IS THE ATLANTIC COAST SINKING ? THE EVIDENCE FROM THE TIDE.

by H. A. MARMER

Assistant Chief of the Division of Tides and Currents of the United States Coast and Geodetic Survey.

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About thirty years ago the late Douglas Johnson discussed in this journal the question of the stability of the Atlantic coast under the title "Is the Atlantic Coast Sinking ?" (1) After referring to the then generally accepted view that the Atlantic coast of North America was subsiding at the rate of one to two feet in a century, he reviewed some recent contributions on the problem that controverted this view. For a number of years Johnson had been arguing in his characteristically lucid manner that "the so-called proofs of land sinking within historic times were open to alternative explanations, whereas the physiographic evidence could only be explained by postulating long-continued coastal stability".

Johnson concluded his discussion by quoting from a report on "Precise Levelling in New York City" by Frederick W. Koop, published in 1915, as follows : "From the determinations above noted, which are the result of spirit levelling of unquestioned accuracy, it is clear that from the standpoint of the geodesist or engineer there is no reliable evidence to show a general progressive subsidence of the Atlantic coast in New York City and vicinity. On the contrary, all the evidence is in favor of stability..... The work of the writer (Koop) on the Board of Estimate levelling must be construed as a striking confirmation of Professor Johnson's theory of coastal stability as set forth in the preceding paragraphs. It is of especial interest because it is a proof based on engineering methods of the absolute stability during the last quarter of a century of the very part of the coast which is generally supposed to be undergoing most rapid subsidence at the present time".

It must be noted that the question of coastal stability was only incidental to the primary purpose of "Precise Levelling in New York City", and the technical results embodied in that report are in no manner dependent on that question. In the light of present tidal knowledge, a careful reading of that portion of Koop's report which deals with the question of coastal stability compels one to characterize "absolute stability" as too strong. Koop based his conclusion on tidal data that are known to have been insufficient to permit so unequivocal a statement. Since that time, however, a very considerable amount of tidal data has been obtained that do permit definite quantitative conclusions, and it is these data with which the present article is concerned.

The difficulties inherent in tide observations and the caution necessary in applying tidal data to the study of coastal stability were discussed by the writer in an article in this journal several years ago (2). With these in mind we may go directly to the tidal data.

The tidal data most directly applicable to the problem of coastal stability are the sea-level values for successive years. In Figure 1 the open circles represent the yearly values of sea level as determined by the United States Coast and Geodetic Survey at seven of its primary tide stations, from Portland, Maine, to Mayport, Fla. These stations were selected because they furnish the longest series of continuous observations in their areas.

For each station the yearly value represents the average height of sea level as determined by averaging the readings of the height of the sea at that station at the beginning of each hour throughout the year. In other words, each yearly value is the average of very nearly 9000 hourly readings. At each station the hourly heights of the

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(1) Geographical Review, N° 3, 1917, pp. 135-139.

(2) H. A. Marmer : Tide Observations at Baltimore and the Problem of Coastal Stability, *Geogr. Rev.*, Vol. 33, 1943 pp. 620-629.

sea were referred to a tide staff the elevation of which could be kept constant by frequent levelling to a number of adequate bench marks.

Although the observations at New York cover the longest period, they really represent two distinct series, an earlier, from 1893 to 1920, made at Fort Hamilton in the Narrows of New York Harbor, and a later series, from 1920 to 1947, made at the Battery, New York City. The longest series made at any one place is that at Baltimore, which began in 1903. It should also be noted that at Atlantic City there was a break during 1921 and 1922.

All the stations show that sea level, as measured directly, varies from year to year, sometimes by only a few hundredths of a foot, sometimes by as much as a quarter of a foot. These variations are due primarily to the variation in wind and

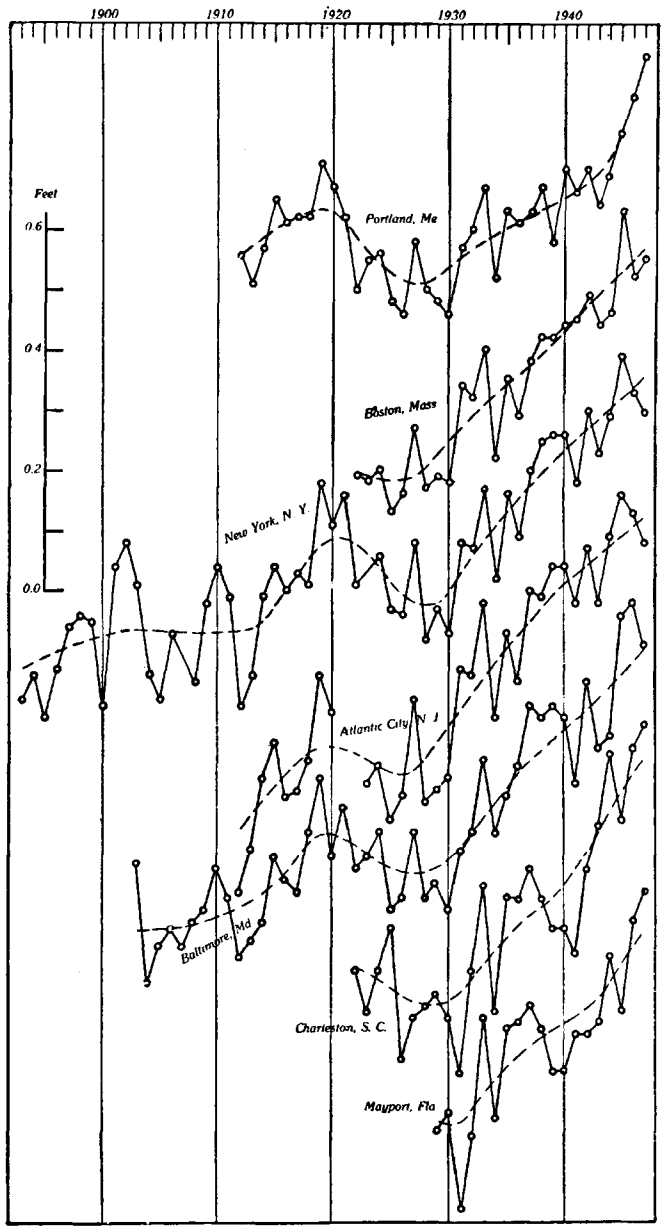

FIG. 1.

Yearly sea level at tide stations on the Atlantic Coast and derived smoothed curves.

weather from one year to another. A simple method of eliminating the larger part of this variation is smoothing by the method of moving means. The broken-line curve associated with the diagram for each station was drawn by determining moving means and then passing a more or less smooth curve through these means. For Portland the curve was not continued beyond 1945, because observations beyond 1947 would be necessary to determine whether the continued rise from 1944 is a chance occurrence or indicates a decided change in trend.

The broken-line curves may thus be taken as a first approximation to the true values of sea level. Let us focus our attention on these curves. It will be convenient to divide the observations into two time series, up to 1930 as one series and from 1930 to 1947 as the other. For the latter period the curves clearly and unmistakably indicate a continuous rise of sea level. The rise at each of the stations exclusive of Portland is as follows : Boston, 0.32 foot ; New York, 0.36 foot ; Atlantic City, 0.35 foot ; Baltimore, 0.35 foot ; Charleston, 0.40 foot ; Mayport, 0.32 foot. As an average, these six stations give a rise of sea level of 0.35 foot for the 17-year period, or almost exactly 0.02 foot a year. For Portland, for the 15-year period 1930 to 1945, the rise is 0.22 foot, or 0.015 foot a year. At this rate, the rise for the period 1930 to 1947 would be 0.25 foot.

For the six stations south of Portland the differences in rise of sea level for the 17-year period are so small that, in view of the variability of sea level from one year to another, the average rise of 0.35 foot may be taken at the most probable value for each of the stations. For Portland the difference from the mean value is relatively so large as to indicate a probable smaller rate of rise.

To say that sea level has risen with respect to a fixed point on shore is only another way of saying that the fixed point has subsided with respect to sea level. To determine which is the active agent and which the passive is another problem. If the coast is the active agent, the subsidence is absolute ; if sea level is the active agent, the subsidence is relative ; but in either case there is a lowering of the coast relative to sea level. To the question "Is the Atlantic coast sinking ?" the answer must therefore be "Yes ; for the past 17 years it has been sinking at the rate of 0.02 foot a year."

Before 1930 the record, as Figure 1 shows, is more complex than after that date. The four stations for which observations are available from 1919 to 1930 seem to indicate a lowering of sea level during those years of about 0.2 foot. But the preceding seven years show a rise by an even larger amount. A detailed study of this matter in connection with the tide observations at Baltimore (3) has proved that the apparent rapid rise from 1912 to 1919 and the apparent rapid fall from 1919 to 1930 are almost wholly chance effects of wind and weather and that the true sea level changed but little from 1912 to 1930.

This conclusion is reinforced by a study of sea level during the summer months, when the disturbing effects of wind and weather are less frequent and less pronounced than during the winter months. In Figure 2 are plotted the sea-level values for each year for the five-month period June to October for New York and Baltimore. The broken-line curves were derived, as before, through the use of moving means. The steady rise from 1930 to 1947 is practically the same as for the yearly sea levels, being 0.33 foot against the 0.35 foot found from the yearly values. But the rapid rise and fall between 1912 and 1930 are no longer evident.

From Figure 2 it is clear that sea level rose somewhat at both Baltimore and New York during the 27-year period 1903 to 1930. For Baltimore the difference from the smoothed curve is 0.08 foot ; for New York it is 0.07 foot. In other words, at these two places the rise of sea level since 1930 has been at a rate about seven times that of the preceding quarter of a century.

For the years before 1903, only New York furnishes data — for a period of 10 years. This is too short to determine precise results. If we accept that part of the curve in Figure 2 at its face value, there was a rise in sea level of about 0.08 foot during the 10 years.

To sum up, it may be said that the tide observations prove that the Atlantic coast of the United States has been subsiding since 1930 at the rate of 0.02 foot a year and

(3) Marmer, *op. cit.*, pp. 627-628.

that during the 35 years before 1930 the coastal region of the Middle Atlantic States had been subsiding at about one-seventh of the rate.

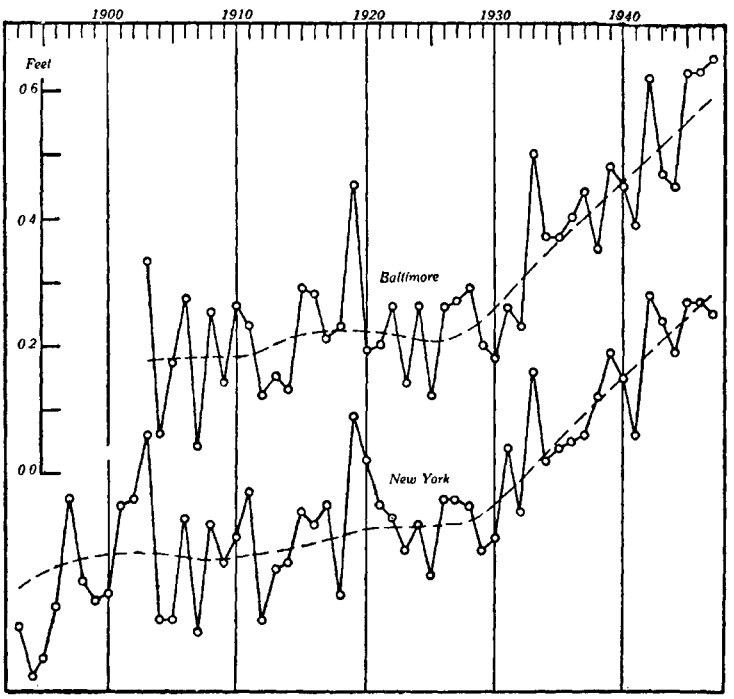

FIG. 2.

Yearly sea level at Baltimore and New York, based on observations for the five-month period June to October, and derived smoothed curves.

This statement still leaves open the question whether the subsidence is absolute or relative. Furthermore, it is not at all improbable that both may have occurred — some actual subsidence of the coast and some actual rise of sea level. Systematic tide observations throughout the world will permit a precise apportionment to each ; for an actual rise in sea level will be of the same magnitude throughout the world except for a slight variation depending on latitude.