

**Morrison, Hershfield,  
Burgess & Huggins, Limited**

Consulting Engineers

Edmonton  
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No: 30M3-64

REPORT  
ON  
THOROLD TUNNEL INVESTIGATION

Submitted to  
MINISTRY OF TRANSPORTATION AND COMMUNICATIONS

Report No. 721551

December 6, 1972

## REPORT ON THOROLD TUNNEL INVESTIGATION

In accordance with instructions received from the Department of Transportation and Communications in May 1972, an investigation into the structural behaviour of the roof and walls of the Tunnel, at the West Service Building, was undertaken. The objective was to assess the probable future behaviour and condition of the structure and to suggest methods of preventing, or at least postponing, its further deterioration.

The reports and data then available showed that there had occurred an inward movement of the faces of the rock cut in which the tunnel had been constructed; and that, as a consequence, undesirably high stressing of the tunnel roof and severe cracking of the south wall had developed. The indications were that the movement of the rock faces should be expected to continue, accompanied by increased stressing of the tunnel roof and cracking of the wall. However, there were also indications that the movement of the rock faces were being impeded by the structure. It was concluded that the possibility of effectively reinforcing the structure, as an alternative to relieving it of further pressure, be explored. Our opinion was that if reinforcing of the structure were found to be practicable it would permit the delay, or perhaps even the elimination, of the more costly solution of cutting slots in the rock to prevent further rock squeeze on the structure.

Accordingly, it was recommended, in our Interim Reports Nos. 1 and 2 which are included as appendices C and D to this report, that steel strengthening struts be installed on each side of the south and north struts in the tunnel roof. The immediate objective was to reduce the anticipated peak compressions in these struts while further observations were made on the behaviour of the structure. Subsequently, an alternative procedure proposed by Acres - cooling of the existing concrete struts in the tunnel roof during the high temperature period in 1972 - was proposed, adopted and implemented.

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Since submission of the above Interim Reports, our efforts have been directed towards the development of a mathematical time-displacement relationship for the rock movements that could be used as a basis for estimating the future movements. The objective was to enable the exploration of reinforcing the structure as an alternative remedial action.

It was assumed that the data reported in Appendix D of Acres' Report, in particular the time-displacement curve for Turbine Deck C-3 of the Canadian Niagara Power Company Wheel Pit, could be taken as being acceptably representative of the rock behaviour at the Thorold Tunnel. It was found that the time-displacement relationship shown for Turbine Deck C-3 could be closely fitted by the curve shown in Figure 1, Appendix B. It was assumed that a similar curve, with appropriate modification of the constants, would apply at the Thorold Tunnel.

The shortenings of the tunnel roof (as of August 1972) that corresponded to the pressures then being exerted by the rock were estimated from the strains which had been measured in the rebars up to that time, from which the stresses presumed to exist were calculated. These estimates were based on the assumption that these stresses included a pre-compression due to shrinkage of the concrete. The shortenings were assumed to be equal to the rock face movements after those faces had begun to exert pressure on the structure. The results are summarized in Tables 1 and 2 of Appendix A.

Although the accuracy of the estimates of the movements so computed is uncertain because they are based on various assumptions made to enable their calculations, there is no doubt that the movements were considerably smaller in the locations where the tunnel roof is stiffer. Presuming that "free" movement of the rock faces would be substantially the same all along the structure, it is believed that the movements have been impeded by the structure and that the effect, at any point has been dependent on the

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stiffness of the structure at that point - the impeding effect being greater where the stiffness of the structure is greater.

Our attempts to evaluate appropriate constants (for the derived time-displacement relationship) that would be applicable to this structure have not been successful. The period over which detailed data are available was found to be too short to permit the establishment of points on the curve that were sufficiently far apart in time to permit evaluation of these constants.

We believed that the future behaviour of the structure could be satisfactorily controlled by (1) stiffening the tunnel roof at the ventilation openings and (2) increasing the stiffness and capacity of the walls to withstand lateral pressure.

The east part of the tunnel roof could be brought up to the stiffness and strength of the west part. Judging from the shape of the hypothetical time-displacement curve and the existing stresses reported, the behaviour of the tunnel roof over the next 50 years, and perhaps more, would then be acceptable.

However, our attempts to devise satisfactory means of adequately stiffening and strengthening the walls have not been successful.

Our study of the conditions in this structure has led us to the conclusion that unless remedial action is taken the strains and consequent stresses which will exist in the tunnel roof and walls will reach unacceptable values within a very few years. Therefore, we concur in the Acres' recommendation to relieve the structure from further pressure by cutting slots in the rock.

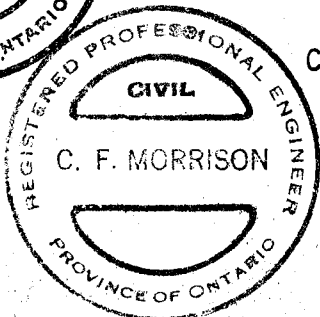
MORRISON, HERSHFIELD, BURGESS & HUGGINS, LIMITED

C. Hershfield, P. Eng.

C. Hershfield

C. F. Morrison, P. Eng.

C. F. Morrison



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ROCK FACE DISPLACEMENTS AT TUNNEL ROOF  
derived from measurements in structure up to August 1972.

TABLE 1 - COMPRESSIVE STRESS IN REBARS - ksi

Bar	May 1972 Note (a)	Increase Note (b)	Aug. 1972	Due to Shrinkage	Due to Rock Pressure
1	20.1	10.0	30.1	9.0	21.1
4	32.7	10.0	42.7	9.0	33.7
2	10.5	7.5	18.0	9.0	9.0
3	12.1	7.5	19.6	9.0	10.6
Average of 2 & 3.....					9.8

TABLE 2 - RELATION BETWEEN COMPRESSION, STIFFNESS AND MOVEMENT

Location	Compression kips per foot length of tunnel Note (c)	Stiffness kips per inch. Note (d)	Movement inches Note (e)
North Strut	228	900	.254
South Strut	364	900	.405
West part of tunnel roof	282	1700	.166

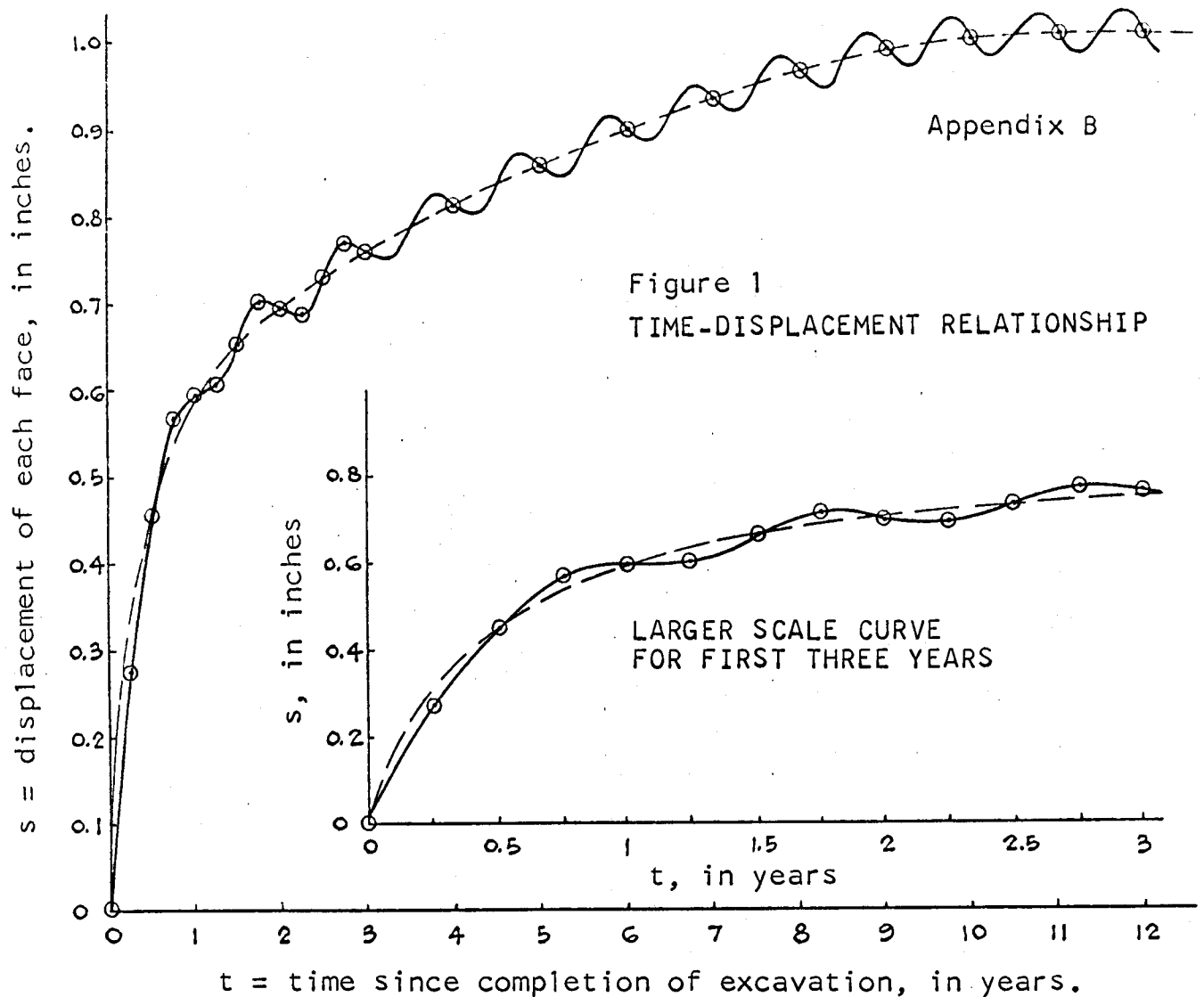
#### Notes

- a) Reported by Acres.
- b) Calculated by MHBH based on our interpretation of strain measurements reported by Acres.
- c) Computed from estimated rebar stresses due to rock pressure.
- d) The value of 900 kips per inch at the struts is the average over the 16 foot wide strip centred on the struts and recognizes the influence of adjacent portions of the tunnel roof slab. The value of 1700 kips per inch is the average per foot measured along the tunnel over the west part of the tunnel roof slab.
- e) Inward movement of each rock face.

#### Assumptions

- f) The effect of shrinkage in the concrete while setting was to postpone the application of pressure on the structure due to encroachment by the rock faces until September 1967.
- g) Compressive stress in rebars due to shrinkage is 9 ksi.
- h) Modular ratio  $E_s/E_c = 15$ .

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This Time-Displacement Relationship has been derived from data contained in Appendix D of Acres' Report - "THOROLD TUNNEL - Investigations to determine the cause of cracking in the structure", dated March 1972, particularly the data on Plate D1 reporting observed movements at Turbine Deck C-3 of the Canadian Niagara Power Company Wheel-Pit.

The displacement is made up of three components; "A", the elastic rebound which is substantially complete by two years after the completion of rock excavation; "B", the continuing unidirectional movement of the rock face; and "C", the seasonal oscillation of the rock face.

Expressed algebraically, the relationship is, -  $s = A+B+C$   
 $= 0.512 (1 - e^{-3.05t}) + 0.317 \log_e (1 + 0.398t) - 0.025 \sin 2\pi t$   
 where  $s$  = displacement of each rock face, in inches;

$t$  = time since completion of rock excavation, in years.

Records show that rock excavation at the Thorold Tunnel was completed February 1, 1966. On the basis of the information available, it was assumed that excavation at the Canadian Niagara Power Company Wheel-Pit was completed February 1, 1904. These dates are relevant because of the relative significance of components "A" and "C" during the earlier years.

INTERIM REPORT No. 1  
ON  
THOROLD TUNNEL INVESTIGATION

Our File No. 72-155

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May 29, 1972

Mr. John B. Wilkes, P. Eng.,  
Executive Director, Design Division,  
Ministry of Transportation and Communications,  
Downsview, Ontario.

Re: Thorold Tunnel

Dear Mr. Wilkes:

Further to your oral instructions and your letter of May 12, 1972 we have proceeded with our study of the problem which has developed as a result rock pressures applied to the north and south walls in the West Service Building of the reference structure.

Based on the data contained in the documents provided to us by Mr. Hewson and on further data obtained in a meeting on May 11th at which Morrison and Hershfield of our firm, and Messrs. MacDonald, Tanner, Bowen and McCreath of Acres were present, and a visit to the structure that same day by Tanner, Morrison and Hershfield, we recommend that remedial measures as described below be undertaken as soon as practicable.

Install steel strengthening struts in the 10 ft. square openings in the tunnel roof slab at elevation 549.83 in the West Service Building, as shown diagrammatically on our Dwg. 72-155-SK1 which accompanies this interim report. To provide for an adjustment of the load in the struts, install a Freyssi Flat Jack with each of the steel struts. It is intentional that the shape and dimensions of these struts and the capacity of the jacks are not shown on this drawing.

We are proceeding with further calculations required for the detailed design of the struts and jacks. We are also working out suitable construction procedures for the installation.

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The various reports, facts, theories, conjectures, and judgements which have led us to conclude that we should recommend this action include the following:

- 1) About one-half of the rock squeeze has already taken place.
- 2) Steel strengthening struts in the openings in the roof slab would reduce the rate of increase of stress in the existing concrete struts.
- 3) Pre-compression of the new steel struts might reduce the present stress in the existing concrete struts.
- 4) The addition of steel struts in the openings would defer the time when the stress in the existing concrete struts will reach an unacceptable value. More time would be available to make strain measurements to establish the rate of increase of rock squeeze and the probable consequences.
- 5) Even if it were eventually concluded that slotting of the rock or of the bulkheads was necessary, there would be more time available to design the slots and to work out the construction procedures. This would be preferable to doing the work on a crash basis.
- 6) It might be established that the roof could be reinforced in such a way that it would be capable of eventually arresting the reduction of the distance between the faces of the rock cut.
- 7) On the basis of studies made to date, we anticipate that the stress in the north reinforced concrete strut will have reached an undesirably high value by August 1972 unless provision is made to relieve that stress.
- 8) Design and construction of the slots before that time would have to be done on a crash basis and might be difficult and costly to achieve.

We would be pleased to discuss any aspect of this interim report with you further at your convenience.

Yours very truly,

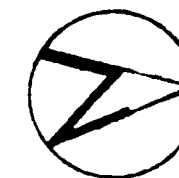
Carson F. Morrison, P. Eng.

CFM/jh

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SOUTH BULKHEAD

NORTH BULKHEAD

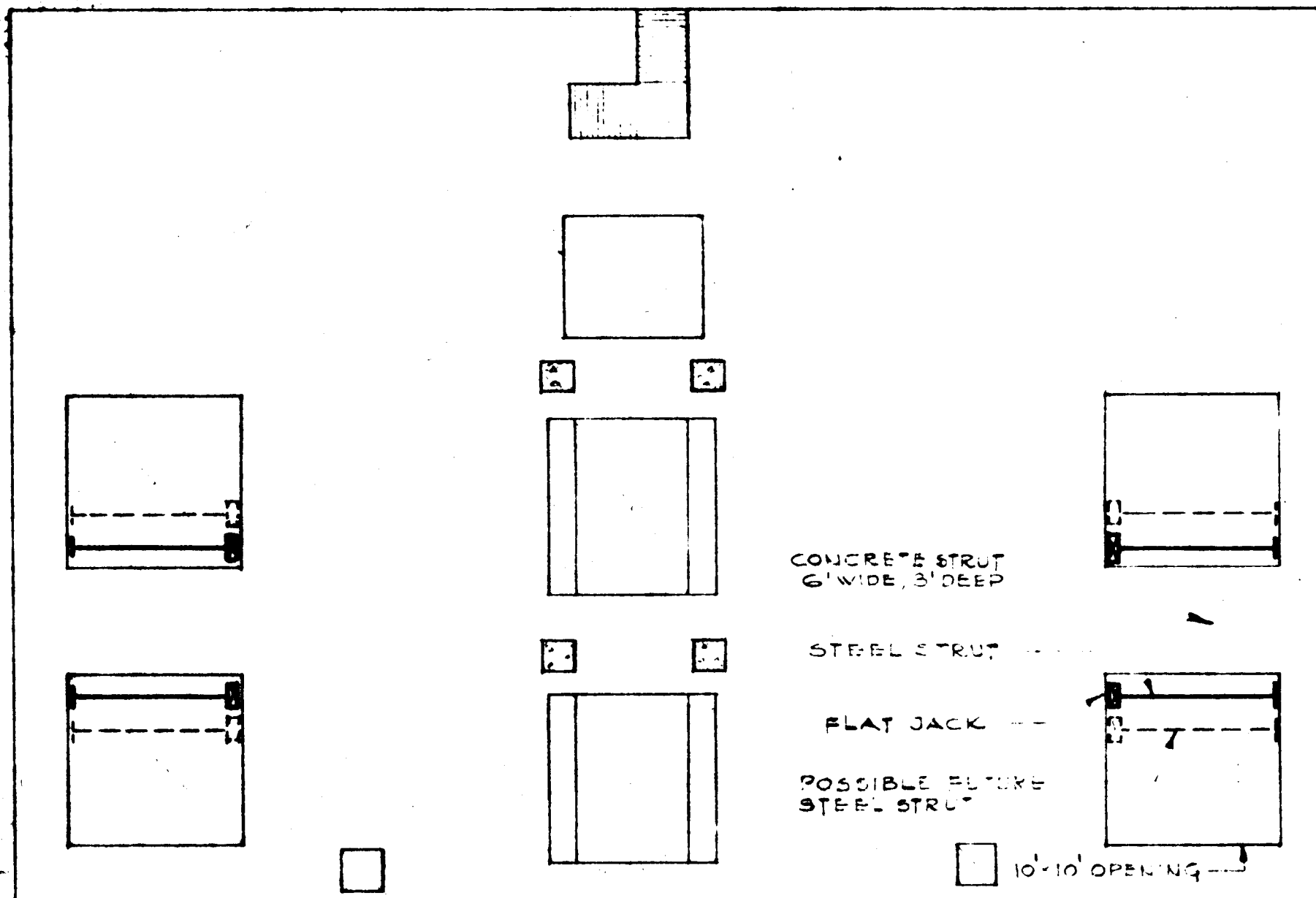


58'-0"

6'-0"

74'-9"

6'-0"



CONCRETE STRUT  
6' WIDE, 3' DEEP

STEEL STRUT

FLAT JACK

POSSIBLE FUTURE  
STEEL STRUT

10'-10' OPENING

WEST SERVICE BUILDING  
PLAN AT EL. 549.83'

MORRISON, HERSHFIELD, BURGESS & HUGGINS, LTD.  
CONSULTING ENGINEERS - TORONTO, ONT.

DESIGNED: C.H.

DRAWN: R.L.

PROJ. ENG.: C.H.

APPROVED:

DRAWING NO.:

72-155-SK1

PROPOSED STEEL STRUTS  
AND PREYSSI FLAT JACKS  
IN THOROLD TUNNEL ROOF

SCALE: 1/8" = 1'-0"

DATE: MAY-26-78

INTERIM REPORT No. 2  
ON  
THOROLD TUNNEL INVESTIGATION

Our File No. 72-155

MIIBII

June 15, 1972

Mr. John B. Wilkes, P. Eng.,  
Executive Director, Design Division,  
Ministry of Transportation and Communications,  
Downsview, Ontario.

Re: Thorold Tunnel

Dear Mr. Wilkes:

We have designed the steel struts whose installation we recommended in our Interim Report No. 1 dated May 29, 1972. The details are shown on our Dwgs. 72-155-SK1 and 72-155-SK2 which accompany this interim report.

We have discussed the fabrication and installation of these struts with Mr. W. J. H. Disher of Frankel Structural Steel Limited. Mr. Disher has visited the structure and has given us a verbal estimate of \$19,800. for the supply and erection of the struts. He has informed us that seven weeks delivery may be expected for mill orders placed within the next two weeks but that delivery of orders placed later is, at this time, uncertain. In the meantime he is exploring the possibility of obtaining the main material from warehouse stocks. He estimates that the additional cost for warehouse material would be \$680. He expects that fabrication and erection of the struts would require four or five weeks.

We have also discussed the Freysssi Flat Jack installation and stressing with Mr. W. Slater of Conenco International Limited. He has given us a verbal estimate of \$3,050. for the jacks, the installation and removal of the hydraulic system, the jacking and the grouting.

For the introduction of prestress into the steel struts and for the measurement of the subsequent behaviour of the struts and the tunnel roof some instrumentation of the struts and the tunnel roof will be required. If it is concluded to install these struts we will work out the details of this instrumentation and a program of observations to be

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made. We believe that you will wish the instrumentation and observations to be integrated with those made for you by others. We recommend that, in the meantime, an allowance of \$2,500. for materials, instruments, and their installation be carried in the estimate of the probable cost of installing and pre-stressing the steel struts.

In summary, the probable cost of the work to be done at this stage is: -

Steel struts - supplied and erected	\$19,800.	
Extra for main material from Warehouse	<u>680.</u>	\$20,480.
Jacks - stressed and grouted		3,050.
Allowance for instrumentation		<u>2,500.</u>
		<u>\$26,030.</u>

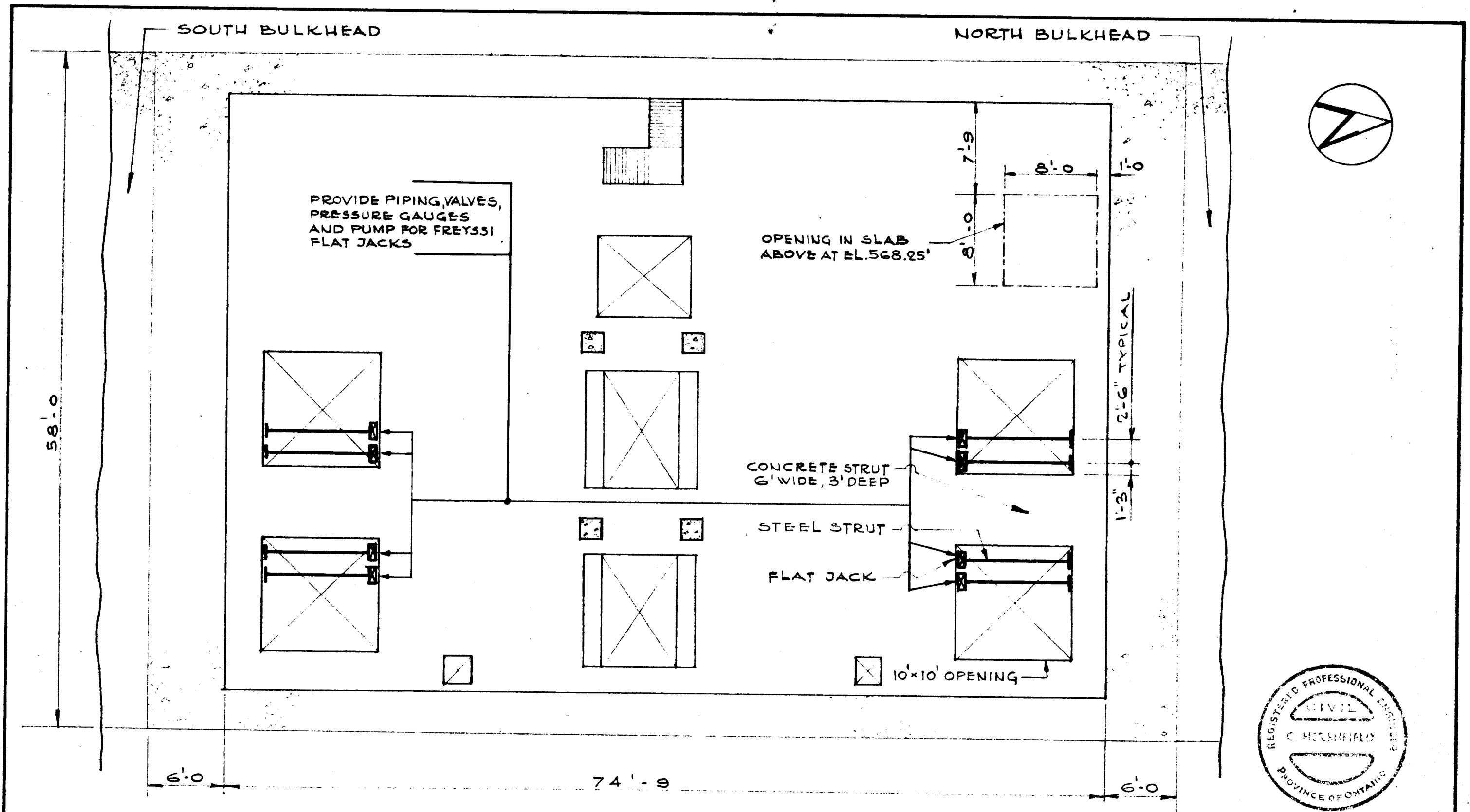
We would be pleased to discuss any aspect of this interim report with you further at your convenience.

Yours very truly,

CH:hb

C. Hershfield, P. Eng.

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WEST SERVICE BUILDING  
PLAN AT EL. 549.83'

REVISED JUNE 14, 1972

MORRISON, HERSHFIELD, BURGESS & HUGGINS, LTD. CONSULTING ENGINEERS - TORONTO, ONT.		DESIGNED: C.H.
PROPOSED STEEL STRUTS AND FREYSSI FLAT JACKS IN THOROLD TUNNEL ROOF		DRAWN: R.L.
		PROJ. ENG.: C.H.
		APPROVED:
SCALE: 1/8" = 1'-0"		DRAWING NO.: 72-155-SK1
DATE: MAY-26-72		

