July 20, 1954 F. H. RUPPEL 2,684,134

STRUCTURAL DIAPHRAGM FOR BUILDINGS

Filed July 28, 1947

4 Sheets-Sheet 1

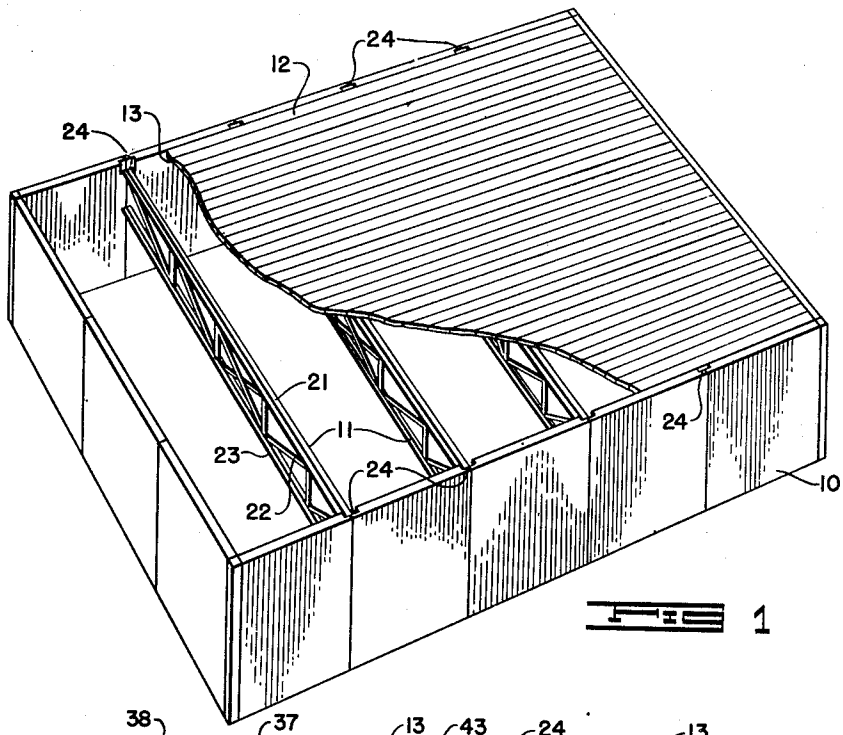


FIG 1

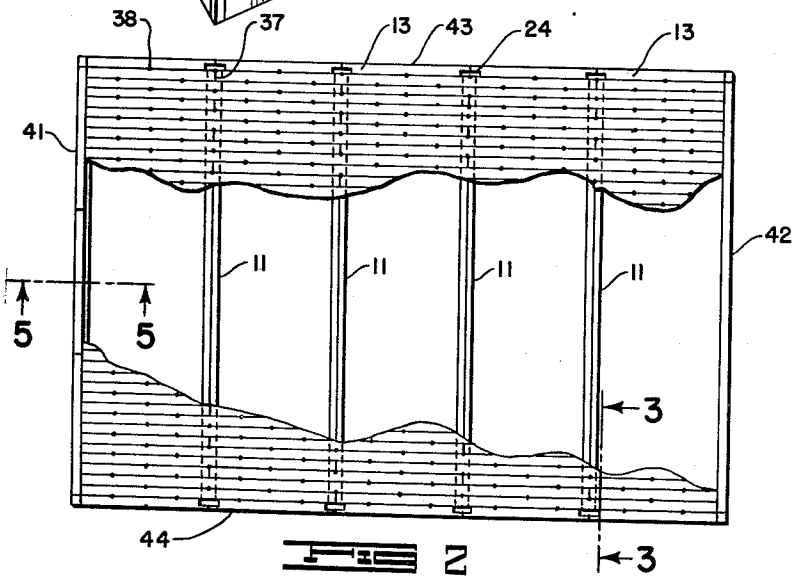


FIG 2

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STRUCTURAL DIAPHRAGM FOR BUILDINGS

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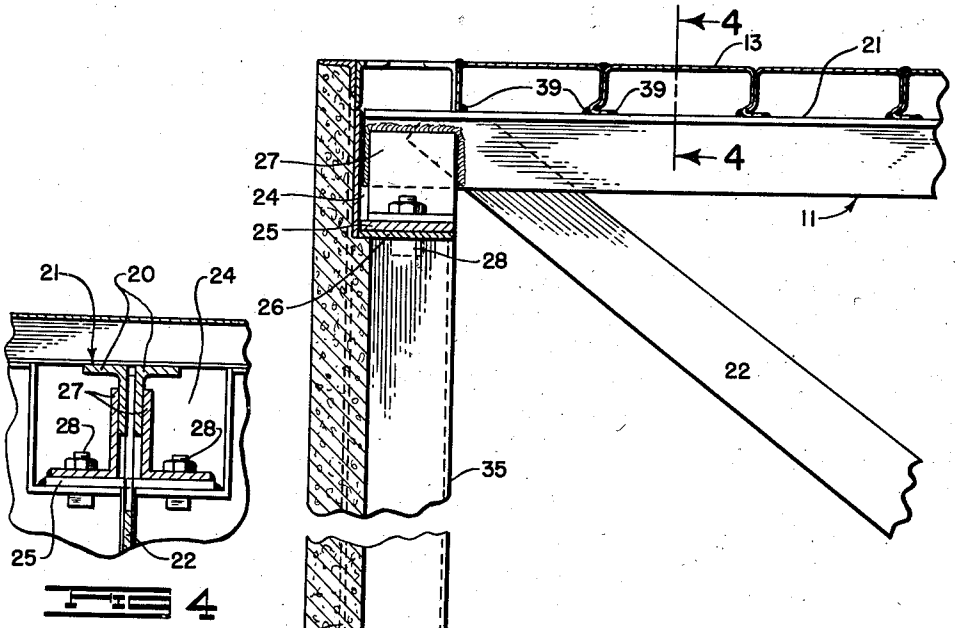


FIG 4

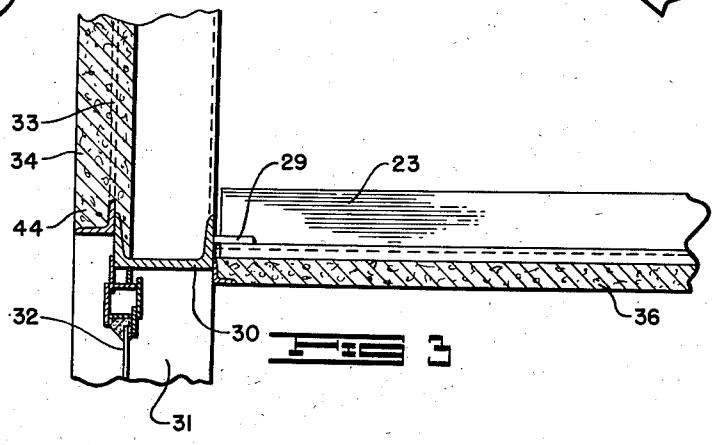


FIG 3

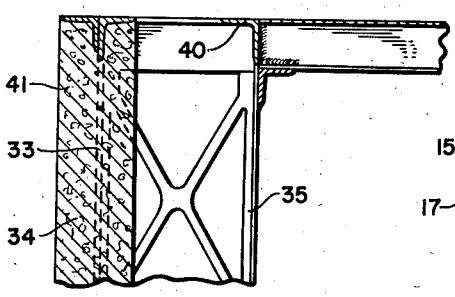


FIG 5

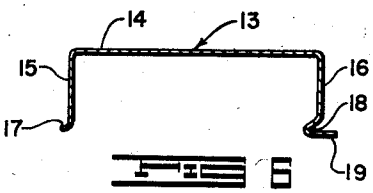


FIG 6

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STRUCTURAL DIAPHRAGM FOR BUILDINGS

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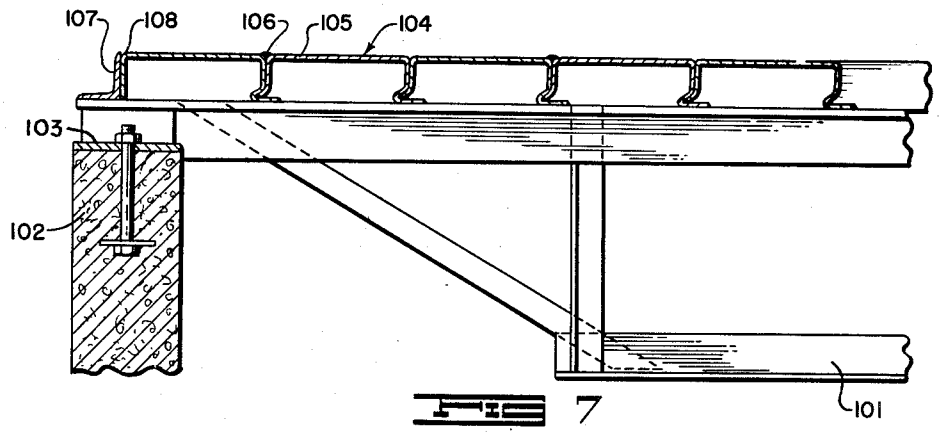


FIG 7

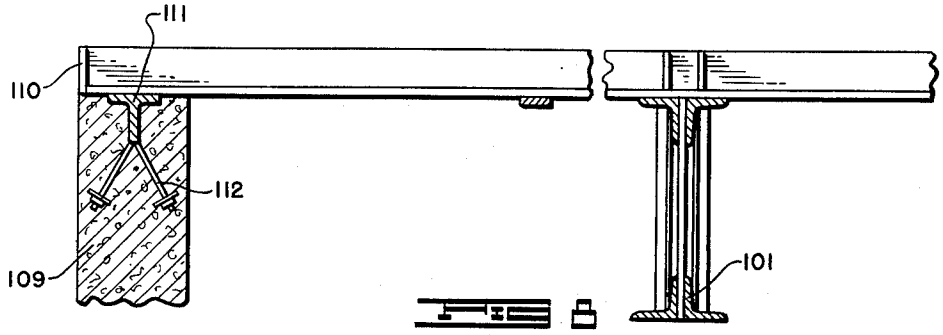


FIG 8

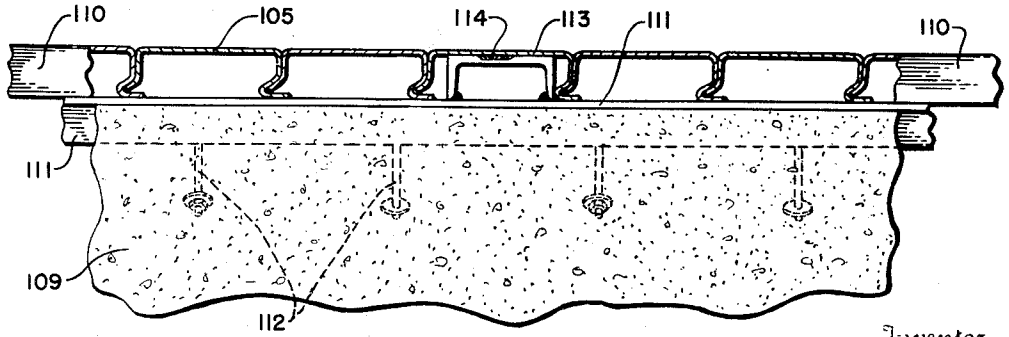


FIG 9

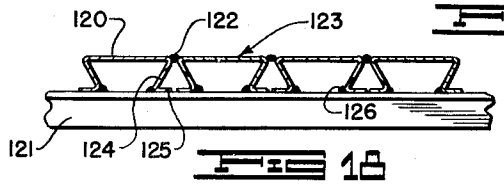


FIG 10

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STRUCTURAL DIAPHRAGM FOR BUILDINGS

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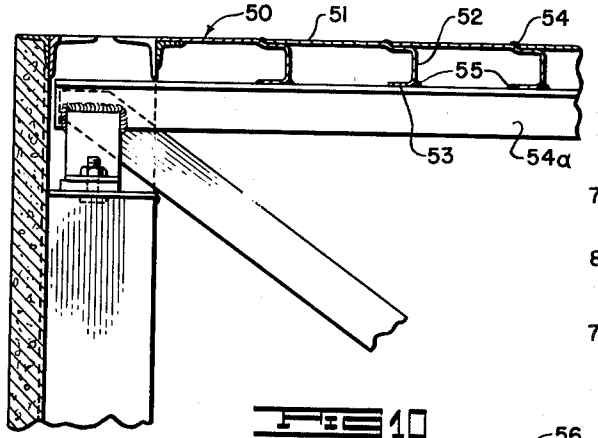


FIG 10

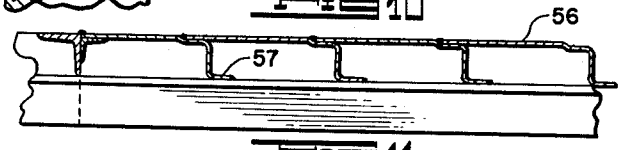


FIG 11

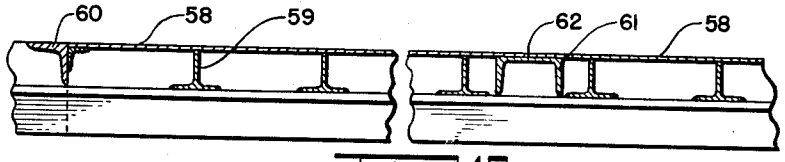


FIG 12

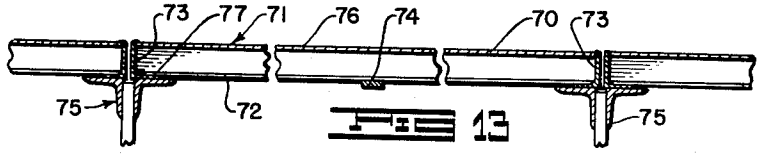


FIG 13

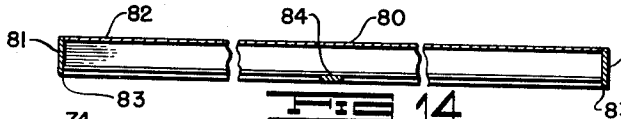


FIG 14

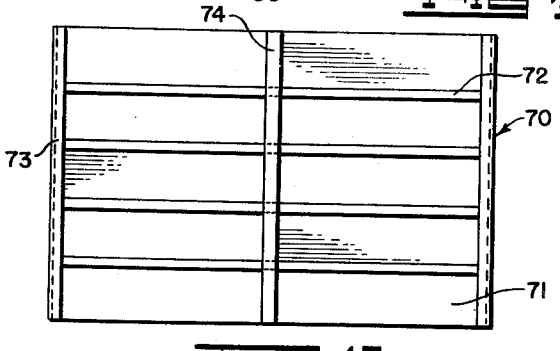


FIG 16

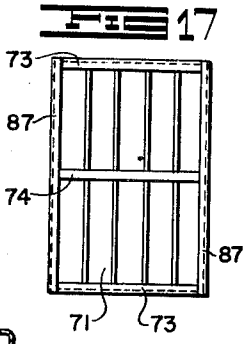


FIG 17

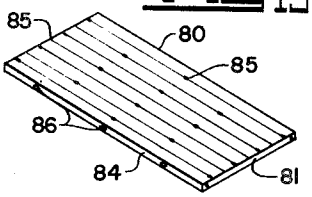


FIG 15

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Patented July 20, 1954

2,684,134

UNITED STATES PATENT OFFICE

2,684,134

STRUCTURAL DIAPHRAGM FOR BUILDINGS

Frederick H. Ruppel, San Marino, Calif.

Application July 28, 1947, Serial No. 764,115

1 Claim. (Cl. 189—1)

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This invention relates to buildings, and is particularly directed to an improved form of construction adapted to form the roof, floor, or wall of a building, and which has a number of outstanding advantages as will appear more fully hereinafter.

A primary purpose of the structural framework of any building, whether it be of steel, wood, or concrete, is to provide adequate resistance to vertical and horizontal loads which may be applied during construction or during subsequent occupancy. Among the vertical loads which must be resisted are:

1. The weights of materials and equipment during erection of the building;
2. Dead weight of the finished structure;
3. Storage loads;
4. Machinery;
5. Furniture; and
6. Live loading of the occupants of the building, etc.

The two principal horizontal forces which must be resisted are those resulting from wind loads and from seismic disturbances. In bracing a building against horizontal forces, provision must be made to transfer such forces to the foundations of the building without excessive deflections or distortions. Among the different horizontal bracing systems conventionally used to transfer loads to the vertical resisting elements are horizontal wood or steel bracing, trusses or ties, reinforced concrete floor or roof slabs, and diagonally sheathed wood floors or roofs. To carry such lateral loads to the foundation of the building, various types of bracing are employed. Those most commonly used in conventional practice are braced wood frame walls or partitions, steel X-bracing, rigid frames of structural steel or reinforced concrete, diagonally sheathed wood walls, and shear walls of brick or concrete.

In accordance with my invention, as applied to a roof or floor, horizontal bracing in the plan of the roof may consist of a welded steel diaphragm.

This diaphragm may be employed in connection with walls of conventional form, such as brick, structural steel, mill construction, etc., or may be carried on shear walls of a composite construction of light structural steel trussed framing, combined and reinforced with an integral concrete slab. The roof sheathing employed in connection with my invention may be of several types and may take the form of interlocking channel sections of cold-formed sheet steel. These sections are welded to the supporting beams or trusses and also welded to each other to form, in effect, a continuous steel sheet or diaphragm capable of resisting the horizontal shear forces imposed upon the building. The use of such light steel units to form a rigid structure shear-resistant diaphragm brings a relatively simple, economical and clean-cut method for bracing a building against horizontal forces, eliminating the conventional horizontal trussing systems which are always objectionable from the standpoint of headroom and appearance, and often seriously inadequate from the standpoint of rigidity.

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Accordingly, the principal object of my invention is to provide a new and improved form of roof or floor diaphragm for buildings, which diaphragm is adequate to brace a building against horizontal forces, thereby eliminating the need for conventional horizontal trussing systems.

Another object is to provide a roof or floor diaphragm of this type which includes a plurality of interlocking deck elements extending longitudinally between parallel trusses, the deck elements being jointed to each other at intervals and being joined to the trusses, together with additional means for resisting distortion of the deck elements under transverse loads.

Another object is to provide a diaphragm of this type which is adapted for use as a roof panel or wall panel in building construction.

Another object is to provide a supporting wall comprising a plurality of interlocking sheathing elements which eliminate the requirement for diagonal bracing within the supporting wall.

Another object is to provide a novel form of supporting wall panel for a building of nominal height and span, in which interlocking sheathing elements are used on end as load supporting members or stud framework, and a horizontal bridging member is used at the mid-height of the wall within the limits of the allowable slenderness ratio in design.

Various other objects and advantageous features of this invention will appear in the following description, and several embodiments thereof may be seen in the accompanying drawings wherein similar characters of reference designate corresponding parts, and wherein:

Figure 1 is a perspective view in diagrammatic form showing an idealized building incorporating a roof diaphragm employing the essential features of my invention.

Figure 2 is a plan view of the building with the roof diaphragm partly broken away, and illustrating a preferred form of welding pattern.

Figure 3 is a sectional elevation taken substantially on the line 3—3 as shown in Figure 2.

Figure 4 is a sectional detail taken substantially on the line 4—4 as shown in Figure 3.

Figure 5 is a sectional elevation taken substantially on the line 5—5 as shown in Figure 2.

Figure 6 shows the cross section of a preferred form of interlocking deck element.

Figure 7 is a partial sectional elevation of a bearing wall showing a floor or roof diaphragm embodying my invention applied to a conventional form of building.

Figure 8 is a sectional view of the arrangement in Figure 7 showing details of connection to an end wall.

Figure 9 is an end view of the arrangement shown in Figure 8.

Figure 10 is a sectional elevation similar to Figure 3, but showing the use of a modified form of interlocking deck elements.

Figure 11 is a view similar to Figure 3 showing another form of interlocking deck elements.

Figure 12 is a view similar to Figure 3 showing a roof or floor diaphragm utilizing a flat sheet extending over parallel rib elements which are T shaped in cross section.

Figure 13 is a transverse sectional view of a roof or floor diaphragm employing a plurality of individual panels, the panels each including a group of interlocking deck elements.

Figure 14 is a sectional view similar to Figure 13 showing a modified form of panel.

Figure 15 is a perspective view of the top side of the panel shown in Figure 14.

Figure 16 is a plan view of the underside of the panel shown in Figure 13.

Figure 17 is a side elevation of a modified form of panel used as a door.

Figure 18 is a sectional view similar to Figures 10 and 11 illustrating a further modified form of decking element employed in connection with my invention.

Referring to the drawings, the building structure shown in Figure 1 may comprise a series of wall panel units generally designated 10 resting on a suitable foundation, not shown. These wall panel units may be of any suitable or desirable construction, and are preferably of the form shown and described in my co-pending application, Serial No. 764,116 filed July 28, 1947. The individual panel units 10 are secured together along their marginal edges to form a continuous wall, and the four walls of the building are constructed in this manner. A plurality of trusses 11 are provided which extend between parallel walls to support the floor or roof diaphragm generally designated 12. This diaphragm 12 is composed of a plurality of individual deck elements 13 which cooperate to form a single unbroken continuous sheath. The cross section of a preferred form of deck element is shown in Figure 6. This deck element includes a top flange member 14 having depending leg members 15 and 16 along the edges thereof. The lower end of the leg 15 carries a projection 17, and the lower end of the leg 16 is provided with a notch 18 and foot 19. As shown clearly in Figure 3, the projection 17 on one deck element is adapted to extend within the notch 18 on an adjacent deck element, thereby providing an interlocking arrangement possessing considerable resistance to transverse loading. The deck elements 13 extend parallel to the side walls of the building structure at right angles to the trusses 11. Each of the trusses 11 may include a pair

of metallic angle sections 20 forming the top chord 21 of the truss. Each of the trusses is provided with internal diagonal bracing 22 and a lower chord 23. The top chord, diagonal bracing, and lower chord may be secured together by any convenient means such as riveting, bolting, or welding.

The trusses 11 may be supported on the walls of the building in any suitable or desirable manner, and a preferred form of connection between the trusses 11 and the side walls formed by the panel sections 10 is shown in Figures 1, 3 and 4. Cooperating halves of a pocket 24 are provided at the adjoining upper edges of adjacent panel sections 10. A plate 25 rests on shoulders 26 provided on the panel sections and spans the joint between them, forming the bottom of the pocket 24. Angle sections 27 are secured to the upper chord 21 of the truss by any convenient means, such as welding, and are held in position by the bolts 28. It will be observed that the top of the wall panels 10 extend above the level of the top of the adjoining portion of the trusses 11.

The lower chord 23 of each truss 11 may be attached to the side walls of the building by any convenient means, and as shown in the drawings, this means comprises a plate 29 secured to the chord 23 which may be welded to the channel piece 30 forming a part of the wall. A ceiling may be provided by the sheathing 33 supported by the lower chord 23 of the trusses 11. If desired, certain of the wall panels may be provided with lateral openings 31 and windows or doors 32. As explained more fully in my co-pending application above referred to, the wall panels 10 may preferably be of composite construction employing a metal lattice or mesh 33 encased within a sheath 34 of cementitious material, such as, for example, concrete. Metallic I beams or channels 35 are secured to the lattice 33 by welding, and project rearwardly from the sheath 34.

The individual deck elements 13 are placed on the top chord 21 in a staggered manner so that the joints 37 between the ends of adjacent deck elements 13 do not occur in a straight line across the building. The individual deck elements are then welded together, employing a pattern as shown in Figure 2. The spacing of the individual welds 38 may be advantageously made one-half the distance between adjacent trusses 11, and the welds on opposite sides of the same deck element are staggered as shown. The legs 15 and 16 of the deck elements 13 are welded to the top chord 21 of the trusses 11 as shown at 39 and are also welded at their ends to the top angle sections 40 on the panels forming the end walls 41 and 42.

The top of the panels 10 forming the side walls 43 and 44 are substantially flush with the top of the decking 12 adjacent thereto, and similarly, the top of the end walls 41 and 42 lie substantially flush with the adjacent ends of the decking elements 13. The decking 12 need not be flat on top, however. The trusses 11 are preferably constructed so that their top chord 21 is somewhat higher in the center if the decking 12 is to serve as a roof. The top of the end walls 41 and 42 remain substantially horizontal and the decking elements 13 which extend from these end walls to the first truss 11 are warped slightly into place.

It will be understood from this description that the cooperative interlocking relationship between

the individual deck elements 13 provides a continuous sheath serving as a floor or a roof, and the provision of the welds 38 and 39 connecting the individual deck elements with each other and with the top chord of the trusses 11 provides a diaphragm which is capable of resisting side loads applied to the side walls 43 and 44, and end walls 41 and 42, of the building structure. A load applied normal to one of the side walls 43 and 44 is spread through the diaphragm generally designated 12 and absorbed by the other side wall and by the end walls 41 and 42. A load applied normal to one of the end walls 41 and 42 is similarly spread throughout the diaphragm 12; that is, resisted by the other end wall and by the side walls 43 and 44.

It should be noted that welding of the ends of the decking elements 13 to the angle section 40 provided along the top of the end walls 41 and 42 serves to resist distortion of the decking elements under loads applied in a direction parallel to the trusses. Bending between the legs 15, 16 with respect to the top flange surface 13 is thereby avoided.

An actual test on a full size building (80' long, 40' wide, 12' high), of the general type illustrated in Figure 1, was performed to determine the efficiency of the diaphragm 12 in resisting forces applied parallel to the trusses 11. 18 gage steel was employed for the deck elements, and the welds 38 were ¾'' to 2'' long and spaced at 5' intervals. The building was horizontally loaded at spaced points by applying loads to the end of the trusses 11, and the loads were progressively increased to values substantially greater than that required by the most severe building restrictions without failure or noticeable distortion. The maximum measured horizontal deflection was only ½'' at the center of the building diaphragm. When the load was released, the residual deflection was only .07 inch. The measured deflection of the shear walls of the building amounted to a maximum of only .05 inch, with a recovery of 65%. The maximum load thus applied to the building corresponded roughly to six times the earthquake load ($\frac{1}{10}$ G) for which the building was designed, or to the forces imposed by a wind load in excess of 90 miles an hour.

Figures 7, 8 and 9 illustrate a floor or roof diaphragm embodying my invention as applied to a building having conventional walls of brick or concrete. A truss 101 extends between parallel side walls 102 and rests on them by means of angle brackets 103. The diaphragm 104 is supported on parallel trusses 101 and is composed of interlocking decking elements 105 extending parallel to the walls 102. The elements 105 may be of the type illustrated in Figure 6, and are joined together at welds 106 in a pattern similar to that shown in Figure 2. An angle section 107 extends out along the top edge of each side wall 102 and the outer row of decking elements 105 is welded to it at 108. Along the top of the end walls 109 is a steel strip 110 which is welded to the ends of the decking elements 105 to resist collapse under transverse loads.

A metallic T section 111 may be embedded in each end wall 109 and anchored by means of ties 112. Short lengths of channel section 113 rest on and are welded to this T section 111, and may be positioned under decking elements 105 to provide additional stiffness against lateral collapse, or used as an alternate method in place of strips 110. The weld 114 connects the channel 113 to its decking element 105. Design experience has shown that sufficient stiffness is provided if one channel 113 is provided for each group of eight decking elements 105.

The particular shape or proportions of the deck elements 13 or 105 may be varied in accordance with design requirements or preferences, and in certain instances it may be desirable to employ sections as shown in Figure 10 instead of the decking sections as shown in Figure 6. The particular shape deck element designated 13 and shown in Figure 6 is cold-formed from sheet steel, and the modified form of deck elements 50 illustrated in Figure 10 may be formed in the same manner. Each of the deck elements 50 is provided with a top flange 51 and a single depending leg 52 along one edge. A return bend forms a foot 53. The flanges 51 are welded together at 54 in the same pattern outlined in Figure 2, and the feet 53 are welded to the top chord 54a of the truss at spaced points designated by the numerals 55 in a manner similar to that described above. The joining of the flanges 51 may advantageously be accomplished with resistance welding apparatus, if desired.

In Figure 11, I have illustrated a modified form of decking element 56 which is similar in many respects to the decking element 50 illustrated in Figure 10. The chief difference in the form of these elements is that the footing 53 on the element 50 extends in the same direction as the flange 51, whereas the footing 57 on the decking element 56 extends in the opposite direction. The elements 56 are welded together to form a continuous sheath in the same fashion described in connection with the decking elements 13 and 50, and each is welded to the top chord of each truss in the manner set forth above.

A further modification is shown in Figure 12. The decking in this instance comprises a series of relatively large rectangular sheets 58 which cooperate with spaced T-sections 59 to form a diaphragm. The T-sections 59 are placed in an inverted position on the top of the trusses and the upper ends of the T-sections are welded to the flat sheet 58 by any convenient means. The sheet 58 is welded along its terminal edges to the angle sections 60 which are positioned along the top edge of the supporting walls. In order to prevent distortion of the T-shaped ribs 59 when a load is applied to the diaphragm in a direction parallel to the supporting trusses, it may be desirable to incorporate stiffener elements 61 into the diaphragm structure. These elements 61 may comprise short lengths of relatively heavy wall channel section, and these stiffener elements may be placed under joints 62 between adjacent sheets 58. Lateral deflection of the sheets 58 with respect to the upper chord of the supporting trusses is thereby minimized. It will be understood that stiffener elements such as the stiffener elements 61 may be employed, if desirable or necessary, in connection with the diaphragm structures previously described and shown in Figures 3, 10 and 11.

The upper surface of the diaphragm provided by the decking elements 13, 50, 56 or 58 may be used as a floor or a roof as described above. Suitable roofing paper or other roofing materials, not shown, are applied over the top surface of the diaphragm to make the building weathertight, or suitable flooring of any desired form may be employed.

Although I have shown and described various forms of roof and floor diaphragms embodying

my invention only in connection with a simple rectangular building having parallel trusses extending between load supporting walls, it is to be understood that this is by way of illustration only. Structural diaphragms incorporating essential features of my invention may be used between upright walls and intermediate structural columns and beams, or between columns and beams only, as in the case of a large building having a grid system of columns and girders at spaced intervals.

Figures 13, 16 and 17 show a modified type of panel 70 which may be used as a wall panel or as a floor or roof panel as desired. The panel 70 comprises a plurality of interlocking decking elements 71 which are preferably of the type illustrated in Figure 6 and the foot members 72 serve as ribs which extend between opposite ends of the panel 70. Angle sections 73 form the ends of the panel and a stiffener strip 74 is provided which extends transversely of the decking elements 71 to the sides of the panel. The interlocking decking elements 71, the angle sections 73, and the stiffener strip 74 are joined by any convenient means such as by welding. When the panel 70 is employed as a roof or floor panel, as shown in Figure 10, the footing members 72 extend transversely between parallel trusses 75. The effective depth of the panel thus formed is the distance from the upper surface 76 of the decking to the lower surface 77 of the angle section 73, and is thus greater than the over-all depth of the decking elements 71. This form of diaphragm as provided by panel 70 provides adequate stiffness against longitudinal and transverse loads without requiring the presence of diagonal braces. Adjacent panels 70 may be secured together by any convenient means such as bolting or welding and the panels may be secured to the trusses 75 in the same manner. Bolt holes 86 as shown in the species illustrated in Figure 15 may be provided along the edges of the panels for joining adjacent panels together to form a continuous diaphragm.

A modified form of panel is shown in Figure 14 and is designated 80. This panel is similar to panel 70 shown in Figure 13 with the exception that the angle sections 73 are replaced by plates 81. As mentioned in connection with panel 70, the effective depth of the panel 80 for structural design purposes is equivalent to the distance from the upper surface 82 to the lower surface 83 on the plates 81. A stiffener strip 84 extends between side plates 81. The individual elements are welded together as shown at 85.

The panels 70 or 80 may be employed as wall panels, and in such event, the footing members 72 and the legs of the decking elements 71 extend vertically to act as ribs or studs while the stiffener strip 74 serves as a horizontal bridging member. Individual panels 70 may thus be bolted together through holes 86 such as are shown in Figure 15 along their boundary edges to provide a wall of any desired length.

The panels 70 or 80 may also be used as doors, and as such may be mounted in any conventional manner. As shown in Figure 17, the panels 70 or 80 are provided with side angle strips 87 as well as end angle strips 73 when they are employed as doors.

The form of decking element 120 illustrated in Figure 18 has the advantage that when assembled on trusses 121 and welded at 122 so that the upper surfaces 123 cooperate to form a continuous diaphragm sheet, that no additional stiffener elements such as the channel members 113 are required, and it is not necessary to weld the individual elements 120 across their ends to a stiffener to prevent lateral collapse under transverse loading. This is true because the legs 124 extend downwardly at an angle and serve as diagonal braces. Adequate bearing area is provided by the foot piece 125, provided on the lower end of each leg 124. The elements 120 may be attached to the truss 121 by welding, as shown at 126.

Having fully described my invention, it is to be understood that I do not wish to be limited to the details herein set forth, but my invention is of the full scope of the appended claim.

I claim:

In combination, a building having a plurality of spaced supporting members extending transversely thereof, a plurality of metallic deck elements extending transversely to and longitudinally between said members and resting thereon, each of said deck elements including a top flange portion and a leg depending from one longitudinal edge of said flange portion, said legs resting upon and being welded to said supporting members, said flange portions forming a substantially planar continuous sheath spaced above the top of the members, said flange portions being welded together substantially in the plane of said sheath by means of longitudinally spaced welds, and means stiffening said sheath against loading parallel to said supporting members, said means comprising channel sections of a length less than the spacing between adjacent supporting members and having flange portions and depending legs, said channel sections being mounted beneath the flange portions of said deck elements and transversely of at least the outermost of said supporting members, said legs of said channel sections being welded to said supporting members, and said flange portions of said channel sections being welded to the overlying flange portions of the decking elements.

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