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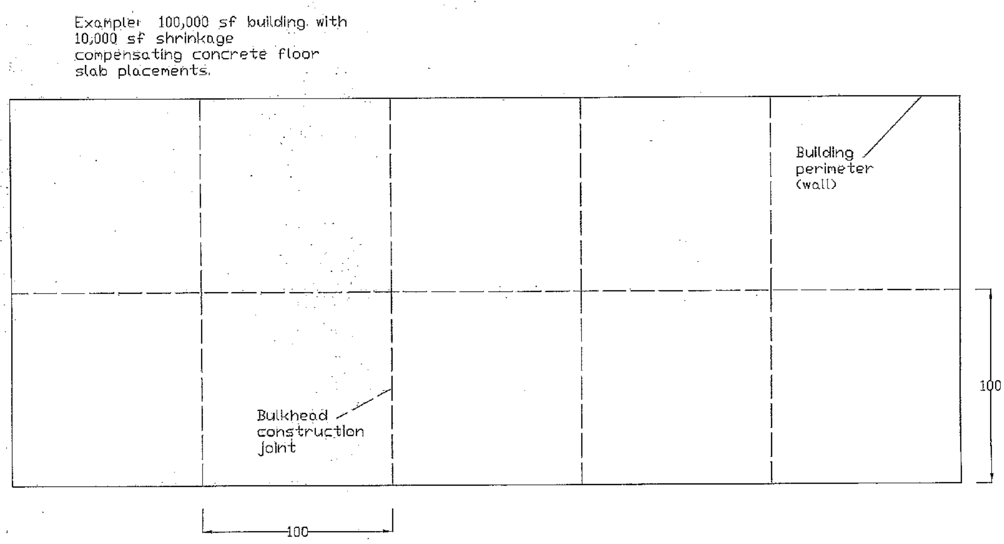
(54) **Title:** UNREINFORCED SHRINKAGE-COMPENSATING CONCRETE FLOOR SLAB



(57) **Abstract:** A shrinkage-compensated concrete slab is formed with no reinforcing structural bars therein, but with plates around its periphery so as to restrain expansive and shrinkage forces. The plates can be made of steel and welded together at their ends, and can include studs extending inwardly from inner surfaces thereof for attachment to the slab.

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UNREINFORCED SHRINKAGE-COMPENSATING CONCRETE FLOOR SLAB

CROSS-REFERENCE TO RELATED APPLICATION

[0001] The present application relates to U.S. Provisional Application Serial No. 60/663,201, filed March 21, 2005, the priority of which is hereby claimed.

BACKGROUND OF THE INVENTION

[0002] The advent of shrinkage compensating concrete (circa 1959) brought the concept of overcoming the disadvantages of concrete drying shrinkage to reality. By chemically increasing the mortar volume between the aggregate in concrete and combining it with an elastic restraint, the concrete structure self-compressed, compression being the ideal condition for concrete because it is weak in tension. The mortar enlarged either because the cement chemistry was modified (such as by using Type K cement) or supplemental chemicals were added to the concrete (such as Type K, S, and M cements where an additive is introduced to the concrete or pre-blended with ordinary Portland cement). This process has often been referred to as 'chemically prestressed concrete' or more commonly known as shrinkage-compensating concrete.

[0003] Ordinarily concrete undergoes a very small expansion once hardened after placement, followed by a significant evaporation process, 90% of which usually occurs in the first year, with perhaps as much as 50% in the first few weeks. Evaporation results in a volume change in the concrete (drying shrinkage) and the concrete shrinks towards its centroid. Floor slabs on ground, in particular, but slabs on any substrate, are restrained from shrinking because of friction between them and the substrate. Thus, all non-shrinkage-compensating (ordinary) concrete floor slabs are in tension (trying to shrink but prevented from doing so) shortly after hardening, and would crack randomly save for joints sawn or tooled into the floor slab to create weakened planes that organize the cracks into neat and manageable joint patterns. A notable exception is when slabs are post-tensioned, put into compression after placement and some curing/hardening by the use of post-tensioning cables. Weakened planes (typically sawcuts) with insufficient frequency and weakness result in floor slabs that crack randomly between the weakened planes.

[0004] Shrinkage-compensating concrete was conceived to enlarge an elastic restraint (such as a deformed reinforcing bar mat) for a time period of about a week at a rate greater than the rate of volume decrease due to drying shrinkage. After this time the rate of drying shrinkage (volume change due to water evaporation) exceeds the rate of expansion and the concrete begins to lose volume. The stretched reinforcing bars in the slab compress the concrete until the concrete shrinkage exceeds the initial elongation. In practice, when the residual shrinkage is small enough and the concrete's tensile strength is not exceeded, it doesn't crack. Hence, the term shrinkage-compensating as opposed to 'shrinkage eliminating' since shrinkage is not eliminated, nor is it often fully compensated. Shrinkage-compensating concrete permits the elimination of joints (weakened planes made by tooling or sawcuts) in the slabs.

[0005] Customary practice is to construct shrinkage-compensating concrete floor slabs in nearly square placements without any interior joints within a placement. Exceptions usually relate to restraints such as from plumbing or barricades penetrating the floor. In such cases interior joints are added to eliminate re-entrant corners. The length to width, rectangular, aspect ratio of the placements is ideally close to 1:1 because concrete shrinks toward its undivided (un-jointed) centroid. If circular, rather than rectangular, concrete slabs were useful, then circles, as opposed to ellipses, would be ideal because uniformly distributed stresses around the centroid of the slab would affect the slab uniformly (i.e., no corner conditions). The American Concrete Institute compiles much of the general industry knowledge in its publication *ACI Manual of Concrete Practice* document *ACI 223 Standard Practice For Shrinkage-Compensating Concrete*, and for the purposes of this document, the ACI 1998 edition has been referenced here as ACI-223.

[0006] Kalman Floor Company, founded in 1916, first commercially constructed shrinkage-compensating concrete floor slabs in 1964. Over the past 40 years it has used most, if not all, of the commercially produced expansive additives and expansive cements. Of course, other construction firms constructed shrinkage-compensating concrete floors and used many of the same cements and cement additives to do so.

[0007] Between December 1996 and May of 1997, Kalman Floor Company (Kalman) fully realized that the industry's spotty performance record relating to cracking of shrinkage-compensating concrete floor slabs was due to the standard practices in composition and integrity of the substrate supporting the slabs, especially the relationship of subgrade friction to slab performance. Consequently, Kalman began using polyethylene slip sheets to minimize or completely prevent bonding of the slab to the substrate and permit the slabs to move more freely. The result was a substantial reduction in shrinkage-compensating concrete (SCC) slab cracking. Theretofore, slip sheets were common only in the post-tensioned slabs on grade installed in the USA and were otherwise recommended against because it was believed (and is true for ordinary concrete) they prevented water from escaping into the ground increasing the moisture gradient across the slab thickness which is the source of upward lift at slab joints known as curling. ACI has subsequently adopted slip sheets as standard practice for SCC slabs in its upcoming publication.

[0008] Apparently, until then, no one had substantiated subgrade friction as a primary factor in cracking of SCC slabs (other than obvious fixed restraints like posts in the slab) that Kalman became convinced of and has demonstrated is so. Before May 1997, it was uncommon to witness, with the naked eye, the compressible linings between SCC slabs and other relatively immovable objects, like walls and columns actually being compressed by slab enlargement. Thereafter, Kalman regularly witnessed the actual expansion of the slabs indirectly by the compression of that surrounding foam. Thus, the original invention circa 1959, patented in 1964, by Professor Alexander Klein of chemically prestressed concrete, was finally installed with repeated success.

[0009] Reference to ACI 223 reveals that the suggested internal restraint mechanism (a rectangular, deformed reinforcing bar mat) is not only intended to restrain the growth of the concrete, but is also to offset subgrade friction. In other words, knowing the bottom of the slab was restrained by the ground, it is recommended by ACI 223 to restrain the upper half of the slab with rebar to provide a more uniform condition of expansion in the slab (so the top wouldn't expand very much more than the bottom of the slab). On that basis, it appears that the monograph in ACI 223 which relates the amount of reinforcing required to the slab thickness and anticipated expansion was developed. In theory, when the amount of expansion is zero (but not less than zero), the amount of reinforcing required to restrain it is zero. Since drying shrinkage always occurs and subgrade friction is never zero, one would assume from ACI 223 that reinforcing must always be used.

[0010] Given that ACI 223 required reinforcing to offset subgrade friction and to elastically restrain expansion, Kalman's use of polyethylene sheeting led to an associated reduction in the required amount of reinforcing. Subgrade friction was greatly reduced by slip sheets. This conclusion was reached after field observations of the shrinkage-compensating concrete slabs Kalman installed with one joint that had the bottoms of adjacent slabs closer together than their tops. By introducing a lower subgrade friction using polyethylene slip sheets, the slab bottom was able to expand more than the top. Obviously less rebar in the top was needed and construction was begun by Kalman in that manner by widening the spacing between the perpendicular reinforcing bars.

[0011] Guidelines for determining the bar size and for determining the bar spacing of the rebar mat (on center, each way) are usually expressed by ACI and others in percent, by the area of a cross-section of a reinforcing bar relative to the cross-sectional area of the floor slab. Thus, for a six inch thick floor slab and an 18" spacing of ASTM A615 #4 rebar, the area of steel is .20 in^2 and the respective area of concrete is 18" x 6" or 108 in^2. Dividing .2 by 108 and multiplying the result by 100 equals 0.185% steel by cross-sectional area of concrete. For a time, Kalman increased the spacing of the rebar to decrease the cross-sectional area of steel relative to the cross-sectional area of concrete, providing less reinforcing bar restraint, allowing the upper 1/2 of the floor slabs to expand more easily and increase the uniformity of expansion of the top of the slab relative to the bottom of the slab.

[0012] Due to continued successful installations of shrinkage-compensating concrete floor slabs on slip sheets using less rebar, resulting in minimal cracking, it became possible to reevaluate the manner in winch a concrete slab placement enlarges. It is my understanding that the enlargement of a given concrete floor slab placement is the cumulative effect of the incremental expansion of each portion of concrete between the slab edge and the slab centroid (devoid of considerations for restraint, creep, temperature, relative humidity, drying shrinkage, and etc.). Thus, it is easy to predict the amount of actual displacement of any point on the floor slab from its centroid relative to its distance from the centroid.

[0013] Kalman's U.S. Patent No. 6,470,640 is based on the conclusion that the cumulative volume change of the floor slabs really resulted in the perimeter of the slabs moving a significant amount, while the interior - held back by the effects of restraint, creep, relative humidity, and drying shrinkage on itself and on the surrounding concrete between itself and the slab edge - didn't move significantly and the reinforcing in the center of the slabs was wasted. The waste occurs because deformed rebar is 'connected' to the concrete periodically along its entire length. After a certain development length, the rebar will act as a restraint mechanism whether it is continuous across the slab or just in portions of the slab. The idea of eliminating the central reinforcement of the floor slab has been demonstrated to work as predicted. The now un-reinforced centroidal area of the slab, if it moves at all, experiences insufficient tension to result in cracking. The slab perimeter moves and is restrained by the internally developed tension ring.

SUMMARY OF THE INVENTION

[0014] According to the present invention a shrinkage-compensating slab of a concrete building structure has no reinforcing bars embedded therein, but instead is elastically restrained around its perimeter by connected steel or plastic plates (or a channel) which are thus tangentially aligned with the expansive and shrinkage forces of the concrete and act as an externally developed tension ring. The plates can include attachment studs on their inwardly facing side or be connected to attachment cables. The concrete itself can include a gradation of aggregate to restrain the expansion of the mortar.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] Fig. 1 shows a schematic plan view of a generally square concrete slab with perimeter steel plates having inwardly-extending connecting studs and diagonal gussets (optional) according to a preferred embodiment of the present invention.

[0016] Fig. 2a shows an inner face of one of the steel plates used in Fig. 1,

[0017] Fig. 2b is an end view of the steel plate of Fig. 2a,

[0018] Fig. 3 is a plan view of a larger generally rectangular concrete slab with a perimeter of steel plates according to the invention, and

[0019] Figs. 4a, 4b and 4c are respectively inside faces, an end view and exterior faces of multiple steel plates welded together to provide a perimeter boundary for the larger concrete slab of Fig. 3.

Example

[0020] Building requirements 100,000 sf of 4,000 psi, 8" thick, concrete floor slab on ground with #4 reinforcing bar spaced at 16" on-center, each way. Sub-base is compacted granular road-base. Coarse and fine aggregates are to be proportioned so that 8 to 18% is retained on standard ASTM sieves; and a top-size coarse aggregate of 3/4" (#57). Sawcut the floor slabs to a minimum depth of the thickness divided by 4, for crack control at a joint spacing of 15′ on-center, each way. An alternate for the use of shrinkage compensating concrete is permitted.

An example of this approach:

[0021] 1. Develop a 4,000 psi concrete mix design containing 6.25 sacks of cement. Fifty-eight percent of the volume of aggregate to be coarse, the remainder to be concrete sand. Top-sized coarse aggregate of 3/4" (ASTM C33 #57 stone) composed of locally available stone such as river rock.

[0022] a. Incorporate shrinkage compensating cement or component adjusting dosage for a desired volumetric expansion of 0.03%.

[0023] b. Reproportion the mix to develop internal restraint

[0024] i. Change size and shape of coarse aggregate to ASTM C33 #467, crushed quarried stone. Adjust the dosage of shrinkage compensating component to again achieve 0.03% expansion.

[0025] ii. Adjust gradation of coarse and fine aggregate by increasing the coarse aggregate to a typically practical limit of 63% by volume of aggregate. Adjust the dosage of shrinkage compensating component to again achieve 0.03% expansion.

[0026] 2. Establish the size and shape of a floor slab placement

[0027] a. Based on crew availability and finishing requirements, select a pour size the crew can practically install, such as 15,625 square feet. To maintain an aspect ratio of the length and width of the placement as near to 1:1 as practical, define the boundaries of each slab placement by bulkhead construction joints spaced at 125' on-center, each way.

[0028] b. Reconsider the joint layout for the building use. If the owner prefers small joints, the re-dimension the size of the slab placement to account for anticipated operating environment. To control joint width account for:

[0029] i. Thermal conditions include seasonal charges and controlled temperature environments. The hardened concrete slab will expand and contract as the temperature rises and falls, for example. This is simply calculated at 10 millionths per degree F.

[0030] ii. As relative humidity rises and falls the hardened concrete slab will expand and contract

[0031] iii. To reduce the joint width due to these factors, change the joint spacing to be 115' on-center, each way.

[0032] c. Dimension the size of the slab placement to account for friction between the slab and the subgrade supporting it. As friction rises slab placement size should fall if cracking is to be minimized, which is the purpose of shrinkage compensating concrete. It is essential for this concept that the friction be reduced as much as possible, and preferably uniform.

[0033] i. Prevent the slab from bonding to the subgrade by installing a break between the slab and the base such as polyethylene sheeting.

[0034] ii. Decrease the friction between the slab and the base by using, for instance, multiple layers of polyethylene sheeting, and, for example, talc between sheets.

[0035] iii. Whenever practical maintain a uniform slab thickness. Especially avoid thickened edges.

[0036] iv. Assume for this example items i, ii, iii above still raise concern the slab may crack. Reduce the joint spacing to 100′ on-center, each way.

[0037] d. Account for undesired slab restraint from walls, columns, posts, dock levelers, drains, and etc., by isolation with closed-cell polyethylene foam, wooden forms, sawcut joints, etc.

[0038] 2. Constrain the expansion of the slab without using a distributed mat of reinforcement or using an internal tension ring of reinforcement.

[0039] a. Surround the slab with 10 foot long steel plates with 6" x 1/2″ headed. "Nelson" studs at 12" c/c top and bottom, offset 6" top to bottom.

[0040] b. Assemble the perimeter of plates by standing each plate on one long edge with studs toward the slab interior. Continuously weld every plate to plate junction on the outside and inside faces, forming a square 100' x 100'.

[0041] c. Choose thickness and height for the plate:

[0042] i. The height of the plate may be as high or less than the height of the slab off the sub-base. If it is less than the slab height, it may be purposely located nearer the sub-base or slab top. Since floor slab tops have no friction and floor slab bottoms do, it is advantageous to install the plate nearer the top. In this example, the plate is to be 8", the full slab depth so as to simultaneously act as the bulkhead.

[0043] ii. The thickness of the plate is sufficient to provide desired slab restraint. The thickness can be gradually changed to adjust the restraint. For economy, the thickness in this example will be uniform for every plate at 3/8".

[0044] iii. The stiffness, durability, abrasion resistance and impact resistance is sufficient to provide protection of the concrete edge from anticipated traffic. A 3/8" x 8" x 10' steel plate will have these properties.

Internally Restrained Shrinkage-Compensating Concrete Made Without the Use of the Non-Concrete Restraints

[0045] Circa 2000, Kalman Floor Company conducted its usual preliminary job expansion testing for one job, monitored by the apparatus described in U.S. Patent No. 5,487,307, but did so for two significantly different sizes of coarse aggregate in the concrete. Typically, materials from the local ready mix concrete plant are shipped to a laboratory contracted by Kalman to mix the materials in a prescribed mix design, and dose the mix with varying amounts of expansive component. The results are used to predict the amount of concrete expansion on the job and, along other things, to discern which dosage rate provides the desired volumetric expansion of the concrete. In this particular case, a No. 3 stone combined with #57 coarse aggregate was incorporated in some mixes while only a #57 sized coarse aggregate was incorporated in other mixes. These two sizes of aggregates were available for the project. Since Kalman wanted to use either aggregate, it expended the effort to obtain test results for concrete mixtures of either aggregate size (357 and 57), so that it could get approval for using either mix on the job.

[0046] It was expected that for similar dosage of expansive component, both concrete mixtures would expand the same amount. For the first seven days - the normal test duration - this was so. However, long-term test results show the concrete with the larger, #357 sized coarse aggregate expanded less than the concrete made with only #57 stone. After more than 90 days, it was evident the difference was approx. 100%. Arguably, only the concrete paste expands.

[0047] For the purpose of this discussion only the paste volume enlarges while the aggregates remain their original size. Also, for the purposes of this discussion the following terms are defined.

[0048] a) Paste = cement mixed with water, including any pozzolans, liquid admixtures, and expansive components.

[0049] b) Mortar = Paste mixed with fine aggregate, where fine aggregate is defined by ASTM.

[0050] c) Concrete = Mortar mixed with Coarse aggregate, where coarse aggregate is defined by ASTM.

[0051] For the purposes of this discussion, the following concepts are employed as factual:

[0052] a) There is more surface area on small aggregates than on equal volumes of large aggregates.

[0053] b) There is more mortar in a concrete containing small coarse aggregate than in a concrete with an equal concrete volume of large coarse aggregate. Therefore, there is more paste in a concrete containing small aggregate than an equal volume of concrete made with large aggregate.

[0054] 1. No literature on, or installation of, concrete floor slabs exists that is based on adjusting the aggregate size, shape, or quantity as a means of adjusting expansion of a shrinkage-compensating concrete floors.

[0055] 2. It is novel to consider the surface area of the coarse aggregate as a measurable factor involved in the amount of expansion (as a restraint mechanism) for shrinkage-compensating concrete floors.

[0056] 3. Paste volume as a percentage of concrete volume has not been explored as a mechanism for determining the volumetric expansion of shrinkage-compensating concrete.

[0057] 4. That the amount of external or internal restraint of concrete can be reduced based on using the coarse aggregate as a restraint mechanism.

[0058] 5. The amount of expansive material can be adjusted based on the size, shape, and quantity of coarse aggregate employed.

[0059] 6. Shrinkage-compensating concrete floor slabs can be constructed without non-concrete restraint mechanisms provided that the volumetric expansion occurs within the elastic limit of the mortar, given sufficiently small subgrade friction, sufficiently small other elastic restraints, if any, and elimination of rigid restraints. Other elastic restraints might be storage racks mounted on the floor, not intended to be part of managing the volumetric expansion.

Externally Restrained Shrinkage-Compensating Concrete

[0060] The invention involves:

[0061] 1. a procedure for elastically restraining volumetric changes of concrete which eliminates all forms of internal elastic restraint other than the concrete materials (sand, stone, pozzolan, cement, admixtures, etc.), by eliminating all non-concrete material forms of reinforcement, such as reinforcing bar, all forms of fibers (for example, steel, polypropylene, and many others) and any other device embedded into or integrally added into the concrete for the purposes of reinforcing for crack control; elastic restraint; inelastic restraint; and moderating the effect of drying shrinkage; of a: shrinkage compensating concrete; low shrink concrete; or non-shrink concrete.

[0062] 2. a device which encircles a shrinkage compensating concrete floor slab with sufficient strength to provide some elastic restraint.

[0063] a. device made of steel bar, channel, plastic which can provide perimeter elastic constraint to a concrete slab and also provide protection of the perimeter slab edge from damage from traffic.

[0064] i. That while serving as a perimeter elastic restraint, its dual purpose is to protect the slab edge.

[0065] b. devices which can be composed of intermediately sized pieces and welded or fastened together to make a continuous elastic band.

[0066] c. devices which can be composed of intermediately sized pieces not welded or fastened together, fashioned to integrally attach to the concrete slab edge.

[0067] d. a device made of steel cable which can be post-tensioned (tensioned after the concrete has hardened to a certain strength) and used separately from or ill addition to that device in item a.

[0068] i. the cable when enveloped by the concrete slab substantially mimics the procedure claimed herein, provided it: forms an ellipse concentric with the centroid and with the same aspect ratio as the rectangular slab length and width; is in a slab that is rectangular or square; provided it is nominally located at the perimeter of the slab at the slab edge mid Points.

[0069] ii. the cable can surround the floor slab placement.

[0070] 1. The cable may be attached to a temporary bulkhead. When the bulkhead is removed the visible cable is flush with the perimeter slab face.

[0071] 2. The cable may be oriented to minimize upward slab edge curling. For instance, higher at the corners of the slab and always above the slab mid-depth elevation.

[0072] 3. Corner plates may be mounted into the slab corners to minimize concrete destruction by the cable force.

[0073] e. devices which may be designed to provide varying restraint across the slab section. For instance, thicker or stronger at the top of the slab edge than at the bottom of the slab edge.

[0074] 3. the use of gussets to improve the perimeter restraint

[0075] a. Where such gussets are elastic

[0076] b. Where such gussets may be connected to the perimeter restraint

[0077] c. Where such gussets may not be connected to the perimeter restraint but located within the slab with or without end points enlarged to provide anchorage

[0078] d. Where such gussets are installed tangentially to an imaginary circle about the centroid when located within the concrete slab

[0079] e. Where such gussets may not be located within the slab, but anchored to the slab at their end points or their end points are fastened to the perimeter restraint.

[0080] f. Where such gussets may be round, square, or rectangular in cross-section.

Despite That External Restraint Is An Idea That
Exists, This External Restraint Is Novel Because:

[0081] 1. It is now defined and geometrically related to the volumetric enlargement of the slab.

[0082] 2. All forms of internal restraint, except the concrete material, are eliminated. Internal restraint is the only approach examined by the ACI 223 document. The only form of external restraint examined is subgrade friction.

[0083] 3. Issues of indeterminate restraint are addressed by gussets and increasing or decreasing the elasticity across the vertical section of the device.

[0084] 4. It has not been done before. It hasn't been done because until 1997, no one was using slip sheets under shrinkage-compensating concrete floor slabs when Kalman introduced the concept to the industry. It wasn't until then that subgrade friction was reduced enough to be able to examine associated reductions in slab reinforcement. It was prohibitively risky and costly to experiment on a image scale, as well. Furthermore, without slip sheets, the industry was accustomed to unexplained random cracking of shrinkage compensating concrete floors. Once freed from the subgrade, each crack became traceable to rigid restraints or imperfections in construction causing discontinuities in the slab cross-sectional stresses.

[0085] 5. Its composition is now defined as related to the practical production of an exterior elastic members. Further, its construction can include edge protection. Please note that customary edge protection devices include the embedment of, for example, a 3" x 3" x 1/4" x 10' long steel angle with 1/2" dia. x 6" long headed Nelson™ studs into the top floor edge at bulkhead construction joints. More commonly used today is a 3/8" x 2" x 10' long steel plate with studs on the interior face plate embedded into the concrete slab. A back-to-back steel edge condition occurs when adjacent slabs are lined with these angles/plates. Traffic across the joints impacts the steel device rather than the brittle concrete, protecting the edge, providing long term durability. The elastic members can incorporate that traditional approach to edge protection while also serving as the mechanism for restraint.

I CLAIM:

1. A shrinkage-compensated concrete structure which comprises a concrete slab having no reinforcing structural bars embedded therein and a plurality of connected plates positioned around a periphery of the concrete slab to elastically restrain expansive and shrinkage forces developed by the concrete slab during setting.

2. The structure as defined in claim 1, wherein the plates are made of steel.

3. The structure as defined in claim 2, wherein the steel plates include attachment studs which extend from inner surfaces thereof into the concrete slab.

4. The structure as defined in claim 2, wherein said steel plates are connected end-to-end by welds.

5. The structure as defined in claim 1, wherein the plates are made of plastic.

6. The structure as defined in claim 1, wherein the concrete slab is square in shape.

7. The structure as defined in claim 1, wherein the concrete slab is rectangular in shape.

8. The structure as defined in claim 1, including a plastic sheeting beneath the concrete slab.

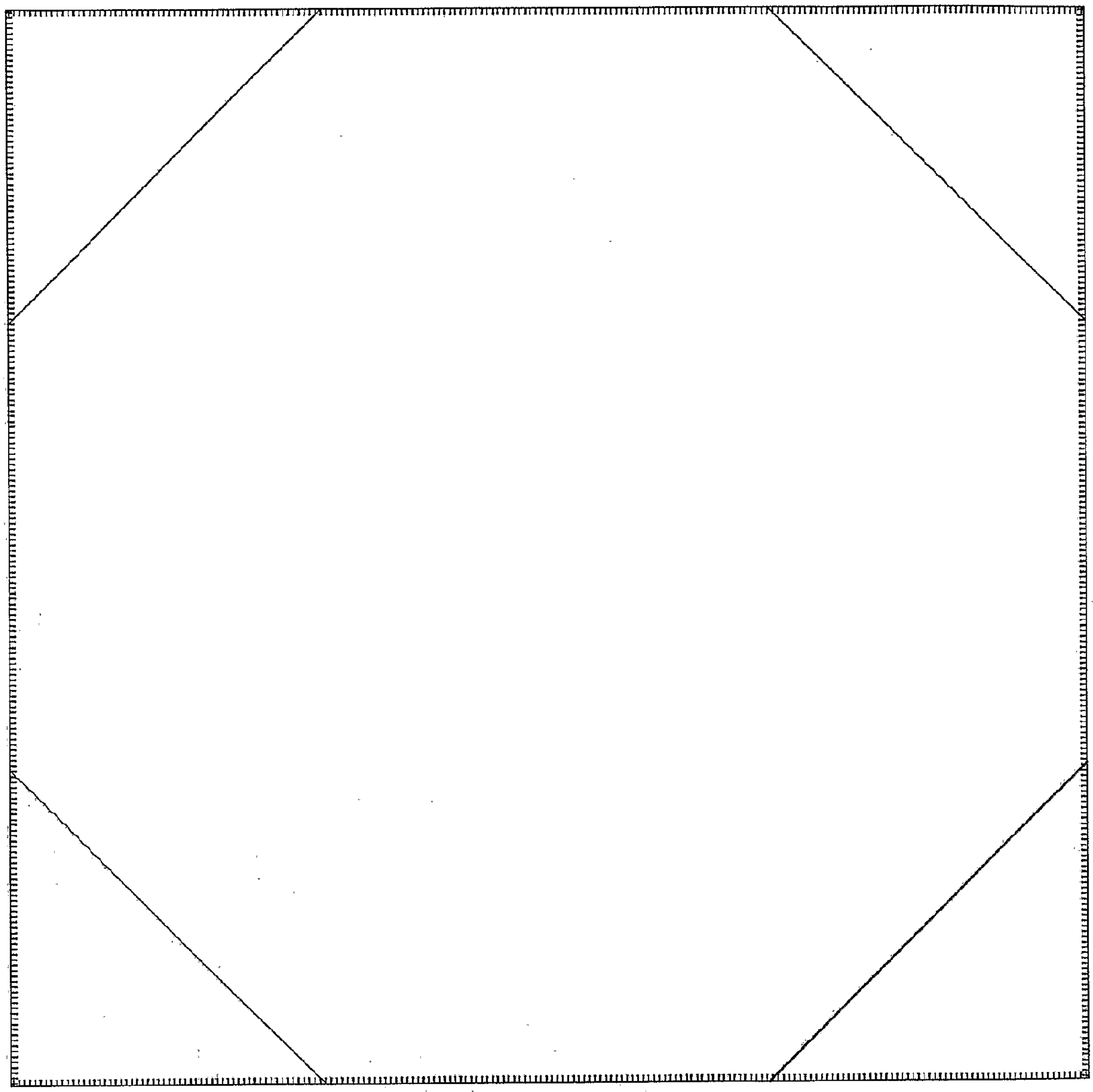
9. A method of providing a shrinkage-compensated concrete structure which comprises forming a concrete slab which has no reinforcing structural bars embedded therein, and encasing a periphery of said concrete slab with a plurality of plates to elastically restrain expansive and shrinkage forces developed by the concrete slab during setting.

10. A method as defined in claim 9, including connecting said plurality of plates end-to-end.

11. A method as defined in claim 10, where said plates are made of steel and are welded end-to-end.

12. A method as defined in claim 9, wherein the coarse aggregate size and shape in the concrete are adjusted to increase internal compression.

Fig. 1



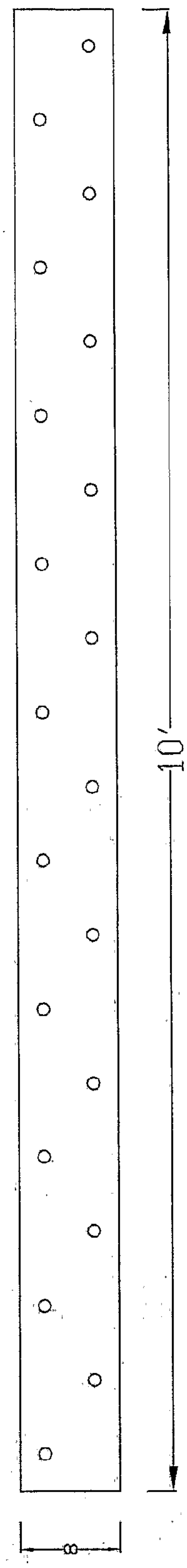


FIG. 2a

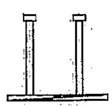


Fig. 2b

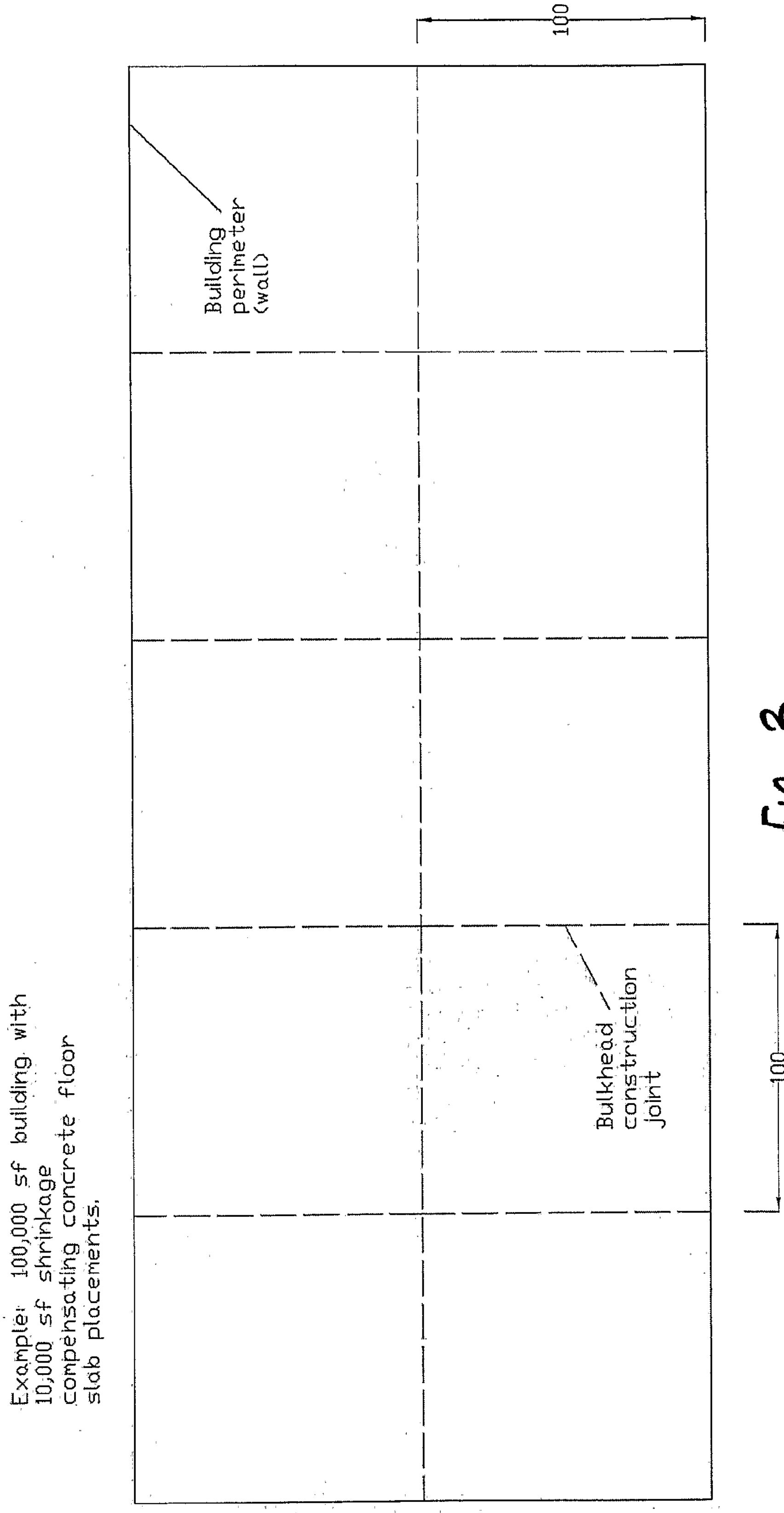
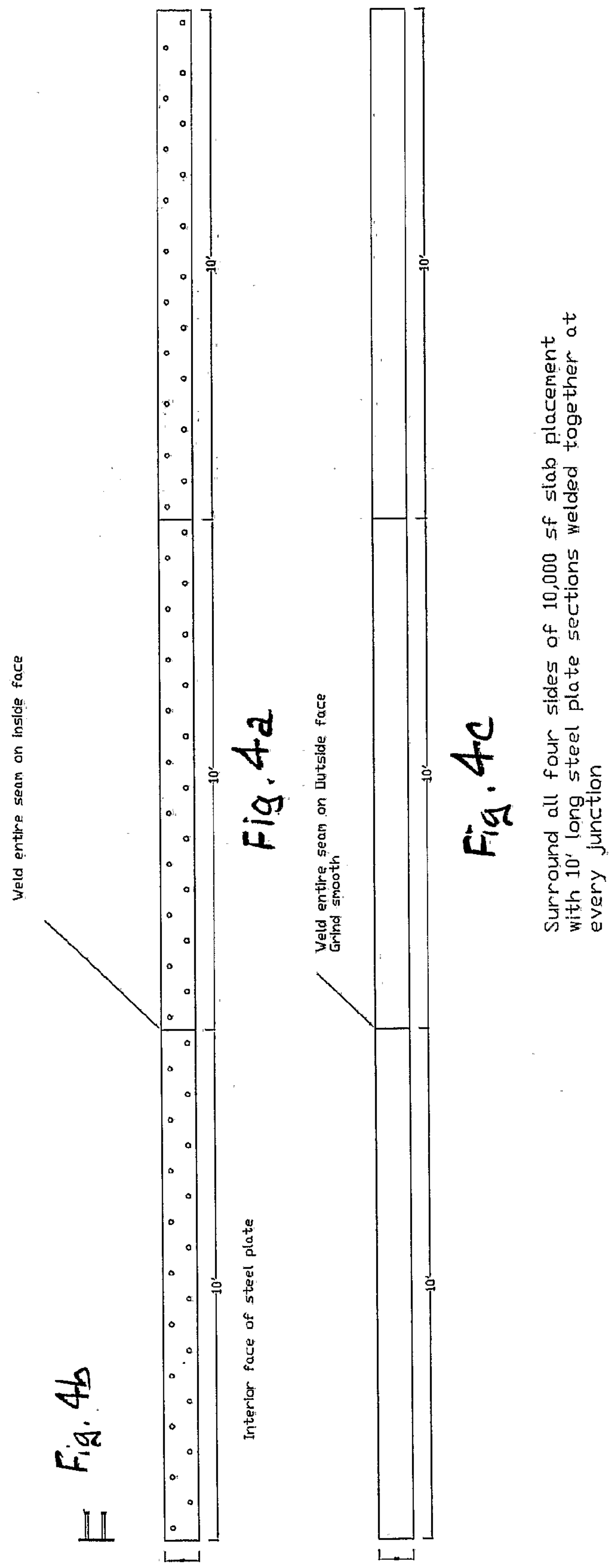

100
Building perimeter (wall)
Bulkhead construction joint
100
Example: 100,000 sf building with 10,000 sf shrinkage compensating concrete floor slab placements.

Fig. 3


Weld entire seam on inside face
Fig. 4a
10'
10'
10'
Weld entire seam on Outside face
Grind smooth
Fig. 4c
10'
10'
10'
Surround all four sides of 10,000 sf slab placement
with 10' long steel plate sections welded together at
every junction
Interior face of steel plate
Fig. 4b