integrated cement tile; and the Montana State Agricultural College in the case of the sewers and culverts of the city of Great Falls. These investigators, however, do not discuss the cause of the destruction other than to mention the sulpho-aluminate of lime formation, and in the case of the cement tile to mention that the silica and alumina were removed.

As the U.S. Government has been locating a large number of its irrigation projects in such regions, it was considered to be within the scope of the investigation of the Structural Materials Laboratories to make a study of this condition, which work was later consigned to the Bureau of Standards.

**Scope of Investigations.**—These investigations were planned for the purpose of determining the suitability and permanency of various cements in structures exposed to the chemical and mechanical action of sea water and alkali salts and, if possible, the cause of failure or disintegration of cements and concretes.

The study of the subject was begun in such a manner as to determine, if possible, just what reaction would take place when the salts, commonly present in sea water and alkaline soils, were allowed to act on cement mortars. In order that this study should be complete, information should be obtained not only as to what salts present in any solution might cause destruction, but also in what manner this destruction is being accomplished. Both chemical and physical investigations were made in the laboratory, and field tests in sea water were made. In both series of laboratory tests there have been used at various times, in addition to sea water from Atlantic City, solutions of sodium chloride, sodium sulphate, sodium carbonate, magnesium chloride, magnesium sulphate, ferrous sulphate, and also solutions in which there were present in equal parts by weight two salts as sodium chloride-sodium sulphate, sodium chloride-magnesium chloride, sodium chloride-magnesium chloride, sodium chloride-magnesium sulphate, sodium sulphate-magnesium sulphate, sodium sulphate-magnesium chloride, sodium chloride-sodium carbonate, sodium chloride-calcium chloride, sodium sulphate-sodium carbonate, magnesium chloride-magnesium sulphate. It will be noted that a solution of calcium sulphate was not used. This salt is comparatively insoluble, and a series of tests using it, even in a saturated solution, would hardly be comparable with the series in which the above were used and in which the solutions contained but 2 per cent. by weight of the anhydride salts. Moreover, when this solution contained the sulphuric anhydride radical, calcium sulphate would be formed in the cement.

With regard to field investigation, while much valuable information can be obtained from an inspection of existing concrete structures in sea water, it is practically impossible to obtain reliable and complete information after a structure is several years old as to the qualities of the materials used and the character of the workmanship in construction. The field laboratory was located at Atlantic City, N.J., as it was readily accessible and the sea water at this point was rather pure and undiluted from fresh-water streams. Atlantic City is situated about 150 miles south of New York on an island 7 miles long and from ⅛ to 1 mile in width, lying about 6 miles from the New Jersey mainland, with bays and salt marshes between. The building used as a laboratory, under which the exposure tests were made, was located on a pier 700 feet from shore, about 20 feet above mean tide with 20 feet depth of water beneath.

Concrete of varied composition was made with Portland, natural, slag, and other special sea-water cements under conditions approaching as closely as possible the various methods used in sea-water construction. Several thousand briquettes and other small test pieces were made and exposed to sea water in connection with the concrete tests for the purpose of comparing various types and brands of cements.

**Conclusions.**—The conclusions must be limited by the scope of this investigation and since the physical tests cover a period of exposure not exceeding 3½ years the conclusions should be considered as somewhat tentative.

1. Portland cement mortar or concrete, if porous, can be disintegrated by the mechanical forces exerted by the crystallization of almost any salt in its pores, if a sufficient amount of it is permitted to accumulate and a rapid formation of crystals is brought about by drying; and as larger crystals are formed by slow crystallization, there would be obtained the same results on a larger scale, but in greater time if slow drying were had. Porous stone, brick, and other structural materials are disintegrated in the same manner. Therefore, in alkali regions, where a concentration of salts is possible, a dense non-porous surface is essential.

2. While in the laboratory a hydraulic cement is readily decomposed if intimately exposed to the chemical action of various sulphate and chloride solutions, field inspection indicates that in service these reactions are much retarded if not entirely suspended in most cases, due probably to the carbonization of the lime of the cement near the surface or the formation of an impervious skin or protective coating by saline deposits.

3. Properly made Portland cement concrete, when totally immersed, is apparently not subject to decomposition by the chemical action of sea water.

4. While these tests indicated that Portland cement concrete exposed between tides resisted chemical decomposition as satisfactorily as the totally immersed concrete, it is felt that actual service conditions were not reproduced, and therefore further investigation is desirable.

5. It is not yet possible to state whether the resistance of cements to chemical disintegration by sea water is due to the superficial formation of an impervious skin or coating, which is subsequently assisted by the deposition of shells and moss forming a protective coating, or by the chemical reaction of the sea salts with the cement forming a more stable compound without disintegration of the concrete, or by a combination of both of these phenomena.

6. Marine construction, in so far as the concrete placed below the surface of the water is concerned, would appear to be a problem of method rather than materials, as the concrete sets and permanently hardens as satisfactorily in sea water as in fresh water or in the atmosphere, if it can be placed in the forms without undue exposure to the sea water while being deposited.

7. Natural, slag, and other special cements tested in concrete mixtures showed normal increase in strength with age both in sea water and in fresh water.

8. In the form of neat briquettes most of the Portland cements of high iron content, several of the cements of high or normal alumina content and one special slag cement did not show any marked difference in tensile strength whether exposed to fresh or sea water for all periods up to two years. Other cements of various com-