

Aug. 10, 1965

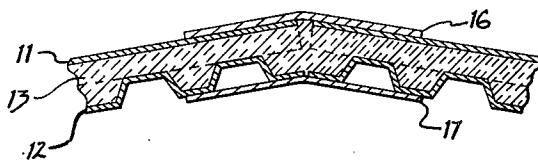
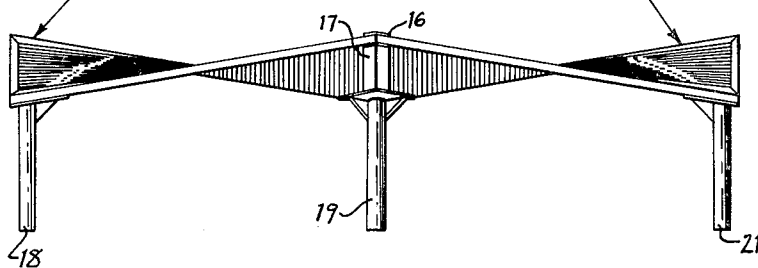
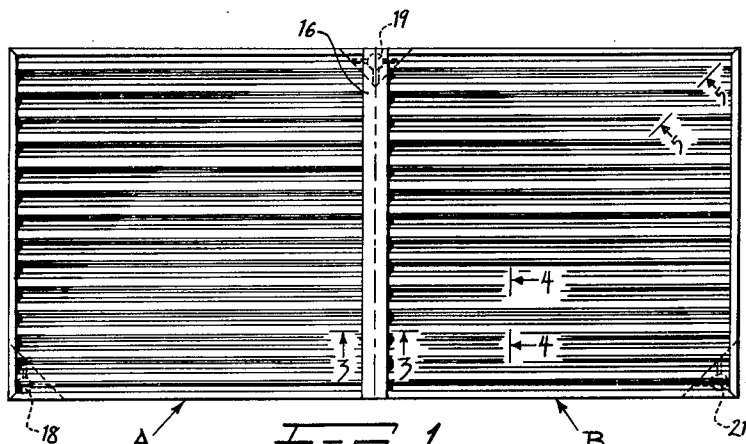
A. T. BROWN

3,200,026

METHOD OF PRODUCING A SHELL ROOF STRUCTURE

Filed April 21, 1960

4 Sheets-Sheet 1



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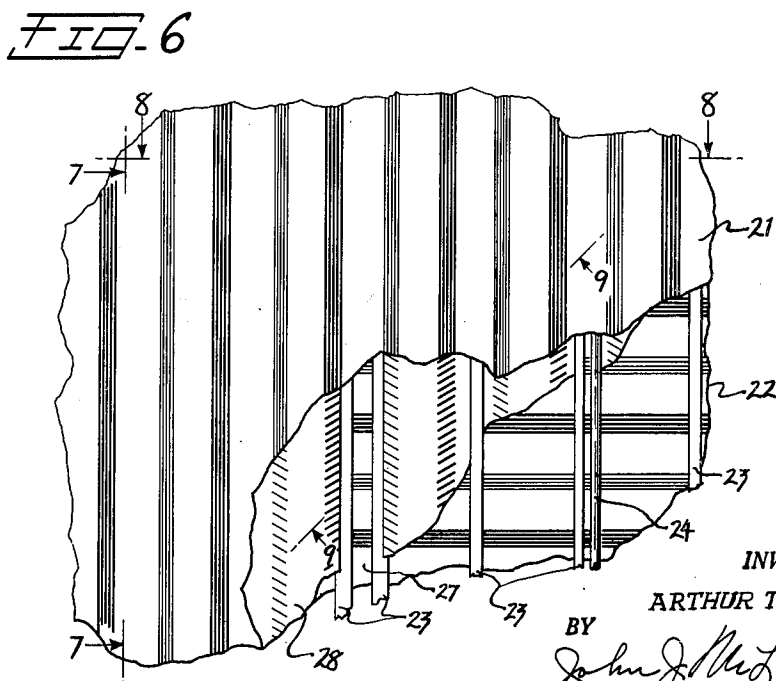
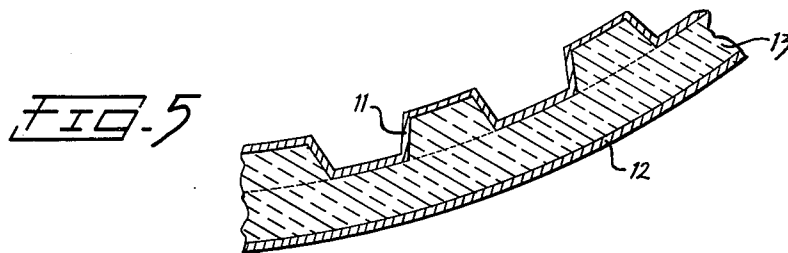
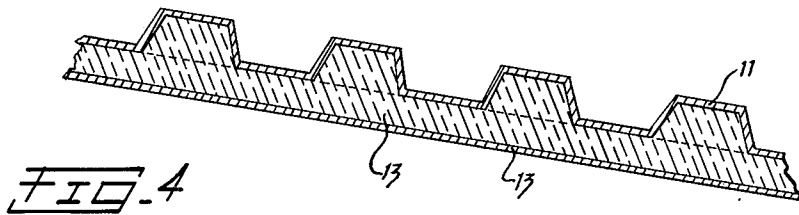
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METHOD OF PRODUCING A SHELL ROOF STRUCTURE

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4 Sheets-Sheet 2



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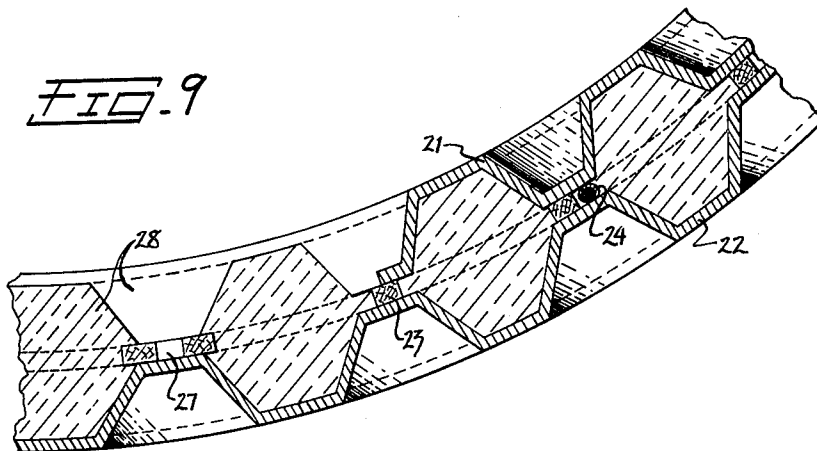
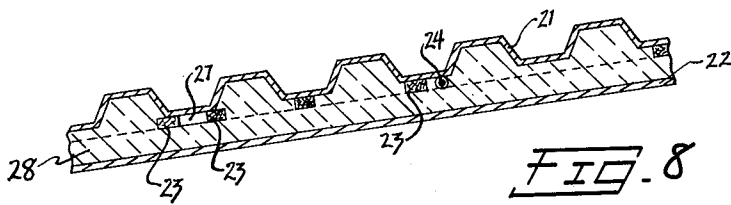
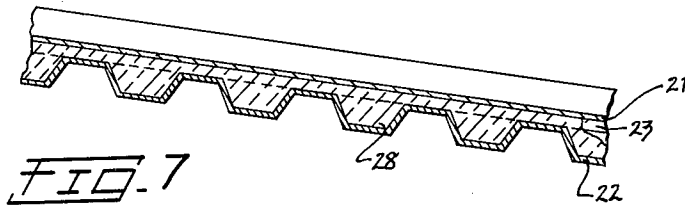
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METHOD OF PRODUCING A SHELL ROOF STRUCTURE

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4 Sheets-Sheet 3



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METHOD OF PRODUCING A SHELL ROOF STRUCTURE

Filed April 21, 1960

4 Sheets-Sheet 4

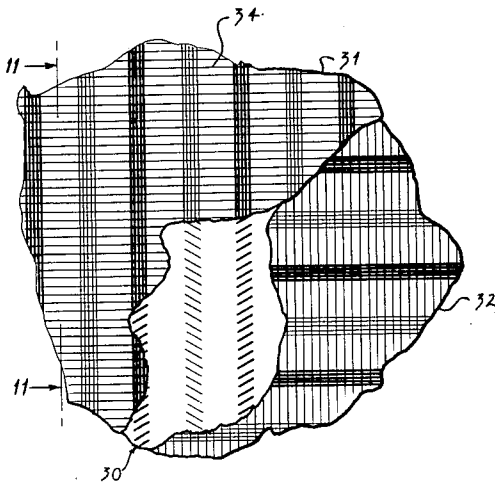


FIG. 10

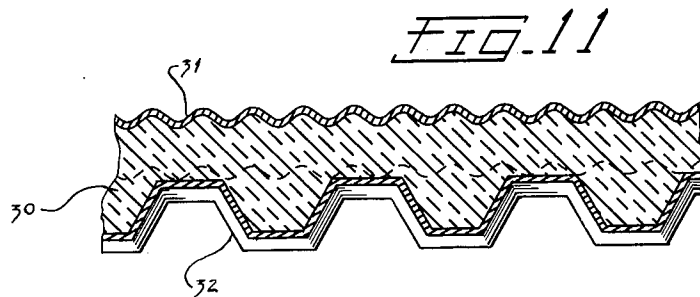


FIG. 11

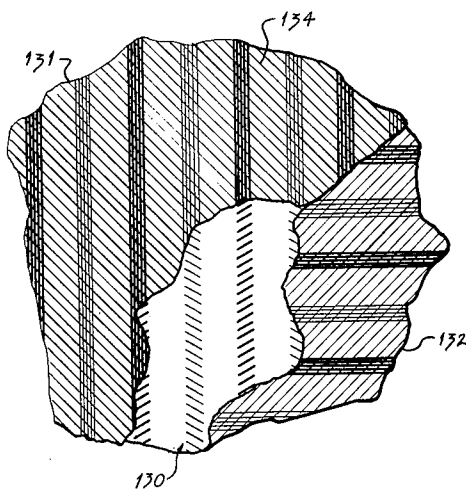


FIG. 12

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3,200,026 METHOD OF PRODUCING A SHELL ROOF STRUCTURE

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4 Claims. (Cl. 156-292)

My invention relates to an improved shell type roof structure and method of producing same wherein the completed roof or the like structure comprises preferably a hyperbolic paraboloid.

In my previous application, Serial No. 785,406, filed Jan. 7, 1959, I disclosed a shell roof structure and method of producing same wherein a plurality of mutually superposed structural sheet members, such as corrugated structural sheets of commerce or modification thereof, have their opposite side edges rotated in opposite directions to produce a shape in which all diagonals are curvilinear and lines running perpendicular to the edges are straight, and securing the sheets together at a plurality of points along their engaging surfaces to retain the composite structure so established. I have found marked advantages in the use of a structure of this type. One feature in the nature of disadvantage, however, as I have utilized the structure of my prior application, is that given relatively thin sheet metal, which is preferred to retain lightness, it is necessary to secure the sheets together at a relatively large number of locations in order to prevent tearing at the points of attachment. I have also found some limitations in the use of the specific structure shown in the drawings of the prior application, particularly where it is desired to incorporate insulation material or provide conduits or similar passageways for wiring or the like.

The principal object of my invention is to improve the shell roof structure of my prior application.

Another object is to provide improved structures and methods utilizing the general features disclosed in my prior application.

Other specific objects and features of my invention will be clear from the following detailed description taken with the accompanying drawings, wherein:

FIGS. 1 and 2 are plan and front elevational views respectively showing one form of the roof of my invention;

FIG. 3 is a slightly irregular enlarged fragmentary sectional view taken on the line 3-3 of FIG. 1;

FIG. 4 is a similar enlarged sectional view taken on the line 4-4 of FIG. 1 at right angles to the sectional view comprising FIG. 3;

FIG. 5 is a diagonal sectional view taken on the line 5-5 of FIG. 1;

FIG. 6 is an enlarged fragmentary plan view showing a modified structure, as contrasted with FIG. 1, part of the figure being broken away to show structure;

FIG. 7 is a sectional view taken along the line 7-7 of FIG. 6 showing a separator strip in broken lines;

FIG. 8 is a sectional view taken on the line 8-8 of FIG. 6;

FIG. 9 is a diagonal sectional view taken on the line 9-9 of FIG. 6;

FIG. 10 is a fragmentary plan view showing the use of small transverse corrugations;

FIG. 11 is a sectional view taken on the line 11-11 of FIG. 10, and,

FIG. 12 is a fragmentary plan view, showing the manner in which the small corrugations may be made to run diagonally.

As in my prior application, I take advantage of the principles developed in the production of concrete shell roofs of the hyperbolic paraboloid type in that curvilinear sections occur only along diagonals; but sections may be taken in one direction and directly at right angles thereto, and both of the latter sections will represent straight lines. In the forming of shell roofs of this type out of concrete, all of the forms used are straight timber; but each timber form is tilted or rotated with respect to the form next to it to develop the curve which occurs along the diagonal lines. As in my prior application also, I may use typical uniformly corrugated sheets of mild steel with the corrugations of successive sheets running at right angles to each other, so that by grasping opposite edges of the corrugated sheets and twisting them in opposite directions, a hyperbolic paraboloid type shape will be generated. If, now, the sheets are secured together in the shape to which they have been adjusted by the twisting action, the resulting unit form will be retained.

While the sheets making up the roof structure of my present invention, for convenience, may comprise typical uniformly corrugated sheets, they may also be of special construction as will be explained later in the specification. While any structure may be used which permits warping and skewing without appreciable loss of strength, a preferred special form is a uniformly corrugated sheet with relatively large mutually parallel corrugations, with small corrugations running across the large corrugations.

In accordance with my present invention, I secure the superposed sheets together over an area comprising substantially all their mutually facing surfaces by means of any suitable adhesive material, preferably an adhesive material which is relatively rigid and has insulation properties, and preferably also a material such as foam insulation which is relatively light in weight. While a single material is preferably employed for adhesiveness, insulation and lightness, it is, of course, possible to use separate materials, particularly in accordance with modifications which will be described. In carrying out the practices of my present invention, the superposed sheets of corrugated or the like material may be secured together directly at the various points where they come in contact, or strips of insulating material, such as wood, rigid cellulosic fibre, pre-cast plastic or the like may be secured to a convex portion of a corrugation, longitudinally of such corrugation, and thereafter the second sheet secured to the said strips adhesively at the points where its corrugations cross said strips.

The insulation employed is a type that may be poured, gunned, blown or otherwise injected into the cavities formed by the irregular structures of the superposed sheets. In the case of corrugated sheets, these cavities take the form of trough-like openings running at right angles to each other interconnected only where they cross each other. The insulation material should be one which will set in the position to which it is injected and will adhere to the superposed sheets. Thus by forming a series of locking projections running cross-ways of each sheet the resulting structure resists deformation because stresses are distributed throughout the completed roof structure. When the separating strips are employed, the insulating material comprises not only the portion filling

the convex portions of the corrugations but also a connecting flat area between the separating strips. While the intermediate adhesive material may be introduced before or after the sheets are "warped" to form the hyperbolic paraboloid type shell, it is essential that they be held in such position while the intermediate material sets.

Any suitable expedient, of which there are many, may be employed to shape the superposed sheets and hold them in position until the adhesive material used for the purpose has set. Some of such expedients are discussed in my prior copending application. One method is to employ framing members on the edges to hold the sheets together with a desired amount of twist until the adhesive and insulating material has been introduced and has hardened in place, after which the individual framing members are removed. Still another method is to first produce the form required, then secure the sheets together at a plurality of points by means such as riveting or welding so that they temporarily retain their shape, and then introducing the adhesive and insulating material which will then set before undue strain has been placed on the superposed sheets such as might cause the temporary fastening means to give away. When the separating strips are used between the sheets, preliminary attachment may be by adhesive material different from the insulating material, or, of course, the strips may be temporarily secured as by riveting and the insulation and adhesive material subsequently introduced. While considerable advantage results from using insulating material for the separating strips, that may of course be any desired material, even strips of metal if the loss of insulation at the points of contact can be accepted. It is also to be understood that if any wire, pipe or the like is to be incorporated in the space between the superposed sheets forming the roof, such objects should be introduced before the foam insulation or the like is applied, or suitable baffles provided to leave a plenum through which wires, pipes and the like can later be passed.

Looking at the drawings now, FIG. 1 is a plan view substantially identical with that shown in FIG. 1 of my prior application, in which the roof structure comprises two units, A and B, each consisting of identical superposed sheets 11 and 12 and each comprising corrugated sheets, with the corrugations of the top sheet 11 running at right angles to corrugations of the bottom sheet 12. Each of the units A and B is a hyperbolic paraboloid, the superposed corrugated sheets 11 and 12 being twisted in the manner described hereinabove and secured together throughout their entire facing surfaces by a plastic layer 13, preferably having both adhesive and insulating properties. An example of such a layer is suitably one of the commercial foaming plastics, such as polyurethane sold commercially under various trade names and having the property of foaming to produce a relatively light structure when applied and the further property of adhering firmly to the sheet material and to itself. Many types of such substances are available as will be mentioned hereinbelow.

As the elevation comprising FIG. 2 shows, and as been made clear in my prior application, all of the exterior edges of the units A and B comprise straight lines, as do all sections taken either transversely or directly longitudinally of FIG. 1 as FIGS. 3 and 4 show. Each section, however, which is taken diagonally of the units is curved as appears clear from FIG. 5.

While each of the units A and B may comprise a separate roof, they are illustratively joined together along their contacting edges by upper and lower gusset strips 16 and 17. These gusset strips may be secured above and below the line joining the sections by riveting, welding or the like; but they may also be secured in position by introducing the same type of material between the gusset strips and the roof units as employed to form the layer 13. As in my previous disclosure, the roof structure comprising FIG. 1 may be supported on three posts

or pillars 18, 19 and 21, post 19 being common to the units A and B and the other two posts 18 and 21 supporting the units A and B respectively at their lowermost outside corners. These supports may be a portion of a load bearing wall, a buttress or any structural member forming a part of an architectural design; or the roof may be supported at one edge to produce an overhang as is sometimes done in shell structures.

Any treatment common to architectural design and construction principles may also be utilized in framing the roof, finishing it and otherwise making it a part of a complete building as indicated by design and utility considerations. Drainage may be handled in the manner suggested in my prior application or in any suitable way common to building practices. While the two unit roof shown is illustrative, many different shapes and sizes may be produced, either of a single unit roof or of a composite roof comprising a number of units. As FIGS. 3, 4 and 5 show, the layer of bonding material 13 not only causes the sheets 11 and 12 to be secured together at each of the points where the corrugations of one sheet engage the corrugations of the adjacent sheet running at right angles thereto, but it also is attached to the entire surface of each of the sheets 11 and 12. Because of the corrugations, much more attaching surface is provided than would exist if these sheets were straight. For example, if a 10' x 10' square sheet of flat material would provide 100 sq. ft. of contact, a corrugated sheet may provide 150 or even 200 sq. ft. of contact. In addition, to this extensive area of adhesive contact of each of the sheets to the layer 13, the plurality of plastic projections extending into the concavities of corrugations produces a plurality of key-ways to positively lock the sheets against creep. While an adequately strong functional unit results from the use of two sheets bonded together in the manner described, a plurality of sheets, such as three or more, may be utilized if desired.

In the modification comprising FIGS. 6 through 9, I employ a top sheet 21 and bottom sheet 22, with separating strips 23 secured to convex portions of the corrugated sheet 22 and engaging crossways of the facing convex portions of the corrugations of sheet 21. The separating strips 23 may be made of wood or any rigid cellulosic fibre, plastic or the like material, preferably one having both strength and insulating properties. The strips 23 separate the sheets 21 and 22 bodily, a distance equal to the thickness of the strips 23. This permits the introduction of any required appurtenances such as a cable 24, or specially shaped and positioned strips can be employed to leave an open space 27 for the later passage of wires or the like. Between the sheets 21 and 22 there is a separating layer of adhesive plastic 28 which is similar to that shown in the first described embodiment, but it has substantially continuous layer between the separating strips from which the projections into the corrugations occur.

Thus it will be observed that whether the strips are used or not to space the superposed sheets, in all instances I employ two corrugated sheets with their corrugations running at right angles to each other, and with an intermediate layer of material substantially completely filling the corrugation. Many different types of intermediate material or mixture of materials may be employed providing the essential property of adhesiveness is always present, whereby the corrugated sheets are secured together throughout their entire facing surfaces to hold the sheet in "warped" position forming a composite unit of substantially hyperbolic paraboloid shape. A second preferred property of the intermediate layer is internal strength in compression and/or shear, which property may be referred to simply as rigidity. This property of rigidity in the intermediate layer causes the projections in the corrugations to act as key-ways to still further guarantee against creeping action and resulting loss of shape of the composite unit. Additional important properties are light-

ness and insulating value as expressed by a low K factor. While my invention is not concerned with the chemistry of substances having the combination of properties described, I have found that many plastic like materials available on the market and having the property of foaming when introduced into the space between the corrugated sheets have the best combination of properties for my purpose. Many solid thermoplastic substances such as bitumen tars, plastics and the like can be used, but generally they are too heavy for most purposes and are deficient as insulators. Many types of cements of commerce can be used but have the same types of limitations. Certain "foam" cements, such as the material known in commerce as "Betacel" are relatively light and fair insulators, but they sometimes bond relatively poorly to such materials as corrugated steel or aluminum, and they also frequently are deficient in compression strength. There are still other properties to examine from a chemical standpoint, such as compatibility of the intermediate layer and the sheets which they secure together. If a thermoplastic intermediate material should be used, it is essential that its setting temperature be higher than any ambient temperature to which it will be exposed.

While the invention as disclosed may be practiced suitably by the use of standard uniformly corrugated sheets of metal such as aluminum or steel, special shapes may be used which have the property of imparting strength while still permitting the skewing action necessary in producing the hyperbolic paraboloid unit. Whenever two superposed sheets are shaped to produce a curvilinear cross-section, the sheet on the outside of the bend will appear to shorten with respect to the sheet on the inside of the bend. When the sheets are separated this behavior is still more manifest. For this reason, in the practice of the invention as heretofore described it has been necessary for the most part to shape the composite unit first and then secure the sheets together. Even then the formation of the special building unit either entails the use of sheets which are not truly rectangular or the slight trimming of the sheets after the intermediate layer securing them together has hardened.

In the form of the invention shown in FIGS. 10 and 11, I employ two sheets indicated generally by the reference characters 31 and 32, these sheets being identical but being rotated 90° with respect to each other. The sheets are bonded together and separated by a layer of plastic or the like 30. Each of the sheets has a plurality of relatively large corrugations 33 with small corrugations 34 running transverse of the large corrugations. These sheets work exactly like the sheets heretofore described in producing the roof unit, but the relatively small corrugations permit adjustment longitudinally of the large corrugations as well as transversely of the same, the latter being the only type of length adjustment possible in the absence of the small corrugations or equivalent configuration. Using the relatively small cross corrugations 34, I have found that to produce the general structure of FIG. 10 with a general hyperbolic paraboloid configuration, that I can fasten the two sheets together when they are flat on the ground, the fastening being applied along the outer edges, the composite sheets then being pulled into shell form and the plastic layer 30 introduced to hold them together. I have also found that these small corrugations appear to assist in bonding the adhesive and providing additional shear strength longitudinally of the large corrugations.

FIG. 12 is a plan view showing a modification of the construction shown in FIGS. 10 and 11. In this form of the invention the small corrugations 134 run diagonally instead of directly transverse of the large corrugations. In this form of the invention substantially the same advantages are obtained as in the case of the FIGS. 10 and 11 structure.

I claim:

1. In the production of a hyperbolic paraboloid type structure for roofs and the like, the improved method of construction comprising

- (a) superposing two substantially flat sheets uniformly corrugated throughout their dimensions defined by two pairs of opposite parallel terminal side edges on each sheet, the corrugations defining each of said uniformly corrugated sheets being straight and parallel to the respective one pair of said side edges and extending continuously between the side edges of the respective other of said pairs, and positioning said sheets with their respective corrugations mutually facing and extending at right angles to each other,
- (b) rotating opposite edges of each of said pairs of each of said superposed sheets in opposite directions to form a hyperbolic paraboloid type shape while maintaining the side edges of said sheets straight and the corrugations in mutually facing relation, and
- (c) substantially filling the space between said sheets with a cellular adhesive filling material and holding said sheets in said hyperbolic paraboloid shape while said filling material sets and becomes substantially rigid to form a series of locking projections running crosswise of the corrugations of each sheet and adhering to substantially all of the adjacent surfaces of said sheets, thereby to distribute roof deforming stresses throughout the roof structure.

2. The method defined in claim 1, including the step of securing separating strips longitudinally of corrugations on one sheet to thus separate the sheets by the thickness of the strips to provide for the formation of a thicker intermediate layer when said adhesive filler material is disposed between the corrugated sheets.

3. The method defined in claim 1 wherein said adhesive filler material is a foamed plastic.

4. In the production of a hyperbolic paraboloid type structure for roofs and the like, the improved method of construction comprising

- (a) providing two substantially flat sheets uniformly corrugated throughout their dimensions defined by two pairs of two opposite parallel terminal side edges on each sheet, the corrugations defining each of said uniformly corrugated sheets being straight and parallel to the respective one pair of said side edges and extending continuously between the side edges of the respective other of said pairs,
- (b) applying separating strips longitudinally of corrugations on a first corrugated sheet,
- (c) superposing a second corrugated sheet on said first corrugated sheet whereby said sheets are positioned with their respective corrugations mutually facing and extending at right angles to each other and across said strips which thereby act as spacers,
- (d) rotating opposite side edges of each of said pairs of each of the so-superposed sheets in opposite directions to form a composite hyperbolic paraboloid while maintaining the side edges of said sheets straight and the corrugations in mutually facing relation,
- (e) introducing between the sheets in foamable condition a relatively light-weight adhesive filler material having the property of adhering to the sheets and setting to form a solid intermediate layer of a substantially rigid cellular filler forming a series of locking projections running crosswise of the corrugations of each sheet thereby to distribute roof deforming stresses throughout the roof structure, and
- (f) holding the composite unit in position until said intermediate material has set to form said locking projections.

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