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OVERFILLED ARCH-SHAPED LOAD SUPPORT STRUCTURE

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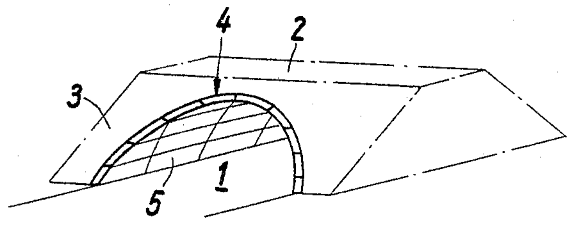

Fig. 1

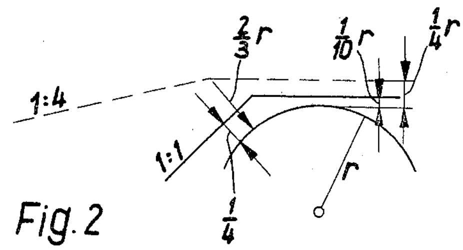

Fig. 2

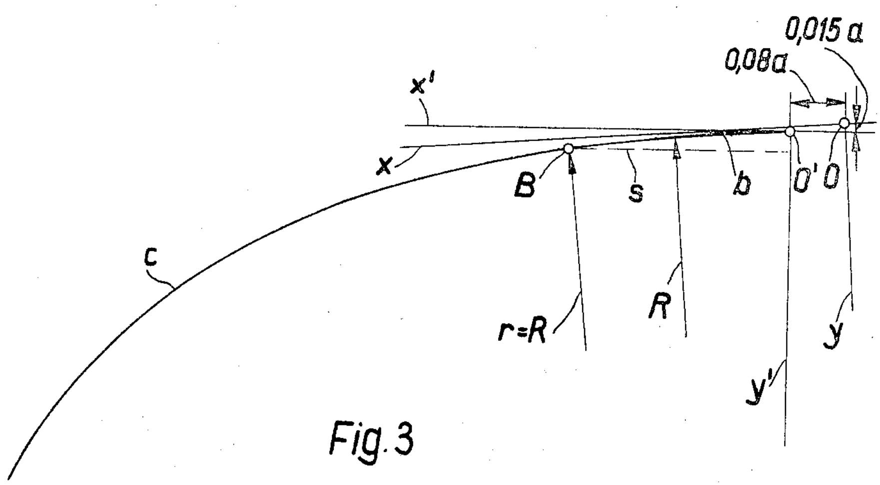

Fig. 3

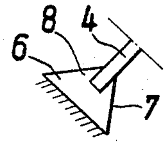

Fig. 5

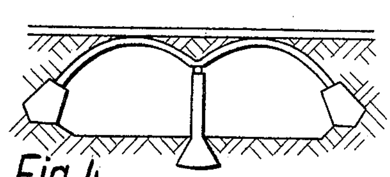

Fig. 4

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OVERFILLED ARCH-SHAPED LOAD SUPPORT STRUCTURE

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U.S. Cl. 61—16 5 Claims

ABSTRACT OF THE DISCLOSURE

This invention discloses an overfilled archshaped load support structure constructed as an arcuate or curved shell or one which is formed from flat slabs in a configuration approximating a curved shell, and which comprises pre-fabricated reinforced concrete components or reinforced concrete compounds cast at the construction site.

The present invention relates to an overfilled arch-shaped load support structure formed as a curved shell or from flat slabs in an arrangement approximating to a curved shell, and comprising pre-fabricated reinforced concrete components or reinforced compounds cast in situ.

The support structure may for example be an overfilled overpass or underpass bridging over a lower traffic route and supporting an upper traffic route. Any embankment material which can be used for road embankments is suitable for the overfill.

With this structure the advantages resulting from the shape of the shell or the like, i.e. deformability and high load support by the overfill, are obtained with a small amount of material. The overfill serves to distribute the load and support the shell and therefore counteracts excessive deformation of the shell structure.

If the structure is for example an overpass or an underpass, then for a given inclination of the ramps and a given headroom for the underpass the adjoining embankment for the overpass can be higher and longer or the cutting for the underpass can be deeper and longer as the overfill is made higher.

According to the usual laws of statics according to the state of the art, the rule was previously followed that the overfill at the highest part of such a load support structure must be at least ¼ of the radius of curvature of the shell (or of the radius of the inner circle or outer circle of an outline of joined flat lines approximating to an arc). With the angle of e.g. 110° usually subtended by the arc at its centre, the overfill at the highest part of the support structure is more than ½ (one half) times the intended height of the arc.

It is therefore evident that the height of the overfill, i.e. the difference in height between the highest, outer part of the support structure and the upper e.g. horizontal plane of the overfill is an important factor in the construction costs. In most cases the making of an underpass support structure with an overfilled arch-shaped load support structure according to the above-mentioned previously employed rules with small constructional volume (thickness) was practically impossible because of the large overfill required.

It is an object of the invention to reduce construction costs and/or to enable the use of an overfilled arch in the above-mentioned cases.

The present invention provides an overfilled arch-shaped load support structure formed as a curved shell or the like and comprising prefabricated reinforced concrete components or reinforced concrete components cast in situ, wherein the thickness of the load support structure with a cylindrical curvature is less than $\frac{1}{30}$th of the radius of curvature thereof and with a non-cylindrical curvature is less than $\frac{1}{40}$th of the largest radius of curvature thereof, and the height of the overfill at the highest part of the support structure with a cylindrical curvature is smaller than $\frac{1}{10}$th of the radius of curvature thereof and with a non-cylindrical curvature is smaller than $\frac{1}{20}$th of the largest radius of curvature thereof.

If a line on the periphery at the highest part of the structure does not extend parallel to the overfill, the above limiting values for the overfill apply at the position at which this line has its smallest spacing from the overfill.

The horizontal upper limit of the overfill may be a plane approximately tangential to the shell or the like (the overfill at the highest point being e.g. only a few centimetres).

According to the above-mentioned previously binding rules from the prior art, and which have heretofore been strictly adhered to in the prior art, such structures should not have sufficient load supporting capacity. However, the considerations on which the invention is based indicate, and the experiments described below confirm, that there is no reason for applying the above-mentioned previously usual dimension and construction rules of constructional engineering and earth mechanics to structures of the present type.

Likewise, the same holds true with reference to the previously binding rule according to which an embankment extending parallel to a tangential plane of the support structure with an inclination of at most 1:4 must have a spacing of at least ⅔ of the radius of curvature from the tangential plane and an even greater spacing for steeper slopes. The considerations and experiments underlying the invention have moreover shown that such an embankment can have an inclination of 1:1 to 1:4 and the spacing of the plane of the embankment from the part nearest thereto of the support structure may be as little as ¼ of the radius of curvature (or of the greatest radius of curvature for non-cylindrical, especially clothoid-shaped arches, [dtv-Lexikon, volume 10, p. 185, Munich, Germany, 1967], that is Cornu spiral shaped arches).

Since there is less overfill according to the invention than with the previously employed accepted rules, the construction costs are considerably reduced. In this way the cost of an underpass can for example be reduced to 70% of the previous amount.

The invention will be more readily understood from the following description, given by way of example, of the embodiments thereof illustrated in the accompanying drawing, in which:

FIG. 1 shows a perspective view of an underpass according to the invention;

FIG. 2 shows a dimension sketch of the structure of the invention in heavy lines and the comparable prior art in dotted lines;

FIG. 3 shows a special non-circularly curved arch shape for the structure of the invention;

FIG. 4 shows a diagrammatic front elevation of an underpass according to the invention with twin arches; and

FIG. 5 shows a cross-section through a foundation for the underpass of FIG. 4

As shown in FIG 1 a traffiic route (which in the present case is a road but which may alternatively be a railway, a river or a canal) has a cutting (not shown) which is lower than a traffic route **2**, and the overfill of the underpass is indicated by reference numeral **3**. The underpass has a load support structure **4** in the form of an arch and comprising pre-fabricated reinforced concrete elements **5** which are curved in accordance with the radius of curvature of the arch and which may be conneted together as described in copending patent application Serial No. 636,779 filed May 8, 1967.

The load support structure **4** is supported directly (i.e. without supporting walls) on a plurality of separate foundations or strip shaped foundations or on connecting beams of a pile foundation. The load support structure **4** is shaped as part of a circularly cylindrical sleeve the thickness of which (i.e. the thickness of the reinforced concrete slabs **5**) is about 1/40 of its radius. The height of the overfill, in the example illustrated, at the highest point of the load support structure **4** is about 1/20 of the radius of curvature of the arch, which in practice is about 50 cm. The road surface of the upper traffic route may, at the highest point of the load support structure **4**, lie directly on the load support structure **4**, the upper limit of the overfill being a plane tangential to the arch.

The load support structure **4** at the ends of the tunnel is inclined at the same angle as the slope **3** and is formed at these positions of reinforced concrete slabs triangular or trapezoidal shape, the trapezoidal-shaped slabs having two right angles, which slabs are formed and connected to adjacent slabs as described above. It has been found that the inclined ends of the arch are sufficiently rigid and can be retained sufficiently by the remaining parts of the arch to retain the slope **3**, and that it is sufficient to connect the inclined ends pivotally or resiliently in a groove in the foundation. At the outer parts of the inclined ends, a foundation may be omitted.

The line of intersection of the plane of the slope **3** with the plane of the traffic route **2** may intersect the longitudinal axis of the traffic route **1** at an acute angle of e.g. 45°.

One advantageous example of the above-described underpass has the following dimensions: radius of curvature of arch 7.5 metres; thickness of slabs 16 centimetres, clearance height of surface support structure at crown 5.30 metres; height of embankment above crown 60 centimetres; width of upper road 15 metres. This underpass would be loaded on an area 7 metres long (in the direction of the upper road) and 4 metres wide at the edge with 370 tons. No unacceptable deformation is caused thereby. This is not, however, the load limit of the structure which, through lack of suitable loads and because of difficulties in providing and transporting them, was not determined, although the loading mentioned above corresponds to a multiple of the maximum heavy road loads.

In FIG. 2 the overfills which can be used according to the invention are indicated by a broken line and the height of the overfill above the crown of the arch, the inclination of a slope parallel to the tagential plane of the arch and the spacing thereof from the arch are indicated in proportion to the radius of curvature r of the arch. The broken line and the magnitudes associated therewith indicate the above-mentioned prior art.

The above-described surface structure, instead of being made of curved slabs, may be composed of flat slabs, in which case the structure comprises a series of flat surfaces which approximate to a curved arch. Flat slabs can be made more simply and with higher concrete quality, are easier to store and transport, and can be used for structures having widely varying arch radii of curvature. The slabs sutiably have, in the peripheral direction of the arch, a width of 1.6 to 2.3 m., preferably 2 m.

The cross-section of the arch may be circularly curved or may have approximately the shape of a crown portion of a clothoid, also known as a cornu spiral, (FIG. 3), the radius of curvature decreasing from the upper, middle part outwardly. This shape has the advantage that the height of the structure is very small and that the weight of the support structure produces only compression and no significant bending moments in the support structure.

An arch shape which is particularly suitable as regards both the static forces and also the profile of its opening is described below with reference to FIG. 3, which shows half of an arch of which the upper, middle part is a circular arc, which at each end meets a clothoid having a radius which decreases outwardly. The half of the circular arc illustrated at b, the end of the circular arc by c. O is the origin of the co-ordinate systems x, y of the clothoid and O^1 is the vertex of the arch, i.e. the middle of the circular arc of which only one half (b) is shown. y^1 is the perpendicular bisector of the chord s (of which only half is shown) of the circular arc and also the line of symmetry of the arch, and x^1 is the tangent at the point O^1. O lies at the side of the perpendicular bisector y^1 opposite the clothoid c above x^1, the spacing of O from y^1 being about $0.08a$ and from x^1 about $0.015a$. y and y^1 diverge downwardly at an angle of about 4 new degrees (corresponding to about $3°36^1$). a is defined at least approximately by the equation $R=2.4a$ in which R is the radius of the circular arc. The clothoid is defined at least approximately by the equation $rL=a^2$, where r is the radius of curvature of the clothoid and L the spacing from O measured along the clothoid. At point B, $R=r$.

The undespass described above may also be made with a plurality of arches or the like. FIG. 4 shows one example of this type with a support structure formed as a twin arch supported in the middle by a pendulum wall.

FIG. 5 shows a front view of a modification of the foundation for the outer end of the twin arch. This foundation, which can be used for example for the underpass shown in FIG. 1, has the shape of a prism made from concrete and having a cross-section which is approximately a right-angled triangle. The widest side **6** lies on ground inclined approximately prependicular to the tangent to the arch end **4**. Advantageously, this widest side has the inclination which usually remains on excavation of the ground. One of the smallest sides **7** extends perpendicularly or outwardly inclined and forms a part of the inner wall surface of the underpass, and the other side **8** extends, as shown in the drawing, inclined upwardly from the left to the right. This foundation can be made without reinforcement and is only subjected to a pressure which spreads through the triangular cross-section. If the surface **8** is approximately horizontal, the construction of this foundation requires a connection only to the side **7**, which can be effected either with connection panels or as a formwork of prefabricated concrete slabs.

The support structure described above having one or more arches, e.g. a twin arch, can also be made of concrete cast in situ, the latter construction preferably requiring less contra-casing than a corresponding single arch. Each arch can also be prefabricated in one piece at the building site.

The support structure described above as an example for two underpasses is considerably less costly than a corresponding prior art support structure. Moreover, the lower overfill is frequently advantageous. For example, in an overpass or an underpass the construction costs mainly depend, as mentioned above, on the height of the overfill, since the height of the embankment or the depth of the cutting and lengths of the ramps (for a given slope) depend on the height of the overfill. For an underpass on a hillside or at an acute-angled crossing of two traffic routes the costs are increased if the inclination of the slope on the valley side in the first case or parallel to the upper traffic route in the second case is small or if the spacing from the clearance space of the underpass is large. Corresponding relationships hold true for other overfilled support structures.

Since the support structure is relatively thin, it adapts to settling differences, shrinkages and temperature differences. (Expansion gaps may be necessary only in the longitudinal direction in long underpasses.) In particular, it has been found that the strength of the fill material limits the deformation of the support structure to acceptable limits. This can be brought about since the pressure exerted by the fill material on the support structure at the points at which the support structure tends to cave inwardly decreases as the caving increases, and at the points at which the support structure tends to cave outwardly increases as the caving increases, and thus opposes any deformation.

The support structure suitably has a shape such that its own weight produces mainly compressions and no significant tensions or bending moments in the support structure. When made of concrete cast in situ, there is the advantage that the shoring can be removed shortly after the casting since the bending moments resulting from the weight of the support structure are small. Therefore no fractures occur even although the age of the concrete is not great. A shape which is suitable for this purpose is an at least approximately circular curvature subtending at its centre an angle of 50 to 100°, and preferably 65 to 75°. The clothoid shape, as mentioned above, is particularly suitable.

The ends of the support structure resting on the foundations preferably have an inclination of 35 to 55°, and in particular 40 to 50°, and in a construction having a plurality of arches the ends of the arches supported on pillars suitably have an inclination of 5 to 25°, and in particular 10 to 20°, relative to the horizontal. Acute angled spaces for filling, in which compacting of the fill material is difficult and which cause increased danger of collapse during construction due to the possibility of landslides, are thereby avoided. Moreover, machine compacting is facilitated. In this connection, the foundation shown in FIG. 5, which has an approximately horizontal side of e.g. 2 metres width, may also be advantageous.

The requirement in practice of providing a given clearance space with a small height is fulfilled since the arch touches the upper corner of the clearance space, and in the case of twin arches the middle thereof touches the upper edge of the clearance space. The space above this upper edge, which does not involve additional costs is for example in long motorway underpasses very useful for ventilation and enables transportation of goods of abnormal height. The vertical faces **7** of the foundations shown in FIG. 5, together with the adjoining sides of the arch, define a space which also does not necessitate additional costs and which can be used e.g. for pedestrians or side lanes and these surfaces may be dimensioned accordingly. In long motorway underpasses this space is also useful for ventilation.

We claim:

1. An overfilled arch-shaped load support structure comprising a relatively thin curved shell of cementitious material curving upwardly from a ground plane, foundation means on said ground plane, said curved shell having edge extremities supported by said foundation means, said curved shell having a cross-section comprising a central portion of substantially cylindrical curvature comprising a circular arc of substantially constant radius R integral with opposite end curvature portions of non-cylindrical curvature, said non-cylindrical curvature portions of said shell each defined by a non-circular curve having a radius r which progressively decreases in length outwardly toward the edge extremities according to the equation $rL=a^2$, where R is approximately equal to $2.4a$, L is the arcuate length of the non-circular curve taken from the origin of the co-ordinate system thereof, said origin being spaced a distance of about $0.08a$ on the side opposite to the perpendicular bisector of the chord of the circular arc from said perpendicular bisector and lying about $0.015a$ above the tangent at the crown of the circular arc, the ordinate of said co-ordinate system diverging downwardly at an angle of approximately 4 new degrees with reference to the said perpendicular bisector and R being equal to r at the ends of the circular arc.

2. An overfilled arch-shaped load support structure as set forth in claim **1** in which said curved shell has a thickness less than 1/40 of said radius R.

3. An overfilled arch-shaped load support structure as set forth in claim **1** including overfill on said curved shell having a depth at the highest part of the central portion of the structure less than 1/20 of the longest or constant radius R.

4. A structure as claimed in claim **1**, wherein the angle subtended at the center of the largest curvature of the central portion by the edge extremities of the support structure resting on the foundations is 50 to 100°.

5. An overfilled arch-shaped load support structure comprising a relatively thin curved shell of cementitious material curving upwardly from a ground plane, foundation means on said ground plane, said curved shell having edge extremities supported by said foundation means, said curved shell having a cross-section comprising a central portion of substantially cylindrical curvature integral with opposite end curvature portions of non-cylindrical curvature, said non-cylindrical curvature portions of said shell having radii of progressively decreasing lengths toward the edge extremities, said curved shell having a thickness less than 1/40 of the longest of the said radii of curvature thereof, overfill on said curved shell having a depth at the highest part of the central portion of the structure less than 1/20 of the longest of the said radii of curvature, said foundation means comprising longitudinally extending unreinforced cementitious material cast in situ, the cross-section of which is approximately a right-angled triangle the hypotenuse of which is approximately perpendicular to the tangent at the end of the end curvature portion and lies on the ground, one other side of the triangle being approximately vertical and forming a part of the inner surface of the support structure and the third side of the triangle being outwardly inclined.

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