so that one comparison is lost. We thus have 117 cases to consider, but on one occasion the diurnal inequality obliterated a high-water, leaving 116 actual comparisons. The maximum range of the tide at Aden is 8 ft. 6 in., and this serves to give a standard of importance for the errors in height.

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| --- | --- | --- | --- |
| *Table of Errors in the Prediction of High-Water at Portsmouth in the months of January, May and September 1897.* | | | |
| Time. | | Height. | |
| Magnitude of Error. | Number of  Cases. | Magnitude of Error. | Number of  Cases. |
| 0“ to 5“ | 69 | Inches. 0 to 6 | 89 |
| 6“ to ιora | 50 | 7 to 12 | 58 |
| ttm to 15" | 25 | 13 to 18 | 24 |
| 16“ to 20“ | IO | 19 to 24 | 6 |
| 21“ to 25“ | II | — | — |
| 26“ to 30“ | 7 | — | — |
| 31" to 35m | 4 | — | — |
| 5≡m | I | ■■ “ |  |
| — | 177 | — | 177 |

|  |  |  |  |
| --- | --- | --- | --- |
| *Table of Errors in the Prediction of High-Water at Aden in March- April and November-December 1884.* | | | |
| Time. | | Height. | |
| Magnitude of Error. | Number of Cases. | Magnitude of Error. | Number of  Cases. |
| om to 5m | 35 | Inches. 0 | IS |
| 5“ to 10m | 32 | I | 48 |
| ιom to 15" | 19 | 2 | 28 |
| 15“ to 20“ | 19 | 3 | 14 |
| 20“ to 25m | 5 | 4 | II |
| 26“ and 28“ | 2 | No high water. | I |
| 33“ and 36“ | ***2*** | — | — |
| 56“ and 57m No high water. | 2 | — | — |
| I | — | — |
|  | ∏7 | — | 117 |

It would be natural to think that when a prediction is erroneous by as much as fifty-seven minutes it is a very bad one, but such a conclusion may be unjust. There was one case in which the high- water was completely obliterated by the diurnal inequality, but there were many others in which there was nearly complete obliteration, so that the water stood nearly stagnant for several hours. A measure of the degree of stagnation is afforded by the amount of rise from low to high-water. Now, on examining all the eleven cases where the error of time was equal to or over twenty minutes, we find five cases in which the range from low to high-water was less than 8 in., and these include the errors of fifty-six and of fifty-seven minutes. There is one case of a rise of 13 in. with an error of thirty-six minutes ; one case of a rise of 17 in. with an error of twenty-two minutes; one of 19 in. rise with thirty-three minutes error. The remaining three cases have rises of 2 ft. 10 in., 3 ft. 9 in., 3 ft. 11 in., and errors of twenty-two, twenty-three, twenty minutes. Thus all the very large errors of time correspond with approximate stagnation, and are unimportant. It is fair to conclude, therefore, that the predic­tions as to time are very good. The predictions as to height are obviously good, for more than half were within 1 in., and only eleven had an error of as much as 4 in.

When it is considered that the incessant variability of the tidal forces, the complex outlines of the coast, the depth of the sea, the earth’s rotation and the perturbations by meteorological influences are all involved, it should be admitted that the success of tidal prediction is remarkable. If further evidence were needed, we might appeal to tidal prediction as a convincing proof of the truth of the theory of gravitation.

§ 5. *General Explanation of the Cause of Tides.—*The moon attracts every particle of the earth and ocean, and by the law of gravitation the force acting on any particle is directed towards the moon’s centre, and is jointly proportional to the masses of the particle and of the moon, and inversely proportional to the square of the distance between the particle and the moon’s centre. If we imagine the earth and ocean subdivided into a number of small portions or particles of equal mass, then the average, both as to direction and intensity of the forces acting on these particles is equal to the force acting on that particle which is at the earth’s centre. For there is symmetry about the line joining the centres of the two bodies, and, if we divide the earth into two portions by an ideal spherical surface passing through the earth's centre and having its centre at the moon, the portion remote from the moon is a little larger than the portion towards the moon, but the nearer portion is under the action of forces which are a little stronger than those acting on the farther portion, and the resultant of the weaker forces on the larger portion is exactly equal to the resultant of the stronger forces on the smaller. If every particle of the earth and ocean were being urged by equal and parallel forces there would be no cause for relative motion between the ocean and the earth. Hence it is the departure of the force acting on any particle from the average which constitutes the tide-generating force. Now it is obvious that on the side of the earth towards the moon the departure from the average is a small force directed towards the moon; and on the side of the earth away from the moon the depar­ture is a small force directed away from the moon. Also these two departures are very nearly equal to one another, that on the near side being so little greater than that on the other that we may neglect the excess. All round the sides of the earth along a great circle perpendicular to the line joining the moon and earth the departure is a force directed inwards towards the earth’s centre. Thus we see that the tidal forces tend to pull the water towards and away from the moon, and to depress the water at right angles to that direction.

In fig. 2 this explanation is illustrated graphically. The relative magnitudes of the tidal forces are given by the numbers on the figure. M is the direction of the moon, V the centre of the hemisphere of the earth at which the man in the moon would look, I the centre of the hemisphere which would be invisible to him, DD are the sides of the earth where the tidal force is directed towards the earth’s centre. The outward forces at V and I are exactly double the inward forces at D and D.

If it were permissible to neglect the earth’s rotation and to consider the system as at rest, we should find that the water was in equilibrium when elongated into a prolate ellipsoidal or oval form with its longest axis directed towards and away from the moon.

But it must not be assumed that this would be the case when there is motion. For, suppose that the ocean consisted of a canal round the equator, and that an earthquake or any other cause were to generate a great wave in the canal, this wave would travel along it with a velocity dependent on the depth. If the canal were about 13 miles deep the velocity of the wave would be about 1000 miles an hour, and with depth about equal to the depth of our seas the velocity of the wave would be about half as great. We may conceive the moon’s tide-generating force as making a wave in the canal and continually outstripping the wave it generates, for the moon travels along the equator at the rate of about 1000 miles an hour, and the sea is less than 13 miles deep. The resultant oscillation of the ocean must therefore be the summation of a series of partial waves generated at each instant by the moon and always falling behind her, and the aggregate wave, being the same at each