The present invention relates to improvements in building slabs, and more especially slabs of the type which are especially adapted for use in roof and floor structures but which may also be used in wall structures.

Of cementitious materials useful in building construction, concrete has many well known attributes but is often limited in usefulness due to excessive weight in relation to load capacity. In engineering a building for use of concrete slab in a deck structure, therefore, loading of columns and supporting framework must be anticipated by specifying heavy weight supporting sections at proportions far in excess of cost.

Attempts have been made to reduce the dead load factor in concrete slab building construction by providing lightweight aggregate, chemically induced porosity, trapped air cellular structure, and the like. These expedients have generally correspondingly entailed sacrifice in unit strength and load supporting capacity of the resulting concrete slab.

An important object of the present invention is to provide improvements in lightweight molded building slab structures attaining substantially conventional concrete slab load capacity with a much lower unit dead load factor.

Another object of the invention is to provide thin lightweight molded building slabs especially suitable for span-type uses normally subject to bending stresses but wherein all of the primary stresses are direct tension and compression stresses oriented to substantially cancel bending stresses under imposed loads on the spanning portions of the slab.

A further object of the invention is to provide an improved precast building panel of reinforced molded material, and of unusually high strength as a result of the geometric surface arrangement and the relation thereto of the internal reinforcement.

Still another object of the invention is to provide a novel cast building slab or panel embodying an advantageous warped quadrilateral or hyperbolic-paraboloidal surface structure.

Yet another object of the invention is to provide a lightweight building slab construction of high bending or deflection resistance and adapted for various deck treatments.

Other objects, features and advantages of the present invention will be readily apparent from the following detailed description of certain preferred embodiments thereof taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a plan view of a precast concrete slab or panel embodying features of the invention;

FIGURE 2 is an enlarged transverse sectional detail view taken substantially on the line II—II of FIGURE 1;

FIGURE 3 is a schematic plan view of the precast panel having appended thereto orthographic projections showing the surface geometry of the panel;

FIGURE 4 is a schematic illustration of one type of deck structure for which precast slabs or panels of the present invention are adapted;

FIGURE 5 is a schematic illustration of another form of deck construction embodying principles of the invention;

FIGURE 6 is a fragmentary vertical sectional view showing one manner of securing panels or slabs of the present invention to a supporting truss or beam;

FIGURE 7 is a fragmentary vertical sectional detail view showing a modified anchorage of the panels to a truss or beam;

FIGURE 8 is a transverse sectional detail view through a modification of the precast beam or slab showing an arrangement of special reinforcing bars or rods to meet certain problems of shear stress;

FIGURE 9 is a plan view of a slab showing a further arrangement of shear stress reinforcement;

FIGURE 10 is a schematic view showing a modified supporting frame structure in a building construction employing lightweight warped quadrilateral or hyperbolic-paraboloidal surface deck slabs.

FIGURE 11 is a schematic view showing a modification of the deck structure wherein the warped surfaces of the slabs are on the upper side; and

FIGURE 12 is an enlarged fragmentary vertical sectional view taken substantially on the line XII—XII of FIGURE 11.

Referring to FIGURES 1, 2 and 3, a precast building panel or slab 15 is shown of quadrilateral form and, although in the illustrated example of square outline capable of being of any preferred other quadrilateral shape such as elongated rectangle, various parallelogram arrangements, rhomboidal, and the like. Depending upon the structural requirements, the slab may be of large or small an outline as practicable, and if preferred both faces of the slab may be provided with the warped, quadrilateral hyperbolic-paraboloidal contours, but in a simple arrangement comprises one substantially flat face and the opposite face contoured.

The novel slab or panel 15 may be considered as a combination of thin shell and slab or beam structures united into one unit distinguished in surface geometry by an arrangement of hyperbolic-paraboloidal quadrilaterals merging at the center of the slab face. Each of the hyperbolic-paraboloidal sections has two outside edges which are coincident with the edges of the panel and two inside boundaries which are joined to the inside boundaries of the respective adjoining hyperbolic-paraboloidal sections as indicated by the crossing dot dash lines in FIGURE 3. The resultant surface contours are indicated by the orthographic projections from the slab outline in FIGURE 3, the central projection indicating the contour substantially along the crossing dot dash dividing lines, the left hand projection showing the contour diagonally between the corners of the slab, and the right hand projection showing the contour across the corners of each of the sections where the outside and inside boundaries of the section join. By preference the contoured surface is provided with a thin flat seating margin 17 entirely thereof for engagement with supporting framework. In practice, the slab 15 may be constructed in a wide range of sizes and thicknesses, with the hyperbolic-paraboloidal surface areas providing juncture ridges respectively extending from the respective sides of the body of the slab and progressively a greater distance generally perpendicularly from the flat face to a common meeting point of maximum projection of the opposite, contoured face of the slab. In a six foot square slab the thicknesses may run from about 1½” to 2” at the margin 17, to about 6” to 8” at the center juncture of the hyperbolic-paraboloidal sections. In a thirty foot square slab, the thicknesses may be 3” to 4” at the margin to 20” to 30” at the center within approximate limits.

Although the panel or slab 15 may be molded in place with suitable forms provided for the purpose, it lends itself especially well to precast molding either at the site of construction or in a factory for transportation to the construction site. In either event, a lightweight molding or casting material and preferably lightweight concrete is adapted to be used, made of portland or other type of
cement with aggregates of varying densities and strengths as found desirable and necessary to meet the structural and economic demands of the construction for which intended. Air-entrained concretes are particularly advantageous for attaining extremely light weight, enabling the use of economical foundation, skeleton and supporting framework for the panels.

Special reinforcement is provided in the panel or slab 15 to coat with the hyperbolic paraboloidal face contour which to a substantial extent counteracts any inherent weakness in the cast cellular concrete body identified as 18 in FIGURE 2. In a desirable form, such reinforcement includes a marginal frame 19 embedded within and preferably in the lower portion of the margin 17 of the slab. Spanning the respective opposite side portions of the frame 17 are respective crossing stress bars 20 which are within the body 18 and preferably of generally V-shape conformable to the hyperbolic-paraboloidal section junctures and spaced a limited distance inside the juncture ridges substantially parallel thereto and meeting adjacent to the common meeting point of the ridges. At their opposite ends the tension bars 20 may be secured, as by welding, to the adjoining frame bars but may alternatively be provided with angular terminal arms 21 lying alongside the adjoining frame bars substantially as shown.

Overlying the marginal frame 19 and the tension bars 20 and generally conformable to the hyperbolic-paraboloidal face shape of the slab is a layer of wire mesh reinforcing 22 preferably of welded strand construction and with the strands running diagonally between the sides of the frame 19 as shown. The concrete material for the body 18 is poured into a mold in which the reinforcing members are supported and the reinforcing members are thereby embedded in and bonded to the material of the body 18 when it sets into a monolithic structure.

A purpose for a reinforcing rod or bar to be more fully described hereinafter, a reinforcing rod 23 may be embedded in the slab body 18 inside and substantially parallel to the flat face of the slab 15, the ends of the rod 23 having angular terminal portions 24 arranged to extend parallel to the contiguous side bars of the reinforcing frame 19. By preference, the reinforcing rod or bar 23 extends across the center of the slab and may overlay one of the tension bars 20.

It will be understood that the reinforcing rods or bars 20 and 23 as well as the reinforcing frame 19 will be calculated in number and weight in any given instance to coordinate with the slab size and loading requirements. In larger size slabs a plurality of moderate size or weight reinforcing rods or bars may function more efficiently than proportionally larger size rods.

It has been found that in a panel or slab 15 constructed as described supported on its margins 17 will support unusual loads in relation to the weight of the slab. My explanation for this is that due to the geometry of the slab and the arrangement of reinforcement therein, the various stresses in the warp surfaces of the slab are efficiently neutralized to a combination of substantially equal tensile and compressive stresses acting in mutually perpendicular directions. This stress condition has sometimes been described as a state of "pure shear."

These mutually perpendicular tensile and compressive stresses vectorially combine at the edges of each of the four warped surfaces to create direct axial tensile or compressive stresses along and parallel to these edges. These direct stresses are carried in the reinforcing 19 and 20. Bend loads perpendicular to the plane of the slab develop axial compression in the reinforcing frame 19 (which may be considered as a ring), tension in the rods 20, and mutually perpendicular tension and compression stresses in the mesh 22. It is to be understood that in all cases the steel and concrete are bonded and share their stresses.

The tension in and along the rods 20 is composed vectorially at its vertical and horizontal components. Where the slab is supported horizontally, the horizontal component of this tension stress is resisted by the external reaction provided by the structure supporting the slab while the vertical component is resisted internally by compression of the concrete near the top surface in an area limited in width by some length of the frame bar 19 symmetrically divided about the tension bar 20, and in length between the opposite sides of the slab.

While the slabs 15 are suitable for use in various structural systems certain exemplary forms have been chosen for illustration. In one form of deck structure as shown in FIGURE 5, a supporting frame 25 affords support against intermediate forces and supports the respective slabs 27 by engagement of the shoulderings 17 of the slab upon the framework. Therefore, the optional top tension bar 23 may be omitted since the vertical load stresses are all uniformly neutralized by the compressive counterbalance effected in the slab by the combination of hyperbolic-paraboloidal surface geometry and reinforcement afforded by the frame 19 and the tension bars 20 as well as the reinforcing mesh 22. It will be understood, of course, that the frame 25 may be of any preferred beam or truss or combination construction.

Where it is preferred to support the slabs 15 in the manner depicted in FIGURE 4, wherein columns 27 carry beams or trusses 28 of several times the length of the individual slabs 15, providing elongated bays in each of which a plurality of the slabs is supported in spanning relation between and on a pair of adjacent parallel supporting members 28 and with only the slabs at respective opposite ends of the bay additionally supported by respective framing cross beams 29, one remaining side of the endmost slabs 15 and two spanning sides of the remaining slabs 15 are unsupported. As a result, there is a tendency toward bending of the unsupported sides of the slab upon vertical load in a direction not counteracted by use of the upper tensioning bar or rod 23 extending on the unsupported horizontal axis of the slabs. This reinforcing tension bar 23 in each instance resists lateral spread or side-wise movement of the sides of the slab at the terminals 24 of the bar 23, by contributing the direction and/or intensities of stresses throughout the entire slab by virtue of tension in the rod 23 acting to replace the compression in the concrete body 18 of the slab in the direction parallel to the rod 23.

Means for holding the slabs 15 down against the supporting frame and against upward displacement due to wind pressure or other forces may take various forms, one such form being shown in FIGURE 6 for anchoring each of the slabs 15 by retaining its seating margin 17 on the supporting frame member, in this instance provided with lateral supporting flanges 38. For this purpose, substantially L-shaped anchor bolts 31 are engaged over the frame bars 19 of the respective slabs and depend from the lower faces of the slabs along the inner side of the respective slab margin 17 to extend below the underfaces of the supporting beam head flanges 39 so that retaining clips 32 carried by the respective bolts can be tightened up against the respective engaged beam head flange 39 by means of a nut 33 threaded onto the depending shank of the bolt. A grout fill 34 may be placed between the edges of the slabs 15, and a surfacing such as roofing 35 may be applied over the entire slab deck.

In another manner of securing the slabs 15 down upon the supporting structure, as depicted in FIGURE 7 and where an insulating layer 37 is applied to a substantial thickness over the top surfaces of the slab deck, upstanding stud bolts 38 may be provided at suitable intervals on the top surface provided by the head flanges 39 of the supporting beams, with the lower ends of the stud bolts welded or otherwise fixedly secured on the median line of the beam head and projecting upwardly a limited distance above the top plane provided by the slabs 15.

Anchor washer plates 39 are clampingly engaged upon
the upper faces of the adjacent slab margins by means of nuts 40 threaded onto the upwardly projecting end portions of the stud bolts 38. Since the upper ends of the stud bolts 38 are embedded within the insulating layer 37, no interference will be encountered against flat application of surfacing such as roofing 41 upon the top of the deck.

Where there may be a tendency due to imposed loads on the slabs to exceed the strength of the concrete so that the intensities of shear stress caused by tension in the reinforcing steel rods 20 and the compression in the upper surface concrete may cause shear planes to develop and force concrete from the body upwardly from the face plate of the slab, additional shear stress reinforcement may be incorporated as shown in FIGURES 8 and 9. In FIGURE 8, a slab 15 is shown in which in general respects is the same as the slab 15 of FIGURES 1-3 but is provided with shear stress compensating reinforcing bars 42 and 43 shaped complementary to and overlapping one of the tension bars 20 and of graduated length so that the faces upwardly and laterally projecting terminals 44 and 45 will lie in predetermined adjacent relation to the top surface of the slab body 18. Depending on the type of load to which the slab is to be subjected, the shear stress bars 42 and 43 may be associated with either one or both of the crossing tension bars 20.

In fact, the slab 15 may be in general respects the same as the slab 15 of FIGURES 1-3 but is provided with a plurality of angularly crossingly related shear stress bars 47 of a length to extend diagonally relative to the tension bars 20" in a more or less uniform sun ray pattern from the center of the slab. In addition, shear stress bars the same as the bars 42 and 43 of FIGURE 8 may be used in the slab 15. It will be understood, of course, that as many or as few of the shear stress bars 47 may be used as calculations indicate may be necessary in any given construction. It will be understood also that the weight of the shear stress bars in any instance will be proportioned to the stress load that must be accommodated.

FIGURE 10 illustrates, schematically, a highly economical deck supporting arrangement for which prestressed or cast in situ slabs according to the present invention are well adapted by virtue of the fact that tension reacting upon the concrete body of the slab in each instance to effect neutralizing compression works in from respective intermediate points on the sides of the slab through the tension bars 20. Therefore, support of the slabs can be directly upon the upper ends of columns 50 upon which the margins 17 of the slabs are engaged substantially in alignment with the respective ends of the tension bars 20, as shown in FIG. 10. Connecting upper end portions of the columns 50 is a system of tie rods or cables 51 preferably running between the adjacent columns diagonally to the direction of the sides of the panels or slabs 15. Up to this point, deck arrangements have been discussed wherein the slabs are disposed upwardly to provide a flat aggregate deck surface with the hyperbolic-paraboloidal surface configurations on the lower or downwardly facing surfaces of the slabs. For architectural reasons it may be desirable to have the slabs in reverse position, that is with the contoured surfaces facing upwardly and with the flat surfaces in a plane on the underside of the deck, substantially as shown in FIGURES 11 and 12 wherein slab panels 55 are disclosed as supported on columns 57, similarly as in FIGURE 10, that is with the columns carrying the slabs by engagement with intermediate and preferably central marginal portions of the slabs and in any event marginal portions in alignment with V-shaped reinforcing rods 58 within a concrete body 59 of each of the slabs 55. In addition, the slabs 55 have preferably straight tie rods 60 extending preferably coextensively with the V-rods 58 and lying parallel and inside the flat surface of the slab. In this instance, mesh reinforcement 61 is disposed upon the tie rods 60. In the margins of the slab 55 is disposed a conforming closed ring rod reinforcing frame 62. If preferred, the end portions of the rods 58 and 60 may be secured as by welding to the frame 62. In addition or alternatively, the ends of the reinforcing rods 58 and 60 may be secured as by welding to metal angle seat members 63 affording an external reinforcement for engagement upon a cap flange 64 on the respective supporting column 57 in each instance. It will be understood that the slabs 15 in FIGURE 10 may also be provided with reinforcing angle seats 63 if preferred.

Since the thinnest portion of the slabs 55 overlies the supporting columns 57, a heat transfer problem may be encountered in cold weather areas in which a building embodying this construction may be erected. This can be overcome by filling in the depressions between slabs and overlying the joints with an insulating type of fill 65 which may be a lightweight cementsitious material. This fill may be level with the apices of the slabs 55, or it may be of any preferred depth less than the maximum thickness of the slabs. Where a flat roof deck or floor deck is desired and the fill 65 is in a plane with the apices of the slabs 55, a flat covering 67 such as roofing or flooring may be applied over the flat base surface provided by the fill and the apices of the slabs.

In the direct column support structural systems of FIGS. 10 and 11, the slabs 15 or 55 may, if preferred, be provided with lap joint flanges at their sides coacting to provide reasonably tight joints between the slabs.

Various structural features although described in relation to specific forms of the invention herein may, of course, be utilized interchangeably in other forms of the invention disclosed, under proper or desirable conditions. Although the invention has been described primarily in connection with deck constructions advantages of efficient heat insulation and high wind load resistance can be attained by using the slabs of this invention in wall structures.

It will be understood that modifications and variations may be effected without departing from the scope of the novel concepts of the present invention.

I claim as my invention:

1. In a lightweight molded building slab especially constructed and arranged to be supported in spanning relation between building supports and with the entire weight of the slab thus supported,
   (a) a monolithic light weight concrete body of quadrilateral outline (1) provided with a thin margin entirely thereabouts and
   (2) having a substantially flat face and
   (3) on opposite face comprising a plurality of adjoining hyperbolic-paraboloidal surface areas providing on said opposite face juncture ridges respectively extending from the respective sides of the body and progressively a greater distance generally perpendicularly from said flat face to a common meeting point of maximum projection of said opposite ridges,
   (b) a marginal reinforcing ring frame embedded within said margin developing stress under loads perpendicular to the plane of the body,
   (c) and stress bars spanning the respective opposite side portions of the ring frame within said body and substantially parallel to said juncture ridges and meeting adjacent to said common meeting point of said ridges and developing stress under said loads perpendicular to the plane of the body,
   (d) the material of the body being bonded to said ring frame and said stress bars and sharing the stresses imposed on the frame and bars by loads imposed upon the body.
2. A lightweight molded building slab as defined in claim 1, including a tension bar spanning the marginal reinforcing ring frame adjacent to said flat face of the body between certain of the opposite sides of the body and adapted to extend in an unsupported direction within the body when said certain sides are unsupported in a building structure which affords support for said margin at other sides of the slab body.

3. A lightweight molded building slab as defined in claim 1, including within said body a plurality of compensating reinforcing bars shaped to overlie one of said stress bars in substantially parallel relation and of graduated lengths and with terminals which project toward and have portions thereof lying in predetermined adjacent relation to said substantially flat face of the slab body.

4. A lightweight molded building slab as defined in claim 1, which includes within said body in addition to said ring frame and stress bars and between said stress bars and said substantially flat face a sunray pattern of a plurality of crossingly related stress bars crossing on substantially the axis of said common meeting point and having their ends located inwardly from said ring frame.

5. A lightweight molded building slab as defined in claim 1, including within said body a layer of wire mesh reinforcing overlying said ring frame and said stress bars and generally conforming to the hyperbolic paraboloidal section shape of said opposite face and embedded within said body.

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