

REPORT OF THE GEOLOGIST

May 8, 1930

To the Honorable Board of Directors:
Golden Gate Bridge and Highway District,
San Francisco, California.

Attention of the Chief Engineer:

Gentlemen:

The Golden Gate at San Francisco, which it is proposed to span by a suspension bridge, was at one time a river gorge thru which flowed the greater part of the drainage of California as a fresh water stream. Beyond the Gate a delta was built out into the deep water out as far as the Farallone Islands, and was spread along the coast by the currents and waves for many miles as a great embankment. When the mouth of the Sacramento River was on the surface of the delta outside the gorge, the coast was much higher relatively to sea level than at present. What is now the Bay of San Francisco was then a broad valley, like that of Santa Clara on the South, or Napa and Sonoma valleys on the north. This physiographic condition was changed by the inauguration of a subsidence of the coast in the region of the outlet of the river and its growing delta. The subsidence, proceeding slowly, allowed the waters of the ocean gradually to invade the river gorge, and then, equally gradually, to expand over the valley through which the river flowed, till it became the magnificent harbor of San Francisco Bay. The islands in the bay are the former hills of the valley land. The bay became a trap for the sediments brought out by the streams from the Sierra Nevada and from the east side of the Coast Ranges; and the depression of the old valley has been largely filled with that deposit. But the rate of subsidence has been sufficient to prevent the depression from becoming completely filled, and so converting it again into a valley floor. The total amount of subsidence may be ascertained approximately from the fact that the deepest part of the Golden Gate is 63 fathoms or 378 feet. When the gorge was functioning as a river channel, it is improbable that its bottom was more than 30 feet below sea level. We may conclude therefore that the total subsidence has been about 350 feet.

At the present time the subsidence, if still in progress, is so slow that it is not appreciable, and there has been no measurable change of level of bench marks established on rock at San Francisco many years ago by the U.S.Coast and Geodetic Survey.

Thus from the point of view of geological history the Golden Gate bridge is a span over a river gorge.

The rocks traversed by the Golden Gate belong to a series of formations which are wide spread and extensively exposed throughout the Coast Ranges of California. It is known to geologists as the Franciscan Series, and is so named from the City of San Francisco. The series comprises many different kinds of rock, some sedimentary and some igneous. The sedimentary formations consist chiefly of sandstones and shales, which are for the most part nonmarine, and are recognized by geologists as continental in origin, having been deposited on the flood plains of rivers or in interior basins. The sandstones are very

strongly indurated as a rule, and are locally metamorphosed into various crystalline schists, among which are bright blue glaucophane schists containing the rare and very hard mineral Lawsonite. These continental formations alternate with marine formations of two distinct types, one known as radiolarian chert and the other as foraminiferal limestone, both well stratified rocks abounding in minute, marine fossil organisms.

During the deposition of these varied strata there were some active volcanoes in the region, for we find occasional sheets of lava between the sedimentary formations.

This entire aggregate of stratified rocks and lavas is over a mile in thickness in the vicinity of San Francisco, and their stratigraphic relations are particularly well displayed in the Marin peninsula, which forms the north side of the Golden Gate.

After the Franciscan series had accumulated to the thickness of over a mile in a basin coextensive with the present Coast Ranges, the region was greatly disturbed by igneous intrusions, and as a result, two general types of igneous rock are found intruded into it at many localities. One of these is peridotite, now very generally altered to serpentine, and the other is basalt usually with a pronounced ellipsoidal structure. It happens that the south pier of the bridge is founded on serpentine and the north pier on basalt. The fact that the narrowest part of the Golden Gate, that selected for the site of the bridge, is bounded on the one side by serpentine and on the other by basalt, is significant of the relatively great resistance of these rocks to the ordinary agencies of erosion.

The serpentine at Fort Point, on the south side of Golden Gate, is derived from peridotite by a process of hydration, whereby the originally anhydrous silicate of magnesia takes up about 13 per cent of its weight of water, and so greatly increases its volume. To accommodate this enlargement the rock shears internally as the hydration proceeds, and when the process is complete it consists of an aggregate of residual unsheared, massive spheroids of strong serpentine embedded in a matrix of sheared and schistose serpentine having a very low tensile strength. The residual spheroids vary in diameter from a few inches up to 10 feet or more. While the tensile strength of this rock is low, under compression and confined, as it will be, it is entirely adequate to support the terminal pier of the bridge. The load stress transmitted from this pier to the foundation rock is less than two hundred pounds to the square inch, and this is a relatively small load. Sand has no tensile strength at all, but under compression and confinement it makes an excellent foundation for structures transmitting a very much larger load stress than is here proposed. Similarly the serpentine, notwithstanding its low tensile strength, could sustain a much heavier load than that of the bridge pier. This fact was practically demonstrated by the test conducted by Mr. Strauss, Chief Engineer of the Golden Gate Bridge and Highway District, at Fort Point on a representative section of the serpentine. An area of the serpentine, 20 by 20 inches at sea level was loaded to the extent of 92 tons, or 460 pounds to the square inch without yielding. The bearing strength of the foundation rock of the south pier, 1000 feet north of Fort Point, will be increased by confinement afforded by the excavation made to receive the pier. I recommend that this excavation, at its periphery, be carried to a depth of not less than 25 feet below the natural rock surface of the sea floor measured from the lowest point of its intersection with the pier.

The cores of the borings made at the site of the south pier show that the rock is identical with that so well exposed on shore at Fort Point, and an examination of the cores indicates that the bearing strength of the rock is not less than that of the rock upon which the test was made.

The south anchorage of the bridge will have to be designed to depend upon dead load rather than upon the tensile strength of the rock or upon the frictional resistance of the latter to the pull of the anchor.

The north pier of the bridge at Lime Point is founded on basalt containing inclusions, large and small, of radiolarian chert, an adjoining formation into which it was intruded. There are present in this rock the usual joints which affect all rocks and some shears; but the rock is very strong and is amply adequate to sustain the load of the pier. The cores from the drill holes show that it is uniform in character except for the occasional inclusions of radiolarian chert, which do not in any way detract from its strength. Since the subaqueous slope at the pier site is rather steep I recommend that the foundation excavation be carried to a depth of not less than 25 feet below low tide and that the south face of the pier be located not less than 20 feet north of the present low water shore line.

The north anchorage is located partly in sandstone and partly in greenstone, a diabase variety of the basalt. Both rocks are all that could be desired for the purposes of anchorage.

Once or twice in a century, it may reasonably be assumed, the region of San Francisco will be shaken by a violent earthquake. Six miles to the west of the proposed bridge is the trace of the San Andreas fault upon which a sudden slip occurred in 1906, with disastrous results to the City of San Francisco. Every design for a large structure on San Francisco Bay should take into account the stresses which may be engendered by a repetition of that movement, or by a fault slip elsewhere in the region. So far as I am aware there is no danger of a dislocation in the Golden Gate itself, whereby a differential movement of the two ends of the bridge might be caused. The danger to be guarded against is the excessive swaying of the bridge induced by the vibration and concussion of the earth due to a slip on some fault within a radius of twenty miles. In such an earth movement there are three components of motion to be considered: (1) that parallel to the length of the bridge, (2) that transverse to the bridge and (3) the vertical component. The parallel movement will throw a sudden strain upon the anchorages, first on one and then on the other, and the strain will cause against damage from this cause is the elasticity of the steel; but the anchorages should be designed to withstand very much greater stresses than those due to the dead load of the bridge - stresses which may be applied very suddenly and for which the only remedy is strength of structure. A remote contingency, which nevertheless should be considered in the design, is the possibility, in a prolonged earthquake, of a longitudinal or north-south swaying of the bridge magnified by resonance. This might happen if the main vibratory movement of the earth were north and south and the period of the earth waves happened to be the same as that of the vibration of the bridge. Owing to the nature of the structure and its great elasticity, this longitudinal swing would also almost instantly be transformed into an up and down sway of the mass suspended between the piers. The strain at the anchorages would be in some measure proportionate to the amplitude of this vertical sway.

In the second case, where the chief component of the earth vibration is transverse to the bridge, the effect would be to cause the structure to swing normal to its length. If the bridge be heterogeneous in structure, that is, if it be not built thruout of the same material, it will suffer more than if it be homogeneous. Thus, if the bridge is carried on masonry towers the masonry will have one period of vibration and the steel another, and the two structures will hammer each other violently. The destructive effect of this reciprocal hammering was well displayed in the destruction of the city hall of San Francisco in 1906. It is important, therefore, in the design of the structure to make it homogeneous. The transverse swing of the bridge may be augmented by resonance, if the natural period of the structure happens to be the same as that of the earth waves. Since such a resonant swing would have a much greater amplitude than that of the earth waves it might be checked by lateral guys extended on either side, not only from the piers but also from the suspended structure. Any horizontal transverse swing which may be induced in the bridge by an earthquake will cause extraordinary stresses to develop in the piers as the load of the bridge is thrown from one side to the other, and lateral tilting of the piers will be inevitable. This can be minimized by using heavier steel sections than would otherwise be necessary, and by securely anchoring the piers into the concrete foundations. The third component of the earth motion, the vertical, will be effective chiefly as a hammer blow upward on the base of the piers. Owing to the great inertia of the mass supported by the piers, this sudden blow will tend to buckle the steel of the piers before the upward movement can be transmitted to the structure as a whole. This tendency may be met by making the lower part of the piers stronger and more rigid than would be necessary merely to support the dead load of the bridge.

In general, the risk of damage to the bridge from earthquake shock is not so great as it is in the case of the skyscrapers of San Francisco. The latter are not homogeneous structures but are built of steel and masonry, and these will not swing in unison, but will tend to be mutually destructive. In the fling of the strong steel frames the veneer of masonry will be thrown off in many cases, causing great damage in the streets. The bridge, on the other hand, if built wholly of steel, will have the advantage of homogeneity.

Even when we contemplate the possible destruction of the bridge by an exceptionally violent earthquake the fact should be borne in mind that the life of a steel bridge near the salt water is limited, and that its life, if never affected by earthquakes, is probably less than the mean interval between heavy, destructive shocks. Any earthquake, so violent that it would destroy the bridge, would also destroy San Francisco. Yet, tho it faces possible destruction, San Francisco does not stop growing, and that growth necessarily involves the erection of large and expensive structures.

I trust that the foregoing memorandum may be of service to you.

Respectfully submitted,

(Signed) ANDREW C. LAWSON,
Consulting Engineer.