W J Hadley

Pier Foundations for a Proposed Bridge Across the Straits of Mackinac

An Engineering Geologic Report

by

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1. Foreword

A question has been raised with respect to a proposed bridge across the Straits of Mackinac - "Are the geological conditions such that one may with assurance assert that stable foundations can be developed for the main and subsidiary piers of the bridge?"

The widespread presence of the Mackinac breccia in the Straits area and the known presence of a relatively deep and ancient inter-glacial stream channel separating the northern and southern peninsulas have caused some questions to be raised regarding the feasibility of the bridge, particularly questions "with respect to the locations and development of firm footings for the bridge piers". It is the objective of this report to answer, insofar as it appears to us possible, these questions.

The study which we have made is based on an appraisal of the data assembled in an excellent report entitled "Geology of the Mackinac Straits Region and Subsurface Geology of Northern-Southern Peninsula" by Kenneth K. Landes, George M. Ehlers, and George M. Stanley; State of Michigan, Department of Conservation, Geological Survey Division, Lansing, Michigan, 1944; on a number of engineering reports, cross sections, and drilling records furnished by Dr. D. B. Steinman, Consulting Engineer, New York City; and on conferences by Mr. Paige with Messrs. K. K. Landes and W. S. Housel of the University of Michigan, at Ann Arbor, and with the State Geologist, Mr. C. A. Eddy and his associate, Mr. F. G. Pardee at Lansing, Michigan; and on the examination of some bulk samples of parts of the Mackinac breccia.

II. Conclusions

It is our considered opinion that a bridge such as that proposed across the Straits of Mackinac is entirely feasible, but there are precautions to be observed that must not be disregarded, as is explained in the body of this report.

The Mackinac Breccia and the elements composing it, which is the principal formation involved in this problem, has the strength required to support the proposed bridge piers with an ample margin of safety.

The collapse of ancient caverns and the primary brecciation of this formation occurred millions of years ago. The heavy loads of sediment that subsequently were deposited over the breccia have effected a consolidation of the rocks, and ample time has elapsed for re-cementation. We are not greatly concerned, therefore, with the caverns that once existed millions of years ago in Devonian time. On the other hand, the actual structural conditions are still relatively unknown at the immediate site and should be determined by a suitable program of exploratory drilling.

A question has been raised regarding the strength of the shales that are present and that may become part of the bridge foundation. Would these shales "flow" toward the valley walls under stresses induced by the load of the bridge? In our opinion no such movement will take place under the moderate stresses with which we are dealing. Furthermore, strength tests can be made on the cores recovered.

When the recommended drilling program has been carried out and its results interpreted by a geologist, we believe that suitable footings for the piers can be constructed. There is nothing unusual in our recommendation that an adequate core drilling program be carried out before construction begins. It is accepted practice and in the interest of suitable construction treatment, economy and safety on a project of such magnitude and importance.

III. Recommendations

We recommend that a program of drilling, carried out by experienced drillers, be undertaken before construction begins at each of the proposed main suspension bridge footings, consisting of four 3-inch core drill holes on each footing, each hole to penetrate rock not less than seventy five feet, the program to be directed toward the recovery of core and geologic information.

We recommend that at least one 3-inch core drill hole be drilled at each subsidiary pier footing.

We recommend that the guidance of a geologist be sought in the interpretation of the drilling, and that he in cooperation with the engineers, direct any further drilling that may prove necessary because of the unusual character of the bedrock.

We also recommend probing or drilling to bedrock in the area surrounding the pier sites to insure an adequate knowledge of the rock floor contour and the relation of the sites with reference to any possible buried channels tributary to the main stream.

IV. The Geology of The Mackinac Straits Area And Its Bearing On the Stability Of The Bridge-Pier Footings Of A Proposed Trans-Straits Bridge.

Introduction

The Southern Peninsula of Michigan with the Straits of Mackinac at its northern border, is underlain by sedimentary strata, limestones, dolomites, shales, and their intergradations with which are associated beds of salt and Gypsum. Structurally the area is known as the Michigan Basin, since all the beds within its boundaries slope gently downward from all directions toward a center some one hundred seventy miles south of the Straits. This structural basin was formed by a progressive downwarp of the ocean floor on which a thick series of sediments, now present, were progressively deposited during millions of years. In the Straits area, therefore, the regional dip is gently southward some twenty five to fifty feet per mile from a point north of St. Ignace Peninsula, across the Straits, southward for a long distance.

Were this the whole story, we would face a simpler engineering problem than we do in appraising the strength of the bridge footings beneath the waters of the Straits. But two episodes in the long geologic history of the region serve to complicate the situation.

One circumstance concerns the nature and formation of the Mackinac Breccia; the other is concerned with a geologically much more recent development, namely, the presence during an interglacial period of a river flowing eastward through what are now the Straits of Mackinac.

The nature and the engineering consequences of these two developments is appraised in what follows. First, the significant facts concerning the nature of the formations that are present are set forth. Next, the origin of the Mackinac Breccia is described and its engineering significance appraised. Then follows an analysis of processes that have operated during the period

when a stream flowed eastward through what are now the Straits of Mackinac, and may be of engineering importance.

Rock Formations Involved

The stratified rock formations of the Mackinac Straits region occupy a position between the Engadine dolomite of middle Silurian age at the base and the Lundee limestone of middle Devonian age at the top, a stratigraphic interval of approximately one thousand feet. Brief descriptions follow of each of the named formations within this interval.

Pointes Aux Chenes Formation

The Pointes aux Chenes formation underlies most of the large St. Ignace Peninsula north of the Straits of Mackinac. The formation, therefore, with parts of the St. Ignace formation would be expected to be the foundation rock for the northerly portion of the bridge.

From the known outcrops which are scanty and from the records of a few deep wells, it is known that the formation consists of green and red shale with intercalated thin beds of dolomite and irregular masses and beds of gypsum. No beds of salt have been found in the outcrop area nor in the few deep wells of the area.

Indications from the deep wells of the region place the thickness of the Pointes aux Chenes formation at five hundred to six hundred feet on the St. Ignace Peninsula. It is probable, therefore, that these rocks are the lowermost strata that will be involved in any engineering problem connected with the construction of the bridge. The fact that these rocks, with some of those that lie stratigraphically above them, have been violently disturbed since their deposition will be discussed further, as will also the fact that they contain gypsum.

St. Ignace Formation

The St. Ignace formation, except for the upper part, consists of even-bedded light-colored dolomite, intercalated with thin beds of bluish to

greenish-gray shale. The upper part of the formation consists of thick-bedded dolomites. It is estimated that the thickness of the formation lies somewhere between two hundred and three hundred feet. In the area we are considering on the St. Ignace Peninsula violent dislocation of parts of the formation has been observed, and the formation is mapped with the Mackinac Breccia, it not being practical to separate the "breccia complex" from the disturbed blocks known to be part of the St. Ignace formation.

Garden Island Formation

According to the reports of the Michigan geologists, the Garden Island formation consists of dolomites, sandstones, and shales, and may aggregate twenty five feet in thickness. We need not discuss the formation further in this study.

The Bois Blanc Formation And The Detroit River Group

The Bois Blanc formation of lower or middle Devonian age consists chiefly of cherty limestones and dolomites. The formation underlies the southern two-thirds of Bois Blanc Island and a narrow belt of land along the northern shores of the Southern Peninsula. Numerous large blocks of this formation are involved in the Mackinac Breccia on the St. Ignace Peninsula. The boundaries of the blocks are poorly exposed, consequently have not been mapped separately but have been included in the map unit known as the Mackinac Breccia.

The lower part of the Bois Blanc formation consists of inter-bedded chert and limestone; the middle part of limestones, and dolomitic limestones. The thickness of the formation is estimated to range from three hundred and twenty five to four hundred feet.

Since the Bois Blanc formation is the uppermost stratigraphic unit with which the engineering of the bridge is likely to have much to do, the succeeding formation of the Detroit River Group needs little comment. It occupies a wide belt of land in the northern part of the Southern Peninsula between the areas occupied by the Bois Blanc and Dundee Strata. The formation consists essentially of lime-

stone and dolomite, some portions of which may appear in the Mackinac Breccia of the Straits area.

Dundee Limestone

The Dundee limestone overlies the Detroit River beds and lies unconformably over the Mackinac Breccia which was formed during the interval between the deposition of the Pointes aux Chenes beds and the Dundee limestone.

The Mackinac Breccia

The most prominent rock formation in the Straits area is the Mackinac Breccia which is made up largely of fragments and masses of earlier strata that range in age from Silurian to Mid-Devonian, and these are included in sediments of Mackinac age. This formation occurs on both sides of the Straits and it is the principal rock that crops out on the St. Ignace Peninsula. The rock fragments involved in the brecciation range in age from the Pointes aux Chenes formation through the St. Ignace, Bois Blanc and Detroit River beds. The lowermost Pointe aux Chenes beds are not brecciated, nor are the Dundee limestones and younger formations lying above.

Brecciation occurs on varying scales. In places great blocks of dislocated sedimentary strata form part of the breccia. These blocks may be tilted up to 75°, and oriented entirely at random. They may be hundreds of feet long. The lateral boundaries of the blocks are marked by faults and slickensided surfaces. Their base is seldom or never seen. Some of these blocks have dropped further downward than others and appear unexpectedly. In places intra-formational breccias have been noted within displaced blocks, overlain and underlain by undeformed strata. There are in addition vertically disposed breccias that cut through the entire stratigraphic section, from the Detroit River beds to the Pointes aux Chenes formation.

Origin of the breccias is discussed at length by Lances. He sets forth a very reasonable conclusion, that deposition of salt and gypsum in the Pointe

aux Chenes formation was the first step. He estimates that as much as twelve hundred feet of salt beds are contained in the formation at a point as far north as Alpena County. Landes believes that the St. Ignace Peninsula was also once underlain by salt-bearing beds which in turn were overlain by the Bois Blanc dolomites, cherts and limestones and the Detroit River dolomites and limestones of the regular series. He argues that deposition of these beds was followed by emergence of the land above sea level, and that in this time salt was leached by groundwaters from the emerged rim of the salt basin, producing a vast series of caves and caverns where the Pointes aux Chenes salt lay above the water table. Collapse followed, as the formation of large caves created instability. We need not pursue the details of this process further, but the important implications of such a process are not difficult to state.

The process of collapse was complete before the Dundee limestones were deposited. In fact, a long period of erosion must have ensued before these latter beds were deposited. Moreover, a thick section of sedimentary strata succeeded the deposition of the Dundee beds. All of this occurred millions of years ago.

It is to be expected, therefore, that this chaotic mass of dislocated and brecciated beds has been re-consolidated by immense loading and re-cemented by circulating waters to present fair stability. It is our opinion that the formation as a whole is reasonably sound in so far as the process surrounding its first collapse is concerned.

But we know that the breccia contains fault planes, gouge, joints, breccia fragments, all of which, even if sealed, are incipient planes of weakness and may have to be taken into account in estimating the strength of footings and the desirable distribution of loads.

The Significance of An Ancient Inter-Glacial Stream Valley In The Straits of Mackinac

The history of the glacial period was a long one. Ice invaded and retreated from the region of the Straits a number of times. Consequently the shape, extent and elevation of the lakes changed greatly from time to time, depending on the position and elevation of their outlets and the position of the advancing or retreating ice sheet.

There appears to be substantial evidence that a river flowed eastward through what are now the Straits of Mackinac in recent glacial time. Soundings have defined the position of the main course of the stream and probings and drillings have developed a partial rock profile of its valley, at least between St. Ignace Peninsula and the tip of the Southern Peninsula. These facts may be of some importance, especially with respect to the contour of bedrock and the distribution of the associated glacial overburden that may be present at proposed pier footings.

The presence of a deep valley between the peninsulas, through which a river flowed, means that this entire area once stood above a sloping water table, the lowermost point of which was the river level. Such a water table sloped upward from the river, lay beneath its valley walls and beneath the bordering uplands. Since we know that the Pointes aux Chenes formation contained limestones and beds of gypsum, it is possible that solution of these rocks, where they stood above the water table, may have been active for a long time.

Solution of this kind has taken place to some extent, and is taking place today, on the surface of Mackinac Island and on the St. Ignace Peninsula. Sink holes are present; cavities are developing, and there must be some underground water circulation with outlets to the lake. Glacial deposits now cover most of these features. Therefore, no one can predict with any degree of precision how porous or permeable the shoulders of the submerged valley walls and the uplands of the submerged hinterland may be. The ancient topography of this terrain has not

been explored sufficiently to know whether sharply cut tributaries to the main stream indent its bordering upland.

All of these factors indicate that exploration by careful drilling and sampling of overburden is important, and core drilling of bedrock, especially directed toward the recovery of cores and the appraisal of geologic conditions, is even more important. At each main proposed pier at least four holes (three-inch core drills) should penetrate bedrock not less than seventy-five feet, and further drilling should be undertaken if new discoveries call for it. Probings should also be undertaken in the vicinity of the pier sites to insure at least some knowledge of the conformation of the rock surface.

Conclusion

In conclusion, it appears on every count that the value of the pier sites cannot be predicted from observation of the present exposed land surfaces alone. Such observations as can be made, and such geologic interpretations as are reasonable, indicate that non-uniformity is to be expected in bedrock. The normal stratigraphic succession has been disturbed in an unpredictable fashion, and the effects of solution in interglacial time may be of practical importance.

Despite the complex history and unusual geological structural conditions indicated at this site, there is no good reason to condemn it as impracticable. It is absolutely necessary, however, to make suitable exploratory borings to determine the actual physical condition of the ground that has to support this great proposed structure. There is ample experience in the field of construction for the treatment of any questionable ground that may be discovered. The foundation thus treated, if necessary, in our opinion would be amply strong enough to carry the moderate loads that will be imposed upon them.

Signed,

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