Aug. 8, 1967 J. C. LEEMHUIS 3,334,458

STRUCTURAL MEMBER

Filed Oct. 21, 1963 2 Sheets-Sheet 1

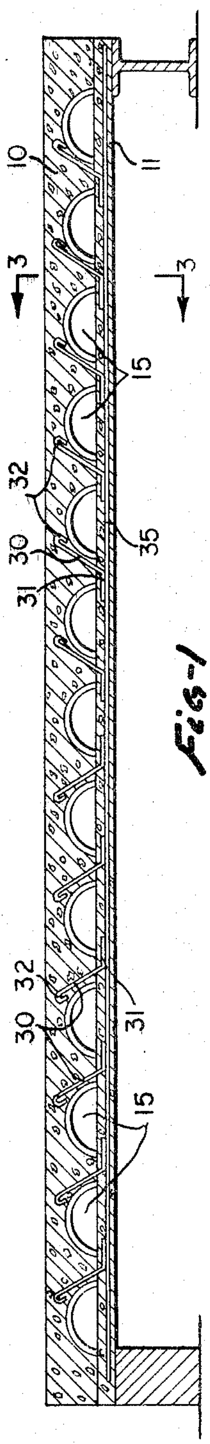

Fig-1

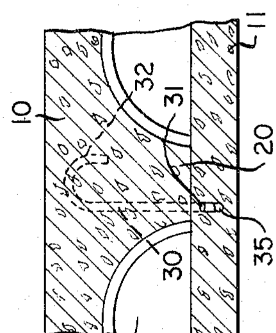

Fig-3

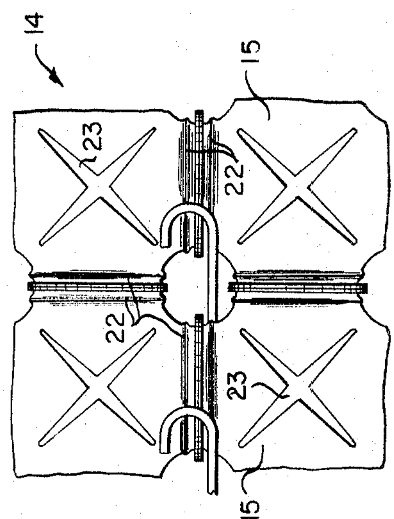

Fig-4

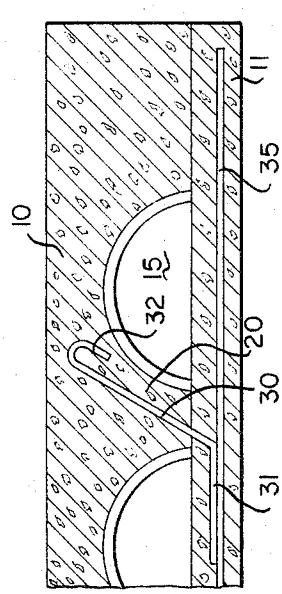

Fig-2

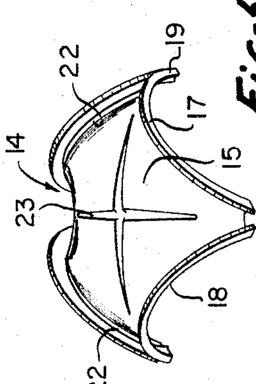

Fig-5

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STRUCTURAL MEMBER

Filed Oct. 21, 1963 2 Sheets-Sheet 2

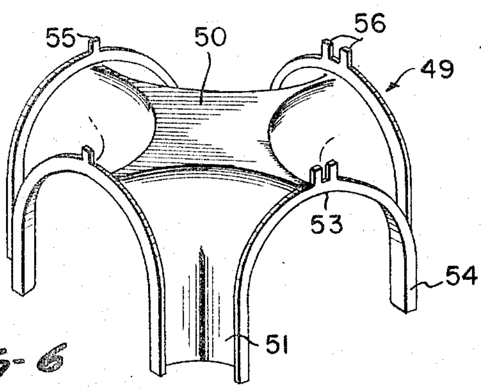


Fig-6

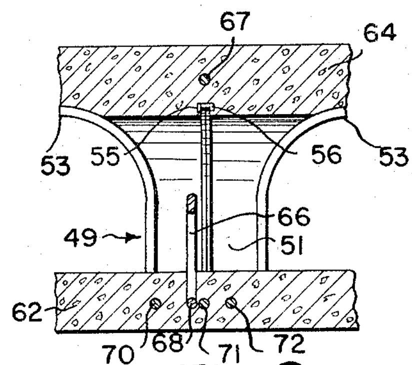


Fig-9

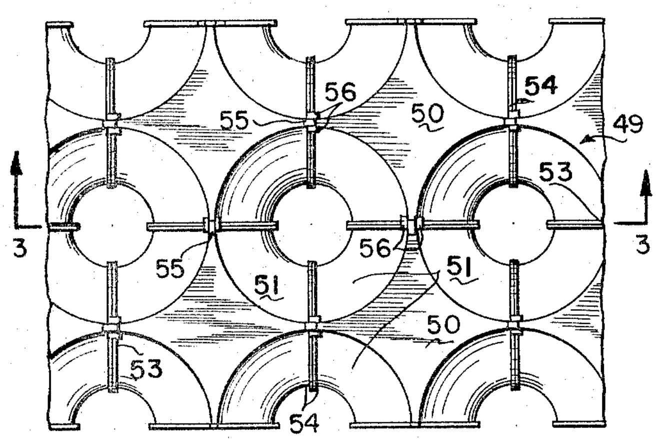


Fig-7

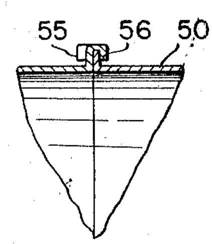
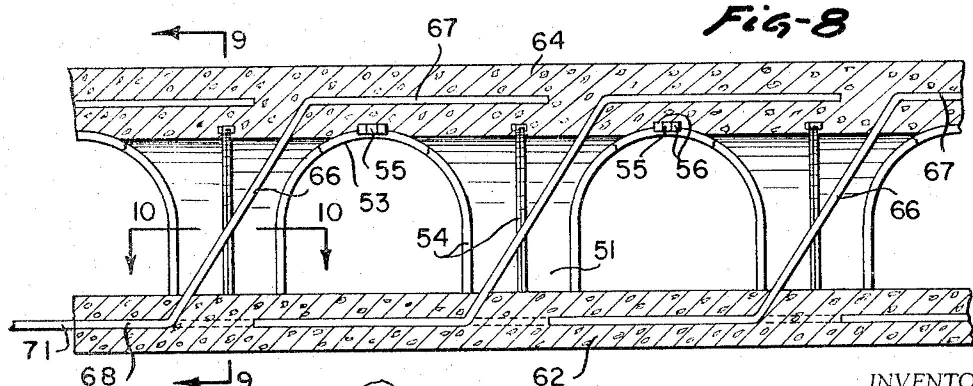


Fig-11

Fig-8



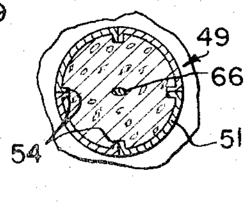


Fig-10

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1

3,334,458

STRUCTURAL MEMBER

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5 Claims. (Cl. 52—223)

This invention relates to a new and improved structural member or structural slab adapted for various and multiple uses in building construction. The member is a truss slab of composite construction embodying two directional continuous raceways therein. The member or unit has very distinctive characteristics and multiple purposes and objectives as will become more apparent from a review of the objects of the invention, and from the detailed description of preferred specific embodiments thereof.

The member or structural slab of this invention is directly related to, and implements the latest concepts having to do with the integration or architecture and environmental control of living and other spaces. This concept has been publicized, as for example in the Architectural Forum of January 1957 in an article identified as A New Approach to Environment. The relationship of the herein invention to this concept will become apparent from the detailed description herein, particularly from the standpoint of physical integration of means for controlling environmental factors into the building construction.

A primary object of the invention is to provide a structural slab or member adapted for multiple purposes, and one which implements the concept of integration of architecture and environmental control. This means the integration of the actual building construction, and the control of conditions conducive to human comfort within the building.

Another object is to provide a constructional slab, which is also a truss, and which is self-supporting.

The invention has additional objects, one of which is to make possible the bonding of two separately poured concrete slabs to form a unitary structurally sound, truss acting slab or member, for on-grade or multi-story buildings. This integrated truss slab serves many functions and realizes many other objectives.

One of such objectives is to realize a comparative mass concrete saving in excess of 40 percent as compared with solid slabs of comparable thickness.

Another objective is to provide improved structural strength on the order of a 200 percent increase.

Another object is to provide a structural slab or member of the type referred to, embodying a hollow plenum for air distribution in any or all directions or for other purposes related to the integration of environmental control and architecture.

Another object is to realize a structural slab or member having the requisite characteristics providing within itself a plenum chamber in which electrical wiring or piping or other implementation of environmental control can easily be concealed and can be run in almost all directions.

The plenum chamber or raceways in the structural slab are provided by way of forms comprising pans or stools, preferably made of metal and having a particularly designed configuration for the purpose. These pans in one form of the invention have domes which are flat on top so that electrical raceways may rest or be anchored on them for electrical wiring, telephone cable, computer cable, etc. The realization of this result is another object of the invention. Preferably these forms are of groined vault shape, this being a crossed vault shape providing intersecting arched channels.

The raceways provided by the arch shaped voids in the pans are large enough to accommodate high or medium

2

velocity air ducts or the like for zoning within the structural slabs, this being another object that is realized by the invention.

Another object is to realize a saving or minimization in the size of all beams, columns, foundations and total amount of concrete needed by reason of the concrete mass saving in the individual structural slabs.

Another object is to reduce the seismic forces in earthquake areas as to which the structural members will be subjected.

Another object is to take advantage of the lighter loads imposed in lift-slab construction stemming from the lesser weight in the improved structural slab.

Another object is to provide a structural slab of the type described having a relatively deep section provided by relatively deep internal pans or stools and as a result making it possible to provide longer spans still having sufficient strength and rigidity. The particular construction as will be described hereinafter, makes possible a greater shear area between the upper and lower slab and facilitates more readily and accurately, the placement of diagonal shear reinforcing which is structurally imperatively necessary. The amount of diagonal tension reinforcing varies with magnitude of the shear in the section, i.e., load on the slab, whereas the tension and compression stresses vary with the load and depth of the section. Where the load remains the same, the greater the depth, the less tensional reinforcing represents another saving.

With reference to the integration of architecture and environmental control, there is an increasing demand for structurally integrated mechanical heating and cooling systems along with electrical systems and structural concrete slabs. Taller buildings require longer spans; ceiling to floor heights are necessarily higher and movable partitions create additional problems. It is an object of the invention to meet these requirements.

Further objects and additional advantages of the invention will become apparent from the following detailed description and annexed drawings wherein:

FIGURE 1 is a cross sectional view of one form of structural slab of the invention;

FIGURE 2 is an enlarged view of one end of the slab of FIGURE 1;

FIGURE 3 is a sectional view taken along the line **3—3** of FIGURE 1;

FIGURE 4 is a plan view of an assembly of the pans or stools used in the slab;

FIGURE 5 is a perspective view of one form of internal pan or stool;

FIGURE 6 is a perspective view of a preferred form of internal pan or stool;

FIGURE 7 is a plan view of an assembly of the pans of FIGURE 6;

FIGURE 8 is a cross sectional view of a preferred form of structural slab of the invention;

FIGURE 9 is a sectional view taken along the line **9—9** of FIGURE 8;

FIGURE 10 is a sectional view taken along line **10—10** of FIGURE 8;

FIGURE 11 is a detail view showing the relationship of adjacent pans to each other.

In the light of the foregoing consideration, FIGURES 1 to 3 show the details of construction of one exemplary form of the invention. These figures show the details of construction of a truss slab or element of construction that might be referred to as a plank, which is suitable for use as a unit in building construction to form any part of the building. This constructional element may, for example, be used in multi-story buildings and has the characteristics discussed in the foregoing. The truss slab or plank shown in these figures comprises upper and lower concrete slabs **10** and **11** each of which, by way of example, may be 2½ inches thick, these slabs being connected by a web system which may, for example, be 3¾ inches in depth or thickness. The web system is formed in part by two-way cells comprising stools **14** as shown more in detail in FIGURES 4 and 5, preferably made of sheet metal or similar sheet material and formed with an upper convex contact surface, as shown at **15**. These stools are laid directly upon the flat foundation, slab **11**, and the upper cement or concrete slab portion is then poured as a single slab over all of the stools fitted together in a cellular pattern as shown. As may be seen the stools thereby define a network of chambers and passages within the truss slab. The stool may be like those in the earlier Patent No. 2,602,323 of Johannes C. Leemhuis. The stools have flanges **17** radially directed upwardly and outwardly and designed to abut one another around the outer ends of the archways **18**. The ends of each stool comprise legs **19** corresponding to and adapted to accommodate pillar or pier portions **20** of the slab **10**. The legs **19** of each stool are designed to rest upon the upper surface of the slab **11**. Each pan has the shape of a groined vault (i.e.) a crossed vault forming intersecting arched channels. The cooperating legs of adjacent juxtaposed stools provide forms to make the circular concrete piers or pillars **20**.

The said reinforcing stools **14** may be provided with reinforcing beads **22** for increased strength and may also be formed with a central cross **23** likewise embossed therein for added strength in the central region of the stool.

In order more firmly to secure together the legs or ends of each stool **14** bandlike annuli likewise preferably formed of metal or optionally formed of other like materials including plastic or resilient members are provided to encircle the four part pillar or pier which is made up of four quarter pillars at each corner of the stools excepting of course that at the edges of the resultant floor or the corners thereof, only one or two of said corner pillars occur. Said annuli retain the stools against relative lateral movement and serve to reinforce the bases of the pillars. Corresponding bands may be provided to encircle there, two or even one of said legs **19** along margins and corners of the slab as may be required. This particular construction may be like that of the earlier Patent No. 2,602,323 which to that extent is incorporated herein by reference.

The height of the passages in the slab may be increased or decreased to compensate for varying conditions and demand by increasing or decreasing the width of the said annuli as described in the earlier patent.

Partitions of generally semi-circular form, but like their corresponding archways, preferably have a straight bottom edge resting flush on the surface **11** and extending vertically to the topmost edges of the flanges **13** may be provided for disposition between flanges of adjacent stools in order to block off selected archways and to provide inner directional channels for the flow of air where a duct like passage is desired between a point of inlet or outlet for the honeycomb passageway under the floor as may be required, e.g. to avoid local areas of excessive heat or cold adjacent or remote from a hot air inlet or outlet point. This detail corresponds to the structure of the previous patent referred to. These partitions may be made of a thin sheet material such as sheet iron and they do not occupy any appreciable space as between the stools. If desired, therefore, in the integral slab construction a continuous long strip of material of equal length to the desired passage may be placed between adjacent rows of blocks or stools in lieu of the individual partial members described above. The height of such continuous strips is preferably such as to cover the archways **18** from the upper surface of the slab **11** but should fall somewhat short of the height of the upper surface of the slab **10**. The thickness of the partitions will be of no importance where the stools are used as forms for the pouring of a

single truss slab. Their height will be of importance only as it bears upon the question of slab joints or lines of separation. Where desired, especially though not necessarily for the latter purpose, heavy tar paper or other yieldable material, etc. may be substituted for sheet metal.

The instant structure as so far described may be economically produced from a large variety of materials, as will be readily apparent to one skilled in any of the arts of radiant heating, tile and cement construction.

The trussed slab includes the diagonal strut members **30** having horizontal portions **31** embedded in slab **11** and hooked end parts **32** embedded in the upper slab **10**. Those members extend upwardly through one of the corner pillars or piers formed by the pans **14**. Centered in the lower slab are one or more longitudinal tension reinforcing members **35** which may be like the corresponding members of the form of the invention shown in FIGS. 6 to 11 which is the preferred form of the invention, and in connection with which the significance of the reinforcing members is described more in detail, such description being generally applicable to the present embodiment also. The struts **30** may be welded to the reinforcing members **35**.

In view of the relatively large passageways and the relatively, small supporting column resistance to air flow and forced air circulation for heating or cooling is reduced to a minimum. Control of flow is also possible as heretofore stated, by the insertion of the partition or the like or from openings or registers adapted for use in forced air circulation. The passageways can also be used for sealed, still air to act as an air cushion for insulation.

The pillars may be treated to prevent capillary action as by setting the stools **14** in tar initially spread over the surface of the slab **11**.

The pillars or piers comprise a series of substantially circular columns spreading outwardly and upwardly to form and harmonize with the contours of the arches and concavities. The smooth rounded surface for unobstructed passages therein in all directions results in the formation substantially of a hot or cold air cushion under the floor.

During installation the stools **14** are laid closely side by side so that the arches are mutually supporting when subjected to a vertical load.

Construction is preferably such that by way of example, the aggregate area of contact between the bottom of the pillars and the base upon which they rest constitutes approximately five to ten percent, preferably eight percent, of the total area of the top surface of the slab **11**.

For radiant heating, the hot air may be forced down through apertures left in the slab **10**. Baffle plates used in conjunction with the partitions or their equivalent assist in directional flow and selective heating. Further circulation may be provided through openings in the surface at any point controlled by registers and the air may be drawn over the surface to a furnace for recirculation. These same principles apply to radiant cooling (i.e.) absorption.

FIGS. 6 to 11 show a preferred form of the structural slab of the invention. In this form of the invention a modified form of steel pan or stool is utilized, having a deeper section. This deeper section makes possible the bonding or tying together of two thin concrete slabs by means of diagonal shear reinforcing members placed approximately one foot on center thereby creating a maximum void, open in all directions within a structurally sound lightweight concrete truss slab. The concrete slab thus formed will act as a load-bearing surface for single and multi-story buildings while at the same time providing a hollow structural member open in all directions, a support for electric raceways and the like, etc.

FIG. 6 shows the steel form, pan, or stool **49** which is used within the slab and between the concrete members. This member is a pedestal-like stool which is generally rectangular having a flat top **50**. It has four downwardly extending legs shown at **51** which are concave and open at the outside as shown extending downwardly from the flat top surface **50**. Between the legs **51** are formed archways, as shown and designated at **53**, having flat peripheral flanges **54** and having upwardly extending lugs or projections **55** and **56** for securement together of adjacent pans. The pan or form **49** is of groined vault, or crossed vault configuration like that of the previous embodiment forming intersecting channels or raceways.

In the forming of the structural slabs the pans are placed together adjacent each other to form a pattern as shown in FIG. 7 with the flanges **51** of adjacent pans abutting and attached to each other by way of the extending projections **55** and **56** as indicated in FIG. 11.

FIGS. 8 and 9 show cross-sections of the improved structural slab of this form of the invention. Numeral **62** designates a base slab which is poured first either on the ground or some rock fill. The prestressed tension members **70**, **71**, **72** are in place when the slab is poured. Then the metal forms, that is, the pans or stools, are installed by setting them on the bottom slab, as shown in FIG. 7, with adjacent forms secured together. Then the upper slab as designated at **64** is poured with the reinforcing members **66** in a position as shown in FIGS. 8 and 9. The reinforcing members **66** have intermediate diagonal parts as shown which pass upwardly through a pillar formed at the corners of adjacent pans as shown, and horizontal portions **67** and **68** embedded in the slabs **64** and **62**. The structure as shown produces a truss slab highly adapted for many uses, including use as a structural element in a multi-story application. In a specific example of a preferred form of the invention, the metal pans or forms have a flat surface or top and are 12" by 12". The arch height in the specific example is 6½ inches. The abutting flanges are ⅜ inch to ½ inch wide. The lips on top of the flanges are arranged in such a manner as to lock in the adjacent form after having been bent over. On each form two adjacent flanges have two lips and through a single lip in the middle, as shown in FIGS. 6 and 7. The reinforcing members **66** may be bonded to the tension members **70**, **71** and **72**.

In the specific example of the preferred form of the invention the upper and lower slabs are each 2½ inches thick and connected by a web system 3¾ inches deep. The web system as described is formed with two-way pans or forms providing two directional raceways. The total depth of the slab is 8¾ inches. Centered in the lower slab are reinforcing members comprising ⅜ inch diameter Bethlehem stress relieved strands **70**, **71** and **72**, the number depending on the particular structural use. Seven might be used in a specific example. The web reinforcing may comprise three No. 4 inclined bars **66** per foot of span as shown in FIG. 8. The top slab is preferably reinforced with four No. 3 mild steel longitudinal bars and 6 x 6 No. 6 x No. 6 mesh throughout (not shown). The casting procedure is as follows. Each reinforcing strand is prestressed to a specific amount, as for example, 14,000 pounds. The bottom slab is cast and strand released at 3,000 pounds per square inch. The pedestal forms or stools are installed and the web and top slab placed.

The concrete slab as so constructed has a number of significant characteristics. The amount of prestressing or post-tensioning and the density of concrete is directly related to the span of the hollow slab with the metal forms and the designed live and dead load that the slab must be able to carry. There is also a definite relationship between thickness of slab and span. One of the significant features of the relatively deep section provided by the deeper pans is that it immediately makes possible longer spans. The amount of tensioned reinforcing in the bottom slab and density of the upper and lower slabs of concrete makes possible a very wide range of loading requirements. The spans are dependent upon the depth to thickness ratio and the amount of reinforcing placed in the bottom slab. The steel pans have a decided effect on the strength of the member. The amount of diagonal tension reinforcing varies with magnitude of the shear in the section (load on the slab) whereas the tension and compression stresses vary with the load and depth of the section. Where the load remains the same, the greater the depth, the less tension reinforcing. The prestressing or post-tensioning may be accomplished using techniques known in the art.

The entire composite slab can be fabricated at the plant if desired and then transported to the building site in the form of a slab of any desired dimensions lengthwise and widthwise within structural limitations. On the other hand, if desired, the lower slab with the prestressed reinforcing and the stirrups bonded therein can be fabricated at the plant and then shipped to the building site at which site the other parts can then be installed or fabricated with any desired distribution system in it and the upper concrete slab poured.

It has been found that the composite truss slab as described possesses remarkable relative efficiency as compared to a regular slab. The composite construction provides for the web spacing between the upper compression slab and the reinforcing bar in the lower slab. The inclined web reinforcing preferably comprises bars hooked at the ends above the domes of the forms at one end and welded to the longitudinal reinforcing at the other end. Compared to a regular flat slab of the same thickness and using the same tensile reinforcement, the composite truss slab weight is about 40% less but is effectively about twice as strong. In multi-story buildings the reduced floor-to-floor heights effect numerous savings due to reduced cost of wall, stairs, elevators, etc. The basic shape of the form is a groined vault. A vault architecturally is an arched structure of masonry usually forming a ceiling or roof, but sometimes carrying a separate roof, a floor, staircase or the like.

From the foregoing those skilled in the art will observe that the invention as described herein achieves and realizes all of the objects and advantages as stated in the foregoing as well as having many additional advantages which are apparent from the detailed description.

The foregoing disclosure is representative of preferred forms of the invention and is to be interpreted in an illustrative rather than a limiting sense, the invention to be accorded the full scope of the claims appended hereto.

I claim:

1. A composite truss slab comprising a slab of concrete, said slab including prestressed reinforcing means extending throughout the extent of the slab, means providing a cellular construction on said concrete slab comprising a web formation defining interconnected dome-shaped chambers configurated to provide a network of spaces allowing air circulation in all directions, an overlying layer of concrete on said web formation with spaced columns of concrete extending through said web formation to said slab, and reinforcing members spaced along the slab having portions embedded therein, intermediate portions extending through said columns and portions embedded in said overlying layer of concrete.

2. A truss slab as in claim **1** wherein said web formation comprises forms generally of stool configuration having legs resting on said lower slab and having a convex upper surface with the overlying layer of concrete directly on top of said forms, the forms having configurations defining a network of open channels within the truss slab, and being juxtaposed to provide openings allowing said reinforcing members to pass therethrough.

3. A truss slab as in claim **2** wherein each of said forms is of groined vault configuration having a dome-like center portion and downwardly extending legs at each of a plurality of corners of the form terminating in a common horizontal plane, the forms being configurated to provide archways between the said legs forming parts of open channels extending transversely through the forms.

4. A slab as in claim **3** wherein the legs of said forms have a transversely arcuate configuration whereby the legs of adjacent juxtaposed forms cooperate to provide a circular form to receive concrete of the upper slab when

poured to provide pillars of concrete at said corners of the forms extending down to the first slab.

5. A truss slab as in claim **2** wherein the said forms have a relatively greater depth than the upper and lower concrete slabs.

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8

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