Sept. 23, 1958 C. DOBELL ET AL 2,852,991

PRESTRESSED PAVEMENTS

Filed Dec. 3, 1953 2 Sheets-Sheet 1

Fig. 1.

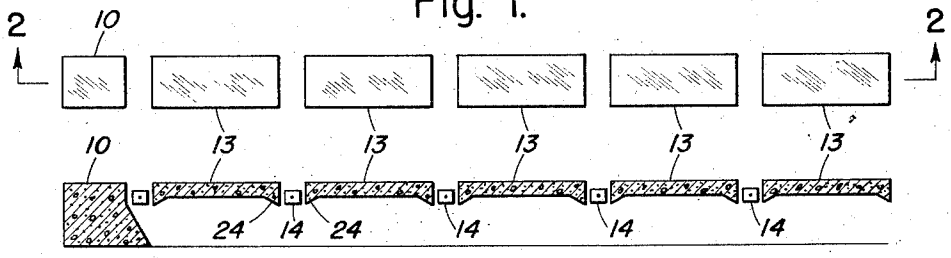


Fig. 2.

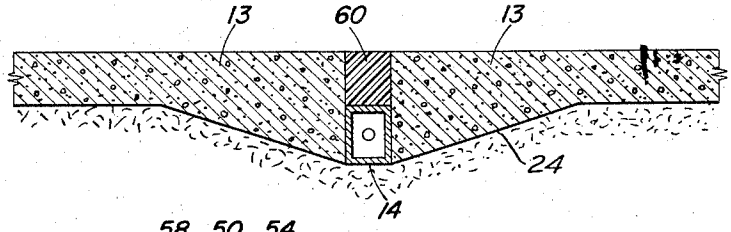


Fig. 8.

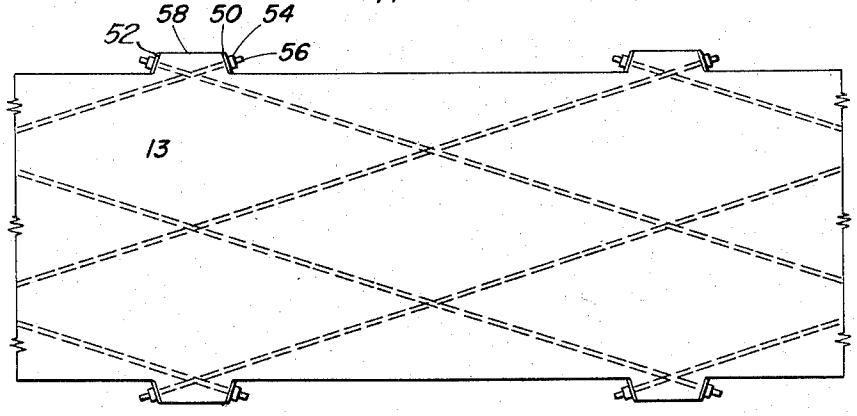


Fig. 7.

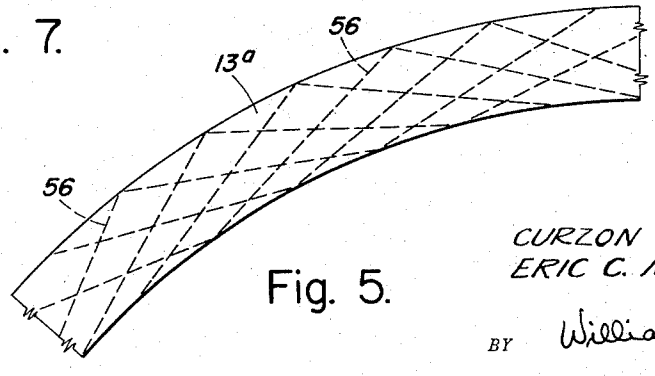


Fig. 5.

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Sept. 23, 1958 C. DOBELL ET AL 2,852,991

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Filed Dec. 3, 1953 2 Sheets-Sheet 2

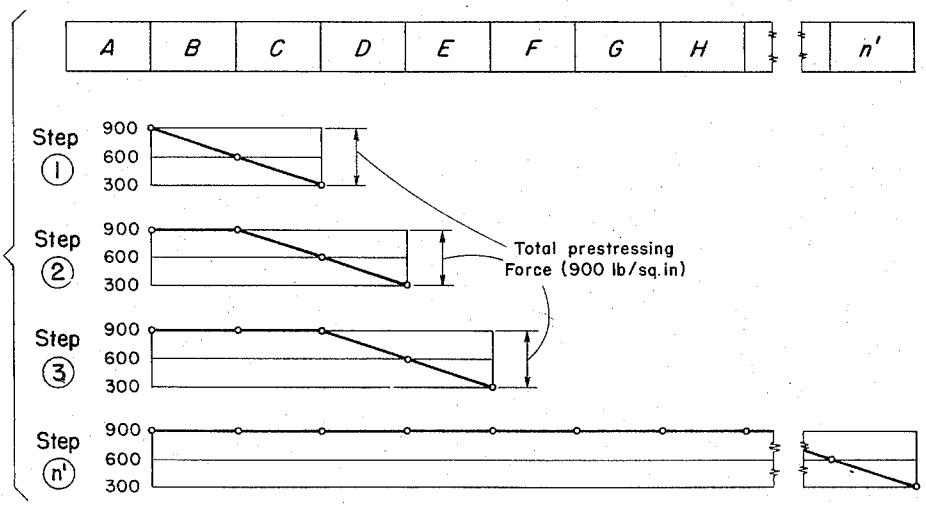


Fig. 3.

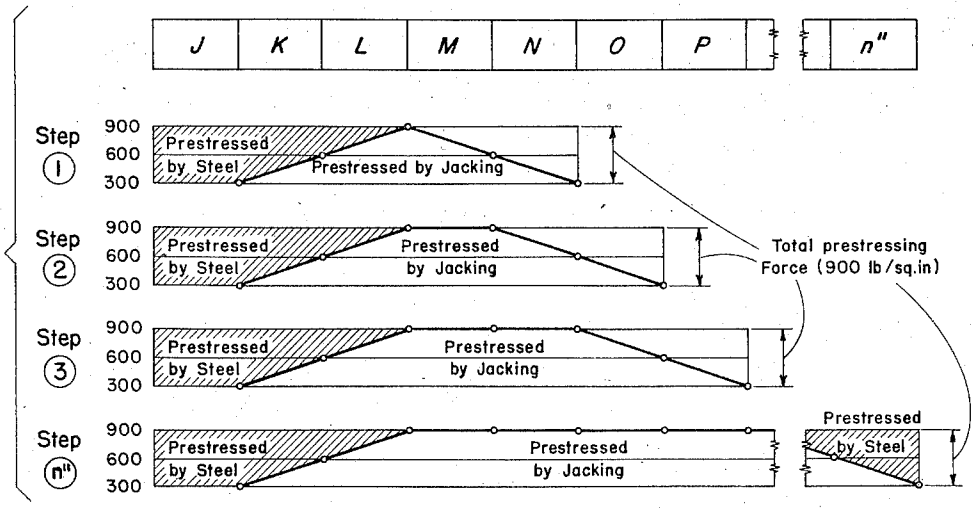


Fig. 4.

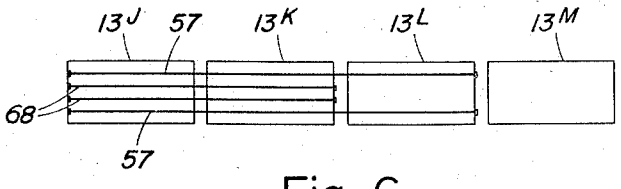


Fig. 6.

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PRESTRESSED PAVEMENTS

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4 Claims. (Cl. 94—22)

This invention relates to the method of making prestressed concrete slabs and more particularly to the method of making such slabs, particularly pavements, in which the quantity of tensioned reinforcing steel is reduced to a minimum.

Pavements are classified as to loading, use and structural behavior. With respect to loading and use, designs vary considerably for highway, airport or industrial pavements.

From a structural point of view, pavements are either classified as rigid or flexible depending on whether they consist of a dense and brittle material such as concrete which must be substantially thick to distribute the load over a sufficient area to prevent such a deflection under load as would rupture the material, or a completely flexible material such as asphalt which has no load distribution capacity and therefore requires a sub-base capable in itself of withstanding design loads without permanent displacement. These two standard types of pavements do not permit a balance between load distribution and elasticity to take advantage of the elastic properties available in many types of sub-base and thus obtain the most economical combination of properties of sub-base and pavement.

Rigid concrete highway pavements are increasingly preferred due to reduced maintenance and longer life. Freezing and thawing trouble can now be successfully overcome by air entraining. The limiting problems are the design of the joints, rigidity of the slab and the warping of the slab. As to joints, it is of course well known that transverse joints are usually provided to give the pavements a degree of freedom to expand and contract under varying temperature and humidity conditions and to avoid shrinkage cracks. Load transfer dowels are often specified in an attempt to minimize the effect of discontinuity and to prevent slab warping. Joint performance is adversely affected by the accumulation of surface water or sub-base moisture under the edges of the joint. Sealing of the joints is usually unreliable and adequate methods of subgrade and joint drainage are very costly. The problem of proper design of concrete slab joints and maintenance of joints is one that has involved much search and study. As to rigidity in pavements, the flexural strength of the pavement largely determines its load distribution capacity and crack resistance. Flexural behavior cannot be judged by strength alone but also depends on the magnitude of deflections. This is particularly true at edges or joints where large deformations cause pumping or subgrade failure.

The idea of prestressing concrete pavements to overcome the above problems therefore has already been suggested and in a modest way has been tried in several experimental pavements in different parts of the world.

The advantages of using prestressed pavements are severalfold. It provides an opportunity to balance the elastic properties of the sub-base with a pavement having a corresponding elastic range. It permits reduction in

pavement thickness which in turn reduces temperature differentials between the lower and upper surfaces of the pavement and this reduced the warping tendencies of the pavement. Cracks are eliminated through prestressing, and if they open up during periods of temporary overloads, they close up after removal of the load and permanent damage is prevented. The pre-stressed unit has the further advantage of being able to follow deformation of the subgrade due to frost action.

One attempt known to us was not quite true prestressing, as it involved the use of compressive forces on the concrete during the first few days of setting in order to prevent cracking while the slab is gaining its full tensile strength before exposure to tensile stresses.

One method of prestressing pavements heretofore has included the post tensioning of elements in unbonded relationship to the concrete, and another involved the maintenance in the joints of pressure cells under seasonal or automatic pressure control.

All of these however, require the use of expansion joints at periodic intervals to accommodate large movements, and have not really solved that problem at all, nor have they developed any technique different than the usual prestressing or post-tensioning of any concrete object.

The previous techniques all involve the use of joints which are difficult to maintain or abutments at frequent intervals. For instance, a 500 foot length of pavement changes in length for a decrease of temperature of 50° F. approximately one and one-quarter inches. A joint of this type would require wheel and dirt protection cover and effective drainage facilities.

It is therefore an object of this invention to provide a method of prestressing concrete slabs such as pavements that eliminates in a great measure the disadvantages in previous techniques. It is an object of this invention to eliminate expansion and contraction joints in long concrete slabs. It is a further object to provide a method of prestressing concrete slabs in which portions of the slab itself are used to support the jacking devices used to compress the concrete in other portions of the slab. It is another object to produce a continuous prestressed concrete slab in which the joints are under the same compressive forces at the ends of the slab immediately adjacent the joints. It is yet another object to provide a fully prestressed concrete slab capable of withstanding loads far greater than is customary for such slabs with only sufficient prestressed tendons to withstand bending and buckling forces. These and other objects will be developed as this specification proceeds.

In summary, this invention proposes to attain these objects by providing a series of concrete slabs arranged in a continuous length with joints between sections and means provided on the ends of each section to support a jacking device used to force the sections apart, widening the joint and thereby placing the sections under compression. It proposes to jack the sections apart by incremental additions to the jacking force and thereby utilize the frictional resistance of a series of the slabs on their sub-base to resist the pressure of the jacking force attempting to move the individual sections from their respective positions.

This invention may be best described by reference to the accompanying drawings, in which:

Figure 1 is a diagrammatic plan view of a prestressed pavement;

Figure 2 is a diagrammatic sectional elevation taken through 2—2 of Figure 1;

Figure 3 is a chart showing the incremental jacking force used with a fixed abutment;

Figure 4 is a chart showing the incremental jacking force used with the pavement forming its own abutment;

Figure 5 shows a diagrammatic plan view of a prestressed highway constructed around a curve;

Figure 6 shows a detail of the steel reinforcement in the beginning sections of the slabs;

Figure 7 shows a diagrammatic plan view of the arrangement of prestressing cables or wires in the finished pavement; and

Figure 8 is a sectional elevation through 8—8 of Figure 1.

In more detail, the pavement or other concrete slab is shown in Figures 1 and 2 with a fixed end abutment **10** of sufficient depth and size to withstand the full forces pressing against it in the compression of the next adjoining first section **13** of the pavement. While this type of abutment is shown, it is to be understood that any type of abutment that will withstand the compressive forces without yielding will be adequate. In the case of the prestressing of the floor of a large building, such as a long warehouse, such an abutment could be a foundation wall, an adjoining floor, or any similar non-yielding abutment.

The pavement is then poured in the conventional manner following the abutment **10** in a series of sections **13**. These sections will be constructed to the desired length of the pavement. Each section is provided at each end with a bearing surface such as haunch **24** for the jacks **14** designed to be below the bottom of the sections. The sections rest on a sub-base (not shown) in the same conventional manner as in any pavement construction. This invention is concerned with the particular method of prestressing the concrete sections having been thus constructed.

In Figure 3, there is shown a chart divided into three steps to illustrate the technique for prestressing a pavement incrementally, pursuant to this invention. The sections have been designated by the letters B through F, with the abutment shown as A. It is assumed in this example that the ultimate prestressing force that will be required is 900 pounds per square inch, but this figure will vary widely with the conditions required by the design of the pavement, and can be caulculated by any of the methods known today for the usual determination of the prestressing force required in the slab.

Assuming an ultimate prestress of 900 pounds per square inch, this invention proposes to attain that prestress by using three jacks **14** positioned in the joints between abutment A and section B, between sections B and C and between sections C and D, respectively. The exact number of jacks that will be required will be determined by the frictional restraint exercised by the sub-base on the sections, so that a total length of sections from the abutment to the end of the sections must be equivalent or greater than that able to withstand the prestressing forces to be exerted between the abutment A and the section B. In this case it is assumed for simplicity that three sections B, C, and D will be adequate. In step 1, the prestressing forces are applied to the jacks at each of the aforementioned joints so that the force applied between sections C and D is 300 p. s. i., between sections B and C is 600 p. s. i., and between section B and abutment A is 900 p. s. i. In this way it is possible to exert the full compressive force on one side of section B without causing movement of the section, even though the section alone would not have been able to withstand these forces with movement in a direction such as to relieve the force.

The jack in the joint between section B and abutment A is left in place and the joint filled with mortar. When the mortar has attained sufficient strength to withstand the reaction of the bursting forces, the jack is relaxed and the compressive forces transfer themselves from the abutment and the section to the joint, placing it under substantially the same compressive force as exists in the edges of the section and the abutment adjoining the joint.

The second step is also shown in Figure 3. The jacks already in place are left in place and an additional jack is placed in the joint between sections D and E. This jack is then activated until it is exerting a 300 p. s. i. force on the joint. The remaining jacks are then increased each by 300 p. s. i., so that the jack between sections B and C is now up to full load of 900 p. s. i., and the same procedure for applying mortar is used as was described in connection with the joint between the abutment and section A. Section N', the last section, may be brought up to full prestressed condition by the use of reinforcing steel to make up the necessary prestressing force or by jacking against a fixed abutment as at "A."

The above outlined procedure is followed throughout the entire length of the pavement and results in a completely prestressed pavement substantially with the use of no reinforcing steel, or a minimum of same. The pavement laying operation can be carried out exactly as in the usual fashion, and there need be no delays caused by the prestressing operation. This is quite an important factor, for such delays, or such special handling of the sections preparing them for elaborate prestressing elements involves an enormous expense considerably detracting from its value.

In Figure 4 there is illustrated the same technique as described above, but with the additional improvement that the special abutment is eliminated and the pavement sections themselves are utilized to form the abutment. This might be referred to as a "friction abutment" relying on the friction of the sections on their sub-base for the abutment function. The "friction abutment" might be said to be composed of two different abutments, a fixed abutment and a progressively moving abutment, as described in connection with Figure 4.

The fixed abutment is developed first. In this figure, in step 1, five jacks are placed in the first 5 joints and are activated so that the jacks in the outermost joints (J—K; N—O) are at 300 p. s. i., the jacks in the next inner set of joints (K—L; M—N) are at 600 p. s. i., and the jack in the center joint (between sections L and M) is at 900 p. s. i. This joint is then mortared and the jack ultimately removed when the mortar has set, as in the previous example of Figure 3.

The joints between sections J and K, and between sections K and L, are each mortared at this step even though the jacks are set at a lower pressure. It is not possible to increase the jacking force as the frictional restraint of the sub-base will not withstand higher pressures. The sections J, K and L are reinforced together with sufficient prestressed reinforcing tendons to make up the necessary total prestressing force when added to the forces applied by the jacks to the respective sections. These tendons will be described later in connection with Figure 6.

The sections J, K and L form the fixed abutment as they are at the extremity of the slab and in effect function precisely as section A in Figure 3. The balance of the reinforcement may be supplied in the manner shown in Figure 6. In this figure, section **13J**, **13K**, and **13L** correspond to sections J, K and L of Figure 4. The reinforcement is preferably furnished in the form of high tensile reinforcing rods **57** and **68**, unbonded to the concrete, and passing through the length of the sections. The rods **57** and **68** are prestressed and anchored by means well known in the art. In this embodiment, rods **57** pass through sections **13J**, **13K** and **13L** reinforcing them together. Since section **13L** does not need as much supplemental reinforcement, because of the relatively high jacking force used, the rods **68** need only extend through sections **13J** and **13K**. Section **13M** needs no substantial reinforcement because the full jacking forces may be applied to it directly.

Having developed the fixed abutment from the sections themselves, the prestressing of the slab continues by means of the progressively moving abutment, that is, after the sections are each brought up to the full prestressing, then that section in turn acts as the abutment for the next series of sections. For instance, after the joint between sections L and M of Figure 4 has been established at 900 p. s. i., then the method of prestressing proceeds as previously described in connection with Figure 3. An additional jack is set in place between sections O and P, and brought up to 300 p. s. i. The jack between sections N and O is then increased from 300 p. s. i., to 600 p. s. i. and the jack between sections M and N is brought up to full amount at 900 p. s. i. This joint is then ready for mortaring. This technique proceeds throughout the entire length of the pavement.

By the method outlined in Figure 4, there is provided a prestressed pavement in which the pavement itself serves as a progressively advancing abutment, by incrementally increasing the jacking forces in the joints between sections until the desired maximum amount is achieved.

With this method however it is necessary to augment with reinforcing steel the prestressing forces in the abutment. The chart of Figure 4 shows that the sections must be prestressed with steel in order to augment the prestressing by jacking. The prestressing by steel is well known in the art today, and may be by wires or rods or a combination of them. Figure 7 shows in detail a possible construction, if rods are used. The edges of the section **13** are provided with projections **58** to accommodate the anchoring means for the rods. The type of anchor shown in the figures comprises a bearing plate **52** and a nut **54** threaded on rod **56**. The rod **56** is jacked (by means not shown) to the desired tension and the nut run down to fix it in position, after which the jack is relaxed and removed.

It should be noted that in each of the aforedescribed methods, there is a resultant of the compressive forces applied between a series of joints during the jacking or compressing operations which tends to move the slabs of that particular series of slabs laterally. It is an important novel feature of the present invention that the total sub-base frictional restraint of the individual slabs of any given series of slabs under compression is at least equal to the resultant of the compressive forces which tends to move the slabs of that series. In other words, the cumulative frictional resistance of all the slabs of a given series is great enough to prevent any lateral movement thereof. In this manner, substantially greater forces may be applied to a given joint than would be possible if only the sub-base restraint of such individual slab were present.

Figure 8 is a section through **8—8** of Figure 1, and shows in detail the condition of the joint when the mortar is in place. Each section **13** has a haunch **24** to support jack **14**. Mortar **60** is placed over the jack when the jack is up to full prestressing force. When the mortar **60** has set, the jack **14** will be relaxed and removed.

In the use of the method of this invention a special problem arises when the pavement or other slab is curved either horizontally (as when a roadway makes a turn) or vertically (as when a roadway goes over a hill). This invention contemplates using only sufficient prestressing tendons to withstand buckling or bending forces caused by such curvature and achieving the balance of the prestressing by incremental jacking as heretofore described. On horizontal or vertical curves, a somewhat unstable condition develops because the prestressing thrust attempts to cause the sections to move outwardly or upwardly, without the usual restraining influence of the reinforcement. It is therefore contemplated to use either the conventional steel reinforcement or to use an arrangement as shown in Figure 5. In this figure, the sections **13a** are curved horizontally. To hold the sections in position, reinforcing rods, unbonded to the concrete, are placed in position as shown and are prestressed as described in connection with Figure 7. This is adequate to prevent the section from moving out of alignment and is inexpensive in construction. To lend strength to the curved sections, more reinforcing steel is needed, however, than is used in the remainder of the horizontal pavement prestressed by methods shown in this specification.

In this specification, concrete and steel have been referred to as the principal materials but it is to be realized that any materials with similar properties will be adequate. For instance, plastic may be substituted for concrete, particularly in large floors for buildings, glass fibers may be substituted for steel, as is being done by some in the prestressing art today.

As this invention may be embodied in several forms without departing from the spirit or essential characteristics thereof, the embodiments described in the foregoing specification are therefore illustrative and not restrictive, since the scope of the invention is defined by the appended claims rather than by the description preceding them, and all changes that fall within the metes and bounds of the claims, or of forms that are their functional as well as conjointly cooperative equivalents, are therefore intended to be embraced by these claims.

What is claimed is:

1. The method of prestressing a continuous slab of considerable length which comprises forming a plurality of sections of slabs supported on a sub-base with a joint space between each section, forming an abutment adjacent the first section, said abutment being of sufficient strength to withstand a force equal to the maximum force applied to prestress the sections, applying a compressive force in the joint between the abutment and the first section of a series of said slabs to compress the first section at the desired compression, simultaneously applying a compressive force between the first section and a second section to compress the sections, the force being less than the force applied between the first section and the abutment by an amount not greater than the sub-base frictional restraint on the second section, simultaneously applying a force between succeeding sections of said series, the force decreasing in amplitude between each section by an amount not greater than the sub-base frictional restraint on the section, applying incremental decreasing forces until the total sub-base frictional restraint in said series is at least equal to the resultant of compressive forces tending to move said slabs of the series, filling the joint between the first section and the abutment with mortar, and relaxing the compressive forces when the mortar has attained a sufficient strength, and subsequently successively incrementally applying compressive forces to a succeeding series of joints wherein the first joint of the succeeding series comprises the second joint of the preceding series, the force applied to each joint of the succeeding series of joints being substantially equal to the force applied to the immediately preceding joint of the first series of joints, filling the first joint of each successive series of joints with mortar, and relaxing the compressive forces when the mortar has attained sufficient strength.

2. The method of prestressing according to claim 1, wherein the abutment adjacent the rfist section is developed by forming a plurality of sections of lab separated by joints between each section, the sections extending in the direction away from the first section, connecting the sections into a continuous abutment by force generating means in each joint bearing on each side of the sections forming the joint and decreasing incrementally in the direction away from the first section the forces acting in each joint, the continuous abutment being of sufficient length so that the total sub-base frictional restraint acting on the continuous abutment is at least equal to the total compressive forces applied to such length of sections subjected to the incrementally decreasing force.

3. A method of prestressing a continuous slab according to claim 2, wherein the sections forming the con-

tinuous abutment are supplementally stressed together with steel in an amount such as to equal the prestressing force applied to the succeeding slabs when added to the incremental prestressing force in the slab.

4. A method according to claim 3, wherein the steel passes in unbonded relationship longitudinally through the sections forming the continuous abutment, the quantity of steel decreasing as it approaches the said first section.

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