Jan. 29, 1935.

J. M. BARR

1,989,223

GRAPHIC CALCULATING DEVICE

Filed Nov. 9, 1928

2 Sheets-Sheet 1

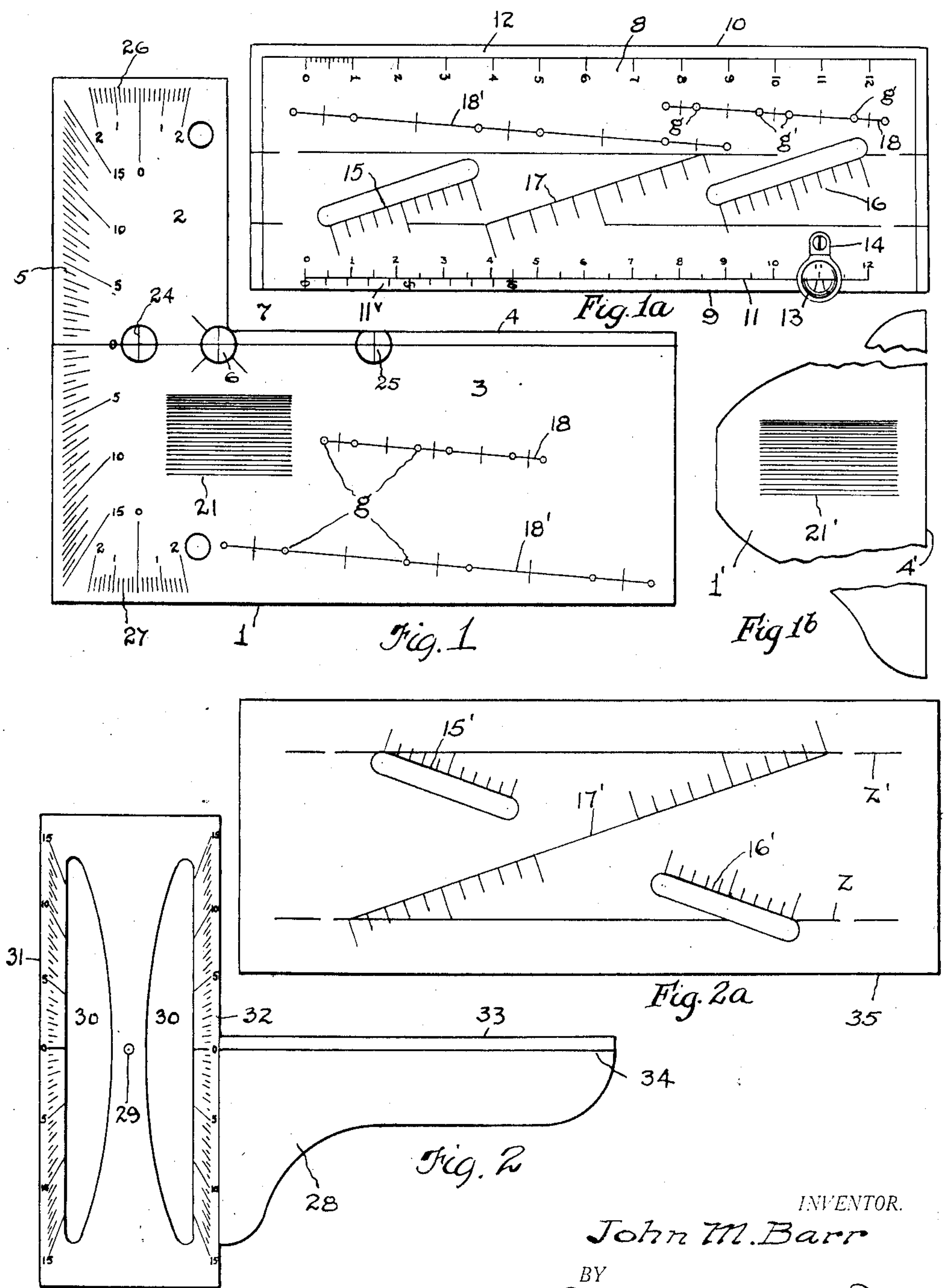

Fig. 1a

Fig. 1

Fig 1b

Fig. 2a

Fig. 2

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GRAPHIC CALCULATING DEVICE

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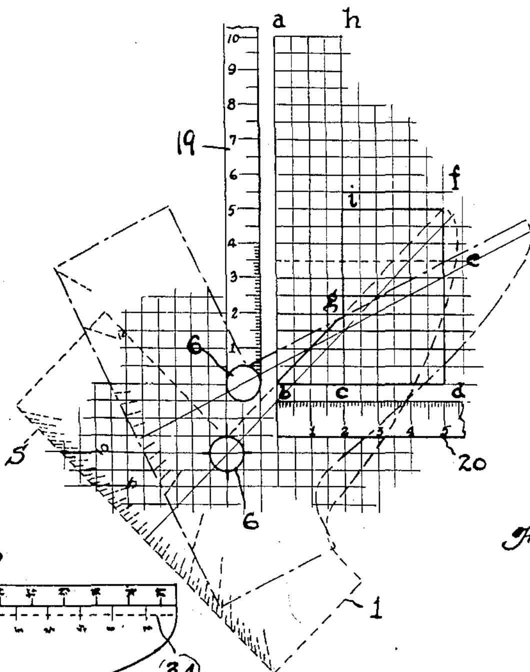


Fig. 4

Fig. 3

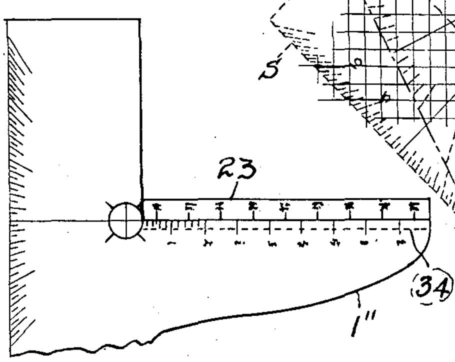
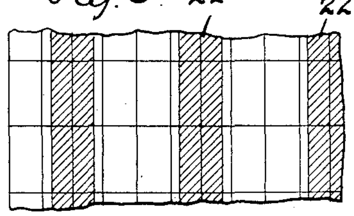


Fig. 6



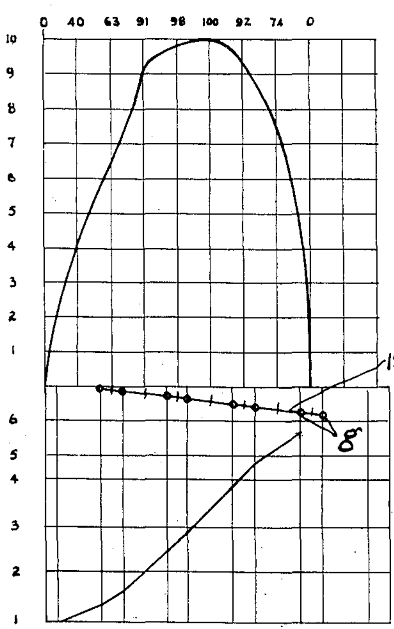


Fig. 5

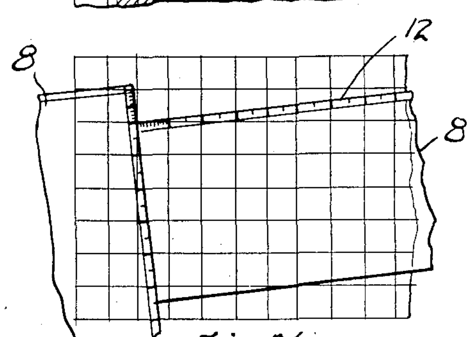


Fig. 7

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UNITED STATES PATENT OFFICE

1,989,223

GRAPHIC CALCULATING DEVICE

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Application November 9, 1928, Serial No. 318,287

5 Claims. (Cl. 33—75)

In designing and general engineering and calculating work, cases are continuously coming up in which the methods of the calculus could be applied to great advantage. Unfortunately, however, very few engineers are sufficiently expert with these methods to be able to make utilization of them in practice, and in fact even where sufficient proficiency obtains, there are many disadvantages in straight calculation as compared with simpler and graphic methods. Moreover, many cases arising in practice present problems of such a character as not to be amenable to integration even although treated with all the interchangeable resources of algebra, geometry, trigonometry and logarithmic functions together; while many tabulations are purely empirical and cannot even be reduced to formulas. There are some twenty or twenty-five soluble fundamental integrals, and even given the experience and continual practice, which very few men have, many expressions require so much work, so much cut and try, that these processes are generally passed by as impracticable. To the practical man, it is accordingly highly important that there be available methods which while embodying fundamentally the powerful agencies available in the principles of the calculus, should be workable on a basis having the simplicity and directness of slide rule practice. Moreover, it is desirable that such practical methods should have the further feature of providing a permanent graphic record of the work. It is accordingly within the purview of the present invention to provide equipment available to the practical man, and capable of affording direct rapid results in calculation, with as much graphic record as desired.

To the accomplishment of the foregoing and related ends, the invention, then, consists of the features hereinafter fully described, and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail certain structure embodying the invention, such being illustrative however of but a few of the various ways in which the principle of the invention may be employed.

In said annexed drawings:—

Figs. 1, 1*a* and 1*b* are plan views showing construction embodying the invention; Figs. 2 and 2*a* are similar views of modified forms; Fig. 3 is a fragmentary plan view of another modification; Fig. 4 is a plan view illustrating the application of the equipment; Fig. 5 is another illustration of a problem treated; and Figs. 6 and 7 are fragmentary plan views of details.

Referring more particularly to the drawings, there is shown in Fig. 1, an instrument comprising a templet 1, which while capable of variation as to its precise form, may conveniently embody two angularly related arms 2 and 3. The arm or as it might be called body 2 may be of a form to present its longest dimension in vertical direction, while the arm or blade 3 projects right angularly therefrom and presents a straight edge 4. In relation to the straight edge, so as to cooperate therewith is a scale 5 on the body or vertical portion, and in convenient straight or arcuate form, the graduation lines of this scale being all directed toward a common point, as for instance the point 6 in relation to the straight edge. In the scale illustrated, the graduations are such that when the blade is properly oriented with respect to a horizontal line as for instance on a plot, then the scale indications are ten times the tangent of the angle between the blade and any horizontal line in relation. Thus, in Fig. 4, the scale comes to register at the point 5, and it will be found that counting over ten divisions horizontally from the intersection of the blade with any horizontal line required a rise of five divisions to again reach the blade. If the edge of the left hand scale be in the form of a straight line as illustrated, the divisions will bear this constant relation, but the scale may be arcuate or other form, and the divisions correspondingly express the same relation. The graduations however may be such as to indicate desired convenient ratios, or trigonometric or algebraic proportions.

The templet 8 similarly has straight edges 9, 10, and adjacent thereto the scales 11, 12. The scale 11 preferably also embodies a vernier 11*v* for closer readings, nine divisions on the main scale being divided into ten on the vernier, as in general vernier practice; and for furthering the accuracy of the setting of a pencil point, a lens 13 may be mounted on the templet over one of the whole division points. A convenient mounting for this may comprise a holding bracket 14 fastened to the templet and carrying the lens at a suitably slightly elevated position to allow insertion of a pencil point or scriber thereunder, the margin being preferably notched or cut into the scale line 11 at this point. An inclined scale 15 is also provided on the body of the templet. This scale in the form illustrated in Fig. 1 is laid out such that ten divisions thereof cover a vertical rise at its highest point of a convenient unit amount, for example one-half inch. These oblique divisions may be further subdivided if desired. A similar scale 16 and a larger division scale 17 on double or any desired ratio may also be arranged. For a purpose to be referred to more in detail hereinafter, a scale 18 having divisions similar to those of the fundamental scale, as for instance scale 12, is arranged with a series of pencil point guide holes *g*. The spacing of these is in conformity with the fundamental terms of some desired formula. In the preferred form illustrated, the guide holes are spaced in groupings of two, and with a distance ratio of ⅔ of the aforesaid division unit between the two lines in the grouping and 4/3 units between groupings, this being in accordance with the requirements of Simpson's rule as will be hereinafter more particularly set forth. An additional scale 18', similar in its proportions, but laid out on a longer fundamental unit may also be provided.

A grating or series of lines 21 on any templet convenient, for instance templet 1 affords an effective means useful for locating direction of tangency in connection with procedure referred to hereinafter. These lines are preferably spaced progressively on a geometric or logarithmic increment, and thus are applicable with various curves irrespective of thickness of the line dealt with.

In use, the templet 1 is applied to a figure on cross section paper for instance, such figure being one to be calculated; as in an elementary or very simple illustration say the area of a surveyor's parcel in which the findings were 10, 10, 10, 5, 5, 5, 5 rods in depth from the front or base line, taken on one rod intervals. In the customary methods of calculation of such, the area would be plotted as at *abdfih*, Fig. 4, and considered as a series of the two smaller rectangular areas *abch* and *cdfi*, each being scaled by reference to scales 19, 20, for instance, and calculated by multiplication of its dimensions, and the total being added to give the whole area, which is thus found to be 20 plus 15 or 35 square rods. By the present procedure the line *bd* may be taken as a base line and placing a sharpened pencil or metal point at the left corner *b*, the templet 1 is slid up against the pencil point and is swung thereagainst so that the scale 5 reads the given first rectangle height, i. e. 10, the 10 division of the scale thus being adjusted to register parallel on any convenient horizontal line, and then adjusting the templet until the center of reference-circle 6 is also brought to the same horizontal, as shown in the short or the lower dot line position of the templet on Fig. 4. Holding the templet, the pencil point is moved out on the straight edge to the other bounding vertical line at *g* of the rectangular portion *abch*. It will be noticed that the pencil now indicates a height or reading 2 (with reference to the plotting scale 19). By virtue of the properties of the scale 5, this reading is 10 per cent. of the integral of area *abch*, and the numerical result may thence be directly had from this per cent. basis; in this case such result is as seen 20. With the pencil at point *g* the templet is now swung thereabout until scale 5 reads for the next rectangle height, i. e. 5 according to the data of the example. This scale line is registered to a convenient horizontal line and the templet is adjusted as before until the center of the reference-circle 6 is also brought to the same horizontal, as shown in the dash-dot line position of Fig. 4. Holding the templet, the pencil is moved out on the straight edge to the other bounding vertical line *e* of the second rectangular portion *cdfi*. The pencil now indicates a height or reading 3.5, which is 10 per cent. of the integral of the combined area and this affords the numerical result sought or 35 square rods for the total parcel. It may be noted here also that the height of any point on the integral line indicates the area to the left thereof under the curve treated at any chosen point on the base. By the well known properties of the integral, the point at which the height of the integral is one-half its final value represents the center of area with reference to a vertical axis. The utility of this will of course be more apparent where the subject matter dealt with involves problems other than simple rectangles and areas. For a permanent record, the line *bg*, *ge*, as above referred to, could be drawn in during the procedure, if desired.

Similarly, a function whose graphic representation is a curve may be integrated. For example, if on the plotting paper of Fig. 4, instead of the points of the upper bounding lines as shown, the points of the initial data were to involve locations on a curve, the areas beneath to the base line would again be considered as corresponding rectangles and the integraphing be carried across each in succession to the total reading at the right hand side. Indeed, it is not necessary to plot out the function in its full details, but the templet is successively swung with the technique described to numerically indicate the height of the points of the curve at the middle of the successive cardinal base divisions, and each such area beneath the curve may be closely approximated by thus treating it as a rectangle whose height is determined as foregoing, the closeness of approximation being more accurate the smaller the cardinal base divisions; and the final position of the templet giving the total reading.

Any area bounded by a curve, no matter how complex, can always be resolved into a series of rectangles and the area thus be found, the ultimate accuracy of the result being a function of the smallness of the divisions. Experience has proven that the fineness required for practical accuracy is not such as to introduce an excessively burdensome or tedious procedure and in addition other methods for reducing the amount of labor involved and increasing the accuracy will be hereinafter described.

Conversely by placing the templet 1 with its straight edge passing through the end of the integral and the zero point, its scale on the same horizontal line as the reference point will indicate the average height of the figure, or in other words, the operation of division has been effected.

Furthermore, it is a property of the parabola that for suitably short distances it can be made to very closely approximate any curve whatsoever. On this basis therefore through any given three points, a portion of a parabola may be assumed, this being in accordance with the derivation of Simpson's rule and in this manner where the figure concerned is of such complexity as would greatly increase the number of division set ups in running the integral line, and so rendering the work tedious and possibly introducing personal errors, the further refinement of the procedure based upon this parabola principle or Simpson's rule as stated may be applied. For this, the templet 35 which advantageously is of transparent material, is laid on the curve in question with the long horizontal line *z* or *z'* forming a chord with respect thereto, (two lines being provided for convenient adjustment to convex or concave curve). In the case of a parabola-topped figure, the equivalent rectangle deviates from the area under the chord two-thirds as much as the maximum deviation of the parabola from the chord. Therefore if the maximum deviation be determined by the scale 17', and scales 15' or 16' are arranged to show two-thirds of this deviation, then by first determining the deviation by 17', sliding templet 35 along a straight edge, for instance straight edge 4 or 33, this two-thirds deviation may be conveniently plotted at the midpoint of the parabola segment by reading to the same scale reading on 15' or 16' as was determined on 17' at the point of maximum deviation. The transparent material of the templet is advantageously cut away at 15' and 16' to allow plotting through the templet. While intermediate values will not in this case represent intermediate values of the area, the final value at the right hand boundary will very closely represent the total area under the parabola. It will thus be seen that in order to accurately locate the point of maximum deviation, it is necessary to graph the curve. At the same time, it is to be noted that the line parallel to the chord through the point of maximum deviation is the tangent to the parabola at the mid-point of any and all possible chords. In the scaling of curves variously, the particular spacing best, whether longer or shorter, will be found readily determinable by inspection, and the method is not limited to equal distances along the base.

By having the symmetrical scales 15', 16', the templet need not be reversed for lines concave either up or down.

By this method of procedure, an unequal spacing may be chosen, but as stated, the curve must be graphed. By the method which follows, it becomes unnecessary to graph the curve however, but equal spacings must be provided, as is usually the case in profile work and mechanical cams and contrivances, also in the case of many tabulations of abstract numbers which involve the value of some quantity at equal intervals as e. g. stock market quotations at the close of the day, rain fall for five minutes, fuel per car mile, etc.

Simpson's rule as mathematically expressed is

$$A=\Delta x[1/3y_0+4/3y_1+2/3y_2+4/3y_3+2/3y_4+1/3y_n],$$

and while it is generally accepted as being extremely accurate, on account of the complexity of the formula and the considerable work involved in calculation by its use, its value is seldom utilized by practicing engineers, and practically never in commercial calculations, but with the further refinement here contemplated such usage becomes feasible and simple and effective. In integrations generally, the successive values of y are taken at equal intervals along the base line and at the midpoint of the designated base unit. If now however, the intervals be taken instead as 1/3, 4/3, 2/3, 4/3, 2/3, etc., the fundamental terms of the Simpson's rule formula are automatically incorporated, because as previously indicated, the use of the templet 1 essentially accomplishes a multiplication of the height at any point by its chosen base. Therefore by suitably choosing the bases, the desired factors may be introduced, and Simpson's or any other formula for obtaining areas or for any other specific purposes may be applied. This may be effected by initially plotting out in each instance a supplemental set of rulings or lines on or adjacent to the field of the curve under investigation, as in Fig. 5, employing the guide 18 and positioning its scale such that the graduations register with the chosen unit divisions but obviously on an inclination in order to effect registration. Then by means of a pencil or other sharp instrument, dots corresponding to the holes g are impressed and these will provide a horizontal spacing in conformity with, in this case, Simpson's rule, or desirably the paper upon which the work is laid may itself fundamentally include such rulings or lines. Under such conditions, the integral at the mid-point of any 2/3 division precisely represents the area under the variously sized and disposed parabolic approximations of the original curve. There thus becomes available a means of integrating with all the advantages pertaining thereto, to an accuracy depending only upon the manual dexterity and closeness with which the given curve may be approximated by means of the previously mentioned parabolas. I do not limit the means for securing these rulings or lines to those stated above, but such rulings or lines may be provided for example by a pattern sheet with suitable lines or grooves placed under the paper, or by a colorless embossing of the paper itself which serves to indicate the end of the required divisions, or by bands printed either in solid color or so-called half tone effect (see Fig. 6), preferably between suitable divisions required by the particular rule, such color bands 22 being in contrast to the general ground, and this arrangement being especially effective in avoiding the confusion due to a multiplicity of lines from superposing those of for instance the Simpson formula upon the conventional cross section paper. Or where desired, tracing paper or the like may be laid or gummed over cross section paper and the Simpson lines required may be readily spaced thereon by suitable guide.

Referring now further to the graduations 5 on the templet 1, it will be noted that these cover quite a range practically. However, in some instances a further range each way is required. By employing the point or indicating cross 24 as the axis of rotation, the scale 5 is multiplied by two as compared with its values when using the point 6 as center for the swinging adjustment movements. Similarly, the point or cross 25 used as a center about which the templet is swung, will divide the scale 5 by two. At the top there will be noticed a smaller scale 26 running from zero both left and right. Usually this scale and the point 24 as its center divides the first two divisions plus and minus into five parts, or in other words each small division is then two-tenths of one whole division. This is useful practically for running lines close to the base line. A corresponding scale 27 may be provided at the lower end.

The templet 1' has a straight edge 4' and positioned at right angles thereto is a grating 21' of the character previously referred to. By placing this templet so that the grating is approximately tangent to the curve at any desired point, it will be found that the line of the curve is apparently distorted into a series of broken lines. If now the templet be slowly moved up and down, these lines will be seen to slowly progress, in the case of a curve, toward or away from a common point; and by sliding against a suitable straight edge, it will be noted that the point of tangency is the point at which this progression ceases. In this manner such a separate templet is especially useful in investigating cams. If now a suitable protracting device be provided either integral or with or adapted to be used in place of the previously mentioned straight edge, the cooperation of such protracting device may be utilized to determine the specific angle of the tangent to a particular set of coordinate lines.

It will be noticed that the templets so far described are independent of specific size or dimensions, and involve rather matters of proportionality.

Paper upon which plots, blue prints, etc. are made is subject to variation with moisture-uptake. For instance, the draftsman's hand introduces moisture and causes expansion, and cross section paper and blue print paper such as customarily used for plots and graphs show this variation. It is found that an allowance of for example 2 per cent. is in general sufficient to take care of this stretch, and it is desirable to incorporate such allowance in these scales, more particularly the scales 11, 12, 17, etc. Inaccuracies so far as referable to paper employed are thus further minimized on a practical working basis.

Referring further to scales 11 and 12, these scales being somewhat greater than the nominal length indicated may be registered in any case with conventional coordinate lines of plotting paper for instance, by placing at a suitable inclination or angle, thereby registering line to line and thus being independent of absolute size. Thus the cooperation of the scale divisions on the templet with the coordinate lines permits the accurate reading of whole scale divisions or portions thereof, the latter being especially cared for by the finer subdivisions shown at the left or by means of the vernier 11*v* as on scale 11. It will be noted that by this means we have not only subdivided our nominal unit of division but we may readily obtain an accurate average thus offsetting inaccuracies due to misplacement of individual lines. To this end it may be desirable, maintaining the same angularity, to slide the templet up and down along a straight edge and take a number of readings.

In the form shown in Fig. 2, the body of the templet 28 has a window presenting a point or cross 29 and may be provided with a lens, the purpose being to accurately locate along a horizontal line in which the pencil is held, when rotating the device to adjusted position in accordance with the scale. At either side of this portion is a cut-out or window 30, these being of convenience in lightening the instrument and facilitating handling. The scales 31 and 32 are analogous to the main scale 5 of the form shown in Fig. 1.

As a further refinement, the straight edge may have a slide portion 28 (Fig. 3) slidable by dovetail or undercut connection along the edge 34 of the templet, as illustrated in Fig. 3, whereby with the use of appropriate scales on the respective parts, a suitable multiplying factor may be introduced and thus further readings such for instance as results corresponding to costs of excavation work at any given figure per yard may be had directly, etc. This form is especially adapted to non-transparent material. The templet 35 as illustrated in Fig. 2, while preserving the fundamental features of templet 8 in Fig. 1, affords a longer range scale line 17′, and the scales 15′, 16′ in a slightly different alignment, and preferably along open slots.

While the templets may be made of any desired material or sheet stock, transparent material, such for instance as celluloid and the like, is particularly desirable, in facilitating rapid location and alignment over plots and figures on cross section paper. The scales are preferably indented into the lower surface of the templet and the markings can be made more legible by color. Red is most desirable, as affording particularly good contrast.

It will be noticed also that while material such as celluloid has been criticized as liable to introduce difficulties in scale-bearing instruments by reason of shrinkage changes, the present invention obviates such difficulties and makes possible accurate usage of scales on this otherwise desirable material. As indicated, I arrange scales for an inclination or slantwise with respect to the fundamental reference lines with which they are to be used. Such scales may then be laid over the lines for instance of cross section paper, (see Fig. 7), and with slight angular adjustment thereto may be readily positioned such that the scale-lines tally with respect to the section lines, and with scales working at right angles to each other, as with the two templets together, proportionality is in all cases the basis, rather than dependence upon the absolute scale length.

It will thus be seen, that in accordance with this invention, equipment is had by which the various range of practical calculations arising in connection with determination of areas, curves, profiles or plots, or even columns of figures may be readily arrived at, and such problems as computation of volumes, center of gravity, moment of inertia, radius of gyration, as well as weights of castings and forgings, etc., may be readily had, without laborious calculations. Even integrations which are impossible exactly, can be thus approximated sufficiently accurately for practical purposes. At the same time, the facility and rapidity with which the equipment may be used is comparable to the methods of slide rule practice, and correspondingly readily available to those lacking a training in the theory of the calculus and its methods.

Other modes of applying the principle of the invention may be employed, change being made as regards the details disclosed, provided the means stated in any of the following claims, or the equivalent of such, be employed.

I therefore particularly point out and distinctly claim as my invention:—

1. In graphic calculating equipment, means for mechanically integrating by the principles of calculus, said means including a templet having a straight edge, a reference point of rotation on said templet spaced a predetermined distance from the straight edge, and a scale on said templet having divisions along said straight edge radially laid from the reference point above and below the normal to said straight edge through said point, the graduations of the scale being in terms of 10 times the tangent of the angle between said normal and the respective graduations, said normal being a base line with reference to which the straight edge is swung.

2. In graphic calculating equipment, means for mechanically integrating by the principles of calculus, said means including a templet having a straight edge arm and another arm at right angles thereto, a reference-point of rotation on said templet spaced a predetermined distance from the line of the straight edge, and a scale on said templet having divisions extending along said straight edge, each division radially laid from the reference-point above and below the normal to the straight edge through said point, the graduations of the scale being in terms of 10 times the tangent of the angle between said normal and the respective graduations, said normal being a selected line with reference to which the straight edge is swung.

3. In grapic calculating equipment, means for mechanically integrating by the principles of calculus, said means including a templet having a straight edge, a reference point of rotation on said templet spaced a predetermined distance from the straight edge, a scale on said templet having divisions extending along said edge and radially laid from the reference-point above and below the normal to said straight edge through said point, a secondary reference-point of rotation on said normal, and another scale on said templet having divisions radially laid from said secondary reference-point along an edge perpendicular to said first-named edge.

4. In graphic calculating equipment, means for mechanically integrating by the principles of calculus, said means including a templet having a straight edge, there being a reference-point of rotation on said templet spaced a predetermined distance from the straight edge, a scale on said templet having divisions extending along said edge and radially laid from the reference-point, said templet having a second straight edge at right angles to said first edge, a slide on the second straight edge, and a multiplier scale on said slide.

5. In graphic calculating equipment, means for mechanically integrating by the principles of calculus, said means including a templet having a straight edge arm and another arm at right angles thereto, a primary reference-point of rotation on said templet spaced a predetermined distance from the straight edge, a scale on said templet having divisions extending along said edge and radially laid from said reference point of rotation above and below the normal to said straight edge through said point, secondary reference-points of rotation on said normal and at opposite sides of said primary reference-point, one secondary reference-point being positioned with relation to the primary reference-point to multiply said scale and the other secondary reference-point being positioned to divide said scale, and another scale radially laid from said multiplying secondary reference-point, and extending along a straight edge on said templet at an angle to the first edge.

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