X. *An Account of Operations carried on for ascertaining the Difference of Level between the River Thames at London Bridge and the Sea; and also for determining the Height above the Level of the Sea, &c. of intermediate Points passed over between Sheerness and London Bridge. By* John Augustus Lloyd, *Esq. F.R.S. F.R.G.S. & F.S.A.*

Read March 3, 1831.

In February 1830, at the suggestion of the Royal Society, I had the honour to receive directions from the Lords Commissioners of the Admiralty to make such observations as I might consider necessary, to ascertain the difference, if any, between the level of the waters at certain points on the river Thames, and the mean level of the sea near Sheerness, as well as the height of different intermediate points above the sea, such as Gravesend, Greenwich Observatory, &c.

Having found, while employed in the Isthmus of Darien, how inadequate the present levelling instruments were to obtain very accurate results, and being desirous of conducting the interesting observations, I now had orders to make, with the most scrupulous exactness, I thought it necessary, in the first instance, to bestow some attention to the improvement of the instruments required to be used, endeavouring to combine superior steadiness and motion in azimuth, more delicacy in the level itself, more permanency in its position, and greater power in the telescope.

After several trials, and by the assistance of Mr. Cary, (to whom I am indebted for many valuable suggestions,) I determined upon having an instrument made exactly after the accompanying Plate.

Fig. 1. is a perspective view of the instrument. It is supported by three foot-screws, similar to those used in the best altitude and azimuth circles, with thirty threads to an inch, and serving to place the instrument horizontal.

The stand is formed by two plates of brass, which are firmly connected together by three pillars. To the limb that carries the telescope, in very substantial Ys, is fixed the inner conical centre, three inches in diameter and eight in length, ground to move perfectly smooth in the hollow conical centre fixed to the stand.

This limb projects over the upper part of the frame about one inch, and is bevelled at the edge, in order to slide in a groove attached in two pieces to a clamp, screwed underneath the upper part of the frame, and which, by means of a tangent screw, gives a slow motion in azimuth to the limb. This limb, having two solid projections, allows the Ys being at some distance over the periphery of the circle, by which means the supports to the telescope are nearer its extremities. One of these Ys has a short vertical motion, with a pushing screw at the side, which fixes it at any height required. The telescope itself is of thirty inches focal length, and magnifies about twenty-two times, having two thick gun-metal collars, by which the telescope rests on and is turned in the Ys. These were quickly worn by the continued friction from the supporting part of the Ys, and would have caused an error in using the instrument; I therefore had small thick steel plates, highly polished and hardened, dovetailed into each supporting part of the Ys. The friction on the collars was now transferred to the pieces of steel; and although they likewise continually wear, it does not affect the correctness of the instrument in any other way, than in altering the adjustment of one of the Ys. (See page 20.)

At the eye end of the telescope is an adjustment with a rack and pinion, for distinct vision, and another by the same means to regulate the distance of the eye from the wires: this I found to be indispensable, as the eye occasionally becomes fatigued, and requires a different focus to view the wires distinctly.

The wires themselves are adjusted as usual, by a sliding piece for azimuth, and two pushing screws for vertical motion.

In the centre of the telescope there are two orifices opposite one another; the one to receive a small lamp, and the other admitting a spindle and speculum at the end, ground to an angle of 45°, which, by reflection, illuminates the wires for night observation. The speculum being made to turn, the quantity of reflected light may be regulated at pleasure.

As the glass would not admit of distinct vision for objects at a less distance than one hundred feet, and it being necessary to use the instrument, at times, not more than three feet distance from the station-staff, several lenses were made of different focal distances, as sixty, thirty, fifteen, eight feet, and thirty inches; which, being applied to the object end of the telescope, converts it, in fact, to a microscope.

To the lower part of the telescope, within the collars, are affixed the cocks, into which fits the tube protecting the level: one of these cocks gives a vertical, and the other a horizontal motion to the tube, in order to place the level parallel to the axis of the telescope.

When the instrument was first made, these motions were effected by means of endless screws; but I found it so difficult (almost impossible) to keep a delicate level in adjustment by this mode, that I substituted the old fashion of capstan-headed pushing screws.

To the upper part of the telescope are attached (outside either points of support) cocks* or braces, carrying a swinging level, having, as well as the cocks, separate adjustments.

This additional level was intended as a check to the lower level, and to detect any occasional variation in the figure of the tube itself.

The glass bubbles themselves were placed in the tubes at first with paper, and wedged at either end with small pieces of wood; but the wedges are liable to distort the bubble itself, and after some time get loose in the tube; and the level alters in its position, and is never to be depended on. I found it better to push the level into its proper place in the tube, not tightly, and with paper underneath, taking care that the paper touches the middle part, and then filling up the two ends with plaster of Paris.

To the upper part of the telescope, near the eye-piece, is fixed a small level, adjusted to the horizontal wire of the telescope, and by the assistance of which the same surface of the large level is used at each observation. There is also another small level at the other end of the telescope, to adjust the vertical wire by, but of less use than the former.

On the upper limb, near one of the Ys, is fixed a small thermometer, with the bubble inclining downwards, at an angle of about 10°, the use of which will be explained hereafter.

The large stand of this instrument is made with a solid top of African oak.

* These cocks are not shown in the Plate.

The legs, which are very strong, are iron-shod, and braced at the bottom, about six inches from the shoeing, with three thick iron rods, rendering the whole steady, and affording the men a purchase to press down with their feet, and rough level the stand ready for the reception of the instrument.

Adjustments.

The above instrument requires several adjustments, which I shall endeavour to describe in the order they are made.

First, To make the lower level parallel to the axis of the telescope :

Place the telescope directly over one of the foot-screws, and clamp it; then bring the bubble of the level, by means of the foot-screw, to the same division on either side the graduated scale affixed to and over the level, taking care that the bubble of the little level at the eye end of the tube (and at right angles to the large level) is in the centre; then reverse the telescope in its collars, observing if the bubble reaches to the same division, and correct one half of that number by the pushing screws on the level itself, and the other half by the foot-screw: this must be repeated until the bubble remains in the same spot.

Second, To place the large level in the same vertical as the axis of the telescope:

Move the telescope in its collars until the level is brought considerably to one side, and observe if the bubble still remains at the same division; if not, move the side pushing screws on the level, until the bubble has returned to its proper place; move the telescope again as much to the other side, and observe if the bubble comes to the same division; if not, it must be re-adjusted, until it is as near as the accuracy of the grinding of the level will allow.

These two adjustments are naturally dependent on one another, therefore they must be both examined, until no alteration in the bubble can be perceived.

Note.—As the collars may wear a little hollow in time, care must be taken that one particular shoulder of the two collars rests against the Y when reversed, in order to use the same point of support.

Third, To place the axis of the telescope parallel to the plane of the instrument:

Loosen now the clamp which confines the telescope over the foot-screw, and adjust the bubble exactly to the centre; bring the telescope and limb half round on its conical centre, and observe the bubble; half the number of divisions, in error on the scale, must be corrected by the foot-screw, and the other half by the vertical motion to the Y, securing it, when it is sufficiently adjusted, by the little side screw.

Fourth, To place the vertical and horizontal wires at right angles, and to connect them with the little levels on the telescope:

Place one of the station-staves about five feet from the ground in a horizontal position (by means of a small hand level and two nails); from the centre thereof, suspend a white plumb-line; adjust the vertical wire to the horizontal one, by loosening the two screws, which admit of its moving diagonally, and making them coincide with the surface of the staff and the plumb-line; then by loosening the screws of the small level at the eye end, move it until the bubble rests in the centre, reverse the position of the wires, making the vertical horizontal, and adjust in the same manner the other little level.

Fifth, To make the hanging level parallel to the plane of the instrument:

Adjust by the foot-screw, until the bubble of the lower level is in its position; then observe the variation of the riding level, and alter it one half the error by the vertical screw on the cock, and the other half by the pushing screws on the riding level itself.

Or, By the foot-screw, bring the bubble of the hanging level in the centre; then reverse it on the cocks; one half the difference is to be altered by means of the adjustment on the level itself, and one half by the foot-screw: now place the lower level perfectly horizontal, and by the vertical screw on the cock, bring the bubble of the hanging level to correspond.

The usual adjustment for collimation is here purposely omitted. The eye tube of the telescope altering continually in its position, renders it most difficult to make this adjustment correctly; for although it may be found in perfect adjustment for a distant object, when directed to a near one there will be a considerable error, which would affect the results in levelling, if the station-staves were not equidistant from the instrument.

To avoid this inconvenience therefore, as well as to avert the difficulty of placing the extra lenses for short distances, so as not to alter the line of collimation, I permitted the wires to be some distance from the axis of the telescope; and, in levelling, a mean of four or six observations were taken, with the telescope turned half round in its collars at each observation.

Note.—I take this opportunity of mentioning a substitute I have occasionally used for wire or cobweb with success, viz. asbestus; very fine fibres of which can be obtained by being thrown into hot water, when it easily divides. These fibres are tough enough to be placed with ease on the diaphragm, and have the advantage of being opaque.

Being now in possession of an instrument equal to perform the most delicate observations, my next object was to make some improvement in the station-staves, so that they might point out as minute a quantity as the instrument could detect a difference of. This was something difficult, without encroaching on the portability and quick application of the staff to its use.—The following is a description of the staves I used, a Plate of which is given.

The staff itself is a rod of six feet six inches in length, of solid seasoned mahogany on the face of which is let-in a slip of brass, riveted at intervals from end to end; by the side of this is also a slip of holly, fixed in the same manner. The divisions are laid down in feet and tenths, on the holly; and in feet, tenths and hundredths, on the brass. The lower part of the staff is fitted into a square tube of brass about eight inches long, four inches of which are occupied by the staff, and the remainder filled up with lead.

The vane is a plane of seasoned holly, with two semicircles of stained ivory let into the face of it (see Plate). It is fixed by screws to a brass box with tightening springs on the staff itself: there is another small slide on the staff, having two clamping screws, and a long tangent screw, which is attached to the box of the vane by a female screw; the last gives a slow vertical motion to the vane.

On the top of this vane, and at right angles to one another, are two small spirit-levels, mounted in brass; affixed to the vane, in a square hole in the centre, and levelled on one side, is a small brass vernier, the edge of which slides on the divisions of the staff reading to the 1000dth, and, by practice, to the 10,000dth of a foot.

The station-staff thus described is in itself complete; but for accurate observation it requires to be immoveable on the picket: a three-legged support is therefore added, having a box and ring with double compass gimbles, and a horizontal motion; into this the staff slides.

There is also a small brass tripod with iron legs, having a hole in the centre plate, over which another small plate slides, fixing to the tripod by two clamping screws; this is used to confine the bottom of the station-staff over the picket.

Adjustment.

The only adjustment required to this instrument, is to enable it to be placed vertically over the picket.

Slide the staff into the piece carrying the gimbles; suspend it with the gimbles as nearly as possible at right angles, and as distant as conveniently may be from the ground. When the staff does not oscillate, observe if the two bubbles on the vane are correct; if not, by means of the small screws at either end raise or depress them, until the bubble remains in the centre.

Having now the means of placing the staff immoveably and vertically over a spot, it is to be accomplished as follows: Fix the support that carries the staff, as nearly as possible over the required spot; pushing the legs into the ground, place the small tripod as shown in the Plate, unclamp the milled heads, and pass the staff through the gimbles of the support into the plate of the tripod. As this plate will move in any direction horizontally, the staff is to be adjusted, until perfectly upright, by means of the levels on the vane; then clamp the plate firmly, and push the staff down to the head of the picket, and turn it until it is directly in front of the level.

In March 1830, having every thing prepared, I departed for Sheerness, determining to commence my observations at that point.

As part of the main object of my commission was to ascertain the height of different places above the level of the sea, it was necessary to endeavour to determine that point with accuracy. From the observations made from time to time, at the caisson at Sheerness Dock Yard, of high and low water, I could only obtain this point within a certain degree of accuracy. I therefore determined to take advantage of the permission granted me by the Admiralty, to commence the erection of a tide-gauge at the Dock Yard. Accordingly, after having a model made on a principle that I hoped would be the most simple and yet the most accurate, I examined the whole of the front of the Dock Yard, and selected the corner of the boat basin adjoining the ordnance basin, as the only spot indeed at all eligible for the erection of a tide-gauge. (The spot is shown on the plan of the Yard.)

By the friendly and prompt assistance of His Majesty's Commissioner at the Dock Yard (J. LEWIS, Esq.), I was enabled to have my tide-gauge quickly and substantially erected, under the excellent superintendence of Mr. MITCHELL, the master millwright at the Yard.

Description of the Tide-Gauge.

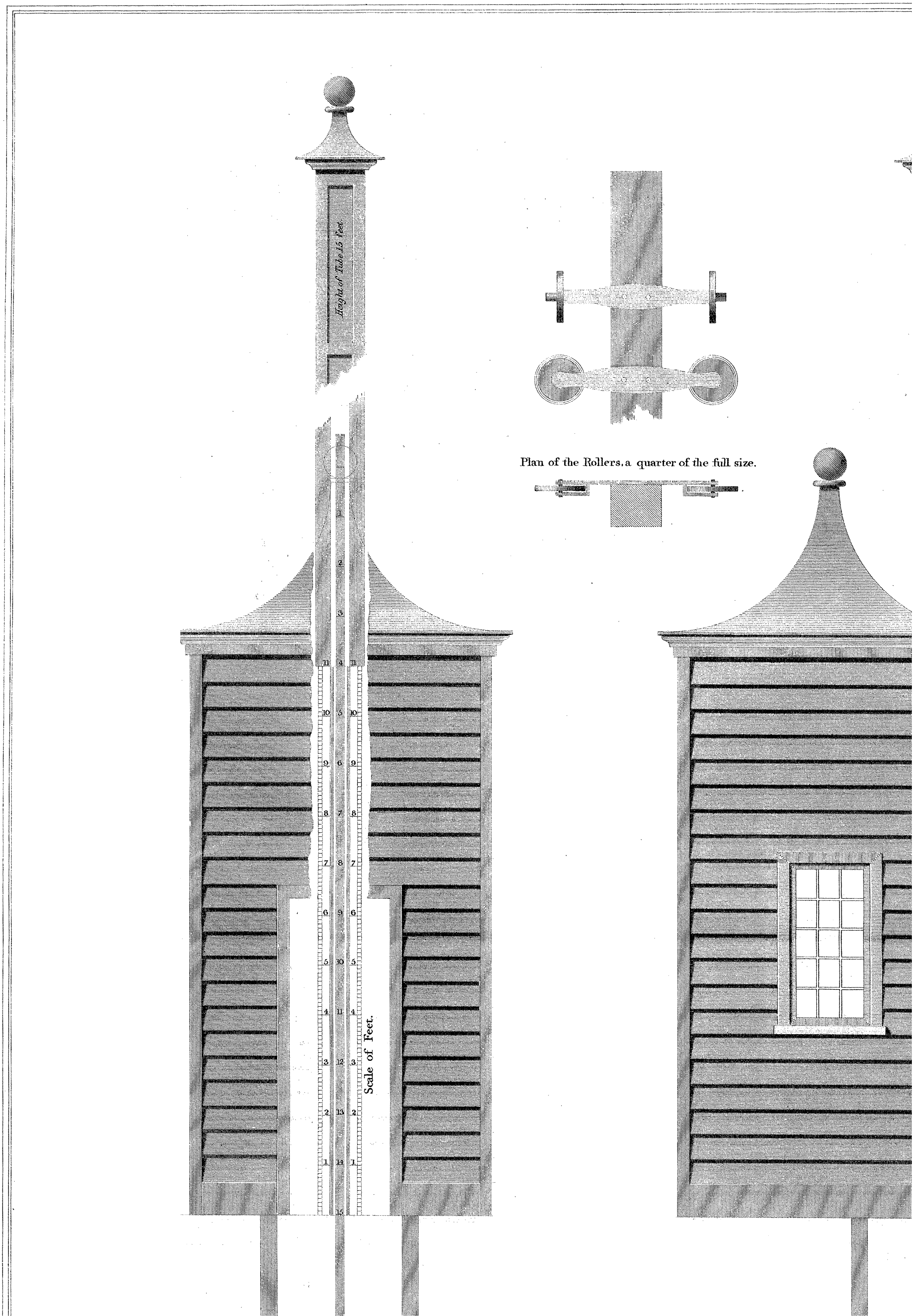
The model is on a scale of three quarters of an inch to a foot.* The flat board on which the house stands, represents the Wharf at Sheerness; it is made long at the back, and balanced so as to be placed on a table, to show the trunk in the actual position of the gauge. The top or cap to the covering of the staff is left unfixed, in order to be taken off, and allow the house to be lifted over it, and show the gauge alone.

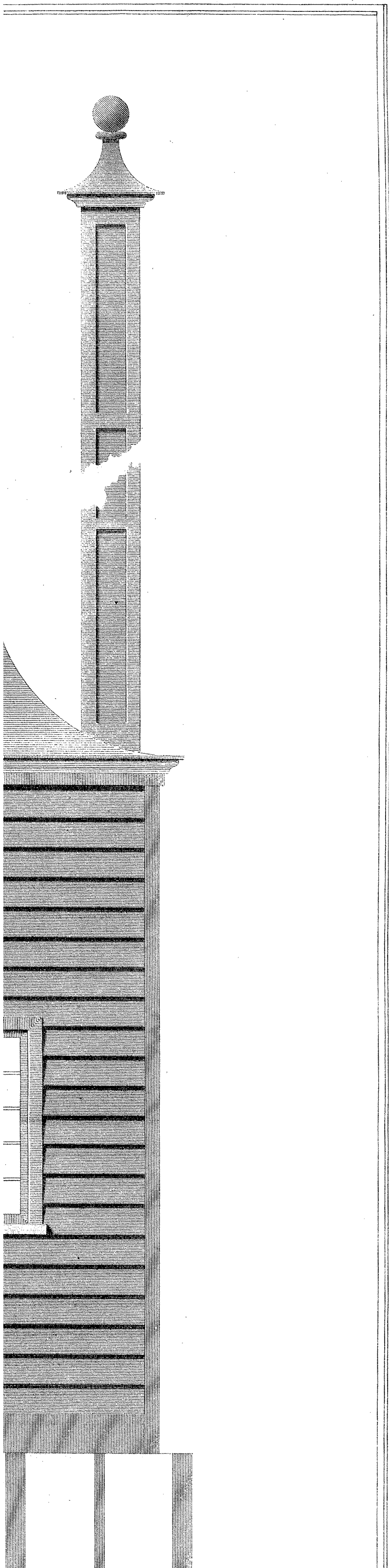
The slide rods in the model are of iron wire, and out of proportion; but no smaller was at that time to be found in the Dock Yard; in the original they are $\frac{7}{8}$ copper bolts.

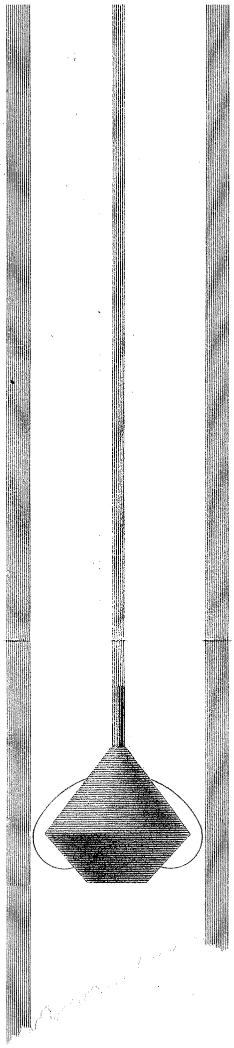
The slides or pointers have springs to tighten them to the rods, but they are too minute to act in the model. The lower end of the tube in the model is nearly filled up with wood, in order to secure it to the trunk, leaving only a part for the gauge-rod to pass; but in the original the tube is left open below, there being sufficient strength in the timber to allow of its being bolted to the trunk and platform. There are three small friction-wheels at the upper end of the rod, to steady it.

There is a distance of fifteen feet between the top catch or point on the rod which brings the slide down to indicate low water, and the point on the middle of the rod which takes the other slide up to indicate high water. Therefore allowing an eighteen-feet tide, the top catch will bring the slide down to four on the index, and the middle catch on the rod will raise the slide to seven on the other index, the difference of which, three added to fifteen (the length between the points), gives eighteen. Therefore it will be observed that the dif-

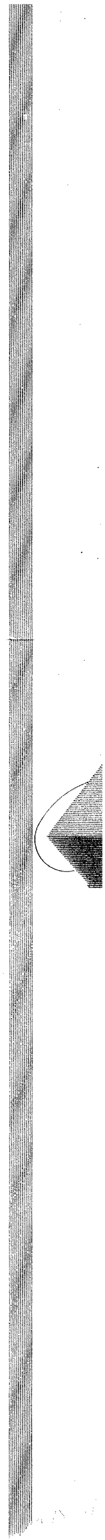
* The model is deposited at the Royal Society's Apartments in Somerset House.

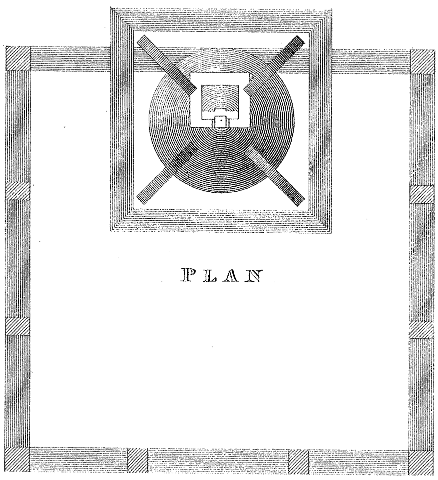

Height of Tube 15 feet.
Plan of the Rollers, a quarter of the full size.
Scale of Feet.





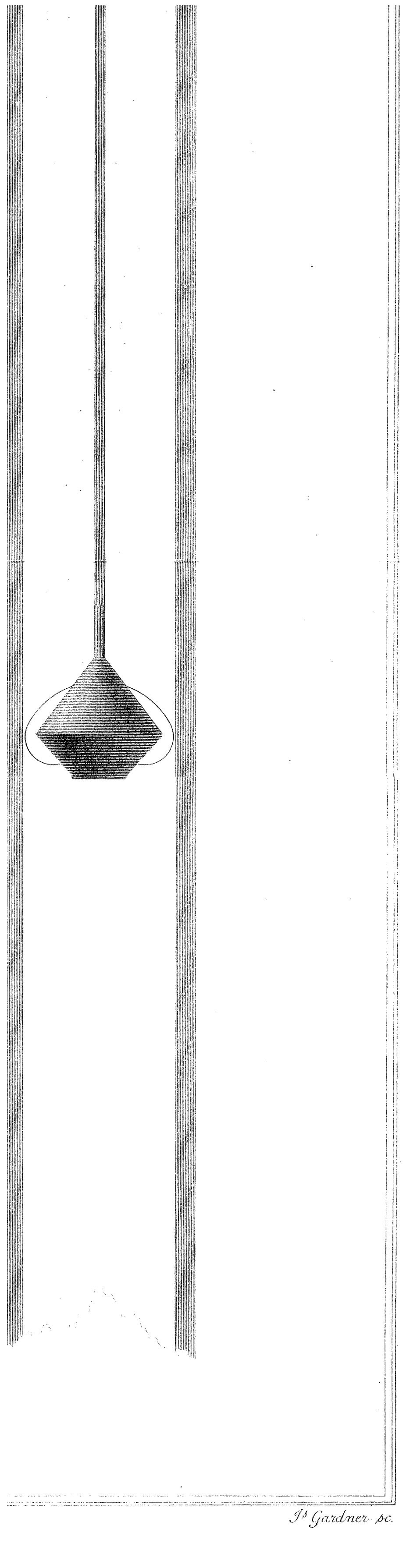
PLAN AND ELEVATION
of the
TIDE GAUGE
at
H. M. DOCK YARD
SHEERNESS,
and at
PORTSMOUTH.





PLAN

Scale $\frac{3}{4}$ of an Inch to 2 Feet.



Jˢ Gardner sc.

ference between the slides is always to be added or subtracted, to or from the length between the points on the rod. The divisions on either index are continued from 0 feet to 11 feet, to allow for any extraordinary tides. The little brass standard in front of the tide-gauge, and about six or eight feet from it, has been connected with it; therefore the height of any particular tide above the standard is easily found, knowing the exact distance from the middle catch to the line of immersion (which is registered). For example: Let the distance from the centre catch or point, to the line of immersion be 12.444, and the face of the brass standard on a level with 0.747 of the indices; and that high water carries the pointer to 6.546 on the index, then $12.444-(6.546-0.747) = 5.151$, the height of that particular tide below the standard. Again, assuming 4.328, as pointed on the index by the upper catch for low water, then $15+12.444-(4.328-0.747)=23.863$, the height of standard above that of low water. The difference between the two, gives 18.712 for the rise and fall of the tide.

Many interesting observations may also be made by the same instrument on the irregular rise and fall of the tides, as there is an excellent clock within the house, and I believe an index connected with a weathercock on the outside.

The trunk of the gauge is substantially fixed between large piles, driven in for the purpose, and the whole partitioned off to low-water mark, to render the gauge secure from boats or vessels*.

My next object was to select a standard mark, from whence to commence my levelling, and to form a zero point.

I made examinations of the Dock Yard in different parts, particularly that part facing the Medway. I at first fixed on the northern part of the Dock Yard wall adjoining the garrison; but upon due inquiry I found that part was not considered so good a foundation, being built on piles driven in at some distance from one another, and to no great depth. Wishing, however, to shorten the distance between my zero point and the long level I should have to take across the Medway to the Isle of Grain, and desirous of having the

* This tide-gauge is on the same principle as that mentioned by Mr. Lubbock in the Companion to the British Almanac.

standard in the vicinity of the tide-gauge, so that future observations might be easily connected with the standard, I selected a large block of granite in the southern pier of the entrance to the boat basin, the position of which is shown in the plan of the Yard. I caused a block of gun-metal (cast for the purpose), two inches and a half square and eight inches long, to be sunk in the centre of the granite, about an inch below the surface, thereby allowing a brass box and cover to be placed over the standard, to protect it from injury.

In order that there should be a sufficient number of checks to the stability of this standard mark, I caused three more to be placed in the Yard; viz. one near the southern extremity on the wall of the Dock Yard, one at the eastern side of the great basin, and one in a large block of stone resting on the brick-work of the navy well 330 feet deep.

But however satisfied I might be that these standards were sufficiently firm, I thought it advisable to seek some spot more unquestionable in its foundation than Sheerness Dock Yard. I found a place that possessed this advantage; it was a slight eminence about two miles and a half to the southward of the Dock Yard, and surrounded by a moat.

On this eminence formerly stood the old castle of Queenborough, within a short distance of the present town of Queenborough. The castle, which was in the form of a pentagon, was some years ago pulled down, but a very small part of the foundation was left. On this foundation, which is rubble and chalk, some feet under the surface a very large block of granite was placed for me, by order of the commanding officer of engineers, and into which was let one of the brass standards. The place is now covered over, but marked by a small mound of earth near it, and reference can be easily made to it if required.

Having now standard marks enough to ensure, by comparison, the knowledge of any alteration (if any should occur) in the zero point, I commenced levelling.

My first business was to ascertain the difference of the several standards in the Dock Yard above the level of the sea.

From a series of observations made at the caisson at the entrance to the great basin, in the years 1827, 1828, 1829, the mean of the tides was as follows:

Mean high water spring tide for	1827, 26.475	Low water 8.700	Mean 17.587
Do. . . . do. . . .	1828, 26.50	. do. . 8.61	do. 17.55
Do. . . . do. . . .	1829, 26.09	. do. . 8.93	do. 17.51
Means . .	26.355	. do. . 8.74	do. 17.549
High water neap tides . . .	1827, 22.56	. do. . 11.12	do. 16.84
Do. . . . do. . . .	1828, 22.69	. do. . 11.44	do. 17.06
Do. . . . do. . . .	1829, 22.72	. do. . 11.45	do. 17.08
Means . .	22.656	. do. . 11.336	do. 16.993

Mean for the three years.

Spring tide high water,	26.355	Spring low .	8.74	Mean level	17.549
Neap tide do. . .	22.656	Neap low .	11.336	. do. .	16.993
Means . .	24.50		10.03		17.27

As there are many blanks in the three years' observations that these were taken from, I have also selected the most perfect year (1827), and taken the mean of all the tides for each month in the year.

The following is the

Summary.

January,	Mean high water	24.78	Mean low	10.20	Mean level	17.49
February . .	do. . .	24.08	. do. .	10.00	. do. .	17.04
March . . .	do. . .	24.70	. do. .	9.60	. do. .	17.15
April	do. . .	24.25	. do. .	9.90	. do. .	17.07
May	do. . .	24.35	. do. .	10.35	. do. .	17.35
June	do. . .	24.31	. do. .	10.29	. do. .	17.20
July	do. . .	24.39	. do. .	10.16	. do. .	17.27
August . . .	do. . .	24.39	. do. .	10.26	. do. .	17.32
September . .	do. . .	24.29	. do. .	10.00	. do. .	17.14
October . .	do. . .	24.79	. do. .	9.66	. do. .	17.22
November . .	do. . .	24.65	. do. .	9.90	. do. .	17.27
December . .	do. . .	24.53	. do. .	9.62	. do. .	17.27
Means . .		24.46		9.995		17.23

These results agree so very nearly, that they may be safely taken as correct. I have given them at length, to afford the data for finding the true level of the sea. It will be seen that the mean level taken from spring tides differs 0.556 *from the mean level deduced from* neap tides. I shall, however, assume the mean level as 17.27, differing only 0.04 from the same of the whole year's observations of 1827.

At the north-western end of the caisson I caused a small cross (+) to be cut in the granite, which corresponded exactly with the XXXI feet of the indices cut in the masonry at the side of the caisson. This cross is situated as follows, with regard to the standard marks in the yard. (See page 3 of Levelling Book.)

The northern standard, which is my zero point, is 0.5789 below the cross. The southern standard at the other end of the Dock Yard wall is 0.0259 above the cross; therefore $0.0259 + 0.5789 = 0.6048$ gives the height of the south standard above the northern one, although they are set equally beneath the surface of the granite.

The standard at the eastern edge of the great basin is 0.6735 above the northern, and $0.6735 - 0.6048 = 0.0687$ above the southern standard, and $0.6735 - 0.5789 = 0.0946$ above the +.

The standard at the navy well is 6.0656 below eastern standard.
5.9968 below south standard.
5.3920 below north standard.
and *5.9710 below the cross.

Now, the mean level of the sea being 17.27 feet, the + or XXXI feet of the indices is 13.73 above the mean level of the sea, and 4.645 above the mean spring tide high-water mark. And

North standard or zero is .	$13.73-0.5789=13.1511$	above the level of the sea, and	4.0661		above spring tide high-water mark.
South do .	$13.73+0.0259=13.7559$	. . . do.	4.6709		. . do.
East do .	$13.73+0.0946=13.8246$	. . . do.	4.7396		. . do.
Navy well .	$13.73-5.9710=7.7590$	. . . do.	4.3260	below	do.
Tide-gauge standard .	$13.73-0.0946=13.6354$	. . . do.	4.5504	above	do.

* In page 4 of Levellings there will be observed a difference of 0.0001 in the two sets of levels, the first set taken in March, the last in June.

Having now completed this part of my observations, I levelled from the Dock Yard to Queenborough:—the result of the operation will be seen in pages 1 and 2 of the Levelling Book. And it will be there observed, that between the levels and proofs there is a difference (in a distance of nearly three miles) of 0.0269 about $\frac{3}{8}$ths of an inch. In the commencement of my commission I had a new instrument, and many little difficulties to overcome. In part of the Queenborough observations, I made use of another level which I had from TROUGHTON, on a different principle to the one by CAREY; and in page 3 of the rough Levelling Book, an observation is there made on the difficulty I had in getting the level to adjust, from the fault I have mentioned in my remarks, of the bubble having been placed in its tube with only a little paper, and becoming loose.

I used also my large instrument with a level adapted to it, made by RIECHENBACH, which was lent me by Captain SABINE. It was of a large diameter, and ground most accurately, but not hermetically sealed, having two plates of glass ground in to the ends. It was exceedingly delicate, but at any considerable motion, the bubble would break into many globules, requiring a long time to collect again. The second day I used it in the marshes the day was hot, and I had not at that time the means of shading it from the sun; the bubble, while observing, suddenly contracted, and almost immediately disappeared. I threw some water on the instrument, and the bubble gradually appeared again, but much lengthened. The next day I placed the level in the sun with a thermometer; when at 68° the end was forced out, and I found it contained ether, which appears to be quite unfit for a level in a high temperature. For future observations I replaced it by one of CARY's make.

The mean of the observations give as follows:—Queenborough standard is higher than southern standard 9.9981, and 10.6029 higher than northern standard; and 14.6690 above spring tide high-water mark, and 23.7540 above the mean level of the sea.

Having driven a large picket into the embankment at the Isle of Grain, at a point the shortest distance I could obtain from the north standard (viz. about 5000 feet), across the Medway, I now commenced the observations necessary to ascertain the difference of level between the zero or north standard, and the picket at the Isle of Grain. One instrument was placed near the standard mark, and the other on the Isle of Grain, about fifty feet from the picket.

Between the high-water mark at the Isle of Grain and the standard at Sheerness, there is a long ledge or bank of mud, extending nearly half a mile, and quite dry at low water. At these times I found it very difficult to make observations, and together with the wind occasionally interfering, and the interruption from the sun's rays, which caused a great vibration in the atmosphere, I spent day after day uselessly waiting at the instrument. I was, however, more successful afterwards, by taking advantage of the first hour or two of day-light, which was more favourable for observation, as the wind had generally lulled, and the air was in a quiescent state.

After the instruments were in perfect adjustment, an observation was made at each side of the river alternately; first by myself at Sheerness, and then by my assistant at Grain. A mean of a considerable number was taken, the difference of which, after the curvature was subtracted from each, would give the refraction, provided the instruments were in good adjustment, and the observations correctly taken. (See page 5 of Levellings.)

Not being satisfied with the observations made at my first visit to Sheerness, I returned at a subsequent period, and made a great number most satisfactorily, from which the best were selected, and a mean taken.

As there was not a fit place for a standard mark near the margin of the river Medway, I caused a block of granite, about 900lbs. weight, to be placed on the foundation of the old church wall (the church was once much larger) of St. James, near the porch-door, into which block was sunk one of the brass standards. (See page 6 and 8.)

The face of this standard is 28.7454 feet above the north standard mark; 32.8115 above spring tide high-water mark, and 41.8965 above the mean level of the sea.

From St. James I almost immediately came into the marshes, levelling in a direct line towards Yantlet Creek. In consulting the Ordnance map of Kent, there appear but two or three ditches in the marshes; but in a distance of less than three miles I passed thirty-three dykes and ditches, from fifteen to twenty-five feet broad, and four or five deep, over which there is no mode of passing, but a bridge perhaps a mile distant.

It was desirable therefore to find some means of conveying my instruments, men and apparatus over, without losing so much time by going round. The men first used leaping-poles; and a case for the instrument was constructed water-tight, so as to swim over the ditches. But from the sides of the ditches being steep, the instrument was constantly subject to heavy blows in being taken out of the water; I therefore adopted another mode. On our arrival at a broad ditch, two leaping-poles, about eighteen feet in length, with cross pieces at the bottom to prevent their sliding too far in the mud, were connected together at the top by passing the eye of a rope just over the ends of them, where it was confined by two thumb-cleets; to this rope was attached, at any height that the depth of the ditch might require, a hook having four tails, and likewise hooks to them; these fixed into the four arms of the box, through which slid the poles for carrying it. The ends of the two leaping-poles were merely placed in the centre of the ditch, forming a pair of sheers, the apex of which was inclined on one side or the other by guys. The instrument was in this manner taken from one bank and landed on the other with the greatest gentleness; it was quickly unhooked, and men and apparatus passed over in the same manner. In this mode 263 ditches were passed between Sheerness and Greenwich.

On my arrival at the marshes, I found, from the nature of the soil, the greatest difficulty in adjusting the instruments; the movement of any of the men at a considerable distance caused a motion in the bubble, and the least alteration in my position whilst standing at the instrument shifted the bubble. In order to avoid moving, which heretofore was necessary to examine the level, I caused a square mirror, about eight inches by five, to be mounted on a mahogany frame, which permitted it to stand on the upper limb with the face placed at an angle of about 60° from the telescope, by which I could, without moving my head from the eye end of the telescope, read off the length of the bubble. This precaution was not however sufficient in some parts of the marshes, where the ground was of hardly more consistence than a bog, but invariably most unsubstantial where the most dry.

At these places, large pickets, from four to six feet in length, were driven in, having a groove on the iron head of each. On three of these, the iron-shod points of the stand rested; and after the observations were made, the pickets were drawn.

The pickets used for the stations were also of a larger class than those used in other parts; but the ground was occasionally so spongy, that it was with much difficulty that a picket could be driven, and frequently the iron heads of several would break off, before we could succeed in getting one down.

It will be seen by the Observation-book, that from a mean of pickets (page 5 to 11), the Queenborough and Sheerness marshes are in some parts 6.3652 below the northern standard; but these marshes are unlike the rest passed over, being particularly rugged and undulating.

In the commencement of the marshes between St. James and Yantlet Creek, it appears by a mean from picket 11 to 17, that the surface of the marshes is 5.8524 below the standard, or 1.7863 below mean spring tide high-water mark; and opposite Allhallows, by a mean from picket 35 to 44, the marshes are 3.7247 below the north standard, rising there $5.8524-3.7247=2.1277$.

About half a mile past the Decoy in St. Mary's marshes, nine miles distant from Sheerness, the marshes again fall: the mean from picket 75 to 86 gives 5.9916 below the north standard at Sheerness, and $5.9916-4.0661=1.9255$ below mean spring tide high-water mark.

Some distance past Cliff Canal, and between that and the Gravesend Canal, in Higham marshes, by a mean from 120 to 124, the surface is 6.6356 below the north standard, which -4.0661 gives 2.5695 below spring tide high-water mark, having fallen in a distance of seven miles and a half 2.9109, and in a distance of five miles 0.6440; the marshes between Northfleet and Greenhithe, by a mean from picket 208 to 211, are 7.4889 below the north standard, and $-4.0661=3.4228$ below spring tide high-water mark.

On the eastern side of Dartford Creek, the marshes, by a mean from picket 247 to 252, are 8.8676 below the north standard, therefore $8.8676-4.0661=4.8015$ below spring tide high-water mark.

On the western side of the marshes, as far as the mean from picket 256 to 259 will show, the marshes are 9.7207 below the north standard, and 5.6546 below spring tide high-water mark, and lower by 0.8531 than the marshes on the eastern side of Dartford Creek.

The marshes to the eastward, and in the immediate vicinity of the arsenal at Woolwich, are (from a mean of pickets 305 to 312) 10.1404 below north standard, and 6.0743 below spring tide high-water mark, and only 3.0107 above the mean level of the sea.

The only remaining pickets that were directly in the marshes, are from 347 to 352, the mean of which gives 9.6321 below north standard, and 5.5660 below spring tide high-water mark.

The following therefore is a statement of the depression of the marshes, from Sheerness towards the source of the Thames.

The Yantlet Creek marshes are 0.5128 higher than the Sheerness marshes.

The Allhallows marshes, in a distance of three miles, are 2.1277 higher than the Yantlet Creek, and 2.6405 higher than the Sheerness marshes.

The St. Mary's marshes are 0.1392 lower than the Yantlet Creek marshes, and 2.2669 below the Allhallows marshes, having fallen that quantity in a distance of three miles.

The Higham marshes are lower than those of Yantlet Creek by 0.7832, than those of Allhallows by 2.9109, and than those of St. Mary's by 0.6440, having fallen the last quantity in five miles.

The marshes between Northfleet and Greenhithe are lower than Yantlet Creek 1.6365, than Allhallows 3.7642, than St. Mary's 1.4973, than Higham 0.8533, being a fall of this last quantity in 6½ miles.

On the eastern side of Dartford Creek, the marshes are 3.0152 below those of Yantlet Creek, 5.1429 of Allhallows, 2.8760 of St. Mary's, 2.2320 of Higham, and 1.3787 below the marshes between Northfleet and Gravesend; being a fall of the last quantity in 4½ miles.

The marshes near Woolwich Arsenal to the eastward of the practising ground are 4.2880 below those of Yantlet Creek, 6.4157 of Allhallows, 4.1488 of St. Mary's, 3.5048 of Higham, 2.6515 of the marshes between Northfleet and Gravesend, and 1.2728 below the eastern Dartford Creek marshes, being a fall of 1.2728 in six miles.

The marshes at Greenwich, as far as the few observations I had the opportunity of making, are 0.5083 higher than those of Woolwich, therefore less that sum than the comparison of the Woolwich marshes.

At picket 131 (page 14), I intersected the Thames and Medway Canal, three miles from its mouth at the Thames.

The above picket was driven into the water's edge, another was at the same minute driven to the water's edge in the basin close to Gravesend. I then levelled along the banks, imagining that from a mean of simultaneous observations made at the two pickets at the water's edge, I should obtain the best proof to my levellings; the results (page 6 of Proof Levels) will show how little confidence is to be placed on water, as a true level, under such circumstances.

At the Lock Gate of the canal, close to the Thames (see page 15), I made some observations of the tides, and found, June 7th, that high-water mark at Gravesend was 1.1018 higher than at Sheerness, and June 8th, was 0.8367 higher; but these two observations are not to be depended on as giving a mean difference between the two places, as the height of the tides at Gravesend are much affected by any winds.

On the new pier at Gravesend, I caused one of the brass standards to be sunk in the granite on the eastern side, the face of which is 0.1828 below the north standard mark, and 3.8833 above mean spring tide high-water mark at Sheerness.

On my arrival at Greenwich Hospital, I commenced a set of branch levels, from thence to the Royal Observatory at Greenwich, in order to determine the height of that place above the level of the sea. From the abruptness of the ascent, the operation was very tedious; and I here found the advantage of the extra lens to the telescope, as there was seldom a distance of more than twelve or twenty feet between the pickets.

I levelled up to a small brass standard already placed for me by the direction of the Astronomer Royal in the block of stone immediately under the eye-end of the transit instrument pointing southward.

This standard (page 31 of Levels) is

140.6806 above the north standard at Sheerness.
153.8317 above the mean level of the sea.
144.7467 above the mean spring tide high-water mark.
162.3611 above the mean spring tide low-water mark.

These observations being completed, it occurred to the Astronomer Royal, after minutely examining my instrument, that it might be used as a proof in ascertaining the correctness of the horizontal point of the two mural circles.

By his directions I placed my level upon the high window-frame in front of and about eight feet from the object-end of the mural circle, pointed towards the north, and at such a height that (from a known principle in optics that all rays are parallel *,) I could intercept some of the rays from the object-glass.

* If any object be placed at the focus of a lens (viz. the wires), the emergent rays are parallel.

Having adjusted my level most exactly, I directed my telescope into the tube of the great telescope of the mural circle; and adjusting as for infinite distance, by placing a disc of white paper about an inch from the eye-end of the great telescope, I observed all the wires most distinctly. I then adjusted my horizontal wire for collimation.

The mean horizontal point was then taken, and the circle adjusted to that by the micrometer; and after again observing my instrument to be in perfect adjustment, I sought for the horizontal wire of the circle, and I was astonished and delighted to see so perfect a coincidence of the horizontal wires of the two instruments, that, until I slightly depressed the eye-end of my telescope, I could not see the horizontal wire of the circle separate from my own. The circle was then altered, and the wires were again made to coincide; the quantity was then read off, and found to agree within a very few hundredths of a second to the horizontal point.

The Astronomer Royal was present at these experiments, and expressed himself much pleased at the proof given of the coincidence of the two instruments.

From the stairs of Greenwich Hospital I crossed the river in order to level up to the different places where tide-registers had been kept.

After crossing the Isle of Dogs, I arrived at a spot on the south side of the lock of the City Canal at Limehouse Reach (see No. 381, page 26), which was 1.9008 above the north standard at Sheerness; and this spot was 3.8446 above the TRINITY HW 1800 Λ marked on the face of the masonry. Therefore 3.8446 — 1.9008 = 1.9438 is the height of Trinity mark at the canal below northern standard at Sheerness, and 4.0661 (height of north standard above mean spring tide high-water mark) — 1.9438 = 2.1223, the height of Trinity mark above mean spring tide high-water mark at Sheerness.

This spot (picket No. 381) is also 0.5202 above a particularly high tide 21/ft. 11 in., 1827, marked on the masonry; but upon referring to the tide-register at Sheerness, of the 20th and 22nd of November 1827, no particular rise in the tide is to be remarked. It must therefore have been caused by land floods, which are the occasion of most of the extraordinary tides near London.

I next levelled to a standard placed at the West India Docks on the S.S.E. side, close to the entrance. This standard is 1.3018 above the northern standard, and 2.3367 above the index mark XXIII. Therefore 2.3367 − 1.3018 = 1.0349, the index mark below the north standard at Sheerness, and 4.0661 − 1.0349 = 3.0312 is the height of XXIII above mean spring tide high-water mark at Sheerness.

Not having succeeded in procuring a copy of the observations on the tides at the West India Docks, I cannot make any other comparison.

At the Regent's Canal Dock, in a very large stone near the office of the canal works (see page 26), I placed another standard mark. This standard is 2.4418 above the northern standard at Sheerness, and 2.2308 above the index mark XXI; therefore the index is 0.2110 above the north standard at Sheerness.

From two years' observations on the tides (1828—1829), the following are the results.

Mean Spring Tide High-Water Mark for				
	1828.		1829.	
	Spring Tide, High Water.	High Water, Neap.	Spring Tide, High Water.	High Water, Neap.
	Ft. In.	Ft. In.	Ft. In.	Ft. In.
January	19.8^{3}	15.	19.1	14.8
February	18.11	14.3	19.1^{5}	13.11
March	19.9	14.3	19.5	14.8
April	19.9^{8}	14.3	19.6	13.7
May	18.9	15.5	19.	14.9
June	18.10	15.7	18.9^{5}	15.2
July	19.2^{6}	15.9	18.9^{6}	15.7
August	19.3	15.4^{5}	19.3	14.7^{6}
September	19.9	14.6	19.7	14.7
October	19.7	14.5		
November	19.1^{5}	14.3	19.3	14.3
December	19.2^{5}	13.9	18.7	14.9
Means	19.325	14.733	19.141	14.592

Spring 1829 ...... 19.141
—— 1828 ...... 19.325

Mean Spring Tide for two years 19.233

Neap 1829 ...... 14.592
—— 1828 ...... 14.733

Mean Neap Tide for two years 14.662

Mean Spring Tide 19.233
Mean Neap Tide 14.662

Mean High Water 16.947

The mean high-water mark, taking every high water through the months, is as follows:

	1828.	1829.
January	17.342	16.904
February	16.904	16.804
March	17.070	17.208
April	16.925	17.270
May	17.352	17.175
June	17.258	17.091
July	17.595	17.350
August	17.466	17.100
September	17.345	17.591
October	17.000	"
November	17.001	17.412
December	16.691	16.787
Means	17.1624	17.1538

17.1581

The difference therefore between the mean of spring and neap tide and the means of the months, as above, is (17.1581 − 16.947) 0.2111.

The index mark XXI at the canal is 0.2110 + 4.0661 = 4.2771 above spring tide high-water mark at Sheerness; and the spring tide high-water mark at the Regent's Canal being 19.233, XXI − 19.233 = 1.767, and 4.2771 − 1.767 = 2.5101, the height of mean spring tide high-water mark at the Regent's Canal above the same at Sheerness.

The index mark XXI is also 6.1321 above mean high-water mark at Sheerness.

And the mean high-water mark at Regent's Canal being

16.947, XXI − 16.947 = 4.053 and 6.1321 − 4.053 = 2.0791

or 17.1581, XXI − 17.1581 = 3.8419 and 6.1321 − 3.8419 = 2.2902 the height of mean high-water mark at the canal above the same at Sheerness.

And the mark XXI is 7.9761 above mean neap tide high-water mark at Sheerness. The mean neap tide mark at the canal being 14.662, XXI − 14.662 = 6.338 and 7.9761 − 6.338 = 1.6381, the height of mean neap tide high water at the canal above the same at Sheerness. Therefore the water of spring tides at the canal above spring tides at Sheerness is higher by 0.8720 than it is at neap tides at both places.

Having no observations of low-water mark at the canal, I have not the means of ascertaining the difference at the two places.

The next place where a comparison of the tides was made was at the London Docks, at No. 418 of the Levels (see page 27), being on an iron on the south-west pier of the main entrance close to the first lock. This iron was 3.7570 above the northern standard, and 5.7682 above the index mark by the side of the gates XXIII†, which mark answers to the 18-feet Trinity $\frac{\text{HW}}{1800}$ $\overline{\wedge}$

Therefore $3.7570 + 4.0661 - 5.7682 = 2.0549$ the height of XXIII above spring tide high-water mark at Sheerness. And $2.0549 + 1.855$ (the difference between spring tide and mean tide high-water mark at Sheerness) $= 3.9099$, the height of XXIII above mean high-water mark at Sheerness.

And $2.0549 + 3.699$ (difference between spring and neap tides at Sheerness), $= 5.7539$, the height of XXIII above neap tide at Sheerness.

And $2.0549 + 9.085$ (the difference between mean level and spring tide at Sheerness), $= 11.1399$, the height of XXIII above the mean level of the sea at Sheerness.

And $2.0549 + 17.615$ (difference between spring high and low water at Sheerness), $= 19.6699$, the height of XXIII above spring tide low-water mark at Sheerness.

By the kindness of Mr. LUBBOCK I have received the following results of twenty-six years' observations on the tides at the London Docks:

	Mean High Water.	Spring High Water.	Neap High Water.
	ft. in.	ft. in.	ft. in.
January	21.275	22.729	19.750
February	21.275	23.002	19.145
March	21.291	23.541	19.125
April	21.395	22.854	19.375
May	21.475	22.708	20.125
June	21.395	22.50	20.250
July	21.291	22.604	19.687
August	21.250	22.708	19.562
September	21.291	23.979	19.292
October	21.291	22.937	19.229
November	21.395	22.687	19.833
December	21.312	22.458	19.870
Mean	21.333	22.812	19.604

Therefore xxiii — 21.333 — 1.667.

And 3.9099 — 1.667 = 2.2429, the height of mean high-water mark at the London Docks above the same at Sheerness.

And xxiii — 22.812 = 0.188, therefore 2.0549 — 0.188 = 2.0361, the height of spring tide high-water mark at London Docks, above spring tide high-water mark at Sheerness.

And xxiii — 19.604 = 3.396, and 5.7539 — 3.396 = 2.3579, the height of neap tide high water at London Docks above the same at Sheerness.

No observations have been made on low-water mark; but from the Trinity mark it appears the spring tide low-water mark is considered to be 17.833 below Trinity mark, or rather below the high-water mark.

Therefore 22.812 — 17.833 = 4.979, and xxiii — 4.979 = 18.021, the height of xxiii above spring tide low-water mark.

And 19.6699 — 18.021 = 1.6679, the height of spring tide low water at London Docks, above spring tide low water at Sheerness.

Taking 22.812 and 4.979, the mean level of the sea is 13.896.

Therefore xxiii — 13.896 = 9.104, the height of xxiii above the mean level.

Then 11.1399 — 9.104 = 2.0359 gives the mean level at London Docks above the mean level of the sea.

The following is a Summary of the different heights.

Spring tide H. W. at London Docks, above the same at Sheerness				2.0361	
					0.2068
Mean H. W. mark	ditto	ditto	ditto	2.2429	
					0.1150
Neap tide Ditto	ditto	ditto	ditto	2.3579	
					0.6900
Spring tide low water	ditto	ditto	ditto	1.6679	
					0.3680
Mean level of the tides	ditto	ditto	ditto	2.0359	

Or taking more correctly the ½ difference between spring high and low water at Sheerness, the mean spring level is 10.8289 below xxxiii, therefore 10.8289 — 9.104 = } . . . 1.7249

Note.—It seems by the above summary that as the water decreases in height, so the height of the water's surface at London Docks, above the same at Sheerness also decreases, with the exception of spring tide at London Docks and the neap tide; these are means, not of the highest tides, but of tides at a particular time of the moon's southing.

The next spot levelled to where any tidal observations were made, was St. Catherine's Docks, where a brass standard was placed close to the south-west side of the Dock-gates at the entrance.

This standard is 4.3143 above the north standard at Sheerness, and 6.2563 above the index mark XXVIII, upon a level with which is a —+— denoting Trinity $\underset{\wedge}{\overset{\text{HW}}{\underline{1800}}}$

Therefore $4.3143 + 4.0661 - 6.2563 = 2.1241$, the height of this index or Trinity mark above mean spring tide high-water mark at Sheerness.

After passing along the Tower Wharf, and placing a standard mark in one of the large blocks of granite lately put down near the Traitor's Arch (see Levellings, page 28), I arrived (not without much vexatious interruption and annoyance in passing along Thames-street and Billingsgate) at the starlings of Old London Bridge, where I had some difficulty in making observations, owing to the tremor caused by the vehicles above. I levelled up to the Trinity mark on the western side of the bridge, and found as follows (see page 29):

No. 443 was 4.1047 below the north standard mark at Sheerness, and the Trinity $\underset{\wedge}{\overset{\text{HW}}{\underline{1800}}}$ was 1.9426 above No. 443.

Therefore $4.1047 - 1.9426 = 2.1621$, the height of Trinity mark below north standard mark at Sheerness.

And $4.0661 - 2.1621 = 1.9040$ gives the height of Trinity mark above the mean spring tide high-water mark at Sheerness.

Having now made all the observations that time and means afforded me, I concluded my levellings at a standard mark sunk in the large plinth of the landing-place (near the wall) of the stairs on the north-east side of the New London Bridge.

This standard was (page 29) 2.3967 below the north standard mark at Sheerness.

I have subjoined a list of the different Trinity marks I have observed, and their respective heights, and also of the brass standards placed by me, as well as various substantial points passed over in the levellings.

	Below North Stand. Sheerness.
Trinity high-water mark near the dock-gates of the City Canal	1.9438
Ditto, answering to XXIII of the indices marked on the south-west side of the entrance to London Docks	2.0112
Ditto, at the west side of the lock-gate at the entrance to St. Catherine's Docks, answering to the index mark XXVIII	1.9420
Ditto, on the west side of London Bridge	2.1621

Finding so great a difference between the marks at the City Canal, London Docks, &c. and that at London Bridge, I levelled again in October last from St. Catherine's Docks to London Bridge, but found the same results. (See page 33.)

List of Standard Marks and other Points of Reference between Sheerness and London Bridge.

		Feet.
North standard at Sheerness		0.0000
South ditto ditto	higher	0.6048
Eastern ditto ditto	ditto	0.6735
Navy Well ditto ditto	lower	5.3921
Little ditto near tide-gauge at Sheerness	higher	0.4843
Queenborough standard	ditto	10.6029
St. James ditto	ditto	28.7454
The boundary post of Hoo, on a little eminence in the marshes, &c. (See page 10.)	below	2.6317
The 3 mile stone at the bank of canal. (See page 14)	above	2.4204
2 mile ditto	ditto	2.0038
1 mile ditto	ditto	1.1448
An iron clamp at second gate of Gravesend Canal. (See page 15)	ditto	0.5564
Brass standard mark on the pier at Gravesend	below	0.1828
The boundary stone of Swanscomb. (Page 18)	ditto	4.7578
Erith Church. (Page 20)	ditto	1.5669
Standard in Woolwich Arsenal	above	1.2019
A ⊡ in a corner-stone near the officers' guard-room	ditto	1.5576
The top of the 4½ mile post in the river (□)	ditto	1.7182
□ on a stone at the west end of the dock-yard	ditto	1.9975

		Feet.
Brass standard in the dock-yard on the eastern point of mast slip	above	1.6545
A ⅂ in small north-east gateway of Greenwich College, from the main road	ditto	9.9975
Small brass standard underneath the transit at Greenwich Observatory	ditto	140.6897
Little brass standard on the plinth of the statue of George II. in Greenwich Hospital	ditto	5.1157
□ on one of the iron plates near the south side of the lock of the City Canal	ditto	1.9008
Brass standard at the West India Docks	ditto	1.3018
Brass standard at Regent's Canal	ditto	2.4418
A □ on the top of a granite post close outside the entrance from Ratcliffe Highway to the London Docks	ditto	16.0915
On the top of a gun in the Docks near the bridge of the eastern basin	ditto	13.1646
Brass standard St. Catherine's Docks	ditto	4.3143
Brass standard near the Traitor's Arch in the Tower	ditto	1.2854
Brass standard at landing-place of New London Bridge	below	2.3967

As it may be expected that I should state the manner in which I made the preceding observations, in order that a judgement may be formed of the confidence to be placed in them, I shall give a concise description of the field operations, and of the calculations necessary to complete the observations, and place them as they are in the book *.

After examining the ground, the particular line for carrying on the levellings was selected and marked out, when pickets were driven in at proper distances, according to the range of the instrument over the ground.

In the first part of the work the levelling was carried on as follows, the instrument being perfectly adjusted, and the station staves placed on their respective pickets. I made four observations, the telescope being in a different

* The field-book and all the other papers connected with the preceding operations are preserved at the Royal Society's Apartments.

position at each observation, and making a complete revolution in its collars: my assistant read off each, and noted it down in a book. I then went to the staff and examined its position on the picket, and read off the last observation myself; my assistant then read from his book the last observation; the two, of course, when correct, would correspond.

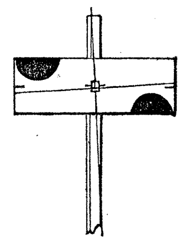
The telescope of the instrument was then reversed in its collars (which is a good check to the adjustment at each observation), and by the motion in azimuth directed to the next station staff, when the same mode was used in observing: the spot was marked, and the instrument moved to the next station, and the station staff turned half round in its collars, and gimbles ready for the next level. At the end of the day's work an additional picket was driven in about twelve or fifteen feet from that just used, and compared with it; this was to ensure the detection of any alteration in the pickets during the intervening time, either from mischief or accident, being compared before the commencement of the day's work. After a few days the ground was gone over again, generally from the opposite end, and two observations taken at each picket, which were sometimes more and sometimes less in number than in the former levellings; these were the proof-levels. The distances were then measured, and the necessary angles taken to lay down the work. In this manner proof levels were taken up to picket No. 111; but finding in this method that I was liable to great inconvenience and loss of time from many circumstances, and amongst others by the pickets being mischievously drawn or moved; and if a trivial mistake occurred in the levellings (of several days back perhaps), it was only detected at the summary of the levels. I determined to endeavour to adopt some method of proof, not liable to the inconveniences of the former.

I accordingly made use of the following mode, which I have found, after repeated trial, to be a most correct proof.

After having finished the four observations at one picket, I threw the instrument out of adjustment by the foot-screws; and after adjusting it again most correctly, I took a pair of observations; but instead of reading off the staff from the picket, it was now read from above, the staff being imaginarily continued to the length of ten feet. The mean of these observations, therefore, gave the complement to 10,000 of the true observation: by this mode much time was saved, and an error, if any, was immediately detected of a tenth of a foot, or a foot (which are the errors most likely to occur), without the trouble of bringing the instrument and adjusting it two distinct times at the same spot. The mean of the four and the mean of the two observations ought of course to make 10,000 *. In the detail of the proof-levels, the correction for curvature is additive instead of subtractive; and in fact the whole operation is reversed, + standing for −.

In the course of my levellings, having instruments not generally used, I made some few notes, which I take leave here to transcribe.

In adjusting the station-staff, it is difficult to know when the zero on the vane is made to coincide with the horizontal wire of the telescope. I have found the most convenient and correct mode to be, to observe with the wire forming a diagonal to the lines on the vane, by which, when the staff is near, the two small black lines at each end of the vane could be seen; and when the vane was adjusted to the proper height, one of these lines was above and the other below the horizontal wire at equal distances, thus:



—At a greater distance, the two little white right-angled triangles, formed by the edges of the vane and bounded by the black semicircle, are very distinctly seen, the one above and the other below the (now-placed) horizontal wire, and can be compared in size with great nicety.

But in observing with the wire diagonally, great care must be taken that, by the vertical wire (the error of which, if any, will by practice be accurately known), the axis of the telescope shall bisect the centre of the staff.

In an instrument with a very sensitive level, there is usually some difficulty in adjusting the level. It arises from no fault in the level itself, but from a

* In the proof-levels it will be found, that generally, upon adding them to the mean of the four observations, there will be a quantity of from .0010 to .0060 to make up the 10,000. I could not discover the cause for some time.

The wires being at right angles to each other, of course have been at different distances from the eye-glass; but the difference not being much more than the thickness of a hair, I did not alter the eye-tube: however, upon examination, I found that at the usual distance I took levels, when I altered from extreme distinct vision of the horizontal wire to extreme distinct vision of the vertical wire (which was the one I used for proofs), it made a difference of from .0020 to .0050, the distinct vision of the vertical wire being that quantity lower than when observed with the same adjustment as for the horizontal wire.

difference in weight of those parts of the telescope outside the collar. I found this difficulty in my instrument: to remedy it, I measured off from one of the resting points half the distance between the two Ys on the collars, and suspended the telescope by a fine wire from this point, which was the proper centre of the telescope. I found the eye-end with the tube close in to be more than four ounces heavier than the object-end. To remedy this, I caused a thick ring of lead of the above weight to be placed inside the tube near the object-end, by which the telescope was balanced; and I found it, when adjusted, to reverse without differing a quarter of a degree.

Distinct vision is certainly desirable, but not so absolutely requisite as that there shall be no parallax of the wires. The best way to avoid this, is, after adjusting for distinct vision, to move the eye as far as the hole in the eye-piece will admit of, and observe if the wires have any motion over the object or vane: if so, it must be remedied by sliding the eye-tube in or out, until the objects appear motionless.

Mirage.

I have found that the tremulous motion or jumping in the air, termed as above, appears not to be caused so much by evaporation as probably by some oscillation in the particles of light: for I have remarked, when the sun shines brightly and is occasionally obscured by clouds, that while the sun is out, the tremor is so great as to prevent the possibility of making a correct observation; yet the moment the sun is obscured, the intermediate space between the instrument and object (provided the sun is obscured so as to cast a shadow the whole distance) will be immediately perfectly tranquil; and again, at the instant of the sun's appearance, the same tremor will be observed.

I have found this motion to be exactly equal above and below any object; for upon placing the wire of the telescope one half the distance between the extreme oscillations, whenever the sun is obscured, the wire will be found to bisect the object.

Description of the Observation-Book.

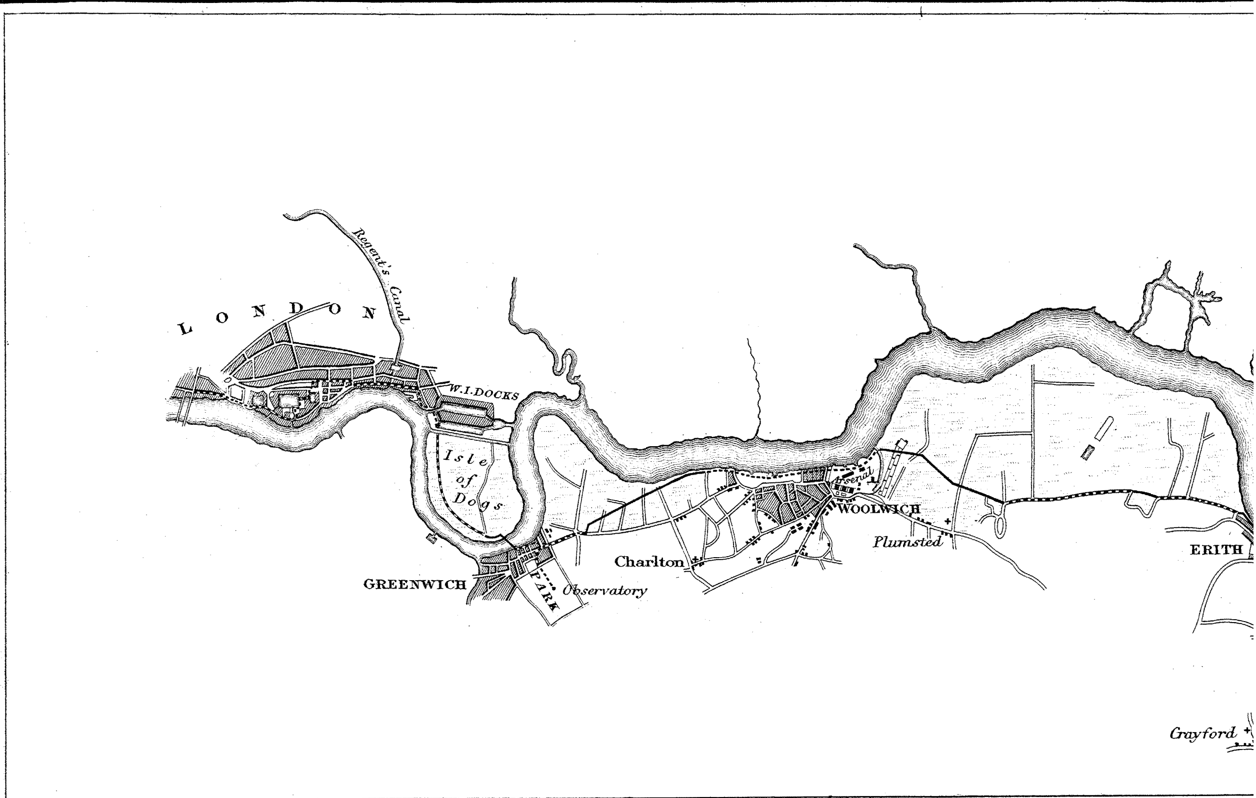
Each page of the book will be found to contain sixteen columns: the first and ninth contain the numbers of each staff or picket; the second and eleventh the mean from the rough book of the four observations at each staff; the third and eleventh the distance in feet from staff to instrument and instrument to staff; the fourth and twelfth the correction for the curvature of the earth; the fifth and thirteenth the mean observations minus the curvature; the sixth and eighth are the length of the bubble and the thermometer attached to the instrument. This last is useful as a check to the bubble, which, when the instrument is moved suddenly, shakes into several small globules, that sometimes do not immediately unite again: this is detected by the length of the bubble, which ought to correspond to a certain degree of the thermometer. Column fourteen is the difference between columns five and thirteen; column fifteen is that difference + or −; and column sixteen is the amount of that difference added or subtracted, according to the sign, from the former quantity. These quantities are a continuation of heights above or below the first picket, or the northern standard in the dock-yard at Sheerness.

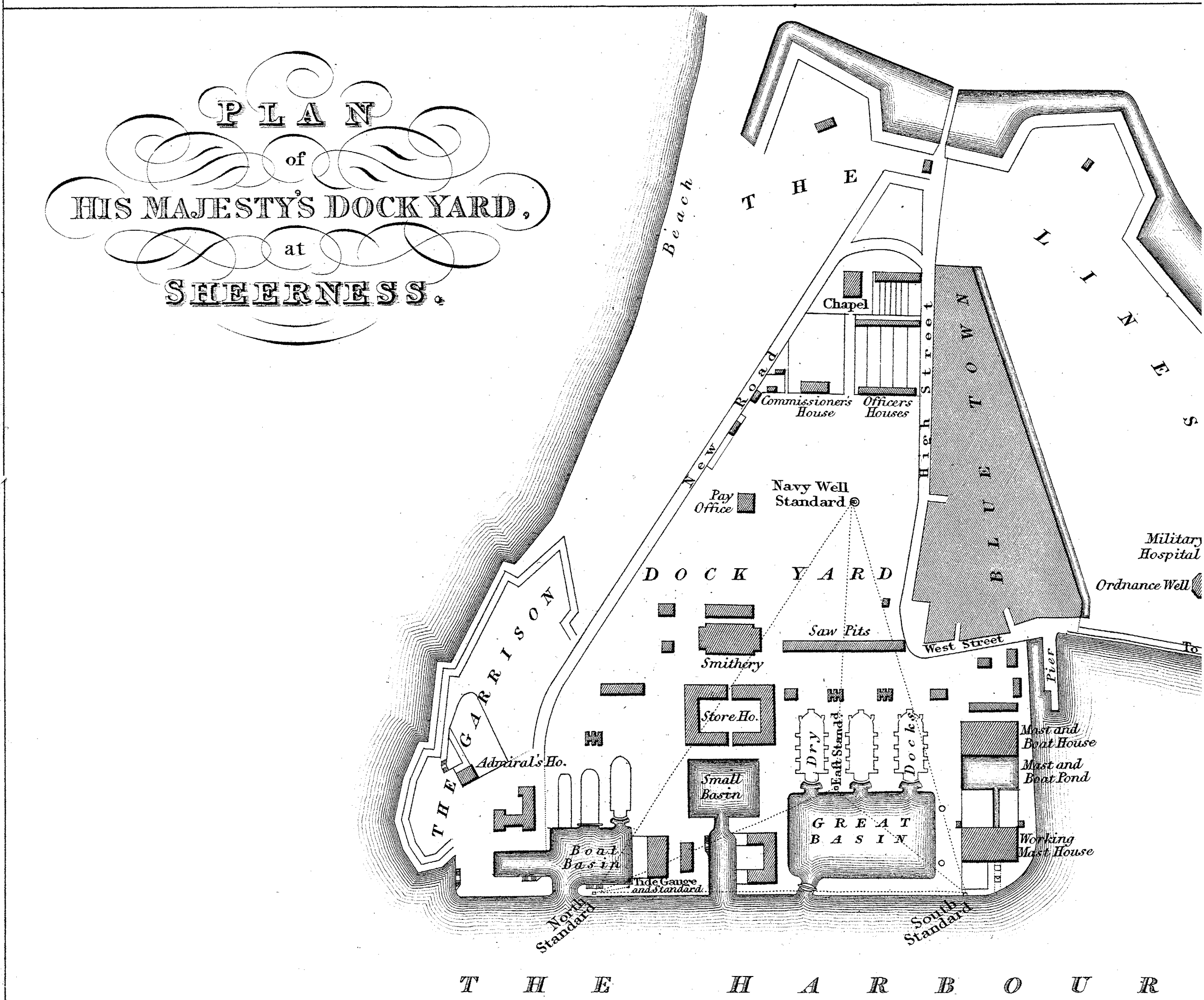
In order to prove the correctness of the different columns, they are summed up at the bottom, when the gross sum for curvature, being deducted from the gross sum of columns two and eleven, show the correctness of columns five and thirteen; and the difference between the sums of columns five and thirteen + or −, added to or subtracted from the little figures above the top line in column fifteen, ought to give the last true level in column sixteen at the bottom of the page.

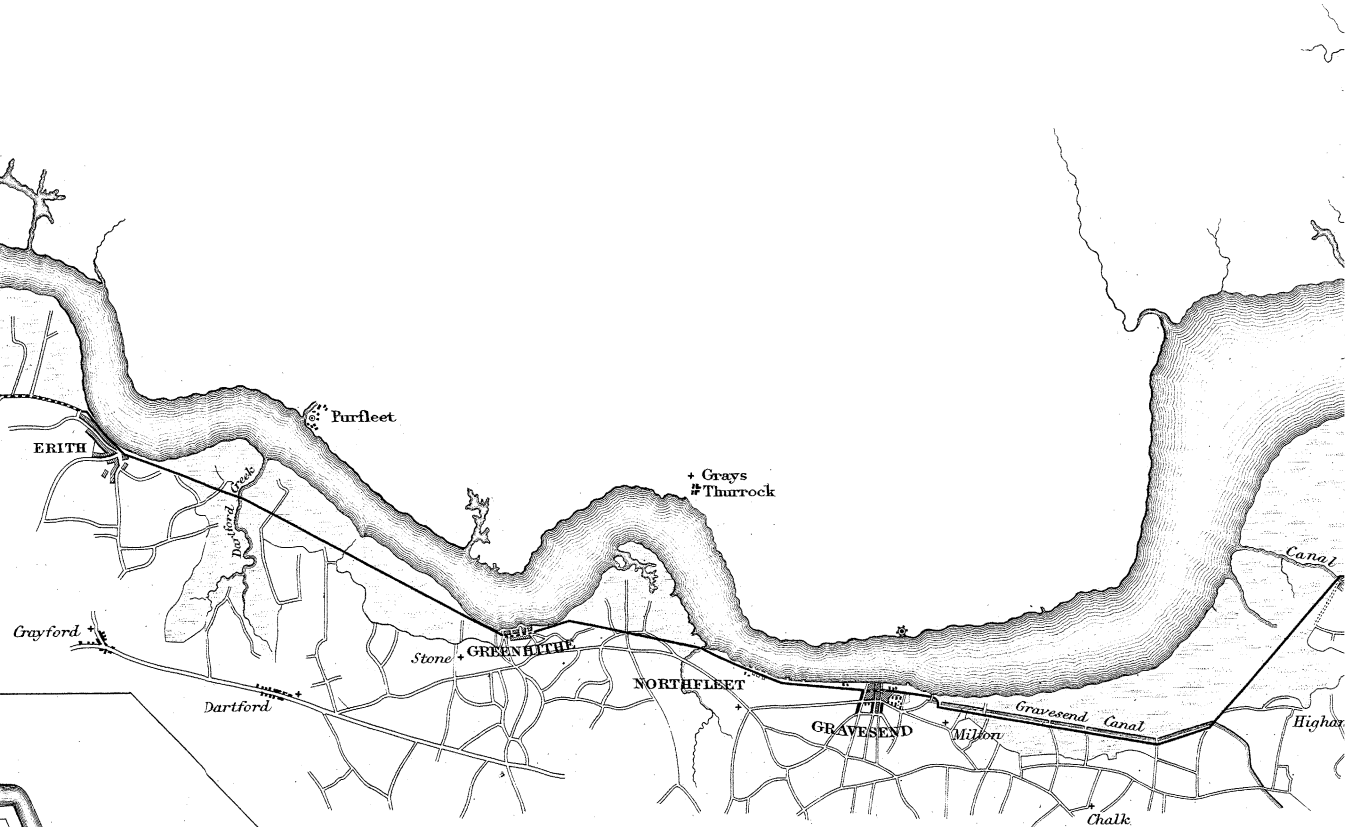
The whole is further proved by taking the sums of columns five and thirteen of each page, and the difference of the whole amount of each gives a proof of the correctness of the whole work, by giving the difference at once between picket 1 and 445.

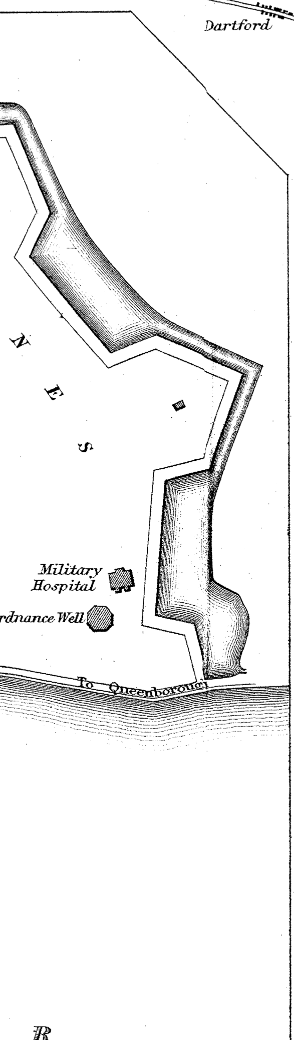
The same method is pursued in the proof-levels up to No. 112: after that, all the corrections become reversed, the curvature being additive (as the complement to 10,000 is read off on the staff). The difference between the proof-levels continue from standard at Sheerness to New London Bridge, and will be found to be 0.0110, and varying at different distances from Sheerness, but never more than 0.0300.

As there is not, in any work that I have seen, a correct table of curvatures of the earth for small distances, I have added one for every five feet from 60 to 1000.


LONDON
Regent's Canal
W.I.DOCKS
Isle of Dogs
GREENWICH
PARK
Observatory
Charlton
Arsenal
WOOLWICH
Plumsted
ERITH
Crayford

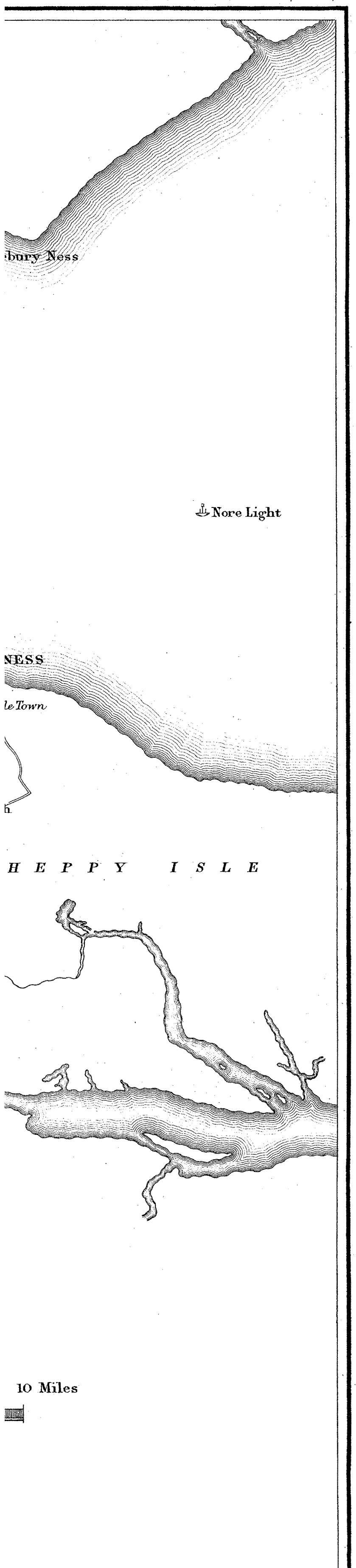

PLAN
of
HIS MAJESTY'S DOCK YARD,
at
SHEERNESS.
Beach
THE LINES
Chapel
New Road
Commissioner's House
Officers Houses
High Street
BLUE TOWN
Navy Well Standard
Pay Office
Military Hospital
Ordnance Well
DOCK YARD
THE GARRISON
Saw Pits
Smithery
West Street
Pier
Store Ho.
Dry Docks
East Standd
Mast and Boat House
Mast and Boat Pond
Admiral's Ho.
Small Basin
GREAT BASIN
Boat Basin
Tide Gauge and Standard
Working Mast House
North Standard
South Standard
THE HARBOUR

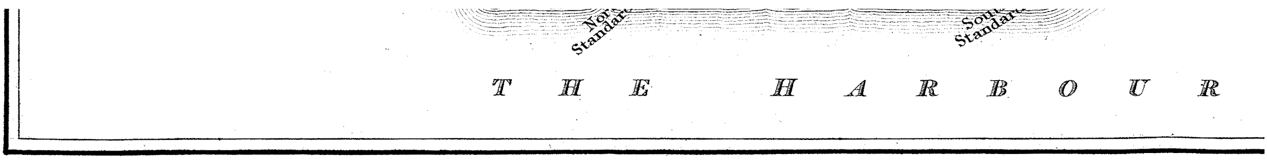


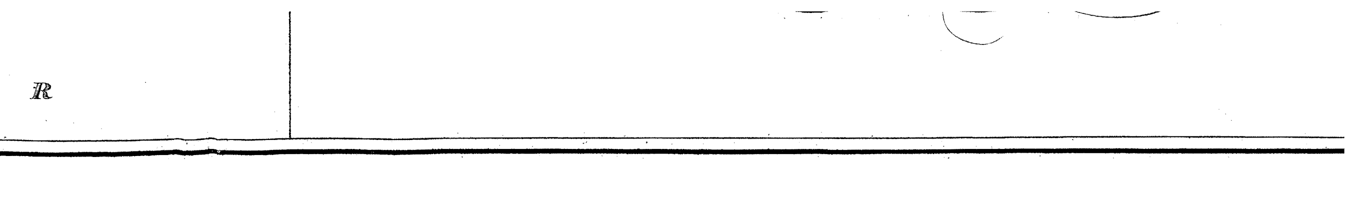


PLAN of the LINE of LEVELLINGS from SHEERNESS to LONDON.

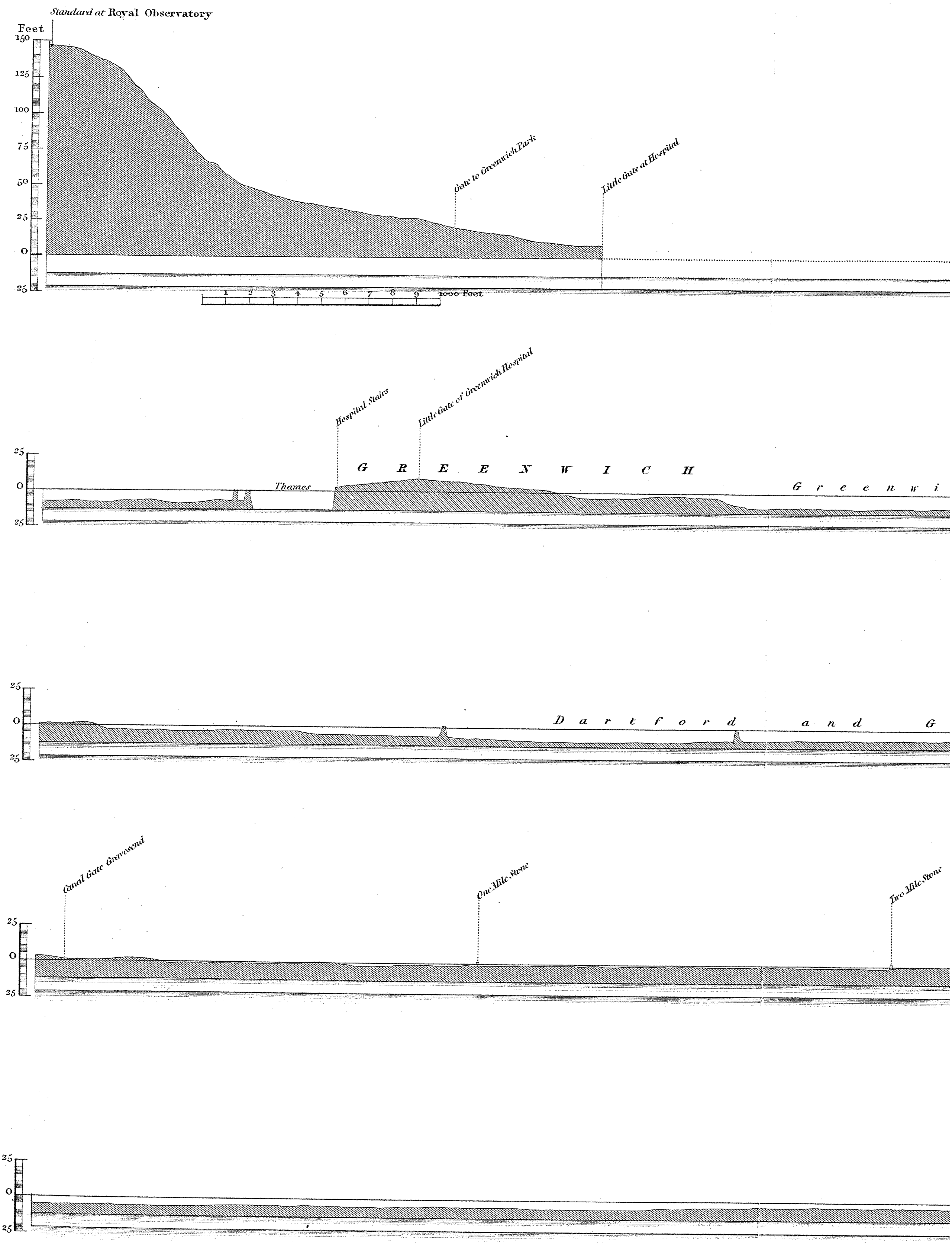

RIVER THAMES
Shoebury Ness
Decoy
Canal
Cliff
All hallows
St. Mary's
Yantlet Creek
St. James
Isle of Grain
Garrison
SHEERNESS
Blue Town
Mile Town
H. Halstow
Stoke
Higham
RIVER MEDWAY
Queenborough
SHEP
SCALE OF MILES.
1
2
3
4
5
6
7
8
9
10 Miles


bury Ness
Nore Light
NESS
le Town
H E P P Y I S L E
10 Miles


T H E   H A R B O U R

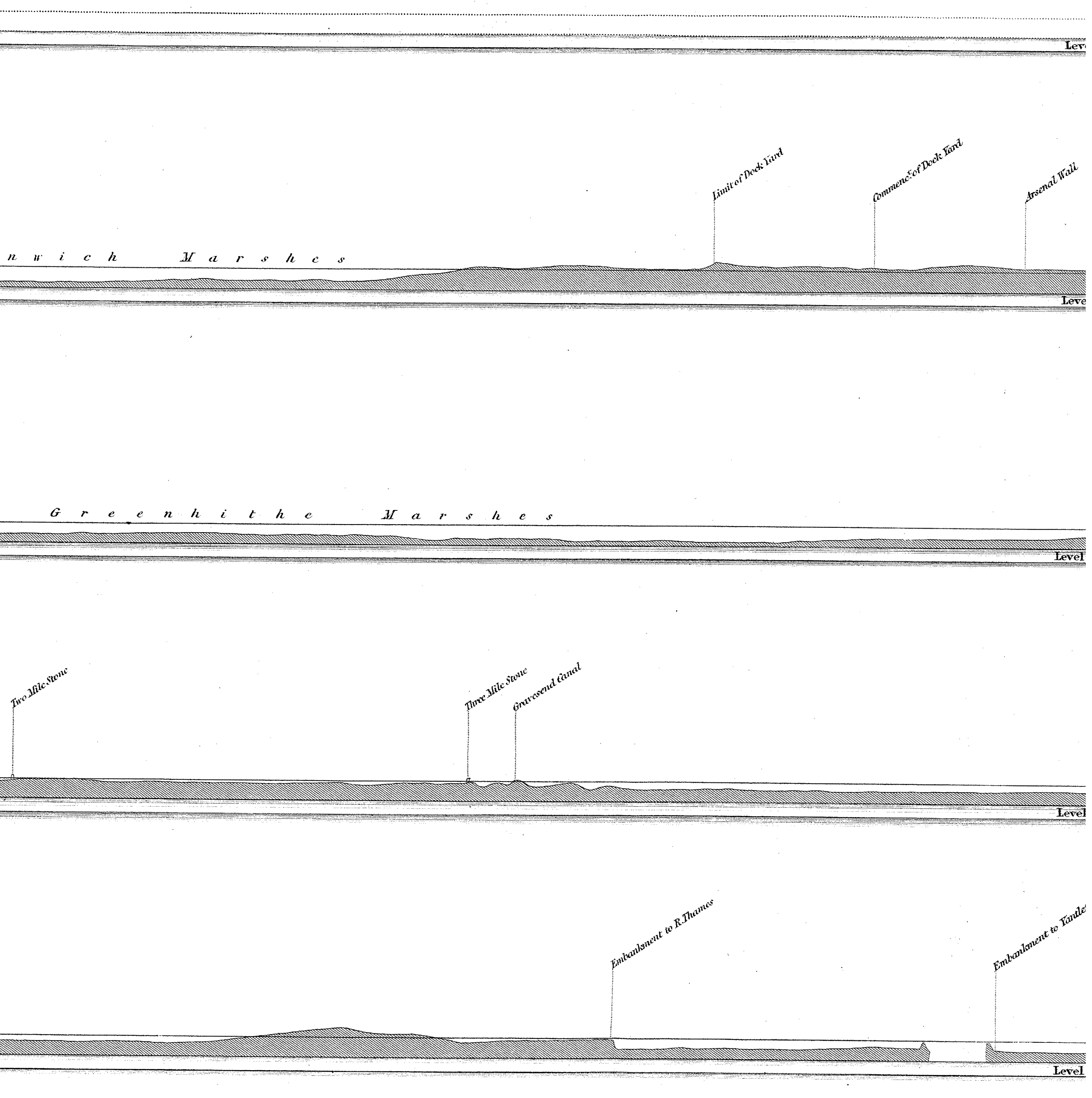

R

J.ᵈ Gardner, pc.

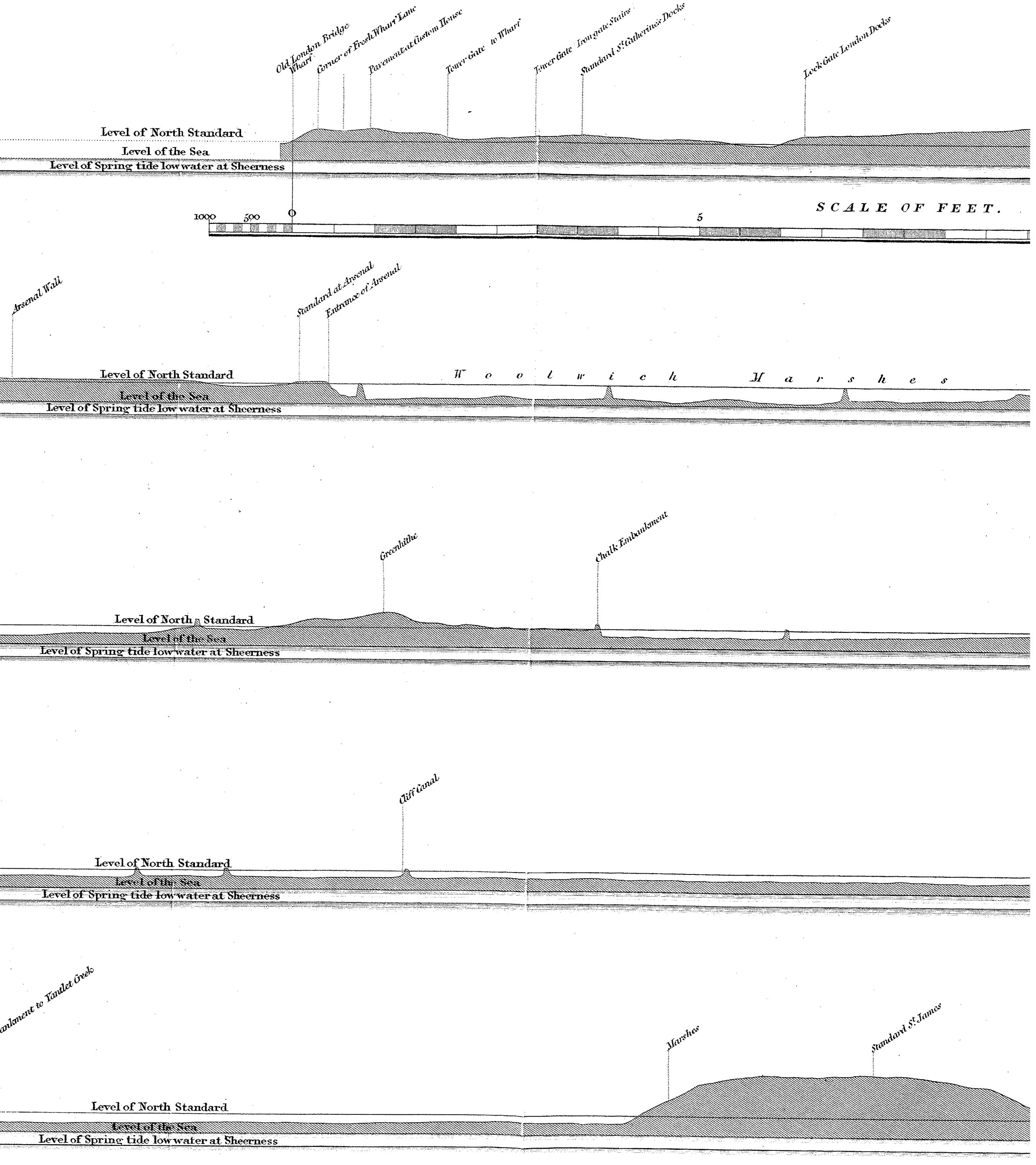


Standard at Royal Observatory
Feet
150
125
100
75
50
25
0
25
1 2 3 4 5 6 7 8 9 1000 Feet
Gate to Greenwich Park
Little Gate at Hospital
Hospital Stairs
Little Gate of Greenwich Hospital
Thames
G R E E N W I C H
G r e e n w i
D a r t f o r d a n d G
Canal Gate Gravesend
One Mile Stone
Two Mile Stone

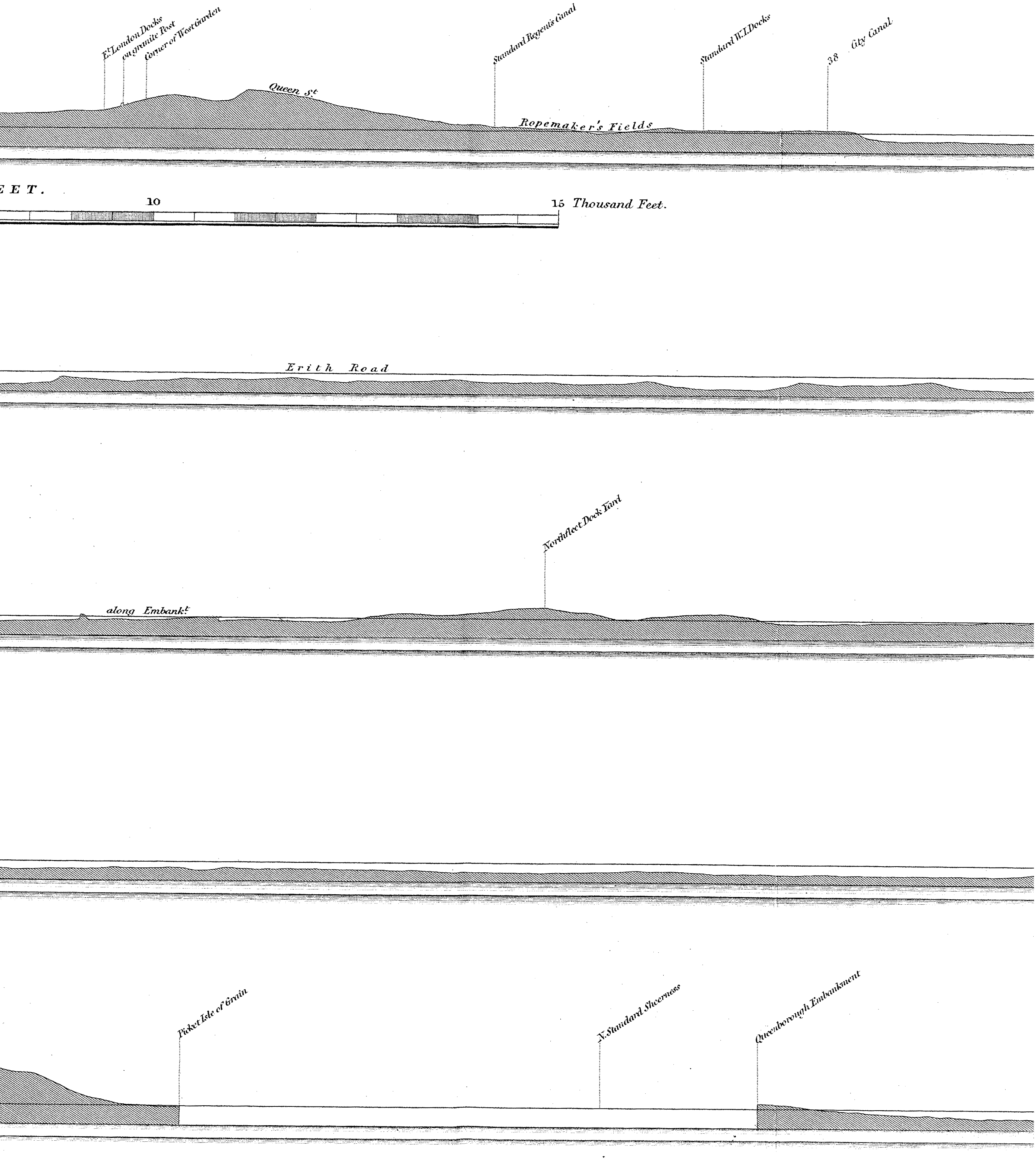
SECTION OF THE LAND PASSED OVER IN T



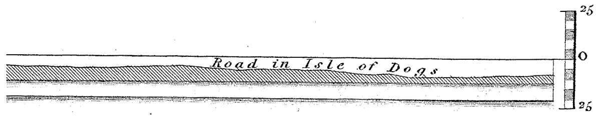
IN THE LEVELLINGS FROM SHEERNESS TO LONDON BRI

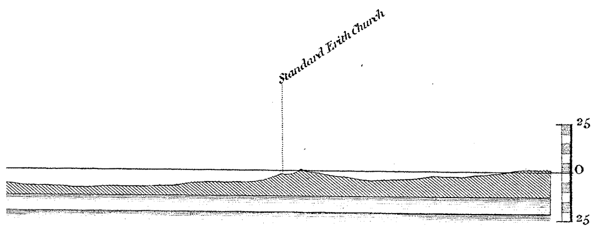


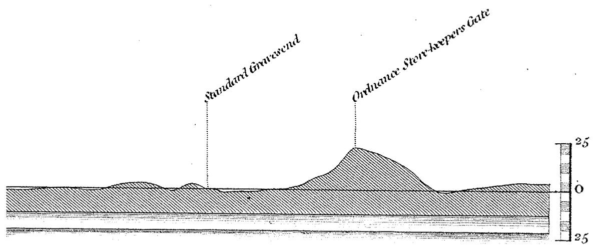
BRIDGE.

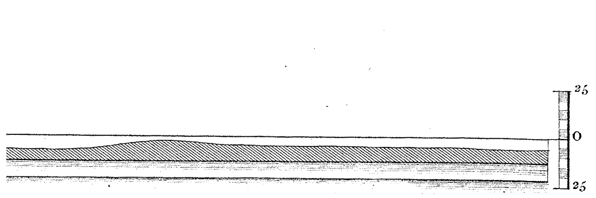


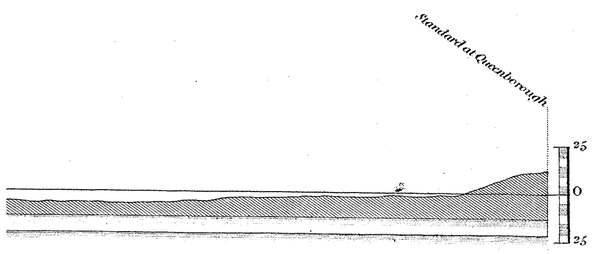
E.t London Docks
on granite Post
Corner of West Garden
Queen S.t
Standard Regents Canal
Ropemaker's Fields
Standard W. I. Docks
38
City Canal
EET.
10
15 Thousand Feet.
Erith Road
along Embank.t
Northfleet Dock Yard
Picket Isle of Grain
X. Standard Sheerness
Queenborough Embankment


Road in Isle of Dogs
25
0
25


Standard Erith Church
25
0
25


Standard Gravesend
Ordnance Store-keepers Gate
25
0
25


25
0
25


Standard at Queenborough
25
0
25

A Table of the Curvature of the Earth, the mean diameter being 41,807,803 feet.

Dist.	Curvature.	Dist.	Curvature.	Dist.	Curvature.	Dist.	Curvature.	Dist.	Curvature.	Dist.	Curvature.
Feet.		Feet.		Feet.		Feet.		Feet.		Feet.	
60	000086	220	001157	380	003453	540	006975	700	011721	860	017691
65	000101	225	001216	385	003544	545	007104	705	011888	865	017897
70	000117	230	001265	390	003637	550	007235	710	012057	870	018104
75	000134	235	001321	395	003730	555	007368	715	012228	875	018313
80	000153	240	001378	400	003827	560	007501	720	012399	880	018523
85	000173	245	001435	405	003923	565	007636	725	012572	885	018734
90	000194	250	001495	410	004021	570	007771	730	012746	890	018946
95	000216	255	001555	415	004119	575	007908	735	012921	895	019159
100	000239	260	001617	420	004219	580	008046	740	013098	900	019379
105	000264	265	001680	425	004321	585	008186	745	013275	905	019591
110	000290	270	001744	430	004422	590	008326	750	013454	910	019807
115	000316	275	001809	435	004526	595	008468	755	013634	915	020025
120	000344	280	001875	440	004621	600	008611	760	013816	920	020245
125	000374	285	001943	445	004735	605	008755	765	013998	925	020466
130	000404	290	002016	450	004843	610	008901	770	014181	930	020687
135	000436	295	002082	455	004952	615	009047	775	014366	935	020911
140	000469	300	002152	460	005060	620	009195	780	014552	940	021135
145	000503	305	002224	465	005171	625	009344	785	014740	945	021360
150	000538	310	002298	470	005284	630	009494	790	014928	950	021586
155	000575	315	002373	475	005397	635	009645	795	015118	955	021824
160	000612	320	002449	480	005511	640	009798	800	015308	960	022043
165	000651	325	002526	485	005626	645	009951	805	015500	965	022274
170	000691	330	002605	490	005743	650	010105	810	015693	970	022505
175	000732	335	002684	495	005861	655	010262	815	015888	975	022738
180	000775	340	002764	500	005978	660	010419	820	016083	980	022972
185	000818	345	002847	505	006100	665	010577	825	016280	985	023207
190	000863	350	002929	510	006221	670	010737	830	016478	990	023443
195	000909	355	003014	515	006324	675	010898	835	016677	995	023681
200	000957	360	003100	520	006467	680	011061	840	016877	1000	023919
205	001005	365	003187	525	006593	685	011223	845	017079		
210	001054	370	003275	530	006719	690	011383	850	017281		
215	001105	375	003363	535	006846	695	011554	855	017485		

NOTE.—I received the following rule for curvature and refraction together, from DAVIES GILBERT, Esq., and it will be found useful in ascertaining heights approximately.

Rule.—Assume the diameter of the earth as 10,000 instead of 7918 miles, and which will give the refraction about one-tenth the intercepted arc.

Front View of Levelling Staff.

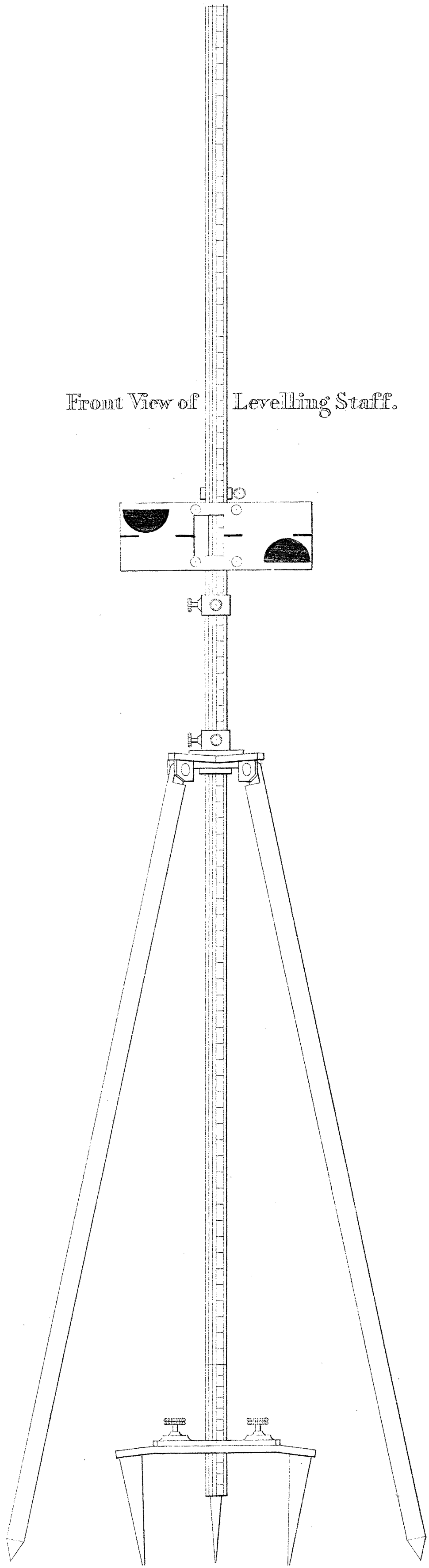
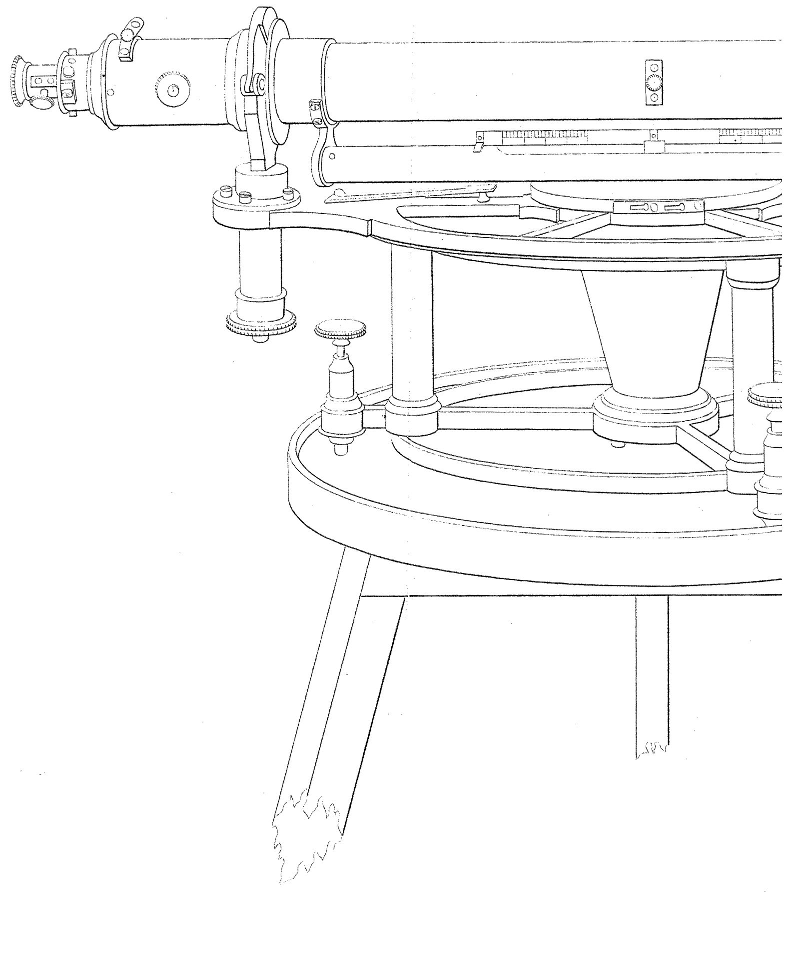
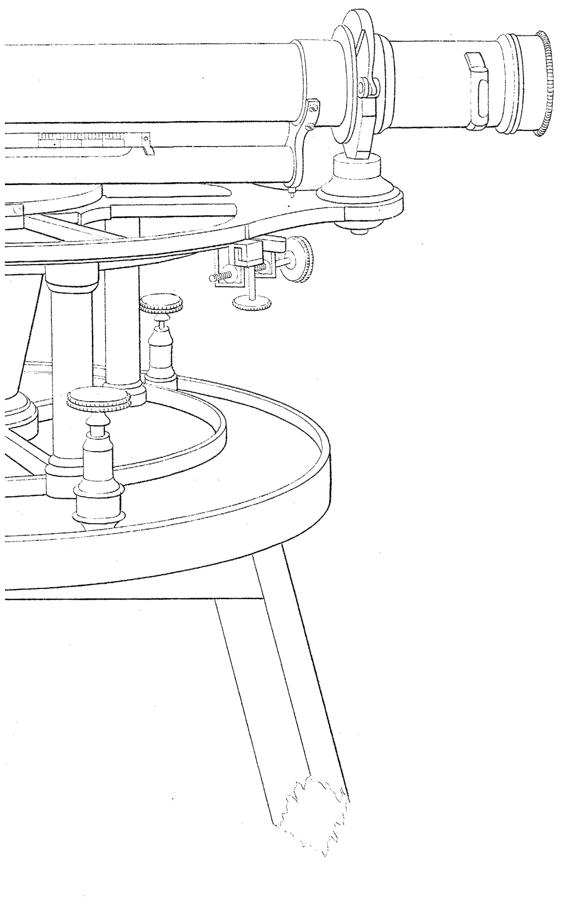


Fig. 1.

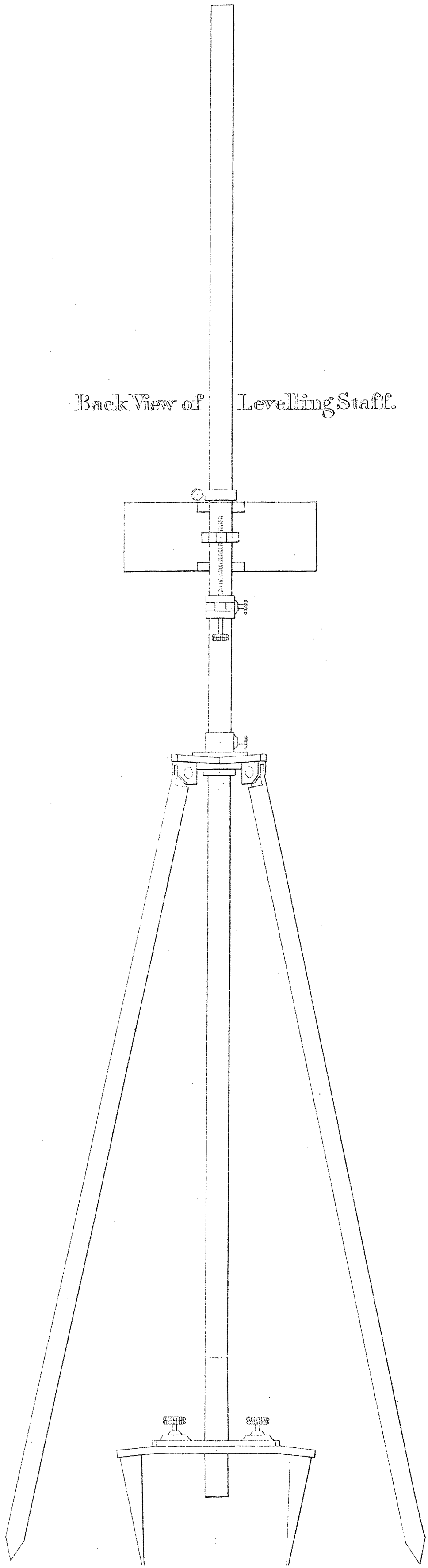
GENERAL VIEW OF THE LEVELLI

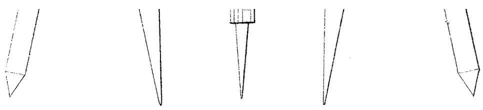


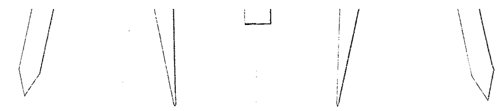
VELLING INSTRUMENT.



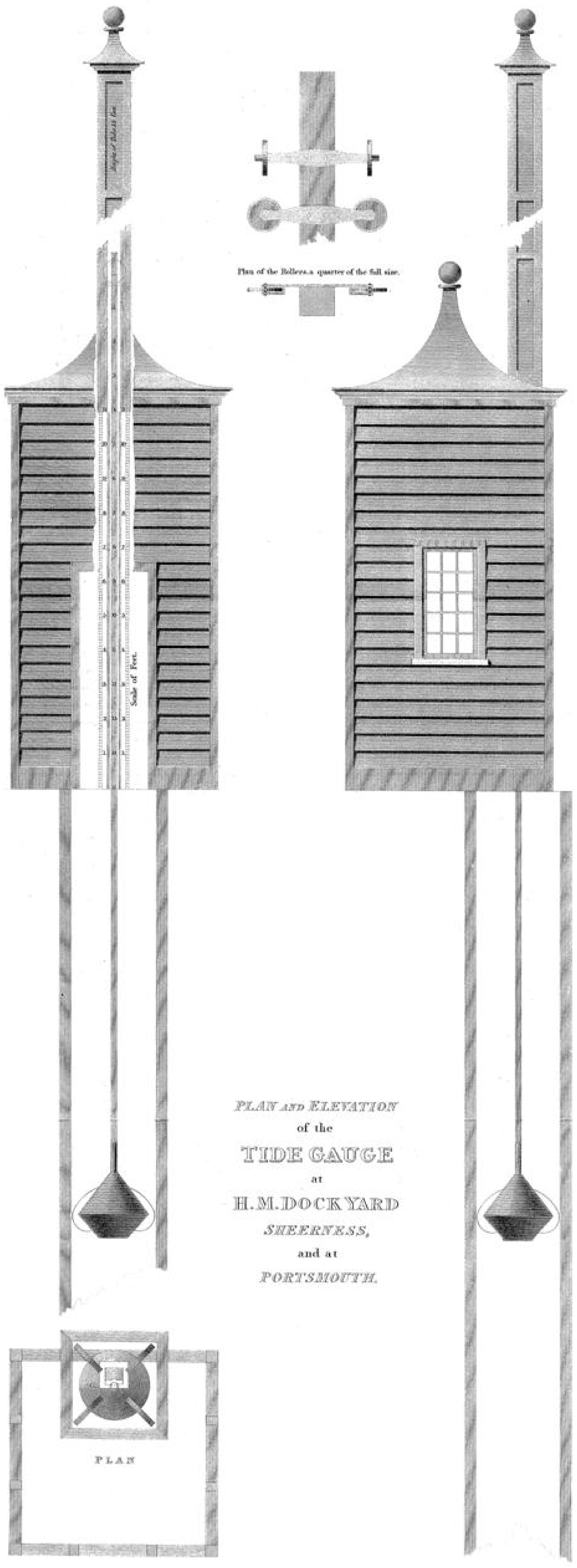
Back View of Levelling Staff.







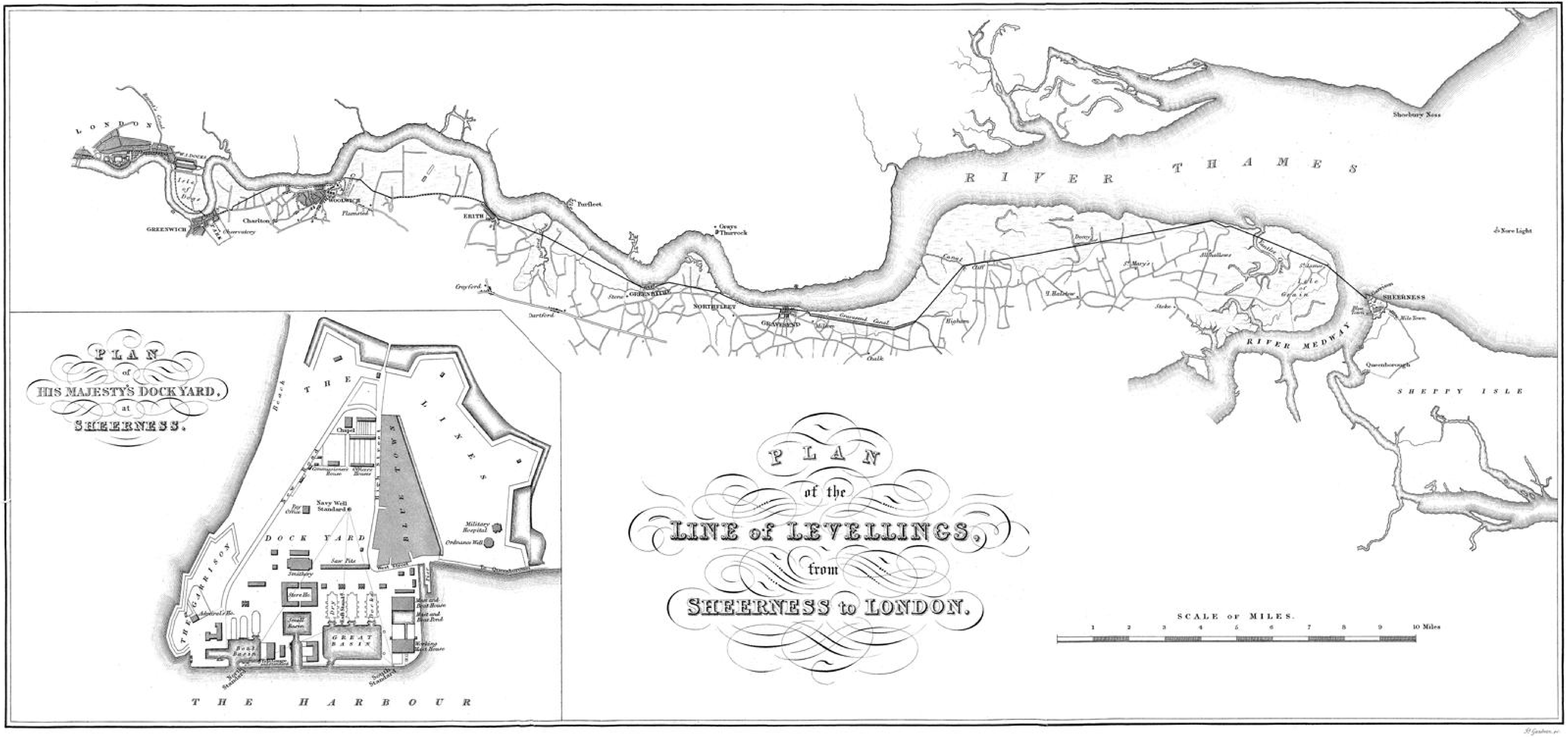
J^s. Gardner, sc.



PLAN AND ELEVATION
of the
TIDE GAUGE
at
H. M. DOCK YARD
SHEERNESS,
and at
PORTSMOUTH.

Scale ¾ of an Inch to 2 Feet.

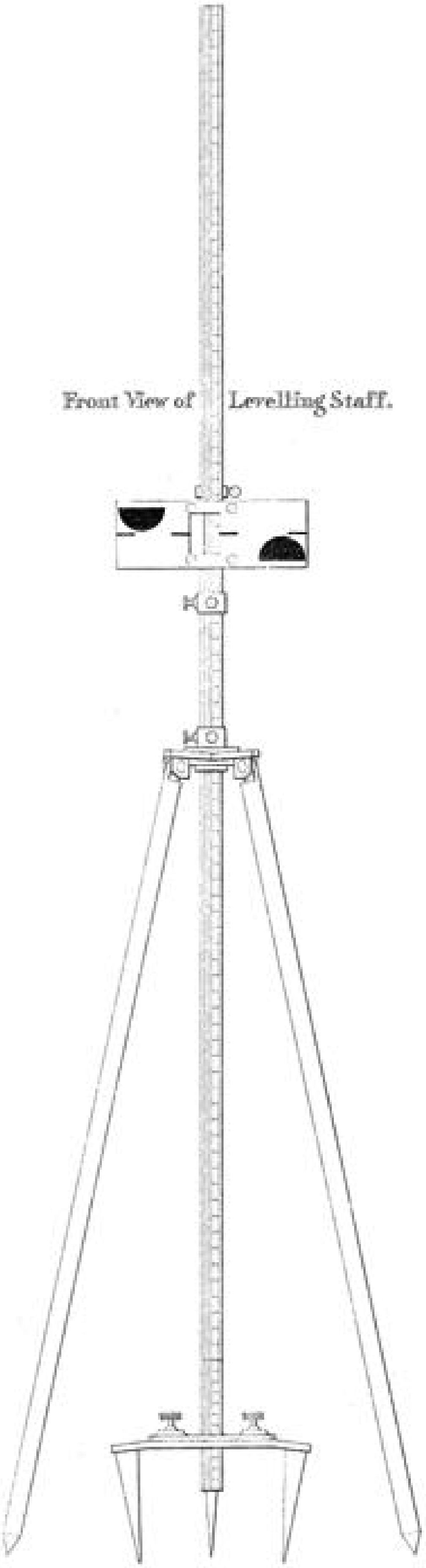
J. Gardner sc.


PLAN
of the
LINE of LEVELLINGS,
from
SHEERNESS to LONDON.
PLAN
of
HIS MAJESTY'S DOCK YARD,
at
SHEERNESS.
SCALE OF MILES.
1 2 3 4 5 6 7 8 9 10 Miles
RIVER THAMES
RIVER MEDWAY
SHEPPY ISLE
LONDON
W.I. DOCKS
Isle of Dogs
GREENWICH
Observatory
Charlton
WOOLWICH
Plumsted
ERITH
Purfleet
Grays Thurrock
Crayford
Dartford
Stone
GREENHYTHE
NORTHFLEET
GRAVESEND
Gravesend Canal
Canal
Chalk
Higham
Cliff
Hoo
St Mary's
Allhallows
Stoke
Isle of Grain
SHEERNESS
Mile Town
Blue Town
Queenborough
Nore Light
Shoebury Ness
THE LINES
BLUE TOWN
DOCK YARD
THE GARRISON
THE HARBOUR
Chapel
Commissioners House
Officers Houses
Navy Well Standard
Pay Office
Military Hospital
Ordnance Well
Smithery
Saw Pits
West Street
Store Ho.
Small Basin
GREAT BASIN
Boat Basin
Mast and Boat House
Mast and Boat Pond
Working Mast House
North Standard
South Standard
Pier
Beach
High Street

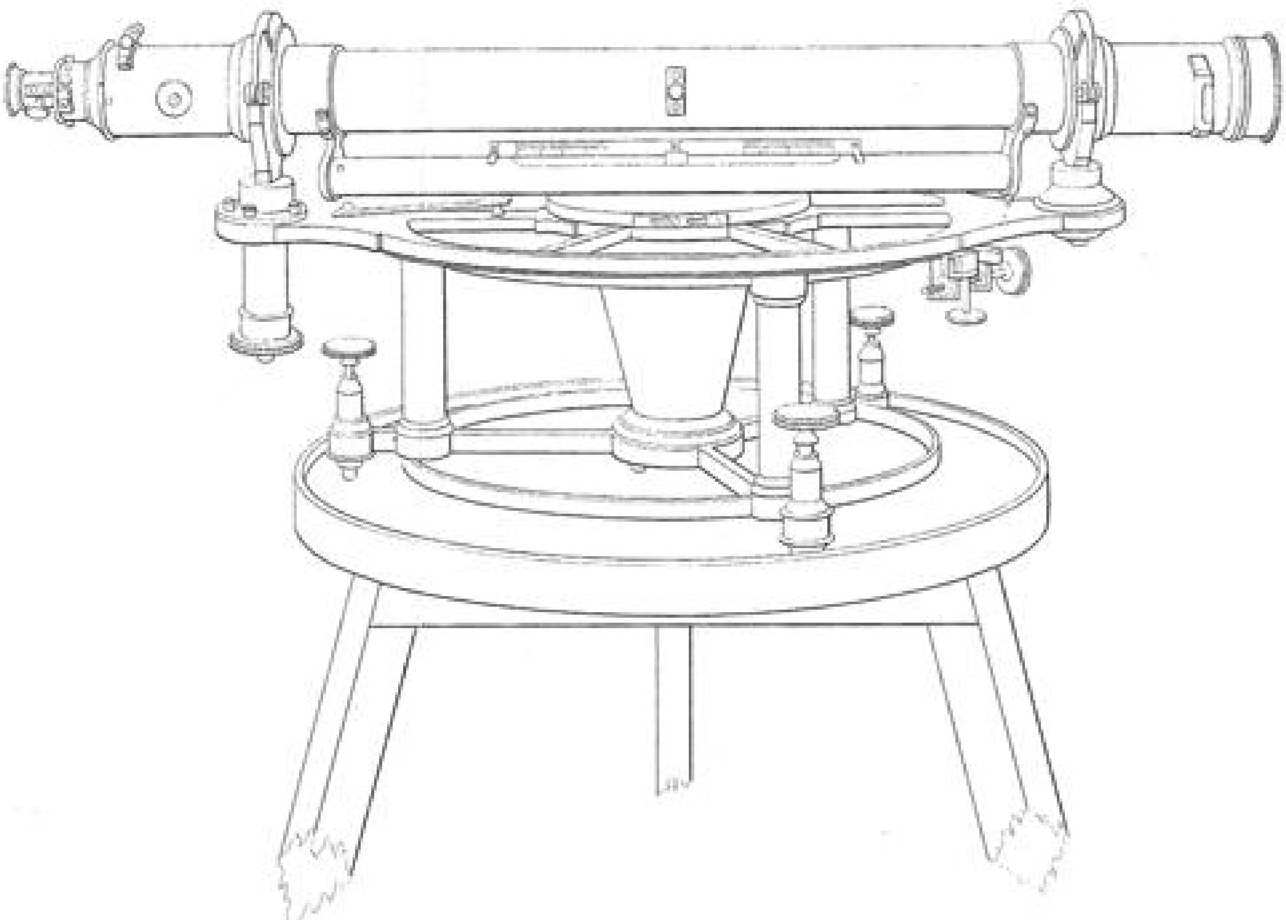
SECTION OF THE LAND PASSED OVER IN THE LEVELLINGS FROM SHEERNESS TO LONDON BRIDGE.

Fig. 1.

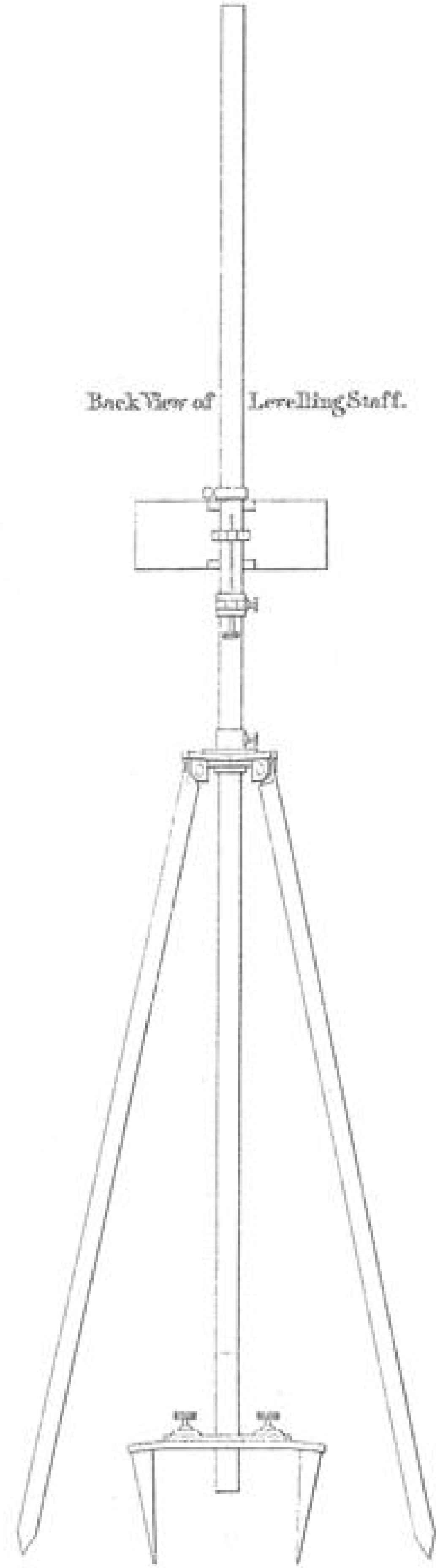
Front View of Levelling Staff.



GENERAL VIEW OF THE LEVELLING INSTRUMENT.



Back View of Levelling Staff.



H. Gladwin sc.