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W.P. # 130-61

WELLAND
TUNNEL

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CABLE ADDRESS "FOUNDANENG" TORONTO

May 29, 1961

Mr. J. Walter, P. Eng.
Director of Planning and Design
Department of Highways, Ontario
Parliament Buildings
Toronto, Ontario

Dear Sir,

W.P. 130-61

WELLAND TUNNEL
UNDER
THE WELLAND SHIP CANAL

In accordance with our proposal of January 30, 1961, and the letter of acceptance dated February 9, 1961, received from Mr. W. A. Clarke, Chief Engineer, we are pleased to submit our report on the proposed tunnel crossing of the Welland Ship Canal in Welland, Ontario.

The report describes the results of our studies undertaken to ascertain the most suitable type of structure for the prevailing site conditions, the physical requirements being as outlined by the Department and the St. Lawrence Seaway Authority.

We recommend that the tunnel be of the trench type, constructed of precast reinforced concrete units, of rectangular cross section. This is as shown on the frontispiece and on Drawing 2301-2.

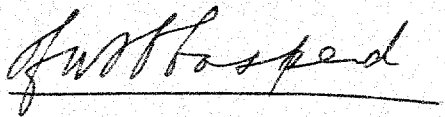
The estimated cost is \$9,073,000.00, inclusive of approach ramps to ground level but exclusive of access and exit interchanges at either end. These were not to be included in this report.

Mr. J. Walter, P. Eng.
May 29, 1961
Page 2

We have been in contact, throughout our studies, with the Foundation Sub-Section of your Materials and Research Laboratory and have greatly appreciated the co-operation received from them.

In the preparation of this report it has been necessary to undertake a greater development of preliminary designs and construction procedures than is customary at this stage of a project. We are, therefore, in a most favourable position to proceed immediately with the detailed design and specifications, should you so wish.

Yours very truly,
FOUNDATION OF CANADA ENGINEERING
CORPORATION LIMITED

A handwritten signature in dark ink, appearing to read 'H. W. H. Casperd', written over a horizontal line.

H. W. H. Casperd, P. Eng.
VICE PRESIDENT

HWHC/hbe
2301

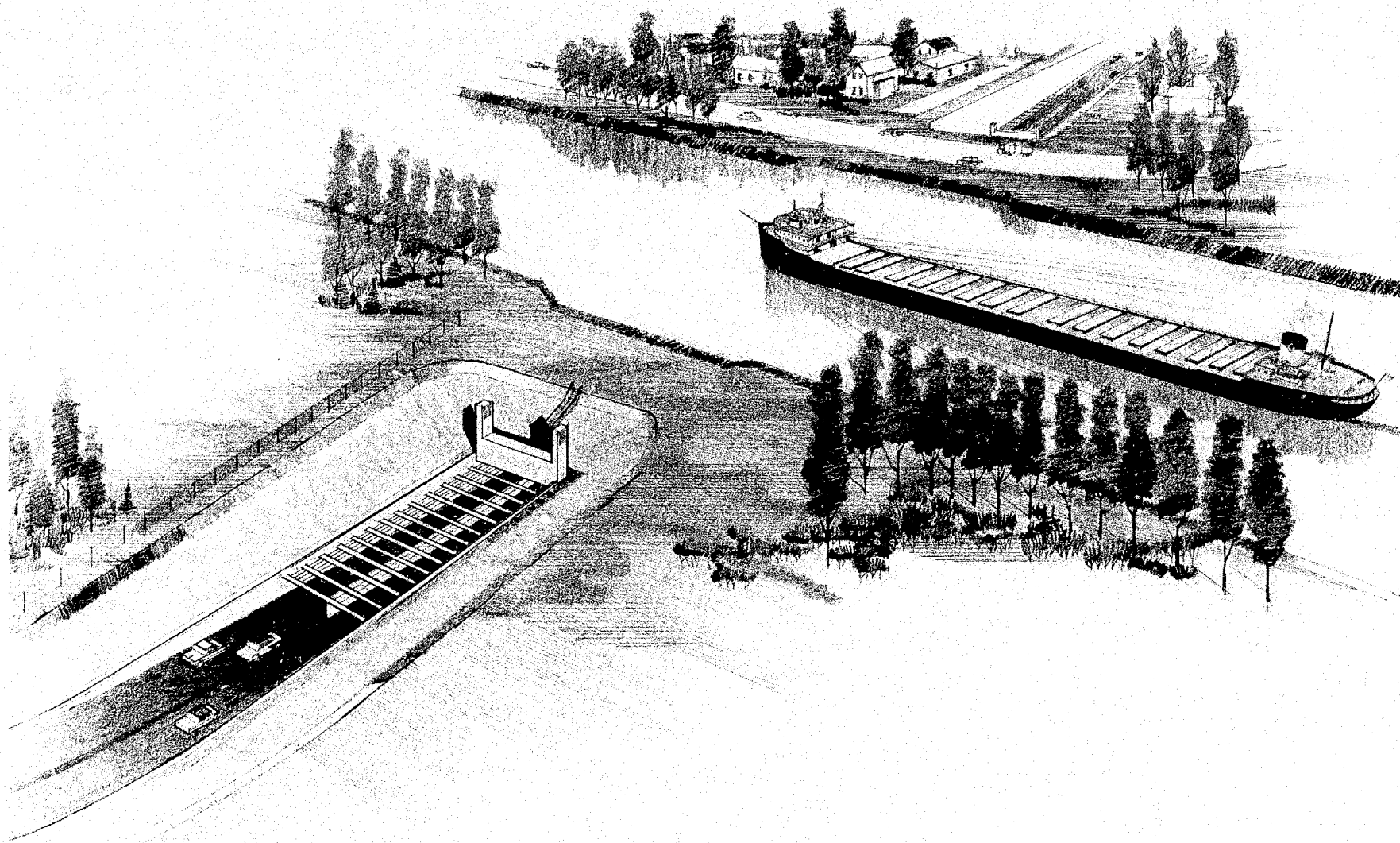
REPORT
ON
WELLAND TUNNEL
UNDER
THE WELLAND SHIP CANAL

TO
DEPARTMENT OF HIGHWAYS, ONTARIO

May 29, 1961

Foundation of Canada Engineering
Corporation Limited

FENCO



WELLAND TUNNEL

FENCO

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INTRODUCTION

In accordance with a letter dated February 9, 1961, from Mr. W. A. Clarke, Chief Engineer of the Department of Highways, Ontario, Foundation of Canada Engineering Corporation Limited (FENCO) has been retained to undertake a study and prepare a report for a tunnel crossing of the Welland Ship Canal in Welland, Ontario. Certain physical requirements have been designated by the Department of Highways and also the St. Lawrence Seaway Authority, which, in part, govern the method by which the tunnel crossing may be constructed. These requirements and conditions are enumerated later in this report.

SUMMARY

After careful consideration of the site conditions and economic requirements involving alternative designs, it is recommended that the four lane tunnel be of the trench type, having a rectangular section and constructed of reinforced concrete. The estimated cost of this tunnel crossing is \$ 9,073,000.00.

REQUIREMENTS

The Department of Highways requires that an uninterrupted year-round crossing of the canal be provided. The tunnel is to be a four lane structure comprised of two 24 foot roadway pavements with a 1 foot 6 inch raised centre curb and a 3 foot wide inspection sidewalk. The minimum clearance above the roadway pavement is to be 15 feet. These physical requirements are shown on a Department of Highways sketch, No. WP.130-61, dated January 17, 1961. The maximum grades prescribed are to be 5-1/2 percent for 750 feet in each direction at the canal crossing, with the balance of the profile limited to a maximum 5 percent grade.

Following meetings which were held between engineers of the St. Lawrence Seaway Authority and a senior engineer from the Department of Highways, a number of requirements have been specified by the Seaway Authority in the event that a tunnel be constructed under the Welland Ship Canal. These requirements as supplied to us are reproduced as follows.

REQUIREMENTS (Cont'd.)

- "(1) There must be no interference with shipping in the canal during the navigation season. Major construction in the 200 foot wide navigation channel would have to be scheduled during the closed shipping season, although limited encroachment for short periods might be permitted.
- (2) Canal banks must be reinstated to the satisfaction of the Authority. The restored banks would require erosion protection in the form of rip-rap at a slope not greater than 1 foot rise in 3 feet.
- (3) Allowance must be made for future dredging of the canal to 30 feet below elevation 568 (Welland Canal Datum). Any permanent structure under the central 200 feet of the navigation channel must have a minimum earth cover of 5 feet and no concrete would be allowed above elevation 535.
- (4) Provision should be made for widening the canal by 50 feet on its west side in order to permit widening of the whole of the curved portion which occurs in the canal, in the region of the proposed tunnel.
- (5) Water level in the canal must be maintained and excavation must be controlled as far as practicable so that turbidity levels are not objectionable to canal water users.
- (6) Land adjacent to the canal, and not already leased, may be utilized for construction provided that such use does not endanger the canal banks and provided that the area concerned is restored to its original condition.
- (7) The electrical power service along the canal must not be interrupted.

REQUIREMENTS (Cont'd.)

- (8) Contractors working on the canal must have liability insurance satisfactory to the Authority. "

SITE AND LOCATION

The proposed tunnel is to cross the Welland Ship Canal in the City of Welland, Ontario. The approximate location was supplied by the Department of Highways, Ontario, and marked on a print of plan No. F3790 "Study Plan, Welland to Port Colbourne".

The site chosen is approximately midway between the two lift bridges presently crossing the ship canal at Water Street and Main Street. A slight adjustment to the center line location would be acceptable to the Department should a study of the soil conditions reveal any advantage in an adjustment.

The limits of this study are to be from ground level on one side to the same level on the other side of the canal. No specific requirements were set for available right-of-way, however, a figure of 250 feet has been adopted. The interchanges providing access to the tunnel at both ends are to be the responsibility of the Department of Highways.

SOIL CONDITIONS

A preliminary soils investigation was carried out by H. Q. Golder & Associates Limited, to determine the soil conditions at the site of the proposed tunnel. This report indicates that the following conditions exist.

At ground surface there are minor thicknesses of top soil and fill. The site is generally underlain by approximately 80 to 90 feet of hard to firm silty clay followed by a thin layer of glacial till. Underlying the till is sound Dolomite bedrock.

SOIL CONDITIONS (Cont'd.)

The hard portion of the silty clay stratum is in the upper 20 to 30 feet where undrained shear strengths range up to approximately 6000 lbs./sq. ft. In the clay stratum below this the shear strengths are relatively constant with an average value of 1000 lbs./sq. ft.

Ground water established at the borehole locations ranged from 3 to 7 feet above normal canal level.

A thorough preliminary study of alternative types of tunnels required further knowledge of the engineering properties and soil characteristics. To obtain this the Department of Highways, at our request, agreed to make four additional boreholes at the site and carry out tests to assess elastic rebound and consolidation properties of the clay and also to obtain a knowledge of the permeability characteristics of this soil. The boring plan and soil stratigraphy inferred is shown on Drawing #2301-4 at the rear of this report.

A general assessment of the laboratory results was made by H. Q. Golder & Associates Limited, and independently by Geocon Ltd, and their findings have been used in the preparation of the preliminary designs outlined in this report. The parameters used for examining long term stability of the lower clay stratum were $\phi' = 25$ degrees and $c' = 100$ lbs./sq. ft. The detailed soils information obtained from this second investigation is available in a separate report, copies of which are retained by the Department of Highways.

DESIGN CRITERIA

The tunnel has been designed in accordance with accepted highway practice for traffic travelling at speeds up to 40 miles per hour and in accordance with the Highways Standards of the Department of Highways, Ontario.

Grading and paving is in accordance with the latest revisions of the "General Specifications" of the Department of Highways, Ontario.

DESIGN CRITERIA (Cont'd.)

All structures are designed for H25-S20 live loading and permissible stresses in accordance with "A. A. S. H. O. Standard Specification for Highway Bridges, 1957".

Slopes and final gradings have been designed to comply with the requirements outlined by the St. Lawrence Seaway Authority insofar as the canal proper is concerned.

GENERAL LAYOUT

Consideration has been given to three alternative types of tunnel. These are the trench type tunnel built in place, the shield driven tunnel and the trench type tunnel using precast units. Each alternative has been carefully studied and its merits analyzed for this specific installation. Engineering estimates have been prepared for the cost of construction of the alternatives.

The general layout for the proposed tunnel structure is shown on Drawing #2301-1. Both the trench type and the shield driven schemes are shown in plan and elevation on our Drawings Nos. 2301-2 and 2301-3 at the end of this report. Each of these structures is considered to have the same installed facilities and to be of the same general arrangement.

In order to eliminate the need for bridging King Street over the open cut approaches on the easterly side of the canal, it is proposed to permanently relocate this through street along the top of the new canal bank. By so doing, full advantage is taken of the newly restored canal bank to provide a suitable and economical means of accommodating this roadway.

The tunnel profile is based on the maximum permissible grades of 5-1/2 percent for 750 feet in each direction and 5 percent thereafter. The vertical curves of the profile have been designed to ensure safe visibility for traffic travelling at speeds up to 40 miles per hour.

GENERAL LAYOUT (Cont'd.)

The approaches of the tunnel are constructed as open structures up to the canal banks on each side to reduce as much as possible the length of the closed tunnel. This general arrangement provides an economical balance between the cost of the structure and those of the technical installations. The reduced length of the closed tunnel made possible by this layout also affords a reduction in operating costs as neither ventilation nor daytime illumination of the open approaches is required. At each of the tunnel portals, air ducts and control buildings are located.

The underwater portion of the tunnel will be placed at a sufficiently low level to provide a minimum clearance of 35 feet below canal datum under the central 200 feet of the navigable channel.

The tunnel is designed to accommodate four traffic lanes, each 12 feet wide, having a vertical clearance of 15 feet. The two lane roadway for westbound traffic in the tunnel is completely separated from the corresponding roadway for the eastbound traffic by a longitudinal partition wall which also extends for some distance into the approaches. An inspection sidewalk 3 feet wide, is provided on the outside of the roadway and a safety curb 1 foot 6 inches wide is provided along the centre wall. Adequate space has been allowed within the tunnel sections to accommodate domestic service crossings such as water and gas mains, telephone and power cables, when and if required. A bituminous road surfacing is proposed for smoothness, ease of repair and sound damping qualities.

Ventilation ducts are provided for the entire length, within the tunnel section.

The lighting fixtures are placed at the intersection between the walls and the ceiling at both sides of the roadway.

APPROACHES

Preliminary estimates show that to the depths required for this project, open cut excavation is more economical than the closed section tunnel. For this reason and with due regard to the soil conditions at the site, we have made the open cut approaches as long as

APPROACHES (Cont'd.)

possible, which also serves to reduce the need for mechanical ventilation in the closed section. The type of open cut approach has been largely dictated by the right-of-way width chosen and the prevailing soil and ground water conditions.

Traffic requirements and gradients have determined the geometry of the approaches. The approach on the east side is somewhat longer than the approach on the west side because of having to pass under Hellems Avenue. Both the approaches and access roads (the latter of which, however, does not form part of this report) are on extremely flat land and favour the adoption of the deep open cut sections.

Owing to the excessive right-of-way which would have been involved, straight open cut approaches were ruled out in favour of concrete ramp construction. The soil conditions in the area require that extremely flat slopes be used to ensure permanent stability, and to obtain such slopes would have meant large volumes of excavation and increased construction costs.

Cut-off walls are provided in the canal banks to improve ground water conditions during the construction of the concrete approach section.

Ground water seepage and rainfall run-off from the area of the approaches will be carried in drains and taken to catch basins and sumps constructed in the approaches and at the tunnel portals where it will be pumped into the canal.

The concrete ramp portion of the approaches will be cast insitu in an open cut made within the walls of a temporary cofferdam from which the water has been drained.

Short cantilevers are provided at the level of the bottom slab, to prevent the reinforced concrete section being lifted by water pressure from beneath. Vertical retaining walls are designed to withstand the earth and water pressure from behind the completed approaches. At the deeper portions of the approaches these retaining walls are strutted with concrete Tee-Beams which help to relieve some of the moments caused by the heavy pressures.

APPROACHES (Cont'd.)

A central wall running between the roadways for a distance of approximately 210 feet from the tunnel portals assists in the ventilation of the underwater portion. This wall will prevent the passage of vitiated air from one tunnel tube to the entrance of the other, where it may otherwise be scooped into the tunnel by traffic. Aluminum louvers are proposed to be placed above the roadway for 210 feet in front of each of the tunnel entrances. These louvers will be carried on the Tee-Beams and will act as sun screens to prevent direct sunlight from penetrating to the roadways. The louvers are designed to provide the proper transition on sunny days for eye adaptation from bright sunlight to the lower intensity of lighting within the tunnel, at a driving speed of 40 miles per hour.

TRENCH TYPE TUNNEL - BUILT IN PLACE

Initial consideration was given to the possibility of cofferdaming the canal in two stages and building the tunnel section in place. During each stage one half of the canal would be blocked off by a cofferdam while the other half would remain open for shipping. However, due to the proximity of the two existing lift bridges, it would not be possible for large ships to manoeuvre past the construction site without extreme difficulty, even if the canal were temporarily widened on both sides. In view of this condition, it is our opinion that a summer construction programme would not be practical.

Alternatively, consideration was given to a winter construction programme. A preliminary examination of a suitable construction schedule indicated that such a scheme could not be attempted without introducing a serious element of risk, involving an encroachment into the shipping season.

Furthermore, the cost of constructing such cofferdams would involve an additional expenditure of approximately one and one half million dollars more than the alternative trench type scheme.

SHIELD DRIVEN TUNNEL (Drawing #2301-3)

In studying a shield driven tunnel, it was immediately apparent that two independent tubes would be required to accommodate the four traffic lanes. The diameter of the circular cross section for a shield driven tunnel depends on the width of roadway required. Consequently the height of the cross section is more than required for the vertical clearance of the roadway and for this reason it would seem impractical to place all four lanes within the same circular section. Two independent two-lane tubes have therefore been adopted. The tubes will be driven between reinforced concrete caissons sunk on both sides of the canal. With some modifications, these caissons will finally serve as control buildings in which will be housed the ventilation air shafts together with lighting and drainage controls. In this design a primary lining of cast iron was chosen with the secondary made up of concrete.

The circular cross section tunnel displaces a greater soil volume per linear foot than is required for the actual roadway section. To compensate for this displacement and the associated uplift from water pressure, it is necessary to provide the tunnel tubes with adequate soil coverage below the future canal bottom. The shield driven tunnel will therefore need to be set at a level generally lower than for the minimum coverage stipulated in the requirements and as the circular section is also deeper than the rectangular, it follows that substantially longer and more expensive approaches will be required.

A certain minimum clearance is required between the two separate tubes for safe tunnelling operation. The distance between the two roadway lanes is therefore greater than necessary and consequently so is the width of the approaches. Horizontal curves could be introduced into the roadways but this solution is not considered satisfactory from a traffic point of view. Since the tunnel is to be driven through water bearing stratum, it will be necessary for the work to be done under compressed air. By using air and a shield, this method of tunnelling will be both practical and safe for the site conditions.

TRENCH TYPE TUNNEL - PRECAST UNITS (Drawing #2301-2)

The third available method for constructing the tunnel is to build the underwater portion from three precast reinforced concrete units, each approximately 267 feet long.

The units will be constructed within the tunnel approaches where initial excavation can be made to form temporary drydocks. By using the approaches as drydocks, a considerable saving will be effected in the cost of the precast units. Upon completion, the units will be closed by temporary bulkheads near both ends and floated into the canal. The units will then be lowered into a trench which has been dredged in advance and seated onto a prepared mattress foundation. They are then joined together by means of special inflatable tubes provided to ensure that the joints are temporarily watertight. When access to the joints is gained, the permanent waterproofing is made continuous and the concrete between the units is cast. The space beneath the units will be grouted to form a stable foundation.

The rectangular cross section of the trench type tunnel permits the development of a minimum width of trench and shallower depth of roadway consistent with requirements. With the shallower profile, the length of the approaches will also be a minimum. This type of tunnel construction can proceed without interfering with the normal canal traffic.

ESTIMATES

Engineering estimates have been prepared for the cost of construction of the two schemes which are considered feasible. No estimate was made for the Trench Type Tunnel - Built In Place, since it has proved to be an impractical method for this site.

These estimates incorporate all phases of construction and include the complete technical installation for the tunnel and approaches with the exception of ventilation fans. The estimates do not include any land appropriation which will be required.

The cost of installation of mechanical fan equipment, if required, would be \$120,000.00.

SHIELD DRIVEN TUNNEL

1,600 Lin. Ft.	Driven Tunnel	\$ 5,962,000.00
560,000 Cu. Yds.	Excavation	823,000.00
45,300 Cu. Yds.	Approaches	3,196,000.00
39,000 Cu. Yds.	Backfill	85,000.00
Lump Sum	Control Buildings	123,000.00
Lump Sum	Relocation Existing Services	50,000.00
Lump Sum	Lighting	140,000.00
Lump Sum	Fire Protection	5,000.00
Lump Sum	Snow Removal	170,000.00
		<u>\$10,554,000.00</u>
Contractor's Fee	7%	738,000.00
		<u>\$11,292,000.00</u>
Contingency	10%	1,129,000.00
		<u>\$12,421,000.00</u>
Engineering & Supervision		850,000.00
	TOTAL	<u><u>\$13,271,000.00</u></u>

TRENCH TYPE TUNNEL

775,700 Cu. Yds.	Excavation	\$ 1,420,000.00 ✓
310,000 Cu. Yds.	Backfill	676,000.00 ✓
19,160 Cu. Yds.	Construction Tunnel Units	1,887,000.00 ✓
5,000 Cu. Yds.	Mattress	48,000.00 ✓
Lump Sum	Setting Tunnel Units	413,000.00 ✓
28,900 Cu. Yds.	Approaches	2,187,000.00 ✓
Lump Sum	Control Building & Air Shafts	106,000.00 ✓
Lump Sum	Relocate Existing Services	65,000.00 ✓
Lump Sum	Lighting	125,000.00 ✓
Lump Sum	Fire Protection	5,000.00 ✓
Lump Sum	Snow Removal	140,000.00 ✓
		<u>\$ 7,072,000.00</u>
Contractor's Fee	7%	495,000.00 ✓
		<u>\$ 7,567,000.00</u>
Contingency	10%	756,000.00 ✓
		<u>\$ 8,323,000.00</u>
Engineering & Supervision	10%	750,000.00 ✓
		<u>\$ 9,073,000.00</u>
	TOTAL	<u><u>\$ 9,073,000.00</u></u>

RECOMMENDATIONS

It is recommended that no further consideration be given to cofferdaming the canal and constructing the tunnel in place since this has proved to be an impractical method for this site.

Both the Shield Driven and Trench Type Tunnel with precast units are considered feasible and practical for the area. The time required for construction, namely eighteen months, is approximately the same for both schemes, and with efficient organization and planning, neither type construction should involve any risk of interrupting shipping in the canal. Both types of construction will provide suitable and satisfactory tunnels, having similar operating and maintenance requirements.

With due regard to the foregoing comments, we consider that the choice of tunnel type to be constructed should be based on economics. The Trench Type structure will cost approximately four million dollars less than the Shield Driven alternative, and we therefore recommend that the Trench Type of tunnel, with precast units, be constructed.

CONSTRUCTION PROCEDURE

Trench Type Tunnel

Although conventional construction methods may be used for most of this undertaking, the design incorporates several unique features related to the application of the trench method for constructing a tunnel of rectangular cross-section, using precast units.

The sinking arrangements have been designed to provide complete control over the placing of the units and concrete grouting is proposed to provide a solid foundation beneath the tunnel. The timing and control of the placing of the units requires a high degree of organization and close supervision of construction methods.

The preliminary design of the tunnel has been developed to suit site conditions and to take advantage of all possible construction economies. As much excavation as possible will be done in the dry since the disposal of material excavated under water will create some difficulties and involve greater expense. In each phase of the work, con-

CONSTRUCTION PROCEDURE (Cont'd.)

Trench Type Tunnel (Cont'd.)

struction excavation has been designed to ensure adequate stability factors of the slopes and cuts that are made.

The underwater portion of the tunnel is constructed of three separate units, each approximately 267 feet long, 70 feet wide, and 23 feet 4 inches high, built on dry land. So that the units may be floated into final position, it is necessary that they be constructed in a drydock. The approaches themselves can be used for this purpose if they are initially excavated to a suitable depth behind the canal banks. The approach on the westerly side of the canal will accommodate one unit and the approach on the easterly side will be excavated for a sufficient length to accommodate the remaining two units.

It is proposed that this initial excavation be carried out using land based equipment and that the drydock base be approximately 25 feet below canal water level. A system of drains will be incorporated into the base of the excavation to ensure a suitable working area at all times. Adequate access roads may be constructed by the contractor and it is anticipated that this work could commence in the Spring of the year without any interference to the ship canal.

Two units have been considered for the easterly side of the canal, since it is on this side that the greater quantity of approach excavation is required to accommodate an underpass of a city roadway. With this arrangement, greater utilization of approach excavation is achieved.

The units will be constructed of reinforced concrete by conventional methods. The elements are basically large reinforced concrete boxes with temporary bulkheads provided at each end to make them watertight for controlled sinking.

Perhaps the most significant feature of the construction of the tunnel units is the extensive waterproofing of the concrete. Each element is protected by carefully designed and applied waterproofing material. The bottoms of the units are protected by a 1/4 inch steel plate incorporated in the reinforced concrete, and the sides and tops

CONSTRUCTION PROCEDURE (Cont'd.)

Trench Type Tunnel (Cont'd.)

of each element are protected by multi-ply waterproofing membrane. In turn, the waterproofing is protected on the outside by timber against damage by the fill material finally placed over the tunnel units. A 1/4 inch steel plate is also welded all around each of the units for approximately 10 feet from the ends to facilitate completion of the waterproofing at the joints between the units, after placing.

Upon completion of the construction of the units, the approaches will be made ready for flooding and flooded by stages. This procedure is recommended to enable the water-tightness of the concrete structures to be tested, before sinking.

The canal banks between the approaches will then be removed. As much of this excavation as is practical, will be done from the land in order to facilitate the dredging operations which must necessarily be completed in a limited period of time.

Upon completion of the tunnel units and while the canal bank excavation is being carried out, the contractor will construct temporary towers which are required for the lowering of the units. At the same time, all anchor blocks, winches and tackle shall be set up for complete control of the sinking operations. The towers are designed to be constructed on land and erected in place, onto a prepared base, from floating equipment.

With the close of navigation on or about December 15, dredging equipment of the required capacity shall move into the area and commence work on the underwater trench for the tunnel units. The disposal of dredge material will be by trucks to a dumping area, considered to be available within two miles from the site.

When the dredging is completed, the mattress on which the tunnel units are to rest will then be placed. Screeding of the mattress to the desired elevation may be achieved in a number of conventional ways. At the same time, as the finish of the mattress is in progress, the temporary towers will be erected.

CONSTRUCTION PROCEDURE (Cont'd.)

Trench Type Tunnel (Cont'd.)

When all is in readiness, the centre unit will be warped out and moored alongside its final position. Immediately following, the two side units will be warped out of the drydocks in readiness for the sinking operations. By careful control of the ballasting within the units and the cables on the temporary towers, the two side units will be lowered separately into position on their prepared mattresses. The center unit will then be lowered in a similar manner by using the same two innermost towers, and will follow immediately after the placing of the two side units.

This unit will be positioned in such a way that it will engage the ends of the side units and will remain clear of the finished mattress. This unit will be suitably ballasted to be stable in this position. When the three units are in place, the temporary seals at the joints will be made and the sinking bulkheads may then be removed from within the units. Any slight differential settlements which may occur due to the filling of the canal banks over the side units has been allowed for in the design of the temporary seal.

It is anticipated that this stage of the work can comfortably be reached by April 1 of the second year of construction, and that shipping in the canal will resume at the usual time without risk of interference from the tunnel operations. Should it so happen, due to circumstances beyond the contractor's control, that only one side unit is in place by this time, then the remaining two units could be warped back into the easterly approach and secured until the following winter when the units could be placed in the liberal amount of time which would then be available. Such an occurrence would delay the construction of the easterly approach for approximately nine months.

However, it is not anticipated that this situation will arise since the construction procedure has been designed with adequate time allowed for each separate operation.

When the units are in position, work may proceed to replace the canal banks and drive the steel sheet pile cut-off wall designed to be incorporated within the new dyke. The required amount

CONSTRUCTION PROCEDURE (Cont'd.)

Trench Type Tunnel (Cont'd.)

of backfill will also be placed over the center unit. With the canal dykes restored and the sheet pile cut-off wall driven, the approaches may then be pumped out and made ready for the final excavation.

After sufficient time has elapsed for complete settlement of the side units, grouting operations may proceed independently from within the units to consolidate the base mattress.

In the area adjacent to the underwater portion of the tunnel, the approach grade must go still deeper than the elevation required for the construction of the units. Vertical walls of steel sheet piling will be constructed to provide for the excavation of final grade. The sheet pile walls will be supported by high tensile steel anchors grouted into rock. These anchors will avoid the need for long strutting and the consequent obstruction to the approach excavation. This portion of the approach excavation will be made from the level of the initial excavation, and will be carried out in the wet using land based machines. Upon completion of the excavation, a gravel bed and drainage system will be incorporated in the bottom of the cut and a tremie concrete working slab poured on the gravel bed, before dewatering takes place. The approach excavation may then be dewatered and the reinforced concrete ramp section constructed in the dry.

At the same time, work within the tunnel may proceed independently, and after the removal of the ballast from within the units the grouting operations may be completed.

When all units are finally grouted, the permanent joints will be constructed by making the concrete sections continuous between the units. The canal banks may then be restored to final grades and relocated to accommodate the future widening on the westerly side.

All of this work will be suitably timed to coincide with canal shipping schedules and any or part of the work may be left until the second winter of construction if necessary.

CONSTRUCTION PROCEDURE (Cont'd.)

Trench Type Tunnel (Cont'd.)

When the concrete structures are completed in the approach sections, the area behind the retaining walls will be filled with granular material. The bank slopes above the concrete retaining walls will be finally graded to a 1 on 4 slope, and landscaped for durability and appearance.

The installation of the technical services within the tunnel as described elsewhere in this report, may then proceed. The ventilating air ducts and the control buildings at the portals of the tunnel will be constructed to provide for installation of ventilating equipment if required in the future. With final grading of the approaches and road paving, the tunnel will then be ready for efficient use and operation.

TECHNICAL INSTALLATIONS

The basic design requirement for the proposed tunnel is the provision of safe rapid passage of vehicular traffic from portal to portal under all anticipated operating conditions.

Ventilation, lighting and adequate detecting and operating controls to govern traffic movements are important requirements.

Ventilation

The question of tunnel ventilation and the need for installed mechanical equipment in the tunnel has been carefully considered.

In tunnel tubes carrying traffic in one direction only, the air drag on the vehicles induces a natural draft which is sufficient to ventilate tunnels of moderate length. Hence, tunnels less than 500 feet in length are not provided with mechanical forced ventilation. For tunnels between 500 and 1,000 feet in length, forced ventilation is dependent upon the circumstances and conditions of operation. For this reason as well as economic factors previously considered, the closed

TECHNICAL INSTALLATIONS (Cont'd.)

Ventilation (Cont'd.)

section of the structure has been kept to a minimum length. The proposed tunnel is 801 feet from portal to portal and therefore falls into a category where ventilation requirements cannot be clearly established.

However, since it will be impractical to install air ducts after the tunnel is completed, the section has been designed to accommodate the future installation of mechanical fan equipment, should it be found necessary. The grilles and air ducts thus incorporated will assist the natural ventilation process by providing an exhaust passage for the induced air.

In the interests of safety, carbon monoxide detectors should be installed within the tunnel. These detectors will record air conditions and will enable a check to be maintained on the effectiveness of the natural ventilation. In addition, illuminated signs will be provided to warn drivers to switch off their engines if traffic in the tunnel should stop for any reason. Such controls are proposed to operate automatically with manual over-ride, and to be of the most reliable nature to ensure that the tunnel functions continue to operate at all times.

It is not anticipated that unfavourable ventilation conditions will occur within the tunnel. For this reason it is recommended that natural longitudinal ventilation be employed with provision for the installation of mechanical fan equipment, if required.

Lighting and Power

It is proposed that the tunnel be illuminated at an average level of 14 footcandles for continuous day and night operation. To achieve a smooth transition and sight adaptation from the different lighting levels during the day outside the tunnel, the approaches will be provided with sun louvers for a distance of approximately 210 feet from the portals. By suitable design, the sun louvers will reduce the daylight intensity beneath the louvered zone to approximately 50 footcandles.

TECHNICAL INSTALLATIONS (Cont'd.)

Lighting and Power (Cont'd.)

This reduction, together with additional illumination within the tunnel near the portals, will provide a sufficient sight adaptation zone for day traffic. The additional adaptation luminaires at the portals will be controlled by a photoelectric cell.

During the hours of darkness some additional illumination will be required within the louvered approaches to raise the level from the 1 to 2 footcandles of street lighting to the 14 footcandles within the tunnel and thus maintain a smooth transition zone.

The luminaires will be of cast aluminum body with a polished aluminum reflector and a one piece shatterproof acrylic plastic globe. The complete unit is to be weatherproof and capable of housing one ballast and two 6 foot HO or EHO fluorescent lamps.

Within the tunnel and approaches the luminaires will be wall-mounted with adjustable aluminum brackets and tilted downwards at an angle of 30 degrees. It is proposed that a 550 volt, 3 phase system be used for the lighting. Convenience receptacles will be provided at approximately 200 foot spacings throughout the tunnel and will be fed from a 120/208 volt system.

The power for the pumping equipment will be installed with a 550 volt, 3 phase, 3 wire system and the float switches will be controlled by 100 volt AC.

It is proposed that power will be brought into the tunnel at the control building located behind the canal bank on the west side, and situated between the ventilating shafts above the tunnel portals. All control equipment, transformers and instrumentation, will be installed in this building. It is considered that the local Hydro Authority will provide a 4,160 volt, 3 phase feeder which will be transformed down to 575 volts. Small capacity transformers will be provided to feed controls, convenience receptacles and house services for the control building.

TECHNICAL INSTALLATIONS (Cont'd.)

Lighting and Power (Cont'd.)

A diesel generator of rated output 150 kw will be installed in the control building to ensure an emergency power supply for a 60-hour period in case of a failure of the normal service.

Tunnel Lining

It is recommended that all the walls and ceilings in the tunnel and approaches be finished with a plastic type paint having a hard glazed durable surface. The paint used should be resistant to gasoline, oil, solvents or detergents, and chosen to provide a weather-proof and fire resistant finish to the concrete.

Fire Protection

Fire protection within the tunnel is provided by a number of hand fire extinguishers which will be located at several points throughout the entire length.

SNOW REMOVAL

Having adopted a combination of open cut and concrete ramp type approaches, it is necessary that careful consideration be given to the means by which snow can be adequately removed from this area of the tunnel.

There are three different means of removing snow from highways in Canada. These are by mechanical means, such as snow plows and shoveling; chemical means, by the use of salt or a mixture of salt and sand, to help provide traction; and the somewhat less common means of heating the roadway pavement. Each of these means has been carefully considered and the following is a summary of our analysis.

1. Mechanical Means

In the concrete approach sections it is not possible to operate a snow plow with any degree of efficiency since there is no

SNOW REMOVAL (Cont'd.)

1. Mechanical Means (Cont'd.)

room to pile the snow at the side of the roadway. It follows that if mechanical means were to be used, then it would be necessary to use front loaders and truck the snow away for disposal. However, there are two objections to this, namely, insufficient room for practical operation and, steep grades which would be slippery and difficult for the outgoing trucks to negotiate, before the snow has been removed.

Further, should there be two snowfalls in rapid succession before the snow from the first fall can be removed, then it is clear that serious problems will arise.

2. Chemical Means

The snow could be disposed of by means of spreading salt. However, to obtain effective removal, high concentration of salt would be required and the end result would almost certainly mean serious deterioration and costly maintenance problems to the concrete structures. If sand were mixed with the salt, to relieve the concentrations, then the solid particles would be carried by the run-off to the sump at the tunnel portal. This again introduces a maintenance problem in the removal of the sand from the sumps. Therefore, effective salting of the approach structures seems highly undesirable.

3. Pavement Heating

Pavement heating could be achieved in one of two ways, either by introducing electrical heating elements into the pavement or by incorporating pipes containing a warm circulating fluid. The electrical heating provides a rapid answer to snowfall, but it is quite costly and rather discouraged by the Hydro-Electric authorities, their objection being the intermittent nature and unfavourable timing of the power supply required. For this reason, they assess extremely high service charges on such an installation.

Heating the pavement by means of a circulating fluid is somewhat more applicable to this particular installation. By using a water heat exchanger, a boiler unit could be installed which does not

SNOW REMOVAL (Cont'd.)3. Pavement Heating (Cont'd.)

require a permanent operating crew. The anti-freeze fluid can be maintained in circulation at a temperature of a few degrees above freezing for the entire winter and boosted to accommodate heavy snowfalls.

The initial installation costs for both types of heating are approximately the same. However, since the boiler can be oil fired with cheap Bunker C fuel, the operating cost of this installation is considerably less than that required for electrical heating. We therefore recommend that this circulating fluid type of pavement heating be installed.

With either of these installations, it is proposed that only one traffic lane be heated for snow removal. It is considered that with this provision, one lane will always be available in each direction and will therefore ensure the flow of traffic under all conditions.

The sections of the approach beyond the vertical concrete retaining walls will be provided with a roadway shoulder of a sufficient width to permit banking up of the snow from mobile plows. In these sections of the approaches, snow removal is not considered to be a serious problem.

CONCLUSIONS

As a result of the investigations discussed in this report, we consider that a trench type tunnel constructed of precast reinforced concrete units of rectangular cross section, will provide the most suitable tunnel crossing. It is further estimated that the tunnel can be constructed in eighteen months and will cost approximately \$9,000,000.00 (nine million dollars).

We believe that the tunnel recommended will provide the Department of Highways with the most economic and satisfactory crossing of the Welland Ship Canal.

FOUNDATION OF CANADA ENGINEERING
CORPORATION LIMITED

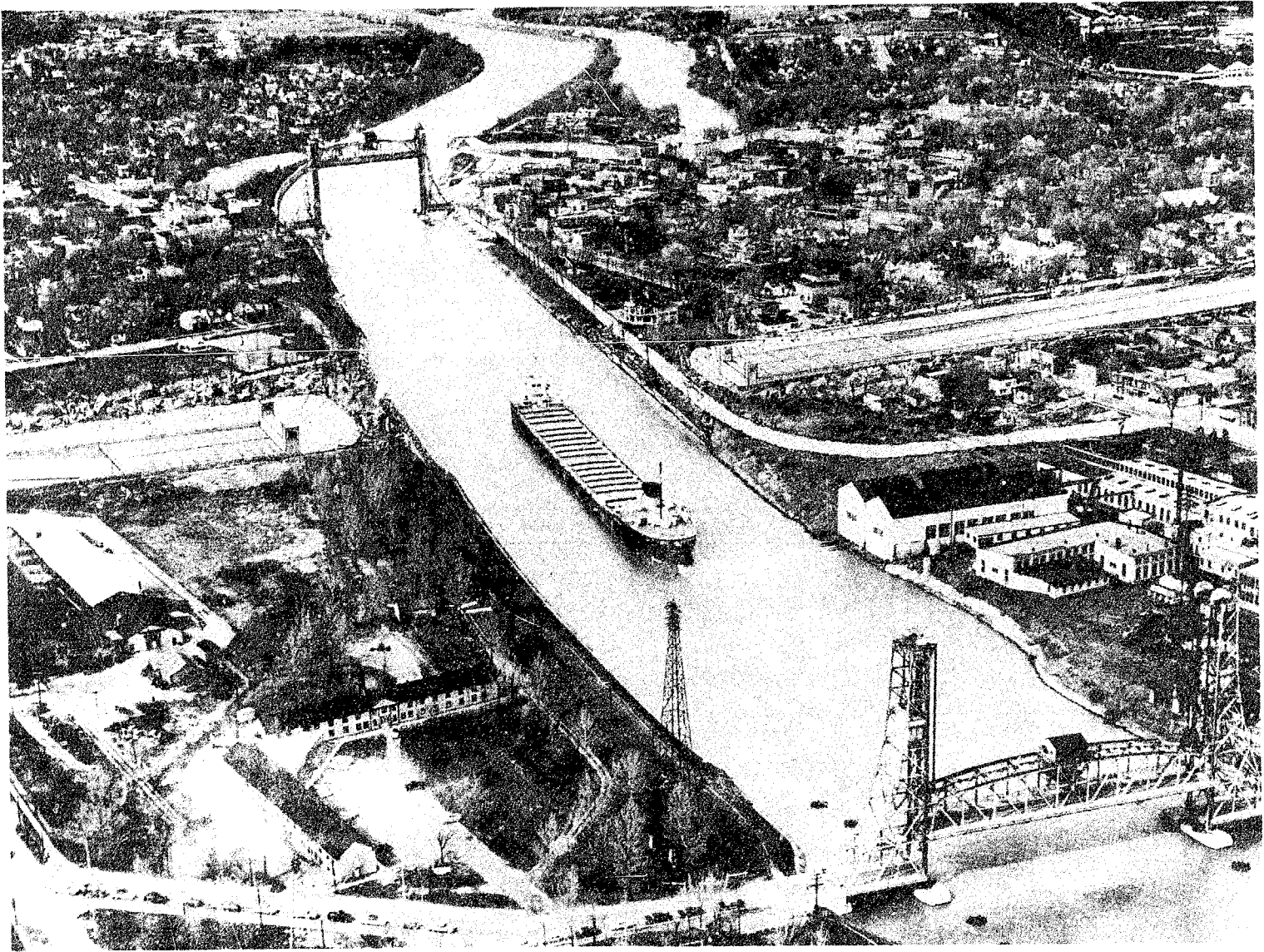


Peter J. Thompson, P. Eng., A. M. I. C. E.
ASSISTANT DIVISION ENGINEER
MARINE STRUCTURES

APPENDIX I

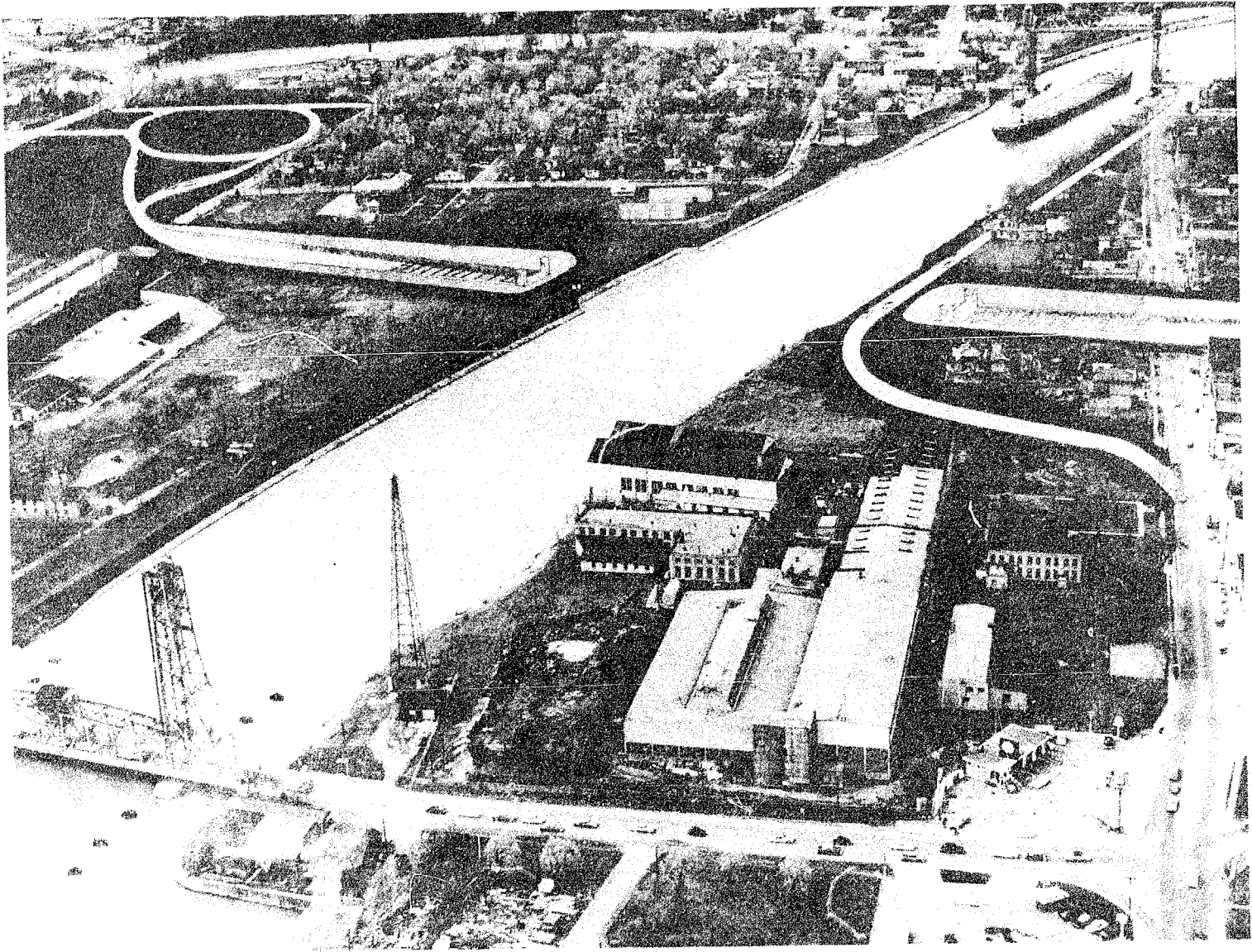
PHOTOGRAPHS

FENCO



WELLAND TUNNEL
(Proposed)

FENCO

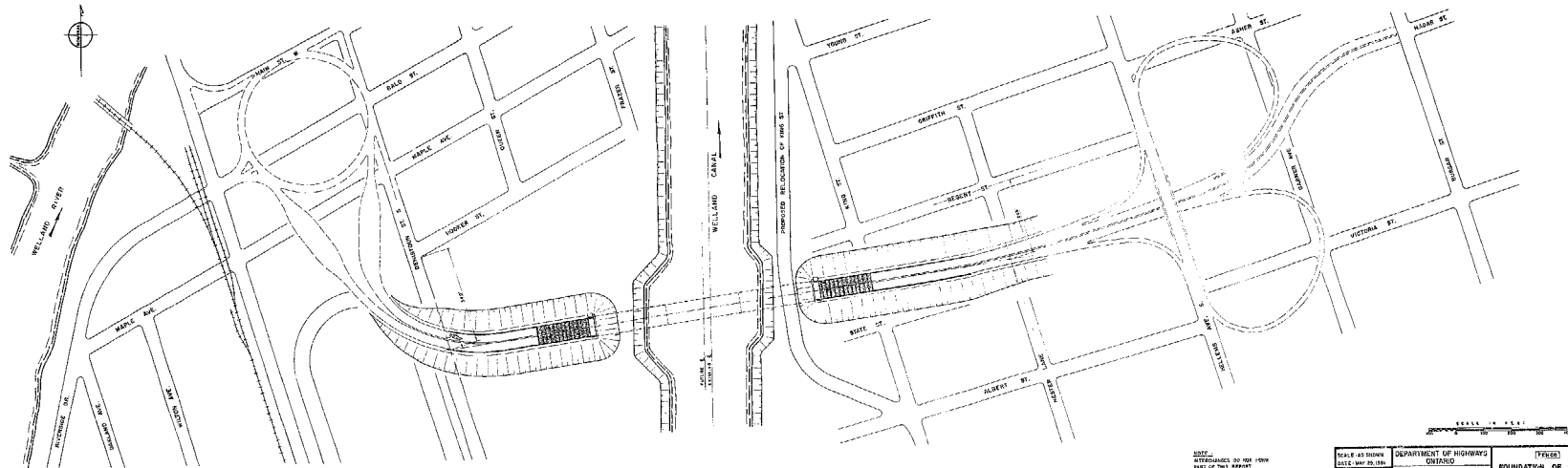


WELLAND TUNNEL
(Proposed)

APPENDIX II

DRAWINGS

2301-1	Welland Tunnel	Site Plan
2301-2	Welland Tunnel	Trench Type Tunnel
2301-3	Welland Tunnel	Shield Driven Tunnel
2301-4	Welland Tunnel	Soil Stratigraphy

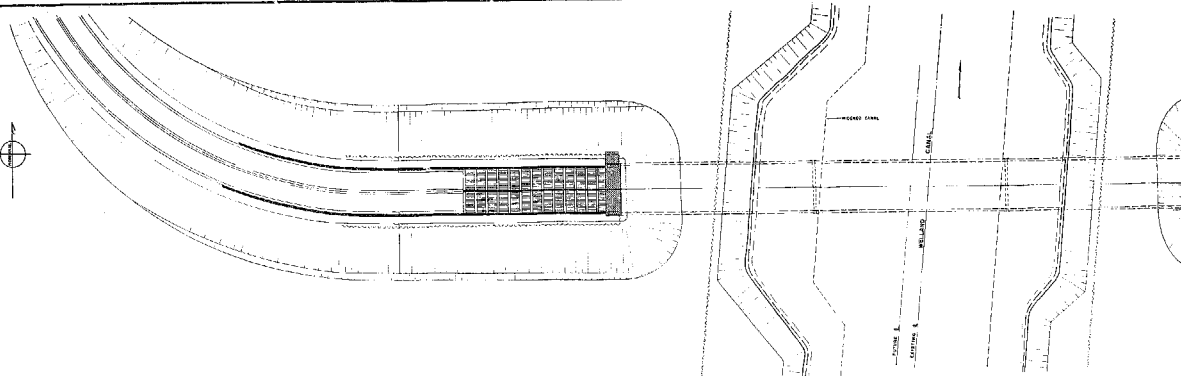
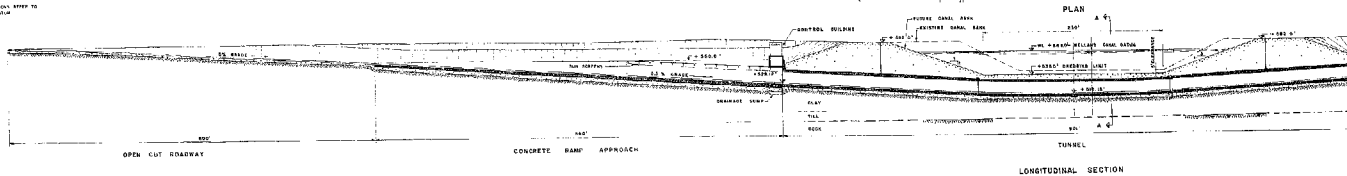


NOTE:
INTERCHANGES DO NOT HAVE
PART OF THIS REPORT

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DATE: MAY 29, 1961		ONTARIO		FOUNDATION OF CANADA	
ENGINEER	DESIGNER	WELLAND TUNNEL		ENGINEERING CORPORATION	
ARCHITECT	D.R.M.	WELLAND ONTARIO		LIMITED	
DRAWN	T.P.-2	SITE PLAN		NA 2301-1	
APPROVED	P.L.T.				

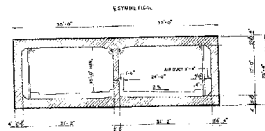
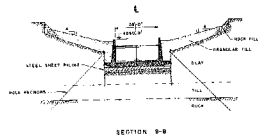
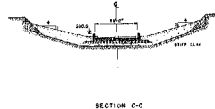
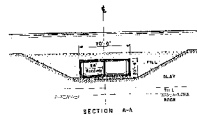
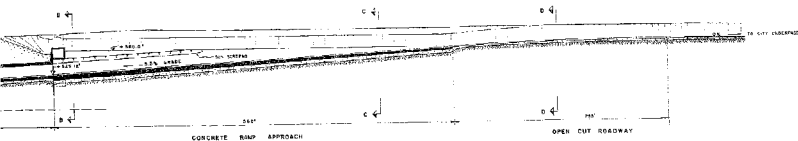
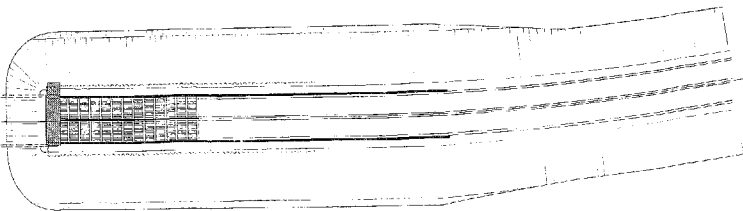
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+160
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+100
+80
+60
+40
+20
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PLAN

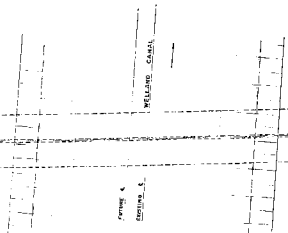
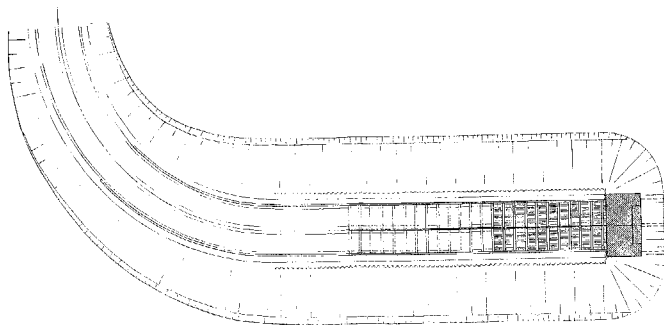
LONGITUDINAL SECTION



TYPICAL TUNNEL CROSS SECTION



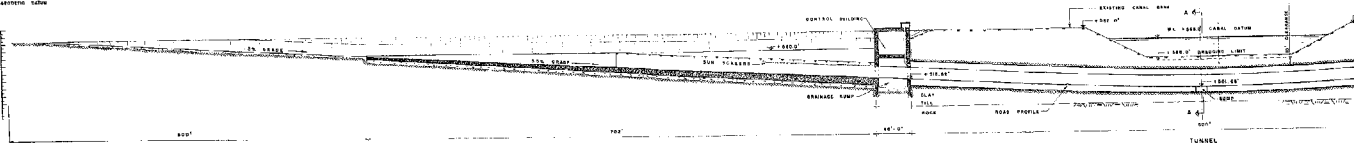
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DESIGNED BY	CLARK	WELLAND TUNNEL	
DRAWN BY	P.F.	WELLAND TUNNEL	
APPROVED BY	P.F.	TRENCH TYPE TUNNEL	2301-2



PLAN

NOTE: ALL ELEVATIONS REFER TO
ARABIAN 1420M

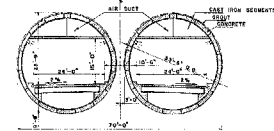
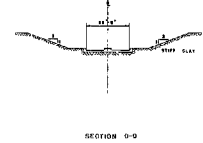
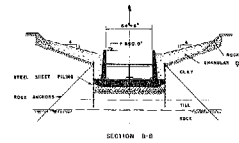
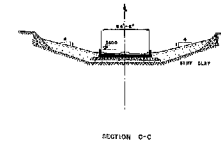
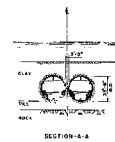
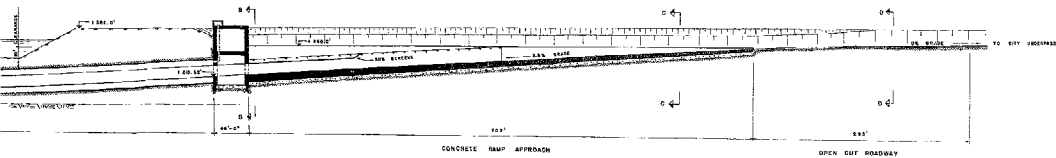
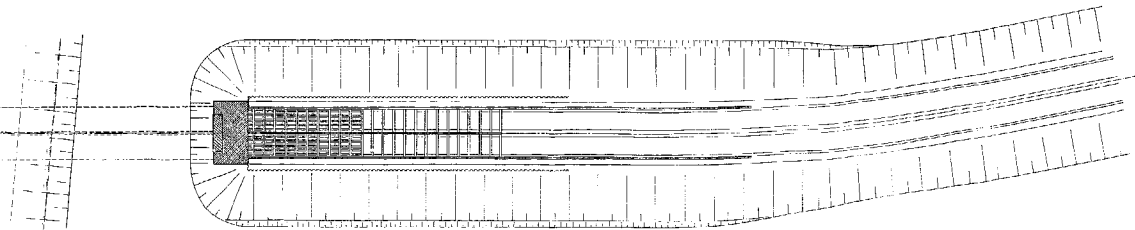
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OPEN CUT ROADWAY

CONCRETE RAMP APPROACH

LONGITUDINAL SECTION



SCALE AS SHOWN	DEPARTMENT OF HIGHWAYS	FOUNDATION OF CANADA
DATE: MAY 1958	ONTARIO	ENGINEERING CORPORATION
DESIGNER: W. J. B.	WELLAND TUNNEL	LIMITED
CHECKED: W. J. B.	WELLAND TUNNEL	
APPROVED: S. L. T.	SHIELD DRIVEN TUNNEL	NR 2501-3



DECATUR ST

DECATUR ST

PUBLIC SCHOOL

HARDEN RESIDENCE

BH 2

BH 10

BH 12

BH 8

BH 11

BH 13

BH 5

BH 12

BH 10

BH 11

WELLAND CANAL

BH 3

BH 17

BH 5

BH 6

BH 11

BH 4

BH 9

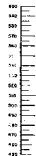
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REPERT ST

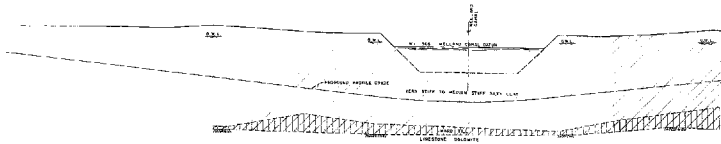
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WESTERN LANE

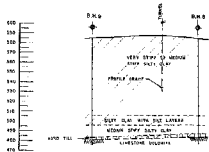
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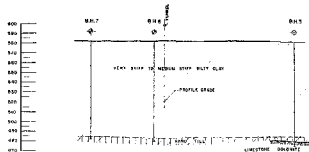
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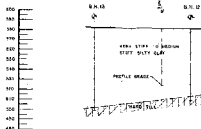
PROFILE



SECTION A-A



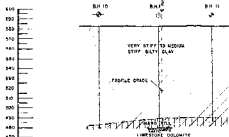
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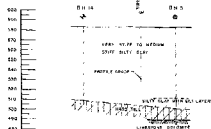
SECTION B-B



SECTION E-E



SECTION C-C



SECTION F-F

BOREHOLE LEGEND

- ◆ BOREHOLES BY D & S MARCH 1961
- ◆ PROFILES BY D & S MARCH 1961
- ◆ BOREHOLES BY H Q GOLDER & ASSOCIATES LTD. DEC. 1960

SCALE AS SHOWN	DEPARTMENT OF HIGHWAYS ONTARIO	FOUNDATION OF CANADA ENGINEERING CORPORATION LIMITED
DATE MAY 29, 1961	WELLAND TUNNEL WELLAND ONTARIO	
SOIL NO. 1		
MARK - S.A.M.		
CHG - A.E.J.		
APP. P. 1	SOIL STRATIGRAPHY	NR 2301 - 4