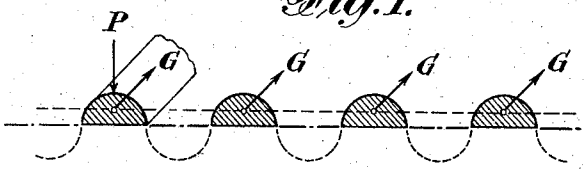
Feb. 27, 1934. K. KNUTSON 1,948,619

MEANS FOR INCREASING THE RIGIDITY OF CORRUGATED SHEET MATERIAL

Filed Sept. 22, 1932 4 Sheets-Sheet 1

Fig. 1.



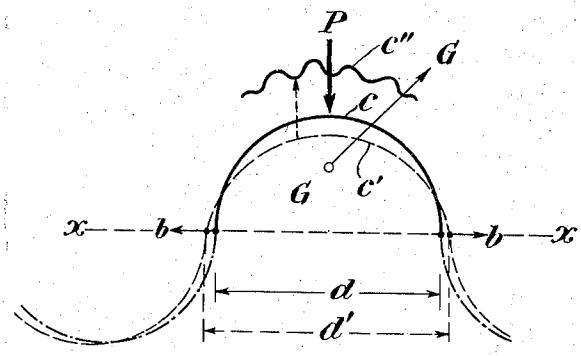


Fig. 2.

Fig. 3.

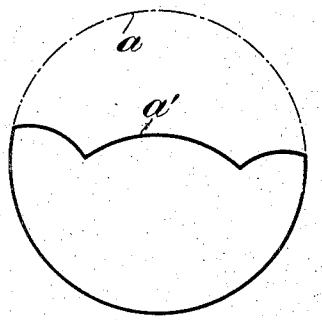
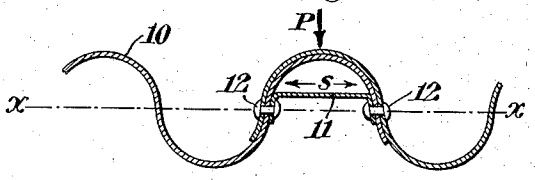


Fig. 4.



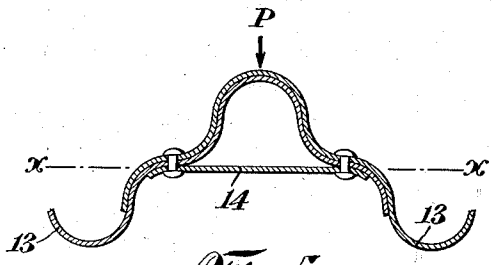
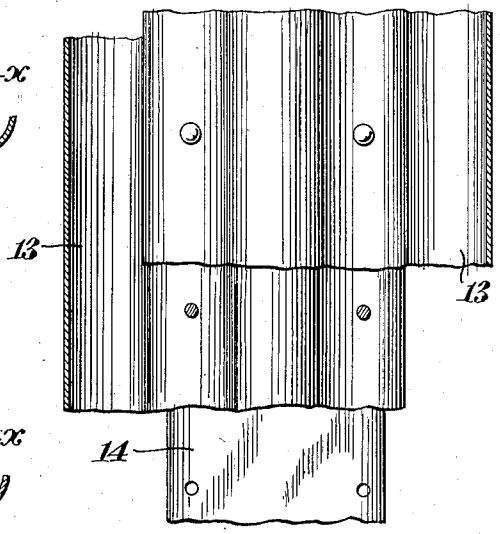


Fig. 5.

Fig. 6.



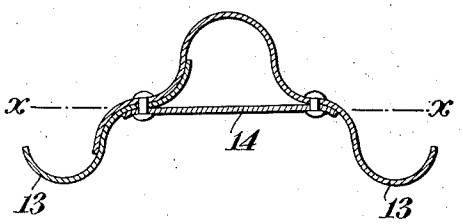


Fig. 7.

INVENTOR
Knut Knutson
BY Knight Bros.
Its ATTORNEYS

Feb. 27, 1934. K. KNUTSON 1,948,619

MEANS FOR INCREASING THE RIGIDITY OF CORRUGATED SHEET MATERIAL

Filed Sept. 22, 1932 4 Sheets-Sheet 2

Fig. 8.

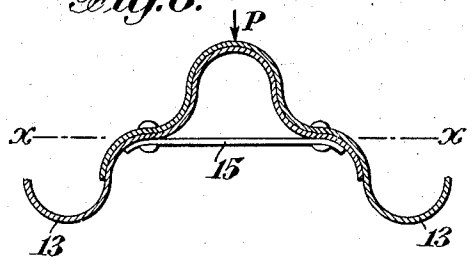


Fig. 10.

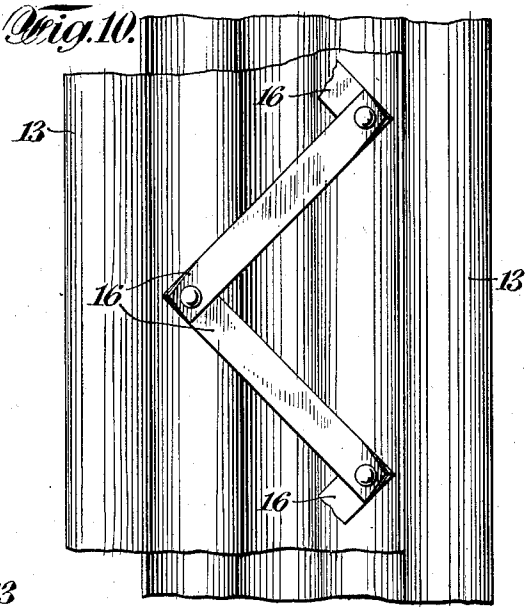


Fig. 9.

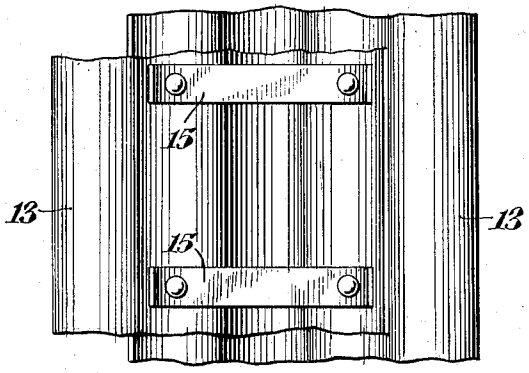


Fig. 11.

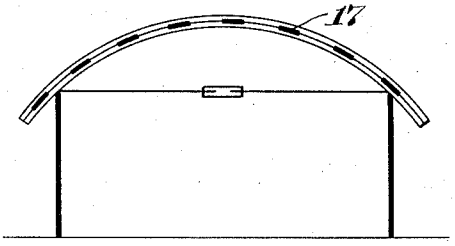


Fig. 13.

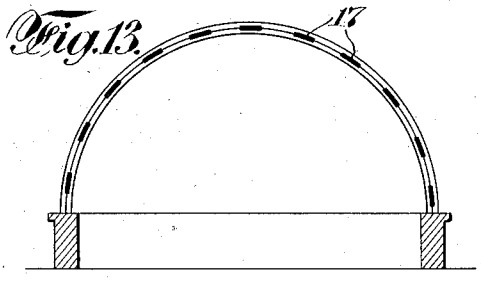


Fig. 12.

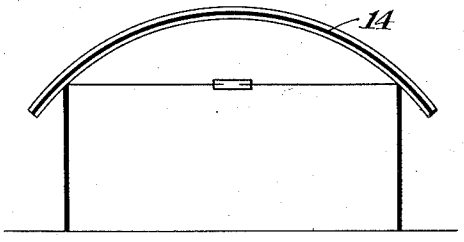
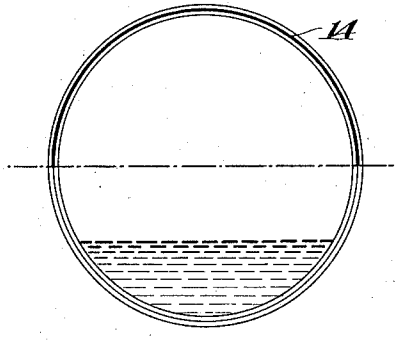


Fig. 14.



INVENTOR
Knut Knutson
BY Knight Bros.
his ATTORNEYS

Feb. 27, 1934. K. KNUTSON 1,948,619

MEANS FOR INCREASING THE RIGIDITY OF CORRUGATED SHEET MATERIAL

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Fig. 15.

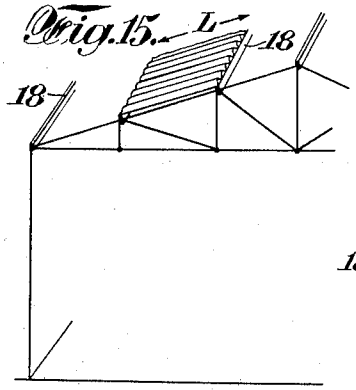


Fig. 16.

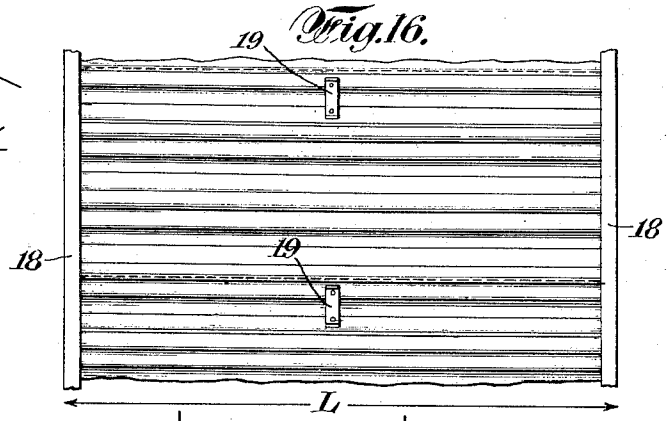


Fig. 17.

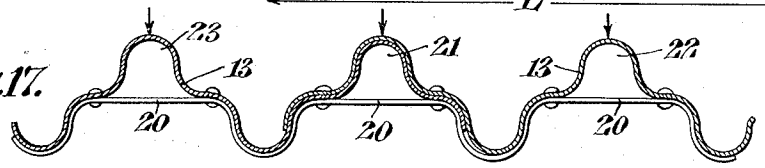


Fig. 18.

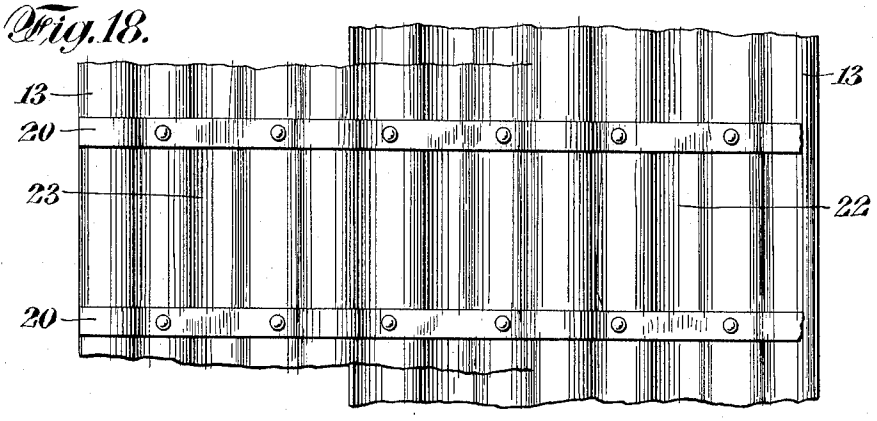


Fig. 19.

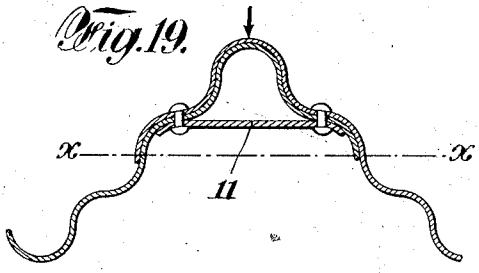
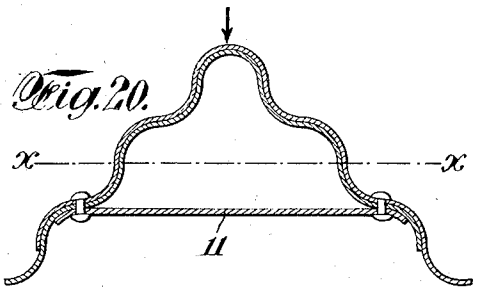


Fig. 20.



INVENTOR
Knut Knutson
BY Kreigh & Barr
his ATTORNEYS

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MEANS FOR INCREASING THE RIGIDITY OF CORRUGATED SHEET MATERIAL

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Fig. 21.

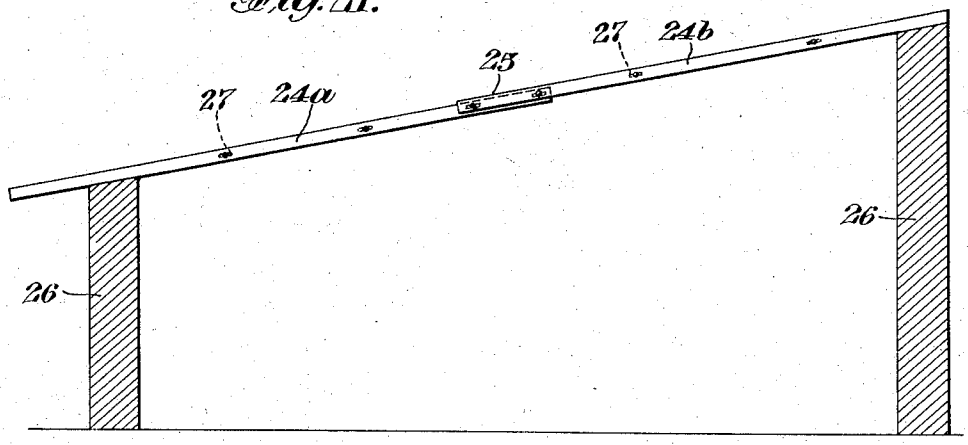
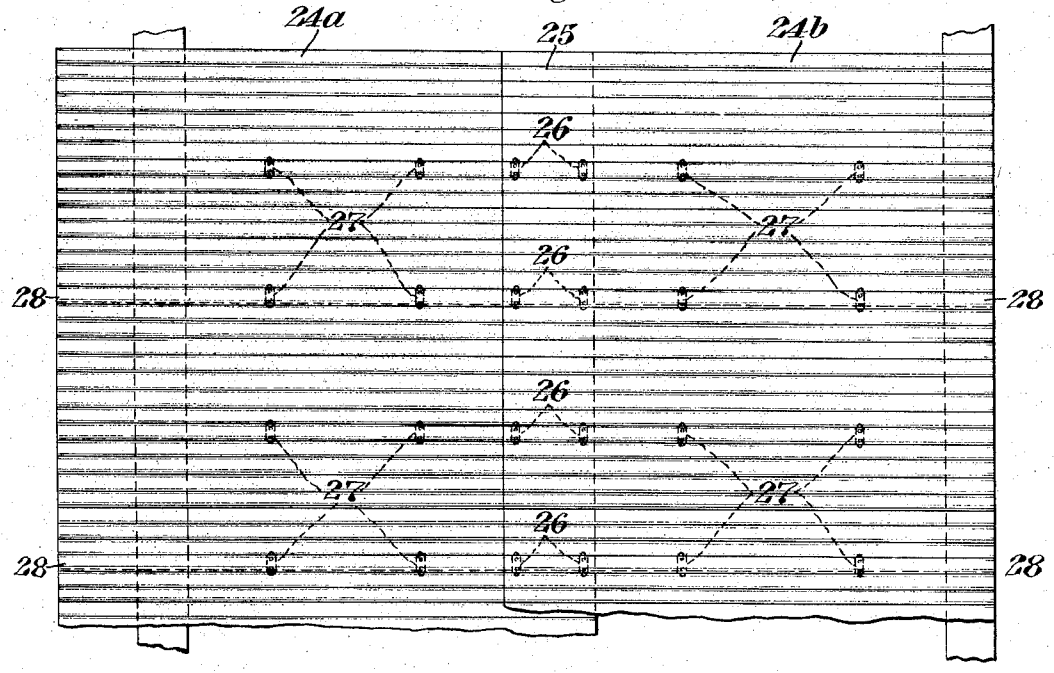


Fig. 22.



INVENTOR
Knut Knutson
BY Wright Brown
his ATTORNEYS

Patented Feb. 27, 1934 1,948,619

UNITED STATES PATENT OFFICE

1,948,619

MEANS FOR INCREASING THE RIGIDITY OF CORRUGATED SHEET MATERIAL

Knut Knutson, Brooklyn, N. Y.; Trine Selmer Knutson administratrix of said Knut Knutson, deceased

Application September 22, 1932
Serial No. 634,293

5 Claims. (Cl. 189—85)

My invention relates to corrugated sheet material, in particular to straight or curved corrugated sheet material, such as is used for structural purposes for walls, floors or roofs in buildings. This sheet material may either have single corrugations, or it may have so-called multiple corrugations such as are illustrated in the U. S. Patent No. 948,733, granted to me on February 8, 1910. The present invention purposes to increase the rigidity of either kind of corrugation, so that the resistance of the sheet against buckling forces is considerably increased, permitting as a consequence the erection of structures with larger spans of self-supporting corrugated sheet material, including even joints between the spans, than was possible heretofore with the standard sizes and forms of corrugated sheet material.

My invention is illustrated in the accompanying drawings in which—

Figs. 1, 2 and 3 represent explanatory diagrams.

Fig. 4 represents in cross-section a joint between two adjacent single corrugated sheets showing the location of a tie element according to my invention,

Fig. 5 represents in cross-section the application of my invention to a joint of double-corrugated material showing the use of a tie strip running the entire length of the corrugation portion,

Fig. 6 represents a top view of Fig. 5, the several layers of material being broken away at different points,

Fig. 7 represents a cross-section similar to Fig. 5, except that the latter figure shows a full corrugation overlap, while Fig. 7 shows a part corrugation overlap at the joint.

Fig. 8 represents in cross-section a joint between two double-corrugated material sections showing the use of tie bars placed at intervals straight across the top corrugation of the joint.

Fig. 9 represents a bottom view of the joint portion Fig. 8,

Fig. 10 represents a bottom view similar to Fig. 9, showing, as a modification, the tie bars placed diagonally across the top corrugation of the joint.

Fig. 11 represents in transverse section a shed with a curved self-supporting corrugated sheet roof employing tie bars as shown in Figs. 8 to 10.

Fig. 12 represents a shed in similar section with a self-supporting corrugated sheet roof employing tie strips as shown in Figs. 5 and 6.

Fig. 13 represents in transverse section a shed with a semi-circular self-supporting corrugated sheet roof employing tie bars as shown in Figs. 8 to 10.

Fig. 14 represents a tubular culvert of corrugated sheet material in which tie strips are employed in the upper half of the tube,

Fig. 15 represents diagrammatically a shed girder roof on the purlines of which the ends of the individual corrugated sheets are supported,

Fig. 16 represents in larger scale and in bottom view two purlines of Fig. 15 showing the joints between several corrugated sheet sections and the manner in which tie bars may be placed to permit larger spans between purlines,

Fig. 17 shows in cross-section a joint between two double-corrugated sheets and tie bars extending across the top corrugation of the joint and beyond either side of the joint to the adjacent top corrugations,

Fig. 18 represents a bottom view of Fig. 17,

Figs. 19 and 20 represent joints between triple-corrugated sheets showing tie strips or bars, respectively placed above and below the neutral axis of the joint, and

Figs. 21 and 22 show in transverse section and bottom view respectively a flat, corrugated shed roof with a span covering two sheet lengths and rendered self-supporting by suitably distributing tie bars, such as shown in Fig. 8, over the roof surface.

Through extensive laboratory tests with all sorts of corrugated sheet material I have ascertained that the maximum stresses at which a permanent material deformation or complete failure actually occurs, are as a rule by far lower than the accepted formulæ for such material would indicate. I have ascertained through long experience in the construction and erection of sheet material structures that very frequently self-supporting corrugated roof portions have buckled or given way unexpectedly under loads far below those which they would be expected to carry according to the conventional formulæ used for calculating such roofs. My recent investigations of this disagreement between theory and practice have shown that the cause of the failure of such sheets lies in the erroneous assumption by the art that the half corrugations of a corrugated sheet can be considered and calculated, with respect to stresses which they are to carry, as solid half round bars. For instance, as shown in Fig. 1, which illustrates a portion of a single-corrugated sheet, it was heretofore the practice of figuring the top corrugation—if the sheet is to serve as a roof—as a half round bar which should support the given load P in the direction of the ar-

row, and which would therefore be figured for bending stresses on the axis of gravity G. In reality this half-corrugation not only is not a solid bar, but does not act as a solid bar when put under load in the direction P in which it is put under buckling stresses. What happens to the top corrugation when put under load in the direction of the arrow is shown in Fig. 2. In this figure the top corrugation and part of a bottom corrugation is shown in larger scale. The neutral axis of the complete corrugation is *x*—*x*. When the load P is applied to the top corrugation in the direction of the arrow, the ends of this corrugation at or adjacent to the neutral axis *x* will spread in the direction of the arrows *b*—*b*, and the entire top corrugation *c* will assume the form shown in the dash line *c'*, and the sheet metal will crumble, assuming a form something like shown at *c''*. If the load P persists we have now a new form of top corrugation, namely *c'* which does not have the axis of gravity G, G for which the original corrugation was calculated and, therefore, the more the corrugation flattens out and spreads in the directions *b*—*b* the weaker its carrying capacity will be and the more it will fold up. The practical tests have proven this beyond any doubt. The spreading of the ends of the top corrugation in the vicinity of the neutral axis *x*—*x* will, of course, affect the adjacent bottom corrugations, and they in turn will transmit the lateral pressures to the remaining adjacent corrugations and thus produce a zone of flattened corrugations with a carrying capacity far below the value for which they were originally calculated. In other words, a self supporting portion of a corrugated sheet does not act, as was assumed heretofore, as an assembly of half round solid bars, but it acts like a corrugated rod which when put under load will spread in the direction of the neutral axis to either side and tend to flatten out, loosing its load resistance the more it flattens out into a straight rod.

For instance, a corrugated tube such as might be used for a culvert and such as is shown diagrammatically in Fig. 3 will, when put under a heavy load such as might be produced by a heavy truck passing over the culvert, give way in its upper portion approximately in the form shown at *a'* in Fig. 3. At the points where the failure occurs the corrugations will flatten out to such an extent that the material can be bent with a sharp corner the same as flat material would be bent.

In order to enable the designer to calculate the half-corrugations of a corrugated sheet, to which the load is applied and which are subject to buckling stresses, as solid bars with a permanent axis of gravity, such half corrugations must be put into a condition in which their ends in or adjacent to the neutral axis of the entire system are prevented from moving relatively to one another in the direction of the neutral axis, especially they must be prevented from spreading apart.

I have discovered that when means are provided which will hold the ends of such a loaded corrugation in fixed position, such a half corrugation may again, as heretofore, be figured as a solid half round bar with respect to its carrying capacity. Thus if, for instance, as shown in Fig. 4 with respect to a single-corrugated sheet 10 a so-called tie element 11 is attached across the half corrugation to which a load P may be applied in the direction of the arrow, and if this tie element 11 is fixed, such as by rivets 12 to the ends of the half corrugation in the vicinity of the *x* axis, this half corrugation will be prevented from spreading in the directions of the two arrows in that figure, and thus this portion of the corrugated sheet may be considered as a rigid bar so far as calculation is concerned.

I have shown in Fig. 4 the point at which the tie element 11 is applied to the half corrugation as a joint between two adjacent sheets 10 with a full overlap of the top corrugation of each sheet. The tie element 11, therefore, serves at the same time for holding the two sheets together at their junction. The forces which tend to spread the two ends of the top corrugation apart due to the load P are at first comparatively small, so long as the corrugation maintains its normal shape. Therefore, the tie element 11 is subject to only very small tension stresses and need not be thicker than the sheet itself, say about one millimeter, or whatever the standard of the sheets may be.

This tie element 11 may, as will be described and shown presently, have the form of a continuous strip extending along the entire half corrugation and riveted to it at intervals, or else as will also be described later, the tie element may consist of individual narrow tie straps, each riveted to the ends of the half corrugation in the vicinity of the *x* axis, and a number of strips may be spaced along that corrugation, for instance at the junction between two sheets. Furthermore, it is not necessary that such a tie element be applied to every half corrugation which is subject to buckling stresses. It may be sufficient for instance at small expected loads to apply such tie elements only to the top corrugations at the joints between two sheets. If there are greater load possibilities tie elements may be applied to one or several half corrugations subject to buckling stresses intermediate the joints. The principal idea involved in the invention, and by which the desired rigidity is imparted to such a sheet, is to change the character of such a sheet from that of a corrugated or wave-shaped spring with variable moments of resistance, more or less to that of a rigid structure which cannot be elongated appreciably under load in the direction of its neutral axis.

When a number of tie elements are thus fixed at a desirable number of unsupported sheet surface portions to the ends of the corrugation half subject to buckling stresses, a corrugated sheet of a given size is capable to freely support without buckling or bending very much greater loads than the sheet is ordinarily capable of sustaining without failure.

As will now be shown, my invention is applicable also to so-called double-corrugated sheets such as are covered by my aforementioned prior patent. Double-corrugated sheets per se have greater moments of resistance than single-corrugated sheets as has been explained in said patent, the ratio being about 1:1,6 if the resistance of a single-corrugated sheet is considered as unity. In triple-corrugated sheets this value will automaticaly be much higher being a number of times that of a single-corrugated sheet. These values for multiple-corrugated sheets, the same as is true with single-corrugated sheets, are only correct when under no load. As soon as load is applied to a double-corrugated sheet, the corrugation half subject to buckling stresses will in its own way fail the same as the half corrugation will fail in a single-corrugated sheet. By the "stressed corrugation half" in case of multiple corrugated sheets, I mean the entire portion of the corrugation located on the compression side

of the neutral axis x—x of the system, irrespective of the number of sub-corrugations which such a portion may contain. Therefore if, as shown in Fig. 5 for a full overlapping joint between two double-corrugated sheets 13, a tie element 14 is fixed to the main half corrugation which is located entirely on the compression side of the x axis, i. e. at which loads are likely to be applied in the direction of the arrow, this main corrugation half will be prevented from spreading, the same as described before with respect to the halves of single corrugations. As will appear more clearly from Fig. 6 the tie element 14 is here assumed to be in the form of a continuous tie strip extending along the entire length of the overlapping joint, and the rivets by which this strip is fixed serve at the same time for riveting the overlapping sheet ends together. It is not necessary, however, to make a full overlapping joint. As shown in Fig. 7 the adjoining sheet ends 13 may overlap only for a part of a corrugation, and the tie strip 14 at one edge be riveted to the joint, and at the other edge be riveted to one sheet only, approximately in line with the neutral axis x of the corrugated system.

As shown in Figs. 8 and 9, instead of using tie strips extending along the entire length of a half corrugation, in either single or multiple corrugated material, tie bars 15 may be attached at intervals to the corrugation half which is subject to buckling stresses. It is further not necessary to attach the tie bars 15 transversely to the direction in which the corrugations run. These bars may, with the same effect, also be attached in zig-zag fashion as shown at 16 in Fig. 10 which shows a bottom view of a double corrugated joint similar to that of Figs. 5, 7 and 8. Any of these forms of tie elements will transform the corrugation half to which they are attached into a rigid beam so far as calculating stresses is concerned. This is particularly important for the overlapping joints between the sheets and has the effect of a rigid stiffening element being provided at each joint.

Figs. 11 to 14 show a few examples of the manner in which my invention may be employed for enhancing the self-supporting character of corrugated sheet structures. Figs. 11 and 13 show respectively a building with a curved and a semi-circular corrugated sheet roof which in each instance is entirely self-supporting and is provided, as indicated by the heavy dashes 17 with tie bars such as are shown in Figs. 8, 9 and 10. I am thus able to cover with the ordinary standard sizes of corrugated sheets spans up to 75 feet without any supports for the sheet material intermediate the walls on which the roof rests. In Fig. 12 is shown a curved corrugated sheet metal roof which is provided with tie strips 14 along a number of corrugations in the manner shown in Figs. 5 and 6. In Fig. 14 is shown a tubular culvert made of corrugated sheet material in which the upper semi-circle of the tube is reenforced at suitable intervals with tie strips 14, such as shown in Figs. 5 and 6. The lower semi-circle of the tube does not require reenforcement in such a case since its corrugations rest uniformly against the soil while in the upper half of the tube, especially at the top extreme stresses transmitted from the road bed may occur at individual points of the culvert.

The enhanced self-supporting character of sheets reenforced according to my invention is important not only in case of entirely self-supporting corrugated sheet roofs, but also of advantage where corrugated sheet material is used for roofing of buildings provided with a girder roof structure. In such cases the corrugated sheets are laid onto the purlines which are carried by the girders. Due to the fact that sheets according to my invention will freely support greater weights, the purlines can be spaced further apart, and thus considerable material and labor can be saved in the roof construction. In Fig. 15 a portion of a girder roof is diagrammatically shown, together with its purlines 18. The distance between two purlines may be L. The corrugated sheet which is shown in Fig. 15 rests with its ends on the purlines on bolsters of suitable form not shown here. In Fig. 16 a bottom view of this sheet, together with portions of the adjoining sheets is shown in larger scale. It may be sufficient for a moderate expected load, such as a man walking on the roof, or the load of ice and snow, to use one tie bar 19 for each joint intermediate the distance L between the purlines. How many tie bars are to be used is entirely within the judgment of the designer in accordance with the prevailing conditions. In cases such as the roof constructions described hereinbefore it may be desirable to extend the tie bars from the joint at which they are applied to at least one other half corrugation on either side of the joint, which will thus impart increased rigidity to such sheet portion. The manner in which these tie bars are applied is shown in Figs. 17 and 18 for double-corrugated sheets. In this case the tie bar 20 is first of all riveted across the loaded half corrugation of the joint between the two sheets 13. It extends, however, to either side of the joint around the bottom corrugations and is riveted across the ends of the adjacent top corrugations 22 and 23, likewise under buckling stresses, so that three top corrugations are thereby reenforced, forming a broad beam running the entire length of the sheet. Fig. 18 shows the bottom view of a sheet roof thus reenforced.

In case of multiple-corrugated sheets it is not absolutely necessary that the tie element, such as a strip or a bar be attached to the corrugation under buckling stresses exactly in line with the neutral axis x of the corrugated system. For instance, as shown in Fig. 19 the tie element 11 may be attached to the stressed half corrugation above the x axis, and as shown in Fig. 20 it may be attached to the half corrugation under buckling stresses below the x axis. Calculations will easily give the most favorable position in each case, to prevent spreading.

Figs. 21 and 22 show a flat shed roof of corrugated sheet material which consists in transverse direction of several sheets, but owing to the arrangement of tie elements according to my invention becomes nevertheless not only self-supporting, but capable of sustaining substantial weights. 24^a and 24^b are two sheets overlapping at one end at the joint 25, and each resting at its other end on one of the shed walls 26. The center joint 25 running longitudinally of the shed is held together by the use of two tie bars 26, first of all at the transverse joints between the corrugated sheets which run in the direction of the channels of the corrugation, i. e. transverse to the shed axis. Furthermore, intermediate longitudinal joint 25 and the points at which the roof rests on the shed walls, two additional tie bars 27 are provided not only at the transverse joints 28 between the sheets, but also intermediate the transverse joints. Comparatively few

tie bars thus distributed over a large surface will impart to such a roof a rigidity which renders it not only self-supporting, but also capable of sustaining substantial loads without increasing the gauge of the metal of which the corrugated sheet is made. In this manner I am able to cover flat roof spans, such as are shown in Fig. 21, up to 20 and 30 feet, using two or three sheets, such as 24^a and 24^b across the span. I find that by using the reenforcing means according to my invention the cost of corrugated sheet construction can be lowered from 25 to 45%, due to the omission of purlines or trusses, and corrugated sheet structures become steadier and can be more easily standardized so far as calculation of stresses is concerned.

The reenforcing method for corrugated sheet material according to my invention is of great advantage and importance not only for building structures, but also for aviation. In certain types of airplanes corrugated sheet metal, especially corrugated sheet aluminum is employed for the fuselage walls and for the wing covering. Especially the latter is subject to greatly varying stresses which have compelled the designers to employ cumbersome and heavy truss constructions inside of the wings. By utilizing tie strips or bars according to my invention at the stressed points, truss structures can be omitted in many places.

These tie elements are intended to be used in air craft in the same manner as described with respect to stationary structures, i. e. these elements must tie together the ends of substantially the entire corrugation half located on the compression side of the neutral axis x of the corrugated system, and irrespective of the number of sub-corrugations (such as exist in multiple corrugated sheets) which such a stressed half may contain.

Therefore, when I refer in the annexed claims to "a corrugation half, subject to buckling stresses", I mean in case of single-corrugated material the single half corrugation located at the compression side of the neutral axis of the entire system, and in case of multiple corrugated sheets I mean substantially the entire main corrugation half on the compression side of the neutral axis, irrespective of the number of sub-corrugations in the main half, because in the latter case that entire main corrugation half would tend to spread under compression stresses.

Also corrugated aluminum roof construction is rendered by the use of my invention cheap enough to render it competitive with corrugated iron construction because, owing to the use of tie elements, much thinner aluminum sheet gauges can be employed than is possible at present.

In the construction of corrugated sheet roofs the further advantage accrues in the use of the improvements according to my invention. Frequently corrugated sheet roofs are sealed on the inside either with board sealing or with plaster applied to wire lath, in order to give the interior a more pleasing appearance. Since, as was explained hereinbefore, the ordinary corrugated sheet roof has the character of a spring which expands and contracts in the direction of the neutral axis, plaster ceiling applied to such a base, cracks and peels off very frequently. Board ceilings will split open. When, according to my invention the desired rigidity is imparted to such a corrugated roof, the aforementioned defects are overcome.

I claim:—

1. A corrugated sheet for spanning spaced supports and having a multiplicity of corrugations, said sheet including a plurality of tie straps extending at the unsupported sheet portions substantially in the neutral axis of the corrugations between, and being secured to the ends of at least some of the corrugation halves of only that group of halves subject to buckling stresses, to tie said ends in fixed relation to one another, to increase the resistance against spreading of the corrugations in the direction of the neutral sheet axis due to an applied load.

2. A corrugated sheet having a multiplicity of corrugations and spanning spaced supports and being composed of a plurality of corrugated sheet sections overlapped at their adjoining edges, said sheet including a plurality of tie straps extending at least at the unsupported overlaps substantially in the neutral axis of the corrugations between, and being secured to the ends of at least some of the corrugation halves of only that group of halves subject to buckling stresses, to tie said ends in fixed relation to one another, to increase the resistance against spreading of the corrugations in the direction of the neutral sheet axis due to an applied load.

3. A corrugated sheet for spanning spaced supports and having a multiplicity of corrugations, said sheet including tie straps extending at the unsupported sheet portions substantially in the neutral axis of the corrugations along the ends of at least some of the corrugation halves of only that group of halves subject to buckling stresses, said straps being secured at their edges to the ends of said halves to tie said ends in fixed relation to one another, to increase the resistance against spreading of the corrugations in the direction of the neutral sheet axis due to an applied load.

4. A corrugated sheet for spanning spaced supports and having a multiplicity of corrugations, said sheet including a plurality of tie straps spaced apart on the unsupported sheet portions along at least some of the corrugation halves of only that group of halves subject to buckling stresses, said straps being located substantially in the neutral axis of the corrugations and being individually secured at their ends to the ends of said corrugation halves to tie said ends in fixed relation to one another, to increase the resistance against spreading of the corrugations in the direction of the neutral sheet axis due to an applied load.

5. A corrugated sheet having a multiplicity of corrugations and spanning spaced supports and being composed of a plurality of corrugated sheet sections overlapped at their adjoining edges, said sheet including a plurality of tie straps extending at least at the unsupported overlaps substantially in the neutral axis of the corrugations between, and being secured to the ends of at least some of the corrugation halves of only that group of halves subject to buckling stresses, to tie said ends in fixed relation to one another, to increase the resistance against spreading of the corrugations in the direction of the neutral sheet axis due to an applied load, said tie straps extending and being similarly secured also to adjacent similarly stressed corrugation halves.

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