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ACOUSTIC STRUCTURAL UNIT

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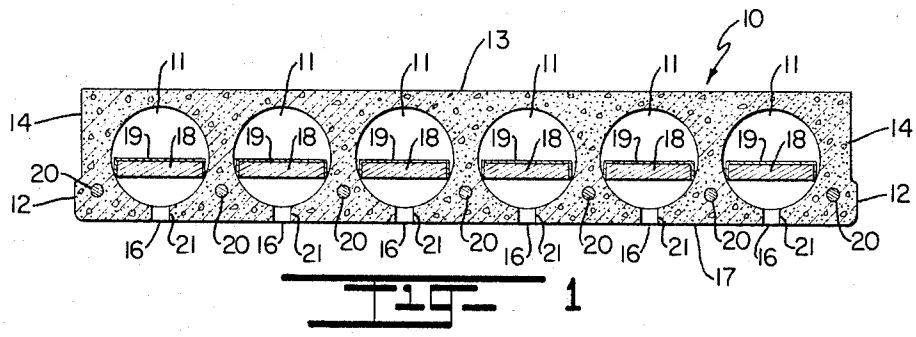


FIG. 1

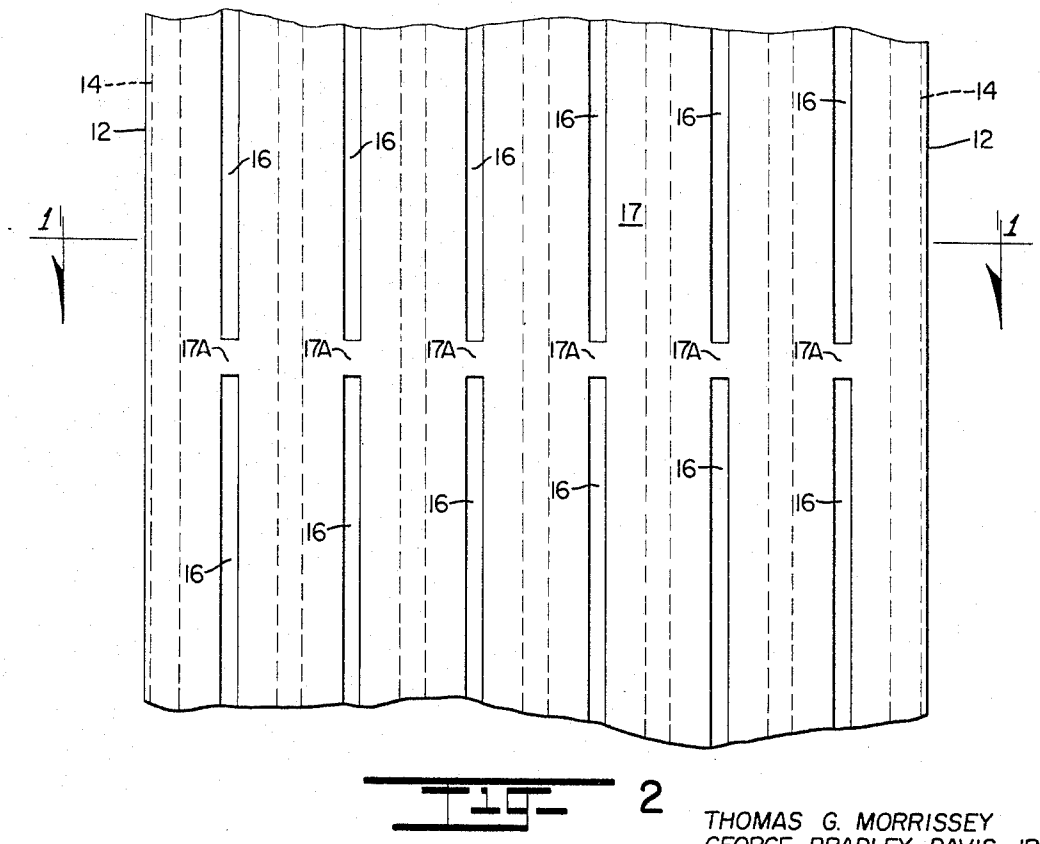


FIG. 2

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ACOUSTIC STRUCTURAL UNIT

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This invention relates to flexural and load bearing acoustic elements or units used for building construction, and particularly to reinforced concrete slaps with built-in sound absorbing properties, and their method of manufacture.

There is need in the construction industry for a strong, efficient low cost structural unit which will bear flexural stresses and can be used in floors, ceilings, roofs and walls of a room, for example, both as a combination structural unit and sound absorbing or acoustic element. In addition, there is need for an efficient method of manufacturing such an acoustic structural unit.

Acoustic structural units of the prior art used for building construction generally require the addition of special materials or elements to their surfaces for absorbing sound, that is, they are not capable of serving a combination acoustic and structural function. A commonly used technique is to apply acoustic tile or acoustic plaster to the structural unit for the purpose of absorbing sound energy and reducing noise levels and reverberations of sound waves within enclosures such as rooms. Such additional special materials or elements add to the cost of the construction, are easily damaged or destroyed, are costly to maintain and are degraded by maintenance or deteriorate with age. For example, acoustic tile of various types, if painted in the conventional manner with a brush or roller, loses to an appreciable extent, its sound absorption properties. Furthermore, hard, durable, structural units, such as concrete slabs, for example, of low initial and maintenance cost, have, in their conventional forms, poor sound absorption properties.

Accordingly, it is an important object of this invention to provide an acoustic structural unit which is designed to bear heavy building loads and is provided with efficient built-in sound absorption properties.

Another object of this invention is to provide an efficient method for economical manufacturing of acoustic reinformed structural concrete slabs.

A further object of this invention is to provide a strong economical structural reinforced concrete slab having permanently built-in sound absorption properties.

Additional objects, features and advantages of this invention will become apparent from the following description, which is given primarily for purposes of illustration, and not limitation.

Stated in general terms, the objects of this invention are attained by providing a flexural and load bearing acoustic structural unit, preferably in the form of a reinforced concrete slab, having an elongate cavity or void formed therein and an elongate aperture, or line of spaced apertures, hereinafter referred to as aperture means, formed through a surface of the slab into the cavity to establish communication between the inside of the cavity and the atmosphere.

The surface to which the cavity is connected by the aperture is the surface exposed to sound energy in the room and is referred to hereinafter as the perforated surface. The volume or space between the aperture and the void or cavity is referred to as a connecting passage or passageway.

The reinforced concrete slab preferably is provided with a plurality, such as six, for example, cavities in transversely spaced substantially parallel relationship with respect to each other, together with an aperture and connecting passage for each cavity. It is not required that each cavity be provided with an aperture. The voids contain fibrous sound absorbing material and/or a barrier or septum. In the preferred embodiment, a board of preformed sound absorbing fibrous material is inserted in each of the cavities adjacent the internal exit of the passageway to absorb sound. For controlling the volume of the respective cavity in communication with the atmosphere through the aperture a barrier may be placed above the absorptive material.

To optimize the acoustical absorption of sound by the reinforced concrete slabs of the present invention, the following four fundamental requirements were developed in the slab.

(1) The ratio of the sum of the areas of the aperture openings to the total area of the slab perforated surface, in any unit of the total area, was established at approximately ten percent with a tolerance of about plus five and minus three percent for optimum conditions based on calculations and test results.

(2) The incremental volume of the void or cavity in relation to the area of the apertures and the volume of the connecting passage from the aperture opening to the interior void was established at an optimum relationship based on calculations and experimentation in accordance with construction of Helmholtz resonators.

(3) The intrinsic nature of the fibrous material placed in the void was recognized and specific characteristics were selected for optimum results as determined by calculations and experiments.

(4) The physical location or placement of the fibrous material within the void was established at an optimum based on calculations and experimentation. Tests of experimental forms of the slab of this invention were made at a distinguished acoustical laboratory verifying the advantages of the above stated acoustical design features.

A more detailed description of a specific embodiment of the invention is given below with reference to the accompanying drawing, wherein:

FIG. 1 is a vertical sectional view of an acoustic structural unit taken as along line **1**—**1** of FIG. 2 showing the arrangement of the cavities; and

FIG. 2 is a partial bottom plan view of the acoustic structural unit showing the structure of the apertures.

Slab **10** is made of predetermined length and width in accordance with architectural and engineering requirements and with longitudinal cavities **11** in transversely spaced substantially parallel relationship with respect to each other. The slab is preferably made of reinforced concrete although other material may be used. Six cavities **11** are shown formed in slab **10**, but more or less than this number can be formed in each slab, as desired. In building a floor or roof member of a structure, a plurality of slabs **10** are positioned in a common plane with their sides abutting at formed edges **12**.

In the case of a roof construction, a built up roof may be mounted on the resulting top plane formed by top surfaces **13** of slabs **10** after grout is filled into channels formed between inwardly sloping sides **14** of adjacent slabs, to produce a sealed, unitary roof structure. Other means for connecting the slabs together may be used. The internal surface of the roof, of course, serves as a ceiling. In a multiple story building the roof of one story serves as the floor to the adjacent upper story. When slabs **10** are used in a floor construction, a composite topping may be filled into the channels formed between adjacent slabs above formed edges **12** and be-

tween sides **14**, and on the top plane formed by the top surfaces **13** of the slabs. The lengths of slabs **10** are placed vertically with surfaces **13** forming an outside wall surface, when the slabs are used in wall construction.

Longitudinal apertures **16** including passages **21** are formed through the bottom surface **17** of slabs **10** forming a perforated surface to establish communication between the respective cavities **11** and the room. Bridging surface portions **17***a* are ordinarily included for structural purposes and/or styling. They can be omitted in some applications, thus converting the slotted apertures **16** into continuous slots running substantially from end-to-end of the slabs. Apertures **16** preferably are centered on cavities **11**, and in substantially parallel spaced relationshap with each other, as shown.

As previously mentioned, it was established that effectiveness of the acoustical properties of the slab structure is a function of the relationship between the incremental volume of the void, the area of the apertures and the volume of the connecting passage from the aperture opening to the interior void. The acoustical properties can be changed by varying any one of these parameters; however, it has been found most expedient to vary the volume of the void and this is done with the use of a barrier in the void as explained below.

Boards **18** of fibrous sound absorbing material such as glass fibers, resinous fibers made of synthetic plastics, mineral wool, felt, cane fiber, wood fiber, etc., are inserted in cavities **11** to absorb the sound entering the cavities. The use of boards **18** made of pre-formed glass fibers of medium bulk density of about 5 lbs. per cubic foot, extending from wall-to-wall of cavities **11** having diameters of about 6 inches, and about an inch above the tops of apertures **16** having about one inch width, were found to give very satisfactory results. A board **18**, as shown in the drawing, functions to control the volume of the sound absorbing chamber of the cavity **11** beneath the board that is in communication with the atmosphere and it is to be noted that each board occupies throughout its length a minor cross-sectional area of the cavity and is of a width less than the cavity diameter whereby the board may be positioned within the cavity on either side of a horizontal plane passing through the cavity diameter to vary said volume of the sound absorbing chamber. As shown by the embodiment of the drawing when a board **18** is below the horizontal plane passing through the cavity diameter it is supported on the inner peripheral surface of the lower half of each cavity. Each board is substantially rectangular and boards of different widths result in permitting further adjustment of the location thereof within each cavity. A barrier **19** may be formed by coating the top of boards **18** with a suitable coating of resins, bridging paint, or other suitable material so that effective sound absorbing chambers or cavities are formed below the coated top of the boards. The barrier **19** may be a separate septum. This fibrous board **18** serves the purpose of absorbing sound. The barrier determines the volume of the sound absorbing chamber required for achieving the desired sound absorption versus frequency characteristics. The sound absorbing fibrous material may be used in loose uncompacted form, such as, bundles or other forms whether barriers are used or not to control the volume of the cavity.

The positioning of the fibrous material in the slab voids is controlled to produce different exposures of the fiber filaments to the sound waves; for example, the fibrous material can be pre-formed into a semi-cylindrical shape so that the sound waves have penetrated a substantial distance within the void before encountering the absorbing material.

The sound absorbing characteristics of the acoustic structural units of the invention are optimized by considering several fundamental factors involved in their use. Sound waves in air, upon coming in contact with surface apertures **16** of slabs **10**, pass through the apertures and into cavities **11**. Cavities **11** act as resonating air chambers in the manner of Helmholtz resonators, which are well known in the art of acoustics and are used for special applications in the absorption of sound energy. Some of the sound energy in these sound waves is transformed into heat energy and is absorbed in cavities **11**. This transformed sound energy is, therefore, not reflected from the surfaces **17** of slabs **10**, as it would be from the surfaces of conventional, hard, untreated concrete slabs.

The transformation of sound energy to heat energy, and its consequent absorption is accomplished by two processes. One process takes place through the function of air molecules in the sound waves, which consist of alternately compressed and rarefied air. This friction of air molecules takes place primarily in the passages formed by apertures **16**. The other process involves setting in vibration filaments or fibers of the fibrous material in fibrous boards **18**.

A special feature of the acoustic structural units of the invention is more readily understood by reference to the pitch or tonal aspects of sound waves given in terms of the frequency of the sound wave variation of intensity. The human ear is responsive to low frequencies of about 50 c.p.s. and high frequencies of about 8000 c.p.s., 1000 c.p.s. being a medium frequency. Different types of sounds are identified by their frequency vs. amplitude characteristics. The human ear responds to these characteristics with a sensitivity-vs.-frequency and amplitude characteristic. The acoustic structural unit of the invention is designed with due consideration of these factors given and incorporated in the structure and construction of the acoustic unit.

Among the fundamental features incorporated in the acoustic structural unit of the invention is the ratio of the sum of the areas of the apertures **16** to the total area of the perforated surface **17** of a slab **10**. It was found that satisfactory sound absorption was obtained when the ratio was maintained in the range from about 7 to about 15 percent, preferably about 10 percent. By thus controlling this ratio it was found that the acoustic unit or slab **10** gave increased sound absorption at the lower sound frequencies in relation to higher frequency sounds. This is a desirable and unique characteristic.

Another feature of the acoustic structural units of the invention resides in their inherent ability to restrict sound waves from passing through slab **10** from upper surface **13** to lower surface **17**, or vice versa. This feature is extremely important in the construction of multi-story structures. The use of surface apertures **16** only on one side of slab **10** and a thick, dense, impervious layer on the other side of the slab restricts the passage of sound through the slab in either direction.

The solid structure of the slab is equivalent to a series of parallel, abutting I beams which are strengthened by reinforcing members **20**. The reinforcing members are preferably, but not necessarily, prestressed cable sections cast in the slab during its construction or manufacture. The use of reinforcing in an acoustic slab to provide a flexural combination structural and acoustic unit is an important feature of the invention. Reinforcing is required to provide flexural strength properties. By "flexural" is meant the property of the unit to withstand stresses from compression and/or tension.

A further advantage of the slab derived from the fibrous material in the voids, is achieved in respect to isolation to solid borne sounds, such as foot falls, originating on the imprevious side of the slab. Sound waves arising from the solid borne or impact noises is absorbed by the fibrous material in the voids. In installations where it is desirable to use the slabs of this invention for walls, the sound isolating properties of the slabs are effective in providing privacy between areas on the two sides of the partition. This type of construction is sometimes referred to as tilt-up-slab wall construction.

The invention is not restricted to a pre-stressed reinforced concrete slab as unstressed reinforced slabs have many applications. Neither is the structure of the slab restricted to a void connected throughout its entire length to the atmosphere by aperture means as some sections of the void may be left completely closed to the atmosphere. It is possible that in a room where certain specified acoustical properties are desired slabs might be used which have aperture means and connecting passages to the void at each end and not in the center, this structure being necessary to attain the required acoustical properties of the overall room. The acoustical material must be properly distributed in the surface area of a ceiling and walls in accordance with its acoustical properties to attain the overall desired acoustical results. The invention includes not only the acoustical slab but the various composite structures which may be constructed from it, such as floors, ceilings, walls and others.

The specific embodiment of the acoustic structural unit of the invention shown in the drawing can be manufactured at the site of construction of a building or other structure. In a specific embodiment of the manufacturing method of the invention, the acoustic structural units are made of prestressed reinforced cast concrete. The units are cast in a rigid mold made of metal. The metal mold is used to form the bottom surface **17** of slab **10** provided with apertures **16** and the two sides provided with surfaces **12** and **14**.

Cavities **11** are formed in slab **10** by removable forms made of elastomer, rubber, plastic, metal, or other suitable materials. Removable forms made of rubber or elastomer are preferred because they can be inflated in position in the mold before concrete is poured into the mold. The removable forms, which form cavities **11**, are held in contact with forms which form apertures **16**, and are mounted in proper position on the bottom of the mold. Reinforcing members, such as prestressed cable, also are mounted in position in the mold.

After the concrete is poured into the mold it is vibrated until the mixture reaches a structural density. After the concrete becomes structurally sound, the removable forms are deflated and removed from cavities **11**. Slab **10** is in turn removed with apertures **16** formed through bottom surface **17** to cavities **11**. Boards **18** of preformed fibrous material are then inserted into cavities **11** above apertures **16**. The resulting slab **10** then is installed in the building structure roof, floor or wall.

Although apertures **16** were described hereinabove as slots or continuous slits, it will be understood that a series of perforations spaced longitudinally can be used. Also, the cross-sectional form of cavities **11** need not be circular but can be square, elliptical, or of any other suitable shape.

The acoustic structural unit of the invention represents an entirely new application, that is, a combination flexural and acoustic unit for constructing floors, roofs and ceilings, providing both acoustic and structural requirements and not requiring additional acoustic elements. Substantially short acoustic building blocks for sustaining compressive stresses are common in the prior art but this invention makes possible for the first time elongated acoustic structural units having sufficient strength for the construction of composite structures, such as, floors, ceilings, and roofs, which are subjected to comparatively large flexural stresses.

Various advantages are provided by the invention supplementary to those mentioned above. The slab can be cleaned without damage to its acoustical properties, is easily painted, and is otherwise easy to maintain. The structure provides an efficient sound deadening void while maintaining required strength properties. Ancillary to its acoustical properties, the void can be used as a ventilation duct, a conduit for electrical wires and the apertures can be used for suspending objects, such as, lighting fixtures so that the use of eye bolts and various other hanging attachments is eliminated.

Obviously, many other modifications and variations of the acoustic structural unit and method of the present invention are possible in the light of the teachings given hereinabove. It is, therefore, to be understood that within the scope of the appended claims, the invention can be practiced otherwise than as specifically described.

What is claimed is:

1. An acoustic load bearing structural unit which comprises an elongated flexural slab of reinforced concrete having a plurality of elongate cavities formed therein in transversely spaced substantially parallel relationship with respect to each other, each of the cavities having elongate aperture means formed through a wall of the cavity forming a perforated surface and establishing communication between the inside of the cavity and the atmosphere, the ratio of the total surface area of the apertures to the total area of the perforated surface being in the range from about 7 to about 15 percent, fibrous sound absorbing material in each of said cavities, said fibrous material occupying throughout its length a portion only of the cross-sectional area of said cavity, and a septum inserted in each of the cavities adjacent the side of said sound absorbing material distal to said aperture means for controlling the effective volumes of the cavities in communication with the atmosphere.

2. An acoustic load bearing structural unit which comprises an elongated flexural slab of reinforced concrete having a plurality of elongate cavities of circular cross-section formed therein in transversely spaced substantially parallel relationship with respect to each other, each of the cavities containing sound absorptive material occupying throughout its length a minor cross-sectional area of the cavity, each of said cavities having an elongate aperture means extending through a wall thereof forming a perforated surface and establishing communication between the inside of the cavity and the atmosphere, and a septum supported in each of the cavities by the lower half of their inner peripheral surfaces above the fibrous material for controlling the respective volumes of the cavities in communication with the atmosphere.

3. An acoustic flexural and load-bearing structural unit for assembly with like units to form a composite acoustic structure, comprising: a reinforced, flexural, acoustic slab of relatively hard and dense material having a low inherent capacity for sound absorption, said slab having faces, ends, and edges constructed for joining with corresponding edges of like slabs and a plurality of substantially parallel cavities of circular cross-section extending longitudinally therethrough, each of said cavities having a passageway connecting it with an aperture to form a perforated surface in the slab, said passageways having a width less than the width of their corresponding cavities whereby the solid portion of said slab is, in effect, formed into a series of integral adjacent I beams; sound absorbing material in at least one of said cavities extending longitudinally thereof and occupying throughout its length a portion only of the cross-sectional area of said cavity, and a septum supported in said cavity by the lower half of its inner peripheral surface above and adjacent the side of the material distal to said passageway.

4. The structural unit of claim **3** provided with prestressed metal members extending longitudinally thereof.

5. The unit of claim **4** in which the ratio of the area of said apertures to the area of said perforated surface is from about 7 to about 15.

6. In a substantially enclosed building unit having an interior surface to be exposed to sound; at least one load bearing flexural slab of reinforced concrete included in said interior surface having at least one elongate cavity formed therein, said cavity having aperture means formed through one of its walls forming a perforated surface and establishing communication between the inside of the cavity and the atmosphere, the ratio of the total surface area

of the aperture means to the total area of said perforated surface being in the range from about 7 to about 15 percent, sound absorbing material in said cavity occupying throughout its length a portion only of the cross-sectional area of said cavity, and a septum on the side of said material distal to said cavity.

7. In a substantially enclosed building unit having an interior surface to be exposed to sound, a first area from which sound emanates and a second area for the reception of sound: the improvement which comprises at least one load bearing flexural slab of reinforced concrete included in said interior surface having at least one elongated cavity formed therein, said cavity having aperture means formed through one of its walls forming a perforated surface and establishing communication between the inside of the cavity and the atmosphere, the ratio of the total surface area of the aperture means to the total area of said perforated surface being in the range from about 7 to about 15 percent, and sound absorbing material in said cavity occupying throughout its length a portion only of said cavity and a septum on the side of said material distal to said cavity; said slab being positioned in said internal surface with respect to said areas to impart the required overall acoustic properties to the interior of said unit.

8. An acoustic load-bearing structural unit which comprises an elongated flexural slab having a plurality of elongate cavities formed therein in transversely spaced substantially parallel relationship with respect to each other, each of the cavities having elongate aperture means formed through a wall of the cavity forming a perforated surface and establishing communication between the inside of the cavity and the atmosphere, at least one of said cavities containing sound-absorptive material occupying throughout its length a portion only of the cross-sectional area of said cavity, and a septum supported above the fibrous material for controlling the volume of the cavity in communication with the atmosphere.

9. An acoustic load-bearing structural unit which comprises an elongated flexural slab having a plurality of elongate circular cavities formed therein in transversely spaced, substantially parallel relationship with respect to each other, each of the cavities having elongate aperture means formed through a wall of the cavity forming a perforated surface and establishing communication between the inside of the cavity and the atmosphere, and a board of substantially rectangular cross section of preformed sound-absorbing fibrous material inserted lengthwise in at least one of the cavities for controlling the volume of the sound absorbing chamber of the cavity below the board that is communication with the atmosphere, said board occupying throughout its length a minor cross-sectional area of the cavity and being of a width less than the cavity diameter whereby the board may be positioned within the cavity on either side of a horizontal plane passing through the cavity diameter to vary said volume of the sound absorbing chamber.

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