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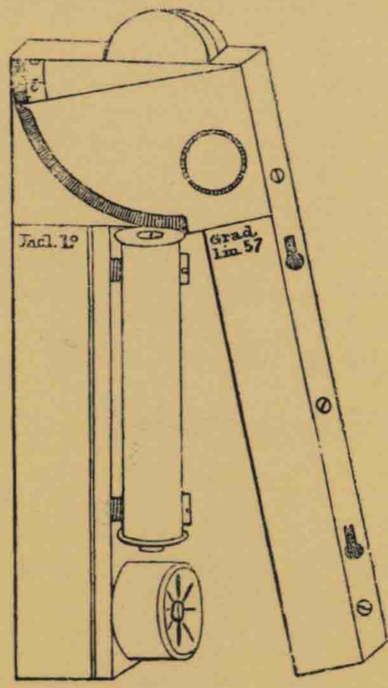
A TREATISE ON ENGINEERING FIELD-WORK

VOLUME 2

PETER BRUFF



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A Treatise on Engineering Field-Work

Comprising the Practice of Surveying, Levelling, Laying Out Works, and Other Field Operations Connected with Engineering

VOLUME 2

PETER BRUFF

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A Treatise on Engineering Field-Work

In the 1840s, the civil engineer Peter Bruff (1812–1900) designed what was then the largest brick structure in Britain, the 1,000-foot-long Chappel Viaduct in Essex. He went on to become a railway entrepreneur and developer, and was responsible for the creation of the resort town Clacton-on-Sea, where he also designed many of the buildings. In this illustrated guide, first published in 1838 and here reissued in the revised and expanded two-volume second edition of 1840–2, he discusses the theory and practice of surveying (calculating the accurate position of points in the landscape) and levelling (calculating the accurate height of points). Volume 2 covers levelling; Bruff gives a brief overview of the theory, then describes the typical equipment used. By discussing such examples as the levelling of a projected railway route, he explains what information should be recorded, and how to avoid common errors of technique that affect accuracy.

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A TREATISE

ON

ENGINEERING FIELD-WORK,

COMPRISING

THE PRACTICE OF

SURVEYING, LEVELLING, LAYING OUT WORKS,

AND OTHER

FIELD OPERATIONS CONNECTED WITH ENGINEERING.

With numerous Diagrams and Plates.

BY PETER BRUFF, C.E.,

ASSOCIATE INST. CIVIL ENGINEERS.

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NOTICE.

I much regret the delay which has occurred in the appearance of the present Volume, but it has been unavoidable. Domestic afflictions have contributed considerably thereto; but still more has the unceasing attention requisite to the successful prosecution of many varied undertakings which I have been engaged in since the appearance of the first volume. I have far advanced with the concluding part, and trust the time which has elapsed, instead of being found injurious to its contents, will be deemed favourable, as affording me more time for consideration of the matters therein advanced, and opportunity of more fully developing my ideas.

P. B.

CHARLOTTE STREET, BLOOMSBURY,
June, 1842.

THE

THEORY AND PRACTICE

OF

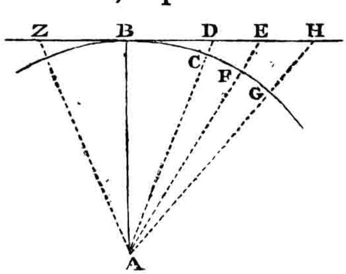
LEVELLING.

CHAPTER I.

THEORY OF LEVELLING, GRAVITY AND THE PLUMB-LINE.—FIGURE OF THE EARTH.—CURVATURE, WITH VARIOUS FORMULÆ FOR COMPUTING.—EXAMPLES OF CORRECTIONS FOR CURVATURE.—ATMOSPHERIC REFRACTION, EFFECTS OF.—GENERAL REMARKS.

In this part of our work we shall strictly confine ourselves to introductory matter and preliminary observations in the first chapter, in order to put the subject in a clear light before such of our readers as are ignorant of its principles, or have never given it due consideration. The figure of the earth may be understood or defined by a surface at every point perpendicular to the direction of gravity, or of the plumb-line when it is unaffected by surrounding objects. This surface is of the same form that the sea would assume if continued all round the earth, and unaffected by wind or tide; the surface of every fluid, when at rest, being perpendicular to the direction of gravity. The visible horizon of an observer on the surface of the earth is a tangent plane at the point of observation to the curve surface formed by the earth's exterior ; or in other words, the line of sight is at right angles to the direction of gravity at that point, or of the semi-diameter of the earth.

The art of levelling consists in finding or tracing a line on a given portion of the earth's surface parallel to the horizon at *all* its points,—consequently parallel to the earth's mean surface ; and any number of such points are on a true level when equidistant from the centre of the earth, considering it as a perfect sphere. Such a line would therefore be a curve ; and if we were to trace curve lines, by levelling from a given point round the earth in every direction, till they returned into themselves, the superficies in which all these lines would lie, is that which we consider as the superficies of the earth. The figure which is bounded by this superficies, is that which is really measured by the combined method of astronomy and practical geometry, and is to be carefully distinguished from the *actual* figure of the earth, including all its inequalities.* But the line of sight given by the operation of levelling is similar to that of an observer,—viz. a tangent to the earth's surface at the point of observation. In the accompanying diagram B D E, &c. represents the line of sight, and B C F G, a portion of the earth's surface, its centre being at A. The line of sight being a tangent to the curved surface of the earth, is perpendicular to its semi-diameter at the point of contact B, rising always higher above the curved surface or the true line of level, the further the distance is extended ; this is called the *apparent* line of level. Thus, C D is the height of the ap-



* Playfair's Natural Philosophy.

parent above the true level at the distance B C; E F, is the excess of height at the distance B F; G H, at B G, &c., the difference, it is evident, being always equal to the excess of the secant of the arc of distance, above the radius of the earth. Where the line of sight does not extend for any considerable distance, the surface may be considered as a plane, but this must by no means be the case where the points of observation are far apart. The *effect* of the curvature of the earth is to *depress* the apparent place of an object, and the measure of its quantity may be deduced from the following simple proportion, (*see last diagram*); (2 A C + C D) : B D : : B D : but the diameter of the earth (2 A C) being so great with respect to C D, at all distances to which ordinary operations of levelling extend, that 2 A C may be taken in this proportion for 2 A C + C D without sensible error; the proportion will therefore stand thus: 2 A C : B D : : B D : C D, whence $C D = \frac{BD^2}{2AC}$ or $\frac{BC^2}{2AC}$ nearly; or, in other words, the difference between the apparent and true level is equal to the square of the distance between the places, divided by the diameter of the earth, and consequently proportional to the square of the distance. Thus, the mean diameter of the earth being taken at 7,916 miles,* if we first take B C = 1 mile, then the excess $\frac{BC^2}{2AC}$ becomes $\frac{1}{7916}$ths of a mile, equal to 8.004 inches, or .667 of a foot, for the height of the apparent above the true level at the distance of one mile. The height of the apparent above the true level, it will be observed, increases as the square of the distance; that is to say, at two miles the difference is four times as great as it is at one mile; at three miles it is nine times as great, and so on. The following example will

* Equatorial diameter 7,924 miles; Polar diameter 7,908 miles; *mean* diameter 7,916 miles.

perhaps set this matter more clear before some of our readers :—A spirit level (see description of that instrument) is planted on a hill, and when accurately levelled, the horizontal wire of the *diaphragm* in the telescope is observed exactly to coincide with the summit of a church steeple, distant five miles ;—required the difference of level (if any) between the summit of the steeple and the ground where the level was planted, the telescope of the instrument being elevated 4.50 feet above the surface :—

Amount of depression due to curvature for 1 mile ..	.667 Feet
Square of distance ; 5 miles	25
	3335
	1334
Amount of depression due to curvature for 5 miles..	16.675 Feet
Height of instrument above the surface of ground to be added..................................	4.500
Difference of level	21.175 Feet.

From this example it will be seen, that although the apparent difference of level was only 4.50 feet (the height of the instrument), yet the summit of the steeple was found to be 21.175 feet higher than the ground where the spirit level was planted, but on account of the curvature of the earth it was apparently depressed to the same level as the centre of the telescope.

The correction for curvature may also be computed by the well-known proposition, "That in any right angled triangle, the square of the hypothenuse is equal to the sum of the squares of the other two sides ;" therefore, by taking the *sum* of the squares of the tangent line or distance, and of the semi-diameter of the earth, and extracting the square root, we obtain the hypothenuse, from which deducting the semi-diameter or radius of the earth, the height of the apparent above the true level is obtained as before.

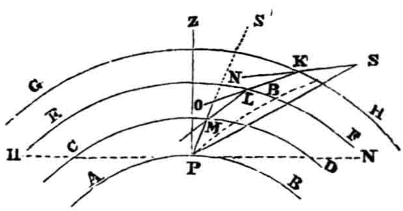
There are several other convenient forms by which the correction for curvature may be ascertained. The following formula will be easily remembered.—Divide the square of the distance in Gunter's chains by 800, the quotient will be the depression in *inches* very nearly; the correction may be obtained in *feet* by merely taking two thirds of the square of the distance in miles. Another convenient form for making this correction for *any* distance is,—to add to the arithmetical complement of the logarithm of the diameter of the earth,* or 2.378861, double the logarithm of the distance in feet, the sum will be the logarithm of the correction in feet and decimals;—thus, for example—required the correction for curvature in 1350 feet.

Log. of 1350 feet	3.130334
	2
	6.260668
Add arithmetical complement of the log. of the diameter of the earth..	2.378861
Log. of .04361 feet	8.639529

But our preceding observations have been made without regard to what is termed "refraction," which is an optical deception, causing the position of an object to appear *higher* than it really is, except it be situated in the zenith. This "optical deception" is caused by the *density* of the atmosphere, which increasing as it approaches the surface of the earth, bends or refracts any

* The arithmetical complement of a logarithm, is what the logarithm wants of 10.00000, &c., and the easiest way to find it is, beginning at the left hand to subtract every figure from 9 and the last from 10. Thus the diameter of the earth is 41,796480 feet, the log. of which, 7.621139, subtracted from 10.00000, &c. gives 2.378861, the arithmetical complement.

particle of light falling obliquely on it, more and more towards the perpendicular as it approaches the surface; consequently, the rays proceeding from any object describe a curved track, concave to the earth's exterior.* Every object invariably appears to lie in the direction of a tangent to such curved track at the point of observation, except, as we have before observed, it is situated in the zenith, when it is wholly free from refraction;—but, when situated near the horizon, refraction is at its maximum. Perhaps this matter will be rendered more plain by the aid of the following diagram.



Suppose A B to be a portion of the earth's surface, G H the upper boundary of the atmosphere, S a star, P the place of the observer, and Z, his zenith; C D, E F, and G H, are assumed boundaries of the strata of the atmosphere, each of different density. A ray of light then proceeding from S, and impinging on the atmosphere at K,—where it encounters a denser medium than in its pre-

* The rays are occasionally affected in an extraordinary manner, sometimes laterally and at other times convex to the earth's surface instead of concave,—whereby objects have appeared depressed instead of elevated. Sometimes it has also been observed that the rays were affected in both ways at the same time, (*i. e.* elevated and depressed) appearing double, with one image erect and the other inverted; but this only occurs when the observed object is near the horizon and under peculiar circumstances of the atmosphere. In the account of the Trigonometrical Survey of England, a case of this kind is mentioned. "In measuring the base on Hounslow Heath—observes the narrator—we had driven into the ground at the distance of 100 feet from each other about 30 pickets, so that their heads appeared through the *boning* telescope to be in a right line; this was done in the afternoon. The following morning proved uncommonly dewy, and the sun shone bright, when having occasion to replace the telescope, we remarked that the heads of the pickets exhibited a curve, *concave upwards*, the farthermost picket rising the highest, and we concluded that they were not properly driven till the afternoon, when we found that the curved appearance was lost, and the ebullition in the air had subsided."

vious path, will be deflected in the direction K L; at L entering a still denser medium, it will be further deflected in the direction L M; similar effects taking place throughout its path, until at length it enters the eye of the observer at P, in the direction M P. The ray whose path we have just traced, is therefore not a straight line, but broken into numerous parts; and if we suppose the several degrees of density which we have assumed the atmosphere to be composed of, to be indefinitely increased, the path of the ray may be considered as curvilineal; its course would then be represented by the dotted line S B P, concave towards the earth's surface, and it would enter the eye of an observer in the direction of a tangent to that curve. The star S, would therefore appear to be at S′, and the angle S′ P S, would represent the refraction. Precisely similar results take place with regard to the rays of light by which terrestrial objects are rendered visible, only that the refraction is greater, consequent on the rays passing more obliquely through the denser portion of atmosphere.

The form and magnitude of the curved track described by a ray of light in its passage through the atmosphere, has been a subject of investigation with numerous scientific men; but as it varies with every state of the atmosphere, results obtained at one time can be rarely if ever applied at another, with any regard to accuracy; it may, however, be considered of regular inflexure, in form approaching an arc of a circle, and in all cases may be estimated either in terms of the curvature, or of the horizontal angle,—termed the arc of distance. When the atmosphere is in a *mean* state it may be estimated in the former case at $\frac{1}{7}$th of the curvature, and in the latter, at $\frac{1}{12}$th of the arc of distance, or angle subtended at the earth's centre. But in all extensive geodesical operations,* where the effect of refraction requires to be estimated; contemporaneous angles should be observed from either station, and the necessary corrections computed.† The variation in refraction which is observed in the atmosphere at different times, is generally produced by changes of temperature; cold condensing the air and increasing the refraction, while heat expands or rarefies the air—diminishing refraction. From this cause refraction is greater in cold than in warm weather; consequently it is less in the evening than in the morning, except under peculiar circumstances. Humidity of the air is *said* not to produce any sensible effect on its refractive power.

The correction for curvature and refraction we have computed and appended in the form of a table at the end of our treatise;—that for refraction being taken for the *mean* state of the atmosphere or $\frac{1}{7}$th of the curvature.

The examples which we gave of the effect of curvature at pages 4 and 5 in depressing the position of an object, will therefore be modified by the effect of refraction. The first example will therefore stand thus:—

Computed amount of curvature................	16.6750	Feet.
Deduct for refraction $\frac{1}{7}$th of curvature..........	2.3821	
	14.2929	
Add height of instrument above surface as before	4.5000	
True difference of level	18.7929	Feet.

* The effect of *ordinary* refraction is to alter the place of an object in a *vertical* plane, but it does not affect the azimuth;—therefore in geodesical operations where the sides of the triangles are not sufficiently large as to require to be treated as spherical triangles, or the heights of the trigonometrical points are not required, both refraction and curvature may be altogether neglected.

† For the method of computing this correction, consult Vol. I. "Trigonometrical Survey of England," Lieut. Frome's "Outlines of Trigonometrical Survey," or Woodhouse's "Trigonometry."