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REPORT OF THE SUPERINTENDENT

OF THE

UNITED STATES COAST SURVEY

SHOWING

THE PROGRESS OF THE WORK

FOR THE

FISCAL YEAR ENDING WITH

JUNE, 1876.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1879.

For general expenses of all the work, rent, fuel; for transportation of instruments, maps, and charts; miscellaneous office-expenses, and for the purchase of new instruments, books, maps, and charts, will require $40,000.

PENDULUM-OBSERVATIONS.

By the measurements of arcs of the meridian, the approximate figure and magnitude of the earth was ascertained at an early period in the history of geodetic surveys. This was matter of necessity, as any extended survey, in respect of final precision, would depend on knowledge of the terrestrial outlines. In confirmation of the result from ordinary geodetic processes, the average figure of the earth, though not its magnitude, has been inferred also from observations of gravity in various latitudes by means of the pendulum. This was the first method employed, and the one preferred by Newton. The several results so derived have been long on record, and although imperfect, as were the instruments and methods used in a former day, the results are in such general accord as to warrant the application of refinements in apparatus and improvement in the methods of observation that had not been reached in the time of Borda and Biot. Natural difficulties that beset the early observers of course yet interfere.

In the measurement of arc local deflections of the plumb-line affect the astronomical amplitudes, and the pendulum reveals deviations in the force of gravity due to inequality of density in the earth's strata. Hence it is, notwithstanding the great precision with which latitudes and longitudes are determined, and the force of gravity ascertained at any one point, that very sensible residuals or apparent errors are found when we attempt to refer these results to any geometrical form. The cause of these discrepancies or "station errors" being beyond reach we can only endeavor to infer from all attainable sources what, under the denomination of figure of the earth, will best reconcile determinations of geographical position. The measure of the force of gravity, commonly denoted by the letter g, independently of what application is to be made of it, is universally recognized as one of the results due in a geodetic survey.

Within the last sixty years the solution of the problem respecting the measure of the force of gravity and figure of the earth as deduced from such measures has been aided by the experimental researches of Kater, Sabine, Plantamour, and others. Fresh stimulus in the inquiry was manifest in 1862, when the Geodetic Association of Europe, after due examination, recognized the pendulum as an instrument of great precision, and approved of its use in geodetic surveys. Since that year it has been employed in the great trigonometrical survey of India, and in 1865 and 1873 the pendulums used in India and in the Russian survey were swung at Kew Observatory, England, so that the results obtained at widely-separated positions on the surface of the earth are now comparable. They are also to be swung in Berlin.

With a view of providing for a comparison of the pendulum-observations of the Coast Survey with European and Asiatic systems which have been further advanced practically, Assistant Chas. S. Peirce was directed early in the spring of 1875 to procure apparatus of the invariable and reversible pendulum, and to observe with them at Paris, Geneva, Berlin, and Kew. His inquiries on the subject in Europe include also the details of the most approved forms of apparatus and the best methods in use for the improvement of the pendulum as an instrument for geodetic purposes. Theoretically and practically the study is such as to require extreme care and special attention in regard to the efficiency of the vacuum-chamber, the elasticity of the support, the loss of energy by propagated vibrations in the stand, the real temperature of the pendulum-bar, and many other conditions. There are several important forms, including that proposed by Bessel, but the two forms of apparatus specially referred to in this notice may be defined as follows: The invariable pendulum is a plain bar having near one of its ends a knife-edge by which it is suspended. This form is usually employed as a differential instrument, and for general use it therefore requires to be swung at a station where the force of gravity has been ascertained. But the reversible pendulum carries a knife-edge near each of its ends, and it may be swung from either. By means of movable weights (the use of which has been generally abandoned) the reversible pendulum can be so adjusted that when swung by either knife-edge the center of oscillation will coincide with the opposite knife-edge. The distance between

the knife-edges is then precisely equal to the length of the mathematical or simple pendulum oscillating in the same time. A chief advantage of the reversible pendulum is that it eliminates the effect of buoyancy and resistance of the air. The axes of suspension being interchangeable, this instrument is known also as the convertible pendulum. If it oscillates in a second of mean time it is known as the seconds pendulum, and the force of gravity at the place may be deduced from accurate measurements of its length. If, as usual, its oscillations do not exactly coincide with mean time, a small correction is applied to its measured length to give the true length answering to coincidence, and for that purpose a measure of the position of its center of gravity is requisite. The length of the reversible pendulum is one meter.

In the Appendix (No. 15), a paper by Assistant Peirce is given descriptive of his pendulum-observations at European stations, and also a scheme for a history and discussion of the pendulum and its relations to gravitation.

Assistant Peirce sailed from New York on the 3d of April, 1875. He proceeded at once to England, where he ascertained that the Kew Observatory is regarded as the initial point for British pendulum-work. This observatory, which is situated in the old deer-park at Richmond, is the property of the Crown, but the operations conducted there, which are chiefly of a magnetical and meteorological description, have been kept up by the Royal Society, through a special committee, and also by the Royal Meteorological Office. R. H. Scott, esq., who directs the Meteorological Bureau, is also chairman of the Kew committee. The pendulums of the Great Survey of India were swung at this observatory, both before and after the operations in India, the observatory being occupied at first by Captain Basseri during a year for this purpose, and afterward by Captain Heavyside during a year and a half. It is believed that the pendulums of Major-General Sir Edward Sabine were also oscillated here; in any case, all the historical English pendulums are here collected, and can be swung at any time if necessary. By the action of the American minister, General Schenck, an application was made, through the British Foreign Office, for permission to experiment with the American apparatus at the Kew Observatory, and to this request a favorable response was eventually received. Late in May, 1875, Assistant Peirce proceeded to Germany, where a Bessel's convertible pendulum, having the length of one meter between the knife-edges and being [redacted] of the instrument used in the Prussian survey, had already been ordered of the Messrs. Re[redacted] may be mentioned that the convertible pendulum, which was invented by Bohnenberger, [redacted] first seriously employed by Kater. Bessel, however, described such an improvement as [redacted]t the complete elimination of all effect of atmospheric resistance and friction. Long after Be[redacted]s death this improved instrument was constructed by Repsold, and was adopted by the Swiss survey and first used by Professor Plantamour, who developed the method of employing it. It is now exclusively used on the continent of Europe, and has received the unanimous sanction of the International Geodetical Association. An instrument of this sort had been ordered by the Coast Survey at the commencement of the pendulum-operations in 1872, but owing to the Messrs. Repsold being then occupied with preparations for the transit of Venus, the apparatus was not completed until the spring of 1875. This is not the place for any description of this instrument, which was executed with the consummate art and precision for which this celebrated firm of mechanicians is distinguished. This instrument having been procured, Assistant Peirce readily obtained from Professor Förster, the eminent director of the Berlin Observatory and president of the Imperial German Commission of Weights and Measures, the permission to make all necessary experiments in the building of the Office of Weights and Measures in Berlin, upon the very spot where the determination of Bessel had been made. This building has been erected expressly for the purpose of making accurate comparisons of standards of length. It is built with very thick walls of hollow brick, and the comparison chambers are lined with systems of flues, through which, by means of an engine in an adjoining building, hot air can be conveyed from a furnace or cold air from an ice-house. This building, which will serve as a model for similar buildings in other countries (as it already has in France), is the most suitable possible place for pendulum-experiments. The building, however, was not sufficiently completed in the summer of 1875 to allow of pendulum-experiments being made there to the greatest advantage. It was thought desirable to make a careful comparison of the

American reversible pendulum with that of Prussia. The celebrated geodesist, Lieutenant-General Dr. Baeyer, the director of the Royal Prussian Survey, who furthered Assistant Peirce's operations in the most gratifying manner throughout his stay upon the continent, at once placed the Prussian instrument at his disposal, and the meter-scale of this apparatus, which had already been carefully compared with the Prussian normal meter at different temperatures by Professor Förster, was submitted to fifty independent series of comparisons with the similar scale of the American standard by Assistant Peirce. These operations, which yielded a very satisfactory result, lasted until July 7. Assistant Peirce afterward proceeded to Geneva, where, upon the return of Professor Plantamour (who was at first absent), arrangements were readily made for oscillating the reversible pendulum at the observatory of this city. Assistant Peirce had thus, at the outset of his operations with Bessel's pendulum, the signal advantage of receiving the counsels of the distinguished *savant* who first introduced the use of it, and who has studied so carefully the methods of its manipulation. Actual experiments were made upon seventeen days, between August 26 and September 17. The method of making the experiments, adopted by Assistant Peirce, may here be described. It has been slightly modified from time to time, but its latest form is as follows: On the first day, the rigidity of the stand and the position of the center of gravity of the pendulum are measured. The next day is devoted to comparisons of the pendulum and standard. The oscillations are then commenced; and no measures of the pendulum are made upon days devoted to these experiments. During the swingings of the pendulum the Repsolds "firma" is always forward. Each day the pendulum is first swung with the heavy end up, then with the heavy end down, and then with the heavy end up again. Two such sets of experiments are sometimes made in one day, but this is considered rather objectionable. After four such sets, the pendulum is remeasured the next day. A day is then devoted to remeasuring the frame of the stand, to interchanging the knife-edges, and to determining the center of gravity before and after this change. In interchanging the knife-edges, they are never reversed end for end. A day is then given to measuring the pendulum. Four more sets of swingings are then made. The pendulum is then again measured as before, and then the determinations of center of gravity and flexure are repeated. Fifteen days might be occupied by such a determination, but in practice it is necessary to vary the proceeding more or less. The times of oscillation are determined by observing transits of the pendulum across the web of a telescope and registering the time upon a chronograph. One hundred transits are observed each time, and in one of the following orders:

A. 25 transits from right to left, then 50 from left to right, then 25 from right to left.

B. 50 transits from left to right, then 50 from right to left.

C. 50 transits from right to left, then 50 from left to right.

D. 25 transits from left to right, then 50 from right to left, then 25 from left to right.

Choice is made between these methods, so that the signals will not interfere with the two-second breaks of the chronometer, which affect the same pen. Four sets of transits are so taken that at their mean times respectively the oscillations of the pendulum have the half-amplitudes 2°, 1½°, 1°, and ½°. Different eye-pieces are used with magnifying powers nearly inversely proportional to the amplitudes, so that the apparent velocity shall remain constant.

The observatory of Geneva is a small building with one main room, opening by large glass doors to the north and south. The floor is of asphalt, and the instrument rested upon the floor. There was necessarily more or less walking about, and several visitors each day entered at the glass doors just mentioned. Assistant Peirce received every possible assistance and attention from Professor Plantamour and his assistants, but it is necessary to note the fact that the place was hardly suitable for such operations. Observations of time were made by the assistants of the observatory.

At Geneva, Assistant Peirce set up a micrometer in front of the pendulum-stand, and by means of a weight passing over a pulley, whose friction was determined, he measured the flexure of the support of the pendulum, and determined the important correction, amounting to over $0^{mm}.2$, to be applied to the length of the seconds pendulum on account of the swinging of the stand from side to side as the pendulum swings.

Proceeding to Paris, Assistant Peirce had the honor and advantage of attending the sittings of

the International Geodetical Association and of its standing committee, which met in September, 1875, in the palace of the Ministry of Foreign Affairs. The whole subject of the pendulum received a thorough discussion, and a resolution was unanimously passed expressing the sympathy and interest of the association in the expedition of Assistant Peirce. The reversible pendulum had unfortunately sustained grievous damage in transportation from Paris to Geneva. Thus one of the great advantages of this instrument received illustration; for if it had been an invariable pendulum, the connection between previous and subsequent operations would have been entirely destroyed; whereas, with the existing construction, the pendulum had only to be put again in condition in order to give results perfectly comparable with those which had gone before. During the interval created by this accident the Geneva observations were completely reduced.

Permission was granted by his excellency M. Wallon, Minister of Public Instruction, Worship, and the Fine Arts, for oscillating the American pendulum at the observatory at Paris. M. Leverrier afforded every assistance; and the operations were conducted in the great Salle du Meridien, where the pendulums of Borda, of Sabine, and others had previously been swung. The experiments were conducted in the recess at the northern end of this hall, and were made upon eighteen days, between January 18 and February 29, 1876. The standard clock of the observatory was made use of, and its corrections were furnished by the observatory. M. Wolf, the well-known astronomer attached to the observatory, to whom the arrangements for the experiments were intrusted by the illustrious director, rendered Assistant Peirce in the most gracious manner all the aid that this magnificent institution could furnish.

On the conclusion of the experiments in Paris, Assistant Peirce again repaired to Berlin, and as soon as the great comparing chamber of the Bureau of Weights and Measures was ready, experiments were commenced there upon a pier at the northern end. As before, every possible assistance was received from Professor Förster and Lieutenant-General Baeyer. The experiments were made upon twenty-four days, from April 19 to June 6, 1876. A clock was furnished by the observatory, which was compared with the normal clock whose corrections were furnished by the observatory.

A standard meter with lines and also cylinders for comparison with an end measure was, at a subsequent visit, furnished to Assistant Peirce by the Imperial Commission of Weights and Measures.

After the experiments in Berlin, a favorable response having been received to the application of Assistant Peirce for permission to make his experiments at the Kew Observatory, he went to England and commenced experiments without delay. The observations commenced in June, and were finished in July. The time was observed by Mr. Henry Farquhar, with the transit of the observatory, and four chronometers were kept running at once.

Mr. Peirce arrived at Boston August 26, 1876. He is at present occupied in completing the connection of the determinations of gravity in Europe and America.

MAGNETISM.

In the operations of the survey from year to year, determinations have been made of the variation of the compass or magnetic declination, and also of the dip of the needle and the magnetic intensity. Part of these observations were merely incidental to the prosecution of other branches of the work, but in that way much information has been gathered, and this from time to time has been combined with data from other sources for the means of marking our coast charts with the variation of the compass. To this prime necessity in the interest of navigation have been added in later years increasing inquiries in regard to the bearing of lines in land-surveys of old date. Numerous inquiries of this kind have been answered at the office, but thus far the means for precision have been limited by the scarcity of observations in the interior. In the course of the coming year it is proposed to select and occupy such points as will most effectually combine with those at which the variation of the compass has been already determined and thus to gain, as early as possible, the means of tracing lines for equal magnetic declination from the interior across the coast and with assured accuracy to continue them out to sea. On sketch No. 2 all the magnetic stations occupied by Coast Survey observers between 1833 and 1877 are marked. At all of these the declination, and at most of them the magnetic dip and intensity have been determined. Several of the stations have