Recent USA Research on Soil Strength and Deformation Characteristics Under Dynamic Loading Conditions

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This paper presented a review of research on the strength and deformation characteristics of soils under transient, repetitive and earthquake type loading conducted in the United States during the past 12 years.

The increase in strength of clays and dry sand under transient loading conditions was illustrated by test data from studies at Harvard University *(Ref. 1)* and M.I.T. *(Ref. 2)* and the mechanics of strength mobilization in saturated sands under transient loading by investigations conducted at the University of California *(Ref. 3)*.

A somewhat more detailed discussion of the results of repeated loading studies was then presented with particular reference to their application in pavement design. Recent studies conducted by the California Division of Highways *(Ref. 4)* have shown that in the case of pavements not only must the cumulative pavement deformation be considered but also the possibility of fatigue failures in the surfacing resulting from excessive resilient deformations.

Even in cases where pavements have shown no appreciable permanent deformation, failures of the surfacing have been observed. By making measurements of resilient deformation of pavements at a number of locations throughout the State it has been found that such failures are associated with large numbers of stress applications and the more resilient subgrade soils. The implication of these results was discussed.

Investigations of the plastic deformation of compacted clays under repeated loading were then described. Apparatus used for testing soils under these conditions was illustrated *(Ref. 5)* and data were presented to demonstrate the influence of frequency of stress application and stress history on the results obtained *(Refs. 6, 7)*. A brief discussion of thixotropy in soils *(Ref. 8)* and its influence in repeated load studies was included in this discussion.

The significant effects that a previous stress history in the form of a series of repeated stress applications may have on the subsequent deformation of a soil was illustrated by a comparison of data from test series in which specimens were subjected to a progressive increase in repeated axial stress and in which previously unloaded specimens were subjected to similar stress intensities.

It was shown that an entire sequence of 240,000 stress applications (consisting of 30,000 repetitions at each of eight different stress intensities) caused only as much deflection as would the last 1,500 applications of the series applied alone. In the light of these results the practical difficulty of assessing the cumulative effects of a series of stress applications of different magnitudes from data concerning their individual effects was emphasized.

Finally, studies of soil strength under earthquake loading conditions were described. The results of model tests (scale 1:150) conducted at the University of California *(Ref. 9)* to investigate the earthquake resistance of rockfill dams were presented and used to show that applied shocks produced no significant effects (appreciable changes of section) on the models until the progressively increasing accelerations exceeded 0.4 g; also that even when the accelerations of the test earthquakes were increased to more than 1 g the models suffered only small changes of shape without any major failure developing.

More recent tests on compacted clay under simulated earthquake loading conditions were also briefly described.

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Foundations for Large Bridges Across San Francisco Bay

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San Francisco Bay, an area of 463 square miles of water connected to the Pacific Ocean by a narrow gorge about one mile wide, has always presented a challenge to the civil engineer. Crossing the Bay and forming a part of the California highway system are four major bridge structures: the San Francisco-Oakland Bay Bridge, the Golden Gate Bridge, the Richmond-San Raphael Bridge and the Carquinez Bridge. The paper outlined the type of foundations used in the construction of these bridges.

The San Francisco-Oakland Bay Bridge, opened in 1936, has a length of about seven miles, including ramps and fills, and spans about 4½ miles across the water. The methods of construction of pier foundations included the use of steel sheet pile cofferdams, Moran pneumatic caissons *(Ref. 1)* sunk in some cases to depths of 240 ft and open caissons *(Ref. 2)*. The techniques of sinking the Moran pneumatic caissons were illustrated and discussed.

The Golden Gate Bridge, spanning across one mile of water, was completed in 1937. The long suspension span of 4,200 ft resulted in only two piers being constructed under water. Difficulties encountered in the construction of an access trestle 1,100 ft long, a concrete fender wall and a pneumatic caisson, finally resulting in the use of the fender as a cofferdam for pier construction, were described *(Ref. 3)*.

The Richmond-San Raphael Bridge, spanning four miles from Richmond to San Raphael, was completed in 1947. Of the 79 piers for the bridge, nine were built on land, eight were built in cofferdams in the shallow waters near the eastern bridge terminus and the remaining 62 were of the bell bottom type for which the contractor elected to use precast concrete structural units. The sequence of construction operations for the bell bottom type piers was reviewed and illustrated *(Refs. 4, 5)*.

The most recently completed of the Bay bridges is the Carquinez Bridge, spanning 3,350 ft across the Bay and continuing to a total length of about 5,300 ft *(Refs. 6, 7)*. The foundations for the Bay portion of the