back-up system through the central core. The back-up system or secondary membrane is considered to be still operating in the elastic range.

For the type of structure **21** shown in FIG. 4, where the interacting back-up or secondary membranes **15** are hyperbolic paraboloids, transverse loading generates edge forces in the prism panels **11** which may be summarized as:

(a) Internal thrusts generated along the paraboloidal elements;

(b) Compression forces in the convex parabolas; and

(c) Tension forces in the concave parabolas.

The equal thrusts exist on coordinates at 45° to the linear edges, combining as components of the characteristic system of internal edge forces.

The common characteristics of structural behavior for any arrangement of interacting laminar shell construction ground support equipment can be summarized as:

(1) A principal shell of double-continuous curvature, usually synclasic arranged to enclose a preselected space or to cover a preselected area. Except for considerations of dimensional stability, and in some instances except for considerations of stable manner of shell action support, the shell would generally be of conventional form to support the imposed loading conditions. In an interacting laminar shell structure the primary membrane **13** carries the principal forces, or principal stresses, to internally resist and thus sustain the imposed loading;

(2) The primary shell or membrane **13**, stabilized by the back-up or secondary membrane **15** acting through some form of web or core such as the cellular web system **17** in FIG. 1 or the solid web system **23** shown in FIG. 3. Transverse buckling forces which may be generated in the primary membrane **13** because of dimensional instability, or for other reasons, are imposed upon the web system **17** or **23** and thus carried to the back-up or secondary membrane **15**. Stating this another way, the primary membrane **13** is continuously supported by the web system **17** or **23** against buckling from inelastic effects or otherwise;

(3) The backup or secondary membrane **15** has imposed upon it, because of its relative stiffness, essentially only the buckling forces which are generated in the primary membrane **13**. And so, the primary membrane maintains its configuration and continues to carry the principal forces up to the point of its ultimate strength;

(4) The pressure pattern of buckling forces in the primary membrane **13** is directly imposed through the web system **17** or **23** upon each back-up or secondary membrane and in the embodiments of the invention illustrated in the drawings, each back-up membrane is a hyperbolic paraboloidal surface;

(5) The back-up membrane **15**, loaded transversely by the buckling forces of the primary membrane **13**, acts in the manner characteristic of all doubly-curved stiff membranes, to convert these transverse buckling pressure forces to direct linear forces LF acting along the edges of each back-up membrane, the linear forces LF being shown schematically in FIG. 6. Thus, these linear forces LF are carried by the edge bands **23** (FIG. 5) of each back-up membrane **15**; and

(6) Generally there are edge bands **25** on the primary membrane **13** directly opposed to edge bands **27** on the secondary membrane **15** (see FIG. 7). Since the two sets of edge bands **25**, **27** are connected by the core system **17** or **23**, a structural system is formed which also has a curvilinear conforming rectilinear grid pattern. The direct forces acting along the edge bands of each back-up membrane **15** are thus thrown into this edge band structural system as coplanar forces. Consequently, the transverse pressure pattern of buckling forces, transversed from the primary membrane to the secondary membrane through the web or core system, is converted to linear forces which are coplanar with the edge band system. Such coplanar linear forces LF are suggested in FIG. 6.

It should be clear that provided the primary membrane is not stable as an entity, then its lateral buckling force pressures are supported, at all places upon the surface, by a back-up shell system which converts these pressure forces to linear forces in a three-dimensional network and effectively distributes these to a well balanced condition.

Although the invention has been described herein with a certain degree of particularity, it is understood that the present disclosure has been made only as an example and that various modifications and changes may be made within the scope of the invention as defined by the appended claims.

What is claimed is:

1. A structural component comprising:

(a) a primary membrane having the shape of a portion of a surface of revolution;

(b) a secondary membrane spaced apart from said primary membrane and having the shape of a hyperbolic paraboloid; and

(c) a core system bonded to both said primary and said secondary membranes whereby buckling stresses which develop in said primary membrane when a load is applied to said panel are transmitted to said secondary membrane.

2. A structural component comprising:

(a) a primary membrane having a synclastic form;

(b) a secondary membrane spaced apart from said primary membrane and having an anticlastic form, said secondary membrane being thinner than said primary membrane; and

(c) a solid core bonded to both said primary and said secondary membranes, whereby said primary membrane and said secondary membrane cooperate to significantly reduce buckling in said primary membrane when the same is under stress.

3. A structural panel comprising:

(a) a primary membrane having the form of a portion of a sphere;

(b) a secondary membrane having the form of a hyperbolic paraboloid, said secondary membrane being thinner than said primary membrane and spaced apart therefrom;

(c) a web member fixed adjacent the peripheral edges

of both said primary and said secondary membranes; and

(d) a core bonded to both said primary and said secondary membranes whereby buckling stresses developing in said primary membrane when a load is applied to said panel are transmitted through said core to said secondary membrane.

4. A structural panel comprising:

(a) a primary membrane having an anticlastic form;

(b) a secondary membrane spaced apart from said primary membrane and having an anticlastic form, said secondary membrane being thinner than said primary membrane; and

(c) a core bonded to both said primary and said secondary membranes whereby said primary membrane and said secondary membrane cooperate to significantly reduce buckling stresses developing in said primary membrane when a load is applied to said panel.

5. The invention set forth in claim 3 wherein:

(a) said core is comprised of a synthetic solid product, including a low-density concrete binder phase of

hydraulic cement, a surface-active additive, and an aggregative phase of expanded polystyrene particles, that is bonded to substantially all of the opposed surfaces of said primary and said secondary membranes.

6. The invention set forth in claim 3 wherein:

(a) said core is comprised of intersecting mutually cooperative web members bonded to a portion of each of the opposed surfaces of said primary and secondary membranes.

7. The invention set forth in claim 3 wherein said secondary member is an elastic foundation for said primary member.

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