United States Patent [19]
Zetlin

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[54] **STRUCTURAL MEMBER OF SHEET MATERIAL**

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[52] **U.S. Cl.** **161/68,** 14/73, 52/87, 52/618, 161/127, 161/69
[51] **Int. Cl.** **B32b 3/12,** E01d 19/12
[58] **Field of Search** 52/615, 618, 648, 650, 52/87; 161/68, 69, 119, 127, 131, 133, 134, 136, 159; 156/197; 94/13; 14/6, 73; 404/34–43

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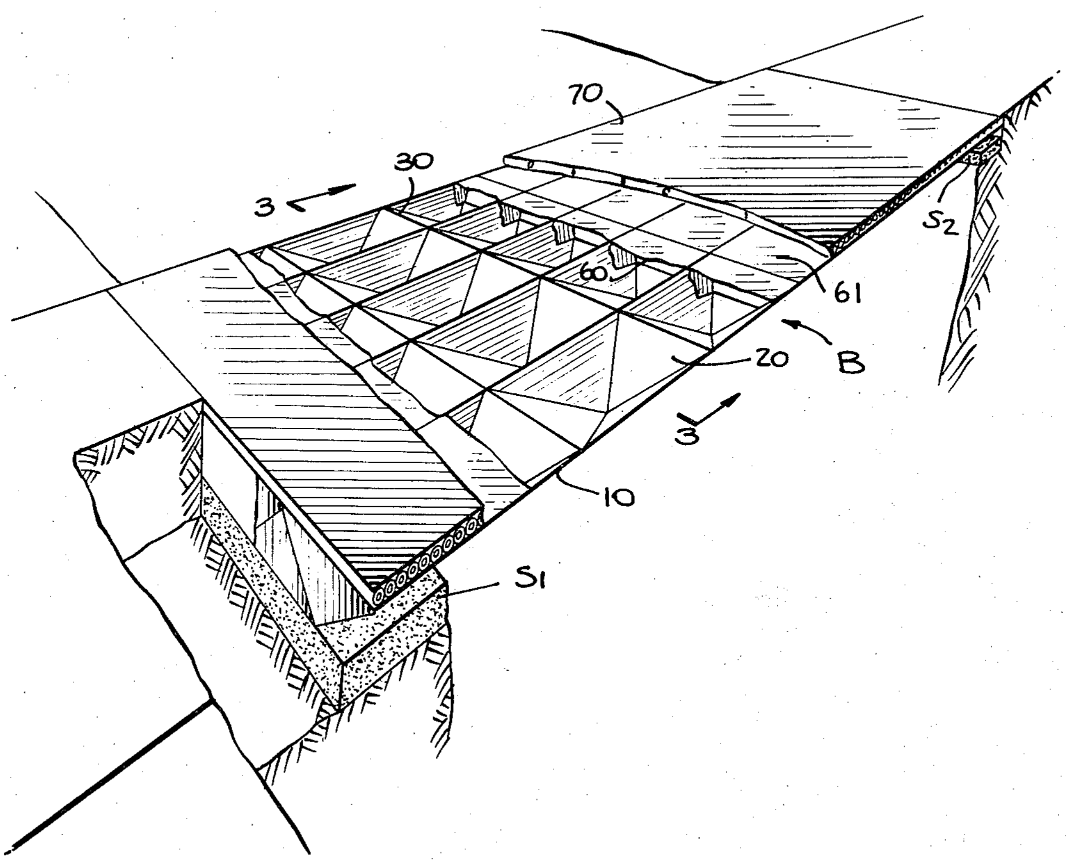
[57] **ABSTRACT**

A structural member entirely formed of sheet material suitably connected together along surface portions thereof. The sheet material is folded or otherwise formed into individual geometric shapes bonded to one another along overlying surfaces thereof.

18 Claims, 16 Drawing Figures



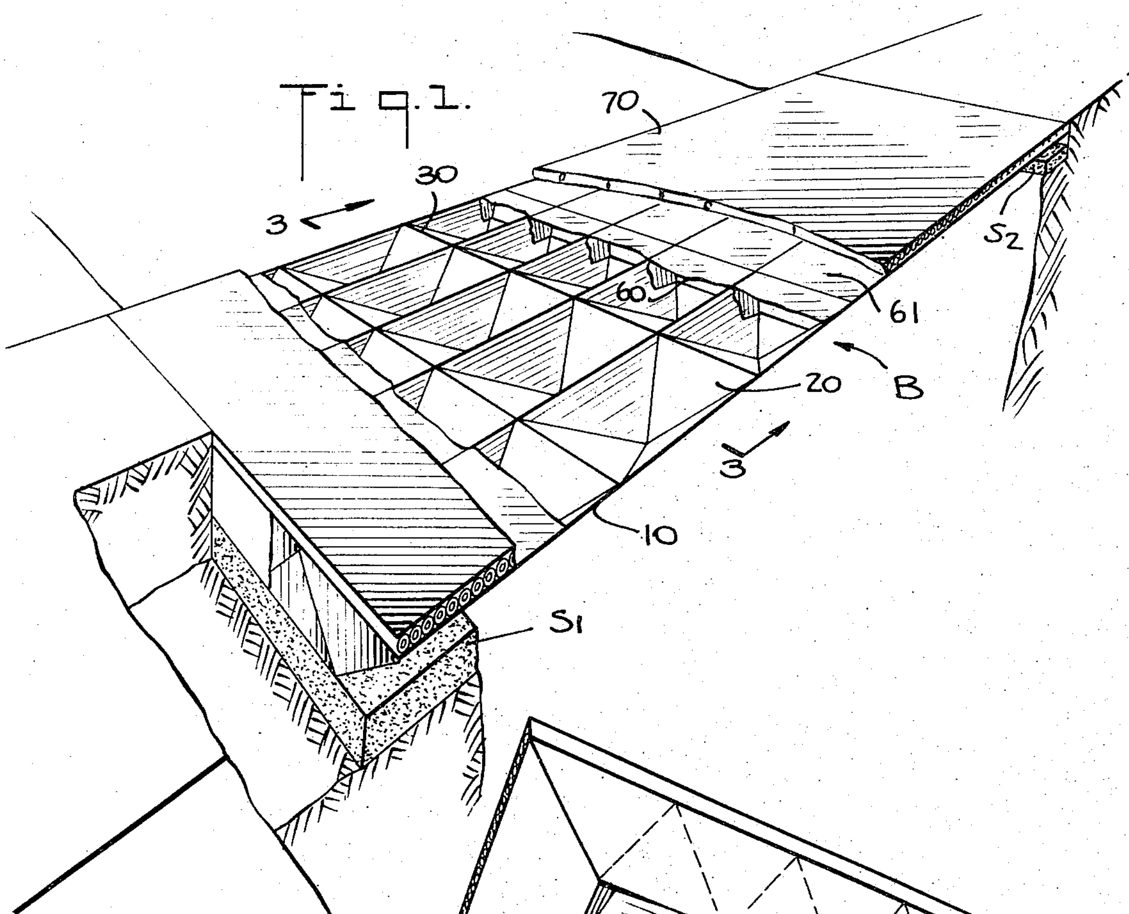


Fig.1.

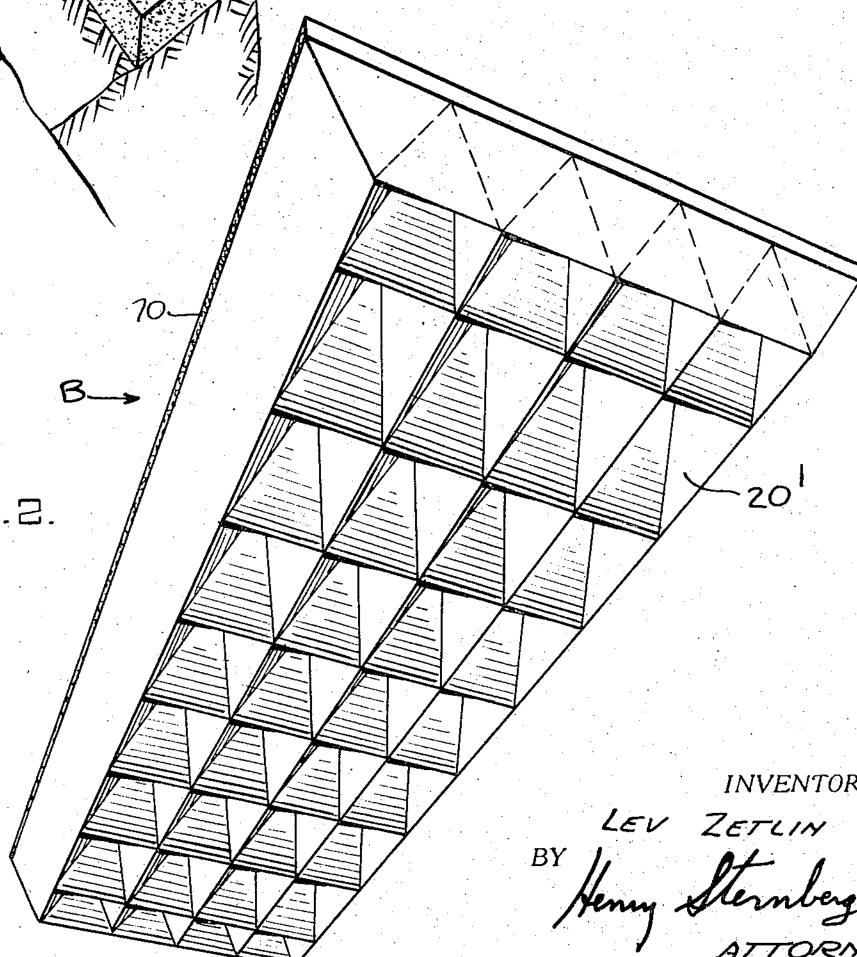


Fig.2.

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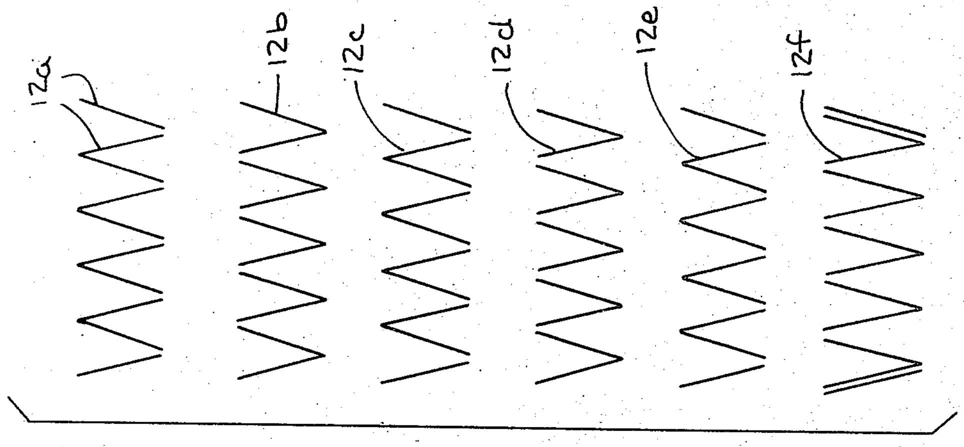

Fig. 7.

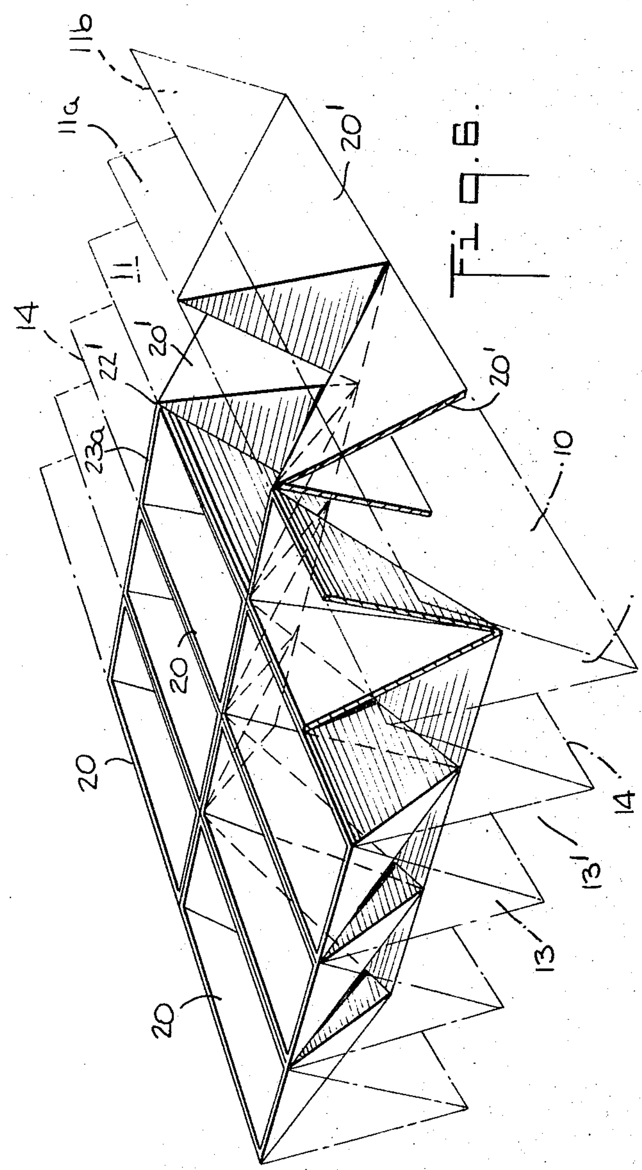

Fig. 6.

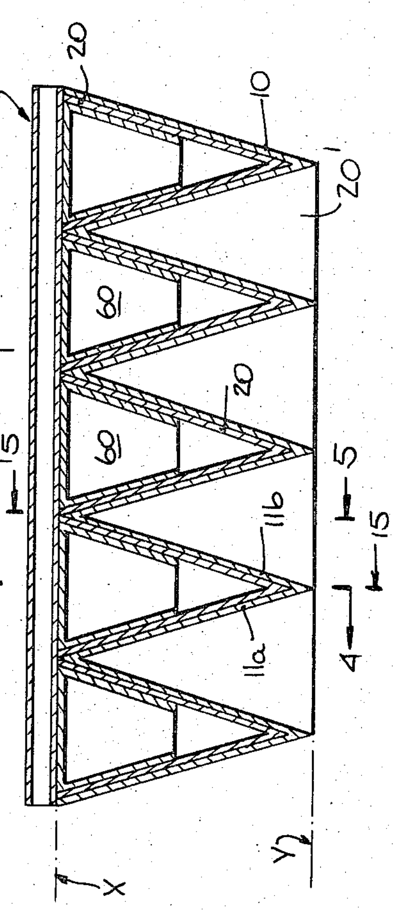

Fig. 3.

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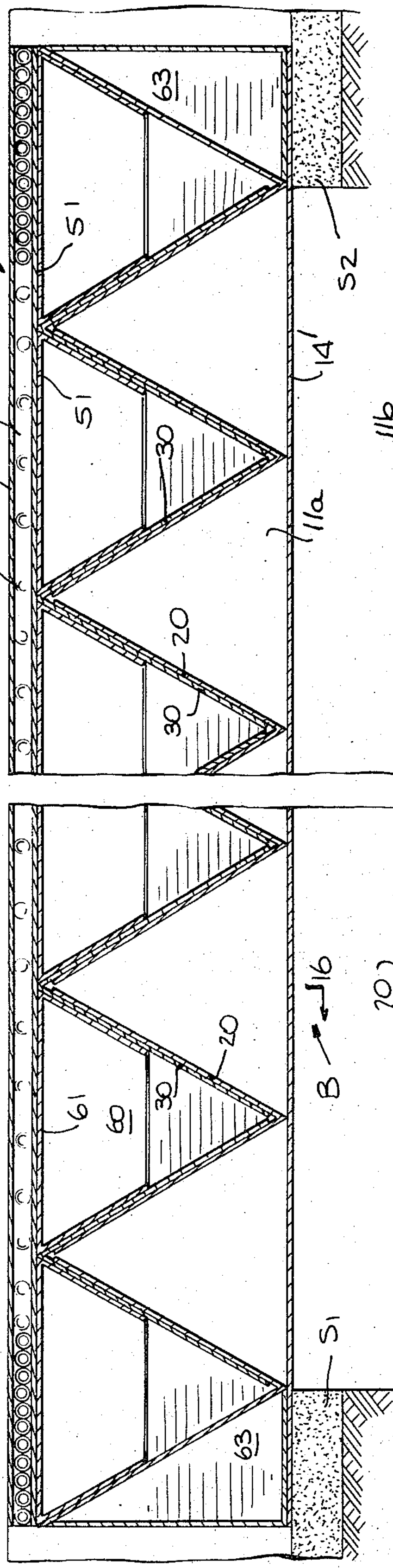

Fig. 4.

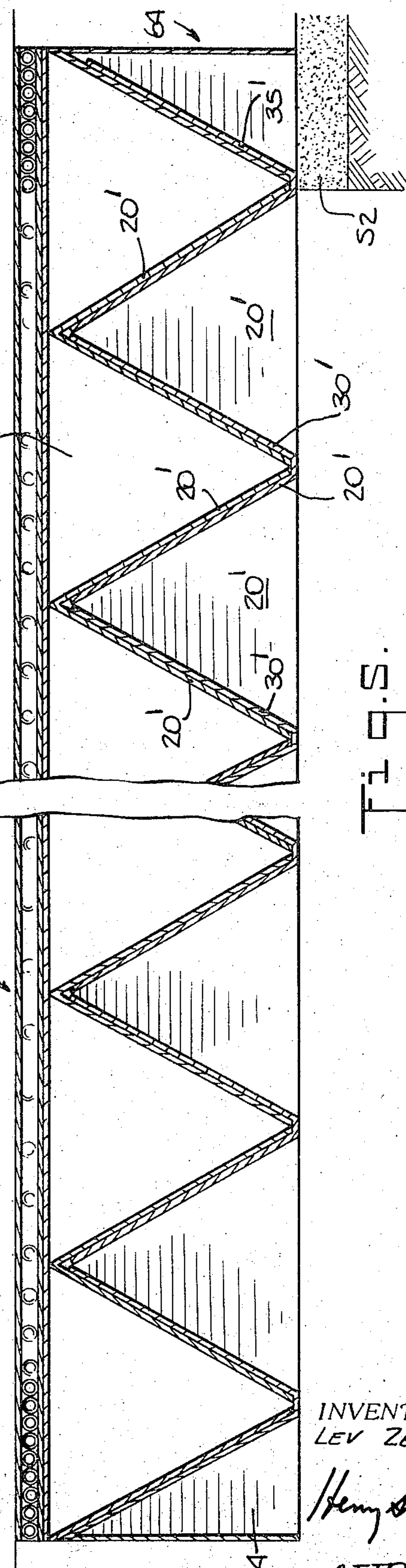

Fig. 5.

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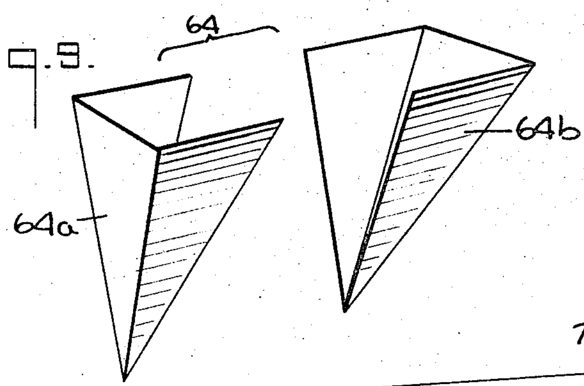
Fig. 9.



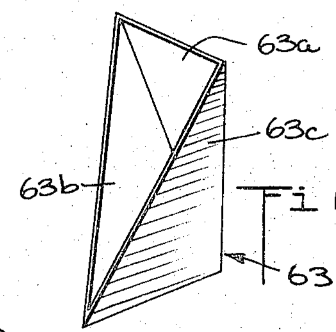


Fig. 10.

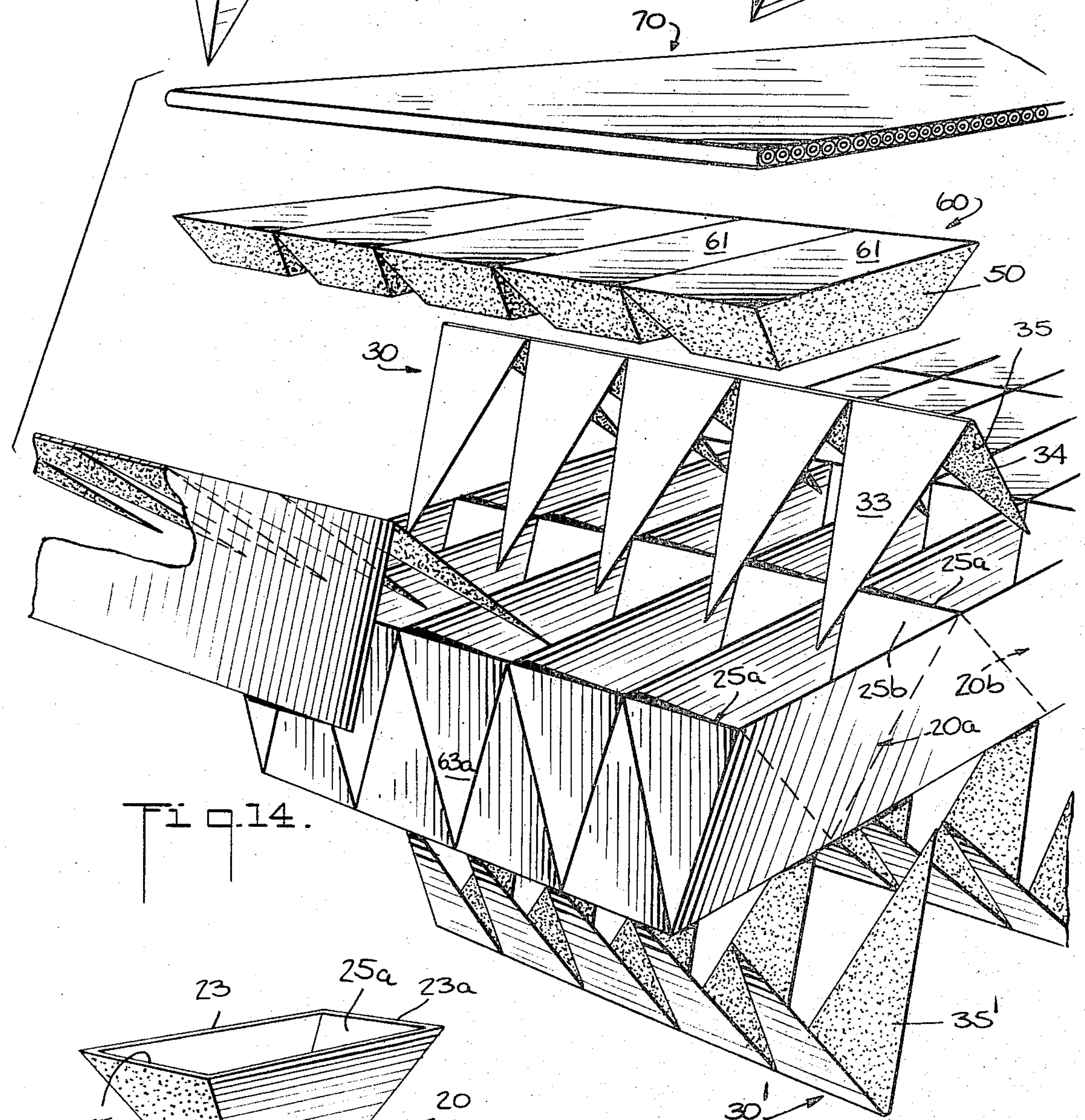


Fig. 14.

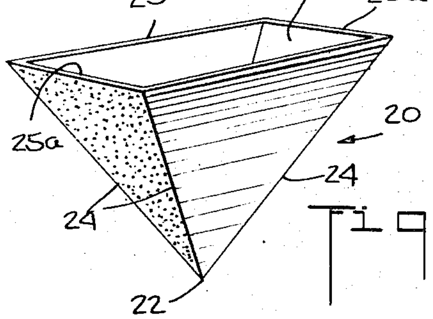


Fig. 8.

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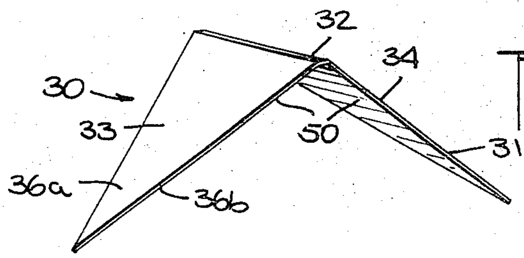

Fig. 11.

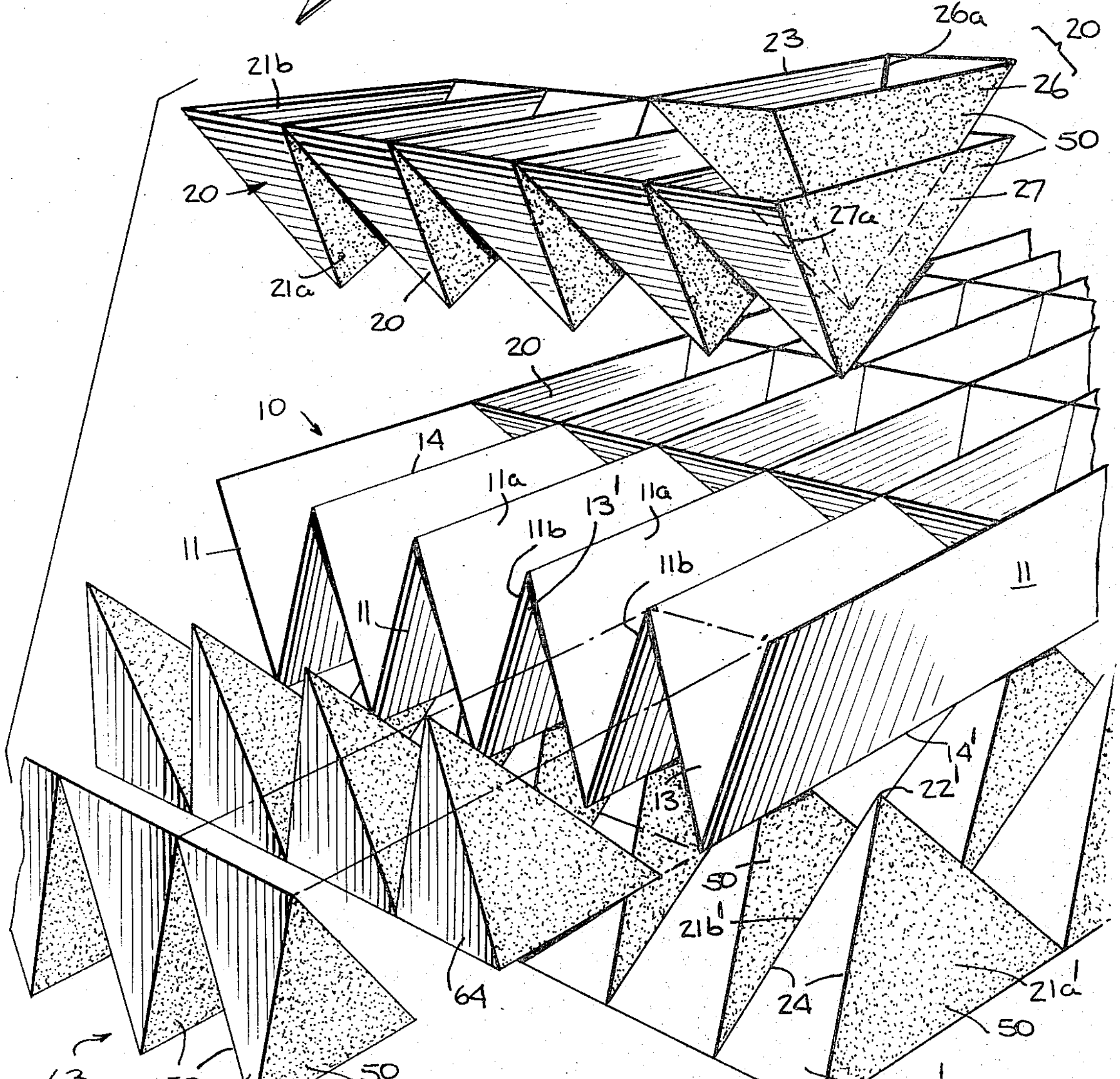

Fig. 13.

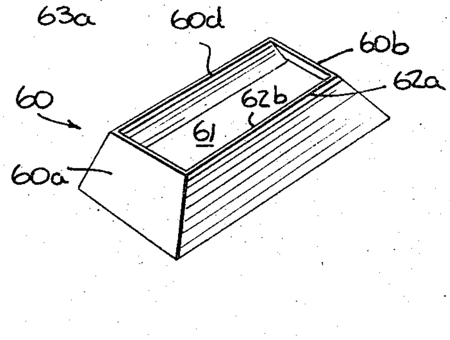

Fig. 12.

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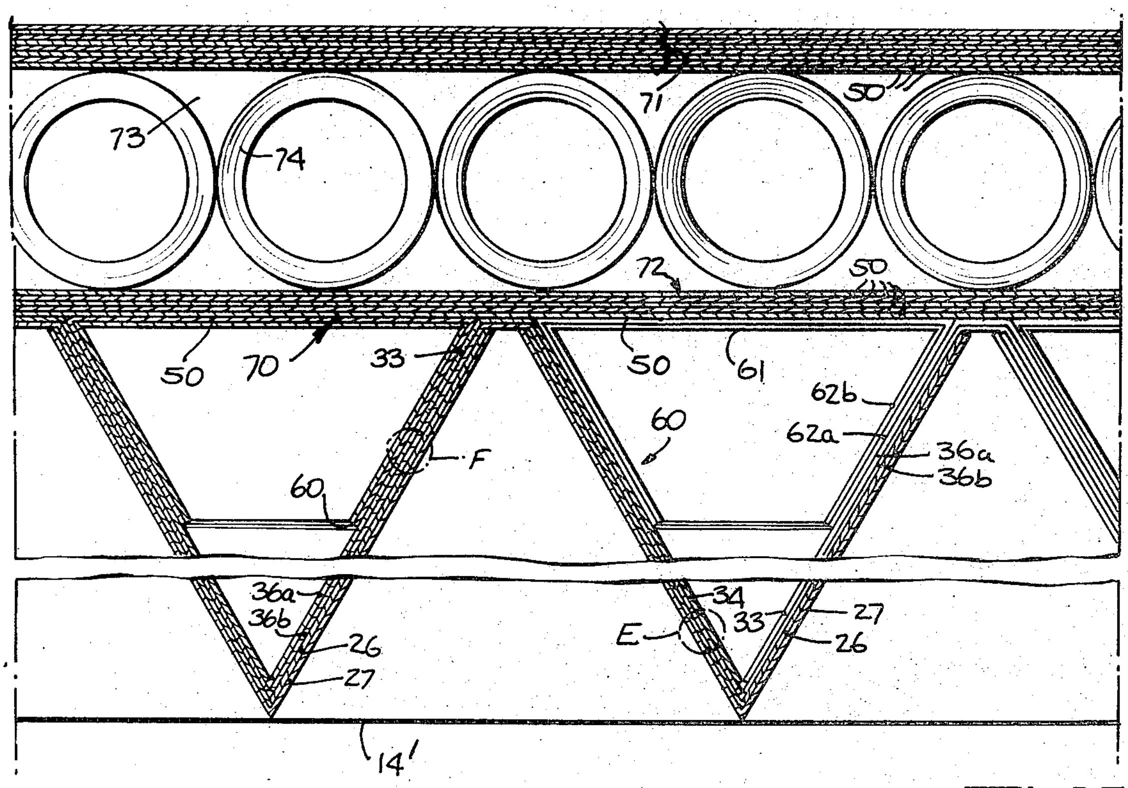

Fig.15.

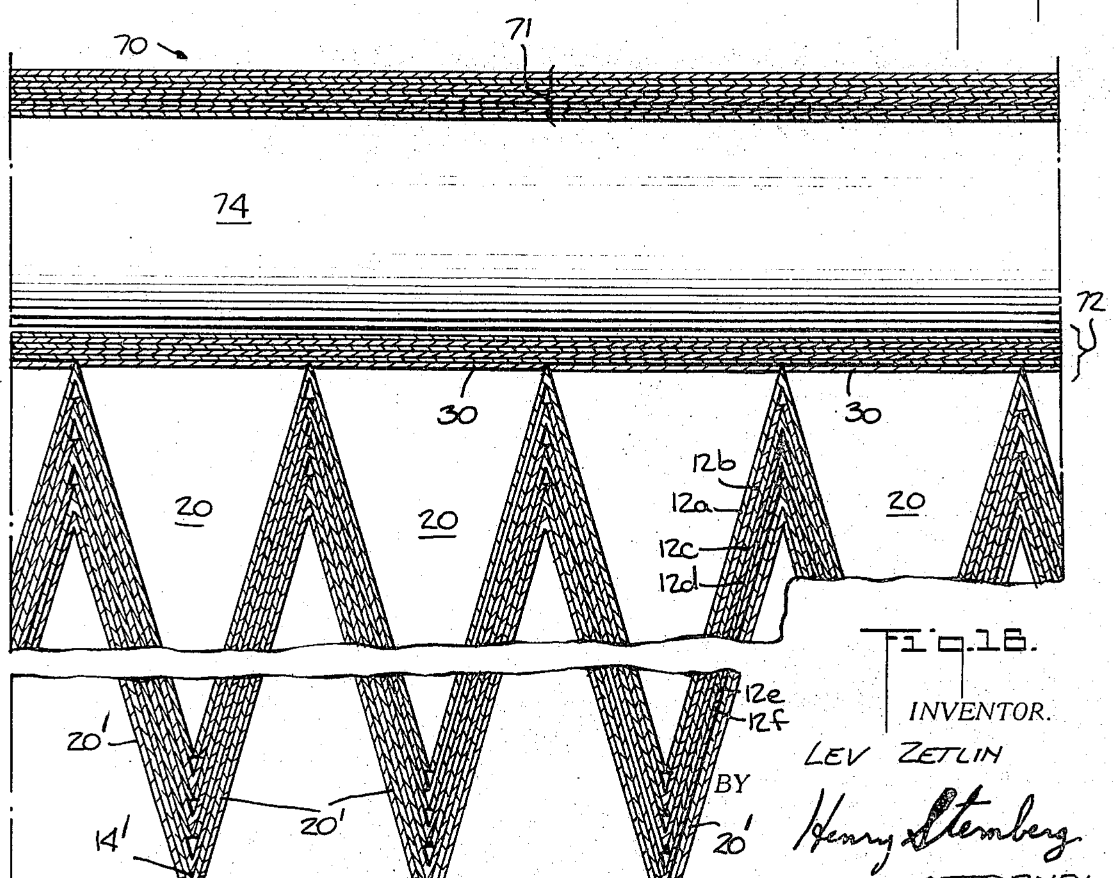

Fig.16.

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STRUCTURAL MEMBER OF SHEET MATERIAL

The present invention relates to structural members, particularly a structural member which may be fabricated almost entirely of sheet material and which is capable of supporting loads and resisting stresses.

One object of the present invention is to provide a structure comprised of one or more interconnected structural members of the above type which is able to support loads while spanning the relatively large distances required to be spanned by a bridge.

A further object of the present invention is to provide a structural member of the type described above which may be formed almost entirely of paper or similar sheet material.

A still further object of the present invention is to provide a structural member of the above type which has a geometric configuration suitable for imparting rigidity and strength to the structures in which it is used.

Another object of the present invention is to provide a structural member having the above characteristics and which also displays a high strength to weight ratio.

A still further object of the present invention is to provide a structural member such as described above which displays the combined structural characteristics of a skeleton frame system and those of a stressed-skin system.

Another object of the present invention is to provide a structural member which, while possessing the above characteristics, may be fabricated out of materials such as sheet metal, sheet plastics, fiberous sheet materials, as for example, paper, or even a sheet material comprised of a thin layer of concrete sprayed or otherwise suitably formed on steel reinforcing mesh.

Another object of the present invention is to provide a structural member, having the above characteristics, which is of modular construction and whose modular elements may be mass-produced, easily transported to, and readily assembled at, the site.

Still another object of the present invention is to provide a lightweight, easily transportable, relatively inexpensive structural member of the above type which is comprised substantially entirely of mass-produceable modular elements of sheet material.

A concomitant object of the present invention is to provide a structural member having the characteristics described above and which may be readily assembled with similar members to form a load carrying structure such as a bridge.

In accordance with the present invention, a system of longitudinal webs of sheet material and hollow shell elements of sheet material are interconnected along overlying surfaces thereof for forming a composite integral structure which displays the combined characteristics of a truss and a stressed skin system.

More specifically, according to the preferred embodiment of the invention there is provided a longitudinal web of sheet material folded, along a longitudinal center-line thereof, into a V-shape. Modular shell elements, also of sheet material and having the shape of hollow pyramids, are longitudinally distributed along and nested in the longitudinal web and bonded thereto along corresponding overlying surfaces of the web and the shell elements. There results a composite structure displaying the characteristics of a series of interconnected triangular truss units providing the rigidity and stability incident to such structural triangulation.

The foregoing objects and advantages of the invention will become apparent from the following description of a preferred form and certain alternate forms thereof and from the following illustrations of those forms, in which:

FIG. **1** is a perspective, partially cut-away, view of a bridge constructed in accordance with the preferred form of the present invention;

FIG. **2** is a perspective view of the bridge of FIG. **1**, showing the internal construction at the underside thereof;

FIG. **3** is a transverse sectional view of the bridge taken along the line **3—3** of FIG. **1**, in the direction of the arrows;

FIG. **4** is an enlarged fragmentary longitudinal sectional view taken along line **4—4** of FIG. **3**, in the direction of the arrows;

FIG. **5** is an enlarged fragmentary longitudinal sectional view of the bridge taken along line **5—5** of FIG. **3**, in the direction of the arrows;

FIG. **6** is an enlarged, perspective, partly sectional, partly schematic view of groups of pyramidal elements arranged, in accordance with the preferred embodiment of the present invention, in the oppositely directed channels formed by a plurality of longitudinal webs;

FIG. **7** is a schematic representation of the interfitting layers of sheet material for forming the longitudinal web according to the preferred embodiment of the invention;

FIG. **8** is an enlarged perspective view of a single pyramidal unit according to the present invention;

FIG. **9** is an enlarged perspective, exploded, view of a pair of sheet sections each folded into half-pyramid shape and together forming an end closure for the opposite longitudinal ends of each upright pyramid series;

FIG. **10** is an enlarged perspective view of an end closure member for the opposite longitudinal ends of each series of inverted pyramids;

FIG. **11** is an enlarged perspective view of a transverse web element in accordance with the preferred embodiment of the present invention;

FIG. **12** is a perspective view of a pyramid-closure member for closing the open ends of the pyramidal members, according to one embodiment of the invention;

FIG. **13** is a perspective, exploded, view of a portion of the structure of FIGS. **1** and **2**, showing the relationship between the longitudinal webs, the upright and inverted pyramids, and the end-closure members according to one embodiment of the present invention;

FIG. **14** is a perspective view of the structure shown in FIG. **13**, showing, in addition thereto, in exploded form, the upright and inverted transverse webs, the pyramid-closure members, and the decking, according to one embodiment of the present invention;

FIG. **15** is an enlarged, fragmentary, longitudinal sectional, view of a bridge built in accordance with the present invention, showing the internal construction of the preferred form thereof; and

FIG. **16** is an enlarged, fragmentary, transverse sectional view of the structure illustrated in FIG. **15**.

According to the preferred construction a plurality of V-shaped members interconnected side-by-side, in rank formation, form a flat structure for use as a flooring, bridge, platform, pontoon, or the like. A flat decking covering the top of the array of the structural members, and secured thereto, serves as means for making the overall composite structure even more rigid and, in the case of a bridge, serves as a flat road-bed.

In its basic form, the present invention includes a substantially V-shaped elongated longitudinal web member having at the interior thereof a core consisting of a chain of hollow, preferably pyramidallyshaped, shell members. A plurality of such V-shaped longitudinal web members may be arranged compactly side-by-side to form a unitary structure such as a flooring, bridge, platform, roof or pontoon.

The pyramidal elements may be nested in the V-shaped longitudinal member with the relatively large surface areas of a pair of opposed walls of each of the pyramidal elements in superposed relation with corresponding surface areas of the V-shaped member and said superposed surface portions bonded to one another substantially over the entire region of contact thereof. It will be noted that not only do pyramidal elements display relatively large surface areas for their volume, but according to the preferred form of the invention, the entire surface area of the four triangular faces of each pyramidal element is in a superposed relation with and bonded to, other elements of the structure. Thus, a first pair of opposite ones of the triangular faces of each pyramidal element overlie and are bonded over substantially the entire surface thereof to corresponding surface portions of the longitudinal web means while the other pair of opposed triangular faces of each pyramidal element are in overlying relation to and bonded over substantially the entire surface area thereof to one of a pair of plane triangular faces of a pair of transverse web means respectively. As will be seen, pyramidally shaped closure elements also have substantially their entire surface area in superposed relation with and bonded to corresponding portions of the pyramidal elements, on the one hand, and a deck member, on the other hand.

Referring now to the drawings, and initially to FIG. **1**, there is shown a bridge B comprising a longitudinal web means **10**, a plurality of pyramidal elements **20** and a decking **70**. It will be seen that the bridge B extends between a suitable pair of spaced supports S_1 and S_2.

According to the present invention the entire structural member, for example the bridge B, is formed of sheet material folded in a prescribed manner and glued, or otherwise suitably bonded together, along relatively large overlying surface portions thereof. Preferably, the sheet material of which the structural system is formed is paper or cardboard. The connections between the elements forming the structural system of the invention are accomplished by bonding together superposed, i.e., overlying surface areas of the sheet material elements. Thus, the structural system according to the present invention is comprised of a system of geometric folded modules which are, according to the preferred embodiment, bonded together at overlying surfaces thereof.

The structural system according to the present invention consists of two basic elements. Each of these basic elements is fabricated of sheet material, preferably a laminate of paper or cardboard such as is commonly used in heavy duty packaging but other material such as sheet metal, aluminum, plastics, sprayed concrete or mortar over steel mesh is also suitable. The first element is a web **10** (FIG. **13**) formed of a system of folded plates **11** developed by laminating several longitudinally creased layers **12***a*, **12***b*, **12***c*, etc. (FIG. **7**), of paper, to each other. The longitudinal web means **10**, thus formed, includes at least one pair of integrally connected, elongated, folded plates **11** having spaced surface portions **11**a and **11**b defining between themselves an elongated channel **13**. In a structural system such as the bridge B, for example, a plurality of these folded elements **12** are transversely interlocked, as illustrated in FIG. **7**, so as to present a saw-tooth profile in a transverse plane. The interlocked elements form the longitudinal web means which extends longitudinally the length of the bridge.

The second basic element is a hollow shell member of sheet material, preferably in the form of a pyramid **20** (FIG. **8**). A plurality of these pyramidal elements **20** (inverted) and **20'** (upright) are positioned between the folded plates **11** on the top and bottom of the first element **10** and nested in the respective channels **13** and **13'** formed by the first element. The pyramids **20, 20'** are longitudinally distributed along and located in the various elongated channels **13, 13'**, with each of the pyramids having a first pair of opposite surface portions **21***a*, **21***b* in superposed relation with the spaced surface portions **11***a*, **11***b*, respectively forming the corresponding channel **13, 13'**. The fold lines of the longitudinal web means alternately form crests **14** and troughs **14'** which respectively lie in a pair of spaced parallel planes defining the bounds of the structural system. The hollow shell pyramids **20** and **20'** are open at their bases and are positioned in side-by-side relationship in the corresponding elongated channels **13, 13'**, in such a manner that preferably the bases of the pyramids **20** lie in one, and the bases of the pyramids **20'**, in the other, of said parallel planes. Thus, the pyramids **20** are located in upwardly opening channels **13**, while the pyramids **20'** are located in downwardly opening channels **13** and are inverted with respect to the pyramids **20**. Furthermore, the pyramids **20, 20'** in a pair of adjoining upwardly and downwardly opening channels **13, 13'** are preferably staggered (FIG. **6**) with respect to each other, in such a manner that the apices of the pyramids **20** will lie substantially in the region of the line of contact between adjacent base edges of adjacent pyramidal elements **20'** located on the opposite side of the plate element **11** separating the channels **13** and **13'**. Thus, the apex **22'** of an upright pyramid **20'**, in one of the channels **13'**, will preferably be located in the region of the base edge line **23***a* of the inverted pyramid **20** located adjacent thereto, in the next adjoining channel **13**, and so on for the remaining pyramid elements, with the result that the inclined edges of the staggered inverted and upright pyramids **20** and **20'**, in adjacent channels, are very nearly colinear and coact to resemble the chords of a truss.

While not here illustrated, it will be understood that pyramids **20** and **20'**, in adjacent channels **13** and **13'**, respectively, need not be staggered with respect to each other, but could be positioned such that the apex of each pyramid **20** will lie in the region of the midpoint of base line **23'** of the next adjacent upright pyramid **20'** on the opposite side of a plate element **11** therefrom.

The hollow-shell pyramidal elements **20, 20'** are developed by cutting out a suitable flat geometric shape of sheet material and subsequently folding the latter along suitable fold lines **24** into desired pyramidal shape (FIG. **8**).

After being nested in the web element **10** the pyramids **20** are preferably tied together with a third element, namely transverse web means **30**, shown in FIG. **11**.

The transverse webs **30** are preferably in the form of diamond-shaped sheets **31** folded along the short axes **32** thereof. As a result, each member **31** includes a pair of integrally connected sheet sections **33** and **34**, suitable for connecting together adjacent ones of the pyramids **20** or **20'**, in the respective channel **13** or **13'**. When folded, the portions **33, 34** of the transverse web members define between themselves second channels **35** extending transversely with respect to the channels **13, 13'** of the longitudinal web means. One of the triangular sheet sections, e.g., **33**, of the transverse web member **30**, is positioned in superposed relation with a second surface portion **25*b*** (FIG. **14**) of one of a pair of longitudinally adjacent pyramids **20**a and the triangular sheet section **34** of the transverse member **30** is positioned in superposed relation with the adjacent one of the second surface portions **25*a*** of longitudinally adjacent pyramid **20*b***. Preferably, the aforesaid triangular sheet sections **33, 34** of the transverse web member **30**, will correspond substantially to the shape of the second surface portions **25*a*, 25*b*** of the pyramids and will overly and be bonded to the corresponding triangular second surface portions of such pyramidal elements, respectively, for connecting together pairs of such pyramidal elements in side-by-side relation. The transverse web members **30** cooperate with the pyramidal elements to even further stiffen the longitudinal web means **10** and thus provide the latter with even greater resistance to buckling. Accordingly, there is developed a very reliable, rigid, structural system capable of economically and efficiently spanning relatively large distances.

As a result of the above described surface-to-surface interconnection of all the elements of the system, external loads applied to the system are distributed therein in all directions, thus alleviating stress concentrations in the directly loaded parts.

A connecting means **50** which may be in the form of household glue or a similar bonding means suitable for the particular sheet material used, is provided for use in erecting the individual hollow shell elements, the transverse web means and the longitudinal web means and for integrally connecting all these elements together at the aforesaid superposed surface portions thereof, to form the composite integral structure just described.

The preferred embodiment of the structure further includes a plurality of closure elements of sheet material. A first group of these closure elements are the elements **60** which are preferably of truncated pyramidal form (FIG. **12**), configurated so as to correspond to and be received in the open bases of the inverted pyramids **20**. Elements **60** have side wall surfaces **60*a*, 60*b*, 60*c*** and **60*d*** adapted to overlie portions of respective walls **25*a*, 25*b*, 25*c*** and **25*d*** of the respective pyramid **20** in which the closure element is nested. The closure elements **60** further have a closed end wall **61** which forms a closure for the otherwise open bases of the pyramids **20**. The closure surfaces **61** of all of these closure members **60** are located substantially in the plane *x*, i.e., the upper one of the aforesaid pair of parallel planes *x* and *y* which delimit the web means **10**. Together the end walls **61** form a substantially flat continuous surface in plane *x*. The truncated pyramidal closure pieces **60**, illustrated in FIG. **12**, are preferably prefolded and prestressed so as to be properly bondable to the inner surfaces of the corresponding pyramidal elements **20** after being nested therein. Alternatively, the pyramids **20** may initially be formed as hollow, fully enclosed, elements.

For closing the ends of each of the channels **13'** (in which the pyramids **20'** are preferably staggered with respect to the pyramids **20** in the adjacent channels **13**, by a distance equal to one-half the length of a pyramid **20'**) there are preferably provided hollow end closure elements **64** (FIG. **9**) each of which corresponds substantially in size and shape to one-half of a pyramidal element **20'**. According to the preferred embodiment, the pyramids **20** and **20'** are of equal size. Each element is preferably formed of a pair of glued-together folded sections **64*a*** and **64*b***.

At the opposite longitudinal ends of each series of inverted pyramids **20** there may, according to the preferred embodiment, be provided end closures **63**, such as illustrated in FIG. **10**. End closures **63** are preferably also in the form of hollow shell elements each of which has three triangular sides and a triangular open face. The apex of the intermediate one, **63*a***, of the triangular sides, is located in the colinear base line of the remaining triangular sides **63*b*** and **63*c***. The hollow elements **63** form a flat end closure **63*a*** at the end of each string of longitudinally distributed pyramidal elements **20**.

The bridge B, according to the preferred embodiment of the present invention, further includes a decking **70** for transferring the loads evenly to the remainder of the structure. This decking, while preferably also formed of sheet material, is so constructed as to be capable of withstanding the concentrated wheel loading of motor vehicles, including heavy trucks. As previously noted, the end walls **61** of the closure elements **60** provide a flat continuous surface on the top of the structural system capable of having bonded thereto, as at **51**, in face-to-face relation, the underside of the flat decking member **70**.

In its preferred form, the decking member **70** is comprised of a pair of laminated layers **71** and **72** of a sheet material and an intermediate layer **73** comprised of a series of parallely arranged cylindrical tubes **74**, also of sheet material. These tubes are preferably in side-by-side contact with one another and preferably extend transversely with respect to the length of the decking so as to reinforce the pair of spaced flat layers **71** and **72** of laminated sheet material located on opposite sides of and bonded to the intermediate tube layer.

As a result of its unique design, the above described components of the structural system (FIG. **14**) may be readily assembled together at the construction site by bonding these together along the aforementioned overlying surface areas thereof. The large surface areas available for bonding result in exceptionally strong and reliable connections. The specific glues and cements best suited for such bonding will depend on the particular sheet materials involved, and are well known to those skilled in the art. A high-load-bearing structural system, such as a bridge, may thus be fabricated solely out of sheet materials, such as paper.

Preferably, each of the component parts, for example the pyramids **20, 20'**, the longitudinal web means **10**, the transverse web means **30** and the closure elements **60** and **63**, is fabricated out of individual, stock size, sheets of paper, by cutting the latter into desired shape, scoring the paper along desired fold lines and then laminating together individual sheets of such scored paper in such a manner that (as illustrated with respect to web **10**, in FIG. **7**) alternate sheets of the paper are positioned with their region of discontinuity in nonoverlapping relation. In FIG. **13**, it will be see, that, for example, the lines of discontinuity **26***a* and **27***a* of the adjacent layers **26, 27**, respectively, of a pyramidal element **20**, are located at opposite edges of the pyramid and are not adjacent to one another. Thus, the region of discontinuity of any individual sheet is reinforced by a non-discontinuous region of an adjacent sheet, so as to minimize any effect of such discontinuity on the structural strength of the element. After folding into desired shape, the scored folds of the pyramid may be filled with flue to provide an even stronger structural joint along such fold lines.

The term "paper" as used herein is intended to include such sheet materials as paper board, liner board, fiber board and cardboard.

Not only do the strength and stiffness properties of paper differ greatly in compression and in tension, but paper is also an anisotropic material, i.e., it displays different structural properties along different axes thereof. According to the preferred embodiment of the present invention, particular advantages result from the latter special structural properties inherent in paper. For example, the tensile strength of the paper is nearly twice as great in the direction of the grain of the paper as it is in the cross direction. According to the preferred embodiment, all of the elements of the structure are comprised of folded and glued flat surfaces shaped to take full advantage of the special properties of paper. Thus the webs **10** are constructed with the grain of the paper thereof extending in longitudinal direction, and the pyramids **20, 20'** are constructed with the grain of the paper thereof extending peripherally, i.e., in a direction about the apex. The pyramid closure elements **60** are cut and prefolded so as to form prestressed, i.e., spring-like inserts for the tops of the inverted pyramids **20.** Coated with glue, the closure elements **60** are inserted into the open faces of the pyramids and press outwardly against the pyramid walls to provide proper bonding along all adjoining surfaces.

Since the structural system according to the present invention is composed of hollow elements and since the hollow pyramidal elements **20** are bonded to the interior surfaces of the longitudinal web means **10**, the pyramidal elements are also subjected to the stresses borne by those portions of the longitudinal web means to which they are attached. Furthermore, the inclined corner portions, i.e., edge portions **24** of each of the pyramidal units **20, 20'**, from the apex **22** down to the base **23** thereof, act as truss members, thereby forming, with the other inclined edges of the remaining pyramidal units, an integrated truss system.

Each of the edges **24**, of the pyramidal elements, thus forms a cord of a truss so that the resulting structure is made up of a series of interconnected triangular truss units having the rigidity and stability incident to structural triangulation. As a result of the surface-to-surface interconnection of all of the elements of the structure, applied external loads are distributed in all directions, thus acting to reduce the otherwise high stresses in the directly loaded portion.

By way of example, a paper bridge, approximately ten feet wide and four feet deep, was constructed in accordance with the present invention. The bridge, having a length of 32 feet was able to easily bear the weight of a 12,000 pound truck when the latter was driven over its 30 foot span numerous times. During load testing, for support of the 12,000 pound truck, the paper structure deflected only ½ inch within its 30 foot span. The bridge weighed approximately 9,000 pounds and consisted entirely of paper and glue. The sheet material (**1**) used for constructing the elements of the structure, for example, the pyramidal elements, the longitudinal webs, the transverse webs and the decking, was 0.1 inch thick Solid Fibre which consisted of four plies of 90 Kraft liner-board (heavy duty paper) laminated together. The various component elements of the structure were bonded together along overlying surfaces thereof, as described above, forming laminated sections such as, for example, section E (FIG. **15**) 0.4 inches thick, and section F (FIG. **15**) 0.6 inches thick. Joined together, these elements form a stressed-skin structure that behaves like an orthotropic bridge. The sheets **12***a*, **12***b*, **12***c*, etc., as well as sheets **26***a* and **27***a*, etc., were each 0.1 inch thick as per above.

The deck **70** (FIGS. **15** and **16**) was fabricated of parallel, side-by-side, cylindrical paper tubes **74** also comprised of laminated sheets of paper. By way of example, the tubes **74** have a wall thickness of approximately ½ inch and an inside diameter of approximately 3 inches. The tubes are sandwiched between a pair of spaced flat layers **71** of laminated sheets of paper **1.**

While the deck **70** has been illustrated with a core of cylindrical paper tubes **74** laminated between flat layers of sheet material **71**, it will be understood that other deck structures, for example, one having a sawtooth-shaped laminated core (not shown), similar to the longitudinal web structure of web **10** described above (FIG. 3), and sandwiched between the pair of laminated sheet layers **71**, would also be satisfactory and is intended to be included within the scope of this invention.

By way of example, the pyramidal units of the latter bridge are each approximately 2½ feet high and have a rectangular open base approximately **48** inches in length (longitudinal direction of web **10**) and approximately 24 inches in width (transverse direction).

The pyramids **20, 21'** are longitudinally distributed, with adjacent base edges thereof in close proximity to one another, in the corresponding elongated channels **13, 13'**. The apex angles of a pair of opposite sidewalls **21***a* and **21***b* of the pyramidal elements **20** are preferably chosen to correspond to the apex angle formed between plates **11***a* and **11***b* of the longitudinal web means **10.** The sheet material used in the structure according to the present invention, while preferably paper, may be any suitable sheet material, such as sheet steel, sheet aluminum, sheet fiberglass, as well as other structural plastic sheet materials, or the like.

It will be seen that the structure of this invention is such that the component parts thereof can be simply and inexpensively manufactured, transported and assembled together.

It can be seen that the structure described herein can have many applications in addition to use as a supporting beam or bridge. For example, a structure according to the present invention would be useful in cases where buoyancy is desired. Thus, by using water resistant materials, or water resistant coatings over water permeable materials, a structure according to the present invention could, for example, be used as a "pontoon" bridge. By using additional closure pieces, similar to elements **60,** to close off the open ends of the bottom pyramids **20'**, a fully enclosed cellular structure is formed. The air-filled, fully-enclosed, pyramidal units and the enclosed spaces therebetween, result in a buoyant structure.

It will be understood that a composite structural unit according to the present invention, i.e., longitudinal web means and pyramidal elements distributed therealong and connected thereto, as described, lends itself admirably to use as a structural element. Such structural element may, for example, be comprised of a single V-shaped web **11***a*, **11***b* and a plurality of longitudinally distributed pyramids **20** nested in the channel **13** thereof and connected thereto, as taught herein. Such composite structural member can span relatively large distances without requiring intermediate columnar supports. The structural system of the present invention combines the structural characteristics of a skeleton frame system with those of a stressed skin system. Thus, the system according to the present invention has an unusually high strength to weight ratio because of the internally continuous braced skin-structure and because of the fact that pyramidal elements have a high ratio of surface area per unit volume and consequently are among the most stable of all polyhedrons.

It can be seen that this invention provides improved strength members for a bridge, or a roof, or the like, comprising uniquely formed sheet material elements uniquely combined to provide a supporting structure which is relatively light in weight and yet very strong.

It will be understood that where sheet material other than paper is used, for example plastic or light-gauge steel or aluminum, the means for integrally connecting the sheet members at overlying surface portions thereof may include such connecting means as spotwelds, solder, rivets, heat seals and any other fastener or bond which permits surface-to-surface connection between the flat surfaces of the geometric shapes formed by folded sheets of such materials. In lieu of the pyramidal elements, of course, other hollow solid-geometric shaped elements can be used provided they have flat surfaces which permit a surface-to-surface connection in substantially the manner herein described.

It will also be understood that by increasing the thickness of the sheet material or the number of sheets of material in each layer and/or by increasing the number of pyramidal elements in a given channel, the strength of the composite structure may be even further increased.

While particular embodiments of this invention have been shown and described, it will be obvious to those skilled in the art that there are changes and modifications which may be made without departing from the scope of the invention in its broader aspects, and it is, therefore, intended in the claims to cover also such changes and modifications as fall within the true spirit and scope of this invention.

Having thus described my invention, what I claim and desire to protect by Letters Patent is:

1. A structural member comprising:

longitudinal web means of sheet material including a pair of integrally connected, elongated first sheet sections relatively inclined to one another and defining between themselves an elongated channel;

a plurality of hollow shell elements of sheet material arranged in side-by-side adjacency in and longitudinally distributed along said elongated channel, each of said hollow shell elements having a first pair of opposite side walls each of which comprising a second sheet section generally parallel to and in substantially full face-to-face contact with the respective one of said first sheet sections and each of said hollow shell elements having a second pair of opposed side walls intermediate of and generally transverse to said first pair of side walls; and

means integrally connecting said hollow shell elements with said longitudinal web means at said respective first and second sheet sections thereof substantially along the full face-to-face contact region therebetween so as to form said shell elements and said web means into a composite integral structure.

2. The structural member according to claim **1** wherein said sheet material is paper and said connecting means comprises adhesive means for adhering the respective superposed surface portions to each other.

3. The structural member according to claim **1,** wherein said hollow shell elements each have a second means integrally connecting one of said intermediate side walls of one of said shell elements with the adjacent intermediate side walls of the next adjacent one of said shell elements in said channel.

4. A structural member according to claim **1** wherein said longitudinal web means comprises an elongated substantially rectangular sheet material folded along a substantially central longitudinal fold line forming said pair of first sheet sections, mutually inclined with respect to each other.

5. A structural element comprising:

a pleated sheet means having oppositely facing longitudinally extending channels formed between the longitudinal fold lines thereof, alternate ones of said fold lines forming the ridges and the remaining ones thereof forming the troughs of said pleated sheet means, respectively;

a plurality of pyramid-shaped hollow elements of sheet material longitudinally distributed along and located in at least one pair of adjacent ones of said oppositely facing channels, said hollow elements having opposed wall portions thereof in face-to-face contact with adjacent channel forming walls of said pleated sheet means and said hollow elements in one of said pair of channels having their bases located substantially in the plane defined by said alternate fold lines, said hollow elements in said opposed one of said pair of channels having their bases located substantially in the plane defined by said remaining fold lines;

a plurality of transverse web means each including a pair of integrally connecting mutually inclined sheet sections for connecting, in each of said channels, adjacent ones of said hollow pyramid-shaped elements, said hollow shell elements having intermediate walls intermediate said opposed wall portions thereof and said inclined sheet sections overlying portions of adjacent ones of said intermediate walls of adjacent ones of said pyramid-shaped elements; and

connecting means for connecting said overlying surfaces of said transverse web means and said pyramid-shaped elements together and for connecting together said pleated sheet means with the corresponding overlying ones of said wall portions of the hollow pyramid-shaped elements.

6. A structural member comprising:

longitudinal web means of sheet material including a pair of longitudinally oriented, elongated, integrally connected, first sheet sections each of said sheet sections having a surface portion and said pair of surface portions being relatively inclined to one another and defining between themselves an elongated channel:

a pair of adjacent hollow shell elements of sheet material longitudinally distributed along and substantially in said elongated channel, each of said hollow shell elements having a first pair of opposite side walls, each of said side walls having a surface portion and said pair of surface portions of said side walls being relatively inclined to one another at substantialy the same relative inclination as and in superposed relation, respectively, with said surface portions of said first sheet sections, and an intermediate second pair of opposed surface portions, each of said first mentioned pair of surface portions of said hollow shell elements being in substantially full face-to-face contact with the respective surface portion of the longitudinal web means which it overlies:

transverse web means of sheet material including a pair of integrally connected second sheet sections located in said channel and defining between themselves a second channel extending transversely with respect to said first mentioned channel, one of said second sheet sections being in superposed relation with one of said second surface portions of one of said shell elements and the other of said second sheet sections being in superposed relation with the next adjacent one of said second surface portions of the other of said shell elements; and

means integrally connecting said hollow shell elements with said transverse web means and said longitudinal web means at said respective superposed surface portions thereof, substantially along the entire face-to-face region of contact therebetween, for forming a composite integral structure exhibiting high load carrying characteristics.

7. A structural member comprising:

longitudinal web means of sheet material including a pair of integrally connected, elongated first sheet sections relatively inclined to one another and defining between themselves an elongated channel;

a plurality of hollow shell elements of sheet material arranged in side-by-side adjacency in and longitudinally distributed along said elongated channel, each of said hollow shell elements having a first pair of opposite side walls each of which comprises a second sheet section in superposed relation with and in substantially full face-to-face contact with the respective one of said first sheet sections and each of said hollow shell elements having a second pair of opposed side walls intermediate of and generally transverse to said first pair of side walls;

means integrally connecting said hollow shell elements with said longitudinal web means at said respective superposed first and second sheet sections thereof substantially along the full face-to-face contact region there-between so as to form said shell elements and said web means into a composite integral structure;

second means integrally connecting one of said intermediate side walls of one of said shell elements with the adjacent one of said shell elements in said channel, said second means comprising transverse web means including a pair of integrally connected additional sheet sections located substantially in said channel and defining between themselves a second channel extending transversely with respect to said first mentioned channel, one of said additional sheet sections being in superposed relation with said one of said intermediate side walls of said one shell element and the other of said additional sheet sections being in superposed relation with the adjacent one of said intermediate side walls of said adjacent one of said shell elements.

8. The structural member according to claim 7 wherein said hollow shell elements and said longitudinal and transverse web means each consists of a plurality of laminated sheets of paper.

9. The structural member according to claim 7 wherein said first and second channels each have a V-shaped cross-section and each of said hollow elements of sheet material is pyramid-shaped.

10. The structural member according to claim 9 wherein the apex angle of said first V-shaped channel is substantially identical to the apex angle formed by said first mentioned pair of opposite side walls of said pyramid-shaped hollow elements whereby the latter may be snugly nested therein.

11. The structural member according to claim 7 wherein each of said first and second sheet sections and said hollow-shell elements consists of laminated sheet material.

12. A structural member according to claim 7 wherein said transverse web means comprises a diamond-shaped sheet of material folded along the shorter diagonal thereof for forming said pair of second sheet sections each having a triangular shape and inclined with respect to each other.

13. A structural member comprising:

longitudinal web means of sheet material including a pair of integrally connected, elongated, generally planar first sheet sections relatively inclined to one another and defining between themselves an elongated channel, each of said first sheet sections having a first and a second longitudinal edge portion and all of said edge portions being substantially parallel to each other with adjacent ones of said first sheet sections being connected to one another along said second edge portions thereof and said first edge portions of said first sheet sections together defining a given plane;

a plurality of hollow shell elements of sheet material arranged in side-by-side adjacency in and longitudinally distributed along said elongated channel, each of said hollow shell elements having a pair of opposite side walls each of which comprises a second sheet section in superposed relation with and in substantially full face-to-face contact with the respective one of said first sheet sections;

means integrally connecting said hollow shell elements with said longitudinal web means at said respective superposed first and second sheet sections thereof substantially along the full face-to-face contact region therebetween so as to form said shell elements and said web means into a composite integral structure, each of said hollow shell elements having a second pair of opposed side walls intermediate said first mentioned pair thereof, and

means integrally connecting, along a fold line substantially located in said given plane, one of said intermediate side walls of one of said shell elements with the adjacent intermediate side wall of the next adjacent one of said shell elements in said channel.

14. The structural member according to claim **13** wherein said connected second sheet sections are respectively located on opposite sides of and inclined with respect to a plane which is normal to each of said pair of first sheet sections and which includes said fold line.

15. The structural member according to claim **13** wherein said hollow shell elements are pyramid-shaped, said hollow pyramid-shaped elements being open at the bases thereof and being formed of a folded flat sheet material, said pyramid-shaped hollow elements being positioned in said first mentioned elongated channel with said base portions thereof located generally in said given plane.

16. The structural member according to claim **15** wherein said connecting means comprises adhesive means for joining together said hollow elements, said longitudinal web means, and said transverse web means, at the corresponding overlying surface portions thereof.

17. A structural member comprising:

longitudinal web means of sheet material including a pair of integrally connected elongated first sheet sections relatively inclined to one another and defining between themselves an elongated channel;

a plurality of hollow, pyramid shaped, four sided shell elements of sheet material arranged in side-by-side adjacency in and longitudinally distributed along said elongated channel, each of said hollow sheet elements having a first pair of opposed side walls and a second pair of opposed side walls intermediate said first pair, each of said first pair of side walls comprising a second sheet section in superposed relation with and in substantially full face-to-face contact with the respective one of said first sheet sections;

means integrally connecting said hollow shell elements with said longitudinal web means at said respective superposed first and second sheet sections thereof substantially along the full face-to-face contact region therebetween so as to form said shell elements and said web means into a composite integral structure;

each of said pyramid shaped hollow shell elements having base edge portions forming an open rectangular base and adjacent transverse ones of said base edge portions of adjacent ones of said shell elements being in close proximity with one another;

and means integrally connecting one of said intermediate side walls of one of said shell elements with the adjacent intermediate side wall of the next adjacent one of said shell elements in said channel.

18. The structural member according to claim **17** wherein said second means comprises transverse web means having surface portions overlying adjacent surface portions, respectively, of said intermediate side walls of a pair of adjacent pyramid-shaped elements whose adjacent transverse base edges are in close proximity with one another.

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