State of Michigan

Mackinac Bridge Authority

PROPOSED MACKINAC STRAITS BRIDGE
PRELIMINARY REPORT

MACKINAC BRIDGE AUTHORITY

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Fred. M. Zeder, *Vice Chairman*
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Mackinac Bridge Authority
Mr. Prentiss M. Brown, Chairman
Lansing, Michigan

Gentlemen:

In accordance with our assignment we present a preliminary report describing our investigation of the feasibility of constructing a bridge across the Mackinac Straits, and including preliminary design plans, estimates of cost of construction, operation and maintenance and a summary of our conclusions.

While the statements and estimates presented are subject to refinement and amplification in our final report, we believe they are adequate as a basis for your consideration at this time.

Possibly, as a result of such consideration, you may wish to give us further instructions on certain phases of the project.

Respectfully submitted

O. H. Ammann
D. B. Steinman
Glenn B. Woodruff

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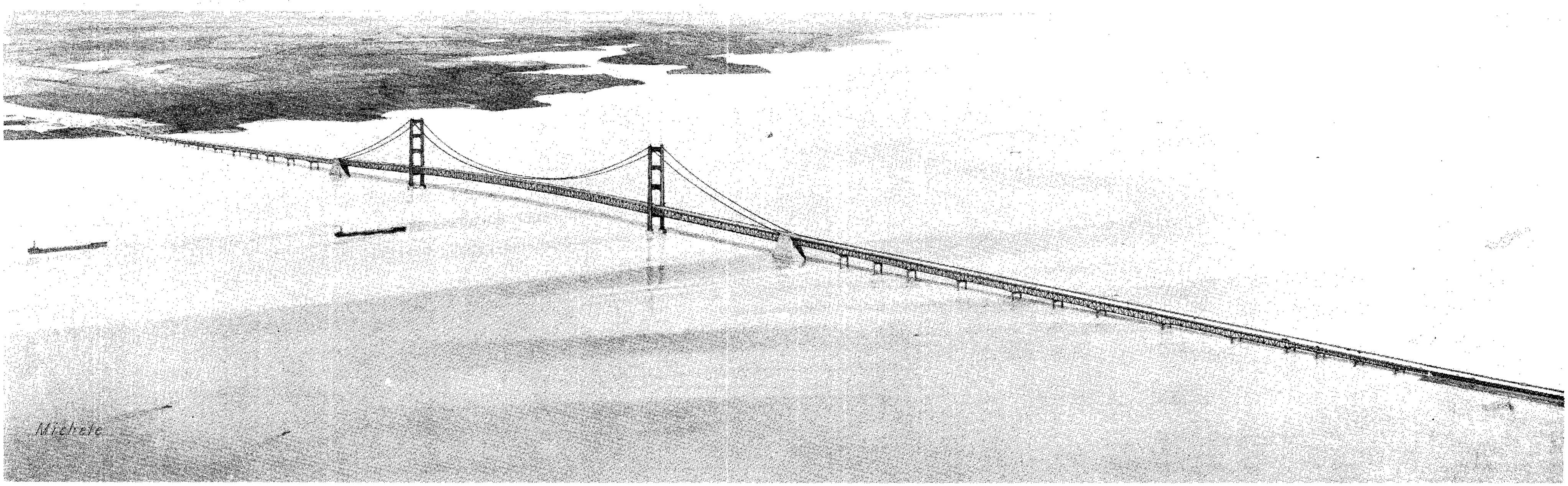
Board of Engineers


Michele

INTRODUCTION

The Straits of Mackinac divides the State of Michigan into the upper and lower peninsulas. The desirability of uniting these areas by a bridge or tunnel has long been apparent. In 1920 the late Horatio S. Earle, highway commissioner, suggested a submerged floating tunnel and invited discussion of its feasibility and advantages. A counter-proposal was made by Mr. C. E. Fowler, who suggested a series of causeways and bridges starting at a point near Cheboygan and proceeding via Bois Blanc Island, Round Island, and Mackinac Island to St. Ignace. In 1923 in response to the growing demand for better facilities the State inaugurated a highway ferry service.

In 1928 after some limited studies, the highway department concluded that it was feasible to build, for about $30,000,000, a highway bridge directly across the Straits from Mackinaw City to St. Ignace. Although negotiations were undertaken and partially completed for the financing of such a bridge, the project was dropped.

Early in 1934, the state legislature created the Mackinac Straits Bridge Authority of Michigan and empowered it to investigate the feasibility of constructing a bridge to connect the peninsulas and to issue and sell the necessary revenue bonds and fix and collect the necessary tolls. In April 1934, Governor Comstock appointed Messrs. S. T. Stackpole, Otto W. Lang, and Patrick H. Kane as members of the Authority.

The Authority engaged Mr. Fowler as temporary chief engineer. The plan developed by Mr. Fowler followed closely the one proposed by him in 1920. In August 1934 the plan was submitted to the Public Works Administration with a request for a loan of 70 per cent and a grant of 30 per cent of the estimated cost of the project. This application was formally disapproved by PWA on July 18, 1935.

In the meantime many objections to the proposed route had been brought to the attention of the Authority. As a result, the Authority continued its studies and ultimately reached the conclusion that a direct crossing was both feasible and preferable. Mr. Francis C. McMath was engaged to prepare such data on a direct crossing as would be necessary for a new application to PWA. Mr. James E. Cissel served as consulting engineer. A new application was submitted to PWA on September 7, 1935.

On December 23, 1935, following a request by President Roosevelt, the Chief of Engineers, U. S. Army, reported on the proposed bridge informally as follows: The construction of the bridge on the direct line appears to be entirely feasible; it will unquestionably be of great public convenience in facilitating communication between the peninsulas; and there is a reasonable possibility that the revenue from tolls will meet the carrying charges of the loan requested. However, PWA disapproved the latest application on September 18, 1935.

In 1938, the Mackinac Straits Bridge Authority engaged Modjeski and Masters, with Leon S. Moisseiff as an associate, to make a further investigation of the project. These engineers submitted their report to the Authority on June 3, 1940, recommending the construction of a bridge "extending almost due north across the Straits from the point at which highway routes U. S. 31 and U. S. 23 converge on the south shore."

This report was submitted by the Bridge Authority to the Governor and the State Highway Commissioner on June 25, 1940. Before further steps could be taken World War II started.

The present Mackinac Bridge Authority was created by Enrolled House Bill No. 24, Extra Session of 1950 of the 65th Legislature of the State of Michigan. Section 4 of this bill provided, "The Authority shall employ three consulting engineers to be recommended by the dean of the college of engineering of the University of Michigan, who shall constitute a board of consulting engineers and who shall determine whether a bridge can be safely and feasibly constructed across the Straits of Mackinac and the probable cost thereof."

The Authority invited the three engineers who were recommended by the dean to meet with them at the site on July 12, 1950. The investigations described herein were started on that date.

The combination of deep channels, exceptional rock formations, severe ice conditions and winds present unusual engineering problems. The extreme peaking of traffic compared to the average volume required careful consideration in establishing the capacity of the bridge.

The work of the Board of Engineers included a review of previous investigations, study of the conditions at the site - geology, currents, wind and ice formations and their effect on the structure - alternate design studies and cost estimates to determine the most appropriate type and arrangement of structure and the preparation of plans in sufficient detail to permit an adequate estimate of the required quantities and the cost of construction.

On recommendation of the board of consulting engineers the Authority also engaged the firm of Coverdale and Colpitts to undertake a traffic analysis and assist in the economic study. In view of the important and controversial question of the suitability of the rock formations under the Straits to carry the bridge foundations the Authority further engaged the advisory services of Dr. Charles P. Berkey and Dr. Sidney Paige, two of the most outstanding engineering geologists.

CONDITIONS AT THE SITE

The Straits of Mackinac are a comparatively narrow body of water joining Lakes Michigan and Huron. They also divide the State of Michigan into Upper Peninsula with its resources of minerals and the Lower Peninsula which, with Detroit as its major city, is rapidly becoming highly industrialized. The Upper

Peninsula is also noted as recreation area. The Straits and the crossing of St. Mary's River at Sault Ste. Marie form a gateway into the Province of Ontario which also provides a vast recreation area.

Geology

With its unusual brecciated formation, the geology of the area has, for over 100 years, attracted the attention of the geologist. With the agitation for a crossing of the Straits, the geology was exhaustively studied by Professors Kenneth K. Landes, George M. Ehlers and George M. Stanley, under the direction of State Geologist R. A. Smith. Two features are pertinent to the planning of the bridge--the breccia formation and the hidden rock gorge. The breccia formation has been fully described by Messrs. Landes, Ehlers and Stanley. We have discussed the matter with Professors Ehlers, Landes and W. S. Housel, and with State Geologist G. E. Eddy and Mining Engineer F. G. Pardee of the State Department of Conservation. The report of Professors Berkey and Paige has been submitted to the Authority under separate cover. In addition, the Authority requested Mr. W. W. McLaughlin, Director of Testing and Research of the State Highway Department, and Professor Housel to make compression tests on samples of the material and also to make "in-place" loading tests. The borings and probings at the site in 1939 are reproduced on Plate 5.

As a result of the above data, with the sole qualification that further core borings at the site of the main piers and anchorages are a prerequisite to the final design of such construction, we have no doubt that the rock strata underlying the Straits along the recommended location are entirely capable of withstanding the moderate pressures assumed in the design.

A second geological feature of importance to the construction of the bridge is the hidden rock gorge underlying the channel between Mackinac City and St. Ignace. (Plate 1) East of the proposed crossing the gorge veers north, makes a loop around Mackinac Island and enters Lake Huron. This gorge was eroded through the breccia at a time when the level of Lake Huron was much lower than at present. The 1939 subsqueous explorations did not extend to depths greater than were necessary to locate the rock bed of the gorge.

Currents

The average volume of water flowing through the Straits is so small that currents produced by this volume are negligible. The maximum currents result from two causes; seiches or oscillations of the lake caused by passing changes in air pressure or barometric waves or from protracted wind in any given direction.

The results of certain observations made in 1939, gave a maximum of 1.97 mph. Higher velocities may be anticipated. It is certain that no current velocities such as those experienced in the construction of the Trans-Bay, Golden Gate and Tacoma Narrows Bridges are probable and that the difficulties, from this cause, of pier construction or of lifting sections of the suspended spans from barges will be less than those experienced in the case of the bridges above listed.

Ice

A very complete report of the ice conditions at the Straits has been made by Mr. W. O. Fremont of the State Highway Department. Mr. Fremont carried his investigations to an appraisal of the forces from the ice. These observations have been supplemented by those of State Highway Commissioner Charles M. Ziegler.

We have carefully considered the data and have further investigated information on ice pressure on engineering structures. As a result of these investigations we have adopted the very severe assumptions of an ice pressure of 230,000 pounds (half of this amount for circular surfaces) per lineal foot of pier width at the water line. The resulting forces are considerably greater than those generally assumed for engineering structures under comparable climatic conditions. We are confident that these forces are in excess of those to which the piers will ever be subjected.

Wind

The Straits of Mackinac are north of the "tornado belt" but are subjected to comparatively heavy wind. The highest recorded velocity at the site was 78 mph on November 11, 1940.

BRIDGE LOCATION

We have considered the locations shown on Plate 1 which are designated as the Fowler, Cissel and Masters locations. Neither Mr. Fowler nor Mr. Cissel had any information as to the depths to rock at the center of the "hidden gorge". With the information now available it is certain that the cost of a bridge at either of the Fowler or Cissel locations would be much greater than at the location herein recommended. Our conclusions in this respect may be summarized as follows:

1. The construction of a bridge on the recommended location is entirely feasible.

2. The recommended location fits the existing State Highway System better than any other.

3. It is possible, though not probable, that a very extensive subaqueous investigation might develop a site that would permit a slight reduction in the cost of construction. In view of the existing mole which will serve to protect the piers of the short spans at the north end of the bridge against ice, the chances of finding a more economical location are so remote that the cost of the investigation is not warranted.

DESIGN OF BRIDGE

From the start of the investigation it was apparent that the project would be finally feasible only by keeping the cost of construction to a minimum consistent with adequate capacity, safety of traffic, conservative design and structural details conducive to economical maintenance. On the other hand it was recognized that reasonable allowance must be made to meet the needs of the future.

Traffic Capacity

From the traffic analysis it appears probable that, immediately after opening of the bridge to traffic, northbound traffic may be as high as 1,500 vehicles per hour. Within the following 50 years it is possible that the volume will be tripled. During the northbound peak southbound traffic will be less than half this volume.

A three-lane bridge provided with moveable traffic barriers or changeable traffic lights, so that the bridge could be operated with two lanes in one direction and a single lane in the opposite direction might meet these requirements except for interruptions caused by accidents or car stoppages. These interferences with smooth flow of traffic do occur, however, and may be serious enough during peak traffic to throw the operation into confusion. This is of particular importance on a bridge of such great length.

For this reason we recommend that a capacity of not less than four lanes, two in each direction, be provided. However, in accordance with instructions, we have also prepared a cost estimate for a three-lane bridge.

Consideration has been given to provision of a traffic barrier along the center line between the two roadways to avoid possible head-on collisions by vehicles getting off the inner lanes. Modern practice with respect to the character of traffic barriers varies greatly. On some large bridges high malls have been installed preventing any crossing by vehicles. On others low curbs, raised traffic markers or even only lines painted on the pavement are used which permit the crossing of vehicles when necessary under proper control.

Barriers of the low type, not over two feet wide, have been assumed for the Mackinac Straits Bridge for the following reasons. While it is not recommended that direction of traffic in any lane be regularly reversed, it is highly desirable, especially on a long bridge with only two lanes in each direction wide, that in the case of emergencies for vehicles to be detoured across the barrier at any point under police control and to permit more direct access by tow cars to vehicles requiring their services.

A low well marked barrier will also induce vehicles to stay closer to it than to a high mall thus justifying a somewhat narrower traffic lane next to it.

These considerations, as well as reasons of economy, have led to an overall width of roadway between curbs of 48 feet, of which not more than two feet would be occupied by the center barrier, 12 feet by each outer lane and not less than 11 feet by each inner lane.

These lane widths compare favorably with those of other modern long bridges and tunnels.

No provision is considered necessary on this four mile long bridge for regular pedestrian traffic. However, footwalks on each side are essential for maintenance and operating personnel and only in emergency cases for occupants of vehicles. A width of three feet between curb and railing has been assumed for each of these two footwalks. Substantial railings are provided on the outside of the footwalks. The overall width of the floor between railings is 54 feet.

Design Specifications

The specifications for materials, loads and permissible stresses which have been used as a basis for the design of the Mackinac Straits Bridge follow general practice for modern structures of this type and magnitude.

For the floor structure throughout and for the shorter main girders and trusses the current specifications of the American Association of State Highway Officials have been followed, with the basic loading of H20-S16-44 as generally applied to the design of bridges on major highways.

The latter specifications are intended to apply to bridges of ordinary type and modern spans. For the design of the stiffening trusses, cables, towers and anchorages of the suspension bridge and for the long trusses of the other spans of the main crossing, special load and stress specifications were adopted in accordance with best modern practice for structures of such magnitude.

For the four-lane bridge design a live load of 2000 lbs. per lin ft. of bridge has been adopted, representating a continuous line of heavy trucks about 50 ft. apart on each of the four lanes, a load which will probably never be obtained under actual conditions. Under ordinary heavy traffic the average load will probably be less than one third of that load.

For the three-lane design the relatively somewhat larger load of 1800 lbs. per ft. has been assumed.

On account of the possibility of high winds of considerable extent and the exposed location of the bridge a static wind pressure of 50 lbs. per square foot of exposed area was assumed over the entire structure. This corresponds to a wind velocity of about 120 miles per hour as compared with the maximum recorded velocity of 78 mph observed in that vicinity.

Type of Structure and Span Arrangements

Fairly extensive borings at the proposed bridge location in connection with the report of Modjeski & Masters in 1940 made it possible to determine the most appropriate type of structure and span arrangement. Time and available funds for the present study did not permit the making of supplementary borings to explore to a greater extent the slopes of the hidden rock gorge under the main channel. However, it may be reasonably concluded from the information available that any piers located closer to the gorge than now proposed would probably become excessively deep and expensive to justify a shorter span across the gorge.

As proposed that span has a length of 3,800 feet between centers of piers. The outstandingly appropriate type of structure for a span of that length is a suspension bridge. The side spans from main piers to the anchorages were given a length of 1,500 feet, which under the given conditions is in the most appropriate ratio to the center span.

A number of alternate layouts made for the remainder of the crossing over the waterway between the south shore and the end of the mole at the north shore led to a series of truss spans on concrete piers as the best solution. Twenty-two spans over the deeper portions of the waterway are of unusual length for a structure of this character, ranging from 560 feet to 302 feet. Four spans near each shore have spans of 160 to 200 feet. The comparatively long spans are economically necessitated because of the deep and expensive piers, which have to be designed to withstand the heavy ice pressures.

Along the mole in the St. Ignace side it was found appropriate to carry the roadway on a viaduct with short spans resting on pile foundations driven through the existing embankment.

Grades, Clearances and Lengths

From the end of the mole and the Mackinac City shore the bridge roadway ascends by easy grades, not exceeding 2.5 per cent, to the towers of the main bridge. Over the center span of the latter the roadway is cambered by a parabolic curve.

These grades allow a minimum clear height above mean lake level of 135 feet for a width over 3,000 feet of the main channel. The minimum clear height at the center of the span is 150 feet.

The clearances under the approach viaducts range from 84 feet near the anchorages of the main bridge to a minimum of 20 feet near the south shore or the end of the mole respectively.

These clearances are believed to meet fully the requirements of navigation. They are subject, however, to the approval of the Department of the Army after a public hearing.

Upon an informal inquiry sent to Lt. Colonel John D. Brister, District Engineer of the Corps of Engineers for the Detroit District, by Mr. Fred M. Zeder, Chairman of the Engineering Committee of the Mackinac Bridge Authority, Col. Brister answered with the statement that "it appears that the indicated horizontal and vertical clearances would be generally adequate for navigation, however, this opinion must be considered an informal expression not binding in any way on the Department of the Army".

The total length of the proposed bridge and approaches if five miles, made up as follows:

Main Crossing			
	Suspension Bridge, including Anchorages	7, 120 ft.	
	South Truss Spans	6, 412	
	North Truss Spans	4, 392	
			17,924 ft.
Approaches			
	Mole Viaduct	3, 420	
	Mackinac City Approach	563	
	St. Ignace Approach	4, 278	
			8,261
Total length - Bridge and Approaches			26,185 ft.

Floor Construction

One of the controlling factors in the economical design of long span bridges is the weight of the roadway floor. Heavy concrete slabs such as are extensively and appropriately used on shorter bridges become too costly on long spans. In the case of the Mackinac Straits Bridge, in particular, it appeared essential to reduce the weight of that structural element as far as considerations of usefulness and economy of maintenance would permit.

A number of different types of light flooring were considered. In the outer lanes preference was given to a solid flooring consisting of a steelgrid filled with a lightweight concrete and topped, either initially or later, with a layer of bituminous concrete. During most of the time traffic will be confined to this lane.

For the inner lanes, which will be used mainly during the exceptional peak hours, an open-grating floor is proposed. It is the lightest type commercially available at present and has for this reason been used on a number of long-span and moveable bridges on which saving in dead weight in the floor is of importance. Its weight is about one third of that of the solid flooring proposed for the outer lanes.

It is recognized that this open grating flooring has certain disadvantages, such as the somewhat annoying effect of a distinct "hum" from tires passing over the grating and the probability that on the Mackinac Straits Bridge a considerable amount of sanding or spraying with salt will be necessary during the winter season, when the surface may become coated with ice. However, these objections are not considered to be of sufficient importance to outweigh the possible saving in cost due to the lightness of the flooring.

Superstructure of Suspension Bridge

With a central span of 3,800 feet the suspension bridge across the north channel will be second only in length to the Golden Gate Bridge in San Francisco, which has a span of 4,200 feet.

In its major carrying members, the cables, towers and anchorages, the design of the Mackinac Straits Bridge follows closely the practice established by other modern long-span suspension bridges.

For the four-lane capacity each of the two cables is to be composed of 37 strands, each strand containing 398 wires of 0.192 inch diameter before galvanizing. The finished cables will be 25.6 inches in diameter. A cable sag of 350 feet, or about one eleventh of the center span, is somewhat less than in some other suspension bridges, but is conducive to gracefulness and greater stiffness of the structure.

The steel towers are of the slender flexible type with fixed base. The tower shafts are of cellular construction, with access for the cleaning and painting of all interior surfaces. They reach to a height of about 565 feet above mean lake level. Service elevators are proposed in the towers for more convenient access to all parts.

The two shafts of each tower are connected by horizontal struts, which are also of closed cellular construction. The shafts and struts form integral parts of a rigid frame designed to transmit the large lateral wind forces to the piers.

The anchorages above foundations are conceived as huge concrete blocks to resist the pull of the cables and transmit the same to the foundations. However, through proper distribution of the mass of concrete and by hollowing out as far as practicable, the weight of the anchorage block is reduced to a minimum so as to lighten the load on the deep foundations as far as possible.

The suspenders which transmit the load of the suspended structure to the cables are standard steelwire ropes. For the four-lane bridge each suspender is composed of four ropes of 1 3/4 inch diameter.

The suspended structure includes two stiffening trusses, one in the plane of each cable. They transmit the floor loads to the suspenders and stiffen the structure against excessive distortions and possible oscillations under the action of dynamic loads and wind forces.

The question of adequate resistance against aerodynamic action has received intensive attention on the part of the engineering profession since the failure of the original Tacoma Narrows Bridge in 1940 both in this country and in England and has been given prominent consideration in connection with the design of the Mackinac Straits Bridge.

This is reflected in several features of the proposed design which differ from those of some of the large suspension bridges built in the past, namely:

1. The stiffening trusses have been given a depth of 45 feet or about 1/85 of the length of the center span. The above ratio is the same as that of the recently completed new Tacoma Narrows Bridge of 2,800 feet span, which under winds of up to 60 miles per hour has not developed any noticeable oscillations. A corresponding ratio of 1/100 has been adopted, after extensive research, for the 3,600 ft. span of the proposed Severn River Bridge in England.

2. The traverse floor-beams which carry the floor and longitudinal stringers and transmit their load to the stiffening trusses are designed as open trusses in place of solid-web girders, so as to minimize wind pressure against them.

3. Double lateral trusses, one in the plane of the top chords and one in the plane of the bottom chords of the stiffening trusses, are provided. This increases very substantially the torsional rigidity of the suspended structure as compared to that provided by a single system which has been used in a number of large suspension bridges.

4. The relatively narrow floor structure and the fact that the supporting stiffening trusses and cables are located considerably beyond the floor with open spaces between render the section of the suspended structure aerodynamically more favorable than if, as in other bridges, the floor would extend the full width between trusses.

5. The tests made in connection with the redesign of the Tacoma Narrows Bridge and for the design of the Severn Bridge demonstrate the beneficial effects of openings in the floor structure. It is quite possible that the openings need not be as extensive as those proposed in our design.

We have arranged with Professor F. J. Maher for tests on a model of the proposed cross section in the wind tunnel of the Virginia Polytechnic Institute. The results of these tests have reinforced our conclusion that the suspension spans as proposed will be aerodynamically stable and safe against any dangerous or objectionable motions under wind action.

To facilitate access for, and thereby decrease the cost of maintenance of the suspended structure travelling platforms carried on tracks suspended from the floorbeams are proposed for all spans.

Superstructure of Truss Spans

Because of the great depth to rock of 170 ft. in the secondary gorge near the Mackinac City side of the crossing, the layout recommended by Modjeski and Masters in their 1940 report, and some of the layouts studied by us included a secondary suspension bridge.

The secondary suspension bridge, however, was found to offer no economy compared to the design we now propose. Moreover, the secondary suspension bridge had the effect of detracting from the general composition and impressiveness of the bridge. Accordingly, we propose to cross the secondary gorge with continuous truss spans ranging up to 560 ft. in length. These spans are balanced by similar, though shorter, spans north of the suspension bridge where the depth to rock nowhere exceeds 60 ft.

The floor adopted for the truss spans throughout their length of almost two miles is the same as that used on the suspension spans. The center lanes of open grating flanked on each side by a lane of grating filled with light weight concrete and an open grating emergency walkway, all supported on cross beams and continuous stringers yield a light roadway and floor system resulting in maximum economy in the supporting trusses. To keep the size of the foundations to a minimum and to effect maximum economy in the floorbeams, the trusses are set 34 ft. apart and the floorbeams are cantilevered to reduce their required section.

Analysis and comparative estimates indicated that fairly long spans would be advantageous from the viewpoint of economy and decrease in hazard involved in the construction of piers to the depths required, particularly for the spans south of the main suspension spans. To reduce the number of expansion joints and at the same time to obtain simplicity and economy of detail and erection and minimum cost, the four-span continuous type of construction was adopted for the truss spans.

Maintenance travellers are proposed which can pass under the floors of all spans between the anchorages and the approaches.

Foundations

The recommended layout of the bridge involves 32 subaqueous piers. Of these the largest are the two anchorages and the two main piers of the suspension spans. The six piers at the secondary gorge with depths from 100 to 170 ft., may also be considered major piers.

As a result of the investigations of the underlying rock and of the ice conditions, the substructure has been designed for the live and wind loads outlined above and for the forces arising from the severe assumption of ice four feet thick with a crushing strength of 400 pounds per square inch. The very conservative bearing pressures of 15 tons per sq. ft. for live and dead load, increased to 25 tons for combinations including wind and ice, have been adopted for the design.

In order to prepare reliable cost estimates, complete designs of all piers have been made on the basis of assumed construction methods. Open dredge caissons have been assumed for the major piers and cofferdams for the remainder of the foundations. The cofferdam for the south anchorage, 115 ft. by 180 ft. in plan and extending 140 ft. below lake level, involves a continuous seal pour of 90,000 cu. yds., eclipsing, by far, all past records.

Approaches

The approaches are naturally divided into three sections: the construction over the 3500 ft. rock faced mole constructed in 1940, the Mackinac City Approach and the St. Ignace Approach.

The rock-faced mole at the north of the Straits was built with the thought that it would be used temporarily as a ferry terminal at its south end and later to carry an earth embankment to support the bridge approach. To protect the roadway from excessive spray from waves breaking on the rock face of the mole, it has been considered advisable to place the roadway surface at a minimum of 30 ft. above lake level. The mole is too narrow to accommodate a four-lane roadway at this level with the necessary side slopes of the embankments. Moreover, tests made on the underlying clays by the State Highway Division indicate the probability of a lateral flow of these clays leading to the failure of the mole if a fill were placed to such height.

Faced with these conditions and after investigating alternate types of construction, we have concluded that the most suitable construction is a series of 29 continuous plate girder spans supporting a reinforced concrete roadway with provision for a future wearing surface of asphaltic concrete.

These girders will be supported by reinforced concrete piers which, in turn, will be supported by concrete piles driven to rock. In this connection, the question arises as to the practicability of driving piles through the rock. During the construction of the fill efforts were made to place the larger rocks at the edge of the fill. This matter has been discussed with representatives of the Highway Department who witnessed the fill construction. The consensus is that, while some difficulties may be experienced, they will not be serious.

For the Mackinac City approach the alternates of filled retaining walls, concrete rigid frames and steel girders with a concrete paving on concrete piers have been considered. The last has been found the most economical and is therefore recommended. The roadway on this approach will be widened to three lanes in each direction, thereby forming a traffic reservoir in order that the capacity of the bridge will not be controlled by the street intersections in Mackinac City.

The St. Ignace Approach consists of a four lane roadway, partly on embankment, partly in cut, extending northward from the mole to a junction with Highway U.S. 2. At this junction the approach splits to accommodate the traffic turning westward and that continuing northward toward Sault Ste. Marie. An alternate plan has been developed eliminating all grade crossings. This would increase the cost by over $100,000. It is not considered necessary at this time and, therefore, has not been included in the estimates of cost.

Electrical Installations

The electrical installations on the bridge may be divided into the following categories:

1. Required for safety of water and air navigation - navigation lights, radar screen, fog siren and airway beacons.
2. Required for operation of bridge -

   Administration building lighting.
   Lighting of toll plaza.
   Convenience outlets - towers and anchorages.

3. Desirable for operation of bridge -

   Tow and fire call.
   Bridge lighting.
   Traffic signals - north end connection.

A question is whether or not, in the interests of economy, roadway lighting may be eliminated. The estimates which follow are based on a complete installation. Approximately $300,000 could be deducted by omitting such provision from the initial installation.

Administration Buildings and Toll Plaza

It is proposed that tolls be collected at a plaza located on the St. Ignace Approach. With the two northbound lanes at their full capacity, approximately 3000 vehicles per hour, and half this volume in the southbound direction, 12 toll collectors will be required. We therefore have based our estimate on a total of 12 lanes through the plaza of which the center four would be reversible in direction.

Adjacent to the Toll Plaza an administration building will be required to house the operating and maintenance personnel. The layout of this building will depend largely on the organization developed for this purpose. We have made layouts of this building, based on experience at other locations, for the purpose of estimates only.

In the case of several major structures it has been found desirable to provide office space for a detail of the State Highway Patrol. Our estimates include $70,000 for this purpose.

Because of the great length of the bridge it will be found desirable to have an auxiliary maintenance building at the Mackinac City end of the bridge. Our estimates allow for this facility.

Our estimates also provide for the necessary operating and maintenance equipment.

CONSTRUCTION SCHEDULE

Because of climatic conditions and especially the ice, the working season for the foundations of the main crossing will be confined to the eight months of April to November inclusive. The erection of steelwork including the spinning of the cables could be carried on during the winter. However, such winter work might be too costly and, for the purpose of setting up the construction schedule, we have assumed a complete shut down during this period.

To minimize the interest charges during construction, it is essential that the total construction period be reduced to a minimum. We have investigated the records on other major bridges and have discussed the program with experienced contractors. With an adequate amount of construction equipment, especially for the foundations, the assumed schedule given below is entirely practicable.

Sept. 1951	Award Foundation Contract
Season 1952	Anchorages 17 and 20 - First Stage Piers 2-8, 18, 19, 28-33 Mackinac City Approach - Foundations Mole Approach - Foundations St. Ignace Approach - Grading
Season 1952	Erection - Main Towers - Suspension Spans Anchorages - 2nd Stage Piers 9-16 and 21-27 Superstructure - Mackinac City Approach Spans Truss Spans between Piers 2 and 6 Truss Spans between Piers 28 and 30. Mole Approach. Paving St. Ignace Approach
Season 1954	Spinning of Cables Superstructure - Truss Spans between Piers 6 and 16 Truss Spans between Piers 21 and 28 Administration Buildings and Toll Plaza
Season 1955	Complete project

ESTIMATED COSTS - FOUR-LANE VEHICULAR BRIDGE

Following is a general summary of our cost estimate of the project. At this critical time, when many of the building materials, more particularly the metals, are becoming scarce and fabricating plants are working at full capacity, it is very difficult to forecast unit prices. We believe, however, that if it were possible to let contracts on a competitive basis at this time and prospective bidders could be assured of a supply of materials, the cost level would be approximately as we have assumed. We believe, therefore, that our estimates are as realistic as possible under present conditions.

Estimate of Cost

Main Bridge	- Foundations	$24,000,000
	- Superstructure, Suspension Spans	29,600,000
	- Superstructure, Truss Spans	10,600,000
Approaches	- Mole Section	2,000,000
	- Mackinac City	500,000
	- St. Ignace	500,000
Administration Buildings and Toll Plaza		500,000
Operating and Maintenance Equipment		400,000
Electrical Equipment		650,000
Borings		250,000
Engineering, Administration & Contingencies		6,900,000
Total Construction Cost		75,900,000
Real Estate		100,000
Preliminary Expenses		300,000
Total Estimated Cost of Project (before financing)		$76,300,000

We have not included an estimate of interest during construction nor other costs connected with the financing, since these will depend largely on the method of financing that the Authority may adopt.

ESTIMATED OPERATING AND MAINTENANCE COSTS--FOUR-LANE VEHICULAR BRIDGE

Pending a determination of the organization for operating the bridge, we submit no estimate in detail of operating and maintenance costs of the proposed structure. Based on the experience of other major toll bridges, considering the differences in conditions from the other major bridges, and based on an estimate of 1,800,000 vehicles for the first year of operation, we believe that the costs of operation, maintenance and insurance in that year will not exceed $300,000.

With increasing traffic the above would probably increase to $350,000 for the fifth year after opening.

THREE-LANE VEHICULAR BRIDGE

For the reasons given above, we recommend that a four-lane vehicular bridge be constructed. The Authority has requested an alternate estimate on a bridge with three vehicular lanes.

We have made no detail plans for the three-lane bridge. We assume the roadway would be as proposed for the four-lane bridge with 12 ft. of grating eliminated, thereby reducing the weight of the floor by only ten per cent. The width of the suspension spans was fixed for adequate lateral rigidity. No reduction would be advisable for the three-lane bridge. The spacing of the trusses for the other spans of the main crossing could be reduced to 28 ft.

By the A.A.S.H.O. Specifications which we are following in general, a three-lane bridge is designed for 2.7 lane loads, a four-lane bridge for 3.0 lane loads. For the suspension spans the corresponding ratio for the live loads is 1800 to 2000 pounds per lineal foot of bridge. The design of the substructure is controlled to a large extent by the forces assumed for ice action.

From the foregoing it is apparent that a comparatively small saving is possible by reducing the width of the bridge from four to three lanes. Our estimate for the three-lane bridge on a price basis comparable to that used for the four-lane bridge is $70,000,000 (before financing) compared with $76,300,000 for the four-lane bridge. The difference in operating costs between a three and four-lane bridge would be negligible.

PROVISION FOR RAILWAY FACILITIES

Rail traffic across the Straits of Mackinac is presently handled by car ferries. At the request of the Authority we have investigated the feasibility of providing facilities on the proposed bridge to accommodate rail traffic in addition to the vehicular traffic.

The suspension type structure is required for the long spans over the deep rock gorge, whether the bridge is designed for railway or highway loading. The same span layout as that used for the highway bridge has been assumed for the combined four-lane highway and single track railway bridge.

A single-track railway has been assumed to be sufficient to handle the traffic which can be expected to use the proposed facility, and an E-50 loading has been adopted as adequate. A single track, located under the center of the roadway, is more advantageous than a double track, particularly for the suspension spans on account of the severe distortions of the bridge which would result from loading of one of the two tracks.

The estimated maximum grade change on the suspension span for combined highway and railway loading and temperature change gives a maximum calculated adverse railway grade of three per cent at the towers.

Our estimate of the cost of a combined highway and railway bridge has been prepared on the basis of carrying the railway between the Mackinac City Abutment and the St. Ignace abutment and does not include the cost of bringing the railway to the bridge abutments.

The estimated additional cost for provision of a single-track railway on this bridge is $60,000,000 (before financing).

STUDY OF A SUBAQUEOUS TUNNEL

We have made a study of a four-lane vehicular tunnel at the same site as that proposed for the bridge. In this study we have had the advice and assistance of Mr. Ralph Smillie, Consulting Engineer of New York, an outstanding expert on tunnel construction.

The assumed tunnel structure would consist of 56 twin-type precast tunnel sections, each approximately 300 feet long, supported generally at the junctures by multiple steel-shell concrete-lined caissons sunk to rock or to firm material. In the gorge the caissons would have to be sunk to the unprecedented depth of about 300 feet below lake level.

The top of the precast tunnel sections would be located to provide a minimum water depth of 50 feet for a channel width of 12,300 feet, which will allow the largest type vessels to pass. As the tunnel roadways climb towards the shores the tunnel structure would be protected on each side and on top by substantial rip-rap fill.

The length of tunnel from portal to portal would be approximately 16,700 feet. Full use would be made, as in the case of the bridge, of the existing mole on the north side of the strait. Two ventilation buildings have been located approximately at the quarter points between portals, each building housing 32 ventilation fans with attendent electrical switch boards and controls. Ventilation in the tunnel will be by the transverse distributed method, similar to that used in the principal vehicular tunnels around New York City.

The study is not entirely completed, but approximate estimates indicate that the cost of the tunnel project may be as high as $141,000,000.00 (before financing).

The estimated cost of operation for the first year is approximately $1,000,000.00.

CONCLUSIONS

The conclusions from our investigations as outlined in this report may be summarized as follows:

1. The construction of a bridge across the Straits of Mackinac with construction methods which have proven successful on other large bridges in entirely feasible.

2. The location of a bridge directly northward from Mackinac Point is more suitable than other locations which had previously been proposed.

3. It has been definitely established that the rock formation underlying the Straits has much greater strength than necessary to resist the moderate pressures which would be imposed upon it by the structure, even under severest combination of ice and wind forces.

4. A bridge designed for two lanes of traffic in each direction is recommended. It will be adequate for a reasonable number of years to come. The proposed design provides for the heaviest vehicular loadings specified by the American Association of State Highway Officials. Special attention was given in the design of the long-span suspension structure to assure safe resistance against dynamic wind action.

5. The bridge can be completed, ready for traffic, within four years of the award of the first construction contract.

6. Based on prevailing prices we estimate that the bridge can be built as proposed at a sum of $76,300,000, exclusive of the cost of financing and interest during construction.

7. Operating and maintenance expenses are estimated at $300,000 during the first year.

8. A bridge with three traffic lanes would cost only about $6,300,000 less than one with four lanes and is not recommended.

9. The construction of a four-lane subaqueous tunnel is feasible, but its construction would involve unprecedented operations. Its construction cost would be much greater than for a bridge and the cost of operation would also be materially higher.

10. Provision for a single track standard railway is feasible, but it would increase the cost of the four-lane highway bridge by approximately $60,000,000 (before financing), in addition to the cost of necessary railway approaches.

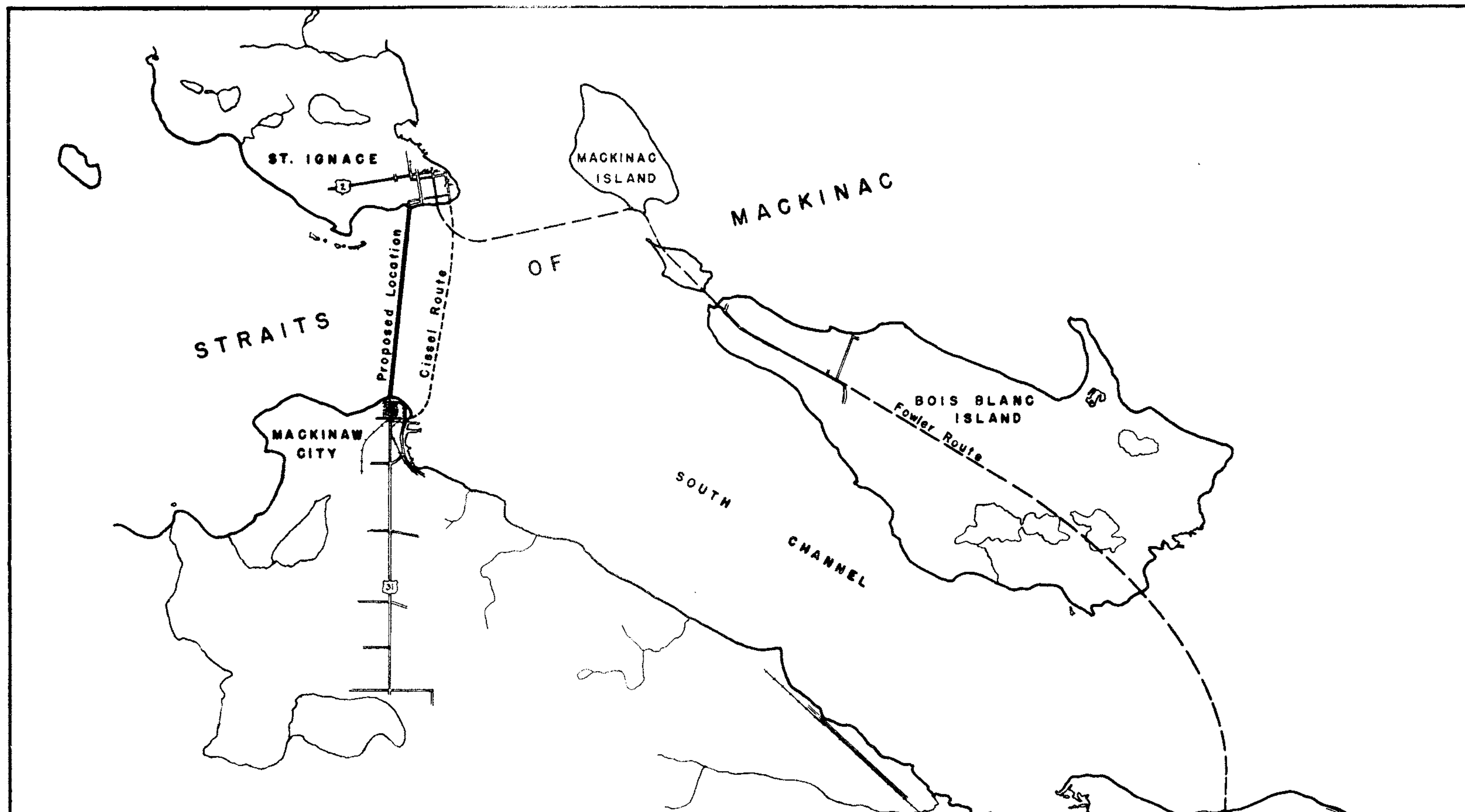
11. The estimates of traffic and revenue made by Coverdale & Colpitts indicate that a four-lane bridge as proposed herein is economically justified and feasible if the saving of present costs of the ferry operation is taken into consideration.

We acknowledge the courtesies extended throughout our investigation by the Authority. Its Secretary, Mr. Lawrence A. Rubin, has been most helpful in securing the basic data for our investigations.

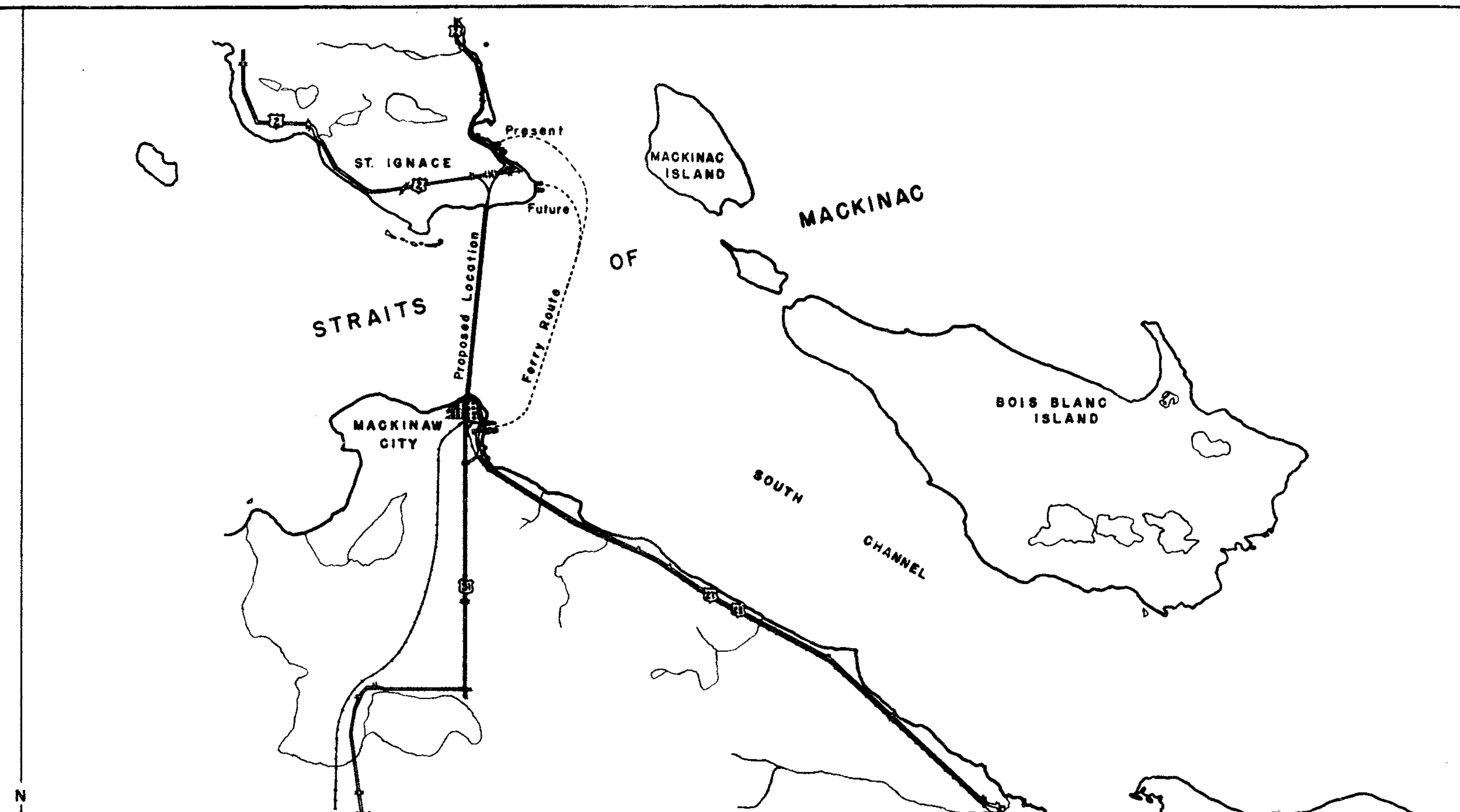
The State Highway Department has rendered valuable assistance in our studies. The advice and cooperation of State Highway Commissioner Charles M. Ziegler, Mr. George M. Foster, Bridge Engineer, Mr. W. W. McLaughlin, Director of Testing and Research, and Professor W. S. Housel have been most helpful.

In connection with our study of the geology of the site we acknowledge the aid freely given by State Geologist G. E. Eddy, Mining Engineer F. G. Pardee, and Professors K. K. Landes and G. M. Ehlers of the University of Michigan.

We have drawn freely on the previous studies for a bridge at this location, including those of Mr. C. E. Fowler, Mr. James E. Cissell and Modjeski and Masters.



ALTERNATE LOCATIONS
Scale 1:240,000



HIGHWAY CONNECTIONS
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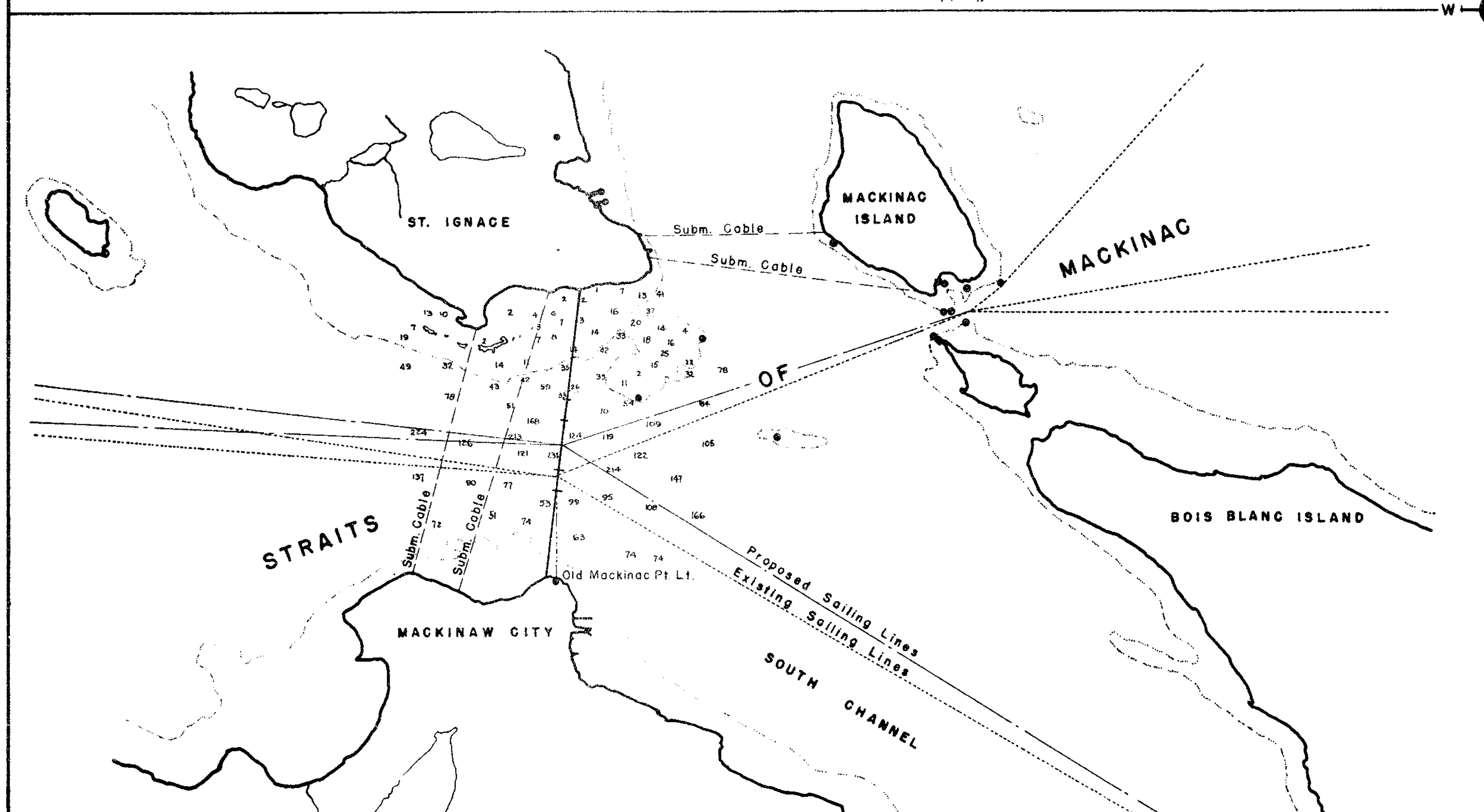

SAILING LINES
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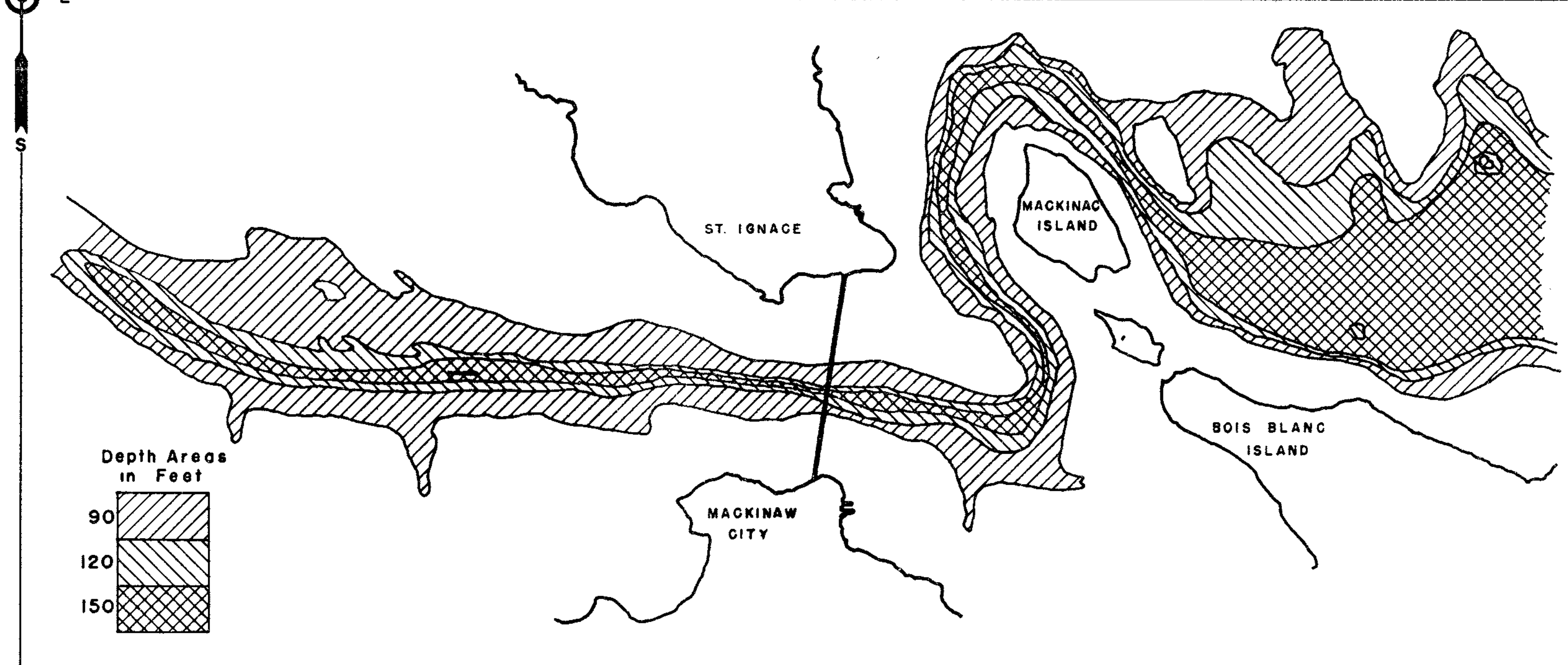

SUBMERGED VALLEY THROUGH
MACKINAC STRAITS
Scale 1:240,000

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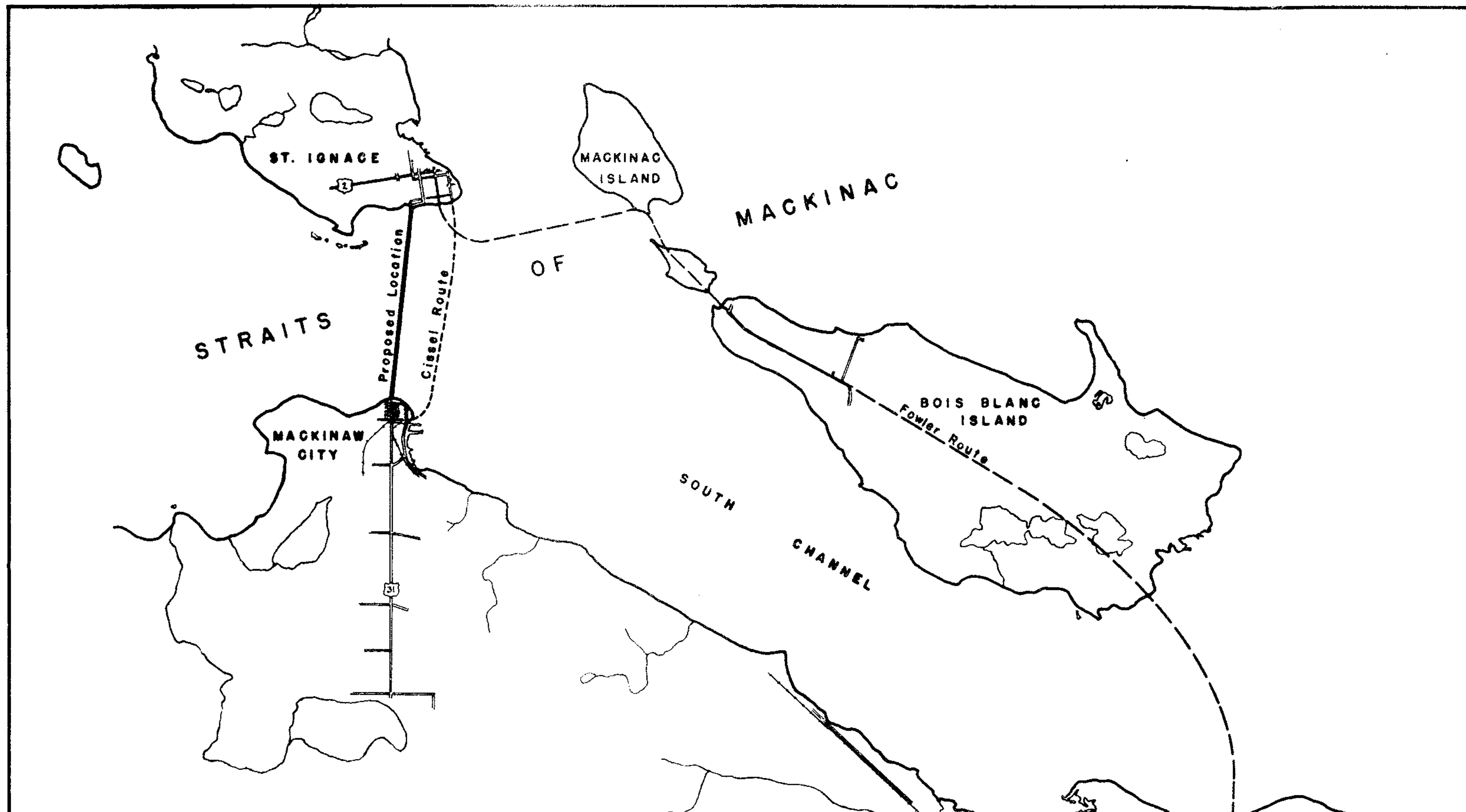
STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY

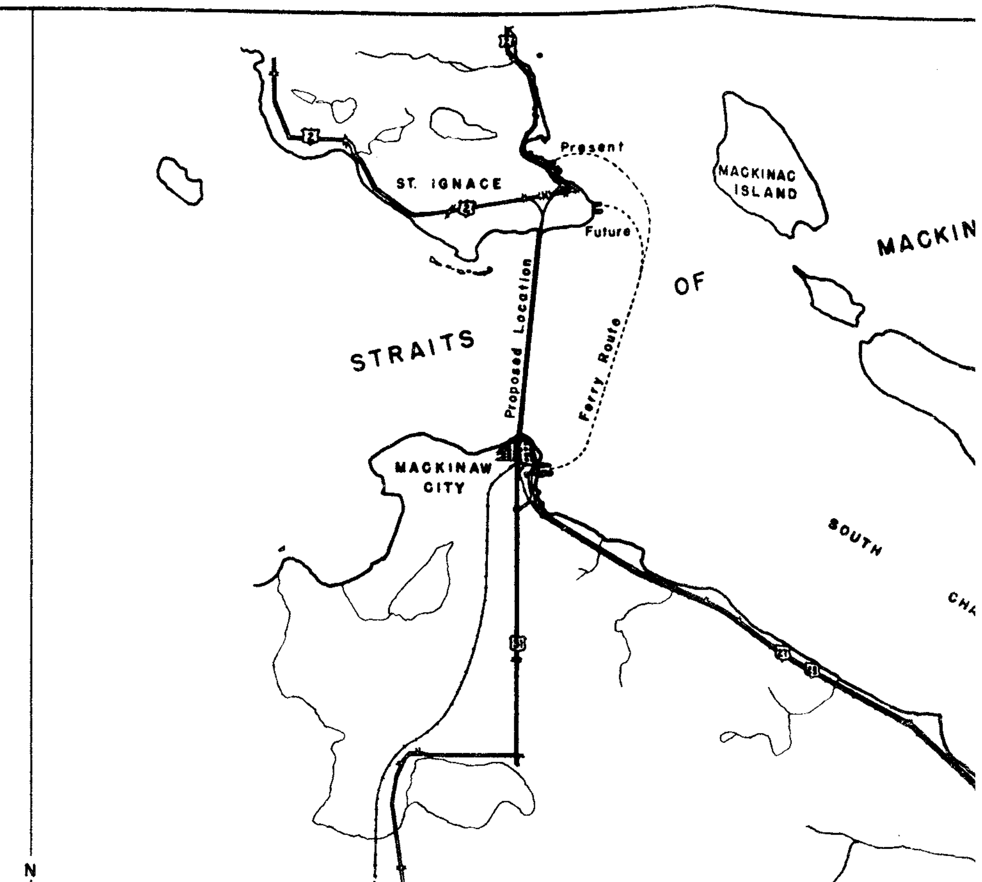
PROPOSED MACKINAC BRIDGE

LOCATION

JANUARY 10, 1951
PLATE PR 1



ALTERNATE LOCATIONS
Scale 1:240,000



HIGHWAY CONNECTIONS
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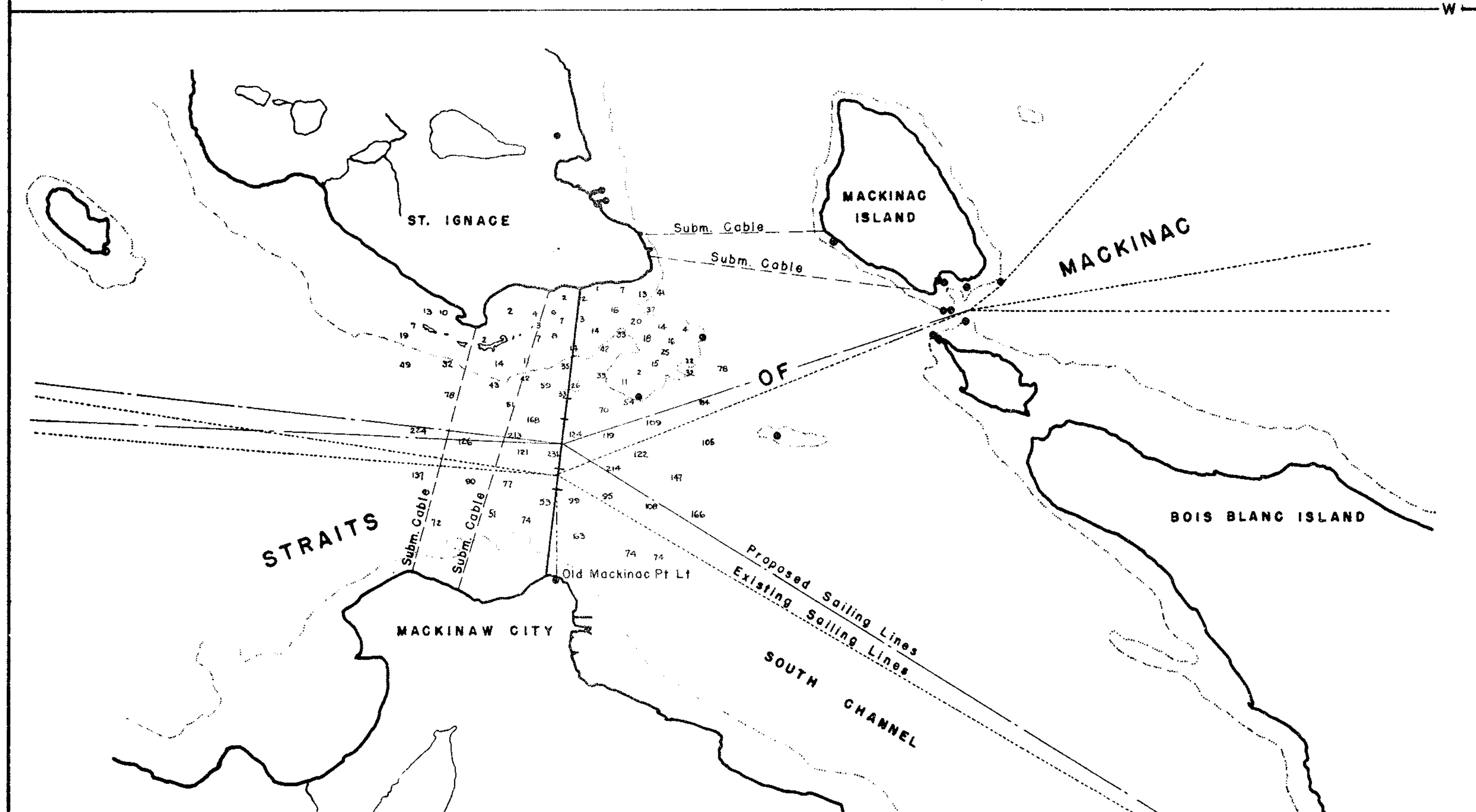

SAILING LINES
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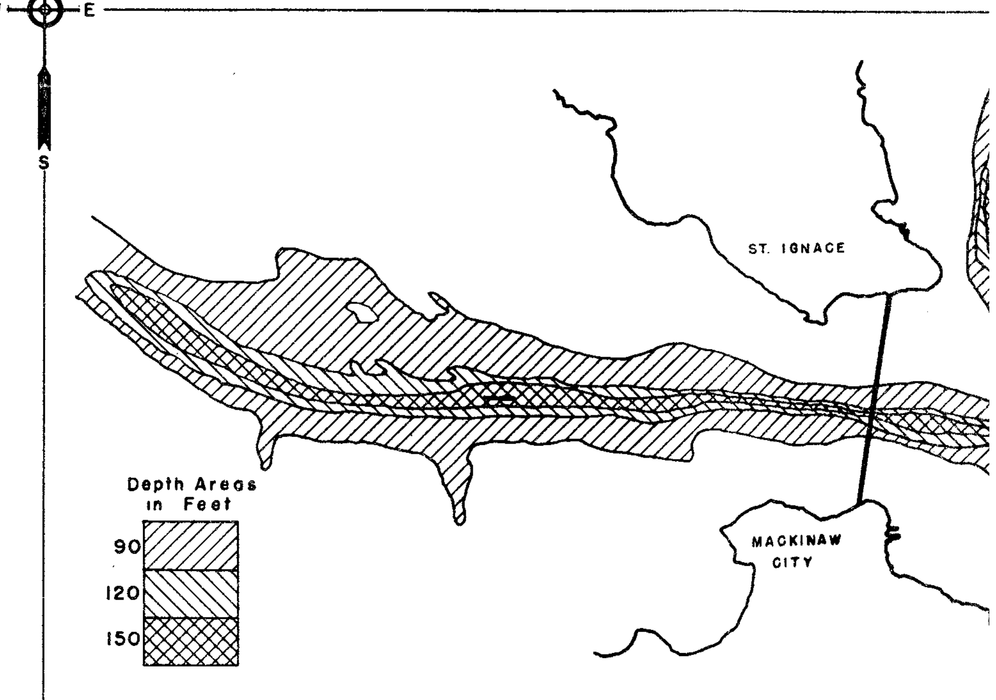

SUBMERGED VALLEY THROUGH MACKINAC STRAITS
Scale 1:240,000

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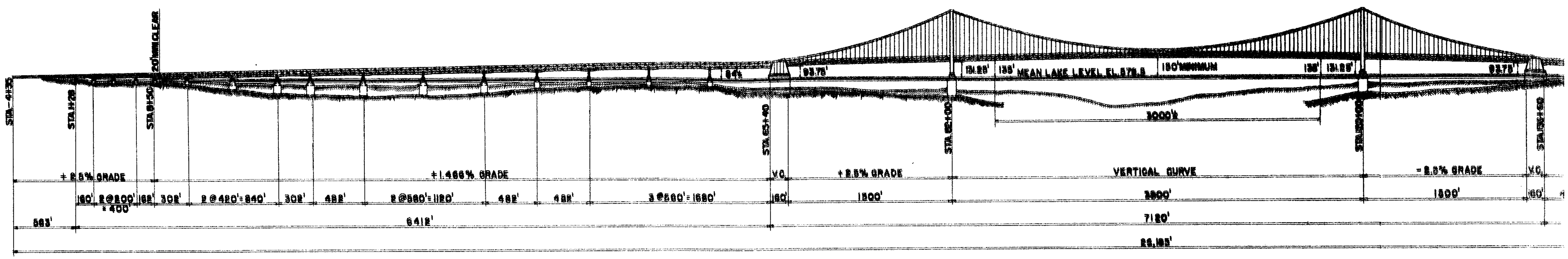
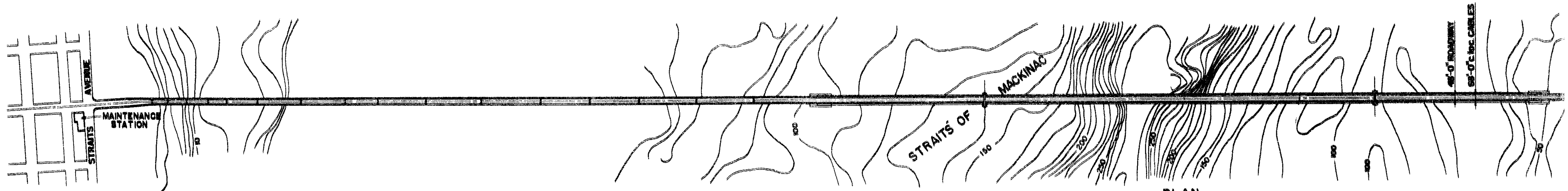
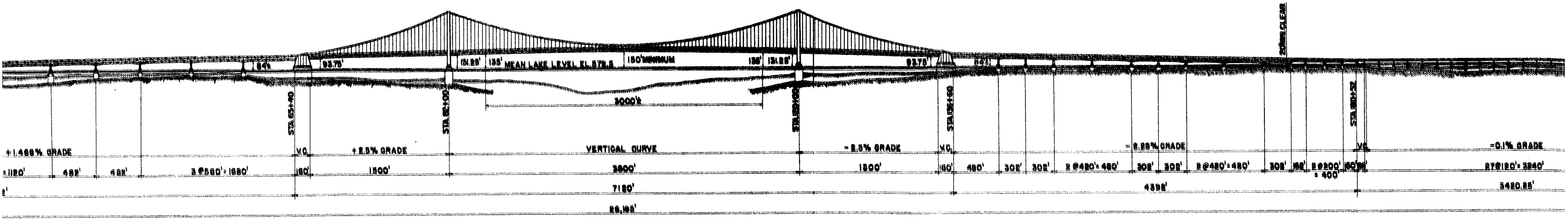


ELEVATION
Scale: 1" = 1,000'



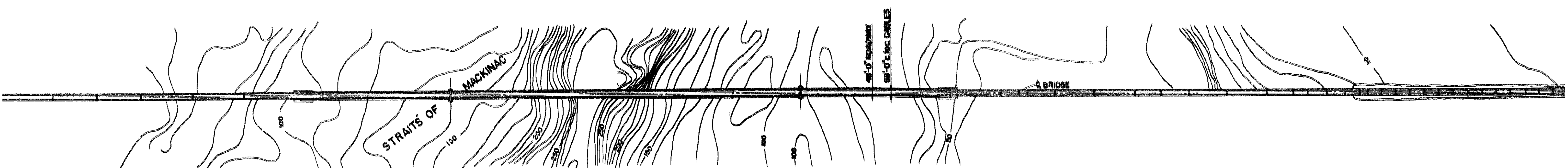
MACKINAW CITY

PLAN
Scale: 1" = 1,000'



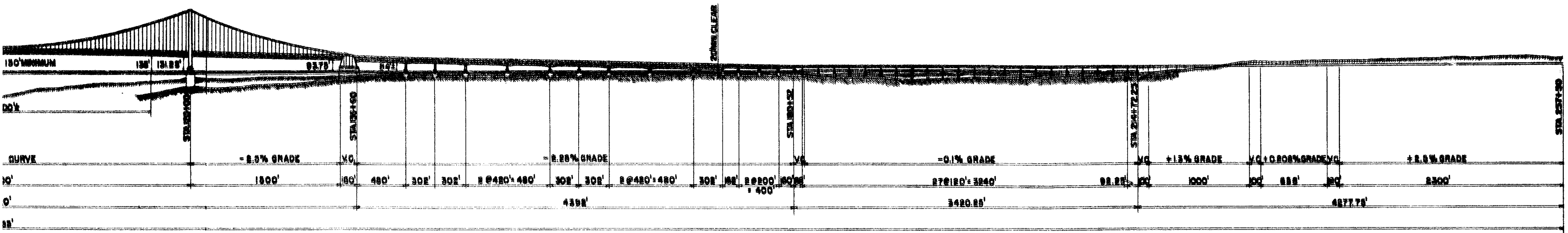
ELEVATION

Scale: 1" = 1,000'

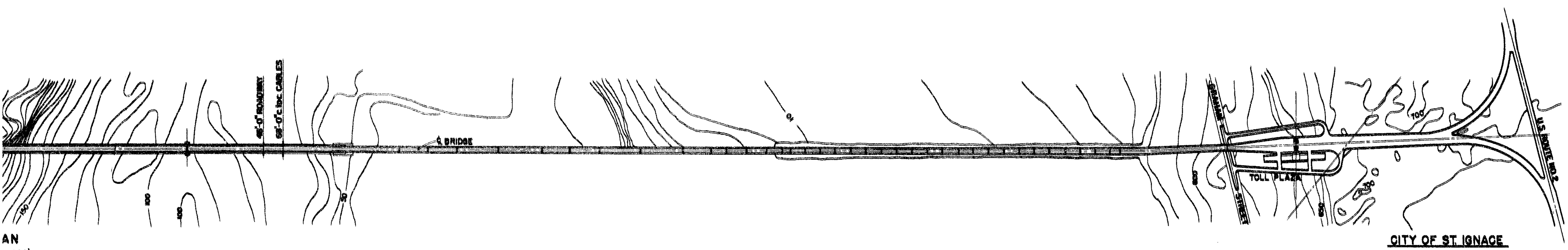


PLAN

Scale: 1" = 1,000'



ATION
=1,000'



AN
=1,000'

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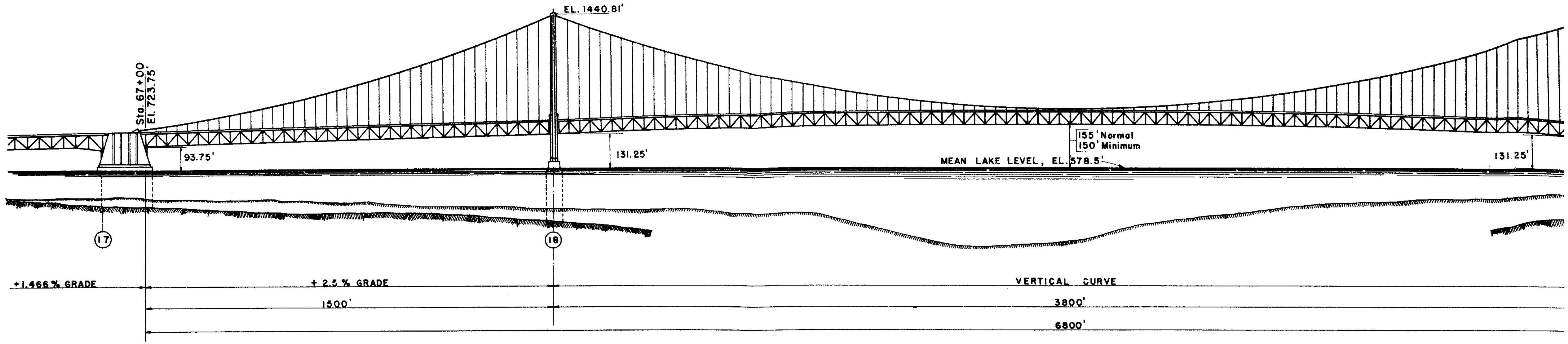
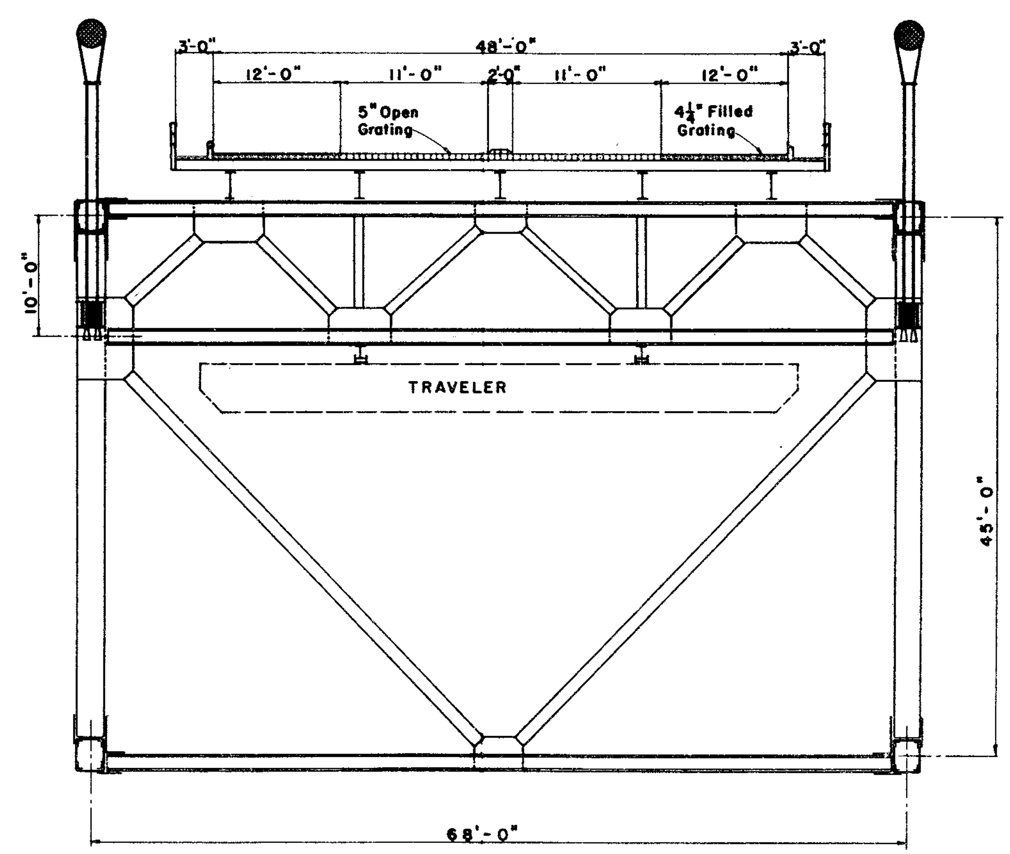
PROPOSED MACKINAC BRIDGE

GENERAL PLAN AND ELEVATION

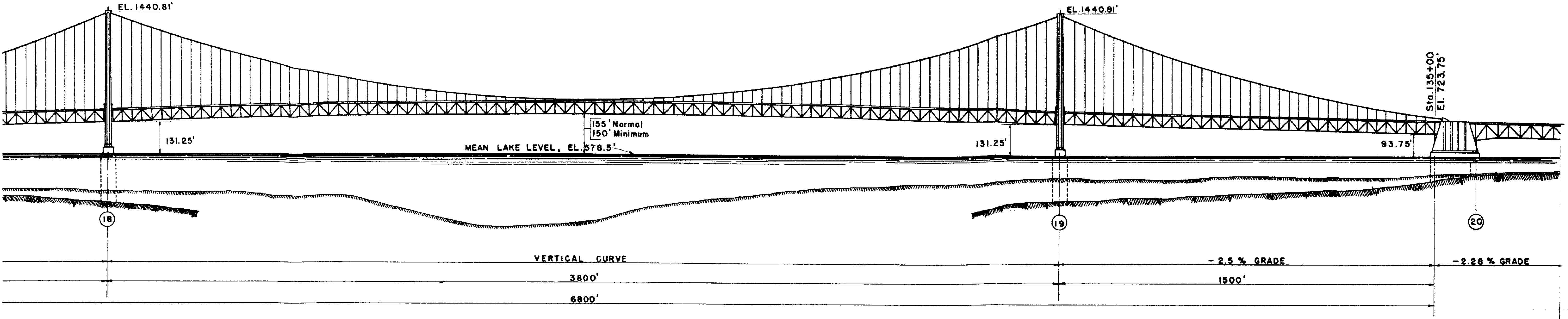
JANUARY 10, 1951
PLATE PR2



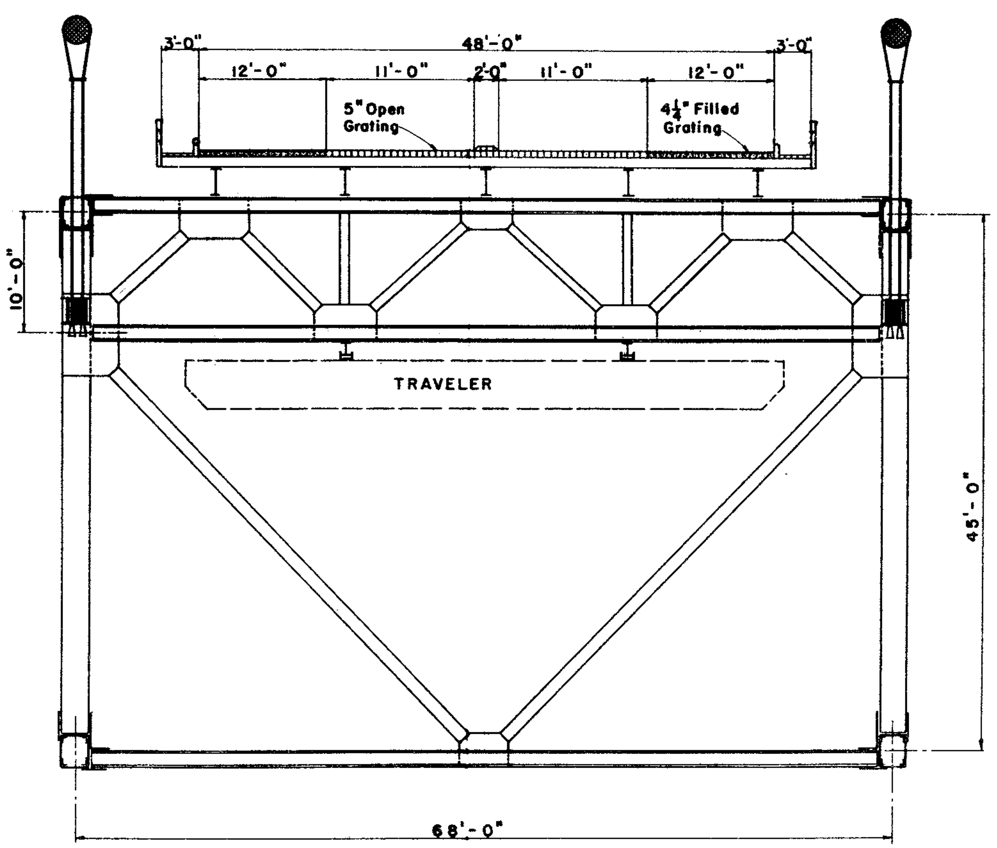
ELEVATION
Scale: 1" = 400'



CROSS SECTION — SUSPENDED STRUCTURE
Scale: 1/16" = 1'



ELEVATION
Scale: 1" = 400'



CROSS SECTION – SUSPENDED STRUCTURE
Scale: 1/16" = 1'

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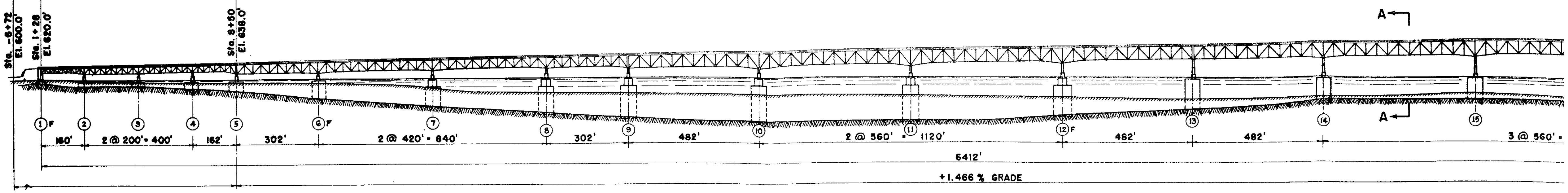
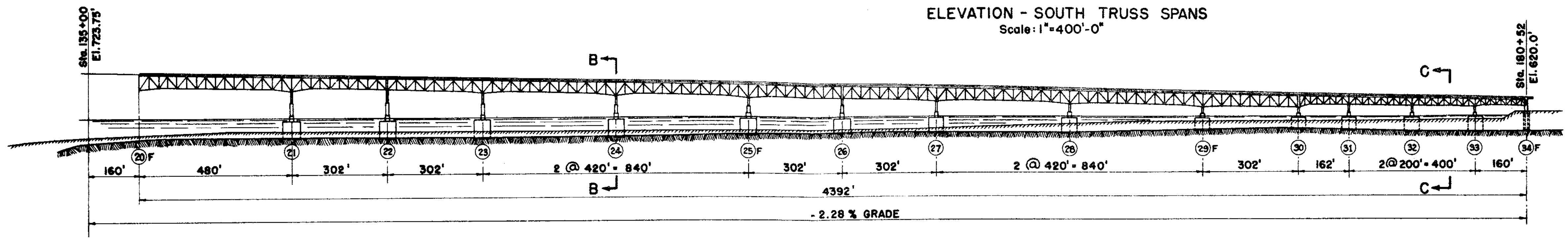
PROPOSED MACKINAC BRIDGE

MAIN CROSSING – SUSPENSION SPANS

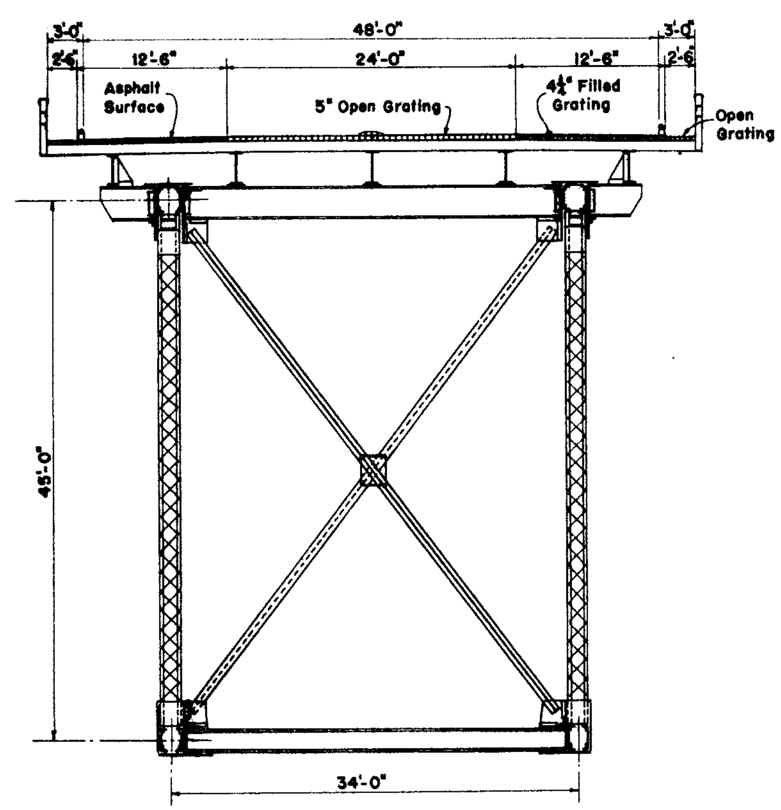
JANUARY 10, 1951
PLATE PR 3



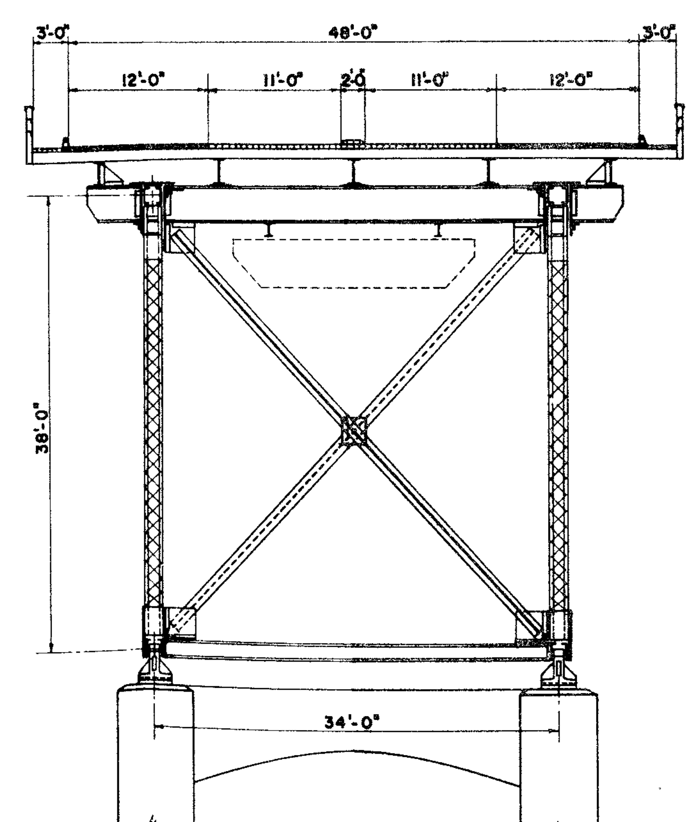
ELEVATION - SOUTH TRUSS SPANS
Scale: 1" = 400'-0"



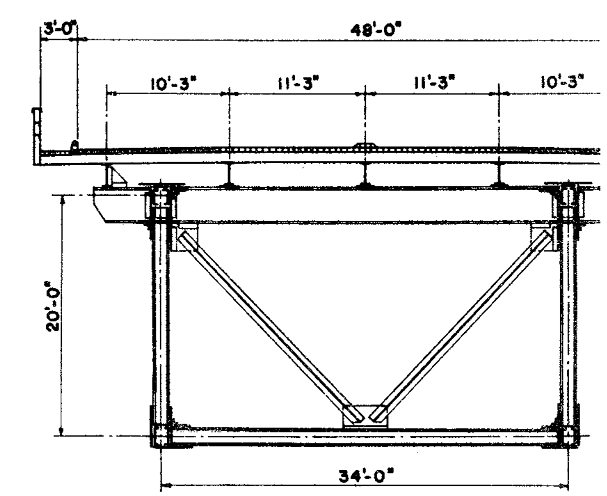
ELEVATION - NORTH TRUSS SPANS
Scale: 1" = 400'-0"



SECTION A-A
Scale: $\frac{1}{16}$" = 1'-0"



SECTION B-B
Scale: $\frac{1}{16}$" = 1'-0"



SECTION C-C
Scale: $\frac{1}{16}$" = 1'-0"

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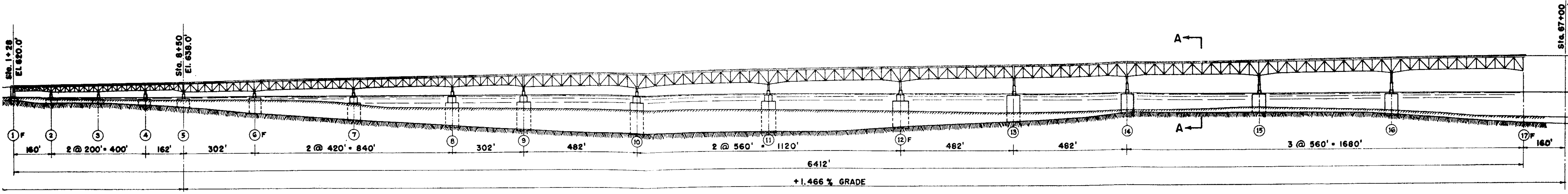
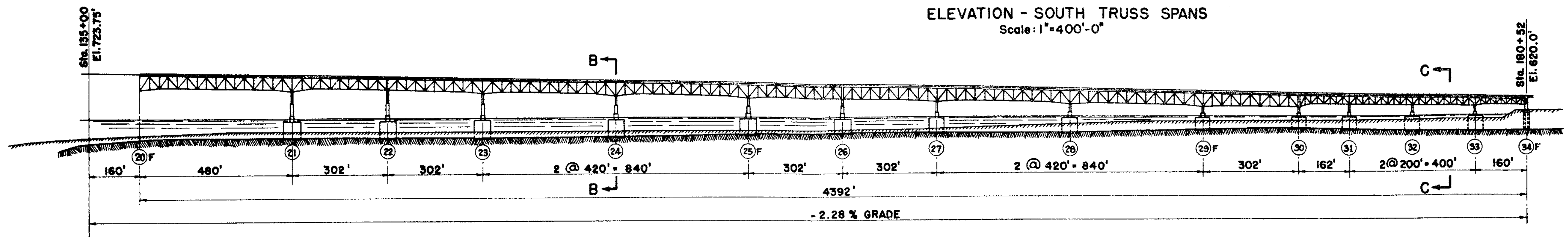
MAC

PRO

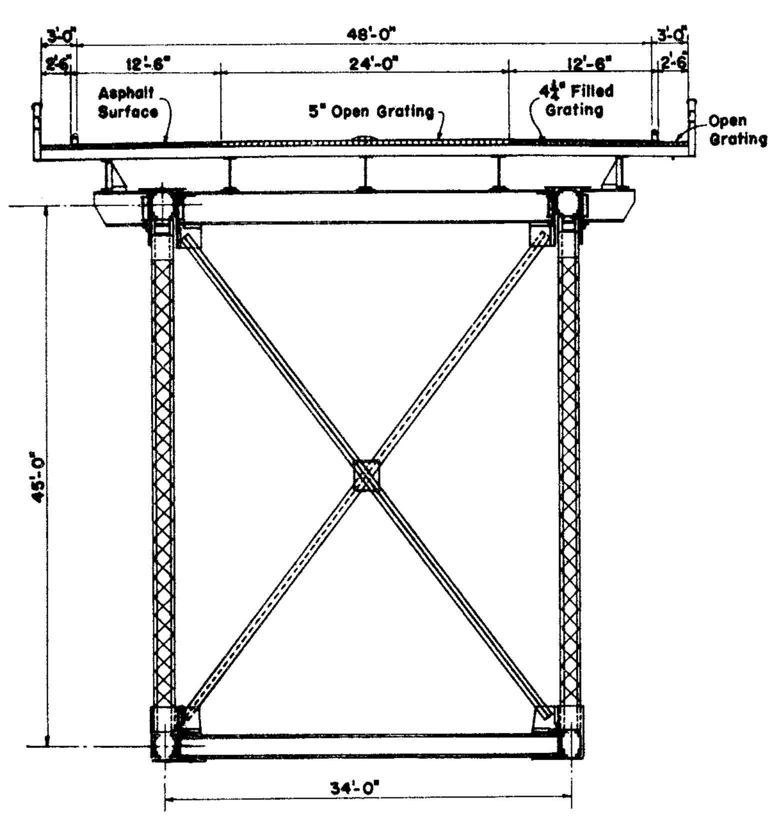
MA



ELEVATION - SOUTH TRUSS SPANS
Scale: 1" = 400'-0"



ELEVATION - NORTH TRUSS SPANS
Scale: 1" = 400'-0"



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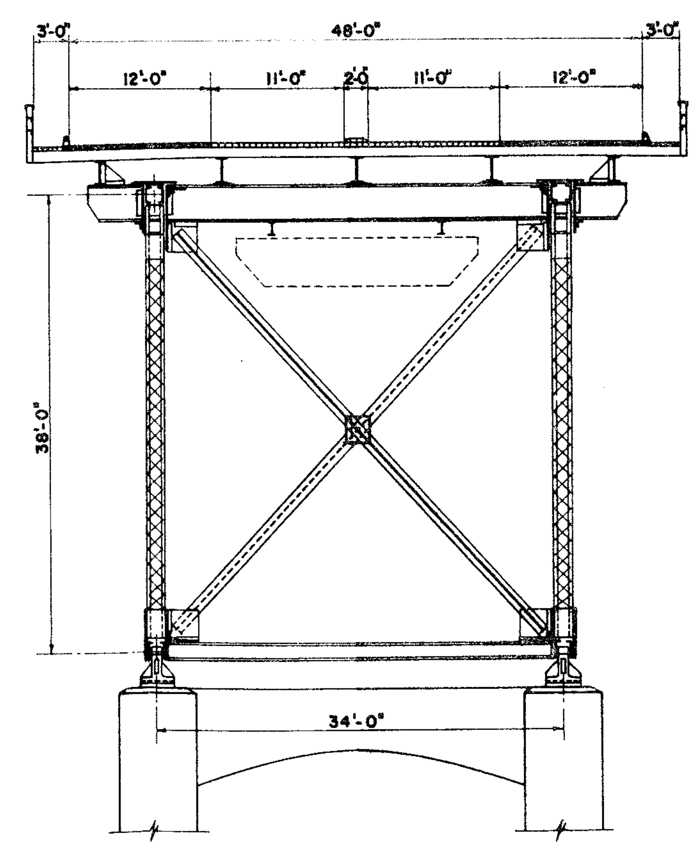

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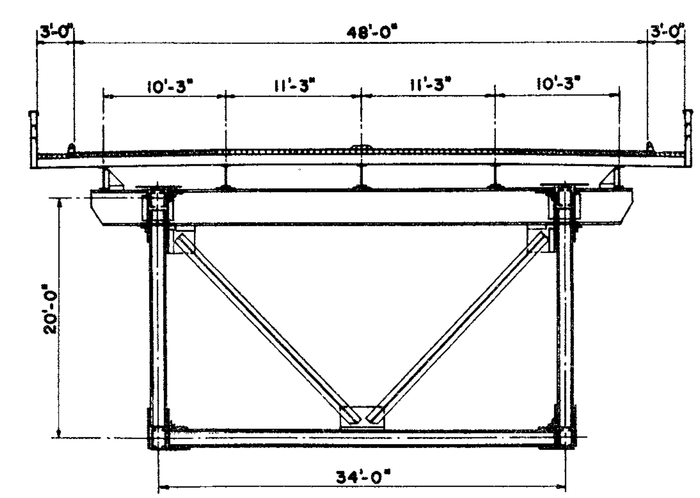

SECTION C-C
Scale: 1/16" = 1'-0"

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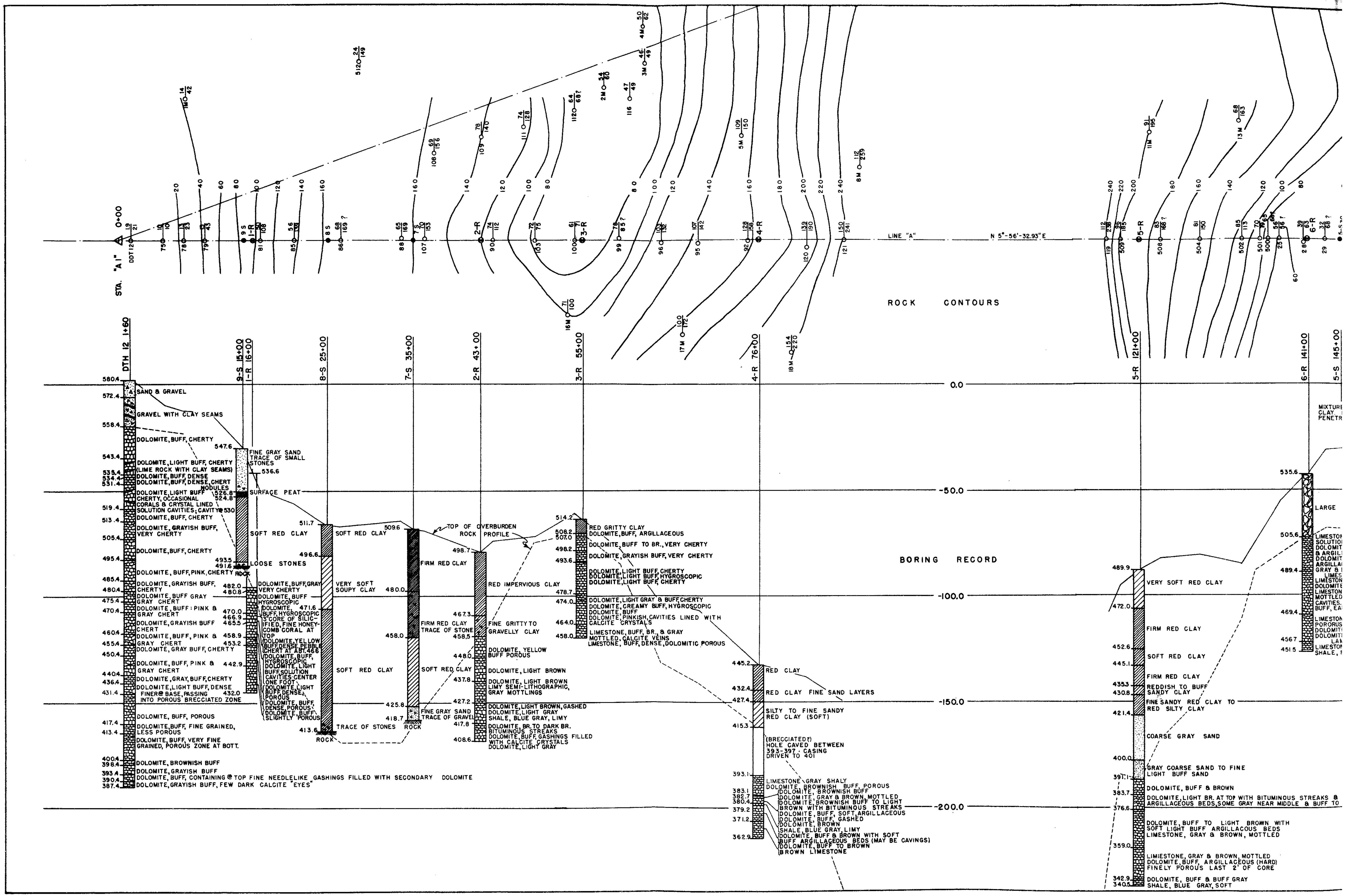
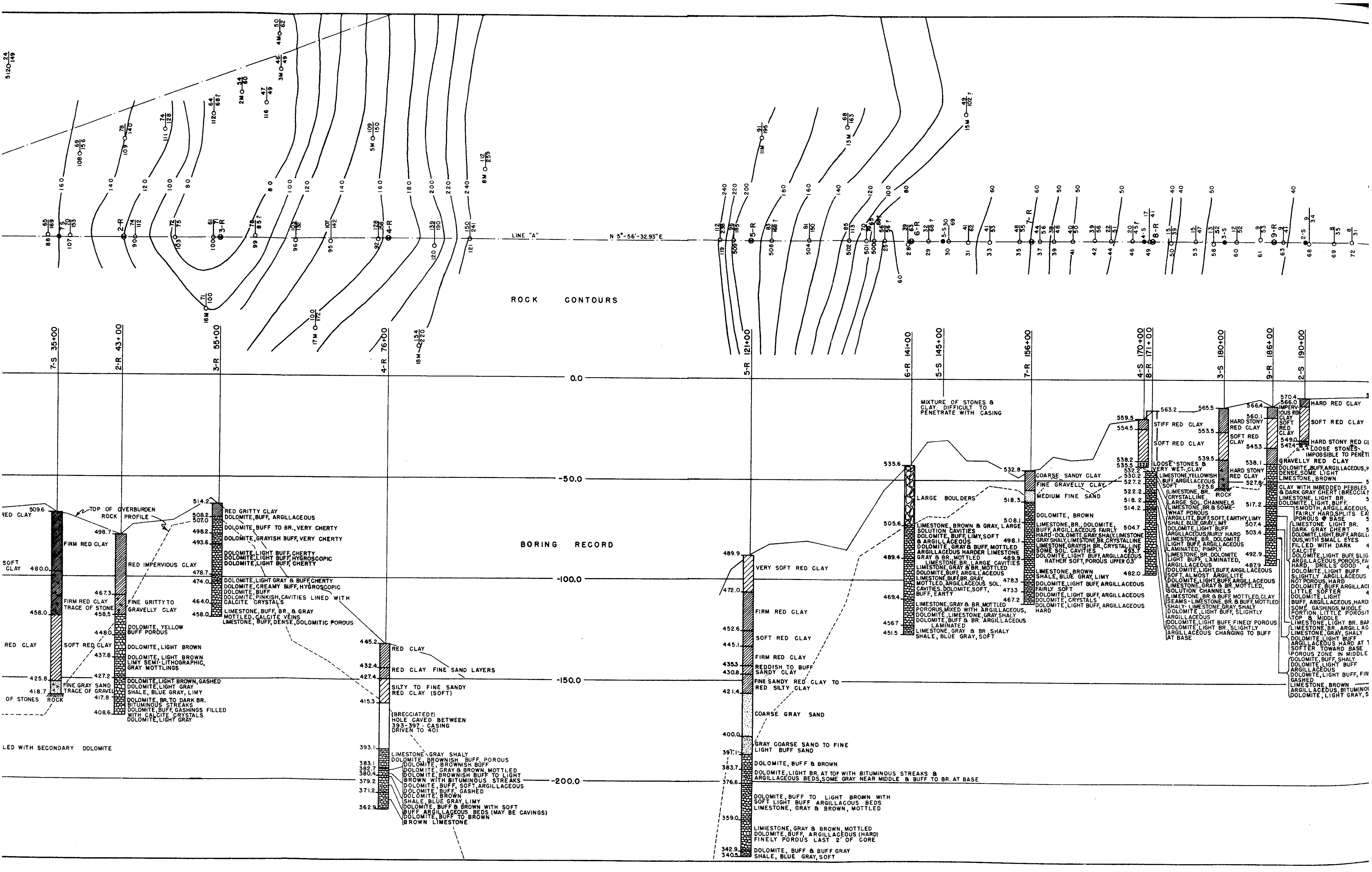
PROPOSED MACKINAC BRIDGE

MAIN CROSSING—TRUSS SPANS

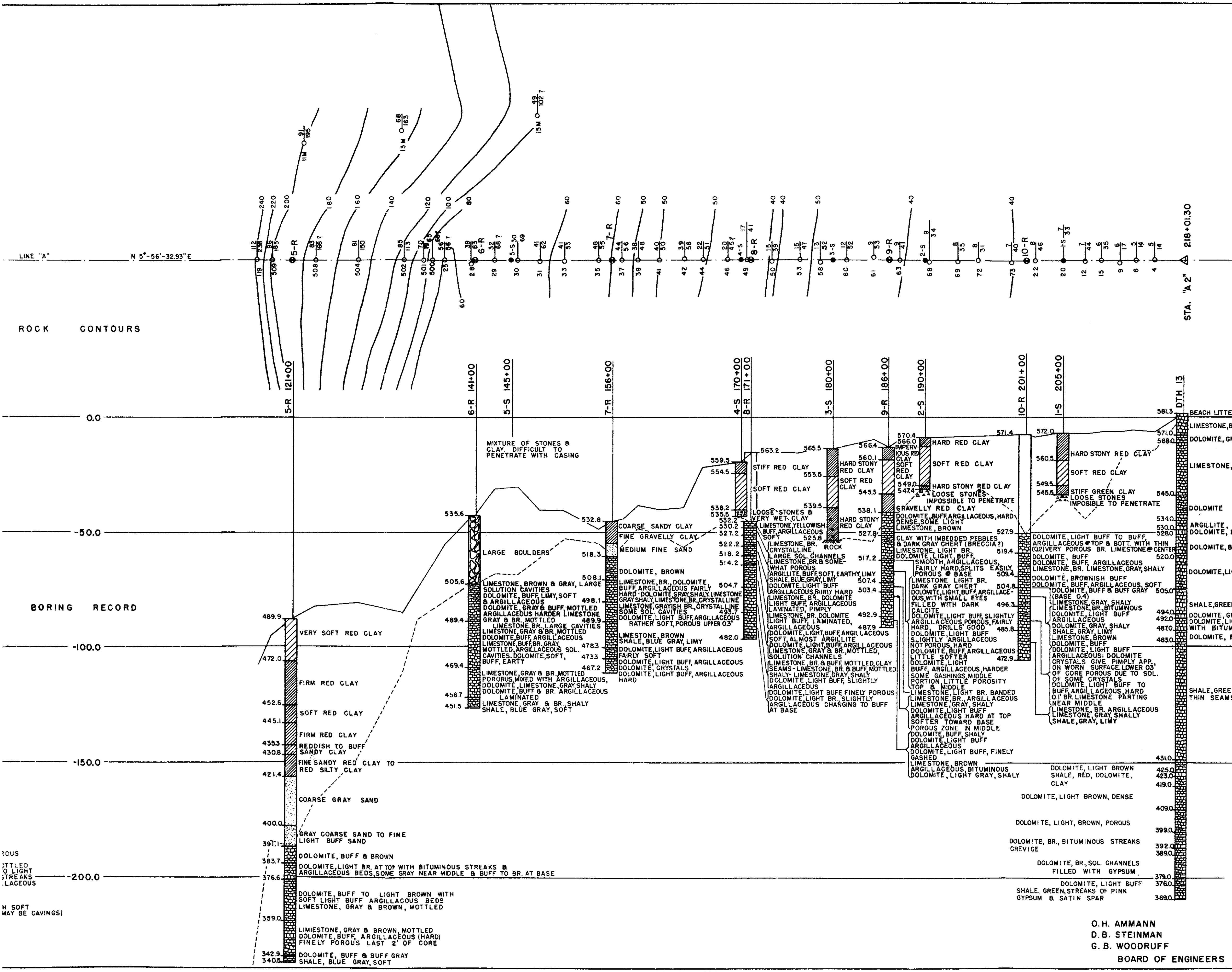
JANUARY 10, 1951
PLATE PR4



STA. "A1" 0+00
LINE "A"
N 5°-56'-32.93"E
ROCK CONTOURS
BORING RECORD
0.0
-50.0
-100.0
-150.0
-200.0
DTH 12 1+60
9-S 15+00
1-R 16+00
8-S 25+00
7-S 35+00
2-R 43+00
3-R 55+00
4-R 76+00
5-R 121+00
6-R 141+00
5-S 145+00
SAND & GRAVEL
GRAVEL WITH CLAY SEAMS
DOLOMITE, BUFF, CHERTY
DOLOMITE, LIGHT BUFF, CHERTY
(LIME ROCK WITH CLAY SEAMS)
DOLOMITE, BUFF, DENSE
DOLOMITE, BUFF, DENSE, CHERT NODULES
DOLOMITE, LIGHT BUFF CHERTY, OCCASIONAL CORALS & CRYSTAL LINED SOLUTION CAVITIES; CAVITY @ 530
DOLOMITE, BUFF, CHERTY
DOLOMITE, GRAYISH BUFF, VERY CHERTY
DOLOMITE, BUFF, CHERTY
DOLOMITE, BUFF, PINK, CHERTY
DOLOMITE, GRAYISH BUFF, CHERTY
DOLOMITE, BUFF GRAY GRAY CHERT
DOLOMITE, BUFF: PINK & GRAY CHERT
DOLOMITE, GRAYISH BUFF CHERT
DOLOMITE, BUFF, PINK & GRAY CHERT
DOLOMITE, GRAY BUFF, CHERTY
DOLOMITE, BUFF, PINK & GRAY CHERT
DOLOMITE, GRAY, BUFF, CHERTY
DOLOMITE, LIGHT BUFF, DENSE FINER @ BASE, PASSING INTO POROUS BRECCIATED ZONE
DOLOMITE, BUFF, POROUS
DOLOMITE, BUFF, FINE GRAINED, LESS POROUS
DOLOMITE, BUFF, VERY FINE GRAINED, POROUS ZONE AT BOTT.
DOLOMITE, BROWNISH BUFF
DOLOMITE, GRAYISH BUFF
DOLOMITE, BUFF, CONTAINING @ TOP FINE NEEDLELIKE GASHINGS FILLED WITH SECONDARY DOLOMITE
DOLOMITE, GRAYISH BUFF, FEW DARK CALCITE "EYES"
FINE GRAY SAND TRACE OF SMALL STONES
SURFACE PEAT
SOFT RED CLAY
LOOSE STONES
ROCK
DOLOMITE, BUFF, GRAY VERY CHERTY
DOLOMITE, BUFF HYGROSCOPIC
DOLOMITE, BUFF, HYGROSCOPIC
3' CORE OF SILICIFIED, FINE HONEYCOMB CORAL AT TOP
DOLOMITE, YELLOW BUFF, DENSE PEBBLE CHERT AT ABT. 466
DOLOMITE, BUFF, HYGROSCOPIC
DOLOMITE, LIGHT BUFF, SOLUTION CAVITIES: CENTER ONE FOOT
DOLOMITE, LIGHT BUFF, DENSE, POROUS
DOLOMITE, BUFF, DENSE, POROUS
DOLOMITE, BUFF, SLIGHTLY POROUS
SOFT RED CLAY
VERY SOFT SOUPY CLAY
TRACE OF STONES
FIRM RED CLAY
FIRM RED CLAY TRACE OF STONE
SOFT RED CLAY
FINE GRAY SAND TRACE OF GRAVEL
TOP OF OVERBURDEN
ROCK PROFILE
RED IMPERVIOUS CLAY
FINE GRITTY TO GRAVELLY CLAY
DOLOMITE, YELLOW BUFF POROUS
DOLOMITE, LIGHT BROWN
DOLOMITE, LIGHT BROWN LIMY SEMI-LITHOGRAPHIC, GRAY MOTTLINGS
DOLOMITE, LIGHT BROWN, GASHED
DOLOMITE, LIGHT GRAY
SHALE, BLUE GRAY, LIMY
DOLOMITE, BR. TO DARK BR. BITUMINOUS STREAKS
DOLOMITE, BUFF, GASHINGS FILLED WITH CALCITE CRYSTALS
DOLOMITE, LIGHT GRAY
RED GRITTY CLAY
DOLOMITE, BUFF, ARGILLACEOUS
DOLOMITE, BUFF TO BR., VERY CHERTY
DOLOMITE, GRAYISH BUFF, VERY CHERTY
DOLOMITE, LIGHT BUFF, CHERTY
DOLOMITE, LIGHT BUFF, HYGROSCOPIC
DOLOMITE, LIGHT BUFF, CHERTY
DOLOMITE, LIGHT GRAY & BUFF, CHERTY
DOLOMITE, CREAMY BUFF, HYGROSCOPIC
DOLOMITE, BUFF
DOLOMITE, PINKISH, CAVITIES LINED WITH CALCITE CRYSTALS
LIMESTONE, BUFF, BR., & GRAY MOTTLED, CALCITE VEINS
LIMESTONE, BUFF, DENSE, DOLOMITIC POROUS
RED CLAY
RED CLAY FINE SAND LAYERS
SILTY TO FINE SANDY RED CLAY (SOFT)
(BRECCIATED?)
HOLE CAVED BETWEEN 393-397. CASING DRIVEN TO 401
LIMESTONE, GRAY SHALY
DOLOMITE, BROWNISH BUFF, POROUS
DOLOMITE, BROWNISH BUFF
DOLOMITE, GRAY & BROWN, MOTTLED
DOLOMITE, BROWNISH BUFF TO LIGHT BROWN WITH BITUMINOUS STREAKS
DOLOMITE, BUFF, SOFT, ARGILLACEOUS
DOLOMITE, BUFF, GASHED
DOLOMITE, BROWN
SHALE, BLUE GRAY, LIMY
DOLOMITE, BUFF & BROWN WITH SOFT BUFF ARGILLACEOUS BEDS (MAY BE CAVINGS)
DOLOMITE, BUFF TO BROWN
BROWN LIMESTONE
VERY SOFT RED CLAY
FIRM RED CLAY
SOFT RED CLAY
FIRM RED CLAY
REDDISH TO BUFF SANDY CLAY
FINE SANDY RED CLAY TO RED SILTY CLAY
COARSE GRAY SAND
GRAY COARSE SAND TO FINE LIGHT BUFF SAND
DOLOMITE, BUFF & BROWN
DOLOMITE, LIGHT BR. AT TOP WITH BITUMINOUS STREAKS & ARGILLACEOUS BEDS, SOME GRAY NEAR MIDDLE & BUFF TO
DOLOMITE, BUFF TO LIGHT BROWN WITH SOFT LIGHT BUFF ARGILLACOUS BEDS
LIMESTONE, GRAY & BROWN, MOTTLED
LIMESTONE, GRAY & BROWN, MOTTLED
DOLOMITE, BUFF, ARGILLACEOUS (HARD)
FINELY POROUS LAST 2' OF CORE
DOLOMITE, BUFF & BUFF GRAY
SHALE, BLUE GRAY, SOFT
MIXTURE CLAY PENETR
LARGE



LINE "A"
N 5°-56'-32.93"E
ROCK CONTOURS
BORING RECORD
7-S 35+00
2-R 43+00
3-R 55+00
4-R 76+00
5-R 121+00
6-R 141+00
5-S 145+00
7-R 156+00
4-S 170+00
8-R 171+00
3-S 180+00
9-R 186+00
2-S 190+00
0.0
-50.0
-100.0
-150.0
-200.0
TOP OF OVERBURDEN
ROCK PROFILE
FIRM RED CLAY
FIRM RED CLAY TRACE OF STONE
SOFT RED CLAY
FINE GRAY SAND TRACE OF GRAVEL
ROCK
RED IMPERVIOUS CLAY
FINE GRITTY TO GRAVELLY CLAY
DOLOMITE, YELLOW BUFF POROUS
DOLOMITE, LIGHT BROWN
DOLOMITE, LIGHT BROWN LIMY SEMI-LITHOGRAPHIC, GRAY MOTTLINGS
DOLOMITE, LIGHT BROWN, GASHED
DOLOMITE, LIGHT GRAY
SHALE, BLUE GRAY, LIMY
DOLOMITE, BR. TO DARK BR. BITUMINOUS STREAKS
DOLOMITE, BUFF, GASHINGS FILLED WITH CALCITE CRYSTALS
DOLOMITE, LIGHT GRAY
RED GRITTY CLAY
DOLOMITE, BUFF, ARGILLACEOUS
DOLOMITE, BUFF TO BR., VERY CHERTY
DOLOMITE, GRAYISH BUFF, VERY CHERTY
DOLOMITE, LIGHT BUFF, CHERTY
DOLOMITE, LIGHT BUFF, HYGROSCOPIC
DOLOMITE, LIGHT BUFF, CHERTY
DOLOMITE, LIGHT GRAY & BUFF, CHERTY
DOLOMITE, CREAMY BUFF, HYGROSCOPIC
DOLOMITE, BUFF
DOLOMITE, PINKISH, CAVITIES LINED WITH CALCITE CRYSTALS
LIMESTONE, BUFF, BR., & GRAY MOTTLED, CALCITE VEINS
LIMESTONE, BUFF, DENSE, DOLOMITIC POROUS
RED CLAY
RED CLAY FINE SAND LAYERS
SILTY TO FINE SANDY RED CLAY (SOFT)
(BRECCIATED?) HOLE CAVED BETWEEN 393-397 - CASING DRIVEN TO 401
LIMESTONE, GRAY SHALY
DOLOMITE, BROWNISH BUFF, POROUS
DOLOMITE, GRAY & BROWN, MOTTLED
DOLOMITE, BROWNISH BUFF TO LIGHT BROWN WITH BITUMINOUS STREAKS
DOLOMITE, BUFF, SOFT, ARGILLACEOUS
DOLOMITE, BUFF, GASHED
DOLOMITE, BROWN
SHALE, BLUE GRAY, LIMY
DOLOMITE, BUFF & BROWN WITH SOFT BUFF ARGILLACEOUS BEDS (MAY BE CAVINGS)
DOLOMITE, BUFF TO BROWN
BROWN LIMESTONE
LED WITH SECONDARY DOLOMITE
VERY SOFT RED CLAY
FIRM RED CLAY
SOFT RED CLAY
FIRM RED CLAY
REDDISH TO BUFF SANDY CLAY
FINE SANDY RED CLAY TO RED SILTY CLAY
COARSE GRAY SAND
GRAY COARSE SAND TO FINE LIGHT BUFF SAND
DOLOMITE, BUFF & BROWN
DOLOMITE, LIGHT BR. AT TOP WITH BITUMINOUS STREAKS & ARGILLACEOUS BEDS, SOME GRAY NEAR MIDDLE & BUFF TO BR. AT BASE
DOLOMITE, BUFF TO LIGHT BROWN WITH SOFT LIGHT BUFF ARGILLACOUS BEDS
LIMESTONE, GRAY & BROWN, MOTTLED
LIMIESTONE, GRAY & BROWN, MOTTLED
DOLOMITE, BUFF, ARGILLACEOUS (HARD)
FINELY POROUS LAST 2' OF CORE
DOLOMITE, BUFF & BUFF GRAY
SHALE, BLUE GRAY, SOFT
MIXTURE OF STONES & CLAY. DIFFICULT TO PENETRATE WITH CASING
LARGE BOULDERS
LIMESTONE, BROWN & GRAY, LARGE SOLUTION CAVITIES
DOLOMITE, BUFF, LIMY, SOFT & ARGILLACEOUS
DOLOMITE, GRAY & BUFF, MOTTLED ARGILLACEOUS HARDER LIMESTONE
GRAY & BR. MOTTLED
LIMESTONE, BR. LARGE CAVITIES
LIMESTONE, GRAY & BR. MOTTLED
DOLOMITE, BUFF, ARGILLACEOUS
LIMESTONE, BUFF, BR., GRAY, MOTTLED, ARGILLACEOUS SOL. CAVITIES. DOLOMITE, SOFT, BUFF, EARTY
LIMESTONE, GRAY & BR. MOTTLED POROUS, MIXED WITH ARGILLACEOUS,
DOLOMITE, LIMESTONE, GRAY, SHALY
DOLOMITE, BUFF & BR. ARGILLACEOUS LAMINATED
LIMESTONE, GRAY & BR. SHALY
SHALE, BLUE GRAY, SOFT
COARSE SANDY CLAY
FINE GRAVELLY CLAY
MEDIUM FINE SAND
DOLOMITE, BROWN
LIMESTONE, BR., DOLOMITE, BUFF, ARGILLACEOUS FAIRLY HARD - DOLOMITE, GRAY, SHALY, LIMESTONE
GRAY SHALY, LIMESTONE, BR., CRYSTALLINE
LIMESTONE, GRAYISH BR., CRYSTALLINE
SOME SOL. CAVITIES
DOLOMITE, LIGHT BUFF ARGILLACEOUS RATHER SOFT, POROUS UPPER 0.3'
LIMESTONE, BROWN
SHALE, BLUE GRAY, LIMY
DOLOMITE, LIGHT BUFF, ARGILLACEOUS FAIRLY SOFT
DOLOMITE, LIGHT BUFF, ARGILLACEOUS
DOLOMITE, CRYSTALS
DOLOMITE, LIGHT BUFF, ARGILLACEOUS HARD
STIFF RED CLAY
SOFT RED CLAY
LOOSE STONES & VERY WET CLAY
LIMESTONE, YELLOWISH BUFF, ARGILLACEOUS SOFT
LIMESTONE, BR. CRYSTALLINE
LARGE SOL. CHANNELS
LIMESTONE, BR. & SOMEWHAT POROUS
ARGILLITE, BUFF, SOFT, EARTHY, LIMY
SHALE, BLUE GRAY, LIMY
DOLOMITE, LIGHT BUFF ARGILLACEOUS, FAIRLY HARD
LIMESTONE, BR., DOLOMITE LIGHT BUFF, ARGILLACEOUS LAMINATED, PIMPLY
LIMESTONE, BR., DOLOMITE LIGHT BUFF, LAMINATED, ARGILLACEOUS
DOLOMITE, LIGHT, BUFF, ARGILLACEOUS SOFT, ALMOST ARGILLITE
DOLOMITE, LIGHT, BUFF, ARGILLACEOUS
LIMESTONE, GRAY & BR., MOTTLED, SOLUTION CHANNELS
LIMESTONE, BR & BUFF MOTTLED, CLAY SEAMS - LIMESTONE, BR. & BUFF MOTTLED
SHALY - LIMESTONE, GRAY, SHALY
DOLOMITE, LIGHT BUFF, SLIGHTLY ARGILLACEOUS
DOLOMITE, LIGHT BUFF, FINELY POROUS
DOLOMITE, LIGHT BR. SLIGHTLY ARGILLACEOUS CHANGING TO BUFF AT BASE
HARD STONY RED CLAY
SOFT RED CLAY
HARD STONY RED CLAY
ROCK
IMPERVIOUS RED CLAY
SOFT RED CLAY
HARD RED CLAY
SOFT RED CLAY
HARD STONY RED CL
LOOSE STONES IMPOSSIBLE TO PENETI
GRAVELLY RED CLAY
DOLOMITE, BUFF, ARGILLACEOUS, DENSE, SOME LIGHT
LIMESTONE, BROWN
CLAY WITH IMBEDDED PEBBLES & DARK GRAY CHERT (BRECCIA?)
LIMESTONE, LIGHT BR.
DOLOMITE, LIGHT, BUFF
SMOOTH, ARGILLACEOUS, FAIRLY HARD, SPLITS EA
POROUS @ BASE
LIMESTONE LIGHT BR.
DARK GRAY CHERT
DOLOMITE, LIGHT, BUFF, ARGILL OUS, WITH SMALL EYES FILLED WITH DARK CALCITE
DOLOMITE, LIGHT BUFF, SLIG ARGILLACEOUS, POROUS, FA HARD, DRILLS GOOD
DOLOMITE, LIGHT BUFF SLIGHTLY ARGILLACEOUS NOT POROUS, HARD
DOLOMITE, BUFF, ARGILLACI LITTLE SOFTER
DOLOMITE, LIGHT BUFF, ARGILLACEOUS, HARD SOME GASHINGS, MIDDLE PORTION LITTLE POROSIT TOP & MIDDLE
LIMESTONE, LIGHT BR. BAN
LIMESTONE, BR., ARGILLAC
LIMESTONE, GRAY, SHALY
DOLOMITE, LIGHT BUFF ARGILLACEOUS HARD AT T SOFTER TOWARD BASE POROUS ZONE IN MIDDLE
DOLOMITE, BUFF, SHALY
DOLOMITE, LIGHT BUFF ARGILLACEOUS
DOLOMITE, LIGHT BUFF, FIN GASHED
LIMESTONE, BROWN ARGILLACEOUS, BITUMINO
DOLOMITE, LIGHT GRAY, S



SYMBOLS AND NOTES

△ TRIANGULATION STATION

$29 \bigcirc \frac{32}{68}$ — 32: DEPTH BELOW ELEV. 578.5 TO BOTTOM OF STRAITS; 68: DEPTH BELOW ELEV. 578.5 TO SURFACE OF ROCK

○ BORINGS 1-S TO 9-S

● BORINGS 1-R TO 10-R

FOR MORE COMPLETE LOGS OF HOLES AND CLASSIFICATIONS OF SAMPLES, SEE REPORTS OF RESIDENT ENGINEER AND GEOLOGICAL SURVEY DIVISION, DEPARTMENT OF CONSERVATION, STATE OF MICHIGAN

O.H. AMMANN
D.B. STEINMAN
G.B. WOODRUFF
BOARD OF ENGINEERS

STATE OF MICHIGAN
MACKINAC BRIDGE AUTHORITY

PROPOSED MACKINAC BRIDGE

BORINGS—1939

JANUARY 10, 1951
PLATE PR 5