L. JORGENSEN.

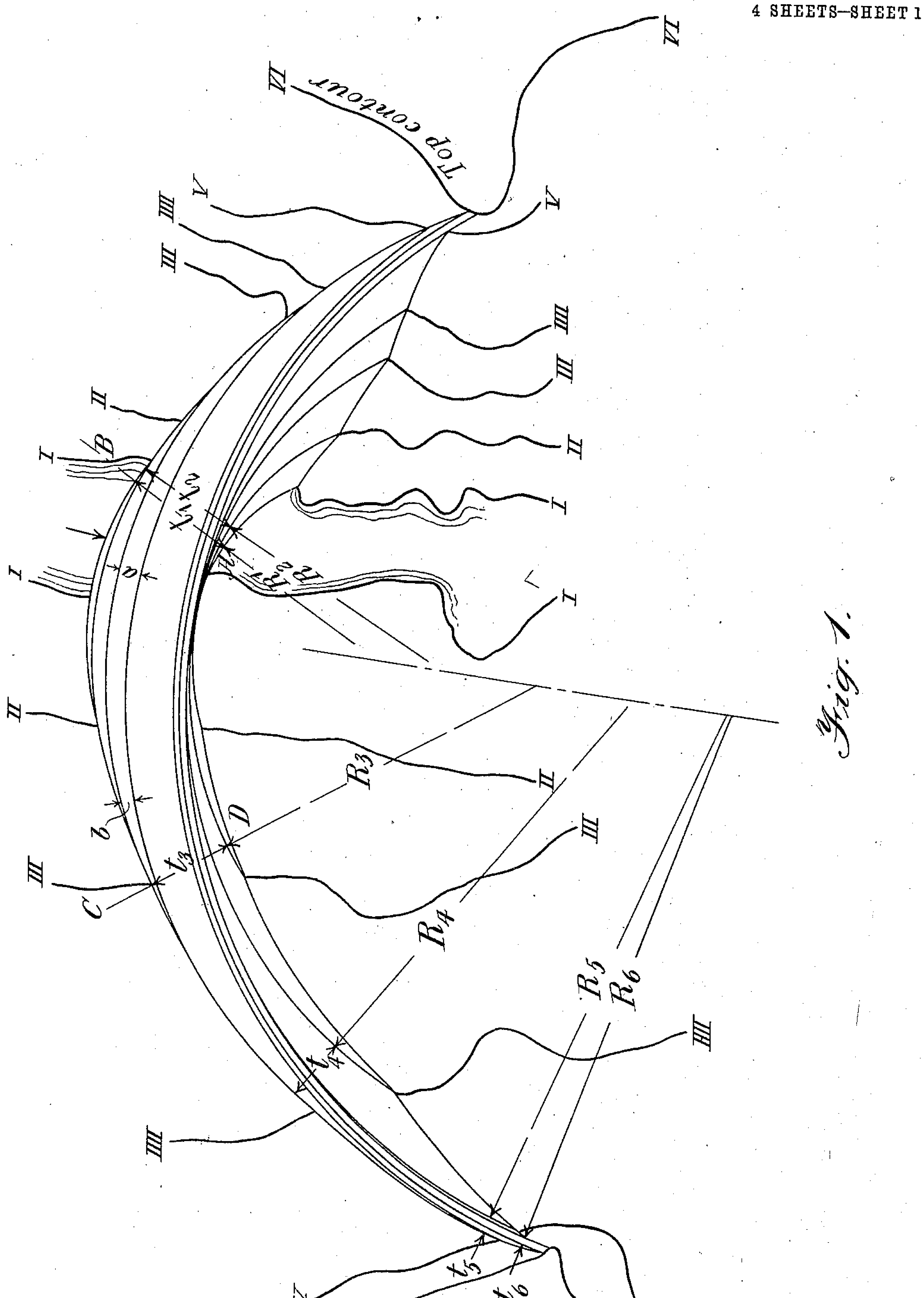
DAM CONSTRUCTION.

APPLICATION FILED OCT. 14, 1910.

986,718.

Patented Mar. 14, 1911.

4 SHEETS—SHEET 1.



Witnesses:

Geo. C. Cheney

Chas. P. Fidden

Inventor

Lars Jorgensen

By his Attorneys

Rosenbaum & Stockbridge

by Wm. A. Rosenbaum

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4 SHEETS—SHEET 2.

Fig. 2.

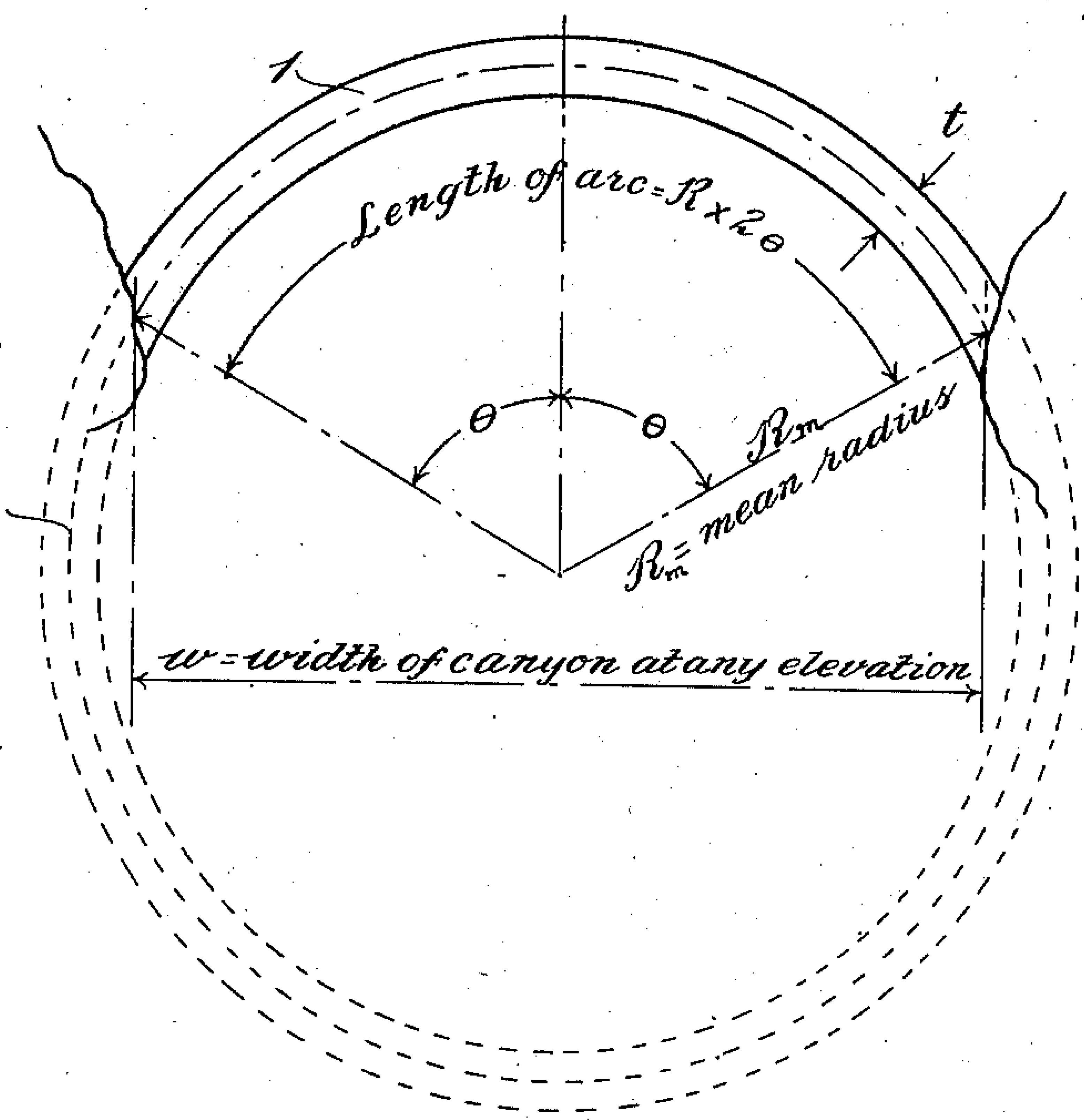


Fig. 5.

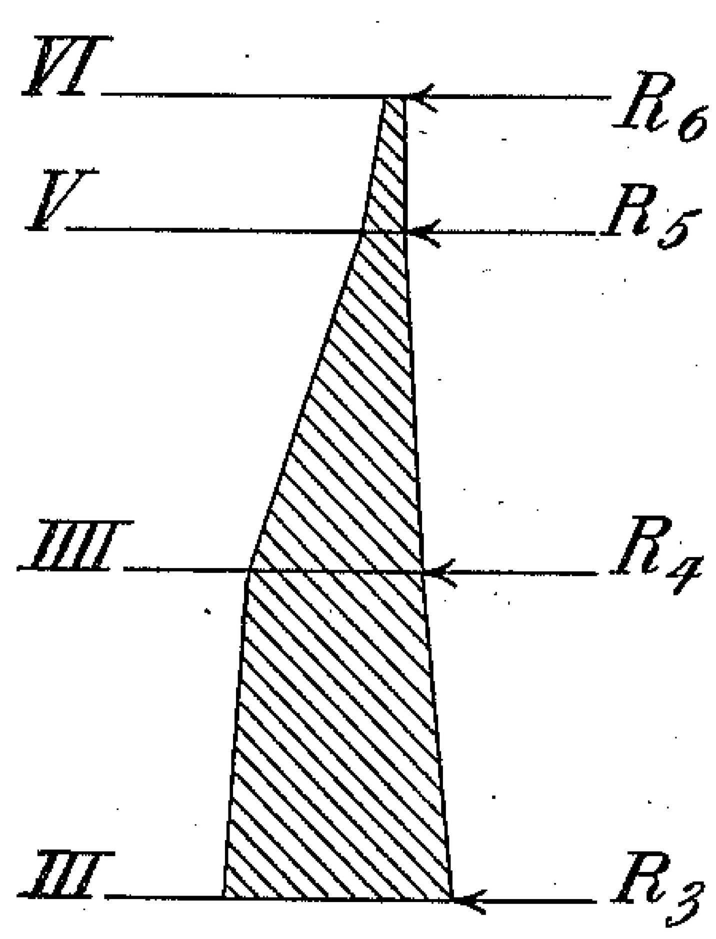


Fig. 4.

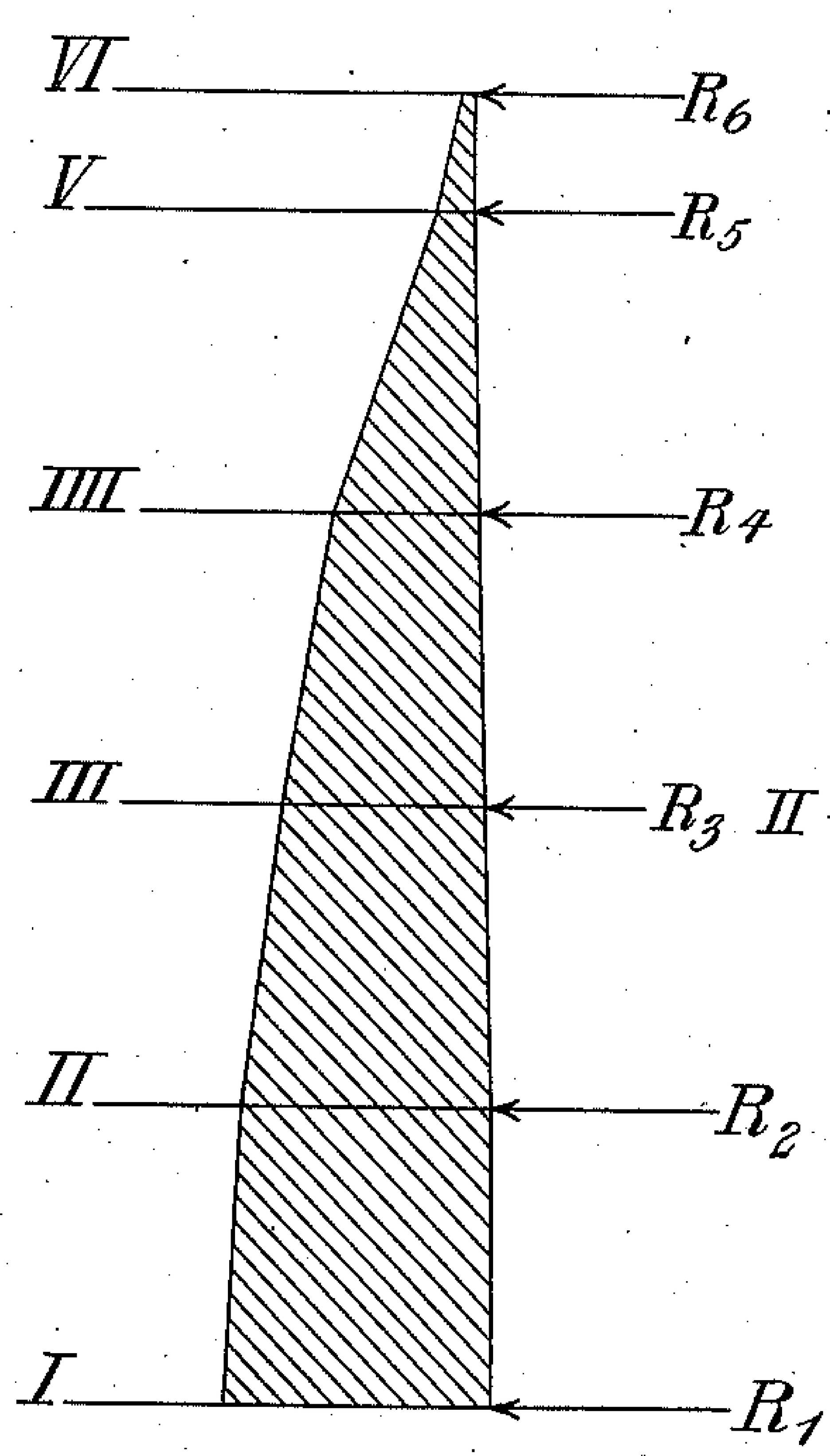
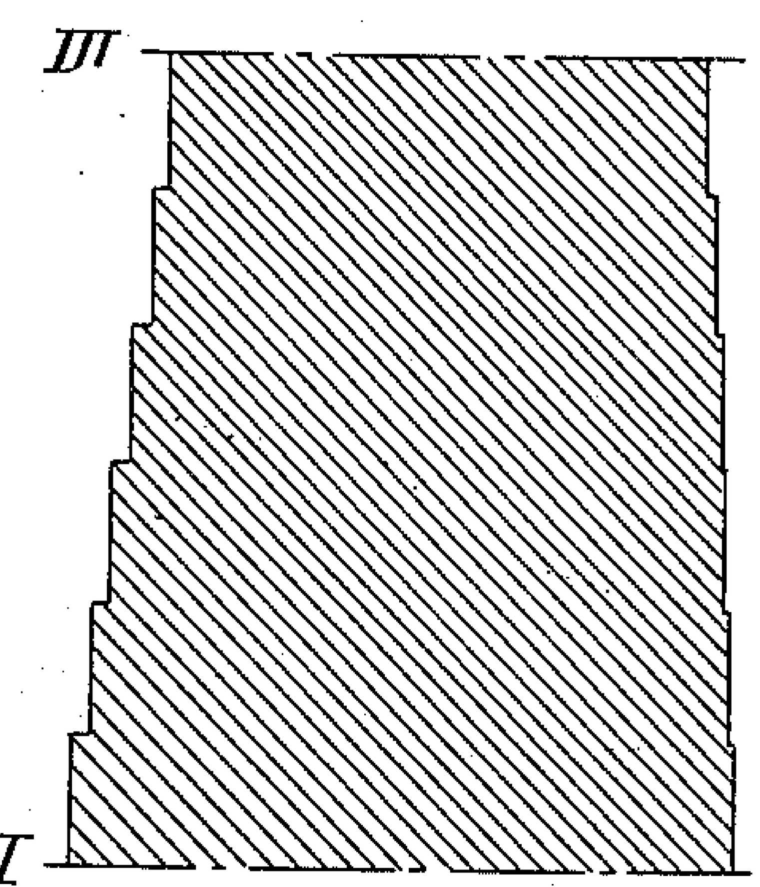


Fig. 6.



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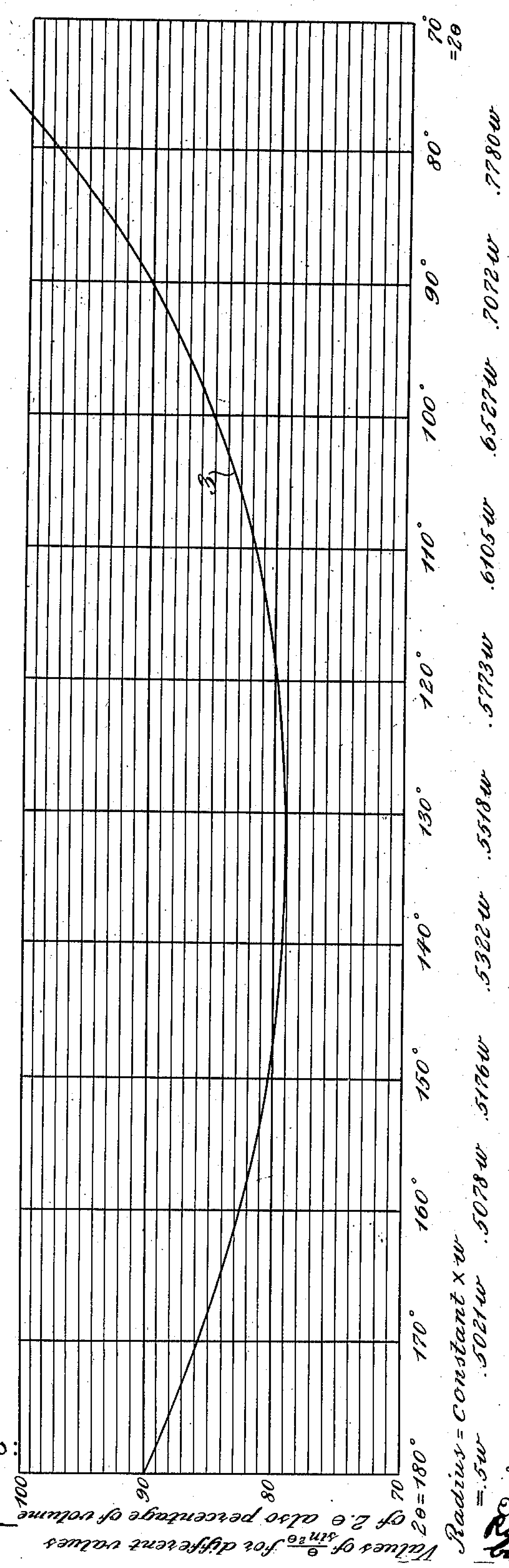
4 SHEETS—SHEET 3.

Fig. 3.



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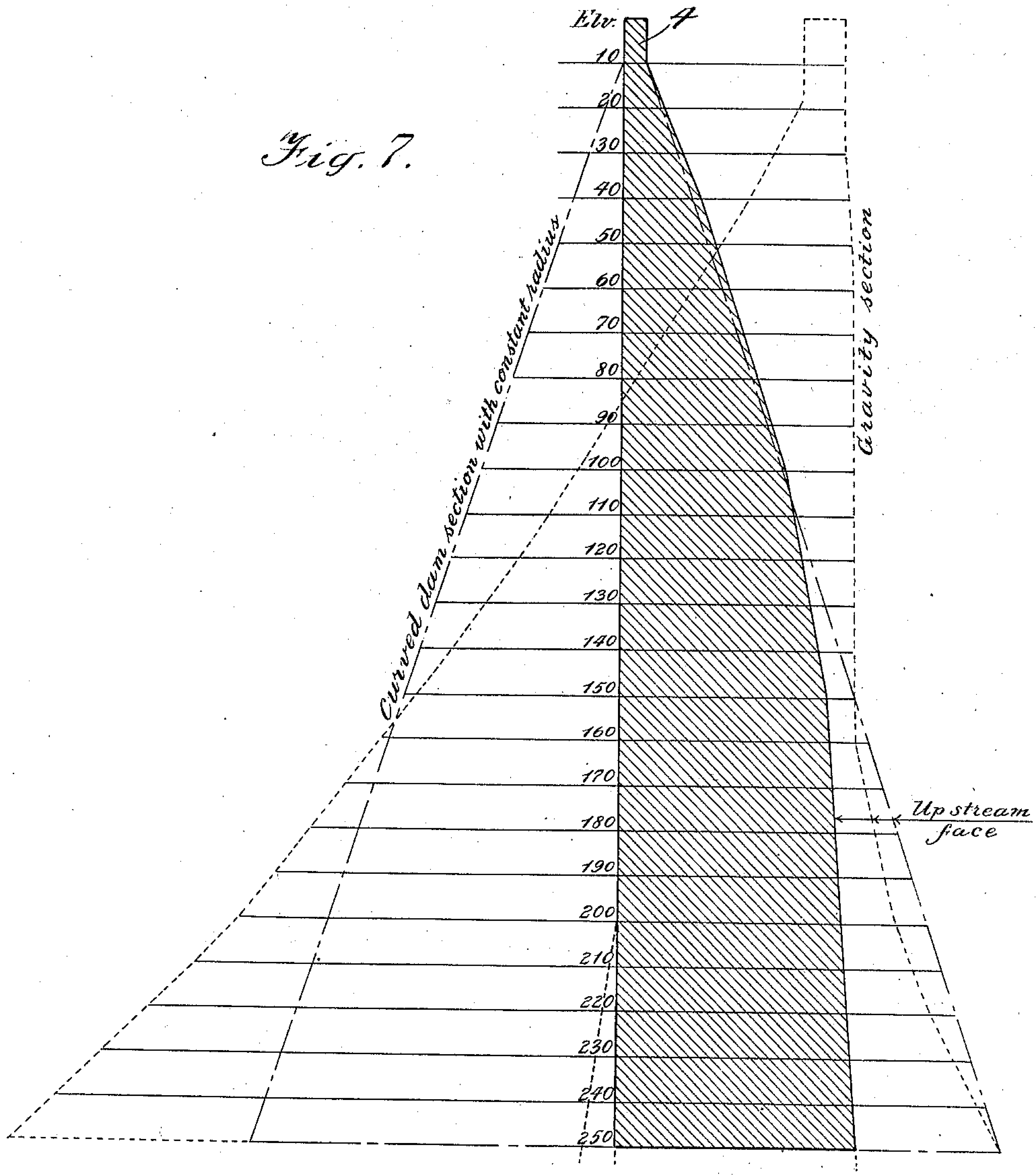
4 SHEETS—SHEET 4.

Fig. 7.



Witnesses:

Geo. C. Cheney

Chas. D. Hidden

Inventor

Lars Jorgensen

By his Attorneys

Rosenbaum & Stockbridge

by Wm A Rosenbaum

UNITED STATES PATENT OFFICE.

LARS JORGENSEN, OF BERKELEY, CALIFORNIA, ASSIGNOR OF ONE-HALF TO FRANK G. BAUM, OF SAN FRANCISCO, CALIFORNIA.

DAM CONSTRUCTION.

986,718. Specification of Letters Patent. **Patented Mar. 14, 1911.**

Application filed October 14, 1910. Serial No. 586,969.

To all whom it may concern:

Be it known that I, LARS JORGENSEN, a citizen of the United States, residing at Berkeley, in the county of Alameda and State of California, have invented certain new and useful Improvements in Dam Construction, of which the following is a full, clear, and exact description.

This invention relates to dam constructions, and has for its object the development of a dam body, the volume of which is reduced to a minimum while affording a maximum of efficiency and strength. My improved dam construction therefore results in the production of a dam which is economical of construction, and the formation or contour of which is distinctively novel; and in which the material is disposed to the best possible advantage.

The dam in question is of the general type known as arch dams. As heretofore constructed, to the best of my knowledge, dams of this type, and, indeed, of all others, have been designed with the object in view of providing sufficient sheer weight of dam to prevent the overturning thereof by the water pressure. This is a very uneconomical way of using the material, such for example as concrete, of which the dam is to be constructed, as such material at the toe of the dam is very highly compressed, while other parts have little or no compression at all. In so far as I am aware, arch dams as heretofore constructed have used an arch of substantially but a single radius; that is, the radius of the arch at the bottom where the valley or cañon is narrow, has been the same, or substantially the same, as the radius of the arch at the top; the only increase in radius which has at all been provided for being due to the slope of the face of the dam; all of the radii being struck from a common center or axis.

As above indicated the principal objects of my invention have been to economize material and, correlatively, labor; practically every portion of material in the dam body being disposed to the best possible advantage.

Other objects of my invention will be hereinafter set forth and more particularly pointed out in the appended claims.

Referring to the accompanying drawings, which form a part hereof: Figure 1 is a plan view of a dam constructed in accordance with the principles of my invention; topographical or contour lines of a cañon in which the said dam is positioned being indicated. Fig. 2 is a plan view of an arch dam; illustrating the usual assumption that any curved dam is a portion of a cylinder ring; this figure being used as a basis for the computation hereinafter referred to. Fig. 3 shows a curve utilized in determining values used in said computation. Fig. 4 is a vertical transverse section taken on the line A—B of Fig. 1. Fig. 5 is a similar section taken on the line C—D of said figure. Fig. 6 is an enlarged fragmentary section corresponding to that portion of the section shown in Fig. 4 which lies between levels II—III; but showing the substitution of hollow-cylinder sectors for the frustum of a cone or approximate cone indicated in Fig. 4, at such portion of the section. Fig. 7 is a comparative study of several forms of dam sections; showing the material decrease in volume effected by constructing the dam in accordance with the principles of the invention herein described.

Referring to said drawings, in which like reference characters designate like parts throughout the several views; and starting with the assumption which is usually made that any curved dam, such as that for example shown at 1, in Fig. 2, is a portion of a cylinder ring 2, in which the average stress q, expressed in pounds per square foot, is equal to the radial load P (in pounds per square foot), multiplied by the radius of the exterior face and divided by the area of the section; as per equation 1:—

$$(1) \quad q = \frac{P(R+t)}{A}$$

in which t equals the thickness of the dam at any given point, R is the inner radius and A, the area of the section. Further, the volume of concrete in any arch dam is equal to the area of the dam section, times the mean radius, times the inclosed angle, times a constant.

$$(2) \quad V = A \times R_m \times 2\theta \times C$$

V being the volume, R_m the mean radius, 2θ the inclosed angle indicated in Fig. 2, and C, the constant. The mean radius—R_m, equals the inner radius plus half the thickness t; and also equals half the width W, of the cañon divided by the sin. of half the inclosed angle.

$$(3)\quad R_m = R + \frac{t}{2} = \frac{\frac{W}{2}}{\sin.\theta}$$

Now as the area of the dam section varies with the mean radius; the volume of masonry:—

$$(4)\quad V = \frac{C' \times \frac{(W)^2}{(2)} \times 2\theta}{\sin.^2\theta} = \frac{K \times \theta}{\sin.^2\theta}$$

in which C′ and K are constants, the latter depending upon the width of the cañon.

From equation 4 it is seen that the volume varies with

$$\frac{\theta}{\sin.^2\theta},$$

and in Fig. 2 the relative values of this term are graphically shown by the curve 3, in which the various angles representing 2θ constitute the abscissæ and the values of

$$\frac{\theta}{\sin.^2\theta}$$

constitute the ordinates; the latter for reasons above set forth corresponding to the percentages of volume of masonry. From this curve it will be seen that the amount of masonry required for any curved or arched dam, at least in a cañon with relatively steep walls, will be a minimum when the mean radius is so chosen that the inclosed angle 2θ is about 133°; and the curve also shows that the variation in the amount of masonry required for a given dam will only be about one per cent. provided that the values of 2θ be held between the limits of 120° and 146°. Outside of these limits the increase in amount of masonry required is very rapid; and hence the length of the different radii used in the dam construction described hereinafter will, as far as possible, be so chosen that 2θ can be kept between these limits.

The dam must of course be safe when the reservoir is empty and excessive overhang must, in some cases, be prevented by increasing the thickness above that found from the formula, in which case it is most economical to throw normal load on the total area by increasing the length of the up-stream radius, for the reason that a relatively flat arch requires less material than a more curved one. By flattening the arch the inclosed angle is necessarily decreased and in order to cover practical cases of this character I desire to state that I consider the varying of the inclosed angles 2θ of the dam sectors between the limits 60° and 140° to be within the purview of my invention.

The method of dam construction, herein disclosed involves the independent determination of the dimensions of successive arch shaped slices of the dam lying between predetermined levels; each slice being considered primarily as an independent structure; such slices being thereafter superposed or substantially superposed to form the dam body.

Referring now to Fig. 1, the procedure of determining the contour of the walls of the dam therein shown is substantially as follows: A topographical survey of the cañon or valley should first be made and the contour lines should be plotted as indicated in the said figure. In the present instance six elevations or levels have been established forming respectively the contour lines I, II, III, IIII, V and VI, the contour lines VI corresponding to a level which will be substantially that of the level of the water retained by the dam when the latter is completed, while the contour lines I—I correspond to substantially the lowest dam level in the gorge or valley; the remaining lines being those of intermediate levels. The distance across the cañon W_6 at the top contour VI of the dam is ascertained. Then the mean radius,

$$R_6 + \frac{t_6}{2},$$

which will give the dam the greatest strength with the least volume of material is found by means of Fig. 2. At this particular elevation (VI) the most economical mean radius will be:

$$\frac{\frac{W_6}{2}}{\sin.\theta}$$

θ being selected by means of Fig. 2. At the top of the dam it will be generally found of advantage to choose 2θ near the upper limit (146°) for great economy, and at the bottom to correspondingly choose 2θ near the lower limit (120°). After the most economical mean radius for this elevation has been ascertained, the thickness t_6 may be algebraically determined, from the foregoing equations. The first relatively abrupt change of slope of the cañon sides preferably coincides with elevation or level V; the distance across the cañon at this elevation being measured and the most economical mean radius of the section at such elevation is found by means of the curve shown in Fig. 2, in the same way as the corresponding mean radius was determined for elevation VI. After the radius has been settled upon, the thickness t_5 is computed and the up-stream radius (R_5+t_5) is correspondingly also determined. The center of curvature of the arch slice at elevation V with a thickness t_5 does not necessarily lie on the same center line as the center of curvature of the arch slice at elevation VI; in fact it practically never will do so, as perfectly even slopes of the respective cañon sides or walls will rarely be found. Hence the shape of the surface of the up-stream face of the dam between elevations VI and V cannot be described as resembling that of any known geometrical body. In general it may be said to have a surface resembling that of a sector of the frustum of a cone. Elevation IIII is coincident with another change of slope in the sides of the cañon; and the most economical mean radius corresponding to the fixed distance W_4 across the cañon at this level is found in the same manner as were found the corresponding mean radii for elevations VI and V; and the location of the center of curvature of the arch slice at this elevation is again chosen regardless of the location of the centers of the slices at elevations VI and V. In other words, the dam has no common center line, and centers are located principally with a view to getting the length of the arch as short as possible for a given distance across the cañon, and in view of the deducted most economical mean radius for such given distance. The radii and thicknesses at elevations III, II and I are correspondingly determined in accordance with the procedure above outlined. After having calculated the different radii and respective thicknesses of the several sectors of the dam, the top thickness is set off and the arcs of two concentric circles with radii R_6 and (R_6+t_6) respectively are drawn in on the contour map; and the centers of such circles will be, of course, on a line drawn perpendicular to the center of the chord W_6. The thickness t_5 is then set off; and the arcs of two other concentric circles, respectively with radii R_5 and (R_5+t_5), are drawn in until intersection occurs with the contour line V—V; bearing in mind that the center common to these latter two circles does not need to be on the perpendicular to the chord W_6 above referred to. These circles, concentric only in pairs, determine the contour of the dam between elevations VI and V. It is usually convenient and preferable to assume the down stream faces of the upper slices of the dam adjacent the center thereof, to be vertical, at least for the first trial; although after the lower slices have been laid in, it may at times, be found desirable to slope the central portion of such face one way or the other. The center of the arch slice at elevation V—V is correspondingly disposed on a perpendicular drawn through the center of the chord W_5; and the thickness t_4 is set off, assuming initially again that the central portion of the down stream face is substantially vertical here also; although some slope may thereafter be given to it. It has been found in practice that a vertical wall at this point usually affords the most economical construction. At other points the down stream face will ordinarily have some slope, due to the above method of construction. The arcs of two concentric circles with radii R_4 and (R_4+t_4) respectively are then drawn in until intersection occurs with contour lines IV—IV; bearing in mind again that the center common to these two circles does not need to and hardly ever will lie on a center line drawn perpendicularly to the centers of chords W_6 or W_5. The same procedure as outlined above is thereafter followed to get the up and down stream face lines at elevations III, II and I.

A certain amount of discretion must be exercised in locating the centers of the respective sectors, especially where a very abrupt change occurs only at one side or upon one wall of the cañon. In general, too, it is desirable, where possible, to bring the sets of arcs of concentric circles which are disposed in the next succeeding elevation as nearly beneath those in the adjoining elevation as possible, so that the respective sectors of the dam may be as nearly superposed as the contour of their faces will permit. Of course it will be impossible owing to the differences in contour of the respective sections to secure exact coincidence, and hence the respective complete lateral faces of the dam both upon the stream side and upon the concave side thereof will be of rather irregular contour, each of said surfaces somewhat resembling a warped surface. In practice, as will be seen from an inspection of Fig. 1, portions of contiguous horizontally alined points in one or the other faces of the dam will normally project out laterally in varying degrees beyond other horizontally alined points which are disposed substantially in parallelism with those first mentioned. For example, considering the convex or stream side of the dam, it will be seen that the substantially vertical surface of one of the lower sectors will project out laterally in varying degrees beyond the corresponding points in one of the upper sectors; on in other words, the distance a indicated in Fig. 1 will be different from the distance b in the same figure, although such distances are measured in the same horizontal plane.

While it is generally preferable to so form the respective slices or sectors of the dam, which lie between the several elevations of such configuration, that the respective tops and bottoms of adjoining slices may be regarded as being superposed in strict coincidence in the manner shown in Figs. 4 and 5, it is desirable in some localities to face the dam with ashlar, cut-stones, or the like, and it may be of advantage in such case to step the faces of the dam off as shown in the enlarged fragment of section A—B shown in Fig. 6. The dam will then consist of a number of partial cylinder rings or hollow-cylinder sectors which are superposed upon each other. The up and down stream radii in such case, however, are ascertained in exactly the same manner as in the foregoing, and these hollow-cylinder sectors when viewed from the top each appear substantially as an arch like that shown in Fig. 2, while each step of the section shown in Fig. 6 corresponds to a sector and shows the height of the same; the height of each sector being uniform throughout the length thereof, and in this exemplification of my invention the width T being of course also uniform throughout. It is also desirable for various practical considerations, to thicken somewhat the upper section, or at least the upper portion thereof; so that the thickness of the dam at this point will be greater than the calculated thickness, as shown at 4 in Fig. 7.

In conclusion I desire to call attention to the fact that while I have proposed substantially 133° as the best angle for use in the dam construction, in practice it is frequently desirable to choose a larger angle at the top, as for instance 140°; since in many cases the use of a considerably smaller angle may be necessitated near the bottom.

What I claim, is:—

1. An arch dam for a cañon or the like comprising a plurality of superposed arch shaped elements of varying radii the radii of such elements varying with the widths of the cañon at the corresponding levels of such elements and bearing a definite relation to such widths.

2. An arch dam comprising superposed arch shaped elements of varying radii, the centers of curvature of such elements being out of vertical alinement.

3. An arch dam comprising superposed arch shaped elements of varying radii and thickness, the radii and thickness of such elements varying with the widths of the cañon at the corresponding levels of such elements and bearing a definite relation to such widths and to the pressure to which they are subjected.

4. An arch dam for a cañon or the like comprising a monolith, a wall of which is of irregular contour and resembles a warped surface.

5. An arch dam having a face thereof of irregular contour, resembling a warped surface, parts of the lower portion of said surface lying in the same horizontal plane projecting in varying degrees out beyond the upper portion thereof corresponding parts in an upper portion of said surface, lying in a second horizontal plane.

6. An arch dam having the convex face thereof of irregular contour, the lower portions of said face projecting out beyond the corresponding upper portions, and the lower portions adjacent the center of the dam projecting farther than corresponding portions adjacent the sides of the dam.

7. An arch dam for a cañon or the like, having a convex face of irregular contour, an extended group of contiguous horizontally alined points in said face projecting out laterally in varying amounts, along the length of said group, beyond other horizontally alined points disposed substantially in parallelism with, but vertically displaced with respect to, those first mentioned.

8. An arch dam having the concave face thereof of irregular contour, the lower portions of said face projecting out beyond the corresponding upper portions, and the lower portions adjacent the sides of the dam projecting farther than those adjacent the center thereof.

9. An arch dam formed of a plurality of sectors the angles of which are between substantially 60° and 140°, said sectors being of different radii of curvature, the axes of curvature of the respective sectors being non-coincident.

10. A dam body for a cañon or the like, comprising a plurality of superposed hollow sectors of differing radii, the radius of the middle element of the convex face of each of said sectors bearing a definite relation to the width of the cañon at the level of such element, and the mean radius proper of each of said sectors being substantially that corresponding to the minimum volume of material employed in the construction of said sector.

11. A dam body for a cañon or the like, comprising a plurality of hollow sectors of differing radii, the relative heights of said sectors being determined by the vertical distances between levels taken through abrupt changes in the slope of the cañon sides.

12. A dam body formed of a plurality of hollow sectors of differing radii, the axes of curvature of said sectors being non-coincident, and the lateral thickness of each sector, along any given horizontal level, being substantially uniform throughout the length of said sector.

In witness whereof, I subscribe my signature, in the presence of two witnesses.

LARS JORGENSEN.

Witnesses:

WM. H. HARRELSON,

F. G. BAUM.