March 6, 1962 R. E. SMITH ETAL 3,023,477

ONE PIECE CASTING FORM

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FIG. 1

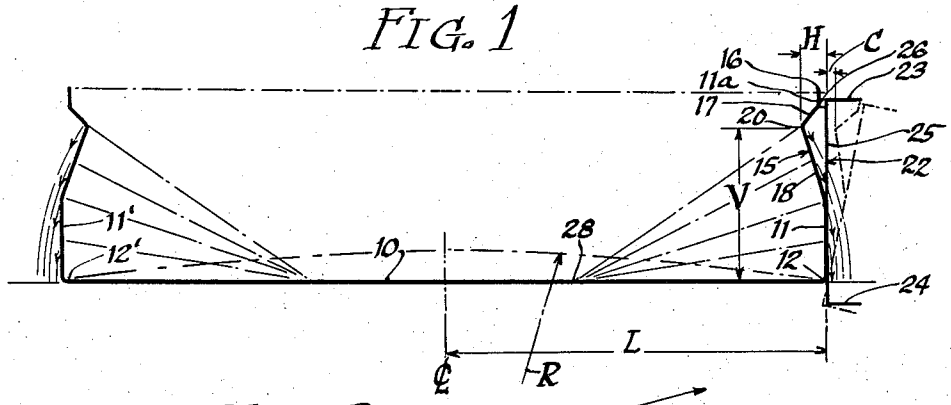


FIG. 2

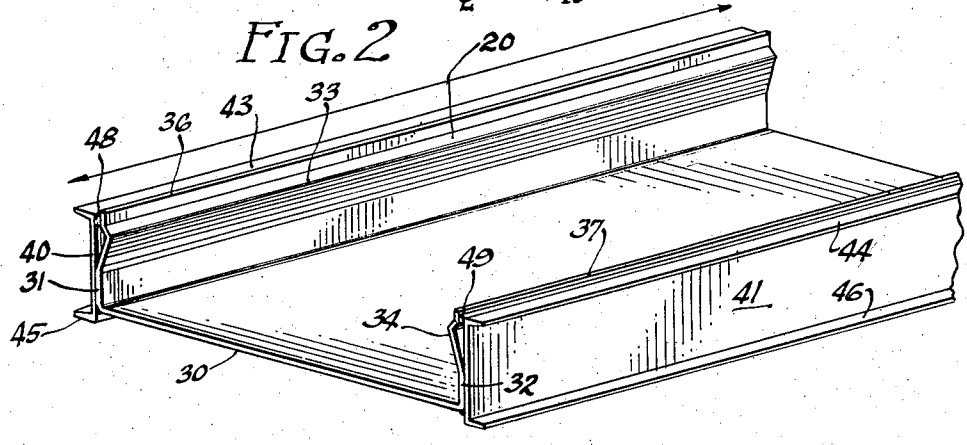
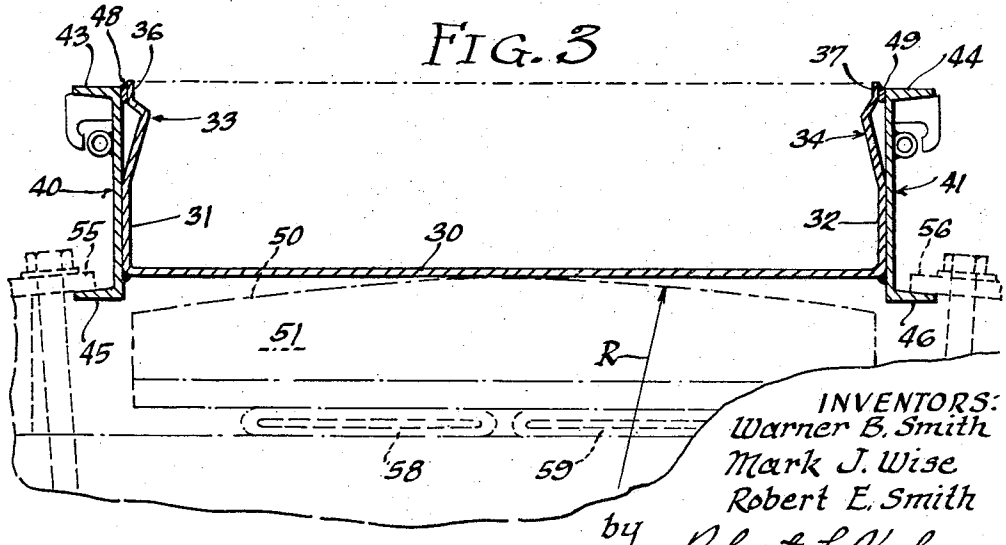


FIG. 3



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FIG. 4

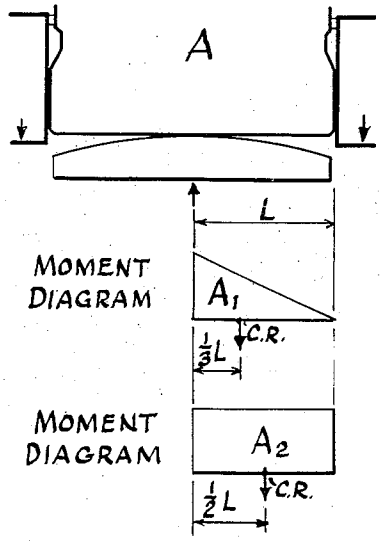


FIG. 5

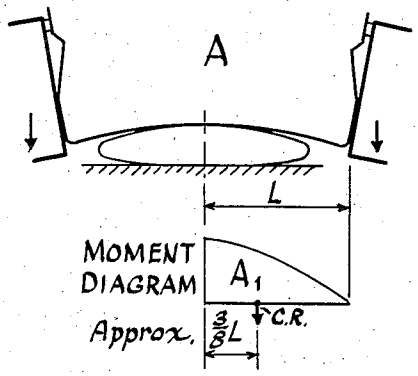


FIG. 6

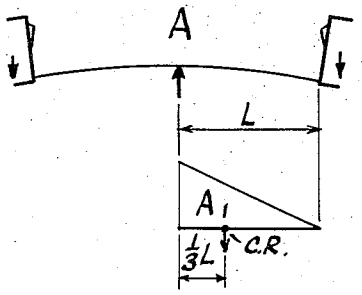


FIG. 8

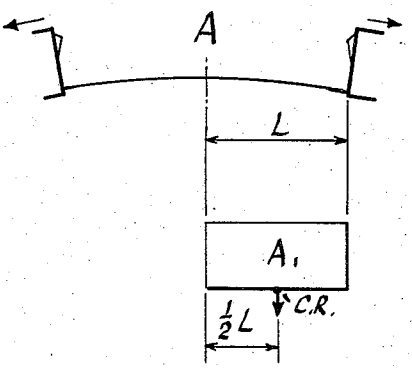


FIG. 7

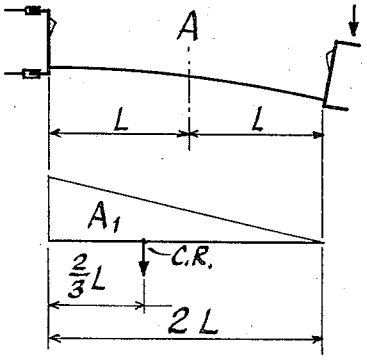
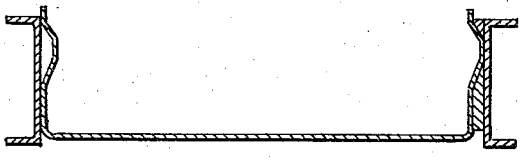


FIG. 9



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3,023,477

ONE PIECE CASTING FORM

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Filed Oct. 2, 1959, Ser. No. 844,012
2 Claims. (Cl. 25—121)

This invention relates to a one piece casting form for concrete slabs. Concrete slabs or beams are disclosed in United States Patents 2,299,070; 2,299,071; 2,299,072; and 2,299,111, issued on October 20, 1942 consist of long slabs or beams along the sides of which are grout keys or channels. Such cast slabs when disposed in side by side relation, have complementary grout keys which cooperate to provide a grout canal so shaped as to lock the slabs together when filled with grout or similar material. The canal in section has a generally bottle shape; i.e., a restricted mouth at the top with a maximum width mid-portion. One slab has one grout key at each side, such key being hereafter designated as semi-bottle shaped. Slabs of the type referred to are cast in forms having a generally U-shaped cross-section with bulkheads for defining the slab ends.

To provide grout keys along the slab sides recourse has been had to one of two expedients. One expedient is disclosed in the 2,299,072 patent previously identified. In this patent, the sides of the form are separable from the bottom of the form. This permits the form sides to incorporate, as a permanent part thereof, means for molding the concrete to provide the grout keys.

The use of a casting form separable into two or more parts leaves much to be desired and in addition is responsible for loss or misplacing of separate parts and the requirement for additional time in assembly and dismantling the form.

In an attempt to overcome the above disadvantage, a generally U-shaped springable form, as disclosed and claimed in United States Patent No. 2,614,309, issued October 21, 1952, was devised. This form has highly desirable advantages but suffers from one drawback. This form requires removable liners for creating the grout keys along the slab sides. The necessity for handling such separable liners, keeping the liners straight and maintaining the liners and the parts of the form covered by the liners clean and free from dirt is undesirable.

Attempts have been made to integrate the liners with the form sides with the object of providing what may be termed a one piece form. Such attempts, however, have generally failed. Incorrect designs of the grout key requiring excessive springing of the form has been responsible for the difficulties. For a casting form to be of one piece, we have determined that it is necessary for the grout key to satisfy certain geometrical conditions.

In the following discussion it will be assumed, for convenience, that the casting form is seen in transverse section and has the bottom horizontal and the sides extending up at right angles from the bottom. Beginning from the top of the key, this would correspond to the mouth of a bottle shape, the key outline will extend downwardly and inwardly (toward the interior of the casting form) until what may be designated a peak is reached. The peak is the innermost (laterally) point on the key during stripping and it is the critical point which the casting must clear for release. Below the peak (in the direction of the form bottom) the key outline will extend downwardly and outwardly (as seen from the outside of the form) so that at or near the form bottom the casting region has full width.

One specific geometrical condition to be satisfied is the location of the center for drawing arcs, as later described

and is dependent upon the manner in which the casting form is stripped; i.e., whether the form sides are both moved or one side anchored and the other side moved or whether the bottom is operated upon directly, all of which will be explained in greater detail later. In all instances, the casting form will have a bottom portion which will be subject to flexing during the stripping operation.

With reference to one side of a casting form, take a point on or near the form bottom which is between about ¼ and about ¾ of the form width distance away. The location of this point is determined by the centroid of the bending moment diagram pertaining to the particular mode of stripping the form. In case a stripping procedure involves one moment diagram at one stage and a different moment diagram at a different stage (as for example, described later in connection with FIGURE 4 of the drawing), then the worst condition should be assumed; i.e., the point determined by the initial moment diagram. From this point, determine the distance to the peak as previously defined and use this distance as a radius. From the point referred to and with the radius as set forth, draw an arc from the peak downward toward the form bottom (or its extension). Every point on the grout key below the peak must lie on or inside of this arc. Furthermore, with the same center, any arc drawn from any point on the grout key outline below the peak must lie on or inside of arcs drawn from points higher up and must lie on or outside of arcs drawn from points lower down on the key outline. Thus, each successive arc drawn from the same center point beginning with a new point on the one form side below the key peak (the radius will of course be determined by the new point) must be on or outside of all parts of the one form side below the new point. From geometrical conditions, it is clear that the portion of the key outline below the peak need only be analyzed in this fashion since any straight vertical form side portion below the key bottom will always meet this condition.

The center point or origin for the radius will lie on the form bottom and will be about from one-fourth to three-fourths of the form width from the side. The range for the location of the center or origin depends upon how the form is manipulated to release the casting as previously stated. By treating the form along its width as a beam, (using conventional stress analysis technique) the ¼ to ¾ factor comes in by virtue of operating on one side of the form or on both sides of the form during the stripping.

Forms of the character contemplated here may range up to about 50 feet in length. The transverse dimensions of the form may range from about 10 inches to as much as 30 inches for width and from about 4 inches to as much as 12 inches for depth. Insofar as stress analysis theory is concerned, the width may vary over the widest range which may be used.

As pointed out in the patents referred to previously, the keyway in the side of each slab comes into use after a slab is positioned alongside of a companion slab. The keyways of two adjacent slabs cooperate to produce a grout joint which must be strong enough to provide an interlock. The keyway in the slab must therefore have substantial depth (this is in a direction parallel to the slab width).

A keyway which is strong enough to provide an interlock between adjacent slabs will obviously produce an interlock between a casting and the casting form. Stripping requires that the form sides be opened enough to free the slab.

A casting form which is sufficiently strong to maintain its transverse shape without external supports when filled with concrete mix obviously requires heavy gauge steel. To this must be added the requirement that the steel must be strong enough to withstand normal conditions of use

in a plant. This means careless handling by workmen, collision with other objects and supporting the casting form on uneven surfaces, which may be irregular because of stones, sand and other debris found in a plant of this type.

From geometrical conditions it is obvious that the deeper a key is and the nearer the key is to the form bottom, the greater is the deflection of the form side to unlock the casting. The form sides and bottom come together to form corners of substantially 90° and these corners are maintained substantially intact during form opening as pointed out later. Consequently, moving the form sides results in arching of the form bottom and this creates stresses in the steel. Conventional beam theory points out that the stresses created in the form bottom increase with steel thickness for corresponding curvature. Theoretically, the thinner the steel that is arched, the lower the stresses. Hence other things being equal, a thin steel form is less likely to be overstressed during stripping than a smiliar form of heavier steel.

This invention provides a construction which has keyways in the slab which are deep enough to satisfy slab requirements and yet at the same time permits the use of heavy steel so that a self-supporting casting form need not be so thin as to be fragile.

A form constructed of suitable material, generally steel, and of proper thickness and shaped to provide a grout key for the slab sides, limited in shape, as herein set forth, has the desirable property of being springable to open the form sufficiently to release a casting while preventing stresses being developed in the form in excess of its elastic limit. Such a form will not acquire any permanent set when sprung to release a casting. The stress requirements as described later will determine the type of steel to be used.

A one piece form embodying the present invention has channels outside of the form along the sides thereof. The reinforced form sides as seen in transverse section will therefore remain straight and will be bent outwardly with arching of the form bottom. It is essential that the thickness of steel used in manufacturing the form must be sufficient to withstand normal use so that the normal right angle existing between the form sides and form bottom should not be permanently changed by any final set of the steel.

In order that the invention may be understood, it will now be explained in connection with the drawings wherein:

FIGURE 1 is a diagrammatic representation of a casting form embodying the present invention to illustrate the underlying principles.

FIGURE 2 is a perspective view of a length of casting form embodying the present invention.

FIGURE 3 is a transverse section of a length of casting form embodying the invention with a suggested means for springing the form illustrated in dotted lines.

FIGURES 4 to 8 inclusive, are diagrams illustrating different modes of stripping and showing the moment diagrams.

FIGURE 9 is a diagrammatic showing of a tongue and groove modification.

Referring first to FIGURE 1, the form has bottom portion **10** and sides **11** and **11'**. Between bottom **10** and sides **11** and **11'** are curved fillets **12** and **12'** of suitable curvature. For convenience, one side of the form will be considered. Side **11** continues upwardly (the direction is with reference to the open top of the form) and has inwardly extending grout key forming portion generally indicated by **15** and free edge **16**. Grout key forming portion **15** consists of top and bottom portions **17** and **18** meeting at key peak **20**. Portion **17** extends toward side wall portion **11*a*** which continues to free edge **16**. Portion **18** extends to side **11**. Portion **11*a*** may be of any size and is laterally offset from side **11** toward the inside of the form. The grout key way formed will therefore have a narrow mouth or opening at the slab face.

It is understood that the casting form extends lengthwise for a desired length. Peak **20**, which is a point on the sectional view, will be a straight line. If a continuous, uninterrupted key way for a slab is desired, then peak **20** will lie on a straight line extending the full length of the form. However, it may be desirable to interrupt a key way along the length of a slab. In such case, a transverse section of a slab at the key interruption point will show a simple rectangular outline for a slab or may show a key way which is shallower. The stripping problem however will be present in such forms and the worst conditions will be determined by the maximum depth grout keys. It is understood therefore that the key outlines illustrated in the drawings represent the deepest key portions along the length of a casting form.

Similarly, other parts **11**, **11*a***, **18**, **17** and **16** are surfaces extending along the form.

Rigidly attached to side **11** is channel **22** having flanges **23** and **24** and web **25**. Web **25** is welded or otherwise rigidly attached to side **11** at a number of places extending from fillet **12** to free edge **16** and it is understood that these places of attachment extend at suitable intervals along the length of the form. Spacer bar **26** is disposed between the form side adjacent free edge **16** and web **25** to provide for the lateral displacement of portion **11*a*** and edge **16**.

Key portion **15**, the part below peak **20**, of the form side must meet the following geometrical condition.

Point **28** on the form bottom is taken as a center. The distance from side **11** along the form bottom may be as little as about ¼ of the form width and as great as ¾ of the form width depending upon the manner of stressing the form bottom for stripping. With the distance between point **28** and peak **20** as a radius, an arc is drawn toward the extension of the form bottom. All points on the form side below peak **20** must lie on or inside of this arc. Next, take a second point adjacent to but below peak **20** as a radius and from point **28** draw an arc toward the form bottom. The second arc must lie on or within the first arc and all points on the form side below this second point must lie on or within the second arc. This procedure can be carried on, point by point, until the bottom of the key is reached. After side **11** has been reached, the vertical side will satisfy the above conditions so no further analysis is required. Different ways of stressing the form bottom to be described will require different locations for the center or origin of the radius vector. In general, however, the center point will range from about ¼ to ¾ of the form width away from the side being analyzed.

Where the height of the peak above the form bottom is small, say less than one-half the form width, great care must be exercised in the key design. Slabs which are wide in comparison to depth, for example 4 inches by 24 inches, must have their key ways designed not only for stripping from the casting form but also for strength of the concrete between the key and the adjacent cored out passage. Hence the part of the key below the peak should slope outwardly as much as possible. On the other hand, the downward component of the slope is essential for clearing the form during stripping. The technique in analyzing a key for stripping clearance is of great importance in shallow forms. Because casting forms are difficult to manufacture and expensive to test, the theoretical analysis is of great value. As will be shown later, the stress characteristics of the steel making up the form bottom is an important factor in the actual design of a casting form and is tied in with the key design. Therefore in testing a casting form, a full scale and practical casting form must be made.

It is understood that the form can be in a normal position shown by dotted lines with the bottom arched and the sides diverging. In such case, the form sides will

have to be closed toward each other during the casting operation.

It is understood that form bottom 10 is arched upwardly to a position such as generally illustrated in dotted lines. Various means for accomplishing the arching may be utilized. Thus the means illustrated in United States Patent No. 2,614,309 may be utilized. The curvature of the arch can be controlled by the use of a suitably shaped contour block on which the form bottom may be pressed while spreading the sides. The manner in which the form will be opened (whether one side or both sides are operated on to move the same) will determine the exact curve assumed by bottom 10.

Referring now to FIGURES 2 and 3, a practical casting form has bottom portion 30 and sides 31 and 32. Sides 31 and 32 have key forming parts 33 and 34 satisfying the general conditions set forth above in connection with FIGURE 1. Sides 31 and 32 terminate in edges 36 and 37.

Key forming parts 33 and 34 are frequently difficult to shape if tough or heavy steel is used. In such cases, bottom portion 30 and the straight parts of the sides above the corners may be of one kind of steel. Key forming portions 33 and 34 may be of steel which can be easily worked or shaped and can be welded to the straight sides. It is also possible to mill key forming portions 33 and 34 out of solid steel. Reinforcing members such as channels stiffen the form sides right down to the fillets and welding at the fillets may even reinforce the fillets.

Permanently attached, as by welding, to sides 31 and 32 of the casting forms are channels 40 and 41. These channels may be of ordinary steel and have top flanges 43 and 44 and bottom flanges 45 and 46. Other kinds of reinforcement, as angle irons or flat plates may be used.

In order to provide the inward offset of edge portions 36 and 37 of the form sides, spacing rods 48 and 49 are disposed between the channels and the form sides adjacent the free edges. These spacing rods correspond to part 26 in FIGURE 1. If portions 33 and 34 are milled spacing may be provided in other ways. The channels or reinforcing members are welded to the form at various points to provide a strong rigid construction. As illustrated in the patent previously identified, particularly 2,299,070, the ends of the casting form may have apertures through the form sides and channels or through the top flanges of the channels to accommodate pins for anchoring bulkheads. Bulkheads of generally conventional construction but conforming to the shape of the form will be provided to determine the ends of the slabs.

As is well understood, a concrete mix is poured into a form having bulkheads and the form is vibrated to compact the mix. Suitable reinforcing or tensioning rods and air tubes may be disposed to produce a typical slab having steel reinforcement and having one or more passages therethrough as disclosed in said aforementioned patents.

After the concrete has set sufficiently for removal of the casting, the form will be sprung to release the casting. A desirable means for effecting this is illustrated in dotted lines in FIGURE 3.

Referring to FIGURE 3, the form with the concrete slab therein is disposed so that bottom 30 rests upon top face 50 of contour block 51. Block 51 may be of steel or other rigid material along the length of the form and has top surface 50 shaped to define a convex surface. This convex surface may have a generally constant radius of curvature such as, for example, part of the surface of a cylinder. The radius of curvature of the surface will be large in comparison to the width of the casting form and the construction of such a block is more fully disclosed in the copending application referred to.

Springing of the form may be effected by rigidly tieing the bottom flanges of the channels to some base support, such as by anchor blocks 55 and 56 extending at spaced intervals along the length of the reinforcing members. In this particular type of springing means, contour block 51 is elevated. This can be accomplished by having a number of inflatable bags 58 and 49 disposed between the bottom of the contour block and the top of same base support. This use of an inflatable bag for springing a form is disclosed in Patent No. 2,614,309 previously referred to. As the inflatable bags are filled with air under pressure, contour block 51 rises and springs bottom 30 of the casting form. The anchoring means for the form channels prevent the form sides from rising and thus tend to bring about a springing of the form along the lines indicated in FIGURE 1. When the form sides are opened sufficiently, the casting may be removed by suitable means.

It is also possible to have the arrangement illustrated in FIGURE 3 inverted so that the casting can drop on to a table. By virtue of the one piece casting form construction, high speed production of casting is facilitated. The absence of joints in the casting form is beneficial. Furthermore, tolerances on a casting can be accurately controlled. Thus, quality is greatly improved. The casting form may have some accessories, as hooks and rods, welded to it for handling.

In the practical design of a casting form embodying the present invention and stripped as illustrated in FIGURE 3, certain design considerations will have to be observed if the elastic limit of the steel is not to be exceeded. By observing the design considerations, a close control over the thickness and quality of steel used is possible. If R is the radius of curvature for the form bottom when it is releasing a casting, then a preliminary value for R can be obtained by the following formula:

$$(1) \qquad R=\frac{.95LV}{H+C}$$

where L is one-half the form width, V is the height from the form bottom to the key or any point being examined for critical clearance while stripping, C is the stripping clearance between a form peak and casting and H is the distance inwardly of key peak from the slab side. A more precise value of R can be obtained by the following formula:

$$(2) \qquad R=\frac{L+C}{\sin\left(\frac{L}{R}\right)}+H\cot\left(\frac{L}{R}\right)-V$$

The solution to Equation 2 is accompanied by setting arbitrary values for R until both sides are equal to at least four significant figures. The angle L/R is in radians. Curves for various values of R can be drawn, where the X-axis shows the width of the form and the Y-axis shows the depth of the form from the key peak to the form bottom. A family of such curves may be used for ready reference to obtain R corresponding to a given form width and depth.

After the value of R has been obtained it can be used to calculate the steel characteristics by using the following formula:

$$(3) \qquad f=\frac{nEt}{KR}$$

where f is bending stress of the form bottom, t is the thickness of steel, E is the modulus of elasticity, R is the radius of curvature, K is a factor equal to about 1.82 and n is a safety factor. In practice, a safety factor of about 1.2 can be assumed. In the above formulas, the linear dimensions are in inches and E is given in pounds per square inch. Thus with n omitted if f comes out 50,000 p.s.i. then 1.2 times that should be assumed. The value of f should in all cases be less than the yield point of the steel used.

By taking f as the yield strength of steel, a minimum value for R can be found from Equation 3. Then when R is found, the curves for Equation 2 can show the form dimensions for that value of R. The above formulas apply particularly to a contour block type of stripping.

Other stripping methods will alter the mathematical analysis to some extent.

It is understood of course that the key profile must in every instance conform to the requirements previously set forth. Where a slab has cored out passages—the area of the void being between about 40% and about 50% of the total slab section—the peak of the key should be well up toward the top surface of the slab. Insofar as the slab height and width are concerned, these will be determined by general engineering requirements in connection with the design of a slab. As hereinbefore pointed out, slabs may have quite a range of thicknesses or heights and quite a range of widths. Whether the cored out passages are circular in cross-section or non-circular will depend on the ratio of slab height to slab width. A slab which is quite wide in comparison to its height or depth can conveniently have non-circular passages to provide the desired void area in a slab section.

To prevent the wall thickness of the concrete from going to an undesirably low value, the peak of the key should be located in the upper corner of the slab where there is considerable concrete to work upon. That part of the grout key above the peak will be determined by engineering considerations relating to the use of the slab after casting. The part of the grout key below the peak will be determined by stripping considerations.

As previously pointed out, the analysis of the stress in a casting form depends upon the intended mode of stripping. Referring now to FIGURE 4, a diagrammatic sketch relating to the previously described contour block stripping is shown. In part A of this figure, a simple illustration of a casting form disposed on a contour block is provided. In this figure, the bottom of the casting form is tangent to the contour plate. Assuming that force is applied to pull the sides of the casting form about the contour plate, then a moment diagram A_1 can be drawn. With the center of the casting form as the origin, a point marked C.R. is located at ⅓ L distance from the center toward the side, where L is one-half of the form width. C.R. is the center of rotation. During the bending of the bottom of the form, the bottom of the form acts as a cantilever beam with reference to the mid-point of the bottom of the form.

As the bottom of the form begins to bend, and at which time there is only point contact between the form and the contour plate, the bottom acts as a cantilever and introduces phase 1 of motion of points on the side wall and the resulting bending moment A_1. All points on the side of the form move about the center of rotation which is located at

$$\frac{L}{3}$$

During this phase, the radius of curvature of the center of the form decreases from infinity to the radius of the contour plate. The bottom now begins to bend around the contour plate and introduces phase 2 of motion of points on the side wall of the form. For all deflection beyond this condition, one part of the form is restrained to the curvature of the contour plate while the remainder continues to bend in cantilever fashion. This motion progresses until the entire form bottom makes full contact with the contour plate. The resulting bending moment diagram is shown in sketch A_2 and the center of rotation is located at

$$\frac{L}{2}$$

In FIGURE 5, there is illustrated stripping of a casting form by the use of an inflated tube. The flanges of the channels will be held down, as indicated by arrows. The bag, as fluid pressure therein rises, arches the form bottom.

Referring now to FIGURE 6, if a concentrated force is applied to the center of the bottom of the form, and the ends are forced downwardly as illustrated, then the entire bending motion and moment diagram is substantially the same as A and A_1 of FIGURE 4.

In FIGURE 7, one side of the casting form is assumed as stationary and all of the bending force is applied to the other side. The bending moment diagram of this is illustrated in A_1.

In FIGURE 8, a still different stripping method is suggested. In this method, the top edges of the form sides are spread outwardly. The form sides are supposed to be rigid so that all of the stress of the arching is taken up by the form bottom. The moment diagram for this type of stripping is illustrated in A_1.

In FIGURE 9, there is illustrated a casting form wherein a so-called tongue and groove type of grout key is provided. As will be evident from this figure, the tongue part extends outwardly rather than inwardly. The basic analysis previously given in connection with assuming a center and drawing arcs applies equally well to the tongue part at the right-hand side of this figure.

What is claimed is:

1. A straight steel casting form for making concrete slabs, said form having a length which is of a higher order of magnitude than the transverse dimensions of the form, said form having a generally U-shaped transverse section with the form bottom during casting being substantially flat and extending continuously around substantially 90° corners into the form sides, said form sides extending from the corners to the free edges and having reinforcement for the sides along the length of the form, the thickness of the steel for the form bottom and corners being substantially uniform and being great enough so that when said form has a casting therein, the form sides and bottom will maintain the transverse shape without external supports, said steel being sufficiently stiff so that when the form sides are sprung the corners will remain substantially intact and will cause the form bottom to arch and thus subject the steel in the bottom to stresses, said form sides having portions integral with the form along the length of the form for creating keyways in the casting, said keyways having sufficient depth in a direction parallel to the flat form bottom in transverse section so that an interlocking grout channel between two adjacent slabs having such keyways is provided, such keyway in the cast slab interlocking with the portions of the form for creating the keyway, the shape of said form portion for creating the keyway having a profile as follows: the keyway extending from its top (nearest the top face of a slab) downwardly and laterally to the peak and then downwardly and laterally in opposite direction to the bottom of the keyway, said keyway profile below the peak being determined by establishing a radius point, said radius point being on the form bottom and being determined substantially by the centroid of the bending moment diagram pertaining to the intended mode of stripping said casting form, said point on the form bottom lying between about one-fourth and about three-fourths away from the form side being considered, from this point as a center draw an arc from said peak of the keyway down toward the form bottom or extension thereof and thereafter repeating this procedure for lower points nearer the form bottom with each new point on the keyway determining the length of the radius and the keyway being so shaped that every arc is on or outside of arcs originating at points lower on the key profile, said keyway being sufficiently deep so that a strong interlock between finished slabs is obtainable and said keyway consequently requires substantial arching of the form bottom for casting release which thereby creates stresses in the steel, the form bottom steel thickness and elastic limit and keyway depth and height combining to provide a self-supporting casting form that can be sprung enough to strip while confining the stresses of the form bottom to the elastic limit of the steel, said casting form making it possible to produce a casting having a deep keyway without damage to the casting form.

2. The steel casting form according to claim 1 wherein the bottom of said casting form has a thickness in accordance with the following formulas:

$$f=\frac{nEt}{KR}$$

and

$$R=\frac{L+C}{\sin\left(\frac{L}{R}\right)}+H\cot\left(\frac{L}{R}\right)-V$$

where f is the bending stress, t is the thickness, K is approximately 1.82, R is the radius of curvature when the form is stressed in such manner that the form bottom in transverse section has the curvature of the arc of a circle, E is the modulus of elasticity, n is a factor of safety, L is one-half of the form width, C is the clearance between a casting and form during stripping, H is the lateral depth of the key peak from the side of the form, V is the height of the key peak from the form bottom, said various dimensions being in the inches and pound system and the trigonometric functions are in radians.

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