FOREWORD

Aside from the applied research work being conducted by the Mining Research Centre of the Mines Branch at Ottawa, Elliot Lake, and other places, certain areas of advanced technology are being monitored so that at least information can be supplied to industry on the current state-of-the-art. Rapid excavation, or mechanical tunnelling, is one such area that is likely to influence mining methods before too long. For that reason, it was considered appropriate to compile the experience already obtained in using tunnelling machines in Canada.

The following report was originally prepared as an internal report. However, to give it wider circulation, the report was forwarded, for comments, to various municipalities and organizations and they, in a very cooperative spirit, supplied the detailed information on their mechanical tunnelling projects. The report was then revised in accordance with the suggestions received from these agencies and is now re-issued as a Mines Branch Information Circular for general distribution.

John Convey

John Convey,
Director

Ottawa, October 1970

AVANT-PROPOS

Outre la recherche appliquée qu'il poursuit à Ottawa, à Elliot Lake et en d'autres endroits, le Centre de recherches minières de la Direction des mines surveille certains domaines de la technologie avancée afin de renseigner tout au moins l'industrie sur les progrès courants qui y sont réalisés. L'excavation rapide, ou le percement mécanique des tunnels, est l'un de ces domaines susceptibles d'influer sur les méthodes minières d'ici peu de temps. Pour cette raison, on a jugé bon de compiler l'expérience déjà acquise dans l'emploi de ces méthodes au Canada.

Le présent rapport était destiné à l'origine à une diffusion interne. Toutefois, pour lui donner une plus grande portée, il a été communiqué à diverses municipalités et organisations qui, dans un bel esprit de coopération, ont fourni des renseignements détaillés sur leurs travaux de percement mécanique de tunnels. Le rapport a alors été révisé suivant les indications reçues de ces organismes, et il est maintenant publié comme circulaire générale d'information de la Direction des mines.

John Convey

John Convey
Directeur

Ottawa, octobre 1970

Mines Branch Information Circular IC 256

THE OPERATION OF MECHANICAL TUNNEL-BORING MACHINES IN CANADA

by

T. W. Verity, P.Eng.*

SUMMARY

The Canadian mining industry is always interested in obtaining information concerning new techniques that may be adapted for use in Canadian mines. Recently, the use of mechanical boring and tunnelling machines has become of interest to Canadian hard rock miners.

Several larger American and Canadian cities have used mechanical tunnelling machines in the excavation of sewer and water tunnels. Many coal mines in Canada have installed cutter-loader and continuous-mining types of mechanical equipment in the mining of coal seams, and underground potash mines have recently installed mechanical boring machines to mine relatively soft potash ore. Mechanical raise-boring machines are also being more frequently used in Canadian hard rock mines. The use of mechanical tunnelling machines for lateral development operations has not, however, as yet found acceptance in Canadian hard rock mines.

The Mining Research Centre of the Mines Branch recently undertook to study mechanical tunnelling projects carried out in Canada and to assess the potential application of tunnelling methods to hard rock underground development and mining methods.

The writer investigated the operation of four mechanical tunnelling operations carried out in Canada during the past ten years.

It was found that mechanical tunnelling machines had been used successfully in a) the boring of sewer tunnels, by both the Municipality of Toronto (in shale rock) and the Municipality of Greater Vancouver (in sandstone rock) and (b) the boring of five water diversion tunnels, by the Prairie Farm

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Rehabilitation Administration, in soft shale rock, at Gardiner Dam, for the South Saskatchewan River Project. However, the use of a mechanical tunnelling machine by the Greater Victoria Water District in boring a water tunnel in medium-hard schist rock was not successful and the tunnel had to be completed by conventional drill and blast methods of excavation.

It was concluded that shallow tunnels can be excavated successfully in soft and medium-hard ground up to about 15,000 psi compressive strength and a Mohs hardness up to 5, but that present types of mechanical tunnelling machines used in Canada were not suitable for lateral excavation in the hard rock mines of Canada.

Direction des mines

Circulaire d'information IC 256

LE PERCEMENT MÉCANIQUE DE TUNNELS AU CANADA

par

T. W. Verity, ing. p.*

RÉSUMÉ

L'industrie minière canadienne est toujours à l'affût de renseignements sur les nouvelles techniques susceptibles d'être adaptées aux opérations minières du Canada. Les mineurs canadiens de roches dures se sont récemment intéressés à l'utilisation du matériel de forage et de percement mécanique de tunnels.

Plusieurs grandes villes américaines et canadiennes ont employé des méthodes mécaniques pour le percement de tunnels d'égouts et de conduites d'eau. De nombreuses mines de charbon au Canada ont installé des appareils mécaniques du type haveuse-chargeuse et à abattage continu dans des gîtes de houille, et des mines de potasse souterraines ont récemment installé des appareils de forage mécanique pour extraire du minerai de potasse relativement tendre. On utilise aussi très fréquemment les méthodes mécaniques pour aménager des remontées dans les mines canadiennes de roches dures. Toutefois, les machines à tunnels n'ont pas encore été adoptées pour le creusage de galeries latérales dans les mines canadiennes de roches dures.

Le Centre de recherches minières de la Direction des mines a entrepris récemment l'étude des travaux de forage mécanique effectués au Canada, et l'évaluation des applications possibles de ces méthodes au traçage souterrain en roche dure et aux techniques d'extraction.

L'auteur a étudié le fonctionnement de quatre installations de forage mécanique utilisées au Canada au cours des dix dernières années.

Il a constaté que les machines à tunnels ont été employées avec succès dans: a) le forage de conduites d'égouts par la municipalité de Vancouver (dans du grès), et b) le forage dans du schiste tendre de cinq conduites de diversion d'eau par l'Administration du rétablissement agricole

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des Prairies, au barrage Gardiner, pour les travaux d'aménagement de la rivière Saskatchewan-Sud. Par contre, l'utilisation de ces méthodes par la Greater Victoria Water District pour forer un tunnel d'adduction d'eau dans du schiste demi-dur n'a pas été un succès, et il a fallu achever le tunnel à l'aide des méthodes d'excavation classiques (forage et sautage).

L'auteur conclut que des tunnels peu profonds peuvent être percés avec succès dans des sols tendres et demi-durs dont la résistance ne dépasse pas 15,000 lb/p^2 et la dureté de Mohs ne dépasse pas 5, mais que les appareils de percement mécanique de tunnels utilisés actuellement au Canada ne conviennent pas pour les forages latéraux dans les mines de roches dures.

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CHAPTER 1

The History of Mechanical Tunnelling Operations in Canada

Introduction

The mining industry is constantly looking for ways and means to improve underground mining technology. A recent concept has been the use of mechanical boring machines. Canadian coal mines have already become highly mechanized. Coal cutting and ripping machines and continuous-miner types of equipment have been installed. Potash mines in Saskatchewan are using continuous-miner types of mechanical boring machines in conjunction with conveyor belts and shuttle cars to mine relatively soft potash ores. Mechanical raise-boring machines are finding acceptance in such hard rock mines as: the Bralorne Pioneer gold mine in British Columbia, the nickel mines of the International Nickel Company of Canada, Limited, in Ontario and Manitoba, and the copper mine of Cupra Mines, Ltd. in Quebec's Eastern Townships.

However, no mechanical boring equipment has been used to drive lateral development headings in Canadian hard rock mines. Steep Rock Iron Mines Limited experimented briefly with a tunnel-boring machine at its underground iron-ore mine at Atikokan, Ontario, in 1957 but, so far as is known, no other mechanical tunnelling machine has been used for lateral excavation work in metal mines in Canada. Dominion Bureau of Statistics reports show that some 800,000 ft of crosscuts and drifts are excavated each year in Canadian metal mines. There is, then, a large market for the use of mechanical tunnelling equipment if it can be adapted for use in the hard rock mines of Canada.

The Mining Research Centre of the Canadian Department of Energy, Mines and Resources recently decided that an investigation should be made of the use of mechanical tunnelling machines for the boring of water, sewer and hydroelectric installations in Canada, in an attempt to evaluate the possibilities of using these types of machines for driving development headings and for mining operations in Canada's hard rock underground metal mines. The writer was asked to carry out this investigation. The present report is a summary of this study.

Hard Rock Tunnelling Machines in the U.S.A. and Canada

A literature search indicated that the first use of mechanical tunnelling machines in North America was in the driving of tunnels at the Oahe Dam at Pierre, South Dakota, U.S.A. in 1954. In the early 1950's, Goodman Manufacturing Company supported the development work of James S. Robbins on so-called hard rock tunnelling machines. This resulted in the design of three machines used for excavating tunnels at the Oahe Dam in 1954-55 and 1959. Modern tunnelling machines may be said to have developed from that time (1).

The first machine was Robbins Model 910 (125-ton weight) and was used by Mittry Construction Co. of Los Angeles, California, in driving upstream diversion tunnels 25'9" in diameter at the Oahe Dam. The second, Robbins

Model 930 (130 tons), was used by Oahe Constructors of St. Paul, Minnesota, in driving downstream diversion tunnels at the Oahe Dam. The third, Model 351 (176 tons), was used by the contracting firm of Morrison, Kundsen, Kiewit and Johnson to drive upstream power tunnels, 7,680 ft in length and 29'6" in diameter, at the Oahe Dam site in 1959. The average hourly rate of advance while cutting was 8 to 12 ft per hour in these tunnels. The cutterheads used a combination of fixed and disc cutters. The rock at the tunnel site was soft shale of approximately 1,100 pounds per square inch (psi) compressive strength. Ground conditions were bad, however, and 8" WF 31 lb/ft steel ring beams, set on 2- to 4-ft centres, had to be used because of badly faulted and squeezed ground (2).

In 1956, Perini and Sons, Framingham, Mass., drove an 8-ft-diameter tunnel in Pittsburgh, Penn., using Robbins Model 101 (17 tons weight) and Dravo Corporation of Pittsburgh also drove an 8'6" portion of Pittsburgh sewer tunnel, using Robbins Model 102 (17 tons). The Pittsburgh tunnels were driven through shale (6,400 psi compressive lateral strength), sandstone (11,300 psi) and slate-limestone (7,900 psi) at a rate of 8 to 10 ft per hour and did not require ground support (2). The cutterheads again used both fixed and disc cutters.

Also, in 1957, A.S. Healy Company drove a 9-ft-diameter sewer tunnel in Chicago, using Robbins Model 103 (17 tons weight). The Chicago tunnels were driven through hard limestone rock of between 18,000 and 24,000 psi compressive strength, and advance was only at the rate of 2 to 4 ft per hour. Fixed cutters were used and proved unsuitable for boring in harder rock. The machine was taken to Canada and used on an experimental basis in driving a short tunnel at Steep Rock Iron Mines Limited, at its underground iron-ore mine at Steep Rock Lake, Atikokan, Ontario. The rock types at Steep Rock Lake were greenstone (1,800 psi compressive strength), geothite (9,500 psi), and carbonate (9,600 psi). The Robbins Model 103 was able to advance up to 10 to 12 ft per hour in the iron ore but Steep Rock Mines decided it would not be economically feasible to use the machine in its development work. This was, however, the first application of a mechanical tunnelling machine in Canada and did arouse interest in the possible use of tunnelling machines in Canada.

The Municipality of Metropolitan Toronto, in 1957, was planning the excavation of a sewer line some two miles in length to run under a portion of Metropolitan Toronto. Because of the proximity to residential areas and the relative shallow depth of the tunnel, it was considered that another method of driving the tunnel, rather than the conventional drilling and blasting method, should be investigated. The use of a mechanical tunnelling machine seemed desirable. The use of the Steep Rock machine, Robbins Model 103, or the Dravo Company machine, Robbins Model 102, was investigated. It was decided that conversion of either of these machines to meet the Toronto tunnel requirements was not feasible, and arrangements were made to have an entirely new Robbins machine designed, known as Model 131. J.S. Robbins and Associates of Seattle, Washington, designed the machine. It was assembled at the Dorr-Oliver-Long plant at Orillia, Ontario, early in Jaunary 1958, and was used by the Foundation Company of Canada, the contractors on the "Foundation Humber" project, to bore 10,210 ft of tunnel between May 8, 1958, and November 26, 1959, or 87 per cent of the total length of 11,810 ft of tunnels and adits. The machine had a bore diameter of 10'9", thrust of 314,000 lb, and torque of 176,000 ft-lb. It weighed 65 tons and was 29'4" in length. Disc cutters were used on the cutterhead. Details of the operation of this machine are given in Chapter 2 of this report.

Much interest was shown in the Toronto tunnel project by civil engineers and contracting firms in Canada. The municipalities of Vancouver and Victoria, which had long tunnels planned for sewer and waterworks purposes, sent engineers to visit the Toronto project.

The next tunnel project, however, in Canada using mechanical boring machines was the Department of Agriculture, Prairie Farm Rehabilitation Administration, South Saskatchewan River Dam Diversion Tunnels. These were a series of five tunnels, each approximately 4,330 ft in length, constructed in the form of chorded arcs in the west abutment of the main embankment of the dam. The rock at the dam site, through which the tunnels were driven, was Bearpaw shale, a relatively soft marine clay shale requiring temporary ground support along the entire length of each tunnel. The situation was rather similar to that at the Oahe Dam in South Dakota, and the Robbins Model 351, used for boring the upstream power tunnels at this dam in 1959, was obtained by the contracting firm of Kiewit-Johnson-Poole, modified at Brandon, Manitoba, and used on the South Saskatchewan River project. The machine, originally designed to cut a bore diameter of 29'6", was modified to cut a diameter of 25'8" and was named as Model 261 by the Robbins Company. The modified machine weighed 200 tons and had an overall length of 48 ft. It originally used a combination of fixed teeth and disc cutters in the cutterhead but these were modified to give 160 tungsten-carbide-tipped cutting teeth anchored into the cutterhead and protruding some 4 in. ahead of the cutterhead face. The redesigned machine had a rated thrust of 500,000 lb and torque of 3,500,000 ft-lb. Actual tunnelling started on February 13, 1961, and was completed on January 25, 1963. The mechanical tunnelling machine bored approximately 18,302 ft, or 94 per cent of the total length of 19,737 ft, of diversion tunnel. Details concerning the operation of this tunneling machine are given in Chapter 3 of this report.

The Greater Vancouver Sewerage and Drainage District, during 1963-65, constructed a concrete conduit, 26,730 ft in length, varying in outside diameter from 8 to 11 ft, under 8th Avenue in the City of Vancouver. The actual tunnel excavation was done between July 21, 1963, and September 19, 1964, using three identical lightweight mechanical tunnelling machines known as "Scott" boring machines. Some 21,000 ft, or 79%, of the total length, was excavated by these machines. They were constructed especially for the job by the contractor, Northern Construction Co. and J.W. Stewart Ltd. Boring machines similar in type had been used previously in tunnelling operations in the U.S.A. The machines weighed about 12 tons, were 22 ft in length, and used fixed tungsten-carbide-tipped teeth in bit holders as the cutting device. The cutterhead could be adjusted to bore holes varying in diameter from 8 to 13 ft. The tunnel was driven through soft sandstone, shales, and unconsolidated fill. The compressive strength of the rocks varied between about 2,000 to 10,000 psi. Details of the operation of one of these Scott machines are given in Chapter 4 of this report.

The Greater Victoria Water District, Victoria, B.C., during 1964-66 excavated a 29,000-ft water tunnel, 8'6" outside diameter, from a water supply area at Sooke Lake, some 20 miles north-west of Victoria, to a reservoir in the Goldstream River Valley. The rocks of the district were composed of sedimentary, thin-bedded, slaty schists, closely folded, with the strata standing almost vertically and the tunnel closely paralleling the strike of the formation. The compressive strength of the rock was between 8,000 and 20,000 psi. Intermountain Construction Ltd., of North Vancouver, was the contractor on the project. The contractor purchased a mechanical tunnelling machine, known as Robbins 81, which had been modified to suit the requirements of the job. The machine was built at Canadian Car (Pacific) Ltd. in 1964, using Robbins plans. Boring commenced on November 28, 1964, and was terminated on April 22, 1966, after excavating only approximately 3,400 ft, or 12%, of the total tunnel length. The operation was delayed by constant breakdowns of the machine and some long periods of inactivity for the machine while waiting for replacement parts. Much of the work of excavating the tunnel was done by conventional drilling and blasting methods, while waiting for the machine parts. Machine break-downs and operating difficulties finally resulted in the contracting company's not being able to complete its contract, and the tunnel was finished by the Greater Victoria Water District itself, using hired crews and drilling and blasting methods of driving the tunnel.

The boring machine had been designed by the Robbins Company, supposedly to suit the job requirements. It was 48 ft long and weighed 36 tons. The cutterhead was conical in shape and had a tricone cutter in the centre and disc cutters on the remainder of the head. There were only two gripper shoes, mounted horizontally on the machine, and the nearly vertical dip of the strata resulted in these shoes breaking down the walls of the tunnel and not gripping properly. The result was that the effective thrust of the machine against the face was reduced and an advance of only about 2.5 ft per hour was obtained when drilling in the medium-hard rock. Also, the uneven grip on the walls resulted in the breaking of three main bearings and several disc cutters and other parts on the machine during boring operations. Details of the machine operations are given in Chapter 5 of this report.

Beaver Underground Structures Ltd. of Montreal also used a Robbins boring machine in excavating sections of 96-in.-diameter sewers for the City of Ottawa during 1965-66. The rocks were relatively soft, however, and details of this project are not given in this report.

Analysis of Operations

The sewer tunnelling operations carried out by the municipalities of Toronto and Vancouver can be directly compared. The relative costs, for mechanical excavation only, were $105 per lineal foot for the Toronto tunnel and $98 per foot for the Vancouver tunnel. In the Toronto tunnel, the first six months were more or less spent in modifying the machine and training the crews. Also, having to advance around a curve when driving from Adit 1 delayed progress. As operating problems were solved, however, it was possible to improve the average daily advance. This was shown by the fact that the average advance while driving between Adits Nos. 1 and 2, around the long curved section, was only 23.4 ft per day but was 37.5 ft per day on the main-line tunnel between Adits 2 and 3 and was 42.3 ft per day between Adit 3 and the open cut at the Humber River. The estimate of $105 a foot of lineal advance for the machine compared favourably with $103 a foot for excavating by drilling and blasting, according to a report prepared by G.A. White, project engineer for the Foundation Company, at the time the tunnel was driven.

Mr. White was interviewed by the author in Toronto during February 1969, and stated that with the experience gained in driving the Toronto tunnel it was probable that his company could drive a similar type of tunnel at considerably lower cost. He was of the opinion, however, that the Robbins machine, as designed for the Toronto tunnel project, would not work successfully in hard rock. The shale and siliceous limestone rock encountered in the Humber Valley had a hardness running between 2 to 5 in the Mohs scale of hardness and had compressive strength between 8,000 to 14,000 psi. In his opinion, the machine would not bore successfully in rocks above the 5 to 6 range of hardness.

The type of rock encountered in the Vancouver Tunnel was probably close to the Toronto tunnel in hardness and compressive strength. Geological plans showed the tunnel route included soft sandstone and shale, till, silt, sand and gravel, fill, basalt, and even a few narrow coal seams. Most of the tunnel route was in sandstone, with some hard concretions. Norman and Stier (3) gave a compressive strength of 6,000 psi for shale and clay and 6,000 to 12,000 psi for dolomite, sandstone, and marble. The Scott tunnel-boring machines used were much lighter in construction than the Toronto machine, being only about 12 tons in weight compared with 65 tons, and 22 ft in length compared with 29 ft. The average advance per shift for the Scott machines was approximately 10 ft, compared with 11 for the Robbins machine in the whole Toronto tunnel and 13 ft while boring in straight sections of the tunnel. The Vancouver tunnel did not have the long six-months delay before starting work on the main tunnel, but the three adits driven in Toronto averaged 250 ft each in length whereas the Vancouver adits and shafts were much shorter. Also, the contractor in the Vancouver tunnel was able to increase the rate of advance by combining mechanical boring with drilling and blasting of hard layers encountered in the rock face, whereas, in the Toronto tunnel, blasting could not be used while the mole was operating in the tunnel.

Considering, then, the relative operating difficulties, limiting factors and restrictions encountered, it may be concluded that the two tunnel contractors obtained very comparable results while using two different types of mechanical boring machines. Both could be considered successful operations.

Mr. F. Langfeldt, a senior official of the contracting firm of Northern Construction Co. and J.W. Stewart Ltd., was interviewed by the author in North Vancouver in January 1969. He stated that in his opinion the Scott machines would not be suitable for driving tunnels in harder rocks, such as the schists encountered in driving the Victoria water tunnel on Vancouver Island, or the type of rocks found in the hard rock metal mines of Canada.

The driving of the diversion tunnels of the PFRA South Saskatchewan River Dam project illustrated another application of tunnel-boring machines in Canada, but could not be compared directly with hard rock mining operations in Canada. The clay shales encountered at the dam site would be classed as soft and could not be compared directly with the type of rocks found underground in the Pre-Cambrian Shield. The techniques used in ground control in the South Saskatchewan River Dam tunnels were of interest, however, and could well be adapted for use in development headings driven by conventional drilling and blasting methods.

The Sooke Lake-Goldstream River water tunnel on Vancouver Island presented operational conditions quite similar to those encountered in the hard rock mines of the Pre-Cambrian Shield. The author made an underground inspection of a portion of the tunnel, driven by conventional drilling and blasting methods, and found the wall rocks rather similar to the greenstones and schists encountered in many underground gold mines in various parts of Canada.

The poor results obtained by the Robbins Model 81/121 boring machine while driving the Victoria Island tunnel were a disappointment when considering the potential use of such types of machines in the hard rock mines of Canada.

The author, however, was of the opinion that the Victoria tunnel project was not a fair test of the use of mechanical tunnel-boring machines in harder-type rocks. The choice of cutterhead design and type of grippers used on the machine was unfortunate and caused many operational problems and numerous mechanical breakdowns. Mr. R. A. Upward, Chief Commissioner, Greater Victoria Water District, and Mr. C. Schroeder, Superintendent of the tunnel project, both expressed the opinion that the Robbins machine could have worked successfully if the following modifications had been made:

(a) Improvement of the cutterhead design and type of cutter used.

(b) Provision of a shield around the machine to support the roof when boring through poor ground.

(c) More gripping legs to provide improved anchorage against the tunnel walls.

(d) An adjustable cutterhead to allow varying the head diameter when boring through ground needing temporary support.

(e) Increased space at the cutterhead so that steel sets could be erected during boring operations through poor ground.

(f) Easy dismantling of the machine into small units for removal from the tunnel.

(g) Improved ventilation methods to remove dust and reduce heat in the air while boring.

It is evident, however, that all these changes would require a complete redesigning of the Robbins machine.

The Robbins machine, after having the initial modifications made to the cutterhead, did give reasonably good results when working in good ground. Unfortunately, it was not able to maintain a steady pace for long without having mechanical breakdowns. The best advance was 68 ft a day and 26 ft per shift. This compared with about 25 ft a day when using conventional drilling and blasting methods. The best advance for the mole during four consecutive weeks was 774 ft in 22 working days, an average of 35 ft per day. The best advance for a month using drilling and blasting methods was 604 ft, or about 27 ft per day. It is evident that the boring machine, under favourable circumstances, could advance at a faster pace. The author estimates, however, that on the basis of available working days, the breakdown and delays encountered while using the mole resulted in an average advance of only 13½ ft per day, compared with 20½ ft while using the conventional drilling and blasting method.

Operating Comparisons

Figure 1 gives a graphical comparison of the cumulative monthly advance in the four underground tunnels covered in this report. It is interesting to note the low productivity periods of several months at the beginning of each contract until the preliminary development work was completed. This involved the sinking of shafts or driving of adits to reach the main tunnel locations, the training of crews in the use of the tunnelling machines, and the modification and repair to the machines to adapt them to the requirements of each job. Once the initial development was completed in each tunnel, with the exception of the Victoria tunnel, then the tunnels progressed at gradually increasing rates of advance. In fact, the slopes of the production curves were nearly similar in the Toronto and PFRA tunnels and in the Yukon West portion of the Vancouver tunnel.

Figure 2 gives a comparison of the cumulative monthly advance for each tunnel, combining the operation of the mechanical boring machine and other methods of excavation, such as conventional drilling and blasting, hand-mining or open cut. It can be seen that in the case of the Victoria tunnel the rate of advance while using the mechanical tunnelling machine was only slightly better than when using conventional drilling and blasting methods. The rate of advance in the Victoria tunnel was much less than in the other tunnels where mechanical tunnelling machines were used successfully. It should be noted, however, that in general only two shifts a day were worked in the Victoria tunnel, whereas three shifts were worked in the other tunnels.

Figures 3 to 6 show the monthly advances for each tunnel. The initial development period and delays while moving, modifying and repairing the machines may be noted.

Tables 2 to 5 give operating statistics and cost estimates.

Manpower Requirements

A direct comparison of manpower requirements in the various tunnels is difficult to obtain. For example, the number of men employed in the Toronto tunnel by the Foundation Company of Canada varied from 10 at the end of June 1958, when the boring machine was being modified, to 182 in June 1959, when mechanical boring, conventional tunnelling methods and concreting operations were underway simultaneously. Again, in the Vancouver tunnel, three small tunnelling machines were in use and at the same time open-cut and concreting operations were underway. The Toronto, Victoria and PFRA tunnels were mainly 6-days-a-week, three-shifts-a-day operations whereas the Victoria tunnel was usually a 5-days-a-week, two-shifts-a-day operation. The author was not able to obtain detailed manpower figures or cost estimates for all the tunnels. What were available were included in the chapters of this report dealing with individual tunnel operations.

Table 6 gives estimates of the daily manpower requirements in mechanical tunnelling operations, and includes hourly rates of pay where this information was available. Estimates were made, by the author, to combine the three boring-machine operations in the case of the Vancouver tunnel and to estimate manpower requirements in the PFRA tunnel. The Victoria estimates do not include a travel allowance of $11 per man per day. This was given because of the need to travel from Victoria, by car or truck, to reach the tunnel location, located some 20 miles northwest of Victoria.

The tables and graphs that follow were mainly compiled as a result of the author examining and analysing daily, weekly or monthly reports on file at the offices of municipal or consulting engineers. In most cases no official reports had been prepared, and often records were incomplete or lacked pertinent information, such as man hours of work or distribution of time between mechanical boring and other operations. The data in the tables, then, do not represent official statistics from the parties concerned but are largely based on the author's estimates.

In the case of the Toronto Humber River sewer tunnel, most of the statistical data were taken from a report prepared by G.A. White of the Foundation Company of Canada Limited. Additional information was obtained from microfilm reproductions on file in the office of James F. MacLaren Limited, Consulting Engineers, in Toronto, and also from the files of the Engineering Division of the Municipality of Metropolitan Toronto.

Statistics for the South Saskatchewan River Dam Diversion Tunnels were compiled from a report received from J.G. Watson, Chief Engineer, Prairie Farm Rehabilitation Administration, Regina, Saskatchewan. The report was entitled "South Saskatchewan River Dam Construction Report, Mechanical Mining of the Diversion Tunnels, Contracts 14 and 21" and was prepared by the Construction Division of PFRA in June 1965. The PFRA organization was formerly under the jurisdiction of the Canadian Department of Agriculture but recently it became part of the Department of Regional Economic Expansion.

Statistics for the 8th Avenue Interceptor Tunnel in Vancouver, B.C., were obtained from the document, "Greater Vancouver Sewerage and Drainage District, Contract No. 66, for Construction and Completion of 8th Avenue Interceptor and Appurtenances". The Sewerage and Drainage District engineering office provided the author with a copy of this document and also supplied maps, photographs, and additional information concerning the project.

Information for the Sooke Lake-Goldstream River Water Tunnel on Victoria Island, B.C., was obtained by the author from personal examination of daily time records and survey records available in the time office at the Japan Gulch Portal of the tunnel. No engineering reports were available and the statistical data presented in the report were based solely on the author's interpretation of the information available.

Conclusions

The use of mechanical tunnel-boring machines in Canada indicates that they can be used successfully in boring sewer, water and power lines underground in rocks having a Mohs hardness up to 5 and a compressive strength of up to around 15,000 psi, but that the types of machines used in Canada to-date would not work successfully in harder rocks.

Mechanical tunnel-boring machines can advance at a faster pace than the more conventional drilling and blasting methods under favourable ground conditions in medium-hard ground.

The use of mechanical tunnelling machines while boring through poor ground, needing extensive ground support, has little or no advantage over more conventional drilling and blasting methods, but a combination of using boring machines while advancing through good ground and drilling and blasting or hand-mining methods while advancing through poor ground would have distinct advantages. This combination method, however, would require the design of boring machines that could be easily moved, dismantled, and reassembled, and also a well-planned method of ground control.

Recommendations

That mining contractors in Canada and the larger mining companies be encouraged to experiment with mechanical tunnelling machines with the objective of developing a type of machine suitable for boring tunnels in rocks ranging from soft to very hard and able to advance through poor ground needing ground support. The machines would also need to be designed to facilitate the removal of dust from the working area.

A literature search gave some clues as to types of tunnel-boring machines that might work in harder rock mines in Canada.

Norman and Stier (3) gave the following data (Table 1) for the type of cutters to be used for rocks of various compressive strengths:

TABLE 1

Types of Cutters Used for Different Types of Rock Formations

DESCRIPTION	COMPRESSIVE STRENGTH (psi)	TYPICAL FORMATIONS ENCOUNTERED	TYPE CUTTERS NORMALLY USED
Soft	6,000 maximum	Shale, clay, red beds	Milled tooth, kerf, disc, drag bits, scrapers
Medium	6,000 - 12,000	Dolomite, sandstone, marble	Milled tooth, kerf, disc
Medium hard	12,000 - 25,000	Limestone gneiss, granite	Carbide kerf
Hard	25,000 minimum	Diorite, quartzite, hornblendes	Carbide

Table 1 indicated that a tungsten-carbide-insert type of cutter would be preferable for hard rock boring.

S & M Constructors of Cleveland, Ohio, U.S.A., bored 10,000 ft of tunnel in 1965-1966 for the Metropolitan St. Louis Sewer District, using a modified Jarva 8 type of mechanical boring machine. The compressive strength of the rocks ranged from 12,000 to 15,000 psi and the hardness was about 4.5 to 5 on the Mohs scale. The rocks were thin-bedded limestone with chert strata and occasional zones of heavy lamination. This could be classed as medium hard but the cutterhead used Reed Type QKC cutters, made of tungsten-carbide-insert roller cutters designed for boring in extremely hard ground. The machine also used eight hydraulically operated holding legs to grip the tunnel wall by means of 48 conical buttons inserted into the curved gripping shoes. The cutterhead had open sections making it easy to replace the rotary cutters. The machine was only 18 ft long, weighed 28 tons, developed 325 hp, and had a maximum thrust of 559,250 lb and torque of 132,405 ft-lb. Diameter of the tunnel was 7'10". Advance was 4 to 7 ft per hour. (1) (4)

Another type, the Alkirk tunnelling machine, developed by Lawrence Machine Manufacturing Company, Incorporated, a subsidiary of Ingersoll Rand Company, used the pilot-hole principle in boring. Instead of pushing itself against the tunnel face, it bored a hole in the centre, locked the pilot drill in the hole, and hydraulically pulled itself against the face to ream the pilot hole to the full tunnel diameter. Cutters used could be either tooth, carbide-button or disc types (5). This type of machine appears to have good potential but has yet to prove itself. An early model, Lawrence HRT 12, was used in driving a 12-ft-diameter water tunnel in 1964, in shale and metamorphic rocks of compressive strength up to 28,000 psi, in the Richmond Tunnel, New York

City, U.S.A., but was not successful due to the failure of the slewing system and the hydraulic pumps and anchor (1). A later model was to be used in boring a sewer tunnel in Chicago, Illinois, during 1969.

Some European tunnelling machines, notably the Demag, Habegger and Wirth, are reported to have been successful in boring in rocks up to 34,000 psi compressive strength (1). The Mining Research Centre has information available concerning the Demag machine and it is understood that Demag Industrial Equipment Limited, Clarkson, Ontario, is attempting to promote the use of Demag tunnelling machines in Canada. As far as is known, none of the European tunnelling machines has yet been working in North America.

Hill (6) estimates that some 3,000 miles of tunnelling will be required in the world between 1966 and 1976. He estimates that some 1,000 miles of this will be done by mechanical tunnelling machines. With such a large potential market, it is hoped that machines suitable for development and production work in Canadian underground hard rock mines will be developed in the near future.

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2. Anonymous: Tunnel Boring Through Harder Rocks, Eng. and Min. Jour. Vol. 161, No. 3, March 60 (Reprint).

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5. Nicholson W.E., Big Bits Drill Big, World Mining, pp. 41-48, Sept. 67.

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TABLE 2

Summary of Operations

	Toronto		Vancouver		Victoria	PFRA	
	Adits	Tunnel	Yukon West	All Tunnels		Upstream Tunnels	Downstream Tunnels
Type of tunnel	Devel.	Sewer	Sewer	Sewer	Water	Power	Power
Outside tunnel diameter	10'9"	10'9"	9'10"	8' to 11'	8'6"	25'8"	25'8"
Date boring started	20 May/58	1 Nov/58	17 Aug/63	21 Jul/63	28 Nov/64	7 May/62	13 Feb/61
Date boring completed	31 Oct/58	19 Nov/59	1 Jul/64	19 Sep/64	22 Apr/66	25 Jan/63	12 Apr/62
Average advance per cutting hour (ft)	n.a.	4.8	3.5	n.a.	2.5	7.2	n.a.
Average advance per shift (ft)	4.0	10.6	9.6	n.a.	8.6	18.1	11.8
Average advance per day (ft)	8.0	31.8	28.8	n.a	17.2	54.3	35.3
Best shift advance (ft)	n.a.	36	n.a.	56	26	n.a.	n.a.
Best day advance (ft)	51	94	n.a.	n.a.	68	124	126
Best week advance (ft)	n.a.	378	412	n.a.	266	n.a.	n.a.
Best month advance (ft)	190	1269	1193	n.a.	817	1660	1670
Total feet bored mechanically	750	9448	5762	21100	3457	9384	8918
Total feet tunnel excavated	760	12293	6290	26720	29000	9816	9921
Per cent bored mechanically	99	77	91	79	12	96	90

TABLE 3

Time Distribution in Per Cent

	Toronto		Vancouver		Victoria	PFRA	
	Adits	Tunnel	Yukon West	All Tunnels		Upstream Tunnels	Downstream Tunnels
Mechanical boring	14.0	26.2	53.7	n.a.	38.0	55.9	45.9
Muck disposal	n.a.	9.5	n.a.	n.a.	n.a.	n.a.	n.a.
Modifications and repairs	49.3	26.9	8.7	n.a.	62.0	--	17.1
Maintenance	4.7	14.5	n.a.	n.a.	n.a.	14.7	16.3
Installing sets, ground control	7.0	4.5	2.9	n.a.	n.a.	n.a.	n.a.
Moving machine and miscellaneous	8.2	15.4	3.6	n.a.	n.a.	29.4	20.7
Breaking rock on curves	16.8	3.0	--	--	--	--	--
Drill and blast hard layers	--	--	31.1	--	--	--	--
Total time distribution	100.0	100.0	100.0	--	100.0	100.0	100.0

Rock Type

	Toronto	Vancouver	Victoria	PFRA
Rock type	Shale, inclusions of limestone bands	Sandstone, inclusions of shale lenses	Schist, inclusions of quartz lenses	Soft, fractured shale, some stone concretions
Lateral compressive strength	6,000 - 14,000 psi	6,000 - 12,000 psi	12,000 - 25,000 psi	150 - 400 psi
Mohs hardness number	2.5 to 5.0	2.5 to 4.0	4.0 to 7.0	Shale 1.5
Cu yd per foot of advance	3.36	2.83 (Yukon West)	2.10	19.17
Tons per cu yd (solid rock)	2.25	2.10	2.30	2.20
Tons per ft of advance (solid rock)	8½	6	5	42

TABLE 5

Cost Estimates,

Mechanical Excavation Only

	TORONTO	VICTORIA	VANCOUVER	PFRA
Daily manhours	512	120	648 (e)	752 (e)
Daily labour cost	$ 1142	$ 440 (1)	$ 2140 (e)	$ 2256 (e)
Cost per hour	$2.33	$3.67 (1)	$3.30 (e)	$3.00 (e)
Cost per foot	$105.00	$110.00	$98.00	$415.00 (2)
Average ft per day	32	17	29	43
Cu yd per ft advance	3.4	2.1	2.8	19.2
Cost per cu yd	$ 31.00	$52.00	$35.00	$21.50 (2)

Note: (1) Does not include travel allowance of $11.00 a day.

(e) Estimated by author.

(2) Includes ground support but not tunnel concrete lining.

TABLE 6

Manpower Requirement Estimate,

Canadian Mechanical Tunnelling Operations

TRADE	TORONTO				VICTORIA				VANCOUVER (e)				PFRA (e)			
	No. Men	Daily Man Hours	Pay Rate $	Total Daily Cost $	No. Men	Daily Man Hours	Pay Rate $	Total Daily Cost $	No. Men	Daily Man Hours	Pay Rate $	Total Daily Cost $	No. Men	Daily Man Hours	Pay Rate $	Total Daily Cost $
	6-day week 3 shifts per day				5-day week 2 shifts per day				(for 3 machines) 6-day week, 3 shifts per day							
Supervision			(Year 1960 rates)				(Year 1965 rates)									
General Supt.	1	8	700. mo.	28.20	1	8	50. day	50.00	1	8	n.a.	n.a.	1	8	n.a.	n.a.
Night Supt.	1	8	138. wk	23.00	-	-	-	-	1	8	n.a.	n.a.	1	8	n.a.	n.a.
Resident Engin.	1	8	550. mo.	22.90	-	-	-	-	1	8	-	-	1	8	-	-
Master Mechanic	1	8	650. mo.	27.10	-	-	-	-	1	8	-	-	1	8	-	-
Office Man.	1	8	525. mo.	21.80	-	-	-	-	1	8	-	-	1	8	-	-
Time Keepers	3	24	85. wk	42.60	-	-	-	-	3	24	-	-	3	24	-	-
Shift Foremen	3	24	2.30 hr	56.20	2	16	3.84 hr	61.40	3	24	-	-	3	24	-	-

- cont'd

(Table 6, cont'd)

	TORONTO				VICTORIA				VANCOUVER (e)				PFRA (e)			
	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost
Mechanical Tunnelling Machine Crew																
Operators	3	24	2.90 hr	69.60	3	24	3.57 hr	85.70	9	72	--	--	3	24	--	--
Mechanics	3	24	2.70 hr	64.80	--	--	--	--	3	24	--	--	3	24	--	--
Electricians	3	24	3.05 hr	74.20	--	--	--	--	3	24	--	--	3	24	--	--
Conveyor Tenders	3	24	1.85 hr	44.40	1	8	3.35 hr	26.30	9	72	--	--	3	24	--	--
Services to the Machine																
Track and Pipe	8	64	1.90 hr	121.60	1	8	3.35 hr	26.30	9	72	--	--	8	64	--	--
Ground Control	6	48	1.90 hr	91.20	--	--	--	--	--	--	--	--	6 12 15	48 (welding ring beams) 96 120 (Guniting)	--	--
Compressor Operators	3	24	2.40 hr	57.60	---	--	--	--	3	24	--	--	--	--	--	--
Muck Disposal																
Locomotive Crew	3	24	1.90 hr	45.60	2	16	3.44 hr	55.00	9	72	--	--	9	72	--	--
Dozer Operators	3	24	2.50 hr	60.00	--	--	--	--	--	--	--	--	3	24	--	--

- cont'd

(Table 6, concluded)

	TORONTO				VICTORIA				VANCOUVER (e)				PFRA (e)			
	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost*	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost	No. Men	Daily Man Hours	Pay Rate	Total Daily Cost
Dumping Area	3	24	1.90 hr	45.60	--	--	--	--	3	24	--	--			--	--
Machine Maintenance Crew																
Mechanics	1	8	2.70 hr	21.60		16	3.93 hr	62.90	2	16	--	--	3	24	--	--
Carpenters	1	8	2.70 hr	21.60	--	--	--	--	2	16	--	--	3	24	--	--
Electricians	3	24	3.05 hr	74.20		8	3.67 hr	29.40	2	16	--	--	3	24	--	--
Survey Crew																
Instrument Men	3	24	425. mo.	53.20		8	550. mo.	22.90	3	24	--	--	3	24	--	--
Rodman	3	24	1.50 hr	36.00		8	2.50 hr	20.00	3	24	--	--	3	24	--	--
Miscellaneous																
Dry House Attend.	3	24	1.00 hr	24.00	--	--	--	--	3	24	--	--			--	--
Truck Drivers	1	8	1.85 hr	14.80	--	--	--	--	1	8	--	--	3	24	--	--
Hoistmen	--	--	--	--	--	--	--	--	3	24	--	--	--	--	--	--
Deckmen	--	--	--	--	--	--	--	--	3	24	-- (e)	-- (e)	--	--	-- (e)	-- (e)
Total	64	512	2.23 hr	1141.80	15	120	3.67 hr	439.90	81	648	3.30 hr	2140	94	752	3.00	2256

(e) Estimated by author.

* Note: Without travel allowance

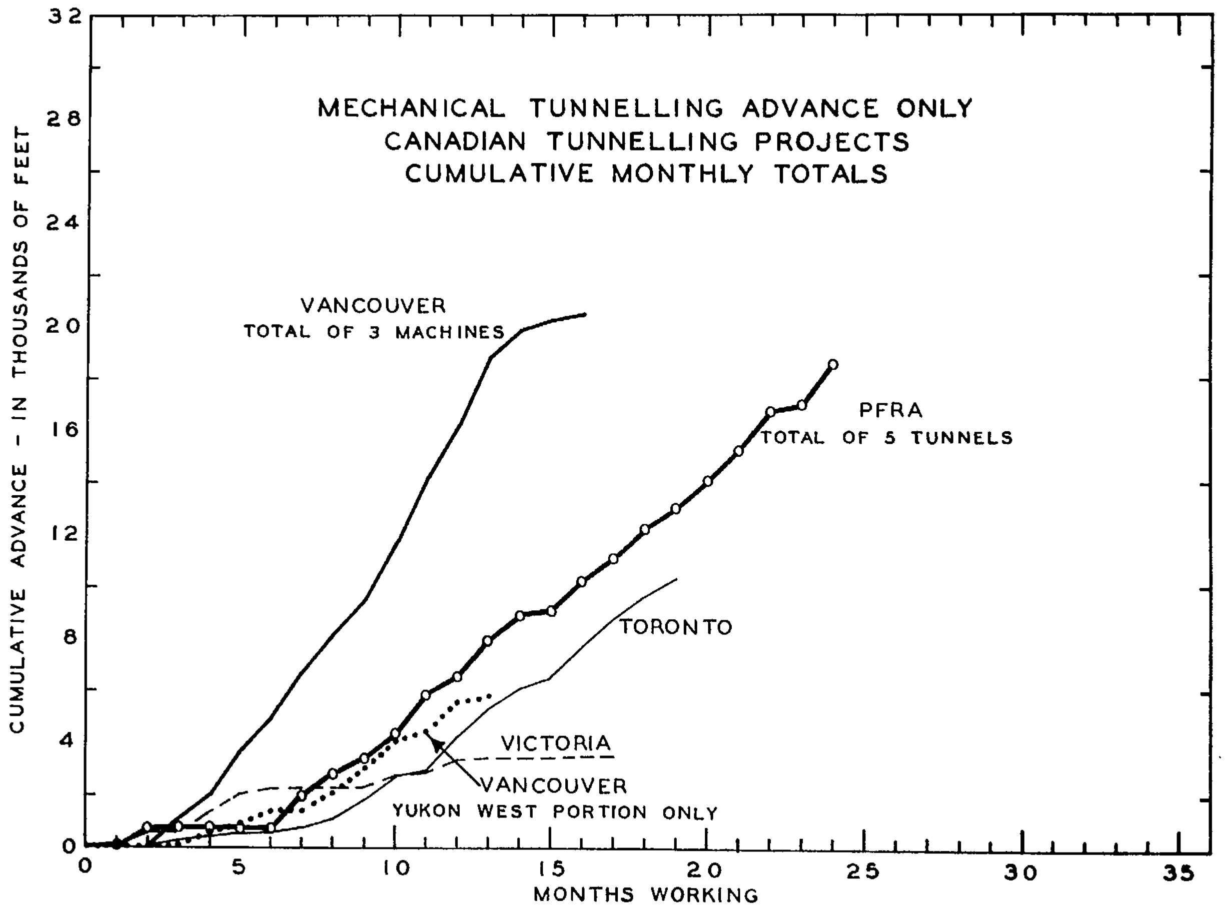
MECHANICAL TUNNELLING ADVANCE ONLY
CANADIAN TUNNELLING PROJECTS
CUMULATIVE MONTHLY TOTALS
VANCOUVER
TOTAL OF 3 MACHINES
PFRA
TOTAL OF 5 TUNNELS
TORONTO
VICTORIA
VANCOUVER
YUKON WEST PORTION ONLY
CUMULATIVE ADVANCE - IN THOUSANDS OF FEET
MONTHS WORKING
0
4
8
12
16
20
24
28
32
0
5
10
15
20
25
30
35

Figure 1

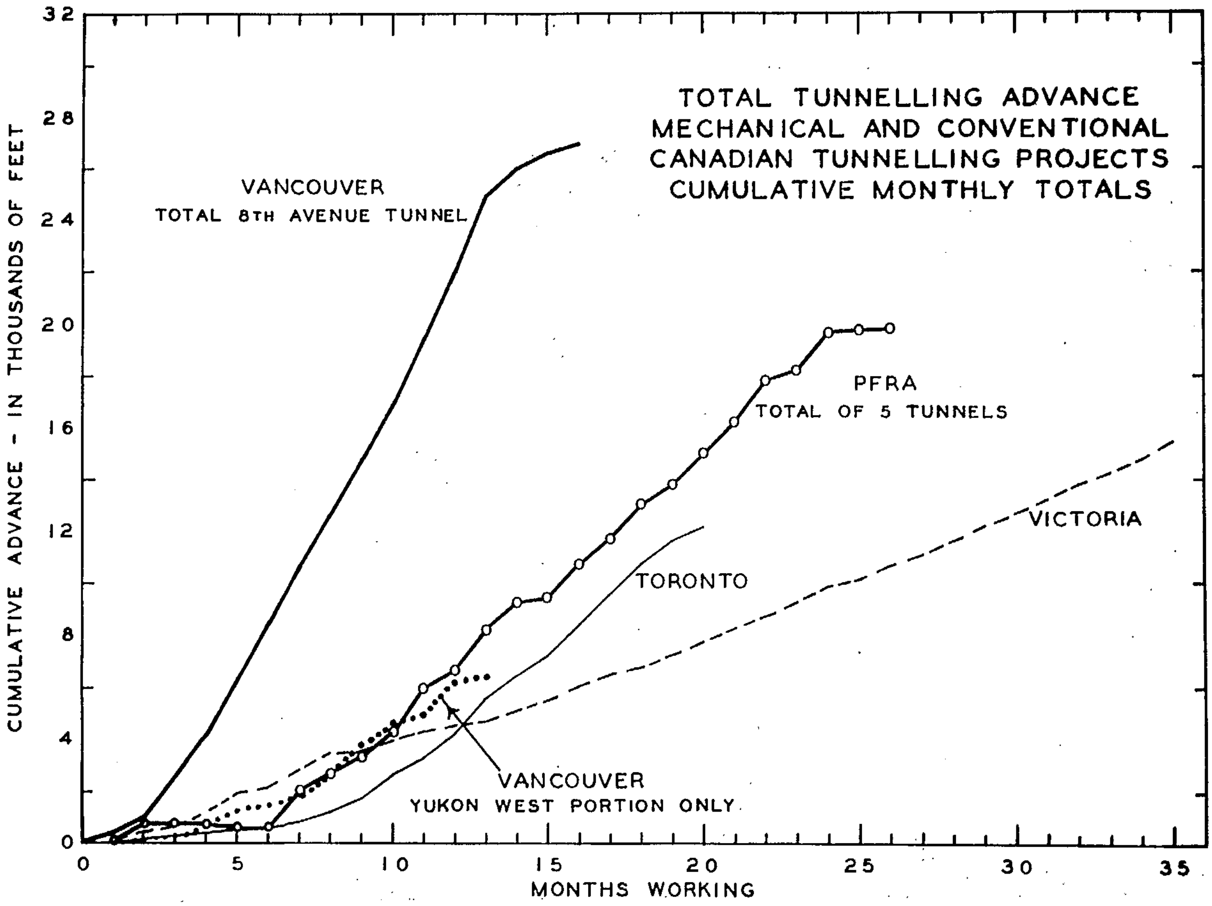
TOTAL TUNNELLING ADVANCE
MECHANICAL AND CONVENTIONAL
CANADIAN TUNNELLING PROJECTS
CUMULATIVE MONTHLY TOTALS
VANCOUVER
TOTAL 8TH AVENUE TUNNEL
PFRA
TOTAL OF 5 TUNNELS
VICTORIA
TORONTO
VANCOUVER
YUKON WEST PORTION ONLY
CUMULATIVE ADVANCE - IN THOUSANDS OF FEET
MONTHS WORKING
0
4
8
12
16
20
24
28
32
0
5
10
15
20
25
30
35

Figure 2

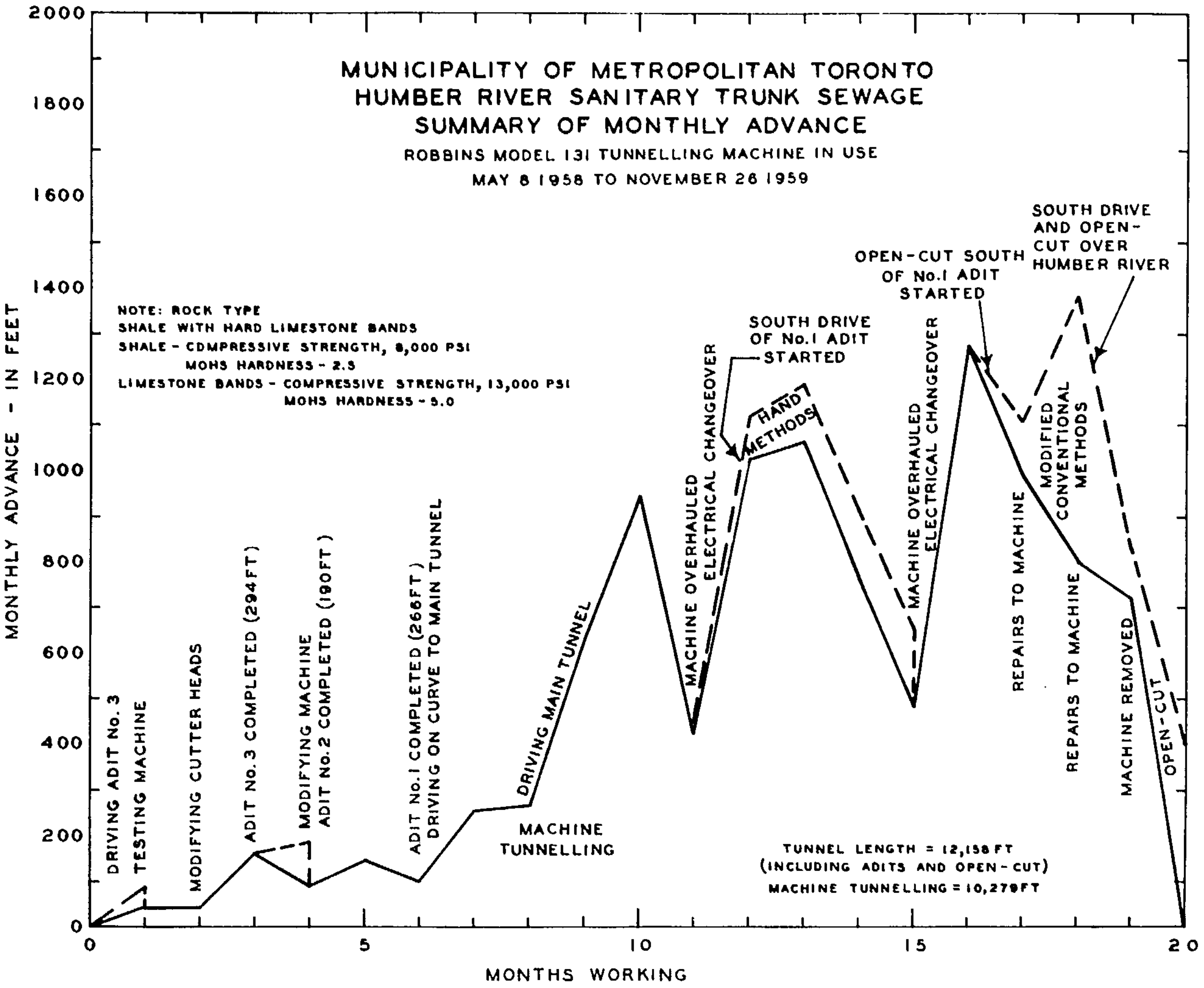
MUNICIPALITY OF METROPOLITAN TORONTO
HUMBER RIVER SANITARY TRUNK SEWAGE
SUMMARY OF MONTHLY ADVANCE
ROBBINS MODEL 131 TUNNELLING MACHINE IN USE
MAY 8 1958 TO NOVEMBER 26 1959
NOTE: ROCK TYPE
SHALE WITH HARD LIMESTONE BANDS
SHALE - COMPRESSIVE STRENGTH, 8,000 PSI
MOHS HARDNESS - 2.5
LIMESTONE BANDS - COMPRESSIVE STRENGTH, 13,000 PSI
MOHS HARDNESS - 5.0
MONTHLY ADVANCE - IN FEET
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
MONTHS WORKING
DRIVING ADIT No. 3
TESTING MACHINE
MODIFYING CUTTER HEADS
ADIT No. 3 COMPLETED (294 FT)
MODIFYING MACHINE
ADIT No. 2 COMPLETED (190 FT)
ADIT No. 1 COMPLETED (266 FT)
DRIVING ON CURVE TO MAIN TUNNEL
DRIVING MAIN TUNNEL
MACHINE TUNNELLING
MACHINE OVERHAULED
ELECTRICAL CHANGEOVER
SOUTH DRIVE OF No. 1 ADIT STARTED
HAND METHODS
MACHINE OVERHAULED
ELECTRICAL CHANGEOVER
OPEN-CUT SOUTH OF No. 1 ADIT STARTED
SOUTH DRIVE AND OPEN-CUT OVER HUMBER RIVER
REPAIRS TO MACHINE
MODIFIED CONVENTIONAL METHODS
REPAIRS TO MACHINE
MACHINE REMOVED
OPEN-CUT
TUNNEL LENGTH = 12,158 FT
(INCLUDING ADITS AND OPEN-CUT)
MACHINE TUNNELLING = 10,279 FT

Figure 3

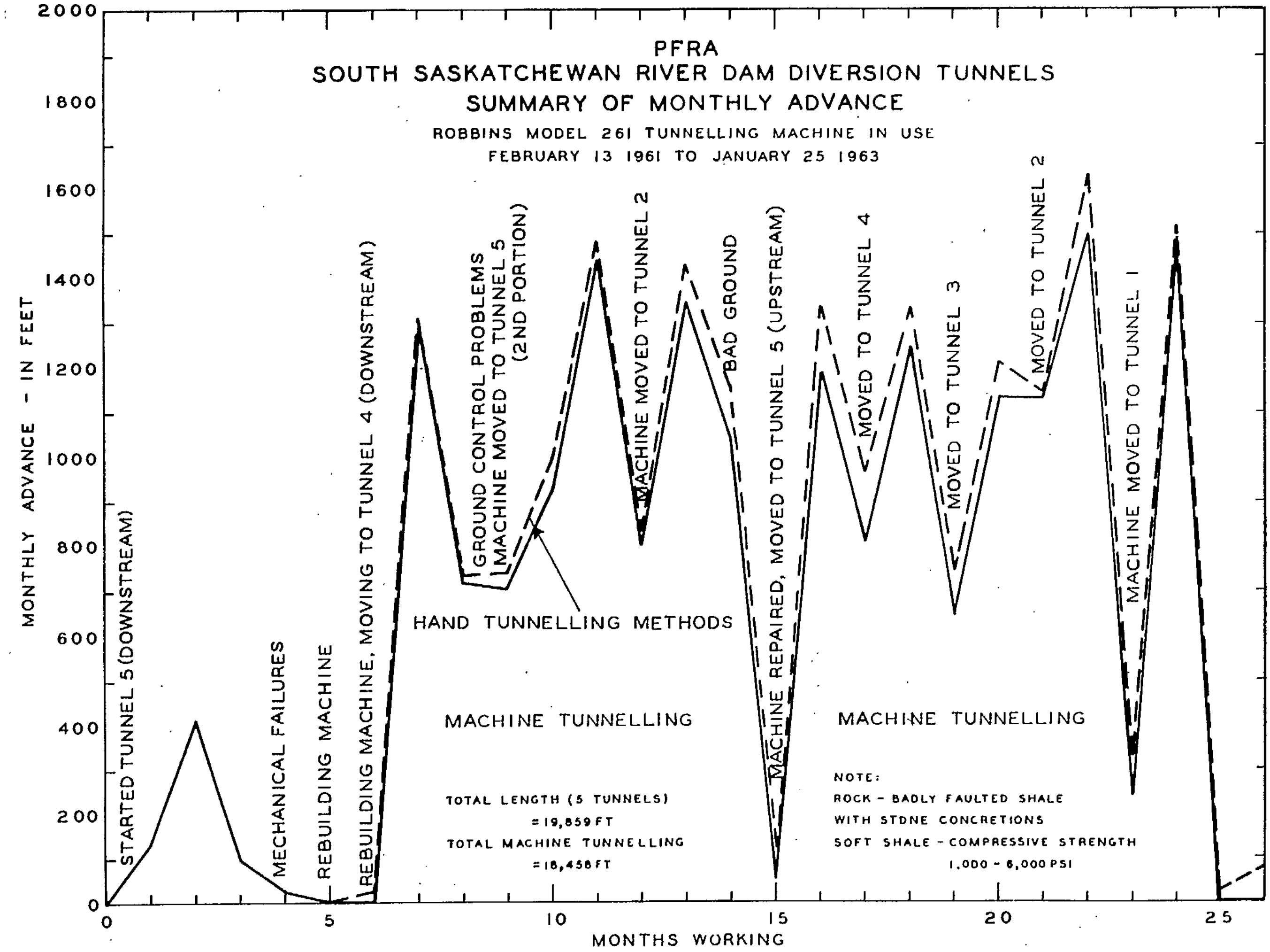
PFRA
SOUTH SASKATCHEWAN RIVER DAM DIVERSION TUNNELS
SUMMARY OF MONTHLY ADVANCE
ROBBINS MODEL 261 TUNNELLING MACHINE IN USE
FEBRUARY 13 1961 TO JANUARY 25 1963
MONTHLY ADVANCE - IN FEET
0
200
400
600
800
1000
1200
1400
1600
1800
2000
MONTHS WORKING
0
5
10
15
20
25
STARTED TUNNEL 5 (DOWNSTREAM)
MECHANICAL FAILURES
REBUILDING MACHINE
REBUILDING MACHINE, MOVING TO TUNNEL 4 (DOWNSTREAM)
GROUND CONTROL PROBLEMS
MACHINE MOVED TO TUNNEL 5
(2ND PORTION)
HAND TUNNELLING METHODS
MACHINE MOVED TO TUNNEL 2
BAD GROUND
MACHINE REPAIRED, MOVED TO TUNNEL 5 (UPSTREAM)
MOVED TO TUNNEL 4
MOVED TO TUNNEL 3
MOVED TO TUNNEL 2
MACHINE MOVED TO TUNNEL 1
MACHINE TUNNELLING
MACHINE TUNNELLING
TOTAL LENGTH (5 TUNNELS)
= 19,859 FT
TOTAL MACHINE TUNNELLING
= 18,458 FT
NOTE:
ROCK - BADLY FAULTED SHALE
WITH STONE CONCRETIONS
SOFT SHALE - COMPRESSIVE STRENGTH
1,000 - 6,000 PSI

Figure 4

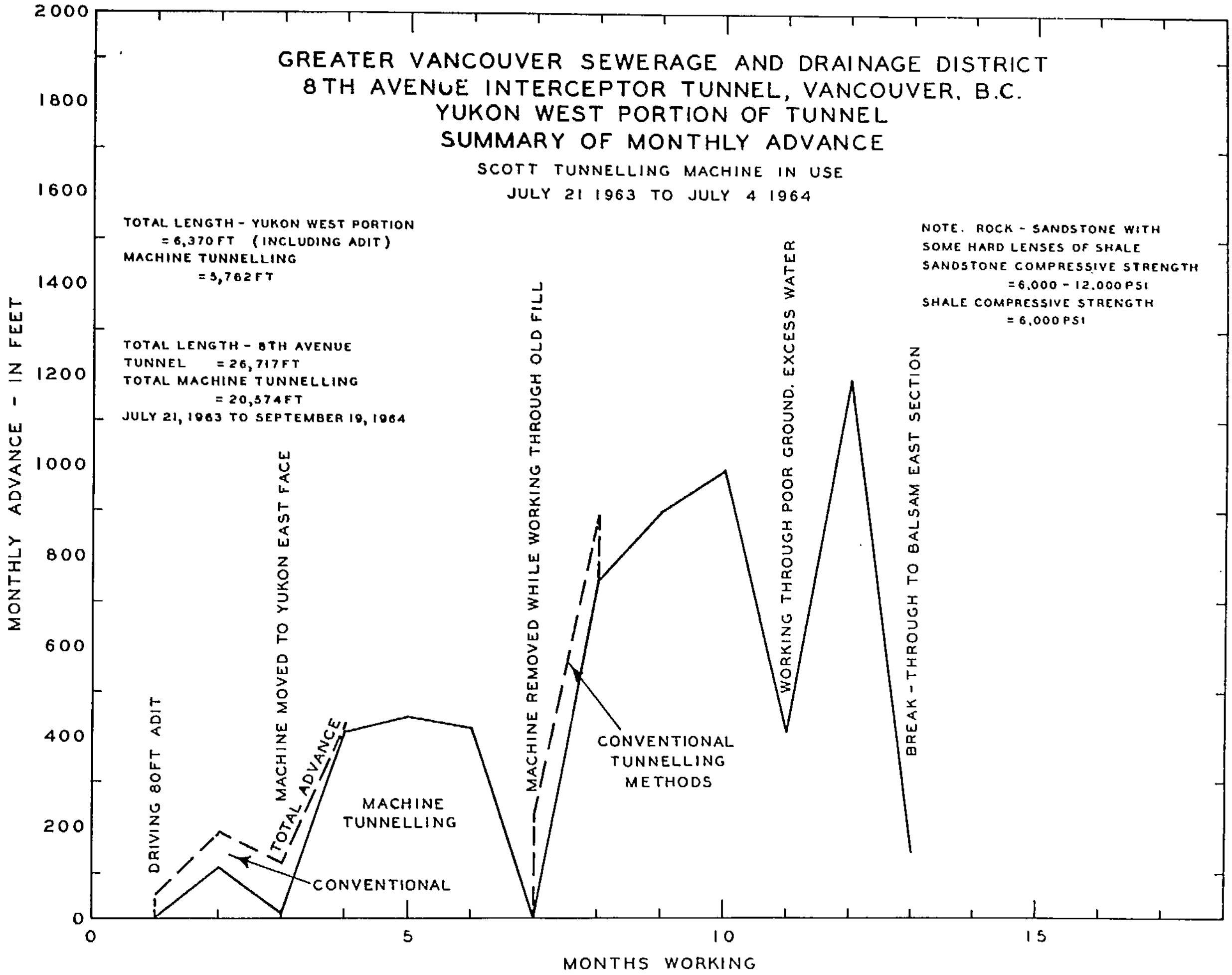
GREATER VANCOUVER SEWERAGE AND DRAINAGE DISTRICT
8TH AVENUE INTERCEPTOR TUNNEL, VANCOUVER, B.C.
YUKON WEST PORTION OF TUNNEL
SUMMARY OF MONTHLY ADVANCE
SCOTT TUNNELLING MACHINE IN USE
JULY 21 1963 TO JULY 4 1964
TOTAL LENGTH - YUKON WEST PORTION
= 6,370 FT (INCLUDING ADIT)
MACHINE TUNNELLING
= 5,762 FT
TOTAL LENGTH - 8TH AVENUE
TUNNEL = 26,717 FT
TOTAL MACHINE TUNNELLING
= 20,574 FT
JULY 21, 1963 TO SEPTEMBER 19, 1964
NOTE. ROCK - SANDSTONE WITH
SOME HARD LENSES OF SHALE
SANDSTONE COMPRESSIVE STRENGTH
= 6,000 - 12,000 PSI
SHALE COMPRESSIVE STRENGTH
= 6,000 PSI
DRIVING 80FT ADIT
MACHINE MOVED TO YUKON EAST FACE
TOTAL ADVANCE
CONVENTIONAL
MACHINE TUNNELLING
MACHINE REMOVED WHILE WORKING THROUGH OLD FILL
CONVENTIONAL TUNNELLING METHODS
WORKING THROUGH POOR GROUND. EXCESS WATER
BREAK-THROUGH TO BALSAM EAST SECTION
MONTHLY ADVANCE - IN FEET
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
MONTHS WORKING

Figure 5

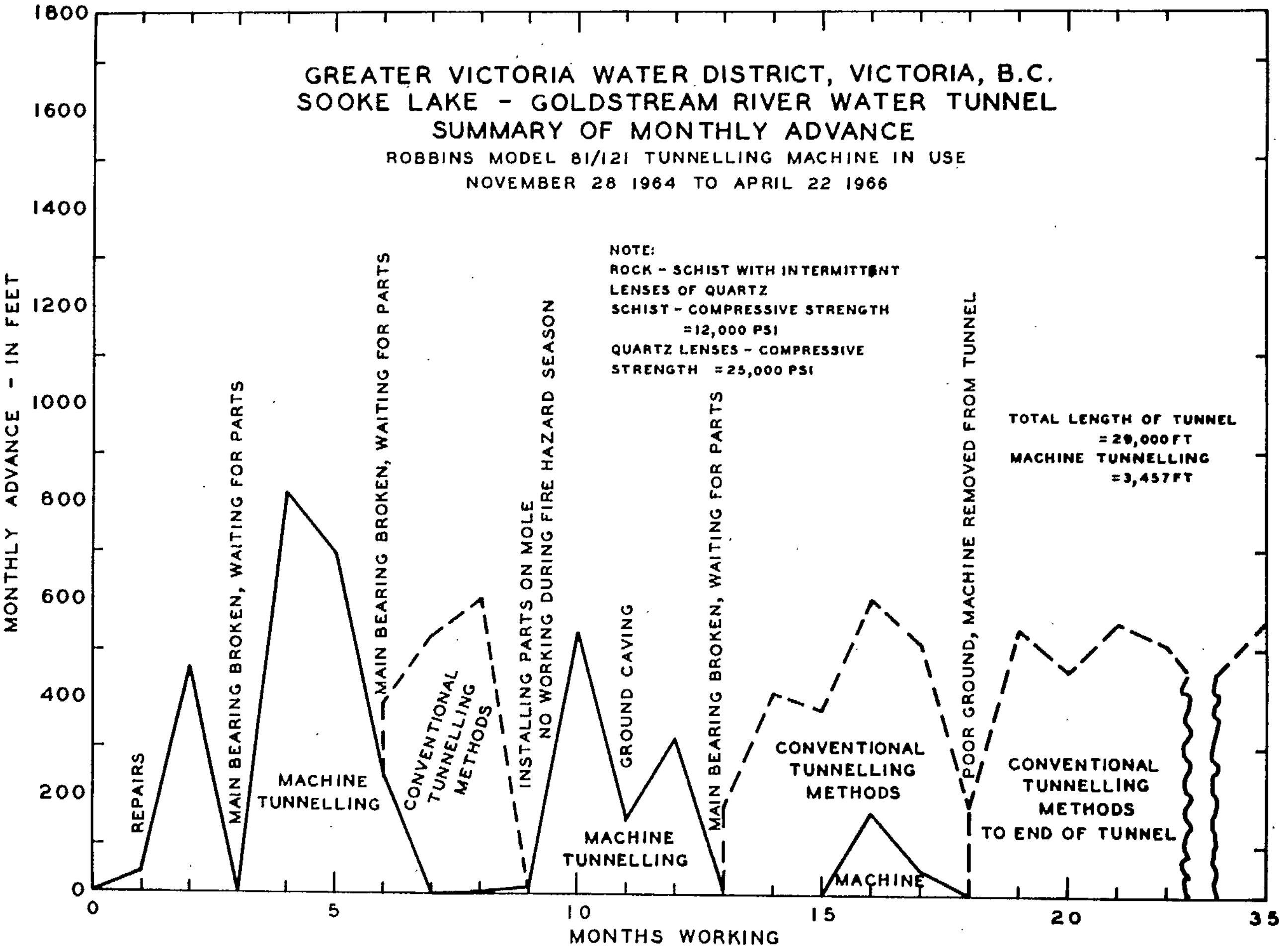
GREATER VICTORIA WATER DISTRICT, VICTORIA, B.C.
SOOKE LAKE - GOLDSTREAM RIVER WATER TUNNEL
SUMMARY OF MONTHLY ADVANCE
ROBBINS MODEL 81/121 TUNNELLING MACHINE IN USE
NOVEMBER 28 1964 TO APRIL 22 1966
NOTE:
ROCK - SCHIST WITH INTERMITTENT LENSES OF QUARTZ
SCHIST - COMPRESSIVE STRENGTH =12,000 PSI
QUARTZ LENSES - COMPRESSIVE STRENGTH =25,000 PSI
TOTAL LENGTH OF TUNNEL =29,000 FT
MACHINE TUNNELLING =3,457 FT
MONTHLY ADVANCE - IN FEET
MONTHS WORKING
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
35
REPAIRS
MAIN BEARING BROKEN, WAITING FOR PARTS
MACHINE TUNNELLING
MAIN BEARING BROKEN, WAITING FOR PARTS
CONVENTIONAL TUNNELLING METHODS
INSTALLING PARTS ON MOLE
NO WORKING DURING FIRE HAZARD SEASON
GROUND CAVING
MACHINE TUNNELLING
MAIN BEARING BROKEN, WAITING FOR PARTS
CONVENTIONAL TUNNELLING METHODS
MACHINE
POOR GROUND, MACHINE REMOVED FROM TUNNEL
CONVENTIONAL TUNNELLING METHODS TO END OF TUNNEL

Figure 6

CHAPTER 2

Municipality of Metropolitan Toronto
Humber River Sanitary Trunk Sewer

Introduction

In August 1957, the Municipality of Metropolitan Toronto awarded a contract to the Foundation Company of Canada to construct a concrete-lined tunnel, some 11,500 ft in length. This tunnel, known as the Humber River Tunnel, was a portion of a sewage drainage system being constructed to service a large area of western Metropolitan Toronto. An anticipated population of 800,000 people would be serviced by this sewer system. The trunk sewer route was to parallel the main course of the Humber River from north of Dundas Street to the Humber sewerage treatment plant near the mouth of the river at Lake Ontario. The completed sewer was to be concrete-lined, with a finished diameter of 8'9". The concrete lining was to be one foot thick with a minimum of 3,500 pounds per square inch (psi) compressive strength.

The southern extremity of the tunnel was about 20 ft below the surface and continued northerly under residential streets on the west side of the Humber River for about 1½ miles, then passed under a bend in the Humber River and tracks of the Canadian Pacific Railway, ending at a drop manhole at the southwest corner of the Lambton Golf Club, where it joined the Black Creek and Etobicoke trunk sewers. The tunnel alignment generally followed the street allowances in order to minimize the procurement of easements under private property. Alignment holes 10 in. in diameter were bored from surface, varying in depth from 20 to 100 ft and spaced from 500 to 900 ft apart. These holes were also used, during concreting operations, as a means of dropping concrete into the tunnel for placing behind the steel forms used to mold the walls of the tunnel. Because of the inconvenience to residential areas above the tunnel and possible claims for vibration and blast damage, which usually follow the conventional drilling and blasting method of driving tunnels, it was specified in the contract that the rock excavation had to be carried out without the use of explosives.

The Metropolitan engineers were able to take advantage of the natural topography of the area to provide access to the tunnel by means of three horizontal adits, driven from the west bank of the Humber River. This eliminated the need for sinking shafts, which because of the noise and clutter associated with them are objectionable to the general public in a residential area. The adits also provided a ready access for the disposal of the waste, or spoil, resulting from the tunnelling operation. The spoil was dumped at convenient spots along the Humber River Valley and helped to repair floodwater damages caused along the valley by Hurricane Hazel in October 1954.

The rock formation through which the tunnel ran was composed of shale with limestone bands of varying degrees of hardness, in layers from 1/4 in. to 24 in. in thickness. There were two main types of rock. The first was a fine-grained argillaceous soft shale of even texture with a Mohs scale of hardness up to 2.5 and a compressive strength of 8,000 psi. The second was a siliceous limestone, high in calcium carbonate, forming a heterogeneous mass of varying coarse grains, with a hardness up to 5.0 and a maximum compressive strength of 13,000 psi. The silica content of the rock was 57.8% total silica and 33.3% free silica. The rock cover over the tunnel varied from 10 to a maximum of 70 ft with a silty grey sand cover, or overburden, of from 10 ft to 30 ft. Ground water was not a problem in the tunnel as most of the tunnel walls were only slightly damp after being exposed for many months.

The Foundation Company of Canada decided to use a mechanical tunnelling machine in order to carry out the terms of the contract. James S. Robbins & Associates of Seattle, Washington, was engaged to design and build a tunnelling machine capable of carrying out the work in accordance with contract requirements. The engineering and design were started early in October 1957, and the assembly of the machine was carried out at the Dorr-Oliver-Long plant in Orillia, Ontario, commencing early in January 1958. The machine was delivered to the portal of Adit No. 3 on May 8, 1958.

The tunnelling machine, named the "Foundation Humber", was designed to bore a hole 10'9" in diameter and had an overall length of 29'4" and a total weight of 65 tons. The model number allocated to it by the Robbins Co. was Model 131. The cutting head weighed 15 tons, was 10'9" in diameter, and on it were mounted three tricone disc cutters, two intermediate cutters, fourteen 10-in. disc cutters and three gauge disc cutters, with removable buckets on the periphery to catch the rock removed by the cutting head. The machine was supported at the front end by a two-foot-wide fixed shield, located back of the cutters, which had the same circular section as the tunnel but with a section of the shield omitted at the top to allow access to the tunnel face. The rear end was supported by a hydraulically operated shoe which also controlled the grade of travel of the machine. Two large curved shoes mounted at the rear on each side were operated hydraulically to grip the tunnel walls and prevent the machine from slipping back when pressure was applied to the cutting face. These shoes could exert a pressure of up to 160 tons each and could be operated individually. Steering of the machine was also controlled by the differential operation of these shoes. The maximum movement of the machine at each setting of the gripper shoes was 24 in. or the stroke of the 10-in.-diameter propulsion cylinder. The operator station, with electrical and hydraulic controls grouped on one panel, was located at the right and to the rear of the machine. The overall electric power supply was 4160 v, 3 phase, 60 cycles carried by a trailer cable from a starter located at the portal of the tunnel. This supplied power for the two 200-hp motor generator sets mounted on the machine which provided 300-v, 3-phase, 120-cycle current for the drive, hydraulic pump and conveyor motors.

As the machine bored ahead, the broken rock from the cutters was scooped off the invert by the four buckets mounted on the periphery of the cutting head and discharged on to a conveyor belt located on the top of the machine, which in turn deposited it on a 92-ft-long trailing elevated conveyor. This conveyor, coupled to the rear of the boring machine, was mounted on a travelling frame large enough to straddle the 3-cu-yd side-dump mine cars used for disposal of the rock. The 4160-v cable supplying power to the boring machine was mounted on the side of the trailer conveyor. For ease in negotiating the various curves encountered in the tunnel, the conveyor was made in four sections each 23 ft long and the frame ran on a special track erected on either side of the main haulage track. The main track was 24-in. gauge and made of 40-lb rails.

The conveyor belt system (24 in. wide) carried the rock over the machine and emptied the waste material into a train of 8 to 10 cars. The train of cars was hauled through the adits to disposal areas by a six-ton battery locomotive.

The load carried by an 8-car train represented approximately four ft of tunnel advance and during its absence the boring machine was backed up for inspection and, if necessary, replacement of the disc cutters. This interval also allowed for mechanical maintenance, installation of additional ventilation pipe, and checking of the tunnel line and grade.

Boring operations presented problems that may not be encountered in a more conventional drilling and blasting method. One of these was the high dust hazard in the tunnel, caused by the dry operation of the boring machine. The worst dust condition was at the face, but the five conveyor-belt discharge points and the final discharge point into the cars also created additional dust problems. The original ventilation system installed proved totally inadequate, giving dangerously high dust counts, and the whole system was revamped while the electrical changeover was being made for the tunnel driving from Adit No. 2. The main exhaust duct was enlarged to 20-in. pipe with airtight connections and multi-stage axial flow fans of 8,000 cfm capacity were placed in the line at intervals of 1,000 to 1,200 lineal ft.

The ground conditions encountered while driving the main tunnel were generally good, and extensive ground support was not necessary. Very slow progress while driving the three adits, however, made it necessary to provide roof support over the machine in the adits. Ribs and liner plates were used but were found difficult to place and slow to construct. The faster progress made in the main tunnel permitted the placing of the roof reinforcing to follow behind the rear of the trailing conveyor. Here, a lattice work of heavy expanded metal mesh, in 4' x 12' sheets, was held tightly against the roof by four roof bolts with plate washers and spaced longitudinally at 3'6" centres.

Operation and Progress of the Tunnel

The early history of the tunnel was that of slow progress with many delays while the machine was modified to meet operating conditions. The Robbins boring machine was brought to the portal of Adit No. 3 on May 8, 1958, but this in itself was two months behind the original delivery date. The period of driving Adit No. 3 from May 20 to July 28, 1958, was taken up mainly with testing the machine and adjusting, modifying and replacing the cutterhead rollers and cutters. Trouble was also experienced through pump failures and a broken shaft on the drive motor. Only 250 ft of adit had been driven by the mole (tunnelling machine) by the end of July. No. 3 Adit was stopped on July 28, leaving a 5-foot pillar between the bottom of the adit and the main tunnel. Modifications were made to the boring machine and it was moved to Adit No. 2 and commenced boring there on August 13, some four months behind schedule. Driving of Adit No. 2 progressed more rapidly but further repairs were needed to the generator and main motor. Driving of Adit No. 2 was completed by September 2. The machine was removed and commenced boring Adit No. 1 on September 12. Driving of Adit No. 1 proceeded around a 115-ft radius curve during September and October. The machine had to be stopped every 3 ft and jacked into position each time while going around the curve, and hand excavation of the material became necessary. Repairs were required to the hydraulic pistons on the machine during October.

The main tunnel location was reached on November 4 but a further 80 ft of tunnelling was required before the end of the curve was reached. The driving of the three adits required six months for a total distance of only 750 lineal ft actually bored.

Once a drilling started on the main tunnel, progress gradually increased and rose from an average daily advance of 23 ft per day at the south end to 45 ft per day at the north end. While the tunnel was being drilled between Adit No. 1 and No. 2, the excavated material was taken out through Adit No. 1. Similarly, as the tunnel passed each adit the pillar left at the bottom of each adit was broken through and the muck was then diverted through that adit, thus lessening the haul distance and also freeing the completed tunnel section for the placing of the concrete lining. The track and electric cable were removed from the Main Adit No. 1 when the mole passed Adit No. 2, and the electric cable and track were then fed through Adit No. 2. The process was repeated when the mole passed Adit No. 3.

The cutterheads on the tunnelling machine were redesigned or modified several times. Trouble developed in the tricone rollers, outer gauge cutters, and intermediate rollers. These were straightened, repaired, and overhauled in a machine shop. Then the tricone cutters split and some smaller cutters and rollers came apart. Early in July 1958, new types of bits and cutters, using manganese steel alloys, were installed. In December 1958, the cutterhead design was modified to be more conical, with the cutters spiralling outwards from the centre of the cutting face of the machine and six additional disc cutters replaced the three gauge cutters. A later design resulted in star cutters being used instead of cone cutters in the centre portion. In advance of each disc cutter, a fixed tungsten-carbide bit cutter was installed on blocks welded to the face (these were later eliminated entirely). Cutters wore down rapidly when running through hard limestone bands, but the final modified cutterhead gave much better advance during the latter part of 1959.

In February 1959, driving of the tunnel south of Adit No. 1 commenced. This section was to link up with the main sewer system running south to the sewage treatment plant near the mouth of the river at Lake Ontario. The rock cover was inadequate (at the extreme south end of the contract the rock cover was minus 3 ft) and the boring machine could not be used; hence a section of some 1,530 ft was hand-excavated. Driving of this section of tunnel by hand methods was originally done by employing pavement-breaker machines to break up the rock, assisted by hand wedges to pry the rock loose. The advance was only at the rate of about 1½ ft per day using this method. However, a new method was devised whereby a coal-cutter machine cut a 6-in.-wide kerf cut in the rock face and a total of nine 6-ft holes were drilled below the kerf cut and four 6-ft holes above the kerf cut at the face. The four top holes were loaded with 2½ sticks of powder and four of the bottom holes were loaded with two sticks of powder, using Gelex No. 2 (Dupont) 70% explosive. The concussion from the blast was light and as the location of this portion of the tunnel was away from residential areas the contract was revised to permit this method to be used. The new method increased the advance to 6 ft per day. The driving of the south heading continued simultaneously with the tunnelling machine which was working on the north end of the sewer project. Concreting and grouting of the adits and completed sections of the tunnel were also underway in April 1959, while the boring machine continued on the north section.

Before crossing under the Humber River where the rock cover was only 3 to 4 feet of weathered shale, a reinforced-concrete culvert, 400 feet long (large enough to permit passage of the boring machine), was constructed.

This was accomplished by building an earth cofferdam to divert the river, excavating the rock by open cut, and building the culvert in the dry. A large manhole was incorporated into the north end of this culvert to enable the muck to be removed from the northerly 700-foot portion of the tunnel, and also to enable the machine to be removed intact without dismantling on backing it up to No. 3 adit.

The tunnelling machine completed its portion of the contract on November 26, 1959. The total distance bored by the machine was approximately 10,200 ft. The average advance for the major tunnel was 11 ft per shift or 33 ft per day, taking into account the time required for preventative maintenance, repairs, and modification. Actual operating time was 26 per cent of the available work time. Based on actual operating time, the average advance was 5 ft per hour or 1 in. per minute.

Summary of Operations

The following data (Table 7 et seq.) were compiled from a report prepared at the time by G.A. White, district superintendent of the Foundation Company of Canada, at Toronto.

1. PERFORMANCE DATA

TABLE 7

Dates Driven	Advance (feet)	Shifts Worked	Lineal ft per shift	Average ft advance per day
Adit No. 3	Adits			
May 20, 1958 - July 28, 1958	294 (5 ft of pillar left)	n.a.	-	-
Adit No. 2				
Aug. 6, 1958 - Sept. 2, 1958	190 (5 ft of pillar left)	n.a.	-	-
Adit No. 1				
Sept. 1, 1958 - Oct. 31, 1958	266	n.a.	-	-
	750 (10 ft of pillar left)	290	2.6	7.8

- cont'd

Table 7, concluded

Dates Driven	Advance (feet)	Shifts Worked	Lineal ft per shift	Average ft advance per day
	Main Tunnel			
Driving between Adits No. 1 and No. 2				
Nov. 1, 1958 - Nov. 29, 1958	232	75	3.2	-
Dec. 1, 1958 - Dec. 31, 1958	338	66	5.1	-
Jan. 2, 1959 - Jan. 31, 1959	587	75	7.8	-
Feb. 1, 1959 - Feb. 28, 1959	847	72	11.1	-
Mar. 1, 1959 - Mar. 10, 1959	434	24	18.0	-
	2,438	312	7.8	23.4
Repairs and Electrical Changeover at Adit No. 2				
Mar. 11, 1959 - Apr.11, 1959	-	18	-	-
Driving Between Adits No. 2 and No. 3				
Apr. 12, 1959 - Apr. 30, 1959	1,097	75	14.6	-
May 1, 1959 - May 31, 1959	1,031	78	13.2	-
June 1, 1959 - June 30, 1959	806	78	10.3	-
July 1, 1959 - July 17, 1959	456	42	10.8	-
	3,390	273	12.5	37.5
Repairs and Electrical Changeover at Adit No. 3				
July 18, 1959 - Aug. 3, 1959	-	16	-	-
Driving Between Adit No. 3 and the Humber River				
Aug. 4, 1959 - Aug. 31, 1959	1,215	69	17.6	-
Sept. 1, 1959 - Sept. 30, 1959	1,051	75	14.5	-
Oct. 1, 1959 - Oct. 26, 1959	653	63	10.3	-
	2,909	207	14.1	42.3
Repairs and Open-cut Excavation				
Oct. 27, 1959 - Nov. 2, 1959	-	12	-	-
Humber River to end of Contract				
Nov. 3, 1959 - Nov. 19, 1959	711	48	14.8	44.4
Total Main Tunnel	9,448	886	10.6	31.8

2. DISTRIBUTION OF TIME

	Adits 1-2-3		Main Tunnel		Whole Job	
	Hours	%	Hours	%	Hours	%
Cutting time	314	14.0	1,855	26.2	2,169	23.2
Maintenance	108	4.7	1,025	14.5	1,133	12.0
Repairs	1,116	49.3	1,902	26.9	3,018	32.4
Installation steel ribs	159	7.0	319	4.5	478	5.1
Surveying	12	0.5	65	0.9	77	0.8
Muck disposal	-	-	674	9.5	674	7.2
Installation vent pipe	-	-	50	0.7	50	0.5
Lunch	-	-	345	4.8	345	3.7
Breaking out rock on curves	382	16.8	216	3.0	598	6.4
Misc. - Transporting machine adit to adit) Scaling rock, waiting on river crossing) Waiting on H.E P.C. approval,) Extending cable)	175	7.7	638	9.0	813	8.7
	2,266	100.0	7,089	100.0	9,355	100.0
Repairs - Sunday	188		202		390	
	2,454		7,291		9,745	

Main Tunnel Only - 9,448 Lin. Ft.	Lineal Feet	Number of Shifts	Advance Per Shift
Advance per cutting hour	4.8	--	--
Advance per shift	9,448.0	886.0	10.6
Advance per day	31.8	3.0	10.6
Best Shift Feb. 9, 1959	36.0	--	--
Best Day Feb. 16, 1959	94.0	3.0	31.3
Best Week Feb. 16-22, 1959	378.0	18.0	21.0
Best Month Aug. 1959	1,269.0	73.0	17.4

3. COSTS*

Capital Costs

Original cost of tunnelling machine, trailing conveyors and starter cubicle, installation of machine, labour on modifications, and engineering services	$189,500

Operating Costs

Excavating costs	996,000	
Roof support	75,000	
		$1,071,000

Cost per lineal foot (machine advance, tunnels, and adits) $= \frac{\$1,071,000}{10,196} = \$105.00$

Cost per cubic yard $= \frac{\$105}{3.4} = \$31.00$

Cost Estimates for Excavating by Drilling and Blasting Methods

Excavating costs	743,400	
Roof support	338,000	
Extra concrete	147,000	
		$1,228,000

Cost per lineal foot (total tunnel advance) $= \frac{\$1,228,000}{11,190} = \$103.00$

Cost per cubic yard $= \frac{\$103}{3.4} = \$30.00$

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* At the request of the Foundation Company of Canada, many cost details shown in the original report have not been included.

4. MANPOWER DATA

Supervision:	1 Superintendent - General 1 Superintendent - Nights 1 Resident engineer 1 Master mechanic 1 Office man 3 Timekeepers 3 Shift foremen
Shift Crew Machine Operations:	1 Operator 1 Mechanic 1 Electrician 1 Conveyor tender
Track & Ventilation Pipe:	2 Miners
Roof Bolting:	2 Miners
Muck Disposal:	1 Locomotive operator 1 Dozer operator
Roving Track Gang:	2 Miners (day shift only)
Survey Party:	1 Instrument man 1 Rodman
Mechanical Crew:	1 Mechanic (day shift only) 1 Electrician 1 Compressor operator
Miscellaneous:	1 Truck driver (day only) 1 Dry House attendant

5. CONTRACT DATA

On July 4, 1959, the equipment and labour in use at the site were as follows: (For Contract D-4-57 only)

Equipment on Site

1 - Pick-up, 3/4 ton truck
1 - Stake truck, 3 ton
5 - Compressors
1 - Bulldozer
4 - Belt conveyors
4 - Battery locomotives
13 - Mine dumping cars
1 - Robbins boring machine
1 - Mucking machine
1 - Pneumatic concrete placer
3 - Air receivers
5 - Air sump pumps
13 - Hand air tools
13 - Airlegs and drifters
1 - Coal cutter
1 - Electric welder
3 - Generators

Labour on Site

1 - Superintendent
1 - Engineer
3 - Shift foreman
1 - Night foreman
3 - Labour foremen
2 - Carpenter foremen
1 - Digger foreman
1 - Mechanical foreman
1 - Master mechanic
7 - Mechanics
3 - Boring-machine operators
3 - Locomotive operators
5 - Compressor operators
3 - Bulldozer operators
4 - Instrument men
4 - Rodmen
1 - Cement finisher
4 - Carpenters
104 - Labourers
3 - Field clerks
7 - Watchmen
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and sub-contractor - C.J. Wilson Ltd.
8 - Electricians

Prices for Contract D-4-57 were as follows:

Item		Approximate Value	
1	Open cut excavation	$97,360	
2	Alignment holes	85,950	(1,202 lineal feet)
3	Tunnel excavation	1,614,900	(12,293 " ")
4	Tunnel concrete	790,000	(11,494 " ")
5	Tunnel grouting	23,385	(6500 bags cement)
6	Tunnel guniting	58,860	(590 lineal feet)
7	Concrete in adit portals and manholes	60,839	(350 cu yds)
	Total contract price	2,731,294	
+	Extra work orders (ground control)	34,254	
		2,765,548	

The original contract called for completion by October 25, 1959. A six-months extension was allowed, however, and the final completion date for the whole contract was May 13, 1960.

James F. MacLaren Associates, 321 Bloor Street East, Toronto 285, Ontario, a firm of consulting engineers, was engaged by Metropolitan Toronto to act as consultant for the Department of Public Works during the Humber River Trunk Sewer project.

Analysis of Operations

Table 8 shows the monthly progress of the Metropolitan Sanitary Trunk Sewer. Very slow progress was made during the first eight months of operations. During this period of time, the crews were becoming familiar with operating the machine, adits were being driven to reach the main tunnel location, and Adit No. 1 was being extended around a curve to reach the straighter section of the main tunnel. A rapid increase in monthly advance may be noted as soon as the main tunnel was reached, being delayed only by the electrical change-overs required as the tunnel progressed northwards past Adits Nos. 2 and 3. The use of hand-mining and open-cut methods while driving south from Adit No. 1 may also be noted, commencing in March, 1959.

TABLE 8

MUNICIPALITY OF METROPOLITAN TORONTO

HUMBER RIVER SANITARY TRUNK SEWER *

MONTHLY SUMMARY OF TUNNEL EXCAVATION

Period Ending	Days Worked	Average Daily Workforce	Total Advance (feet)	Boring Machine		Hand Mining		Concrete Lining (feet)	Remarks
				Days Working	Advance (feet)	Days Working	Advance (feet)		
Year 1958									
May 31	24	38	84	10	40	14	44		Testing machine. Started Adit No. 3.
June 28	24	32	43	5	43	-	-	-	Modifying machine.
July 26	22	36	168	16	168	-	-	-	Repairs. Adit No. 3 completed.
Aug. 30	26	64	172	22	95	n.a.	77	-	Driving Adit No. 2.
Sept. 27	23	78	145	23	145	-	-	-	Driving Adit No. 1.
Oct. 25	22	84	102	22	102	-	-	-	Completed curve, Adit No. 1.
Nov. 29	30	63	257	29	257	-	-	-	Driving main tunnel between
Dec. 27	20	64	265	22	265	-	-	-	Adits Nos. 1 and 2.
8 months	191	50	1236	150	1115	n.a.	121	-	

- cont'd

Table 8, concluded*

Period Ending	Days Worked	Average Daily Workforce	Total Advance (feet)	Boring Machine		Hand Mining		Concrete Lining (feet)	Remarks
				Days Working	Advance (feet)	Days Working	Advance (feet)		
				Year 1959					
Jan. 31	28	67	635	25	635	-	-	-	Driving main tunnel.
Feb. 28	24	73	948	21	948	-	-	-	Driving main tunnel.
Mar. 28	24	77	454	16	424	n.a.	30	40	Repairs and electrical changeover Mar.11-Apr 11.
Apr. 25	24	86	1,120	24	1,055	n.a.	65	100	
May 30	29	104	1,190	28	1,063	n.a.	127	300	Driving between Adits No. 2 and No. 3.
June 27	24	152	915	23	762	n.a.	153	1,201	
July 25	23	163	655	16	483	n.a.	172	443	Repairs and electrical changeover July 18 - Aug. 3. Driving to Humber River.
Aug. 29	29	157	1,275	23	1,275	n.a.	-	1,370	
Sept. 26	23	160	1,112	20	990	n.a.	122	1,138	
Oct. 31	29	170	1,385	17	797	n.a.	588	1,472	Repairs and open-cut excavation Oct. 27 - Nov. 2.
Nov. 28	25	170	833	22	732	n.a.	101	1,488	
Dec. 5	6	111	-	-	-	n.a.	-	1,793	Completing contract.
11 months	288	107	10,522	235	9,164	n.a.	1,358	9,345	
19 months	479	84	11,758	385	10,279	n.a.	1,479	9,345	
			Open-cut Portion (south heading)						
Dec. 31, 1959	18	n.a.	400	-	-	18	400	-	Different contract.

* NOTE: This table was compiled from microfilm records of James T. MacLaren Limited, consulting engineers for the Municipality of Metropolitan Toronto on the Foundation Humber project.

Maintenance of Line and Grade in the Tunnel

Boring around the 115-ft radius curve of the Adit No. 1 extension presented operating difficulties. Because the Joy conveyor was so high, being almost level with the top of the machine, it was impossible to set up a transit surveying instrument any closer than 120 ft from the cutting face. All the control points had to be laid out by means of measuring offsets from the produced chords, while the machine was advancing around the curve. This created a source of cumulative errors. Also, the Robbins machine could not make a curve of less than 475-ft radius. It had to be jacked over after boring only 3 ft when going around curves, and hand chipping of the wall rock was necessary to negotiate the curve. This only occurred at No. 1 Adit. The rest of the job presented no difficulty in so far as curves were concerned. The direction of travel (line), and the inclination from the horizontal (grade) of the machine, also had to be checked constantly. When the rock formation was harder on one side than the other, the machine tended to go towards the side with the softer rock. When the rock was hard on the bottom the machine would rise, and if soft would sink. The line and grade at the head of the machine had to be checked for every two ft of advancement on curves and for every four ft on straight sections of the tunnel.

Ventilation and Dust Control

The Robbins tunnelling machine was designed to operate without water and would not function properly under wet conditions. Water on the tunnel walls reduced the amount of friction between the gripper shoes and the walls, and sometimes caused slippage of the gripper shoes. This condition, however, was seldom encountered. Also, wet conditions caused the waste conveyor system to become plugged. This condition was common after the machine was idle for several shifts. The dry operation of the machine caused high dust concentrations at the working face and the five junction points of the conveyor belt system. The operation of the machine and belts also resulted in heat dissipation which raised the air temperature in the tunnel. Abrasive action of the dust increased wearing action in the machine bearings and various electric motors in use in the tunnel.

Water sprays were tried to reduce the dust and heat. They could not be used because the waste disposal conveyor-belt system would not operate and fog generated in the tunnel reduced visibility and caused high humidity which made working conditions unpleasant.

The original ventilation system used while driving between Adit No. 1 and 2 had a 16-in.-diameter pipe carried up to the rear of the conveyor and a smaller 10-in.-diameter pipe to the cutterhead. This system did not work satisfactorily and was revamped when the electrical changeover was made at Adit No. 2. The main exhaust pipeline was enlarged to a 21-in. duct with air-tight connections and multi-stage axial flow fans of 8,000 cfm capacity were placed in the line at 1,000-ft intervals. The pipeline was kept close to the rear of the conveyor and ended in a Y branch adapter. A 12-in.-diameter pipe, permanently fastened to the top of the travelling conveyor frame, was attached to this adapter by means of a flexible hoseline. At the tunnelling machine, the pipe was joined to a Y adapter from which two 10-in.-diameter ducts were fed up to the face of the machine.

In addition, 6-in. ducts picked up the dust from the various transfer points in the conveyor system and fed it into the 12-in. line. A special hood was provided at the discharge end of the conveyor and fitted with side curtains to cover the tops of the mine cars. An 8-in. flexible hoseline from the hood connected with the adaptor at the end of the 21-in. main line. Nineteen-in.-diameter aerofoil fans were used to exhaust the dusty air. A fan was located outside the adit entrance and other fans were used for every 1,000 lineal ft of pipeline. A 15-in. fan was located at the Joy conveyor.

The results obtained with the revised system were very good, as shown by the following report prepared by the Provincial Department of Health:

Operation	Dust Count (in millions of particles per cu ft of air)		
	3 Mar 59	6 May 59	12 Aug 59
Beside the operator, machine operating	1,370	126	28
Beside the operator, machine not operating	146	9	--
Beside the tracklayer, machine operating	1,240	194	33
Loading mine cars, machine operating	183	15	18
Beside locomotove operator, machine operating	9	10	6

The ventilation system was revamped during the electrical change-over and repairs to the machine at Adit No. 2 between March 11, 1959 and April 11, 1959. Dust counts were taken, using a midget impinger, and counted by the standard procedure.

Ground Control

Difficulties were experienced in providing adequate ground support in the adits during the first stages of the tunnelling operations. Steel ribs, made from 13 lb/ft 4-in. WF "H" beam sections curved to the same radius as the tunnel, were placed around the tunnelling machine at three-ft intervals, with liner plates being bolted to the top third of the rings. These rings were difficult to install and interfered with the operation of the gripper shoes on the machine and with the placing of the conveyor tracks. A modification was made later, with the ribs being used only on the top third of the tunnel and being supported by steel pins set in the rock.

After Adit No. 1 was passed, a new system of ground control was used in the tunnel. Sheets of heavy expanded metal mesh, Pedlar style 3-10-15, and 4x12 ft in area, were held tightly against the roof by means of four expansion-type rock bolts equipped with plate washers. The two centre bolts were 5/8-in. diameter by 6 ft long, the two outer bolts 5/8 in. by 4 ft and the plate washers 3/8 in. thick and 6 in. square. The four bolts were spaced longitudinally at 3'6" centres.

In the south end of the contract, where excavation was by hand-mining or more conventional tunnelling methods, a different system of ground support was used. The roof and walls were supported by 13 lb/ft 4 in. WF circular steel ribs spaced at 3-ft centres. The circular steel ribs purchased for use in supporting the ground in bored section of the tunnel, were modified for use in the tunnel driven by conventional methods. The ribs were cut and welded to make a horseshoe-shaped section. Steel plates, 6x6x3/8 in. in size, were welded to the bottom of the horseshow section and straight legs, four ft in length, were bolted to each side of the horseshoe ribs with 2 3/4-in.-diameter bolts. Three-in. hardwood planking was used for cribbing between the ribs and the roof of the tunnel. Softwood spreaders, 4x4 in., were used to brace the ribs to the tunnel wall.

Conclusions and Recommendations

The main problems faced while using the Robbins tunnelling machine were as follows:

1. The size of the cutting head could not be varied to meet varying operating conditions and the machine itself was too large to be withdrawn through the concreted section of the tunnel without dismantling and removal in sections.

2. The original cutter on the machine had to be completely redesigned and modified on the job. Even when modified, the cutterhead was not suitable for boring in rocks harder than shale or limestone.

3. The machine was not suitable for boring in softer ground, such as clay or sand, because of difficulties in (a) supporting the back of the tunnel, (b) propelling the machine forwards, and (c) maintaining the line and grade of the machine, and because (d) the disc cutters design was not suitable for boring soft rock.

4. The machine could not advance around a curve of less than 475-ft radius unless the walls were first chipped by hand.

5. The machine would not operate in shale rock when a considerable amount of water was present, because of the gumming up of the buckets on the machine and the conveyor pulleys and rollers.

6. There was considerable vibration and noise when the machine bored close to surface, and this was annoying when passing under a residential area.

The Foundation Company of Canada suggested that the Robbins machine would work more effectively if the following modifications were made:

1. Redesign the cutterhead by (a) eliminating the tricone centre cutter as supplied with the machine with a different type of cutter, and/or using a star-type holder with tungsten-carbide bit inserts; (b) improving the method of attaching the disc cutters to the cutter head,

the cutter edges themselves and the bearings and seals used; and (c) correcting the mounting block angle of the intermediate cutters.

2. Redesign the motor generator set or remove it from the machine and place it (a) immediately behind the machine, (b) at a temporary station located behind the machine, or (c) at the tunnel portal near the starter cubicle.

3. The rear support shoe should have the piston enlarged and the type of gripper cups changed.

4. The positioning shoe should have enlarged pistons.

5. The drive motor should be equipped with dirt guards.

6. The hydraulic system should have valves changed to give 5,000 psi pressure.

7. The electrical system should have the rectifiers permanently mounted at the rear of the machine.

The report prepared by G.A. White of the Foundation Company of Canada came to the following conclusions:

1. The Robbins tunnelling machine successfully accomplished the task that it was called upon to perform. The first six months of operations were spent in development work and modifications, and repairs to the machine, and progress was slow. However, as operational problems were solved a steady rate of advance was maintained during the last year of operations.

2. The boring-machine method of tunnelling, in built-up areas, caused less disruption to community life and fewer claims for damages than did the conventional methods of drilling and blasting.

3. The walls of the tunnel were structionally stronger with a cut made by the mechanical boring machine, by comparison with drilling and blasting methods. The rock in the latter system was shattered well beyond the face and required more concrete to fill the overbreak. Considerable grouting of the ground was required in the blasting method, whereas overbreak and grouting with the machine cut were practically nil.

4. When using the mechanical tunnelling machine, in spite of the considerable sum spent on development, repair work, training of crews, development of new mining techniques, and a 100 per cent write-off on the machine, the cost was comparable to that of the drilling and blasting method. It was felt that, if the machine were used again on a similar project, the operating costs could be reduced drastically because of the experience gained in the Foundation Humber operation.

5. The type of mechanical boring machine used in the operation was considered best suited for tunnelling in shale and limestone types of rock where the action of the cutter was crushing rather than cutting of the rock. The harder the type of rock the more power would be required, and under these circumstances the type of cutter used on the Toronto operation would not stand up at all. Considerable experimentation would be required in harder rock types to find the best type of cutters and boring machine design to use.

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G. A. White, District Superintendent

Photographs

The attached photographs, Figures 7 to 16, were supplied through the courtesy of Mr. G. A. White, of the Foundation Company of Canada Limited, Toronto, and the Municipality of Metropolitan Toronto. They illustrate the Robbins Boring Machine, Model 131, and show the location of the tunnel and type of ground encountered.

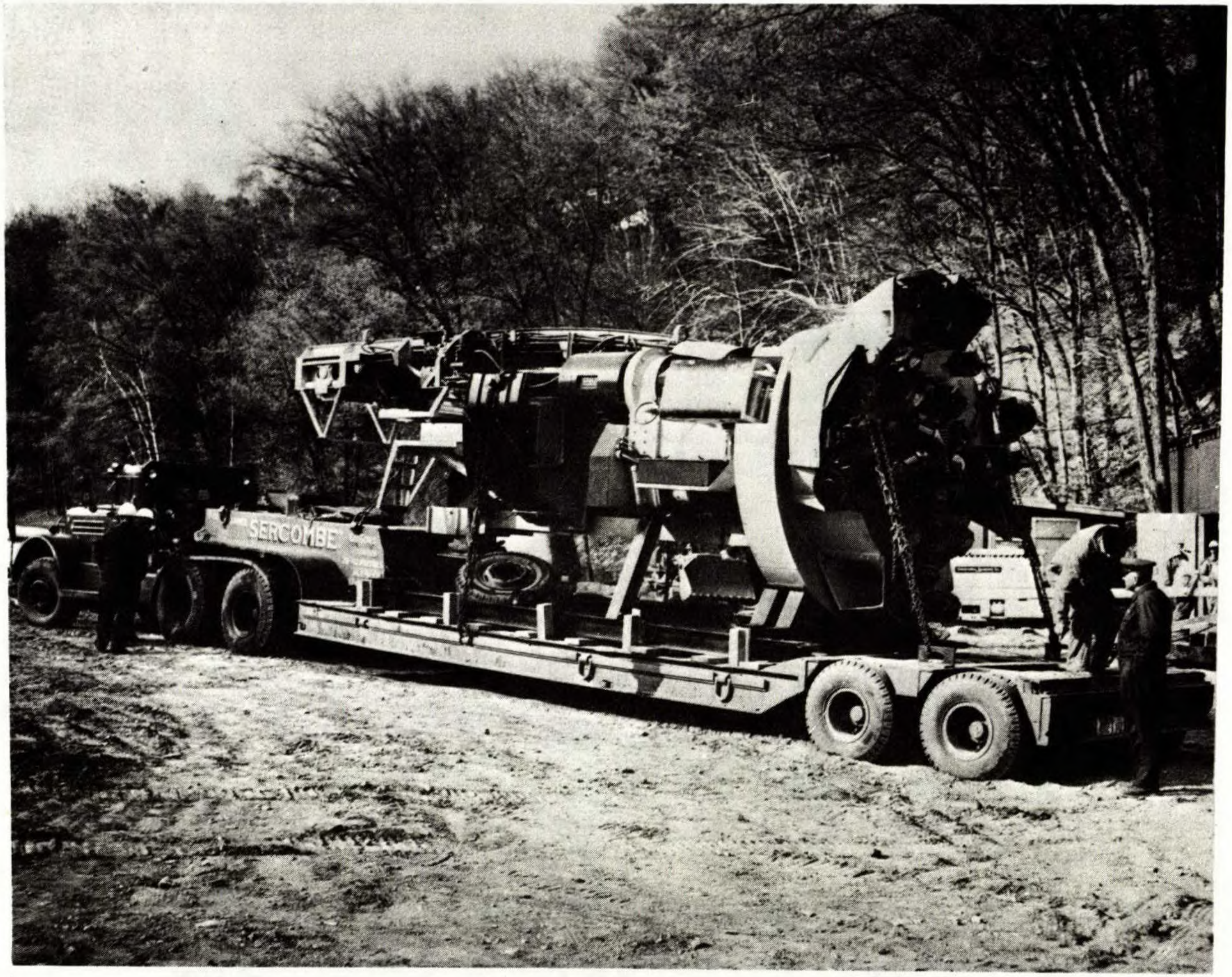

Figure 7. Robbins Boring Machine, Model 131, on arrival at Adit No. 3 site on May 8, 1958.

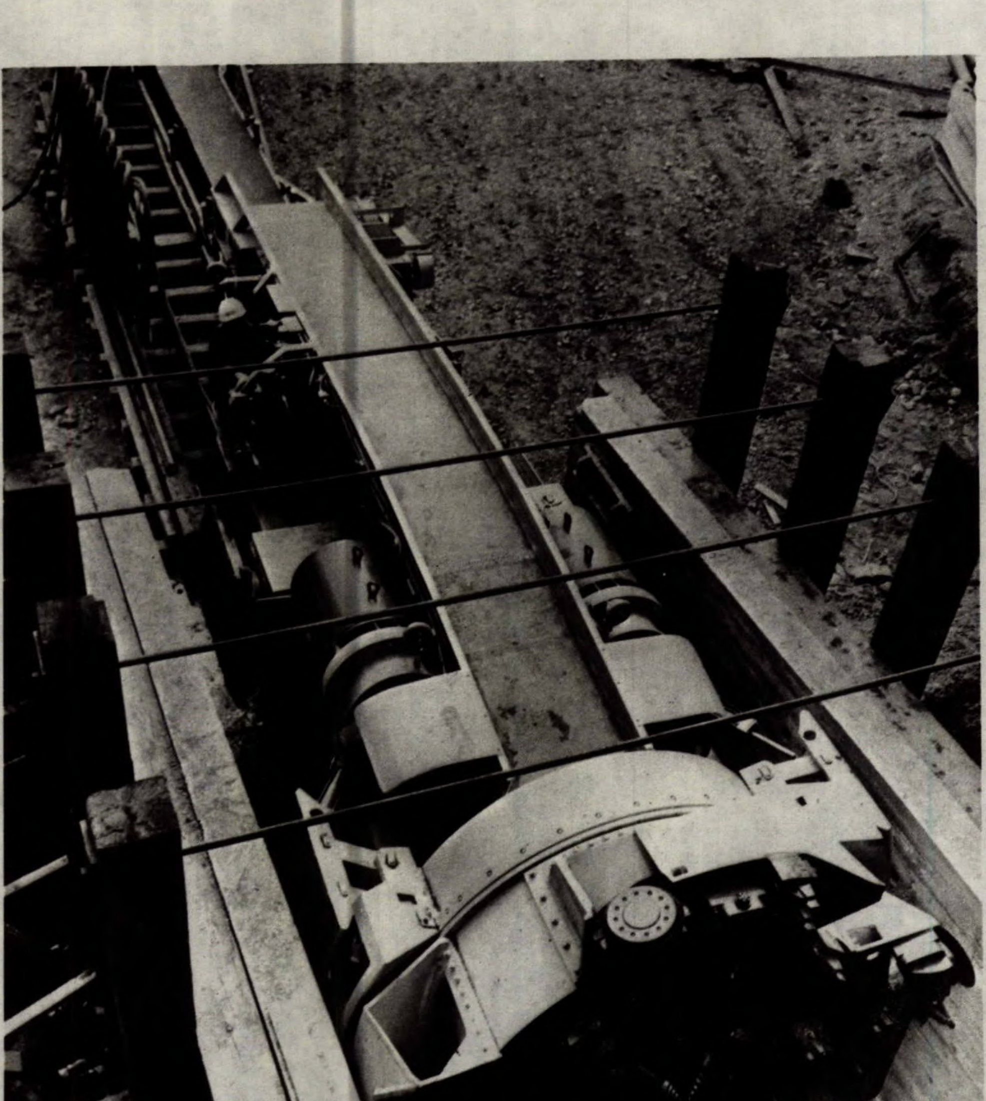

Figure 8. The "Foundation Humber" boring machine in position to begin boring Adit No. 3. Note arrangement for holding mole to start boring operation.

Figure 9. General arrangement of Foundation Humber boring machine with trailing conveyors and muck train in position at commencement of boring operations.

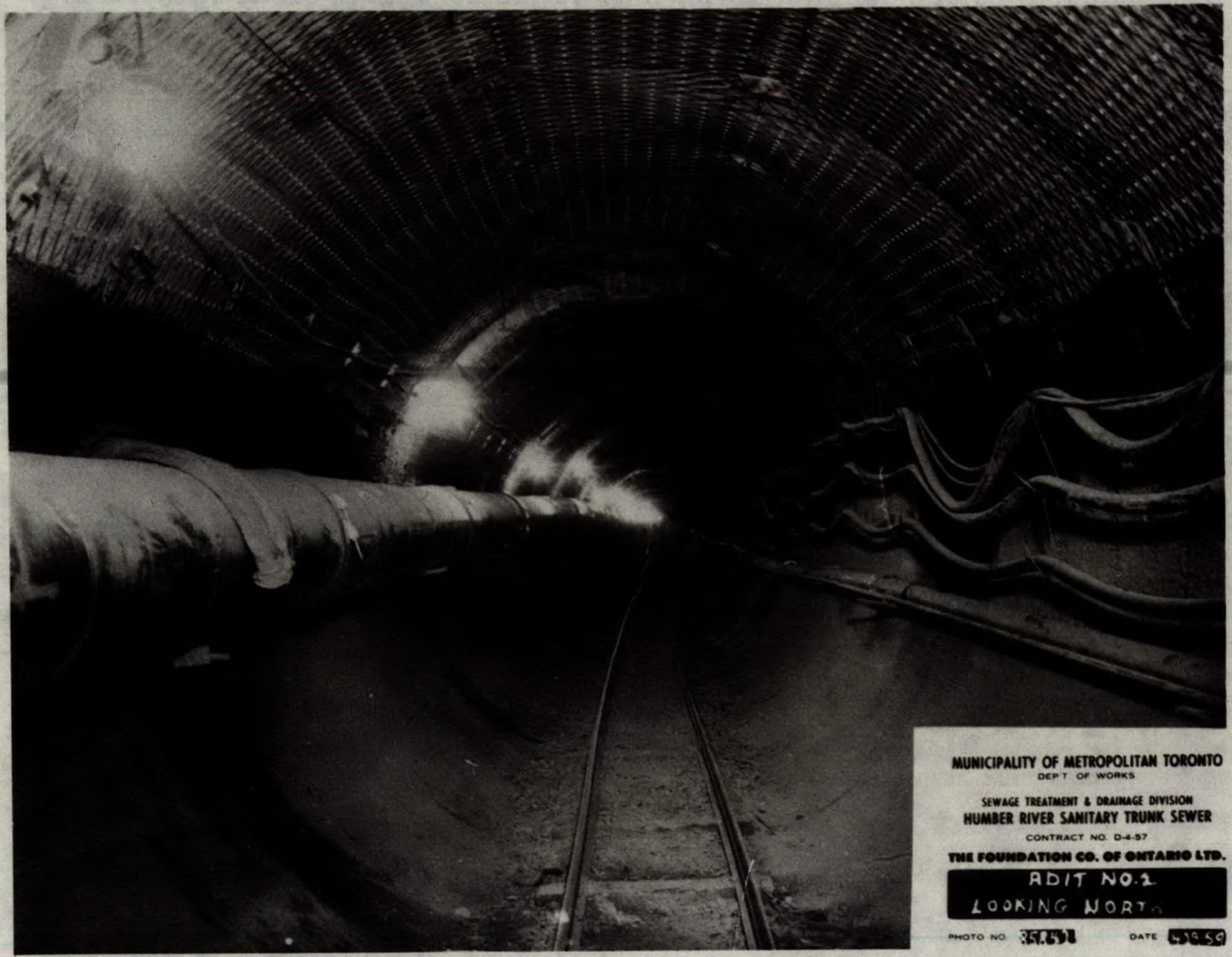

Figure 10. General view of bored tunnel, showing method of ground control and track, ventilation pipe, air and water pipes and electrical services.

Figure 11. View of collapsible steel forms in place to receive concrete for construction of concrete lining. Note concrete section already in place in tunnel invert and carrier for moving the forms in background.

Figure 12. View of a soft shale rock face with a harder limestone band running across the face at the top.

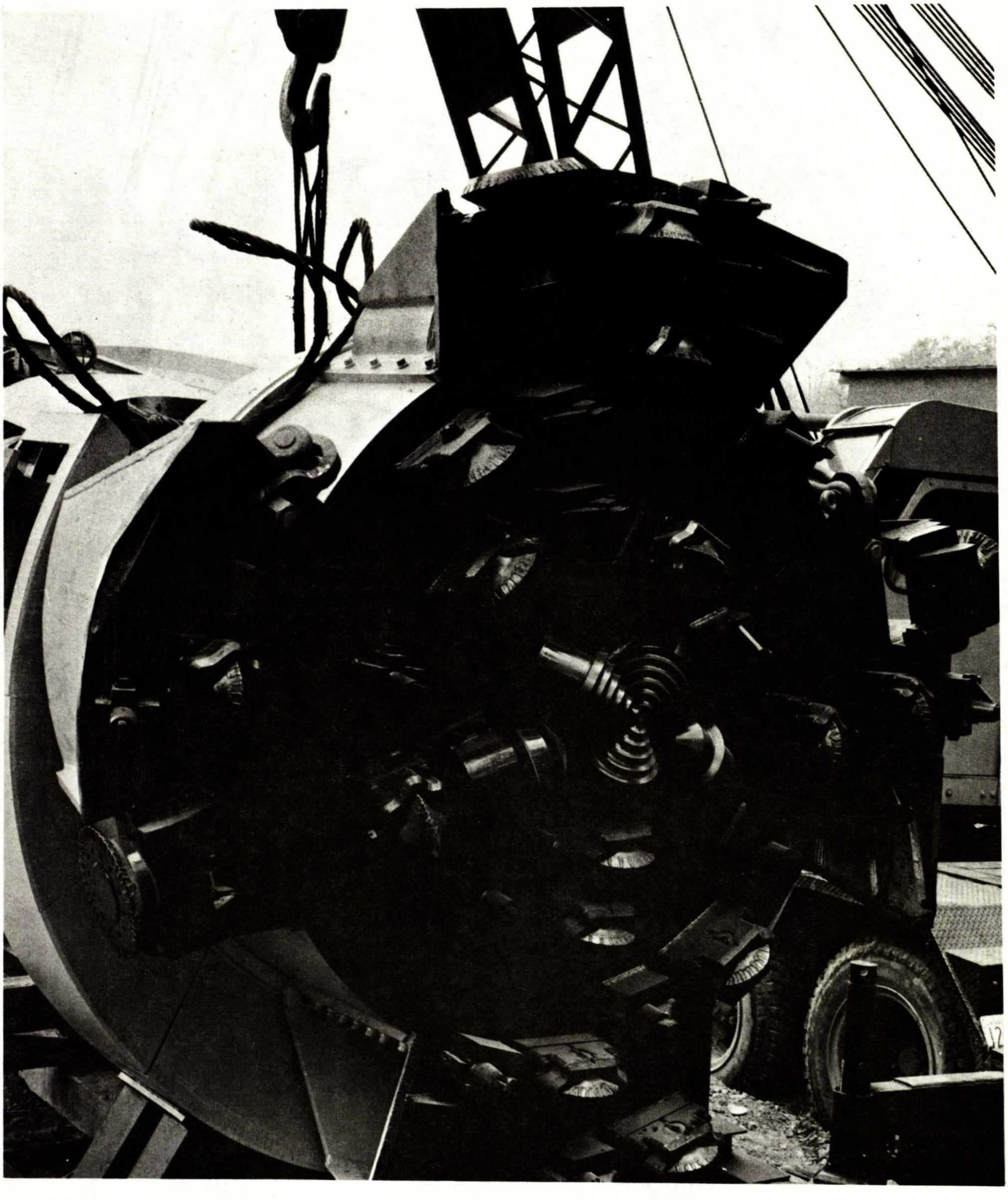

Figure 13. Front view of cutterhead assembly when boring started on May 8, 1958.

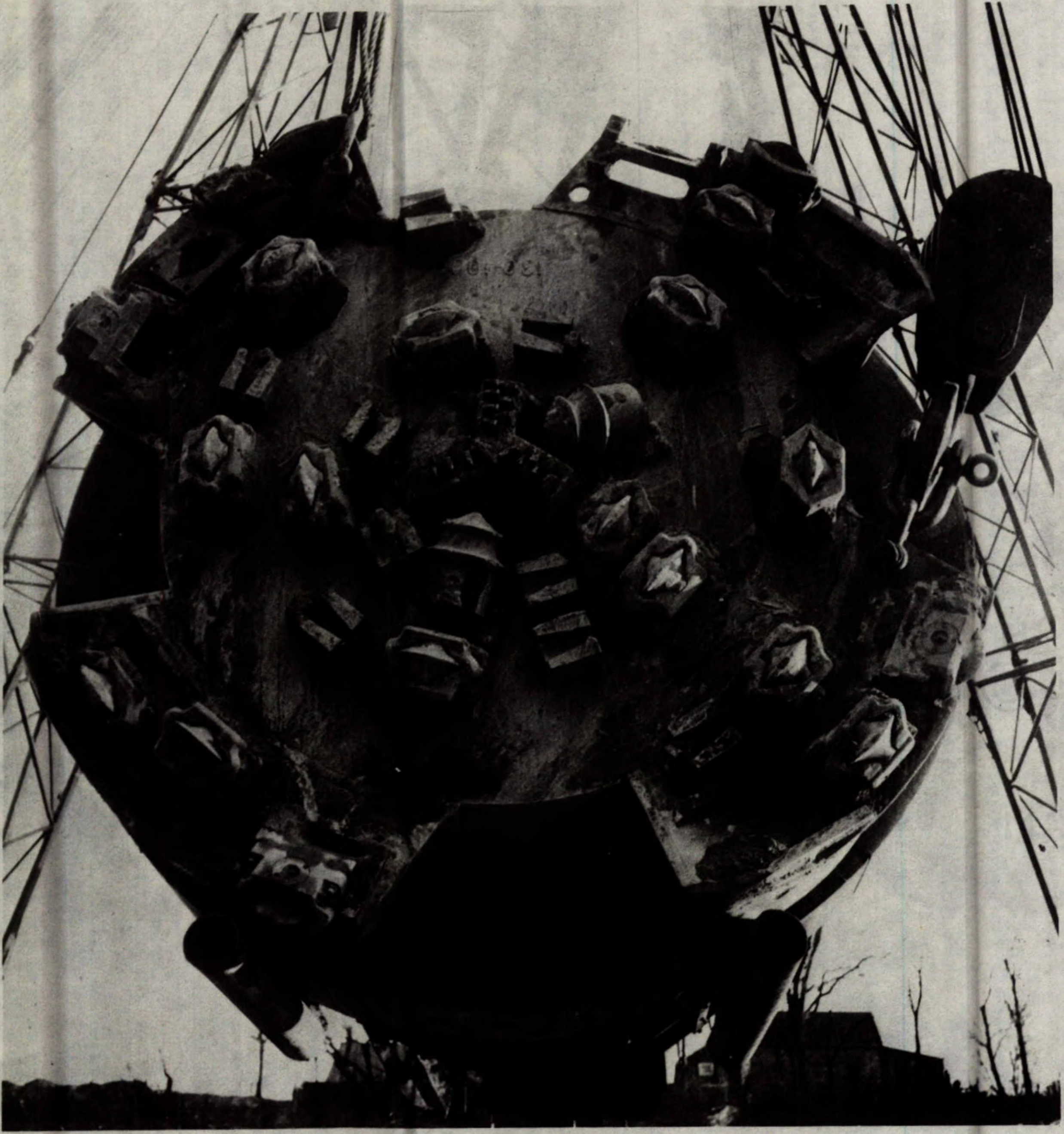

Figure 14. Front view of cutterhead on removal from the tunnel on November 26, 1959. Note star cutter in centre of head has been modified and stationary kerf cutters removed.

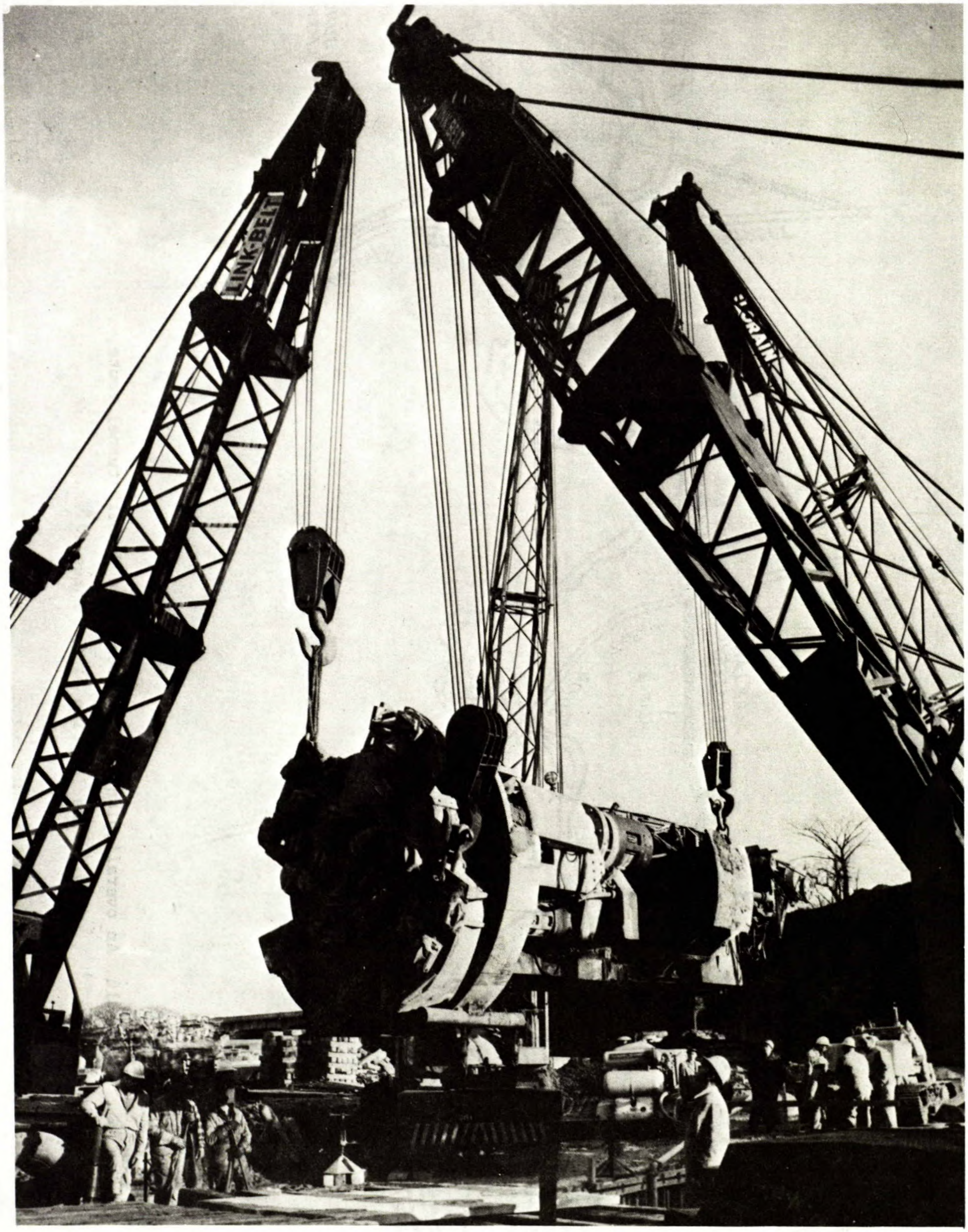

Figure 15. The Robbins boring machine, Model 131, being removed through shaft after completion of tunnel excavation on November 26, 1959.

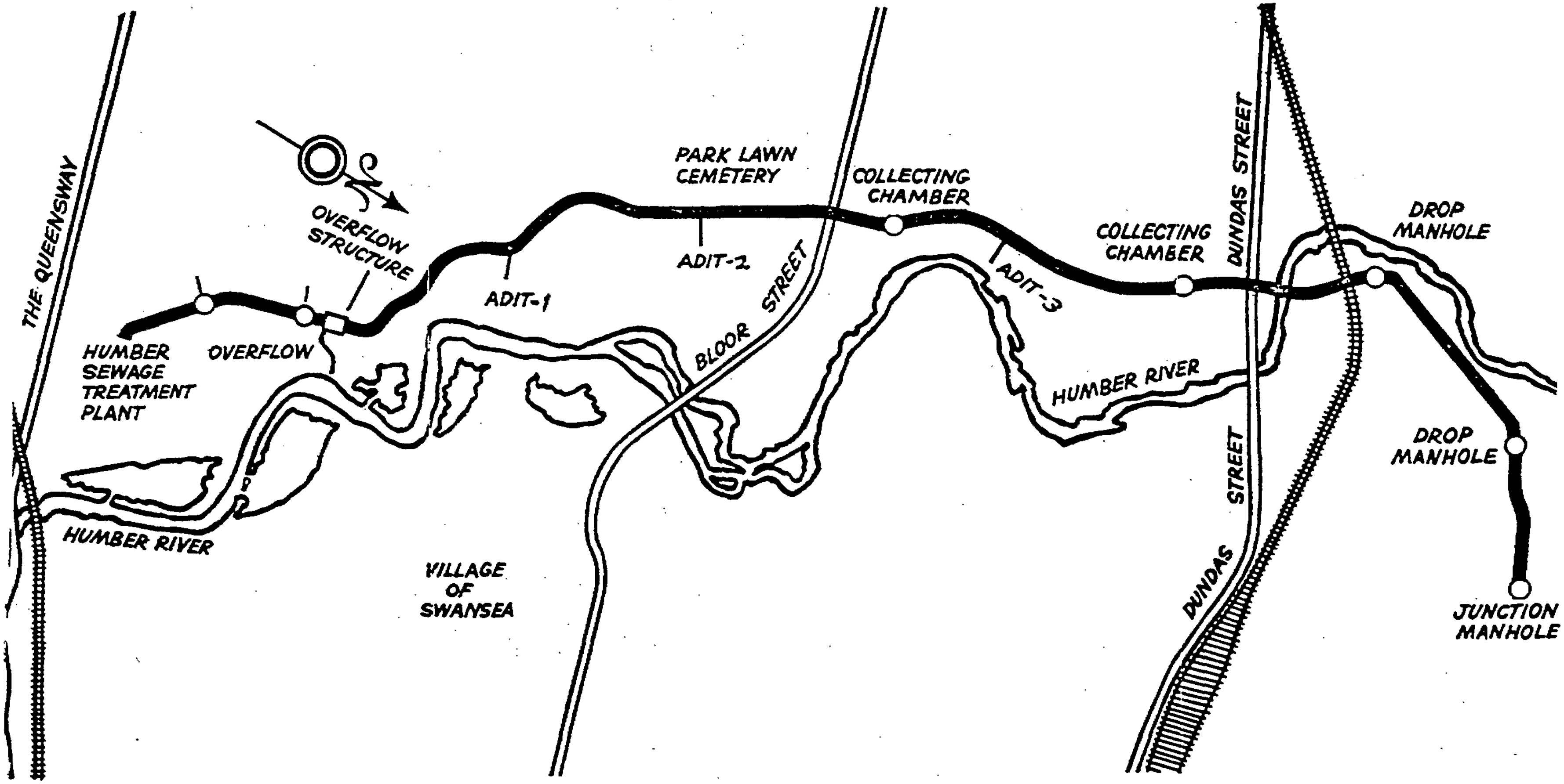

Figure 16. An overall plan of the "Foundation Humber" tunnel route, showing the location of the three adits.

CHAPTER 3

Prairie Farm Rehabilitation Administration (PFRA)

Gardiner Dam Diversion Tunnels

Introduction

The diversion structure at the Gardiner Dam, South Saskatchewan River, consisted of five parallel tunnels located in the west abutment of the main embankment. The tunnels were constructed in a chorded arc into the west abutment and in profile had the shape of an inverted siphon to avoid poor ground at higher elevations. The inlet and outlet portal structures were located approximately 2,000 ft upstream and downstream from the dam centreline, respectively. The control shafts were located near the dam centreline and consisted of five vertical shafts, 37 ft in diameter by 246 ft deep, with each containing two wells for the accommodation of an emergency bulkhead and a service gate.

The tunnels were mined for their entire length through a marine clay shale of Upper Cretaceous age. This material was a relatively soft, poorly cemented bedrock which had been consolidated by pressure from overlying sediments and glacial ice. Because of the soft nature of the shale, it was necessary to provide temporary ground support throughout the entire length of each tunnel during the mining operation and until the permanent lining was constructed. The tunnels were excavated to a diameter of 25'8" and were supported in the interval between mining and the placement of a 2½-ft-thick concrete lining with steel ring beams and lagging spaced at close intervals along the length of the tunnel. (Figure 17)

The work required to construct the Diversion tunnels was tendered in three contracts which were all subsequently awarded to a joint venture, Kiewit-Johnson-Poole, comprising the firms of Peter Kiewit and Sons Co. of Canada Ltd., Al Johnson Construction Co. of Canada Ltd., and Poole Construction Co. Ltd. Contracts 14 and 21 covered the work required to construct the downstream and upstream portions of the tunnel sections, and contract 25 covered the work of constructing the control shafts and the 40-ft transition sections which connected the control shafts to the upstream and downstream sections.

The mechanical mining of the tunnels was performed with a mining machine called the "Mole" by the contractors. This boring machine was originally designed and built by J.S. Robbins & Associates, Inc. of Seattle, Washington, and modified by Robbins at the plant of Canadian Brown Tank Co. of Brandon, Manitoba. The machine had been used to excavate the power tunnels at the Oahe Dam on the Missouri River at Pierre, South Dakota, U.S.A., by Morrison-Knudsen-Kiewit-Johnson in the mining of the upstream portion of seven power tunnels at a diameter of 29' 6" through Pierre shale. The machine was purchased by Kiewit-Johnson-Poole in November 1960 and was modified at Brandon, Manitoba, to cut a bore of 25' 8". It was named Model 261 by the Robbins Co. (Figure 18).

After modification at Brandon, the machine had the following characteristics: over-all length - 48 ft; over-all weight - 200 (short) tons; weight of cutterhead - 30 tons; height of jumbo (used for placing steel rings for ground control) - 14 ft; width of jumbo - 14 ft; diameter of bore - 25'8"; distance from face of cutterhead to ringbeam jig - 8 ft.

The cutterhead was powered by eight 85-hp, 440-v motors. The diameter of the main crown gear was 19'8". The face of the cutterhead was provided with 43 carbide-tipped teeth which cut a kerf 4 in. deep, and each tooth was followed by a disc cutter. Eight buckets were positioned on the circumference of the cutterhead, which rotated in a clockwise direction. The cutterhead rotated at 4 rpm in high gear and 1 rpm in low gear.

The mole equipment was mounted on three decks on the frame. The lower deck contained the transformers, generators, circuit breakers, switch gear, hydraulic tanks, and pumps. The centre deck contained the welding units, muck conveyors and operating console. The upper deck was equipped with a ringbeam conveyor and hydraulically operated hoist.

A 20-hp, 3,000-psi Dennison hydraulic pump provided power to the two main propulsion rams located at the tunnel springline position. Each propulsion ram cylinder was 6 in. in diameter and provided a thrust of 85,000 lb per ram at 3,000 psi. The pump operated to a maximum pressure of 5,000 psi which provided a thrust of 140,000 lb per ram.

A 2-hp, 5,000-psi Geco hydraulic pump provided power to the rear steering jacks, the front and rear dolly jacks, and the jacks used to raise and lower the top canopy shields. Electrical power was supplied to the machine through a 5,000-v insulated power cable. The input voltage of 4,160 v was transformed down to 200 v, and 110 v for small motors and lighting. Two motor-generator sets were supplied, each set consisting of a 500-hp, 4,160-v motor driving two 220-hp, 120-cycle, 440-v generators. Each generator provided power for two cutterhead motors. The ringbeam conveyor, situated on the top deck of the mole, was a chain-link-type conveyor run by a 7½-hp motor.

A series of three belt conveyors, each equipped with 7½-hp motors, carried the muck from the bucket discharge chute at the cutterhead to the front of the muck jumbo, located approximately 90 ft back from the rock face. The muck jumbo contained a conveyor belt and five bins each holding one carload of shale cuttings. After all the bins were filled, they were dumped into a train of five mine cars positioned beneath the muck jumbo. Two muck trains, each consisting of a diesel locomotive and five cars, were used to remove the shale from the tunnel, each carrying approximately 45 cu yd of muck. One cu yd of solid shale produced about 2 cu yd of broken muck. One trainload was removed from the tunnel every 10 minutes when the machine was mining at the rate of 1½ in. per minute. (Figure 19)

The portion of the muck jumbo used for loading purposes was some 90 ft long. A 30-ft extension on the muck jumbo and closest to the rock face contained two gunite mixing machines. The gunite machines were used to apply a 2-in. thickness of mortar on the mined shale surface within 48 hours after exposure.

The mine cars containing waste rock were emptied into a pit located in the work area outside the tunnel. The muck was conveyed from the pit to a storage bin by a conveyor belt and later hauled to the disposal area by a Caterpillar DW 20 truck.

Overall Operation of the Mole

Mining of the downstream tunnel, Contract 14, commenced in tunnel 5 on February 13, 1961. The initial mechanical mining operation was not satisfactory due to the design of the cutterhead teeth and the power units of the mole. While mining the first 658 ft of tunnel 5, eight fallouts (cave-ins) of the roof crown occurred, and the mechanical mining operation was terminated with the mole being removed from the tunnel on July 5, 1961. An experimental hand-mining of tunnel 5 continued until October 17, when the mole returned and completed tunnel 5. The mechanical mining of the five downstream tunnels, on Contract 14, was completed on April 12, 1962. The mole excavated 8,918 ft, or 89.9%, of the downstream tunnels. The remaining 1,003 ft, or 10.1%, was excavated by hand-mining. The mechanical mining operations were terminated by major fallouts in each tunnel at increasing distances from the control shafts, with the distance mined by hand-mining methods being 73 ft in tunnel 5, increasing progressively to 350 ft in tunnel 1.

The mining of the upstream tunnels commenced in tunnel 5 on May 7, 1962, and was completed in tunnel 1 on March 22, 1963. The mechanical miner excavated 9,384 ft, or 95.6%, of the upstream tunnels. The remaining 432 ft, or 4.4%, was excavated by hand-mining methods. Major fallouts occurred in all five tunnels between the end of the horizontal curve and the downstream limit of the contract. These fallouts caused termination of mechanical mining in all five tunnels. In addition, major fallout occurred between the portal and the start of the horizontal curve in each of tunnels 5, 2 and 1, but the contractor was successful in mining through these fallouts after a delay of several days in each case.

Modifications Made to the Mechanical Boring Machine during Mining of the Diversion Tunnels (Contract 14) (Figures 20 to 27).

March 9 to 13, 1961

The top shields were extended further towards the front of the cutterhead until all but 6 in. of the buckets was covered with the shield. To allow extension of the shield, the buckets had to be cut down by 3 in. and a 6-in.-wide "wear ring" or ring plate was attached to the buckets underneath the leading edge of the shield to allow the buckets to rotate without interference from the protruding shield. Tail pieces were welded to the rear or following edge of the shield at 4-ft intervals. These consisted of steel plates 4'6" wide and 3/4" thick. These pieces provided support to the crown between the rear edge of the shield and the blocked and positioned ringbeam.

April 20 to May 20, 1961

The disc cutters on the face of the mole were replaced with drag teeth which were positioned at an angle of 45° to the cutterhead face. A large hydraulic ram was installed to assist in turning the cutterhead when the motors stalled out. The bottom support plate was strengthened with gussets. A bucket elevator was installed near the front of the machine to lift shale chunks and rubble from the tunnel invert (bottom) section into the muck conveyor on the centre deck.

June 23 to July 22, 1961 (After mole was removed from tunnel 5)

1. Cutterhead Modifications

All the fixed teeth, disc cutters and their mounting plates were removed, leaving the face of the cutterhead smooth. One hundred and twenty new teeth were installed. These protruded 4 in. ahead of the cutterhead face and were 1 1/4 in. wide with carbide tips.

2. Top Shields

The top shields were all replaced. Three adjustable top shields were installed to cover the top 90° of the cutterhead. These shields extended 1 in. in front of the cutterhead, with the leading edge of the shield being located 3 in. back from the front edge of the cutting teeth. Fixed side shields were installed on each side to cover the area extending from the edge of the top shield to 4 ft below springline (centre line of tunnel on each side).

3. Motors

Twelve new 75-hp motors were installed. These motors were connected to two-speed gear boxes through hydraulic clutches which were synchronized to engage when the clutch pump reached a pressure of 130 psi. The cutterhead rotated at 1 rpm at low speed and 4 rpm at high speed.

4. Electrical Changes

A new 125-KVA transformer with 4,160-v input and 440-v output was installed for the 12 motors. New circuit breakers and new controls and starting switches for the motors were installed.

5. Miscellaneous Changes

A new cutterhead support shoe with an area of 40 sq ft was installed to replace the old shoe which measured 10 sq ft in area. Counter-weights were placed on the right-hand side of the machine frame to resist the torque resulting from the rotation of the cutterhead.

On Contract 21

An 18-in. extension shield was welded to the back end of the top canopy after mining tunnel 5 on Contract 21. This extension enabled the wire mesh and steel lagging, used in ground control, to be installed under the shield extension before the shale was exposed.

Description of Cutterhead After Final Modifications

The cutterhead rotated in a clockwise direction on a 2-ft-diameter shaft centered in the face of the machine and was driven by twelve 75-hp electric motors connected to two 2-speed gear boxes by hydraulic clutches. The driving shafts from the gear boxes were connected to small pinion gears. These gears meshed with a 10' 8" diameter "bull" gear that was bolted to the inside face of the cutterhead. The motor clutches were operated by a hydraulic pump and were synchronized to engage simultaneously when the pump reached a pressure of 130 psi. The synchronization of the clutches avoided the danger of overloading single motors when starting the machine. The power was supplied to the motors by a 125-KVA transformer with an input of 4,160 v and an output of 440 v.

The face of the rotating portion of the cutterhead was equipped with 160 carbide-tipped cutting knives, inserted into the smooth face of the head and anchored into place, and protruding 4 in. ahead of the cutterhead face. The front, or rotation, section of the cutterhead dislodged the shale as the head was rotated into the tunnel bore, and eight buckets, with a 14-in. width along the radius, picked up the broken shale from the bottom section and deposited it into a chute leading down from the top of the cutterhead and into the drag conveyor and muck conveying system on the centre deck. The rear portion of the cutterhead did not rotate and was equipped with thrust bearings on which the forward-rotating section rode. This portion of the head was ringed with plates or shields, mounted on a steel framework attached to the head. An adjustable canopy operated by hydraulic rams was attached to these shields over the top 90° of the head and a fixed canopy, solidly attached to the shields, extended from the adjustable canopy to a point located 4 ft below the centreline of the machine. The adjustable canopy had three sections which could be raised about 4 in. with hydraulic rams to provide support to the crown section of the tunnel. A "wear" ring attached to the top of the buckets allowed the cutterhead to turn freely under the canopy. The cutterhead turned at 4 rpm in high gear and 1 rpm in low gear. High gear was used whenever possible, but beyond the horizontal curves in the tunnels most of the mining had to be done in low gear. Continuous mining in low gear caused fine material to build up along the tunnel periphery and also in the buckets. This build-up of fines exerted a large frictional force on the cutterhead, with the result that the frame of the mole rotated counter-clockwise (or against the normal rotation of the cutterhead). This condition was called "rotation" and in some cases lifted the right side of the machine up as much as 12 in. Operating the machine in high gear for 20 minutes was generally enough to remove the accumulation of broken shale and correct the rotation.

Propulsion or Forward Thrust of the Mole

As the cutterhead turned, the mole was pushed forward by two propulsion rams mounted at each springline. Steel rails were welded between the ring beams (25-ft-diameter, 8-in.-wide flange, steel beams spaced at intervals ranging from 2- to 4-ft centre to centre along the tunnel centre-lines) to distribute the thrust of the mole to adjacent beams. Power was supplied to the propulsion rams by a 20-hp, 3,000-psi hydraulic pump. The pressure could be supplied to both rams at once, or to only one ram when required. Working pressure used on the rams ranged from 2,000 psi to 5,000 psi. Each ram had a

6-in.-diameter cylinder which produced a total thrust for the two rams of 28.3 tons at 2,000 psi and 70 tons at 5,000 psi. When pump pressures in excess of 3,500 psi were used, double or triple rails were welded between the ring beams at both springlines to resist the thrust exerted by the rams. The front end of the machine rode on a shoe located behind the cutterhead and the back end was supported by dollies which ran on gantry tracks mounted on the tunnel ring beams, on both sides of the tunnel.

Control of Lines and Grades During the Tunnelling Operation

Each tunnel section on the upstream and downstream end included a 1-in-10 downward slope at the portal, a vertical curve, a horizontal tangent, a horizontal curve, and another horizontal tangent. The contractor was responsible for the maintenance of lines and grade during the mining operation and survey lines, and levels were carried into the tunnels from reference hubs and targets installed by the Surveys Section of the South Saskatchewan River Dam Construction Division of the PFRA

The contract specified that the position of the ringbeam inverts be within 1 in. of established lines and grades and that the position of the crown and springlines of the beams be within 2 in. of the established lines and grades before placement of concrete. The contractor's survey crews set reference marks on previously placed ringbeam inverts beneath the mole from which the ringbeams were set to line and grade as they were installed. As the mined diameter of the tunnel was 25'8" and the outside diameter of the ringbeams was 25 ft, it was possible to correct some of the error in mined lines and grade by the setting of the ringbeams. During the mechanical mining of the diversion tunnels, 5,875 ringbeams were placed from the mole. A minimum concrete thickness of 30 in. was required. In some cases, chipping of the walls and resetting of ringbeams were required to bring the location of the ringbeams within the 2-in. deviation allowed from the theoretical "A" line of the tunnel.

The mined grade of the tunnels was controlled, during operation of the mole, by raising or lowering the cutterhead with the hydraulic ram attached to the front support shoe. The grade was also controlled by raising or lowering the back end of the machine with hydraulic rams located above the rear dollies. The alignment of the mole head to right or left was controlled by side shoes located in the cutterhead support 4 ft below springline, by the propulsion rams, and also by swinging the back end of the machine to right or left with hydraulic rams positioned on the rigid dolly frame located at the back of the mole. The mole frame was equipped with a hinged joint that could be wedged to allow the machine to work on a 500-ft-radius horizontal curve. The frame could also be wedged for a vertical curve, but this procedure was not necessary due to the short length (49.8 ft) of the vertical curves in the diversion tunnels.

To keep on a straight and level line, the cutterhead was raised or lowered by increasing or decreasing the pressure on the support shoe and at the same time lowering or raising the back end of the mole frame with the hydraulic rams positioned above the rear dollies. If the cutterhead swung off line it could be realigned by changing the pressure on the side shoes and propulsion ram or by swinging the back end of the mole.

When the machine was travelling down the 1:10 vertical curves, the grade on the first half of the curve was maintained by lowering the back of the mole and increasing the pressure on the cutterhead support shoe. Grade was maintained on the last half of the curve by removing the rear dollies and replacing them with shallow steel skids. The skids were left in place until the cutterhead was well clear of the end of the vertical curve.

The horizontal curves were 219½ ft in length and curved 10° towards the river. Grade control was maintained in the same way as when proceeding in a straight line, but special procedures were used to keep the cutterhead on line throughout the curve. The cutterhead was kept on line for the first 20 to 25 ft of curve by swinging the back of the mole towards the landside and propelling the machine forward, using only the landside propulsion ram. After mining forward this 20 to 25 ft, the machine was in a position where the back end had swung 12 to 15 in. to the landside, the cutterhead was 2 in. in towards the riverside, and the face of the cutterhead was in the radial plane of the curve. At this point, wedges were placed at the wedge points, located at the top and bottom of the machine at the hinge point. Double-length wedges were installed on the two landside wedge points. After installation of the horizontal curve wedges, the rear of the mole was approximately centered relative to the rear dollies. Alignment and grade on the balance of the curve were maintained using standard procedures. Wedges at the hinge point were removed and replaced with equal-length wedges after the cutterhead had advanced 12 ft beyond the end of the curve.

Collaring of the Tunnels (Figures 28 and 29)

The shale faces in the downstream and upstream portal structures were supported by steel 8H25.9 collar beams, timber lagging, horizontal and vertical 8WF40 steel struts in bulkheads and shale anchors in portals No. 1 to 4 and concreting of walls completed before the machine was used to collar the tunnels. Tunnel 5 used T-beam steel lagging of 8H25.9, cut in half, all around the portal opening, with a concrete canopy, heavy concrete walls and shale anchors, before the mole was moved in for boring. The shale anchors (used to support the portal excavation bracing) were withdrawn from within the tunnel periphery about two weeks before mining commenced in each tunnel. The wood lagging and about one-half of the steel bulkheads were removed, and the mining machine was moved within 2 ft of the portal face where the remainder of the steel bulkheads were removed. Mining was commenced immediately and the front dollies on the machine were dismantled as soon as the cutterhead had completely buried itself in the shale. Considerable difficulty was encountered with broken and falling ground in the crown area during the collaring of downstream tunnel No. 5. This was caused by the lack of support between the cutterhead and the ringbeam jig and this was corrected in the other tunnels after modification of the mining machine.

The upstream tunnels were collared with the assistance of an umbrella of spiling installed over the crown area just outside of the tunnel periphery. This umbrella consisted of 3-in. "I" beams and 3-in.-diameter pipes which were grouted into 6-in. by 20-ft-deep holes drilled into the shale on 1-ft centres. The shale face in the upstream tunnel portals was protected and supported by grout which was placed behind the timber lagging. The mole mined through the grout facing quite easily and the shale behind the grout was in good condition.

Ground Conditions

Fossil layers, bentonitic shale seams, and highly slickensided joint planes were encountered within the tunnel bore. These features generally resulted in fallout of varying degrees in the crown area when the seam or zone inclined upward and ran outside of the tunnel bore. The terminal fallouts that occurred in each tunnel section were generally associated with some inward movement of the shale in these areas. Shalestone concretions were also encountered occasionally during the mining operation. These hard stones were sometimes difficult to break up and resulted in damaged cutterhead teeth and, in some cases, produced minor overbreak due to the scoring of the mined shale face with the broken shalestone pieces. When the mole was mining in good ground, the shale cuttings produced by the cutterhead teeth were slivered in appearance. When fallouts were occurring, fewer slivered cuttings and more chunky blocks were present. The condition of the shale cutting during mining was used as a guide to detect the occurrence of fallout above and in front of the mole cutterhead.

Ground conditions were classified in general as follows:

Good ground. The tunnelling operation resulted in a smooth bore, with kerf marks from the cutterhead teeth being evident over the bore periphery, and there were no cracks apparent in the ground.

Fair to good ground. Fine cracks were apparent in the bore but no noticeable movement had occurred. There was occasionally some slight surface spalling.

Fair ground. The ground broke away in chunks ranging from 6 in. to 2 ft on a side and moved against the support shield. Little ground was lost from outside the bore. Steel ringbeams, spaced 3 to 4 ft apart, with steel lagging, wood blocking and wire mesh, were sufficient to hold this type of ground.

Fair to poor ground. There were minor fallouts where shale had been overmined up to 2 to 3 ft, rarely to 6 ft. The shale generally fell from two well-defined joint planes which came together at the limit of the overbreak. This type of ground was gunited and cribbed and grouted when necessary.

Poor ground. The crown area generally consisted of shale chunks which had fallen away from their original position. When a void existed behind the rubble, the area was formed and grouted from the mole or the muck jumbo.

Fallout

Ground fallouts that occurred during the mining operation were designated as minor or major according to their extent. Minor fallouts ranged in volume from 1 to 25 cu yd and did not result in significant mining delays. Major fallouts ranged in size from 25 to 70 cu yd and resulted in a delay of several days or caused the termination of the mechanical mining operation. An estimation of the void resulting from fallouts was made by a car count during mining. When excavating in sound shale, the machine advanced at a rate of 3½ to 4 in. per carload of muck. A comparison of the car count and the distance mined enabled the inspectors to arrive at a reasonably accurate estimate of the void volume in each fallout area.

Ground fallouts were generally caused by blocks of shale falling away from the slickensided joint planes which sloped down towards the cutterhead of the mole. These blocks appeared to be fed by gravity into the revolving cutterhead, resulting in little or no advance of the machine and leaving a void which generally extended ahead and upwards from the cutterhead. Removal of these blocks resulted in a progressive failure of the shale into the voids behind the blocks, resulting in crown fallout of varying degrees. When major cavities developed, it was difficult to determine the extent of the fallout because large blocks of shale covered the cutterhead. The weight of these blocks prevented further rotation of the cutterhead and generally they had to be removed by hand excavation before mining could resume. An intermittent type of minor fallout was caused by shale blocks falling away from joint planes located on the walls of the tunnel. These fallouts occurred immediately behind the cutterhead and were generally quite shallow but often extended for a considerable distance.

Method of Repairing Fallout Cavities (Figures 30 to 36)

Minor cavities. Shallow fallouts were supported with timbers and filled with gunite. Fallout cavities over 2 ft deep were formed (with plywood strips over ringbeams) and grouted from the muck jumbo. When the volume of fallout approached 15 to 25 cu yd, the mining operation was halted temporarily; the area was formed and mining was resumed when grouting of the forms filling the fallout area was completed.

Major cavities. The initial approach used to negotiate fallout areas was to mine through the broken zones as quickly as possible and catch good ground with the cutterhead before excessive cavities developed. This method was used successfully in two fallout areas in downstream tunnel No. 4 (in September, 1961) but was unsuccessful in a third area (October, 1961). Here a large cavity was created which resulted in a subsidence at the ground surface. Subsequently, the contractor was directed to halt mining operations and grout the cavities present in front of the mining machine when the estimated volume of the void approached 20 to 30 cu yd. A special attempt was made in downstream tunnel No. 1 to mine through poor ground (between Station 43 + 68 and 43 + 11 in April, 1962) by excavating a drift ahead of the mole and installing a reinforced concrete arch beam over the crown section of the tunnel. This procedure enabled the mole to mine through the supported area, but additional fallout at the end of the beam prevented further progress. The method that was eventually developed to enable the machine to mine through fallout areas is described below.

Major fallouts were negotiated in three cases on Contract 21 in upstream tunnels 5, 2, and 1. This was achieved by drilling 4 to 8 holes into the void. The cutterhead and buckets were protected from grout by first filling the cavity in front of the cutterhead with sand. The cutterhead was then freed by excavating over the top and down the front of the head. While the overmining was being carried down to the springlines, 40-ft-long, 4-in.-diameter holes were drilled in a 90^{o} arc over the crown of the tunnel and 3-in.-diameter pipes or 3 in. "I" beams were grouted into the holes to form a crown spiling umbrella. When the spiling was installed, the temporary bulkhead was blocked to the front face of the cutterhead and all steel was removed from in front of the machine. As soon as the mole head was turned, the timber kickers or bracings were released and a large void always developed in front of the cutterhead when the bulkhead gave away, but the umbrella of spiling held up the crown. After advancing about 1 ft, the buckets were plugged with timber and mining was terminated until the buckets were cleared. As the mole advanced, the cage that had been constructed in the overhead mined section was supported on greased timber skids which were positioned on the cutterhead canopy. These greased skids allowed the mole to move ahead under the load from the overmined section. When a full face was obtained, the mole was shut down until the cage was permanently blocked to the ringbeams. This was done by welding an "H" beam from the cage steel to the outer flanges of the tunnel ringbeams. The mining operation then continued in a normal fashion.

Installation of Temporary Ground Support System (Figures 37 to 41)

The temporary ground support system consisted of 25-ft-diameter wide-flange (8 in.) steel ringbeams weighing 40 lb per ft, spaced at intervals ranging from 2- to 4-ft centre to centre along the tunnel centrelines. The shale between the ringbeams was supported by wire mesh and steel lagging, weighing 4.17 lb per ft. The width of the lagging was 4-17/32 in. and was cut in lengths corresponding to the ringbeam spacing. The wire mesh used was 2 in. x 2 in. by No. 12 gauge, supplied in rolls varying in width from 24 to 48 in. The lagging was spaced at approximately 2-ft intervals above the tunnel springlines and 4-ft intervals below the springlines, and was blocked against the shale from the ringbeams with wooden wedges pre-cut from fir timber. The shale surfaces were prevented from drying by covering with a 2-in.-thick coat of pneumatically applied mortar (gunite) within 48 hours after exposure.

The ringbeams were fabricated in quadrants and were delivered and stockpiled at the dam site under separate Contracts 15 and 30. Each ringbeam quadrant was equipped with a four-hole butt plate and a splice plate, 6 in. wide, positioned at each end of the beam. Ten-inch splice plates were used on the outside of the beam to facilitate the welding operation. The contracts specified that the ringbeams had to be permanently blocked in place before the heading had advanced 6 ft beyond the installed ringbeam. When the mechanical miner was being used, however, the ringbeams were placed 8 ft behind the face of the heading and were permanently blocked in position 10 to 11 ft behind the heading. This spacing was the closest possible because the mole cutterhead canopy and forward support shoes occupied approximately 8 ft of space, from the face back. Fractured shale, in the crown area close to the face, was prevented from dropping by the raisable canopy positioned on the cutterhead of the mole.

An Austin-Western, 4-ton, hydraulically operated crane was used to lift the ringbeam quadrants from the upper deck storage rack, mounted on the mole, and transfer them onto the ringbeam jig. This jig was a ring located immediately behind the cutterhead and could be rotated in either direction with a 10-hp electric motor. The first ringbeam quadrant was placed on the jig in the crown position, and was held in place by a pin through the web of the beam with two hook clamps on the jig holding the beam in position. The jig was then rotated counter-clockwise in 90° intervals while the remaining three quadrants were placed and bolted together. The butt plate holes were aligned by driving a drift pin through them. Drift pins were removed, in succession as required, and bolts were inserted and tightened with an air-driven impact wrench. When the ringbeam assembly was completed, spreader bolts were placed between the newly assembled beam and the one previously installed and the beam was pulled off the jig as the mole moved forward. Wire mesh was inserted between the top of the newly installed ringbeams and the shale crown and walls. The mesh was left out of the invert (bottom) section on Contract 21 (upstream tunnels), as it was found that this facilitated the cleanup of the shale prior to guniting. After the wire mesh was placed, steel lagging was installed on the top of the ringbeams, underneath the wire mesh, and blocked, by wooden wedges, to the previously placed ringbeam. Wire mesh and steel lagging were generally in place by the time that the ringbeam had cleared the jig. A crew working below the bottom deck of the mole set the beam to grade, using chain hoists and a spirit level. At the same time, the ringbeam spacing was adjusted over the crown section and down the springlines by tightening the spreader bolts with an air wrench. When this operation was completed, the steel lagging was blocked to the newly installed ringbeam and the buttplate bolts were tightened. Whenever possible, all of the splice plates were welded as the mining progressed. The lower splices were welded under the mole and the upper splices were welded from the muck jumbo. Welds which were not completed at this time, or were later rejected due to faulty welding, were left and done just before placement of the concrete. The time required to set ringbeams into position did not cause delays when mining progressed at a rate of 1½ in. per minute, unless the ringbeam spacing was 2 ft or under.

Guniting Operation (Figures 43 to 44)

A 2-in. thickness of mortar was placed on the mined shale surfaces within 48 hours after exposure, to avoid drying and consequent slaking of the shale. Two Tru-Gun-All Model G-4, wet-mix machines, were used to mix and apply the mortar. Both of these machines were mounted on the front end of the muck jumbo. Each machine had two chambers which provided a continuous mixing operation. One chamber was under the working pressure required to apply the gunite while the other section was receiving the dry batched material with a regulated quantity of water being added through a water meter. An air-entraining agent was added to the mixture, as it was found that this agent promoted better placement and less rebound on impact with the shale surfaces. The gunite was forced through a 2-in. rubber hose by compressed air admitted through a regulating valve situated at the bottom of the mixing chamber. Additional air was added at the nozzle to provide greater impact on application. The gunite batch proportions used were 425 lb of sand, 125 of cement and approximately 48 lb of water to each batch.

During the initial gunite operation on the downstream tunnels, considerable difficulty was experienced with plugged valves and hoses in the gunite machines. This was caused by the occasional stone which was present in the fine aggregate processed for concrete. Damp sand also caused problems. To avoid these difficulties, the contractor installed a separate gunite batch plant which included a kiln used to dry the fine aggregate and a screen which removed all + 3/8 in. rock from the dried sand.

A bond was required between the tunnel concrete and the ringbeams to develop the tensile strength of the beam. It was necessary to remove all gunite, adhering to the ringbeams, prior to the placement of concrete. Removal of hardened gunite required the use of jackhammers in downstream tunnels 4 and 5. Subsequently, in tunnels 3, 2 and 1, the contractor cleaned the ringbeams by scraping them with wooden wedges before the applied gunite had hardened. When mining commenced on the upstream tunnels, an air-water jet was used to clean the ringbeams. This proved more efficient than the scraping procedure and left the ringbeams in a reasonably clean condition.

Supplies for the Mechanical Mining Machine (Figure 45)

Supplies for the temporary ground support system and gunite were brought into the tunnels on flat cars driven in front of the muck trains. The ringbeam supply cars were left in the tunnel until the materials were elevated by the Austin-Western hoist to the top deck of the mole. Ringbeam quadrants were hauled from the stockpile area to the work area by means of a truck with a load capacity of 24 ringbeam segments. A stiff-legged crane was used to load the supply cars. Each supply car could carry two ringbeams and sufficient lagging, spreader tie-bolts, wire mesh and wood blocking to allow installation of the two ringbeams. Other supplies--such as steel rails for the gantry and service track, propulsion rams, and oxygen and acetylene bottles for welding operations--were also brought in with the ringbeam supply cars.

The ringbeam quadrants, wire mesh and wooden wedges for blocking were stored on the top deck of the mole on a chain conveyor which moved the ringbeam quadrants and supplies forward as they were required. The steel lagging sections were placed on a series of rollers beside the ringbeams and were pushed forward manually as they were required. The steel rails for the gantry and service tracks were installed beneath the mole and were positioned by means of an air-operated winch (or "air-tugger"). The empty gunite and ringbeam supply cars were removed from the tunnels with the outgoing muck trains. Muck trains were winched up and down the one-in-ten slopes at the exit and portal ends of the tunnels with a Hayes double-drum electric winch.

Removal of the Mechanical Mining Machine

Major fallouts terminated the mechanical mining operation in each tunnel section. When this occurred, the cutterhead was advanced ahead as far as possible, hand-mining of the crown and walls was carried out, and a temporary bulkhead was carried down in front of the cutterhead to within 3 ft of the bottom of the tunnel. The canopies, buckets and shields were removed from the head of the mole as the bulkhead excavation proceeded. The bottom shoe was unbolted from the cutterhead and the front dollies were replaced. The cutterhead was then rotated until alignment slots in the cutterhead were in line with the gantry and service tracks. The machine was then pulled back along the tunnel, on the gantry rails, using three diesel locomotives which ran on the service tracks. At the bottom of the one-in-ten slope, at the entrance of the tunnels, the locomotives were disconnected and the machine was pulled up the slope with a Hayes double-drum electric winch.

Bulkheads placed in the tunnels were designed by the contractor. The first one installed in tunnel No. 4, Contract 14, showed a progressive inward movement during the four months it was observed and had to be strengthened by adding extra beams. The bulkhead was redesigned for use in downstream tunnels 5 and 3 and modified again for subsequent tunnels. This redesigned bulkhead used four horizontal 8WF40 beams and four 8WF40 vertical struts welded between the horizontal members. Nine 8WF40 raker beams were carried back, at an angle, from the bulkhead beams and welded to the tunnel ringbeams. The bulkhead was completed by placing 3-in. timber lagging vertically between the horizontal beams and then covering the face of the bulkhead with gunite. The shale face was supported with timber kickers until all the steel members were installed and welded. Horizontal steel beams were welded to the last 10 ringbeams on each side of the tunnel to support the bulkhead during excavation of the invert headings (done on a separate contract) in the middle section of each tunnel.

Summary of Operations

The information contained in this report was the result of correspondence between Dr. D.F. Coates, Head, Mining Research Centre, and the Canadian Department of Agriculture, Prairie Farm Rehabilitation Administration. Letters between Dr. Coates and the Saskatoon and Regina offices of the PFRA resulted in the receipt of an internal draft report of the South Saskatchewan River Project as received from J.G. Watson, Chief Engineer, PFRA, Regina, Saskatchewan.

The present report summarizes information contained in the PFRA report. The original report did not contain information concerning costs of tunnel projects and only limited data were available on manhours worked.

Table 9 gives information on operational conditions, summarized from the PFRA narrative and from plans attached to the report. The available work days were estimated by the writer and machine-drilling days and feet of advance were taken from PFRA plans.

Table 10 summarizes weekly operations and was compiled from tables shown on PFRA plans. Advance footages shown differ somewhat from those in Table 9, probably due to adjustment made for footage going around curves and for cases where the boring machine advanced twice over the same section of tunnel when caving occurred. The tables do not include the work done in driving the high-level intake structures or control shafts (done on separate Contract 25).

Figures 17 to 45 are photographs selected by the writer from over 100 photographs contained in the original report. Figure 46 is a photo-reduction of a plan and section of the Robbins Model 261 boring machine.

(Additional Information)

J. G. Watson, Chief Engineer, Department of Regional Economic Expansion, Western Region, in February 1970, forwarded to the author information concerning costs for the Gardiner tunnel, as follows:

Contracts 14 and 21

South Saskatchewan River Project

Tunnel Mining Costs

(a) Quantities

Mined diameter = 25 ft 8 in.
Mined length = 19,737 ft
Excavation volume = 380,000 cu yd

(b) Contract Costs

Excavation		$3,239,930.70
Ground Support System		
- ring beams -	$3,797,984.20	
- lagging -	869,376.00	
- wire mesh -	260,412.43	
- mortar -	580,821.75	
	$5,508,594.38	
Total Cost		$8,748,525.08

(c) Unit Costs

	Per Lineal Ft	Per Cubic Yard
Excavation	$164.00	$ 8.50
Ground Support	$279.00	$14.50
Total	$443.00	$23.00

TABLE 9

South Saskatchewan River Project P. F. R. A.
Summary of Mechanical Mining of Diversion Tunnels
Weekly Advance and Operating Conditions

Date by Weeks	Available Work Days (6 day week)	Machine Drilling Days	Advance in Feet	Remarks
	Downstream Tunnels, Contract 14			
Tunnel 5, First portion				
Feb. 13-18/61	6	6	15	Slow progress. Mole sinking below grade. Shale failing along joint planes. Installed ringbeams reinforced with timber struts and 8 in. steel "H" beams. Fallouts general on Feb. 28.
19-25	6	3	25	
26-Mar. 4	6	6	92	
	18	15	132	Slow progress made through fallout areas.
Mar. 5-11	6	1	6	The shale was hard and blocky and fell out in large pieces leaving voids (holes) in the crown (roof) of the tunnel. Voids filled with timber cribbing. Hand mining Mar. 7-13. Modified shield plates welded to mole. Grouting into voids from surface through 6 in. drill holes. Major fallout on Mar. 27 halted boring from Mar. 27-Apr. 1.
12-18	6	5	152	
19-25	6	5	241	
26-Apr. 1	6	1	19	
	24	12	418	
Apr. 2-8	6	0	--	Further fallouts halted the machine. Cutterhead covered with oil (to prevent grout from adhering to face). Grout pumped into voids from surface and from tunnel. Hand excavation made ahead of machine. On Apr. 13 the mole reached the original position it had attained on Mar. 27. Mining progressed slowly.
9-15	5	1	30	
16-22	5	1	10	
23-29	6	4	57	
2 days holiday	22	6	97	
Apr. 30-May 6	6	0	--	Numerous fallouts, mechanical troubles and machine failures resulted in little actual advance. Finally, on June 5 the contractor decided to withdraw the mole from the tunnel and rebuild it. Hand mining of the tunnel commenced on July 5 and continued until Oct. 17.
May 7-13	6	0	--	
14-20	6	0	--	
21-27	5	2	10	
28-June 3	6	2	13	
1 day holiday	29	4	23	
June 4-10	6	0	--	The mole was removed from the tunnel and rebuilding and remodelling of the machine was started about the middle of June.
11-17	6	0	--	
18-24	6	0	--	
25-July 1	5	0	--	
1 day holiday	23	--	--	

- cont'd

(Table 9, cont'd)

Date by Weeks	Available Work Days (6 day week)	Machine Drilling Days	Advance in Feet	Remarks
July 2-8	6	0	--	Modifications to mole were carried out (see details in main report) throughout the month of July.
9-15	6	0	--	
16-22	6	0	--	
23-29	6	0	--	
	24	--	--	
		Tunnel 4 (Downstream)		
July 5-Aug. 5	6	0	--	Modifications to the mole were completed and it was moved to the portal of Tunnel 4 on Aug. 9. Minor breakdowns occurred until Aug. 14. Fairly good ground conditions were encountered and the machine advanced at a rate of approximately 70 ft per day.
Aug. 6-12	6	3	70	
13-19	6	5	292	
20-26	6	6	458	
27-Sept. 2	6	6	477	
	30	20	1297	
Sept. 3-9	5	4	284	Good progress was made until Sept. 9, when fallouts occurred in front of the mole. A large void developed above the crown. A subsidence occurred on surface above the tunnel. Holes were drilled from surface and large quantities of grout were introduced. Intermittent boring continued with numerous fallouts.
10-16	6	2	15	
17-23	6	3	102	
24-30	6	5	219	
	23	14	720	
Oct. 1-7	6	3	28	A new void opened up on Oct. 4 and it was decided to hand mine the rest of the tunnel. The mole was moved back to Tunnel 5 between Oct. 5-18. Mining resumed on the 19th but a fallout occurred immediately. The machine was able to mine through this fallout and good progress was made until Oct. 30.
8-14	6	--	--	
Second portion - Tunnel 5 (Downstream)				
15-21	5	4	198	
22-28	7	7	480	
Worked 1 Sunday 1 day holiday	23	14	706	
Oct. 29-Nov. 4	6	7	412	A fallout occurred on Oct. 30 and grout was pumped into the void. Slow progress was made until Nov. 8 when mining ceased. A void occurred in front of mole. Grouting was carried out. Mining continued on the 10th but more fallouts occurred. On Nov. 13 the mole was removed and hand mining was used to complete the tunnel. The mole was removed to Tunnel 3 between Nov. 13-24.
Nov. 5-12	6	4	165	
13-18	6	--	--	
19-24	6	--	--	
Tunnel 3 (Downstream)				
25-Dec. 2	6	7	356	
Worked on 3 Sundays	30	18	933	

(Table 9, cont'd)

Date by Weeks	Available Week Days (6 day week)	Machine Drilling Days	Advance in Feet	Remarks
Dec. 3-9	6	7	652	Fair ground conditions encountered. Good progress made until Dec. 20 when machine was halted in badly broken shale. Grouting of voids was carried out and ground allowed to set over Christmas period. Another major fallout occurred on Dec. 29 and the contractor decided to remove the mole on Jan. 3.
10-16	6	6	520	
17-23	6	3	142	
24-30	4	3	135	
Worked 1 Sunday 2 days holiday	22	19	1449	
Dec. 31-Jan. 6/62	5	1	12	Moved mole to Tunnel 2 between Jan. 3-15. Boring continued in fair to good ground for all of Jan. 1962. An advance of 122 ft occurred on Jan. 25, the greatest advance in one day to that date.
Tunnel 2 (Downstream)				
Jan. 7-13	6	0	--	
14-20	6	5	184	
21-27	6	6	603	
1 day holiday	23	12	799	
Jan. 28-Feb. 3	6	6	573	Good advance continued until Feb. 9, when mining was stopped by a major fallout in very poor shale. Grouting did not hold the ground and the mole was moved out to Tunnel 1 between Feb. 10-21. Boring commenced on Feb. 22. Slow progress was made until the 27th when advance increased to about 80 ft per day.
Feb. 4-10	6	4	310	
11-17	6	--	--	
Tunnel 1 (Downstream)				
18-24	6	2	75	
25-Mar. 2	6	5	398	
	30	17	1356	
Mar. 3-9	6	6	633	Advance was good, with a record of 126 ft on Mar. 8 and 633 ft for the week of Mar. 3-9. On Mar. 15 a major fallout halted progress. Hand mining commenced on the 17th and continued until Apr. 2. A reinforced concrete arch beam was constructed through the poor shale section.
10-16	6	5	406	
17-23	6	0	--	
24-30	6	0	--	
	24	11	1039	
Mar. 31-Apr. 6	4	0	--	Large quantities of grout were forced around reinforced steel beams. Repairs were made to the cutterhead and drive pinions. The mole commenced drilling again on Apr. 9 but a large void opened up in front of the face. The contractor decided to remove the mole on Apr. 12 and it was moved to Tunnel 5 (upstream).
Apr. 7-13	6	2	52	
14-20	6	--	--	
21-27	6	--	--	
2 days holiday	22	2	52	

- cont'd

(Table 9, cont'd)

Date by Weeks	Available Work Days (6 day week)	Machine Drilling Days	Advance in Feet	Remarks
Apr. 28-May 4	6	0	--	Movement of the mole to upstream Tunnel No. 5 was completed on May 6. Slow progress was made, through good ground, until the 15th when the rate of advance increased to about 80 ft per day.
Tunnel 5 (Upstream)				
May 5-11	5	5	162	
12-18	6	3	220	
19-25	6	5	360	
26-June 1	6	6	450	
1 day holiday	29	19	1192	
June 2-8	6	1	12	A major fallout in front of the mole halted mining operations on the 2nd. The fallout area was grouted. Sixty-four cu yds of cement grout was pumped into the void and mining continued. A major fallout on the 23rd halted progress and damaged the machine. The tunnel was completed by hand mining.
9-15	6	4	263	
16-22	6	7	542	
23-29	6	--	--	
Worked 1 Sunday	24	12	817	
June 30-July 6	6	0	--	The mole was moved to Tunnel 4 (upstream) between June 23-July 11. Good progress was made through good to fair ground during July.
Tunnel 4 (Upstream)				
July 7-13	6	2	50	
14-20	6	5	330	
21-27	6	6	513	
28-Aug. 3	6	5	360	
Worked 1 Sunday	30	18	1253	
Aug. 4-10	6	6	392	Progress was slower around the horizontal curve of the tunnel and a major fallout on Aug. 13 delayed mining for a week, until the 20th. Additional fallouts caused further delays and the mole was removed on Aug. 25 with the remaining 63 ft of the tunnel being hand mined.
11-17	6	3	228	
18-24	6	3	31	
25-31	6	--	--	
	24	12	651	
Tunnel 3 (Upstream)				
Sept. 1-7	5	0	--	The mole moved to Tunnel 3 between Aug. 25-Sept. 9. The mole advanced through fair to good ground at about 70 ft per day during the month of September.
8-14	6	5	230	
15-21	6	5	398	
22-28	6	6	510	
1 day holiday	23	16	1138	

- cont'd

(Table 9, concluded)

Date by Weeks	Available Work Days (6 day week)	Machine Drilling Days	Advance in Feet	Remarks
Sept. 29-Oct. 5	6	6	425	Progress continued until a major fallout occurred on Oct. 10. On the basis of experience gained in Tunnel 4, the contractor decided not to try mining through the fallout with the mole and it was removed on Oct. 11 and the remaining 180 ft of tunnel were hand mined. The mole was moved to Tunnel 2 between Oct. 11-23.
Oct. 6-12	6	3	168	
13-19	5	0	--	
Tunnel 2 (Upstream)				
20-26	6	3	140	
27-Nov. 2	6	6	400	
1 day holiday	29	18	1133	
Nov. 3-9	6	5	500	Mining continued at a rate of about 80 ft a day until a major fallout stopped the mole on Nov. 9. Repairs were made to the mole's hydraulic system, hand mining was started and a spiling umbrella constructed over the crown. Mechanical mining continued on Nov. 16 until another fallout occurred on Nov. 26. No attempt was made to continue mining with the mole. The remaining 58 ft of tunnel was mined by hand and the mole moved to Tunnel 1 (upstream) between Nov. 27-Dec. 7. A major fallout stopped the mole on Dec. 14. After grouting the fallout, mining was attempted on the 15th but another fallout occurred. A 40 ft spiling umbrella was erected. Mechanical mining did not resume until Jan. 2/63. Mining resumed through the fallout area without any trouble. A major fallout stopped the mole on Jan. 25/63. No attempt was made to resume mechanical mining. The remaining 115 ft of tunnel was hand mined and the mole was removed from the tunnel, completing the mechanical mining portion of the contract.
10-16	6	1	83	
17-23	6	6	481	
24-30	6	3	240	
	24	15	1504	
Dec. 1-7	6	0	--	
Tunnel 1 (Upstream)				
8-14	6	5	242	
15-21	6	1	4	
22-31	86	0	--	
2 days holiday	24	6	246	
Jan. 1-4/63	3	3	150	
5-11	6	6	535	
12-18	6	6	430	
19-25	6	6	388	
1 day holiday	21	21	1503	

SUMMARY - BY YEARS

	Available Work Days (6 day week)	Machine Drilling Days	Advance in Feet	Remarks
1961-10½ months	269	126	5,787	Mechanical mining commenced on Tunnel 5 (downstream) on Feb. 13/61 and was completed on Tunnel 1 (upstream) on Jan. 25/63.
1962-12 months	297	159	11,168	
1963- 3 weeks	21	21	1,503	
Total-23 months	587	306	18,458	

TABLE 10

SUMMARY

TUNNEL MINING PROGRESS

		Mechanical Mining Progress						Hand Mining Progress				
						Daily Footage						
Tunnel	Length, ft	Start Date	Finish Date	Working Days	Length Mined, ft	Average	Maximum	Start Date	Finish Date	Working Days	Length Mined, ft	Average Daily Footage
5 - Downstream	2,051	2-13-61	6- 5-61	77	658	8.5	60	7- 6-61	9-15-61	28	57	2.0
4 - Downstream	2,018	8-10-61	10- 4-61	53	1,945	36.7	114	10-18-61	11-18-61	24	73	3.0
5 - Downstream	•	10-19-61	11-13-61	24	1,265	52.7	102	11-23-61	12-13-61	17	71	4.2
3 - Downstream	1,984	11-26-61	1- 4-62	34	1,811	53.3	105	1-19-62	3-30-62	54	173	3.2
2 - Downstream	1,951	1-17-62	2-12-62	23	1,672	72.7	124	3- 7-62	7- 3-62	77	279	3.6
1 - Downstream	1,917	2-23-62	4-12-62	42	1,567	37.3	126	5- 5-62	9- 6-62	87	350	4.0
5 - Upstream	2,040	5- 7-62	6-22-62	41	2,022	49.4	111	12- 5-62	12-20-62	9	18	2.1
4 - Upstream	2,002	7-12-62	8-24-62	40	1,939	48.5	118	9-12-62	10- 3-62	21	63	3.0
3 - Upstream	1,963	9-10-62	10-10-62	27	1,784	66.1	104	8-30-62	12-11-62	45	179	4.0
2 - Upstream	1,925	10-24-62	11-26-62	30	1,868	62.3	124	12-11-62	1-10-63	19	57	3.0
1 - Upstream	1,886	12- 8-62	1-25-63	35	1,771	50.6	102	10-25-62	3-23-63	33	115	3.5
Totals	19,737			426	18,302					414	1,435	
Averages						42.9						3.5

Note:

1. The total tunnel length of 19,737 ft shown above does not include the 600-ft length (120 ft per tunnel) through the control shafts and control shaft transitions and the 210 ft (42 ft per tunnel) through the high-level intake shafts.

Figure 17. Tunnel section after installation of a temporary ground support system.

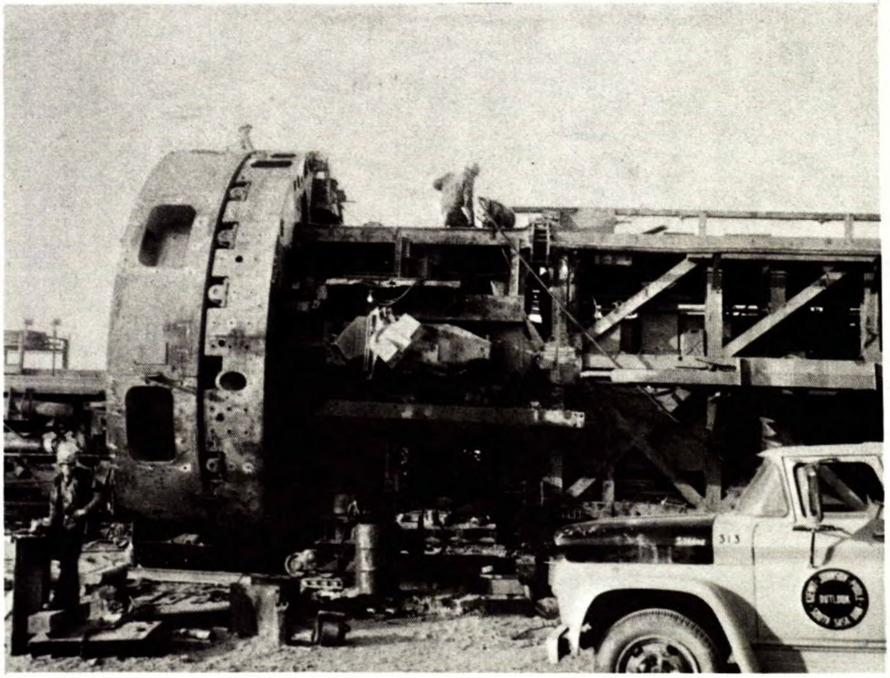

Figure 18. A side view of the mining machine (with wear ring and buckets removed from the cutterhead).

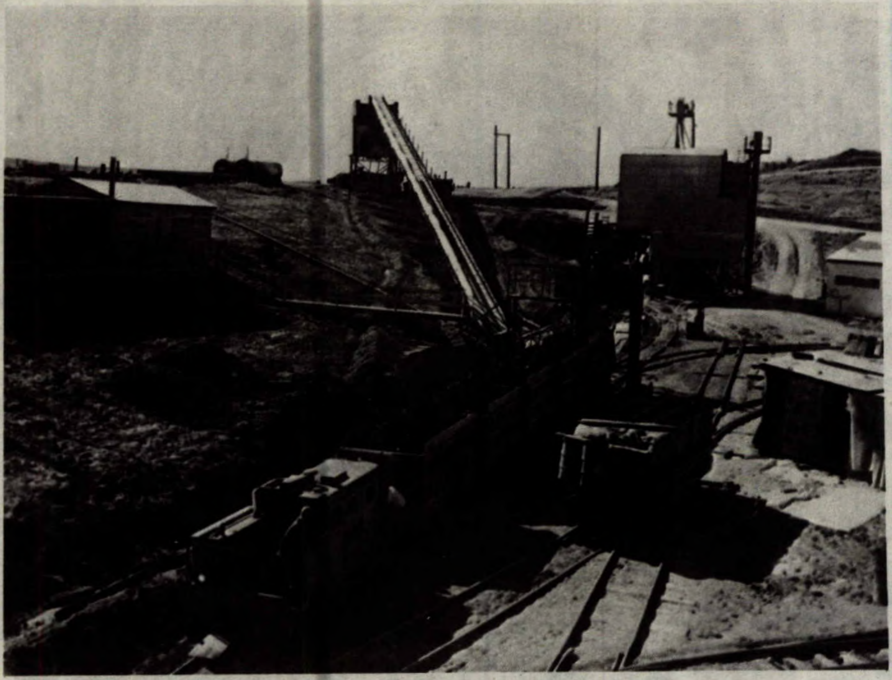

Figure 19. The muck disposal system used in the Contract 21 work area.

Figure 20. A side view of the cutterhead, with the wear ring and buckets removed.

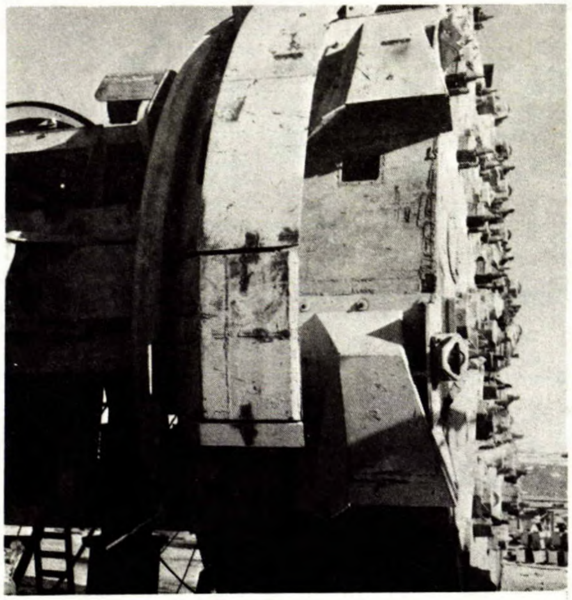

Figure 21. A side view of the cutterhead, original design.

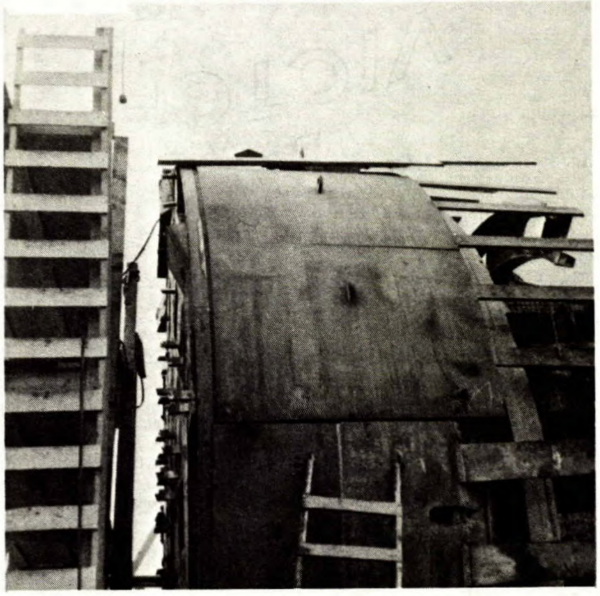

Figure 22. A side view of the cutterhead, modified design.

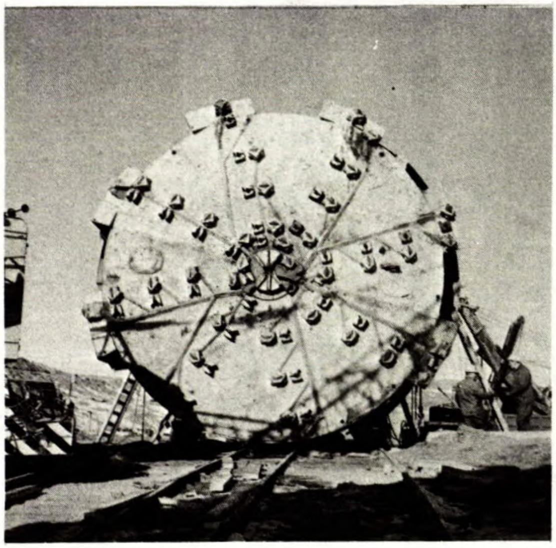

Figure 23. A front view of the cutterhead, original design.

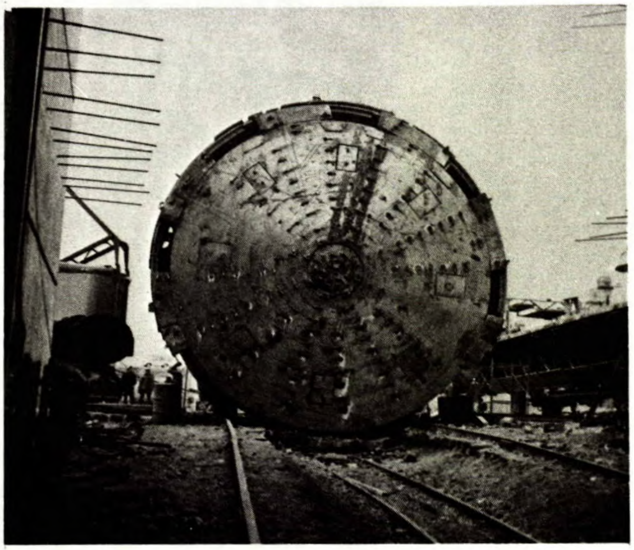

Figure 24. A front view of the cutterhead, modified design.

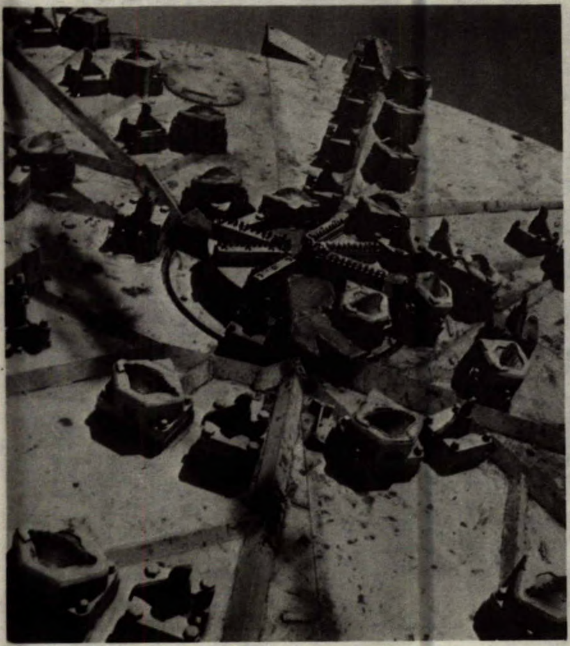

Figure 25. A view of the cutterhead teeth, original design.

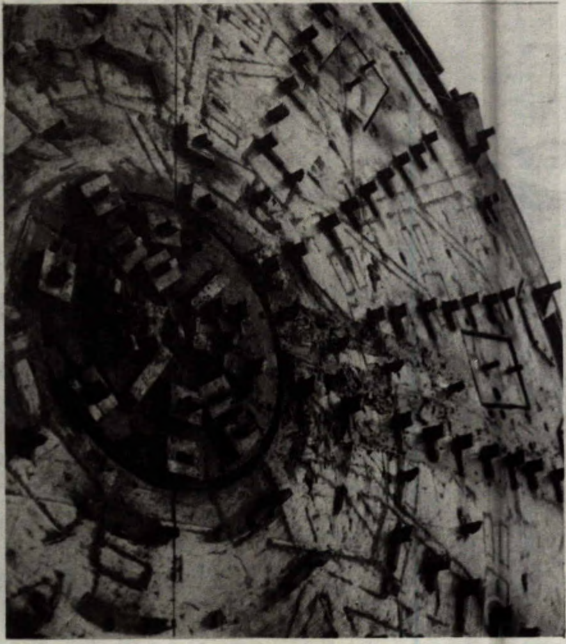

Figure 26. A view of the cutterhead teeth, modified design.

Figure 27. The carbide-tipped cutting knives, used as teeth in the cutterhead.

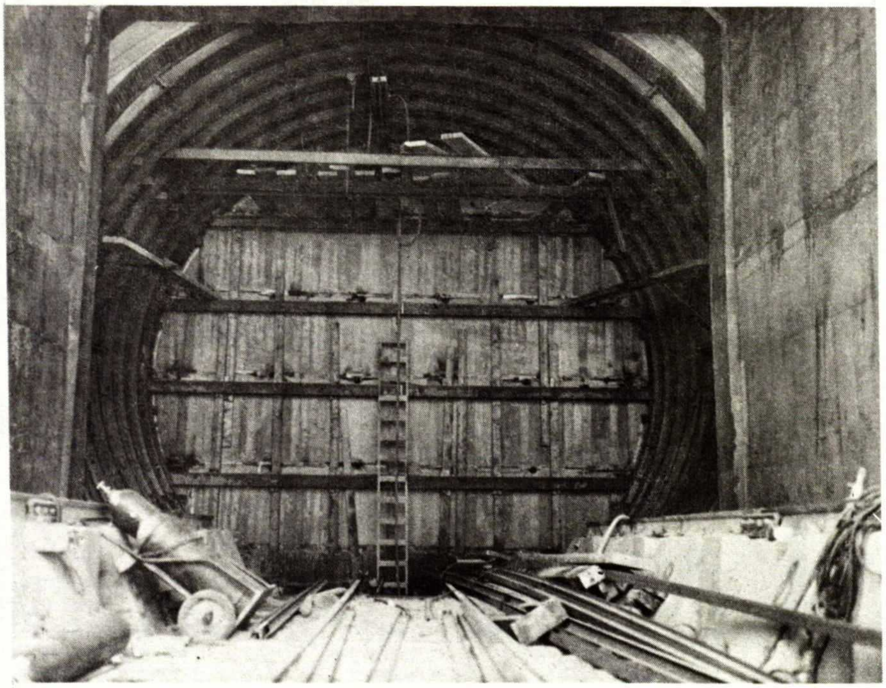

Figure 28. The grout face in an upstream tunnel portal, with timber lagging removed.

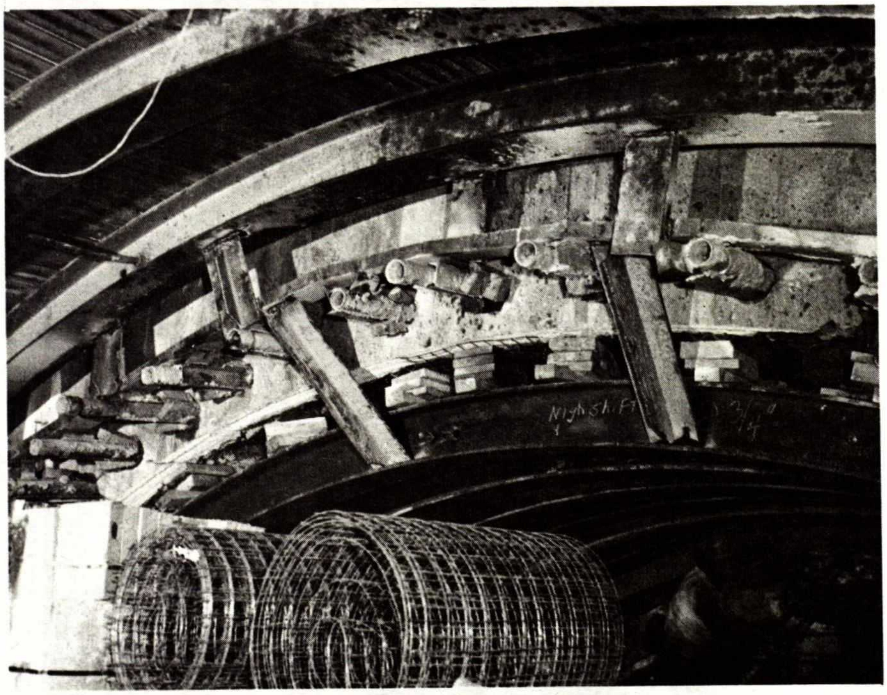

Figure 29. A spiling umbrella installed and grouted.

Figure 30. A fallout area with a grout pipe installed.

Figure 31. Forming method for holding cement grout; grout pipe shown at upper right.

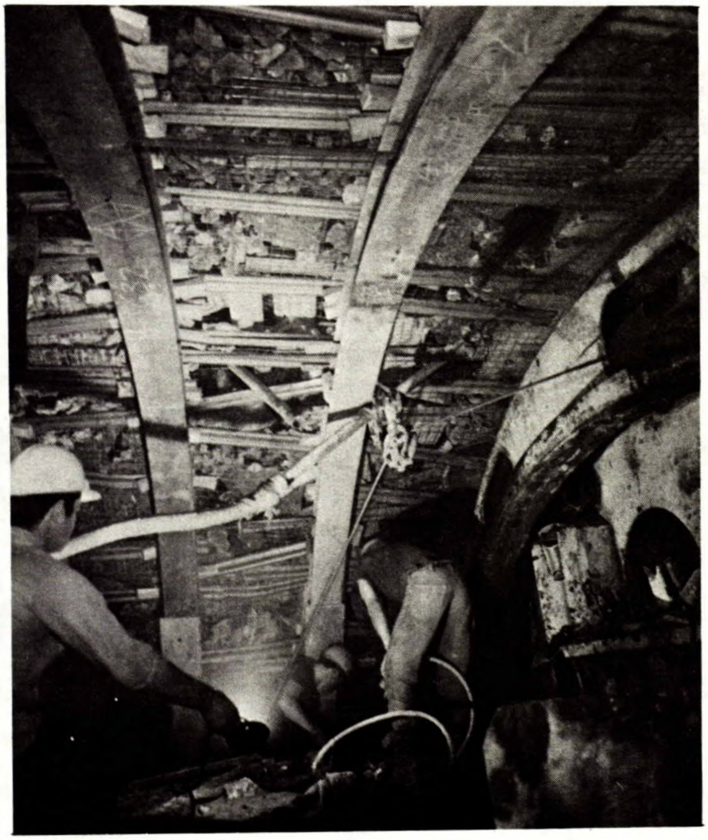

Figure 32. Pumping grout into a fallout area.

Figure 33. Over-mining support above the top of the cutterhead canopy.

Figure 34. A hand-mining area in front of the cutterhead, with the front of the cutterhead shown at left.

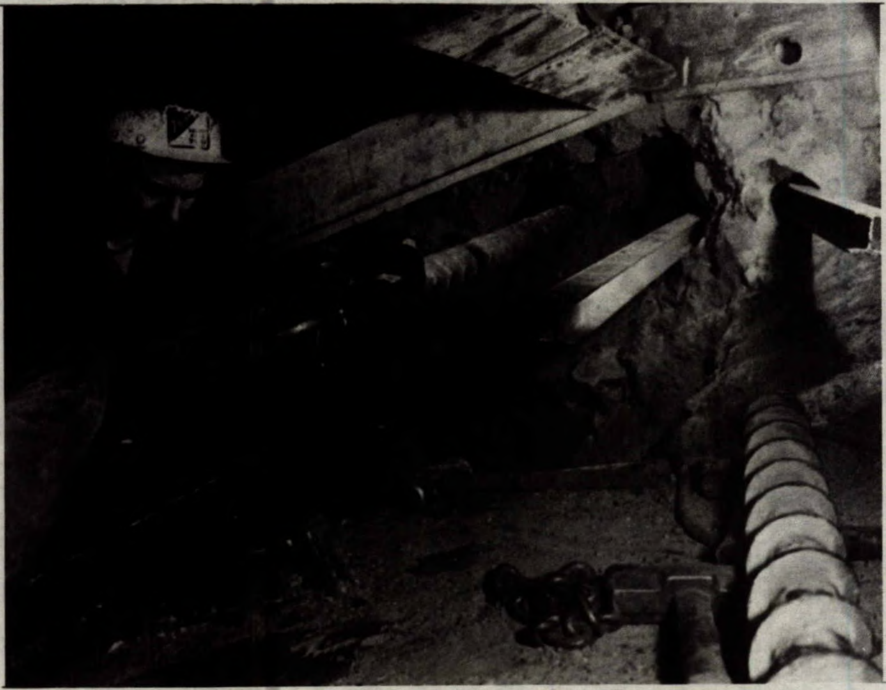

Figure 35. Drilling and setting "I" beams in a crown spiling umbrella.

Figure 36. A greased timber skid resting on the cutterhead canopy; steel beams forming a cage support are shown at the top of the photograph.

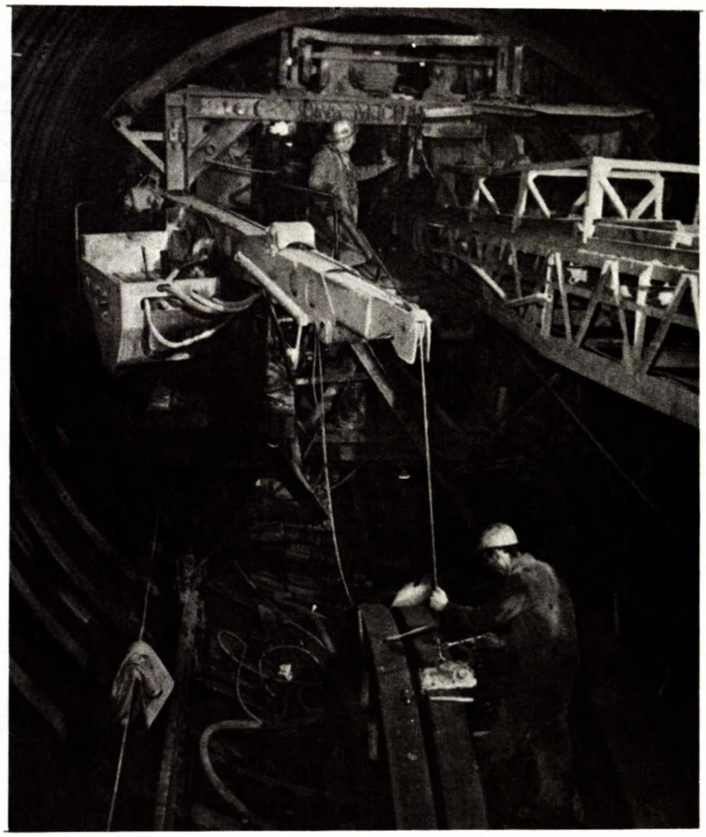

Figure 37. The Austin-Western hoist raising ringbeam quadrants onto the top deck of the mole.

Figure 38. The hydraulically operated ringbeam positioner in action.

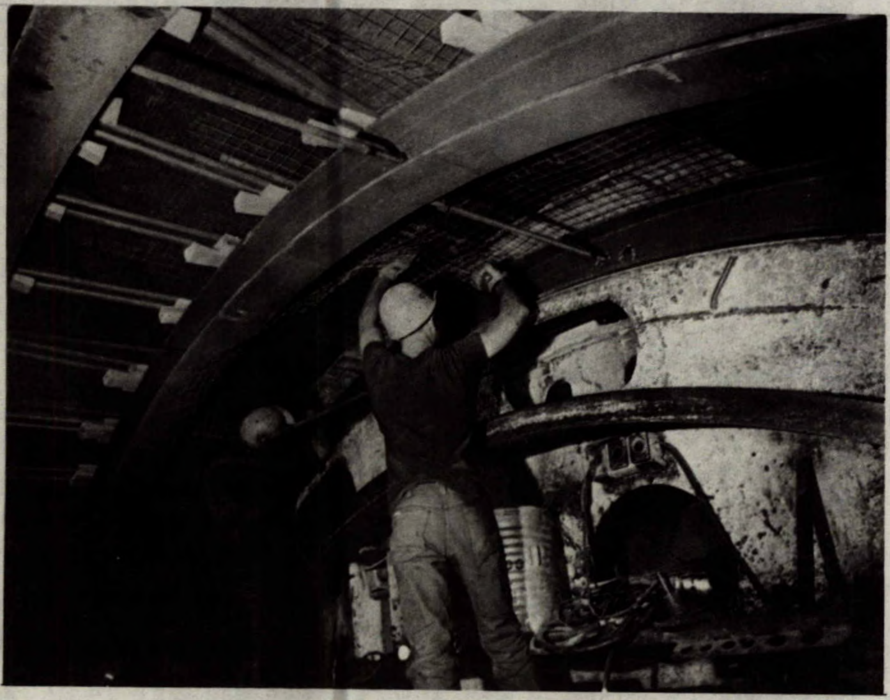

Figure 39. Installing wire mesh in the crown section of a tunnel.

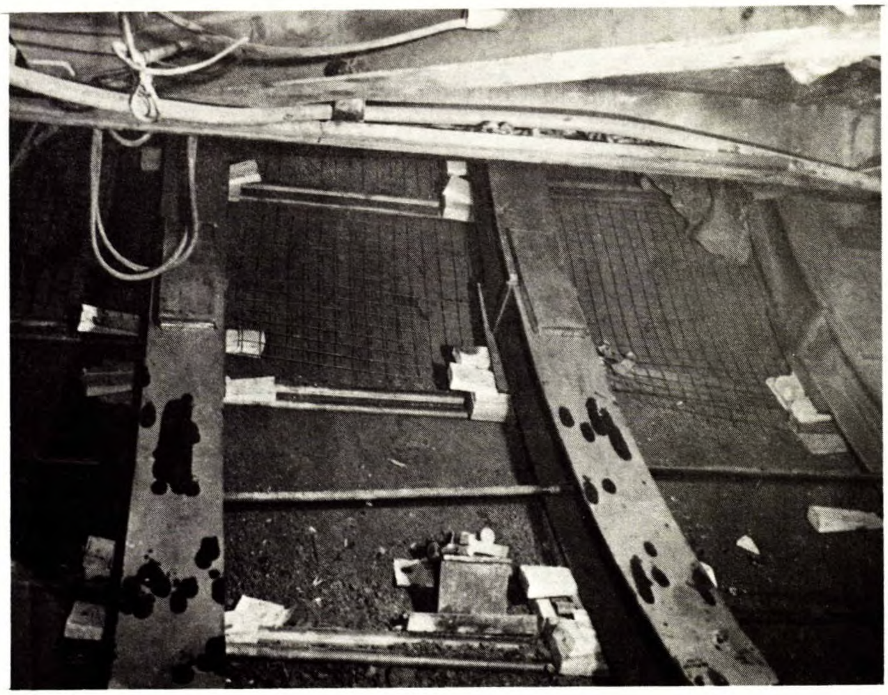

Figure 40. Wire mesh installed down to the haunch points in an invert section. Note the wide splice plates at the back of the ringbeams, and narrow plates on the inside.

Figure 41. Blocking steel lagging to ringbeams with wooden wedges.

Figure 42. A view of the shale surface before guniting.

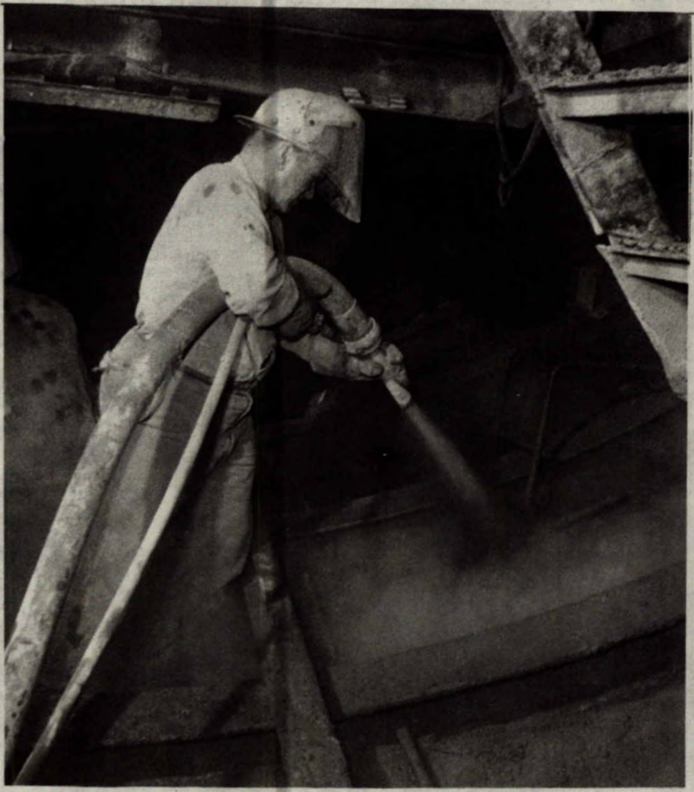

Figure 43. Placing gunite in the tunnel invert section behind the mole.

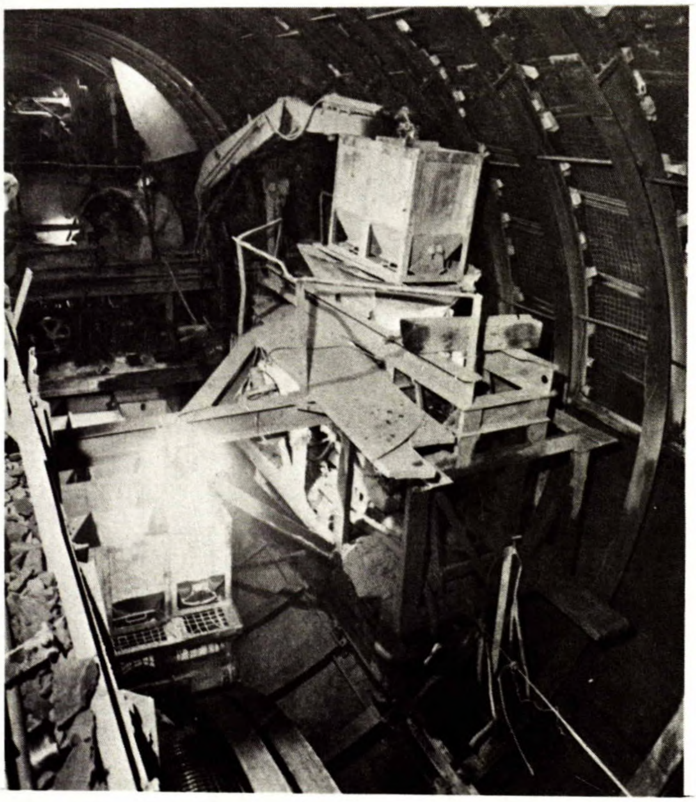

Figure 44. View of the gunite machines mounted on the front of the muck jumbo (photograph taken from rear of the mole).

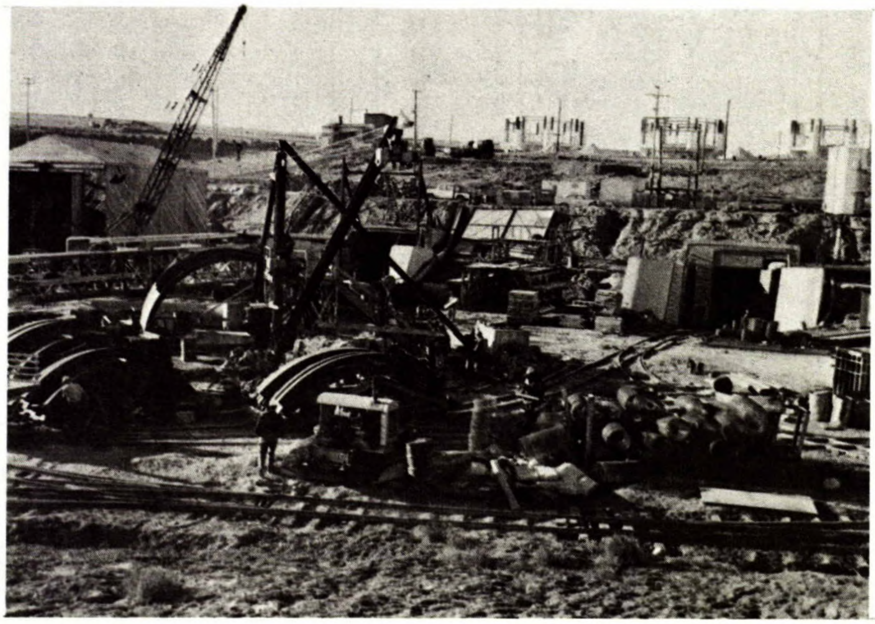

Figure 45. The supply yard for the upstream tunnels, showing the ring-beam stockpile and stiff-leg crane used to load the flat cars.

Figure 46

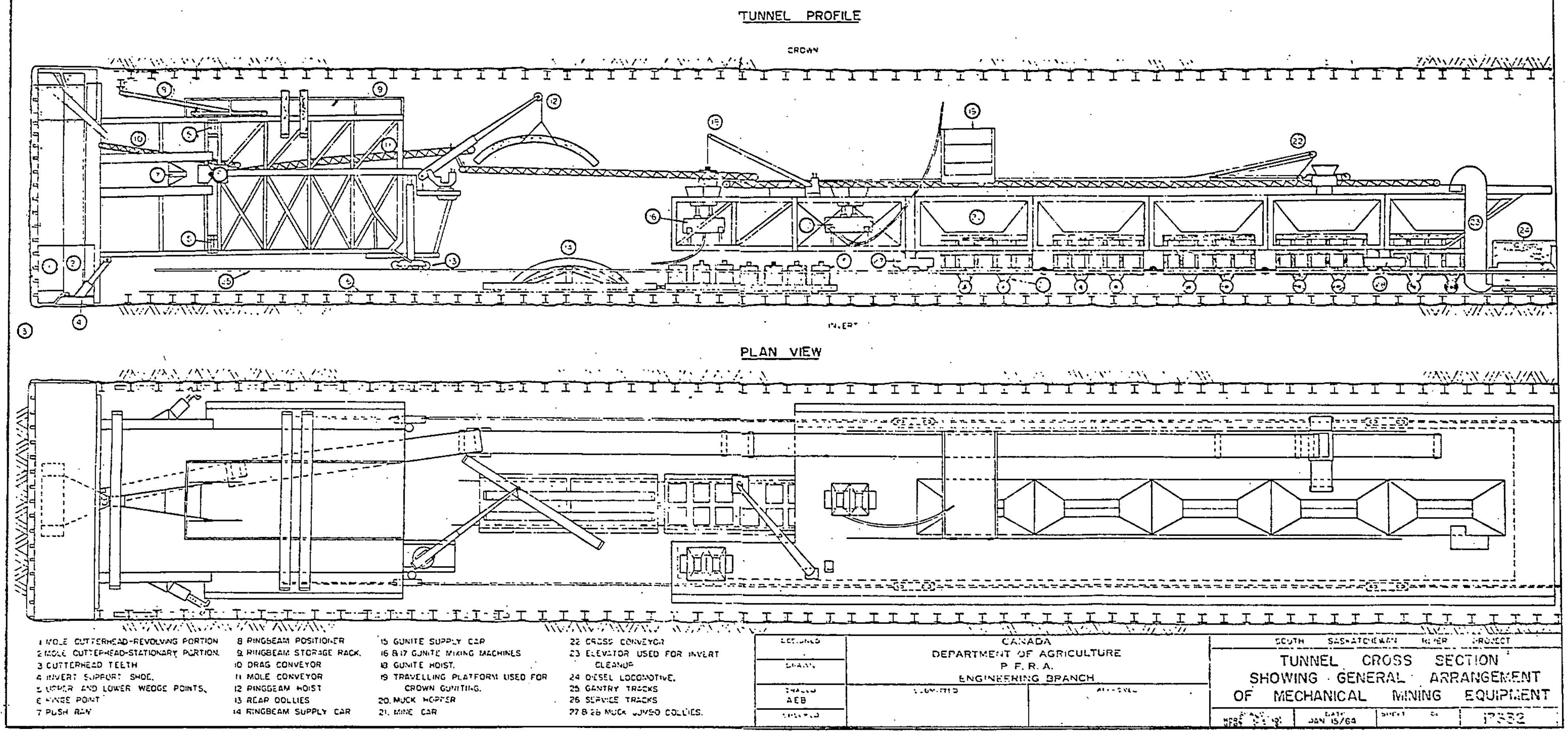

Figure 46: A plan and section view of the Robbins Model 261 boring machine.

CHAPTER 4

Greater Vancouver Sewerage and Drainage District, 8th Avenue Interceptor Tunnel, Vancouver, B.C.

History of the Operation

The Greater Vancouver Sewerage and Drainage District in 1963-65 constructed a 26,730-ft concrete conduit under 8th Avenue in the City of Vancouver, British Columbia. The conduit ran from Highbury Street to Clark Drive and was to be used for the purpose of intercepting present and future sewage flows and conveying them to the Highbury Street Interceptor sewage system. The work on the conduit consisted of three main sections: (1) that part of the interceptor that was to be constructed by tunnelling; (2) that part that was to be constructed by open-cut methods, and (3) other structures connecting the conduit to existing sewers and to the Highbury Interceptor.

Specifications called for the tunnel to be excavated to a diameter varying from 8 to 11 ft, with concrete lining varying from 8 in. to 14 in. thickness. The contract called for (Section C) 9,254 ft of concrete conduit with an inside diameter of 79 in. (Section B), 14,126 ft of concrete conduit with an inside diameter of 94½ in., and (Section A) 3,350 ft of conduit with an inside diameter of 103 in. The tunnel was to slope downwards some 33 ft from east to west.

The Drainage District had carried out a preliminary soil investigation during the winter of 1961-62, for the purpose of establishing the route of the tunnel, by drilling holes with a cable tool rig and taking drill samples at intervals. The logs of these holes were recorded on drawings.

A further soil investigation was carried out in the winter of 1962-63, using rotary drilling rigs. Drill samples of unconsolidated soils were taken at 5-ft intervals above bedrock and continuous core sampling was done through bedrock to below tunnel depth. The position and log of these holes were recorded on drawings.

Drill and core samples taken during the above drilling program and the drawings showing drilling results were made available to contractors bidding on the sewer project.

The maximum depth of ground over the planned conduit route was only 95 ft and in some portions would run through unconsolidated fill. For contract purposes, the tunnel excavation was divided into three types according to ground conditions, as follows:

Class 1 Excavation advanced in sandstone, shales, or other consolidated rocks not requiring rib support and lagging for ground support.

Class 2 Excavation advanced in sandstone, shales or other consolidated rocks requiring the use of rib supports and lagging.

Class 3 Excavation advanced in unconsolidated soils.

The Drainage District Corporation prepared a very comprehensive brief concerning the tunnel project for the information of the tenderers. This brief listed in detail all aspects of the project, including general specifications, materials to be used, and construction methods. Some 51 drawings were included in the contract documents. The contract pay rates were broken down into 33 different items. Table 12 of this report lists the items that concerned the actual excavation of the tunnel and also the open-cut construction portion.

Tenders were called for in April 1963, and the Northern Construction Co. and J.W. Stewart Ltd. was the successful bidder.

The contractor decided to use mechanical boring machines to excavate the portions of the tunnel to be driven through rock, and three lightweight machines, known as Scott excavators, were constructed by the contractor in its North Vancouver Shops. It is understood that this type of excavator had had little or no prior use in Canada for tunnel work but similar types had been used previously for tunnel excavations in the United States--in the states of Minnesota, Michigan, and Washington. The machines used in the Vancouver tunnel were custom built and were designed specifically for use in relatively medium to soft ground. An official of the contracting company stated that such a machine would not be suitable for boring in harder rock, such as that encountered in the Sooke Lake-Goldstream River Tunnel on Vancouver Island. In fact, his company had considered bidding on the Vancouver Island project but had decided against it, because of the hardness of the rock at the tunnel site.

Work on the Vancouver 8th Avenue Interceptor Tunnel commenced on June 14, 1963. Working areas were fenced off and construction offices built. Three main work areas for the tunnel project were established at Balsam, Yukon and Windsor Streets. The east end of the tunnel ended in an open cut at China Creek and work in this area commenced at the Windsor Street adit. Driving of the Windsor Street West adit started about July 2, 1963, and this heading broke through into the Yukon East face after advancing 4,687 ft, on January 31, 1964. Driving of the Windsor East face, from the open cut, did not commence until April 11, 1964, and was completed about July 4, 1964. All work up to July 21, 1963, was done by drilling and blasting methods. On that date, a Scott excavator arrived from Michigan, U.S.A., and was used in the Windsor West heading until three new Scott machines were constructed late in August. The borrowed machine was returned from whence it came at that time.

The work in the Yukon Street area consisted of driving an adit and tunnelling both east and west from this adit. The adit was completed to 80 ft length from the portal by August 10, 1963. The Yukon East heading started about August 17, 1963, and broke through into the Windsor Street West tunnel, after advancing 2,108 ft, on January 31, 1964. The Yukon West heading also started around August 17, 1963, and broke through into the Balsam East heading, after advancing 6,290 ft, on July 1, 1964. A Scott boring machine started work on the west face during the week of August 24, 1963.

The Balsam Street location had a shaft sunk to 107 ft depth and a headframe, hoist and chutes were installed there by August 24, 1963. Driving east and west from this shaft commenced about August 31, 1963. A Scott boring machine started excavating in this portion of the tunnel project on September 7, 1963. The Balsam West heading holed through to the Highbury Interceptor Sewer system, at the west end of the tunnel project, on September 19, 1964, after advancing 6,758 ft from the shaft. The Balsam East drive broke through in the Yukon West heading on July 4, 1964, after advancing 6,052 ft.

Summary of Operations

The author visited the Greater Vancouver Sewerage and Drainage District offices in January 1969, and studied plans and information on file concerning the tunnelling operations. No formal report had been prepared by the Corporation covering the operations. Records, giving daily advance information, were available but were complicated by having three separate Scott boring machines working simultaneously. It was decided to choose only one portion of the tunnel and study its progress in detail. The Corporation advised that the Yukon West Portion was fairly representative of all portions of the tunnel. This, then, was chosen for detailed study.

Table 11 gives details of the excavation of this portion of the tunnel. The information is simplified by showing it on a weekly basis. It can be seen that the tunnel was advanced 6,290 ft in 254 days, with 5,762 ft (91½%) being driven by a Scott excavator and 528 ft (8½) by drilling and blasting methods.

One of the peculiarities of the Vancouver tunnel project was that sometimes the Scott boring machines were advancing drilling "full face" and other occasions were only drilling "part face". In the "part face" operations, the boring machine was pulled back some distance from the face and short holes were drilled into the face when harder layers of rock were present. These holes were blasted to loosen up the face, the loose muck was removed and the Scott machine then was moved back to the face and continued boring until more hard rock layers were encountered, when the whole process was repeated. Table 11 shows the time when the machine was boring full face in the "Machine Boring" column, and when advancing part face in the "D&B Hard Layers" column. The combination of these two columns gives the time when the machine was actually in use. In the case of the Yukon West tunnel the Scott machine was in use about 85% of the time.

General Operating Information

Information obtained from the Drainage District showed that 79% of the total 8th Avenue Interceptor Tunnel project was done using Scott boring machines, with an average advance of from 4 to 30 ft per shift depending on the rock hardness. The peak advance was 56 ft per shift. Tunnelling was 89% in sandstone and shales, with the remaining 11% in glacial tills. The maximum depth below surface was 95 ft, near Alder Street. The material excavated amounted to 125,000 cu yds and went to City, C.P.R. and C.N.R. fills. Some 53 service holes were drilled from the street level to the tunnel for various services such as electricity, ventilation, pumping of water, and dropping of concrete. Most of the concrete was batched at the foot of Clark Drive and mixed on the site to provide optimum quality. The tunnelling machines were quieter and faster than the usual drilling and blasting procedure. City residents had few complaints about the work. The machines made a smooth neat bore with no overbreak, which meant a saving in concrete for lining the tunnel.

Ground conditions were generally good in the tunnel. Table 12 shows that 15,147 ft, or approximately 57% of total tunnel length, was in Class 1 ground, which required no wall support other than intermittent rock bolting supplemented with steel wire mesh or expanded metal reinforcing. Some 8,750 ft, or 33%, was in Class 2 ground, which required the use of steel ring beam rib supports reinforced with timber lagging. Only 2,020 ft, or approximately 7%, was in Class 3 ground, which was unconsolidated soils and generally required a hand-mining method of excavation and close ground support. Some 800 ft, or 3%, was open-cut construction.

Rock bolts used were 5/8-in. minimum diameter and 6 ft in length. Bolting material was required to conform to specification for Carbon Steel Bar to Mechanical Property Requirements ASTM A306, latest issue, Grade 32510. The wire mesh used with the rock bolts was of black wire woven 12 gauge, with 2 x 2 in. openings, or made of an approved expanded metal. Normally only two rock bolts were used at the crown of the tunnel, set at 4-ft centres, and driven at a 60° angle from the centre line of the tunnel.

The steel ribs used in ground support were made of medium structural steel, at ASTM Standard Specification A7, such as used for construction of bridges and buildings. Specifications called for the ribs to be accurately curved to the proper radius of the tunnel section, and rib segments were to fit closely for bolted connections and segmented and transverse joints. Any pressed steel plates used were to conform to ASTM Standard Specifications for Hot Rolled Carbon Steel Bars A107, Grade 1008, with 0.10 per cent carbon maximum. The steel sets actually used were 4 x 4 in. WF 13 lb/ft, supplied in curved quadrants, and were usually erected at 6-ft centres with structural-grade timber blocks, lagging and wedges being used to block the sets against the walls of the tunnel (see Figure 48). The same type of sets were used when supporting the tunnel in the drilling and blasting method of excavation, except that the sets were adapted to a horseshoe shape by using straight legs toed into the side of the tunnel rather than curved segments (see Figure 49). The type of ground conditions resulting from drilling and blasting in sandstone are shown in Figure 50.

The Scott Tunnel Excavator

No plans were available to show the construction of the Scott boring machine, but Figure 47 illustrates the general layout of the machine. The machines were built by the contractor at a cost of approximately $150,000 each and were designed specifically for use in medium to soft ground. The spoke diameter and mucking wheel on the cutterhead could be varied in length to give a boring diameter of 8 to 13 ft. The cutter devices were tungsten-carbide-tipped teeth mounted in bit holders. The number of teeth in use could vary up to about 98. The penetration rate was a maximum of 7 ft per hour and the speed of the cutterhead was 8 rpm. The weight of the machine was between 12 and 14 tons. The length was 22 ft, or 36 ft including the first muck conveyor. Conveyor belts and additional conveyors were used to load eight 2-ton mine cars and 6- to 8-ton battery locomotives on a 24-in. track were used to remove the muck cars. The cutterhead was powered by two 90-hp motors, 300-v, 3-phase, 120 cycles. The hydraulic pumps used were powered by 8-hp motors and the muck conveyors by 8- to 10-hp motors. The cutterhead had a mucking wheel mounted on the periphery with 10 x 2 in. fins inside which caught up the broken rock and discharged it by gravity on to a conveyor belt at the top. Hydraulic cylinders mounted horizontally at 5-ft and 15-ft locations back from the cutterhead gave a four-point grip on the tunnel walls. A large horizontal cylinder located along the centre of the machine supplied forward thrust to hold the cutterhead against the face. The hydraulic system was said to generate 3,000 psi. A suction fan at the cutterhead exhausted dusty air into a main 12-in. exhaust airline. A water spray was used at the conveyor belt to reduce dust.

The cutterhead design was different from the Robbins design used in other tunnel projects in Canada. A number of teeth were mounted in a bit at the centre of the head. Four rows of cutters, each containing 7 teeth, radiated from the centre in a cone shape. The outer portion of the head contained four adjustable spokes, mounted at 90^o angles. Each spoke held 7 teeth, when boring an 8-ft-diameter hole, but more teeth could be added as required when the diameter was increased. (See Figure 47.)

The Drainage District carried out the original surface surveys and established the bench marks and reference marks showing the centre line of the tunnel. The contractor was responsible for checking these and transferring the line and levels to all points of construction. The line and grade were maintained in the tunnel by setting up transit instruments in the tunnel and sighting a target mounted on the machine.

The dust hazard was not high in the tunnel, due to the many openings to surface and the wet conditions encountered. Control of water was not a serious problem. Water tended to flow into the tunnel from the adits and shaft during periods of heavy rain, and had to be pumped out. As the Yukon West tunnel was progressing downgrade, the volume of water handled tended to increase as the tunnel advanced. On occasion, excess water halted the progress of the machine, especially after a holiday (such as Thanksgiving and Easter) or when working in an area where the tunnel was close to surface and water could seep through the unconsolidated soil or surface fill.

The Scott machines were relatively easy to dismantle and move. A machine could be dismantled and moved out of the tunnel in one shift and could be moved back from one working face to the other face heading in the opposite direction in about one shift. The machine could also be moved back from the face easily to allow the drilling and blasting of hard layers in the face without removing the machine from the tunnel. Blasting did cause some damage to the mole and replacement of main shafts, and other repairs on the Scott machine in the Yukon West heading were due in part to damage caused by flying rock and concussion from blasting operations. Blasting operations increased the need for more ground control when the mole was in use with hard layers in the face being blasted. There was little need for any ground control, other than occasional rock bolts and wire mesh, when the machine was boring full-face in Class 1 ground.

During the time that the Scott machine was in use in the Yukon West portion of the tunnel, it was not necessary to use ringbeams any closer than 5- to 6-ft centres and roof lagging to support the ground in Class 2 type of ground. A buried gully was encountered at 1,534 ft west of the adit on December 28, 1963, and a distance of some 300 feet had to be excavated by hand-mining or drilling and blasting methods, with the mole being removed from the tunnel. Ringbeams were set at 4- to 6-ft centres in this section of tunnel, and some breast boarding and spiling was required to support the ground. The mole returned on February 5, 1964, after the Class 3 unconsolidated section of ground had been passed through.

Cost estimates for the construction of the 8th Avenue Interceptor, as far as tunnelling operations are concerned, are shown in Table 12. Estimates for the Yukon West Portion only are shown in Table 13.

Figure 51 shows a map of Greater Vancouver Sewerage and Drainage District, with particular reference to sewerage and drainage facilities. The 8th Avenue Interceptor conduit can be seen running parallel to 10th and 12th Avenues. By far the largest complex for sewage disposal in the District consists of the Iona Island Sewage Treatment Plant, the crossing of the North Arm of the Fraser River, the Highbury Tunnel, 4th Avenue Interceptor, Spanish Bank Pump Station, and the 8th Avenue Interceptor, all of which have been completed to eliminate the continuous discharge of raw sewage into English Bay. Only during periods of very-high-intensity storms will some very dilute sewage be able to escape into the Bay via emergency overflows.

Acknowledgements

The author wishes to acknowledge the assistance of the undernoted in gathering information, photographs and data concerning the 8th Avenue Interceptor Tunnel project:

Greater Vancouver Sewerage and Drainage District
2294 West 10th Avenue, Vancouver 9, B.C.

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Northern Construction Co. & J.W. Stewart Ltd.
North Vancouver, B.C.

F. Langfeldt, Project Manager

TABLE 11

GREATER VANCOUVER SEWERAGE AND DRAINAGE DISTRICT
8TH AVENUE INTERCEPTOR TUNNEL

SUMMARY OF EXCAVATION OF YUKON WEST PORTION OF TUNNEL

Date (Week Ending)	Distance from Portal (feet)	Days Worked (6-day week)	Total Manhours Worked	Water Flow (g.p.m.)	Remarks
1963					
June 14	-	-	-	-	Work started on tunnel adits.
July 5	-	-	-	-	Work started on Yukon Street adit.
24	-	-	-	-	Adit advanced to 6' by drill and blast (D&B) method.
Aug 10	-	-	-	-	Adit advanced to 80' by D&B method (in sandstone).
	-	n.a.	n.a.	n.a.	
Aug 17	14	2	$384^{(e)}$	-	Tunnels driven 48' east and west from adit by D&B method.
24	77	5	$960^{(e)}$	-	Boring machine (mole) started on west face. Some D&B.
31	154	5	$960^{(e)}$	3.0	Tunnel being supported with steel ringbeams and lagging.
	-	12	$2304^{(e)}$	3.0	
Sept 7	157	3	496	3.0	Mole dismantled and moved to Yukon East face.
14	180	6	576	3.0	D&B method of excavation in use (sandstone).
21	219	6	576	3.5	" " " " "
28	273	6	912	3.0	" " " " "
	-	21	2560	3.0	
Oct 5	344	6	1000	6.0	Mole moved back from Yukon East face.
12	485	6	744	6.3	Repairs to wheel and hopper on mole.
19	528	5	620	n.a.	Repairs to wheel. Erecting steel sets.
26	582	6	932	n.a.	Main shaft broken on mole, removed for repairs (64 manhours).
Nov 2	700	6	928	n.a.	Reassembled mole (84 manhours). Repairs to teeth.
-	-	29	4224	6.1	
Nov 9	848	6	1024	8.5	Electrical repairs (84 hrs). Moving power unit (124 hrs).
16	930	5	616	10.0	Conveyor repairs. D&B in part and erecting steel sets.
23	992	6	1152	n.a.	Main shaft broken on mole on 19th. Repairs 5 shifts.
30	1143	6	1120	n.a.	Installed vent. fan, erected sets, D&B hand layers in sandstone.
-	-	23	3912	9.2	

Note: (e) = estimated.

- cont'd

Table 11
(continued) (1a)

Date (Week Ending)	Total Advance	Mole Operation (e)						Drill Blast Method	
				Machine Idle (Manhours)					
		Advance	Machine Boring	Repairs	Ground Control	Moving	D&B Hard Layers	Advance	Total Manhours (Days)
	(feet)	(feet)	(Manhours) (Full face bored)				(Part face bored)	(feet)	
1963									
June 14	-	-	-	-	-	-	-	-	-
July 5	-	-	-	-	-	-	-	-	-
24	6	-	-	-	-	-	-	6	-
Aug 10	74	-	-	-	-	-	-	74	-
-	80	(Adit only)						80	(n.a.)
Aug 17	14	-	-	-	-	-	-	14	384(e) (2)
24	63	33	284	-	-	120	172	30	384(e) (2)
31	77	77	586	-	-	-	374	-	-
12 days	154	110	870	-	-	120	546	44	768(e) (4)
Sept 7	4	4	64	120	56	256	-	-	-
14	23	-	-	-	-	-	-	23	576 (6)
21	39	-	-	-	-	-	-	39	576 (6)
28	53	-	-	-	-	-	-	53	912 (6)
21 days	119	4	64	120	56	256	-	115	2064 (18)
Oct 5	71	54	240	-	-	288	224	17	248 (2)
12	141	141	416	188	-	-	140	-	-
19	43	43	264	132	112	-	112	-	-
26	54	54	488	356	-	64	24	-	-
Nov 2	118	118	364	100	232	-	232	-	-
29 days	427	410	1772	776	344	352	732	17	248 (2)
Nov 9	149	149	792	232	-	-	-	-	-
16	82	82	444	24	64	-	84	-	-
23	62	62	596	296	208	-	52	-	-
30	150	150	668	40	168	-	244	-	-
23 days	443	443	2500	592	440	-	380	-	-

Note: (e) = estimated (based on daily reports).

- cont'd

(Table 11, cont'd)

(2)

Date (Week Ending)	Distance from Portal	Days Worked	Total Manhours Worked	Water Flow (g.p.m.)	Remarks
Dec 7/63	1269	6	912	20.0	D&B on hard layers.
14	1422	6	1152	n.a.	Electrical repairs and power failure. D&B hard layers.
21	1557	6	1152	26.4	Repairs to front ram. D&B hard layers. Erecting steel sets.
28	1558	3	384	32.7	Mole removed while working through filled section.
Jan 4/64	1575	4	544	34.6	Conventional mining methods in use while working through old fill (Class III excavation for 105 feet).
11	1615	6	1080	33.9	
18	1651	6	1080	57.7	Old storm sewer removed at face.
25	1714	6	880	61.8	Hand excavating required. Spiling walls for 12 feet.
Feb 1	1774	5	560	52.0	D&B and timbering.
-	-	27	4144	47.9	
Feb 8	1949	6	1080	48.5	Mole returned on 5th. Erecting steel sets.
15	2200	6	1080	43.0	Electrical repairs. D&B on hard layers. Unsupported sandstone.
22	2448	6	1080	46.8	" " " " " "
29	2662	5	900	39.6	" " " " " "
-	-	23	4140	44.5	
March 7	2890	6	1152	42.1	Excess water halted mole. D&B hard layers.
14	3028	6	1136	45.0	Repairs to conveyor (120 hrs).
21	3201	6	1152	62.7	D&B hard layers. Unsupported sandstone walls.
28	3562	4	768	62.4	Repairs to teeth holders in cutterhead.
-	-	22	4208	53.0	
Apr 4	3784	6	1140	57.3	Repairs to teeth holders (56 hrs). D&B hard layers.
11	3923	6	1152	52.3	Changing power connections (80 hrs). Repairs (64 hrs).
18	4105	6	1152	51.2	Ram repairs (32 hrs). D&B hard layers.
25	4443	5	960	58.0	Repairs to tube (48 hrs). D&B hard layers.
May 2	4550	5	916	56.6	Pump repairs, face flooded. D&B hard layers.
-	-	28	5320	55.1	

- cont'd

(Table 11, cont'd)

(2a)

Date (Week Ending)	Total Advance (feet)	Mole Operation (e)						Drill & Blast Method	
		Advance (feet)	Machine Boring (Manhours)	Machine Idle (in manhours)				Advance (feet)	Total Manhours (Days)
				Repairs	Ground Control	Moving	D&B Hard Layers		
Dec 7	126	126	736	-	-	-	176	-	-
14	153	153	564	68	68	-	452	-	-
21	135	135	588	48	68	-	448	-	-
28	1	1	32	-	20	332	-	-	-
21 days	415	415	1920	116	156	332	1076	-	-
Jan 4/64	18	-	-	-	-	-	-	18	544 (4)
11	40	-	-	-	-	-	-	40	1080 (6)
18	36	-	-	-	-	-	-	36	1080 (6)
25	62	-	-	-	-	-	-	62	880 (6)
Feb 1	60	-	-	-	-	-	-	60	560 (5)
27 days	216	-	-	-	-	-	-	216	4144 (27)
Feb 8	175	40	436	-	-	196		135	448 (3)
15	251	251	520	44	-	-	516	-	-
22	248	248	696	24	-	-	360	-	-
29	214	214	516	84	-	-	300	-	-
23 days	888	753	2168	152	-	196	1176	135	448 (3)
March 7	228	228	652	84	-	-	416	-	-
14	138	138	256	172	-	-	708	-	-
21	173	173	396	48	-	-	708	-	-
28	361	361	692	76	-	-	-	-	-
22 days	900	900	1996	380	-	-	1832	-	-
April 4	222	222	600	164	-	-	376	-	-
11	139	139	328	144	-	-	680	-	-
18	182	182	544	60	-	-	548	-	-
25	338	338	820	80	-	-	60	-	-
May 2	107	107	220	88	-	-	608	-	-
28 days	988	988	2512	536	-	-	2272	-	-

- cont'd

(3)

(Table 11, cont'd)

Date (Week Ending)	Distance from Portal	Days Worked	Total Manhours Worked	Water Flow (gpm)	Remarks
May 9/64	4659	6	1088	51.8	Nose cone repairs. D&B on hard layers.
16	4724	5	640	53.2	Minor repairs - Drilling grout holes.
23	4805	5	768	54.6	Minor repairs - D&B on hard layers.
30	4960	6	896	61.8	New wheel on mole, moving fan. D&B hard layers.
-	-	22	3392	55.3	
June 6	5348	6	1056	71.0	Repairs to conveyor. D&B hard layers.
13	5659	6	1040	75.2	Switch repairs. D&B hard layers.
20	4965	6	1108	77.0	D&B hard layers.
27	6153	5	952	77.0	D&B hard layers.
-	-	23	4156	75.0	
July 4	6290	3	512	70.0	Break through to Balsam East section of tunnel.
			Yearly Summary -		Yukon West Tunnel -
June 4- Aug 14/63	-	-	-	-	Driving 80' adit to tunnel location.
Aug 15- Dec 28/63	1558	106	16,600	-	Driving Yukon West Tunnel by mole & D&B methods.
Dec 29/63 July 4/64	6290	148	25,872	-	Driving Yukon West Tunnel by mole & D&B methods.
Total	6290	254	42,472	-	45½ weeks (10½ months)

STATISTICAL SUMMARY

Average advance per day = $\frac{6290}{254}$ = 24.8 ft. (Using both mole and D &B methods)

Average manhours worked per day = $\frac{42472}{254}$ = 167 manhours

Average number of men working per day = $\frac{167}{8}$ = 21 = 7 per shift.

- concluded

(Table 11, concluded)

(3a)

Date (Week Ending)	Total Advance (feet)	Mole Operation (e)						Drill & Blast Method	
		Advance (feet)	Machine Boring (Manhours)	Machine Idle (manhours)				Advance (feet)	Total Manhours (Days)
				Repairs	Ground Control	Moving	D&B Hard Layers		
May 9/64	109	109	136	132	-	-	820	-	-
16	65	65	-	-	-	-	640	-	-
23	82	82	152	36	-	-	580	-	-
30	154	154	512	40	-	-	344	-	-
22 days	410	410	800	208	-	-	2384	-	-
June 6	288	288	660	84	-	-	312	-	-
13	412	~~412~~	928	64	-	-	48	-	-
20	305	305	1076	-	-	-	32	-	-
27	188	188	912	-	-	-	40	-	-
23 days	1193	1193	3576	148	-	-	432	-	-
July 4	137	137	512	-	-	-	-	-	-
			Yearly Summary -	Yukon West Tunnel -					
June 14-Aug 14/63	(80) -	Adit only	(to give access to	tunnel) -				(80)	n.a.
Aug 15-Dec 28/63	1558	1382	7,126	1604	996	1060	2734	177	3080 (24)
Dec 29/63 July 4/64	4732	4380	11,564	1424	-	196	8096	351	4592 (30)
254 days	6290	5762	18,690	3028	996	1256	10830	528	7673 (54)

STATISTICAL SUMMARY - YUKON WEST TUNNEL

Mole average advance per day = $\frac{5762}{200}$ = 28.8

Total hours of mole operation = 18690+3028+996+1256+10830 = 34,800

Total hours using drilling and blasting excavation method = $\frac{7,672}{42,472}$

Utilization of mole in full-face boring= $\frac{18690}{34800}$ = 53.7 %

Combination of boring part-face and blasting hard layers on face= $\frac{10830}{34800}$= 31.1%

Total 84.8 %

Repairs to mole = $\frac{3028}{34000}$= 8.7%. Moving Mole = $\frac{1256}{34000}$= 3.6%

Ground Control = $\frac{996}{34000}$= 2.9%

TABLE 12

Greater Vancouver Sewerage and Drainage District

Construction and Completion of 8th Avenue Interceptor and Appurtenances

Extracts Taken From Contract No. 66

Schedule of Quantities and Prices

Item	Classification	Unit	Estimated Quantity	Unit Price	Total Price
	(103" Diam. Conduit)			$	$
1	Tunnel Section A, unreinforced Class I excavation	Lin.ft.	1,500	85.00	127,500
2	" " " " Class II "	"	1,450	112.00	162,400
3	" " " " Class III "	"	400	227.00	90,800
		"	3,350	113.80	380,700
	(94½"diam. Conduit)				
7	Tunnel Section B, unreinforced Class I excavation	Lin.ft.	8,000	79.00	632,000
8	" " " " Class II "	"	5,900	97.70	576,430
9	" " " " Class III "	"	220	254.00	55,880
		"	14,120	89.50	1,264,310
	(79"Diam. Conduit)				
13	Tunnel Section C, unreinforced Class I excavation	Lin.ft.	5,647	70.00	395,290
14	" " " " Class II excavation	"	1,400	96.00	134.400
15	" " " " Class III excavation	"	1,400	204.00	285,600
		"	8,447	96.60	815,290
	Total Class I excavation	Lin.ft.	15,147	76.30	1,154,790
	" II "	"	8,750	99.60	873,230
	" III "	"	2,020	214.00	432,280
		"	25,917	95.00	2,460,300
19	Rock bolts in Class I excavation	Each	1,500	5.00	7,500
19A	Wire mesh for use with rock bolts	Sq.yds.	1,500	4.30	6,450
	Total rock bolts	-	1,500	9.30	13,950
22	Tunnel dewatering-gallons pumped from tunnel	50,000	1,000	47.60	47.600
23	Tunnel - test holes	Lin.ft.	1,650	1.24	2,046
20	Open cut construction, Section C (79")	Lin.ft.	800	115.00	92,000
	Total excavating, without concrete lining	Lin.ft.	26,717	98.00	2,615,896
	Total completed contract	Lin.ft.	26,717	175.50	4,694,718

TABLE 13

SUMMARY OF YUKON WEST PORTION OF TUNNEL ADVANCE AS RECORDED ON OPERATING PLANS

Tunnel Section	Distance Excavated (feet)	Machine Excavated				Conventional Excavation				Total Holes Sunk (feet)
		Class I	Class II	Class III	Total	Class I	Class II	Class III	Total	
B	5716	4753	612	-	5365	30	111	210	351	365
C	574	238	159	-	397	-	177	-	177	40
Total	6290	4991	771	-	5762	30	288	210	528	405

Cost Estimates - Yukon West Portion (e)

Item	Classification	Unit	Estimated Quantity	Unit Price $	Total Price $
7	Tunnel Section B (94½") unreinforced Class I excavation	Lin ft	4783	79.00	378,000
8	Tunnel Section B (94½") unreinforced Class II excavation	" "	723	97.70	70,600
9	Tunnel Section B (94½") unreinforced Class III excavation	" "	210	254.00	53,400
			5716	88.00	502,000
13	Tunnel Section C (79") unreinforced Class I excavation	" "	238	70.00	16,700
14	Tunnel Section C (79") unreinforced Class II excavation	" "	336	96.00	32,300
15	Tunnel Section C (79") unreinforced Class III excavation	" "	-	204.00	-
			574	85.50	49,000
	Total Class I excavation	" "	5021	78.60	394,700
	Total Class II excavation	" "	1059	97.00	102,900
	Total Class III excavation	" "	210	254.00	53,400
			6290	87.70	551,000
19	Rock bolts in Class I excavation	each	630(e)	5.00	3,200
19A	Wire mesh for use with rock bolts	sq yds	630(e)	4.30	2,700
	Total rock bolts		630(e)	9.30	5,900
22	Tunnel dewatering	50,000 gals	240(e)	47.60	11,400
23	Tunnel - test holes	Lin ft	405	1.24	500
	Total		6290	90.40	568,800

(e) estimated by author

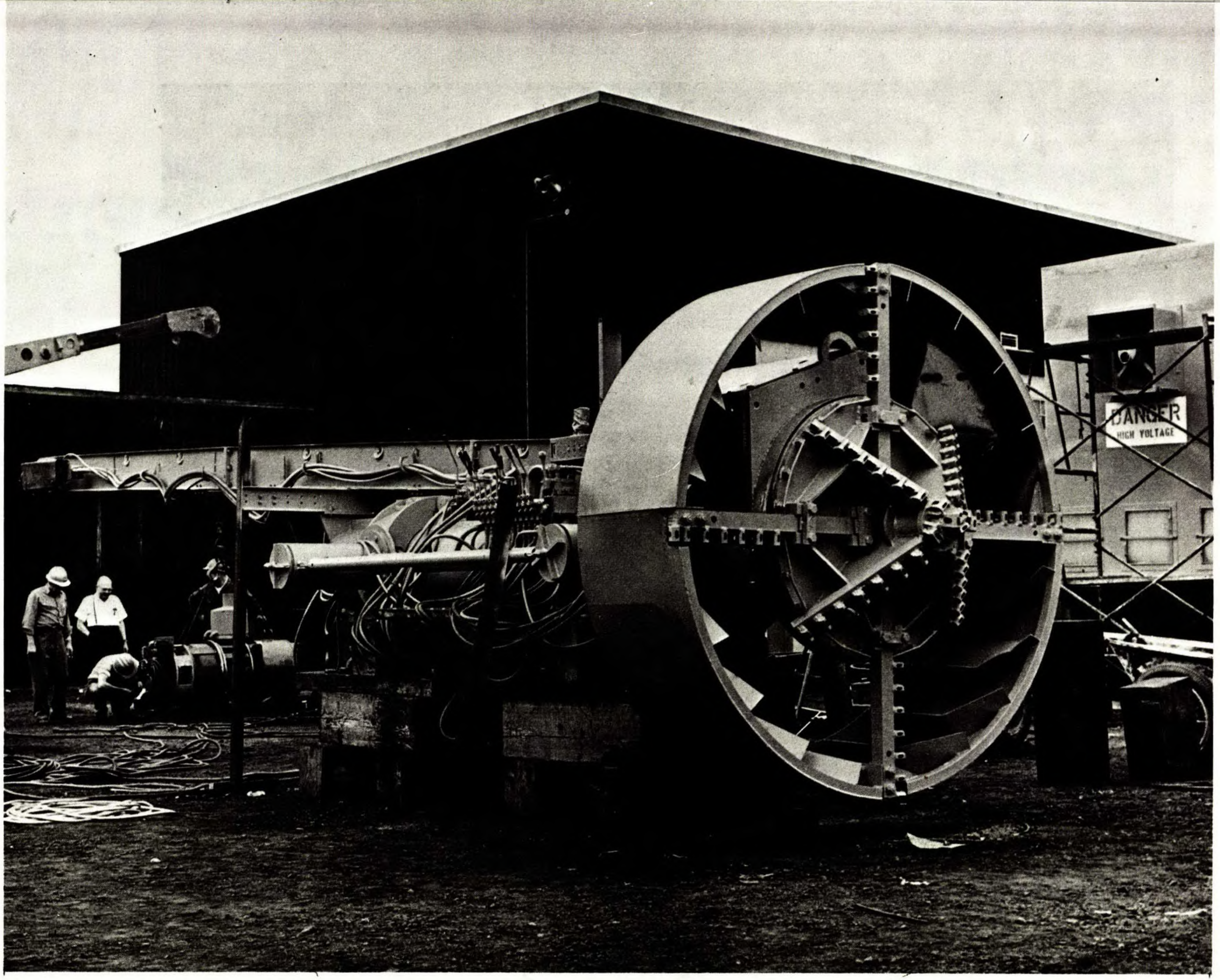

Figure 47. View of the Scott tunnel excavator.

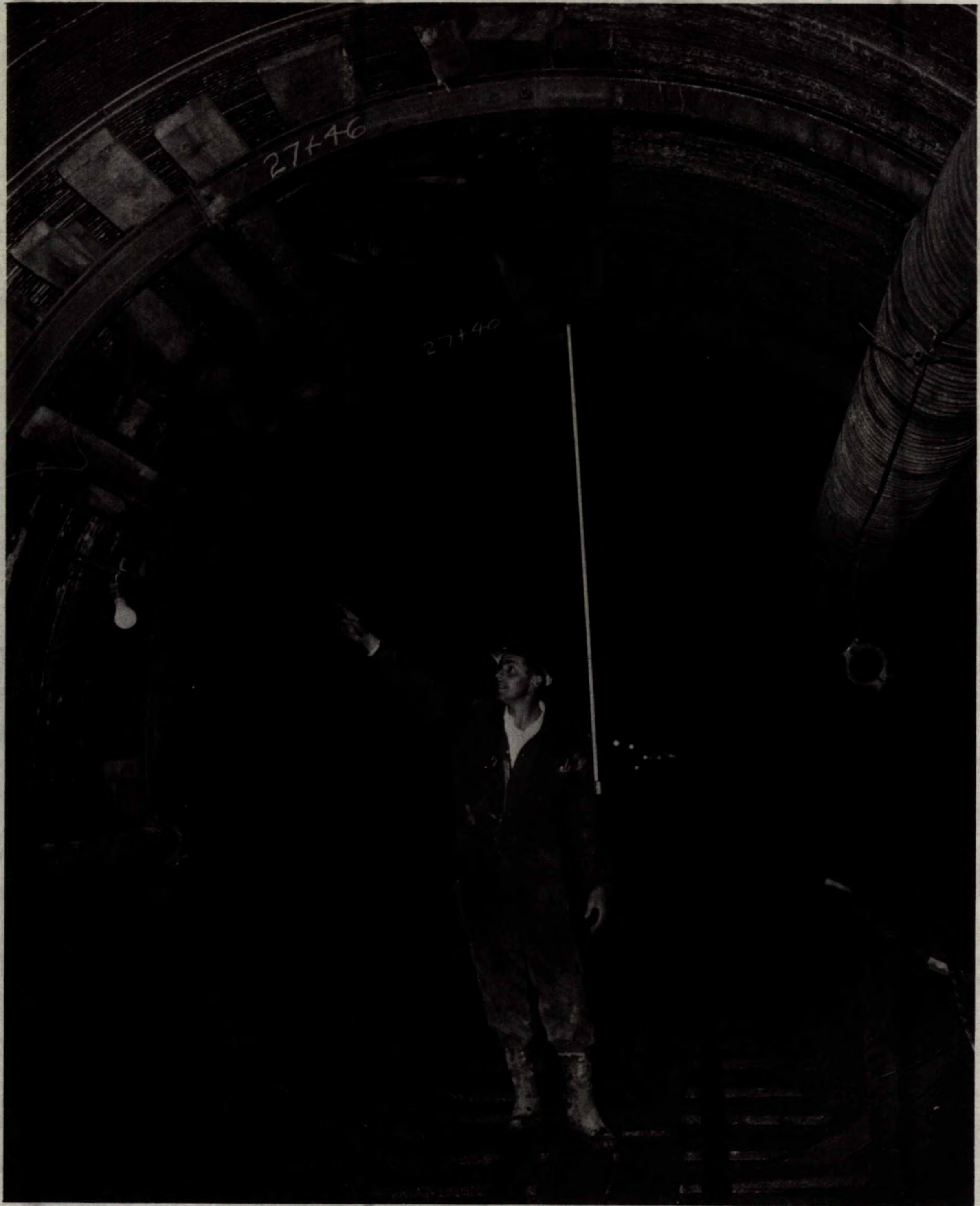

Figure 48. Ground control in bored section of tunnel.

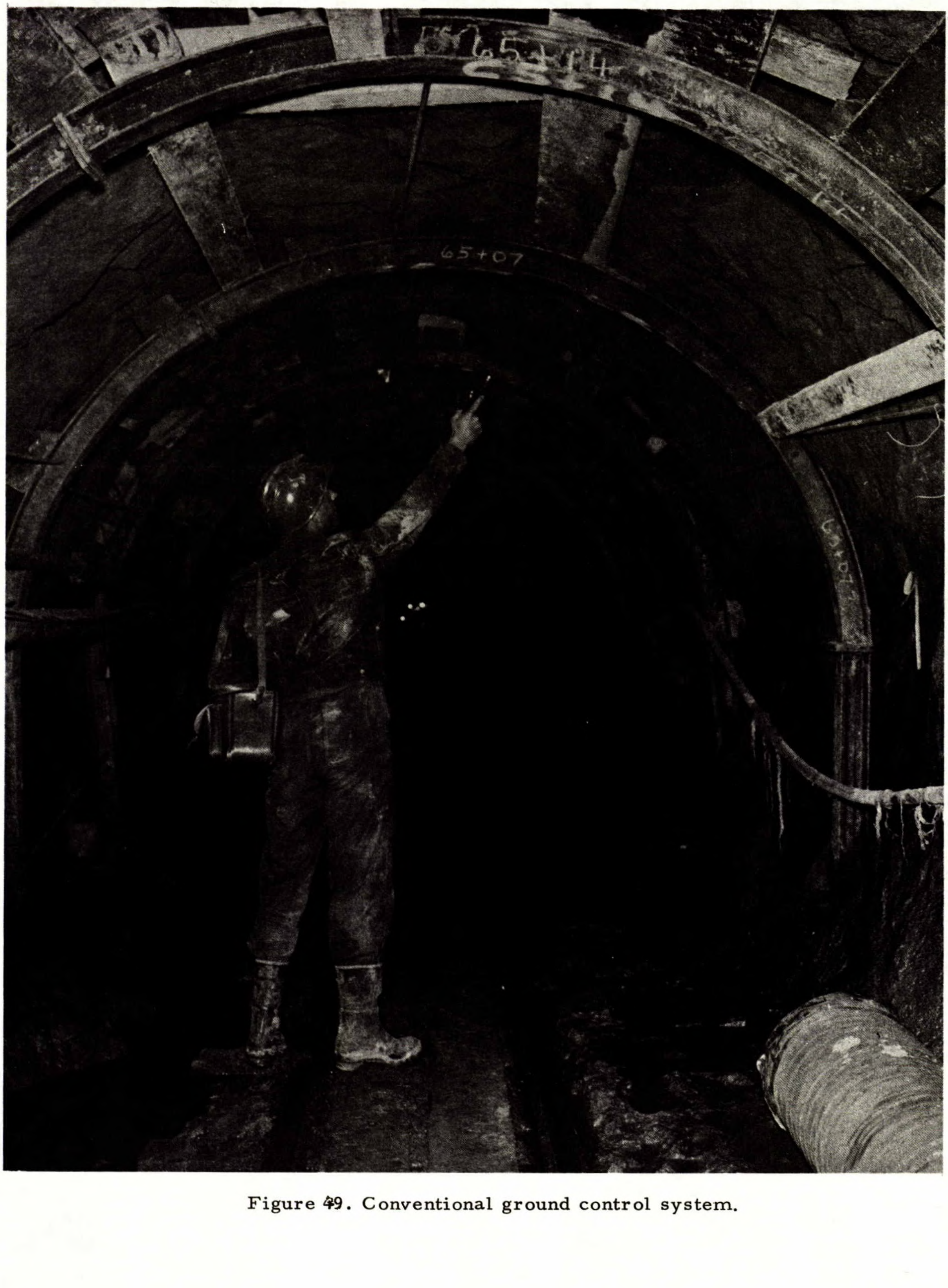

Figure 49. Conventional ground control system.

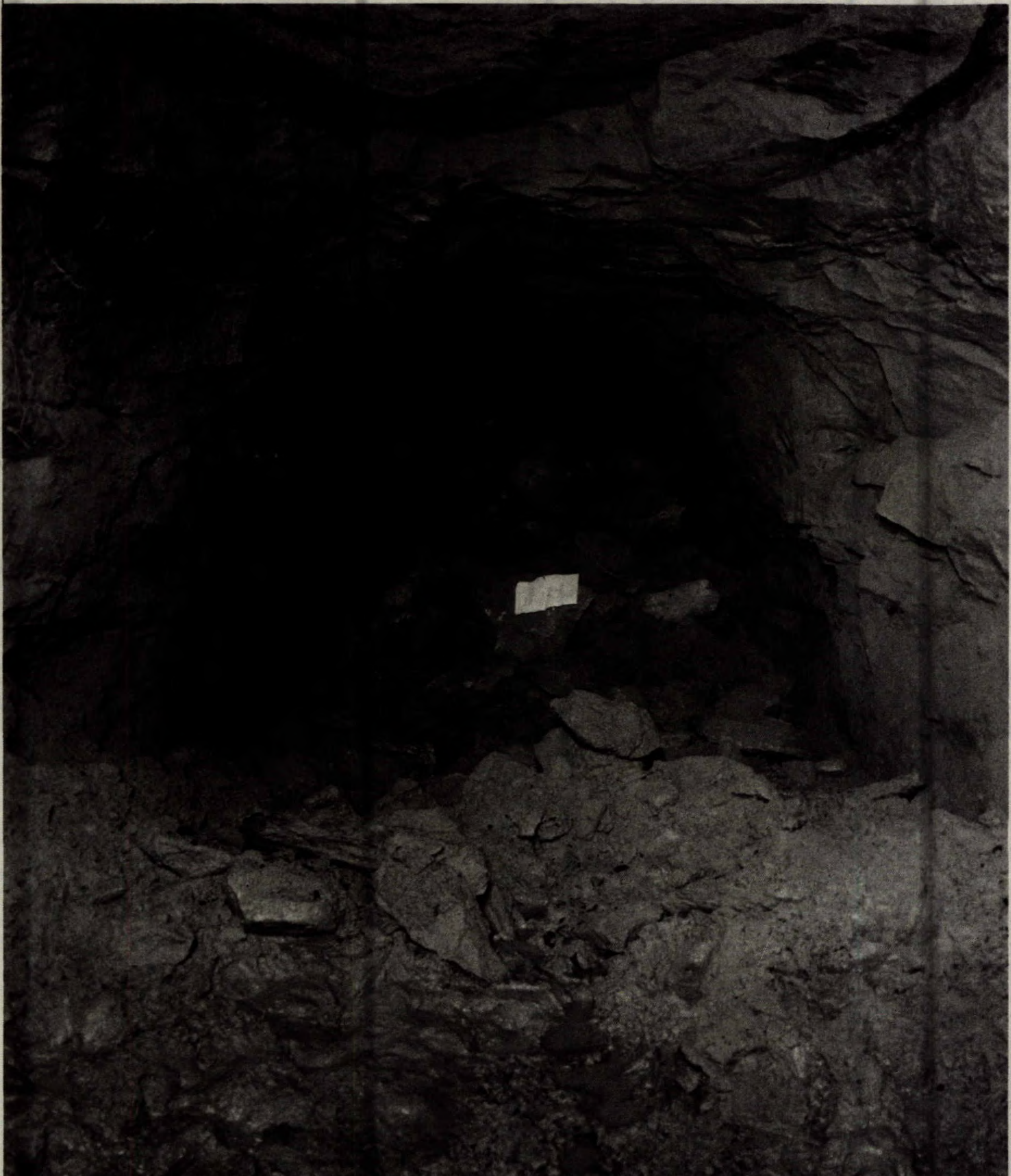

Figure 50. Sandstone as broken by conventional drilling and blasting.

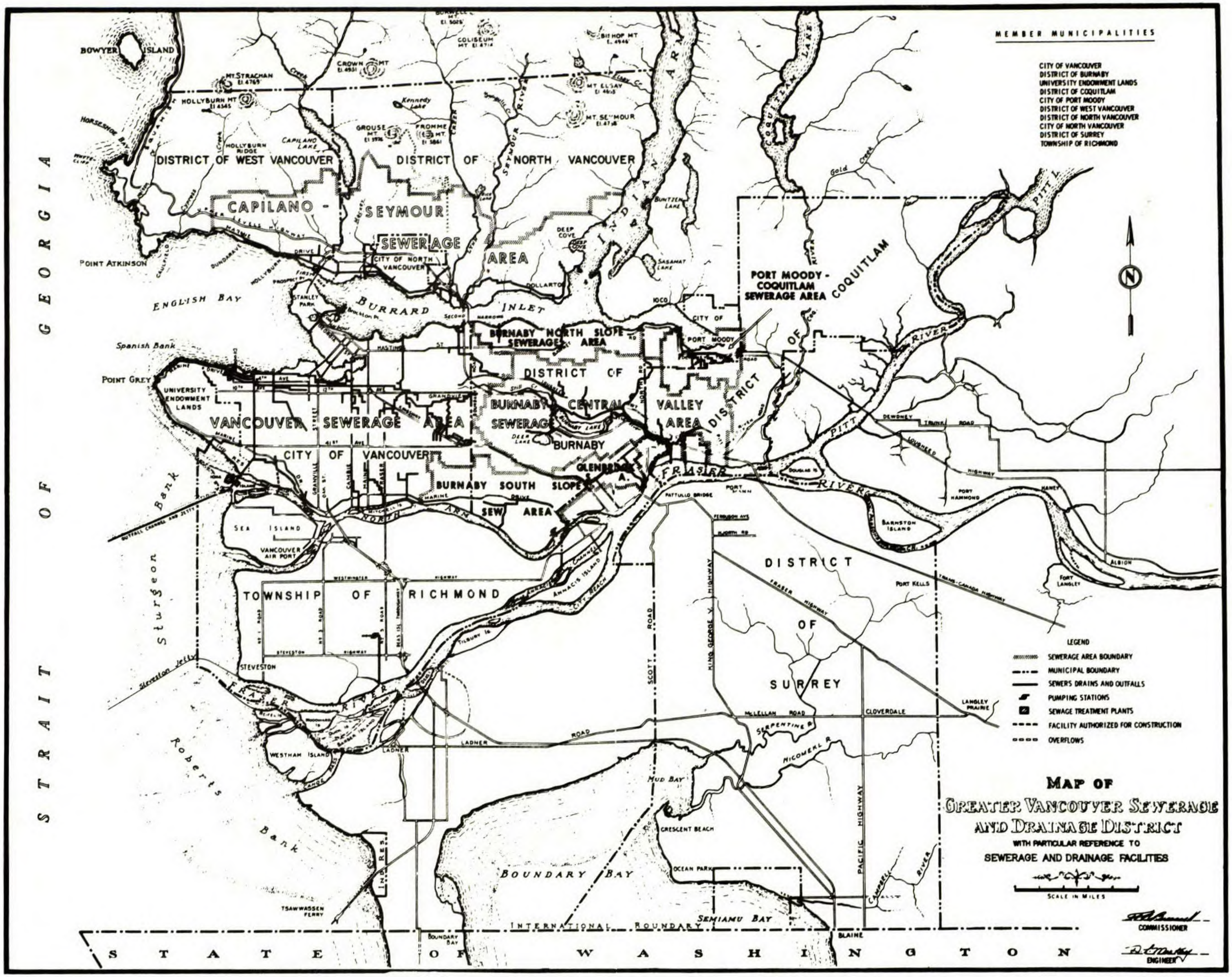
MEMBER MUNICIPALITIES
CITY OF VANCOUVER
DISTRICT OF BURNABY
UNIVERSITY ENDOWMENT LANDS
DISTRICT OF COQUITLAM
CITY OF PORT MOODY
DISTRICT OF WEST VANCOUVER
DISTRICT OF NORTH VANCOUVER
CITY OF NORTH VANCOUVER
DISTRICT OF SURREY
TOWNSHIP OF RICHMOND
LEGEND
SEWERAGE AREA BOUNDARY
MUNICIPAL BOUNDARY
SEWERS DRAINS AND OUTFALLS
PUMPING STATIONS
SEWAGE TREATMENT PLANTS
FACILITY AUTHORIZED FOR CONSTRUCTION
OVERFLOWS
MAP OF
GREATER VANCOUVER SEWERAGE
AND DRAINAGE DISTRICT
WITH PARTICULAR REFERENCE TO
SEWERAGE AND DRAINAGE FACILITIES
SCALE IN MILES
COMMISSIONER
ENGINEER
DISTRICT OF WEST VANCOUVER
DISTRICT OF NORTH VANCOUVER
CAPILANO - SEYMOUR SEWERAGE AREA
CITY OF NORTH VANCOUVER
BURRARD INLET
INDIAN ARM
PORT MOODY - COQUITLAM SEWERAGE AREA
COQUITLAM
CITY OF PORT MOODY
BURNABY NORTH SLOPE SEWERAGE AREA
DISTRICT OF BURNABY
BURNABY CENTRAL VALLEY SEWERAGE AREA
DISTRICT OF COQUITLAM
UNIVERSITY ENDOWMENT LANDS
VANCOUVER SEWERAGE AREA
CITY OF VANCOUVER
BURNABY SOUTH SLOPE SEW AREA
GLENBROOK S. A.
FRASER RIVER
PITT RIVER
SEA ISLAND
VANCOUVER AIR PORT
TOWNSHIP OF RICHMOND
STEVESTON
WESTHAM ISLAND
LADNER
DISTRICT OF SURREY
BOUNDARY BAY
SEMIAMU BAY
MUD BAY
CRESCENT BEACH
OCEAN PARK
BLAINE
INTERNATIONAL BOUNDARY
STATE OF WASHINGTON
STRAIT OF GEORGIA
ENGLISH BAY
POINT ATKINSON
POINT GREY
Spanish Bank
Sturgeon Bank
Roberts Bank
BOWYER ISLAND
TSAWWASSEN FERRY
IND. RES.
BARNSTON ISLAND
FORT LANGLEY
PORT KELLS
CLOVERDALE
LANGLEY PRAIRIE

Figure 51

CHAPTER 5

Greater Victoria Water District, Victoria, B.C.

Sooke Lake - Goldstream River Water Tunnel

A Brief History of the Operation

The Greater Victoria Water District, Victoria, British Columbia, excavated a tunnel from the Greater Victoria Water Supply Area at Sooke Lake, some 20 miles northwest of Victoria, B.C., to a reservoir at Japan Gulch in the Goldstream River Valley, for purpose of carrying domestic water from Sooke Lake to the City of Victoria and its neighbouring municipalities. The tunnel followed a straight course and had a total length of some 29,000 ft (see Figures 52 and 53). The depth of the tunnel varied from zero to 1,000 ft with an average depth of about 600 ft. It was driven through sedimentary rocks of thin-bedded types of slaty, quartzose and chloritic schist. The strata and the schistosity were parallel to one another and stood practically vertically. They were striking north 70 to 80 degrees west and parallel to the boundaries of the formation. The outside diameter of the tunnel was designed to be 8'6" with a concrete lining of a minimum thickness of 4 in. It sloped downwards at 0.17%.

It was thought that the use of a mechanical boring machine would be feasible for driving a tunnel of over 5 miles in length. Tenders were invited on this basis and Intermountain Construction Ltd. of N. Vancouver, B.C., was the successful bidder.

The contractor purchased a mechanical boring machine, Model 81, from James S. Robbins & Associates Inc., of Seattle, Washington, U.S.A. This machine was assembled in Vancouver at the Canada Car Company plant using Robbins plans, and was a modification of Robbins Model 121, designed in 1962. The revised model used a cone-shaped cutterhead design rather than a straight-faced head, with disc cutters being used to break the rock.

The Robbins machine was delivered to the Sooke Lake portal of the tunnel on November 28, 1964. Some 325 ft of the tunnel at the Sooke Lake end and 2,900 ft at the Japan Gulch end had already been excavated in 1961, using drilling and blasting methods of mining.

When the Robbins machine started excavating in the tunnel, it was found that the cutting pattern of the rotating disc cutters on the machine was not suitable for drilling the slaty ground encountered in the tunnel. The cutters were jamming on their bearings as the machine rotated. Some three weeks were required to burn off the old cutter brackets and weld them back on again at a different angle to improve the cutting pattern and to modify the cutter design. Operating problems continued to hamper progress. The gripper ram broke on December 21, due to a faulty casting, and there was a week's delay while securing a new part. Power failures, hydraulic arm failures, and cutter repairs followed in early January and the main bearing of the mechanical mining machine broke on January 20. The machine had to be removed from the tunnel, dismantled, and a new bearing obtained.

The mechanical boring machine (mole) was not ready to continue boring again until March 2, 1965, following a five-week delay. The drilling rate was slow and minor shut-downs frequent. Only one or two shifts a day were operating until the middle of March, when a three-shift-per-day five-day week was inaugurated. Good progress was made in softer drilling ground for the next two months, but it was difficult to maintain line and grade in the soft ground. The gripper rams tended to break away from the walls, because of the slabby conditions and nearly vertical dip of the rock strata. This placed a heavy load on the machine bearings and finally resulted in another broken bearing on May 10.

The mole did not work again until September 1. In the meantime, drilling and blasting methods advanced the tunnel a further 1,300 ft. Progress was again slow in September and the Water District and contractor entered into an experimental contract between September 16 and December 31, 1965. This was necessary because a bad section of ground was encountered in mid-September which required rock bolting on the roof of the tunnel, the installation of steel sets, and the use of wooden blocking to shore up the walls and roof and fill up voids created by caving ground. An extra work contract was allowed between October 5 and 27, 1965, for ground control purposes. During this period, not only were heavy steel sets constructed but also sections of heavy channel iron, reinforced with concrete to form an arch, were erected. The advance by the mole was very slow, being only 110 ft in September and 154 ft in October 1965.

Better ground conditions were encountered in November and only rock bolting was required to hold the ground. The main bearing broke once again, however, on November 11 and the mole was out of action until March 18, 1966. Drilling and blasting methods of mining were used in advancing the tunnel a further 176 ft from the Sooke Lake end in December 1965, and driving from the Japan Gulch end commenced in January 1966 and continued after the use of the mechanized boring machine was terminated.

The mole returned to the tunnel on March 18, 1966, and continued advancing at a very slow pace through poor ground conditions until April 22, 1966, when the use of the mole was discontinued, and the tunnel was completed by the Greater Victoria Water District, using drilling and blasting methods. The actual distance driven by the mechanical boring machine was only approximately 3,400 ft, out of a total distance of some 29,000 ft.

The author visited the Greater Victoria Water District offices and the tunnel location in January 1969. It was found that the Inter-mountain Construction Ltd. had not been able to complete the contract on time and the boring machine had been sold back to the Robbins Company by the contractor. The excavation of the tunnel had been completed by Water District engineers with hired crews, and concrete lining of the tunnel was still underway.

The driving of the tunnel, using the boring machine, had been difficult for all concerned. The Robbins Company had guaranteed a good workable machine and officials of the company made frequent visits to the tunnel project. A total of three main bearings had to be replaced by the manufacturer, which paid for the removal and reinstallation of the parts and the transportation costs. The contractor, however, was responsible for taking the machine out of the tunnel and returning it to the working face. Several modifications to the cutterhead, rotary disc cutters, and cutterhead supports were also made by the manufacturer of the mole. The Greater Victoria Water District suffered by having long periods of delay while the machine was awaiting parts and being dismantled and reassembled. Drilling and blasting methods were used to advance the tunnel during the major shut-downs, but progress was slow during the time the mole was out of commission.

Officials of the Greater Victoria Water District expressed the opinion that, in spite of the rather poor results obtained in using the boring machine, the use of some type of mechanical excavator could be successfully adapted to drive tunnels in rock similar to that encountered in the Victoria tunnel.

Penetration rates were good when there were no mechanical or other troubles and approximated 2.5 ft per hour. The best advance by the mole was 68 ft per day or 26 ft during an eight-hour work shift. This compared with an advance of about 25 ft a day using drilling and blasting methods.

The Robbins Model 81/121 Boring Machine (see Figures 54 to 56 for details of the machine construction)

Manufacturer's specifications for the Model 121 (Series 90) listed the following:

Bore diameter - 8'6"   Speed - 9 rpm

Over-all weight - 36 tons

Over-all length of machine - 48 ft

Forward thrust - 660,000 lb

Penetration rate - maximum 2.4 in./min = 12 ft/hr
- average 1.4 in./min = 7 ft/hr

Mining rate at 7 ft/hr = approx. 30 tons/hr or
22 cu yd broken rock/hr

Electrical supply current - 4160 v, 3 phase, 60 cycles

Main power current - 440 v, 3 phase, 60 cycles

Power - cutterhead - two 100-hp motors

Power - hydraulic pump - 15 hp
- conveyor - 5 hp

The original cutterhead design had twenty 11-in. disc cutters mounted at varying angles, with the head being square with the mining face. This was modified to give a conical shape to the cutterhead with a tricone cutter in the centre and disc cutters on the remainder of the face.

The cutterhead had four removable buckets mounted on the periphery. These picked up the broken material and dumped it into a hopper mounted at the top of the mole. The hopper fed the broken rock onto a belt conveyor which in turn fed it onto a trailing belt conveyor. A train of five mine cars was loaded under this last conveyor.

Vertical steering was accomplished by a front vertical-steering shoe, activated by hydraulic cylinders. Horizontal steering was done by means of front side-steering shoes also activated by hydraulic cylinders. Hydraulically operated mechanisms provided gripper support to the walls, at the mid-point, on each side and provided torque and thrust reactions against the face. Rear steering was accomplished with hydraulic rams and rear support was provided by a shoe on which the machine slid.

Line and grade of the machine in the tunnel were maintained by using a Wild T1A transit instrument. Survey platforms were erected at the crown of the tunnel, at about 500-ft intervals. These platforms were some 12 in. deep and 18 in. wide, with the Wild transit instrument mounted and levelled on the platform and this could be sighted forward to a target mounted on the mole and backwards to a backsight survey point. There were no curves in the tunnel and this simplified survey requirements.

The removal of dust from the boring operation was a major problem and was one of the reasons for finally abandoning the use of the boring machine. Fine water-spray nozzles were used at the face to allay the dust, and a series of six exhaust fans mounted in the tunnel and one inflow fan at the portal were used to exhaust the dusty air by suction from the cutterhead location.

Geology at the Tunnel Site

The entire region was geologically mapped and studied in detail by H.C. Clapp of the Geological Survey of Canada, whose reports and maps were published as Memoir 96 in 1917.

The tunnel site lies entirely within one large formation called the Leech River slates. This formation consisted of only two or three kinds of sedimentary rocks. These rocks were closely folded and the strata stood practically vertically with the direction of the tunnel closely paralleling the strike of the formation.

Only three types of rock were found in the tunnel area. These were: (a) black argillaceous schist consisting of biotite, quartz, carbonaceous material, and large amounts of argillaceous minerals which consisted of hydrated silicates of alumina; (b) grey quartzose schist or quartzite, which consisted mainly of quartz with some biotite, muscovite, and small amounts of argillaceous minerals; and (c) greenish chloritic schist, which besides quartz, muscovite and biotite, contained considerable amounts of feldspar and chlorite and was believed to be partly volcanic in origin. The quartzose rocks were much harder than the black and green schists but not nearly as abundant. Throughout the formation there were numerous quartz veins and lenses, usually only a few inches but occasionally several feet in width. These contained, besides quartz, small amounts of pyrite, pyrrhotite, and probably a little gold. In locations where the rocks have been intensely faulted, talc and graphite were found. These minerals were very soft and slippery and, when present in large amounts, caused the rocks to cave easily. Minor faults were encountered in the tunnel, containing considerable mud or gouge along the contact, and the ground in these locations required temporary support during the time between the excavation and the lining of the tunnel. Water was encountered in the tunnel but not under high pressure. The rock cover over the tunnel was too deep to permit easy access of water, and ground water encountered was only small in quantity.

An underground inspection was made, by the author, of a half-mile section of the tunnel, driven by drilling and blasting methods of mining, before it was lined with concrete. In general, the ground conditions could be considered better than those encountered in most underground mines. The tunnel required no ground support for most of its length. Some sections of poor ground were encountered and these were supported either by rock bolts, by rock bolts with steel plates or angle iron strapping, or by light steel sets and timber blocking. Other portions of the tunnel, however, driven by the mole, were known to have required considerable ground support.

Ground Control in the Tunnel

The first portion of the tunnel, with the mole boring from the Sooke Lake end of the tunnel, required no ground support. Soft ground, encountered some 600 ft from the portal, caused difficulty for the machine inasmuch as the gripper shoes could not get a firm support in the soft walls of the tunnel, but no cave-ins occurred in the crown of the tunnel.

Some 1,760 ft from the portal in April 1965, poor ground was encountered which continued for some 200 ft. Here steel plates supported by rock bolts were used to control the ground, with a small amount of timber also being used to shore up the roof. The ground was hard on the left and soft on the right at this location. No further difficulty in ground control was encountered up until the time when the main bearing of the machine broke in May 1965, some 2,590 ft from the portal.

Conventional mining continued for some 1,300 ft until the boring machine returned in September 1965. Ground conditions were good until a section of poor ground was encountered in late September at 4,250 ft from the portal, with the ground caving on the left side of the tunnel. Rock bolting and timbering were not enough to hold the ground, and at 4,400 ft steel sets had to be used, with caving occurring on both sides of the tunnel. This bad ground persisted all during October to a distance of some 4,600 ft from the portal, when better ground was encountered that could be held by occasional rock bolts.

Extra costs were allowed to the contractor while progressing through the bad section of ground in October. One section of some 80 ft required heavy iron arches (constructed from 4- or 6-in. I and H beams) reinforced by poured concrete to fill up the voids caused by cave-ins, before the ground could be supported.

The main bearing on the boring machine broke again on November 11, 1965, some 4,880 ft from the Sooke Lake portal. After returning in March 1966, the machine again encountered poor ground conditions at 5,034 ft, with cave-ins occurring. The mole advance was negligible in April and the machine was finally removed on April 22. Steel sets were erected and cement grouting was required to fill in voids.

Drilling and blasting methods continued in the tunnel after the boring machine was removed, and the ground was controlled mostly by 4-in. I-beam steel sets, as required. In October 1966, ground conditions improved, and only rock bolting and steel plates or timber bracings were required during 1967.

The steel sets used in excavating the tunnel were not standard in design. They were made up from material from various sources, belonging to the Victoria Water District. They varied in size and shape, and were primarily designed for use in a conventionally shaped tunnel. They had to be modified to fit the circular tunnel.

Comments Based on Victoria Tunnel Experiences

(1) Improvements were required in the mole design to give a narrower propulsion section and to give more working room to make repairs to the machine and change cutter discs. The replacement of outside cutters on the cutting head required chipping a hole in the side of the tunnel to replace the perimeter cutters. There was a lack of room between the face of the tunnel and the head of the machine, and also back of the head, to put in temporary ground support during boring operations.

(2) There was a need to have a means of easily adjusting the diameter of the cutting head when driving through ground needing temporary support. The shoring and steel sets required in poor ground left insufficient room, in some cases, for ventilation and service pipelines. (Also, in a circular tunnel, the rails and road bed are well up from the invert and, in a tunnel less than 9 ft in diameter, may leave insufficient room for service pipes.) This resulted in ventilation and service piping having to be all removed each time the machine had to be withdrawn from the working face.

(3) Changes in design of the mole were required so it could easily be dismantled in relatively small units for removal from the tunnel. This would allow it to pass through temporary sets constructed for ground control and avoid having to remove long sections of ventilation and air and water lines. This would allow the machine to be used in drilling through favourable ground conditions and to be removed in areas of caving ground when hand-mining or drilling and blasting methods with heavy ground support were required and the use of the mole was impractical.

(4) There was no problem from excess water running into the tunnel but dust generated from boring operations was difficult to remove. Water sprays used at the face caused muddy operating conditions and a foggy atmosphere. The exhaust system used to remove dusty air proved inadequate and there was need for an oversized ventilation system to be designed for operating conditions as encountered in this tunnel.

(5) A wider roof-support shield was required, back of the cutterhead, to support caving ground and protect the cutterhead from damage and also to assist in controlling dust at the working face. A complete expandable circular shield or hood, equipped with an exhausting system to collect the dust from the boring operation, would have been an advantage.

(6) Much time was lost at the beginning of the boring operation in experimenting with different types of cutterhead design. Different styles of cutterheads should be made available by the manufacturers to suit varying types of ground conditions.

(7) The method of lubricating the main bearing in the boring machine was not satisfactory. Modifications were made substituting an oil bath method rather than grease. Improvement in the lubrication of moving parts of the mole was indicated as being desirable on later models.

(8) The Robbins machine used in the operation had difficulty gripping the walls of the tunnel, due to the soft ground conditions encountered. A better design of gripper shoe was required, with larger clamping units.

(9) Ground support methods used in the tunnel were haphazard and not standardized. There was a need for preplanning of ground control methods to be used to meet varying operating conditions in driving a tunnel of this type. For example, arrangements could be made to have available a supply of steel ringbeam quadrants, prefabricated, and suitable for use with the particular model of boring machine (such as the ringbeams used in the PFRA, South Saskatchewan River Diversion Tunnels).

Summary of Operations

Table 14 gives a summary of operations on a weekly basis. No formal report on the operation had been prepared by the Greater Victoria Water District or the contractor, and the information and data contained in the table are the result of an analysis, by the author, of daily work records. Estimates were made of working days available and, in some cases, manhours of work. The production summary in the table is the result of this analysis. The economic analysis shown in Table 15 is based on information contained in payments made to the contractor as recorded by the Water District office. The cost estimates of Table 16 are based on Intermountain Construction Ltd. estimates.

Figure 52 gives a plan of the tunnel location. Figure 53 shows a cross-section of the tunnel project. Figures 54 to 57 give details of construction of the Robbins Model 121 boring machine. A considerable number of modifications were made to this machine to produce the Model 81 actually used in the tunnelling project, but no final plans or photographs of the modified machine were available to the author.

Acknowledgements

The author wishes to acknowledges the assistance of the undernoted in the gathering of information and data concerning the Sooke Lake-Goldstream River Water Tunnel project:

The Greater Victoria Water District
479 Island Highway, Victoria, B.C.

R. A. Upward, P.Eng., Chief Commissioner
C. Schroeder, Superintendent of Tunnel Project

GREATER VICTORIA WATER DISTRICT

TABLE 14

SOOKE LAKE - GOLDSTREAM RIVER WATER TUNNEL

	SUMMARY OF OPERATIONS						
Date by weeks	Working days (6-day week)			Manhours Worked		Reported Advance, Feet	Remarks
	Available	Worked	Mole Drilling	Mole Drilling	Other Work		
1964	Mechanical Mining		Using Robbins	Model 81/121	Boring Machine		
Nov 28-Dec 7	9	9 (e)	-	-	504 (e)	-	Repaired and repositioned cutters. Mole moved to face on the 18th. Gripper ram broken on 21st. Waiting on parts and repairing the ram until Jan. 4, 1965.
Dec 10-17	7	7 (e)	-	-	336 (e)	-	
18-21	3	3	2	36	92	41.5	
22-Jan 3	7	1 (e)	-	-	56 (e)	-	
	26	20	2	36	988 (e)	41.5	Only one shift per day working (4-7 men)
1965							
Jan 4-9	6	6	6	393	135	201.5	Gripper shoes not holding in poor ground. Minor power failures and breakdowns delayed advance. Main bearing broken on 20th. Mole removed Jan. 21-25. Waiting on parts until late in Feb.
10-16	6	5	5	333	235	167.3	
17-25	7	6	3	220	140	95.1	
26-31	5	-	-	-	-	-	
	24	17	14	946	510	463.9	2 to 3 shifts per day working during month (11-15 men)
Feb 1-28	20	3 (e)	-	-	144 (e)	-	Waiting for parts then installing them on machine.
Mar 1-6	6	5	5	215	161	72.4	Mole moved to face. Drilling started on 2nd. Generator and cutterhead repairs. Waiting for parts on 10th. Gear box and hydraulic ram repairs. Waiting on parts on 22nd. Trouble holding in soft ground. Robbins & Assoc installed new cutters on 3rd.
7-13	6	5	5	235	205	107.0	
14-20	6	5	5	350	250	161.5	
21-27	6	5	5	430	138	266.0	
28-Apr 3	6	5	5	394	174	210.4	
	30	25	25	1624	928	817.3	1 to 3 shifts working per day (7-15 men)
Apr 4-10	6	6	6	275	349	126.2	Hydraulic pump breakdown. Waiting parts on 7th. Poor ground between 8-17th. Rock bolting and timbering required. Good ground to end of month. No rock bolting needed. Air dusty.
11-18	4	4	4	208	240	100.7	
19-24	6	6	6	346	310	222.0	
25-May 1	6	6	6	310	290	238.7	

- cont'd

(Table 14, cont'd)

Date by weeks	Workdays			Manhours Worked		Reported Advance, Feet	Remarks
	Available	Worked	Mole Drilling	Mole Drilling	Other Work		
	22	22	22	1139	1189	687.6	2-3 shifts working per day (11-15 men)
May 2-8	6	6	6	518	202	212.4	Fan motor repairs. Lubricating system on motor bearing changed. Welding buckets. Main bearing broken on 10th. Moved out mole 10-15. Waiting parts. Tunnel advanced 1300 ft. by drill and blast method.
9-15	5	5	1	112	96	23.0	
15-31	-	-	-	-	-	-	
	11	11	7	630	298	235.4	
June 1-30	-	-	-	-	-	-	
July 1-31	-	-	-	-	-	-	
Aug 1-12	-	-	-	-	-	-	No work during fire hazard season (Aug 2-10)
Aug 13-31	10	10	-	-	440 $^{(e)}$	-	Installing bearing and cutter heads etc.
Sept 1-4	3	3	2	96	232	22.4	Boring started on 1st. Machine off-line, advance slow. Motorchange. Tri-cone cutter changed. Installed trailing conveyor on 15th. Hydraulic pump breakdown on 20. Caving occurred on 21st. Rock bolting, timbering, ring-beams needed to end of month.
5-10	4	4	4	360	120	97.9	
12-18	5	5	5	363	237	198.1	
19-25	5	5	5	134	466	93.9	
26-Oct 2	5	5	5	130	432	118.6	
	22	22	21	1083	1487	530.9	Working 3 shifts, with a 5 day work week.
Oct 3-9	5	2	1	5	235	2.3	Mole idle Oct 6-11 due to caving of soft ground. Steel sets and timber blocking installed. Some channel iron arches and concrete grouting need to hold ground. Rock bolts and steelsheets also used.
10-16	4	4	4	116	407	33.4	
17-23	5	5	5	178	422	32.8	
24-30	5	5	5	190	430	85.8	
	19	16	15	489	1494	154.3	Working 3 shifts / day, with a 5 day week.
Oct 31-Nov 6	5	5	5	253	355	189.4	Better ground starting Nov 1. No rock bolting or ground control needed until Nov 5-10 when 30 rock bolts were installed. Main bearing broken again on Nov 11. Mole moved back, dismantled and removed from tunnel between Nov 15-Dec 3.
7-13	5	4	4	140	340	126.9	
14-20	5	5	-	-	352	-	
21-27	5	4	-	-	176	-	
28-Dec 3	5	5	-	-	112	-	
	25	23	9	393	1335	316.3	One to 3 shifts working (3-15 men)
Dec 4-9	1	1	-	-	24	-	Removed cutterhead and accessories to ship to Vancouver.
10-31	-	-	-	-	-	-	Drill and blast mining underway, Sooke Lake tunnel.
Jan 1-Apr 30	-	-	-	-	-	-	Drill and blast mining, Japan Gulch end of tunnel.
1966							
Feb 17-20/66	3	2	-	-	48	-	Repairing rear support on mole, and conveyor.

- cont'd

(Table 14, cont'd)

Date by weeks	Working			Manhours Worked		Reported Advance, Feet	Remarks
	Available	Worked	Mole Drilling	Mole Drilling	Other Work		
21-26	5	6	-	-	208	-	Repairing and preparing equipment for mole. Pumping water, repairing track cleaning up for mole return.
27-Mar 5	2	2	-	-	80	-	
	10	10	-	-	336	-	One shift (3-5 men) working per day.
Mar 6-12	-	-	-	-	-	-	Mole moved into face by March 18. Changed cutters, adjusted mole. Hydraulic cylinder trouble. Slow advance with cave-in on 30th. Steel sets and wood blocking installed.
13-20	4	4	1	6	50	1.5	
21-26	5	5	5	118	290	82.8	
27-Apr 2	5	4	4	155	285	79.1	
	14	13	10	279	625	163.4	Two shifts (7-11 men) working a 5 day week.
Apr 3-9	5	4	1	126	226	3.2	Working on ground support and grouting. More cave-ins on 5-6th. Pouring concrete into voids. Installed shield on mole. Mucking and shoreing ground. Mole stopped and removed from tunnel. Hand mining rest of tunnel.
10-16	5	5	4	54	441	24.4	
17-23	5	5	3	86	374	18.8	
24-30	5	5	-	-	440(e)	-	

Dates	Indicated Available Workdays	Advance (feet)
		Mining by Drilling and Blasting Method
Prior to 28 Nov 64		316 (Sooke Lake portal excavated by hand methods)(1961) 2900 (Japan Gulch portal excavated by hand methods) (1961)
May 15-31/65	10	151 (Drill and blast mining carried out in Sooke Lake tunnel
June 1-30	21	529 (while awaiting parts for Robbins boring machine
July 1-31	22	604 (" awaiting parts for Robbins boring machine
Aug 1-12	1	16 (" awaiting parts for Robbins boring machine
Dec 10-31/65	15	176 (" awaiting parts for Robbins boring machine
Jan 1-31/66	22	408 (drill and blast mining, Japan Gulch tunnel
Feb 1-28	20	376 (" " " mining, Japan Gulch tunnel
Mar 1-31	22	432 (" " " mining, Japan Gulch tunnel
Apr 1-30	20	466 (" " " mining, Japan Gulch tunnel
	153	3158 (20.'7/day)

- cont'd

(Table 14, cont'd)

Drill and Blast Mining Sooke Lake Tunnel - After Robbins Machine Removed

Dates	Indicated Available Workdays	Advance (feet)	Steel Sets	Steel Plates	Rock Bolts	Timber (board feet)	Fuse Caps	Forcite Cases	Xactex Cases
May 1-31	24	180	1-12" CH. 7-6" H Beam 31-4" I Beam		-	8725			
June 1-30	24	538	13-4" I Beam		-	1800			
July 1-31	24	453	69-4" I Beam 45-4" I Beam		-	11250			
Aug 1-31	25	565	45-4" I Beam 6-5" CH.	120	160	9144	-	-	-
Sept 1-30	23	511	4-4" I Beam 6-5" CH.	190	309	1000	-	-	-
Oct 1-31	25	412	-	238	380	-	-	-	-
Nov 1-30	24	506	-	225	323	-	3391	159	17
Dec 1-31	24	365	-	149	231	-	2441	103	9
	193	3530	(18.'3/day)						
Jan 1-31/67	24	523	-	255	293	-	3423	135	18
Feb 1-28	23	490	-	321	424	-	3324	131	18
Mar 1-31	25	545	-	274	300	1251	3612	154	20
Apr 1-30	22	532	-	256	275	1117	3507	146	18
May 1-31	24	557	-	361	452	1170	3656	150	20
Jun 1-30	23	521	-	341	420	1094 (ties)	2378	139	17
July 1-31	24	483	-	275	301	1014 (ties)	3226	128	16
Aug 1-31	24	548	-	243	283	1150 (ties)	3683	147	19
Sept 1-30	23	507	-	342	419	1064 (ties)	3505	141	18
Oct 1-31	24	557	-	477	590	1170 (ties)	3691	151	20
	236	5263	(22.'3/day)						
Total Hand	582	11,951	(20.'5/day)						

NOTE: (e) = estimated.

- cont'd

(Table 14, concluded)

SUMMARY BY MONTHS

Date	Indicated Workdays			Manhours Worked		Reported Advance, Feet	Remarks
	Available	Worked	Mole Drilling	Mole Drilling	Other Work		
Nov 28-Jan 3	26	20	2	36	988	41.5	Start-up problems.
Jan 4-31/65	24	17	14	946	510	463.9	87 rock bolts used.
Feb 1-28	20	3	-	-	144	-	Waiting for machine parts (Main bearing)
Mar 1-Apr 3	30	25	25	1624	928	817.3	
Apr 4-May 1	22	22	22	1139	1189	687.6	
May 2-31	11	11	7	630	298	235.4	Main bearing broken again, waiting on parts.
June 1-30	-	-	-	-	-	-	Tunnel advanced by drill and blast method.
July 1-31	-	-	-	-	-	-	" " " " " "
Aug 1-31	10	10	-	-	440	-	Repairing boring machine.
Sept 1-Oct 2	22	22	21	1083	1487	530.9	121 rock bolts, 44 steel hoops, 486 b.f. timber.
Oct 3-30	19	16	15	489	1494	154.3	90 rock bolts, 9 sets, 2 arches, 9 hoops, 485 b.f. timber.
Oct 31-Dec 3	25	23	9	393	1335	316.3	30 rock bolts & washers, 11 plates.
Dec 4-31	1	1	-	-	24	-	Main bearing broken on 11-Nov. Waiting on parts. Hand mining tunnel.
Jan 1-31	-	-	-	-	-	-	Hand mining tunnel.
Feb 17-Mar 5	10	10	-	-	336	-	Repairing equipment, preparing for return of mole.
Mar 6-Apr 2	14	13	10	279	625	163.4	5 steel sets, 1 timber set.
Apr 3-30	20	19	8	266	1481	46.4	8 steel sets, 80 ft timber.
	254	212	133	6885	11279	34570	

PRODUCTION SUMMARY

Mole Utilization: Days drilling/available days = 133/254 = 52%
Manhours drilling/total manhours working = 6885/11864 = 38%

Mole Advance: Total advance = 3457 ft
Maximum advance/day = 68 ft per shift = 26 ft. (Both on 29 Apr 65)
Maximum advance/week (5 days) = 266 ft (Mar 23-27/65)
Maximum advance/4 consecutive week period (22 days) = 774 (Apr 11-May 8/65)
Average advance/days drilling = 3457/133 = 26 ft
Average advance/hour drilling = 3457/6885 = 0.52'ft (0.1"/min)
Average advance/days worked = 3457/212 = 16 ft

TABLE 15

An Economic Analysis of the Sooke Lake Portion of the Tunnel *

Summary of Payments on Contract 30 - to Dec 31/65

Drilling by mechanical mole	489'	at 49.50	= $123,206
Work by mole on experimental contract (Sept 16-Dec 7/65	679'	at 69.50	= 47,191
Drilling by mole only - Total -	3168'		= 170,397
Drilling and blasting method	1476	at 55.53	= 81,667
Materials used (ground control)	-	-	= 8,935
Extra ground control work (between Oct 5-27/65)	-	-	= 22,066
Total - Sooke Lake portion contract 30 to Dec 31/65 (4644 ft)			$283,065

Notes on Payments

Extra ground control work Labour ($11,804), supplies (2974), rentals (5282), 10% overheads (2626) = $22,066

Materials used on contract			Cost
Steel	5565 lb at $55 , 8739 lb at $.1141		= $2,945
Rockbolts	7-3', 91-4', 196-5', 47-6' (Rates $2.09 to 2.32 each)	(Total 341)	= 3,668
Ground support timber	311 b.f.m. at $200/1000 b.f.m.		= ,622
Hole drilling	1700 ft at $1/ft		= 1,700
		Total	8,935

Rates paid on Contract 30

Excavation by mole - $49.50/ft advance
Drilling and blasting - $55.33/ft advance
Steel - $.35/lb (short pieces of steel, rock bolt plates)
Rockbolts (each) 3 ft = $2.16, 4 ft = $2.09, 5 ft = $2.16, 6 ft = $2.32
Corrugated hoops - $.1141/lb
Lumber for ground support - $200 per thousand board feet
Reinforcing steel - $.30/lb (corrugated steel, wire fabric)
Hole drilling - $1.00 per ft drilled
Grouting (cement) = $5.00/ft

Steel Sets erection (Sets supplied by Greater Victoria Water District)

196 # 4" I Beam sets)
16 #/ft 6" H Beam sets)
160 # 5" (channel sets) $20 a set installed.
(Angle Iron sets)
198 # 6" (channel sets)
(Angle Iron sets)
)
33.35 # plates 14" x 16")

Note:* Based on information supplied by Greater Victoria Water District.

- cont'd

(Table 15, concluded)

Daily Labour Cost (1965)

Trade	Number Employed	Rate per Hour	Amount per 8 hr Shift	Travel Allowance per Day	Less Subsistence Cost	Shift Total	Daily Total
Mechanics	2	3.93	31.44	11.00	5.00	37.44	74.88
Shift bosses	2	3.84	30.72	11.00	5.00	36.72	73.44
Electricians	1	3.67	29.36	11.00	5.00	35.36	35.36
Mole operators	3	3.57	28.56	11.00	5.00	34.56	103.68
Motor men	2	3.44	27.52	11.00	5.00	33.52	67.04
Miners	2	3.35	26.28	11.00	5.00	32.80	65.60
Superintendent	1	$50 a day	50.00	-	-	50.00	50.00
	13	-	-	11.00	5.00	260.40	470.00

Add 20% (cost of surveyors and overheads) 94.00

564.00

Equipment Rentals (1965)

	Rate per Hour $
Locomotive, batteries and charger	3.30
Stoper drilling machine	0.21
Truck	0.67
Bus (WCB)	0.21
Transportation	0.73
Underground lamps	0.17
Ventilation fans	0.42
Robbins boring machine	$30/ft
Flyte pump	0.21
Sump pump	0.13
Trailers	0.17
(Added in 1966)	
Locomotives	$1.15
620 air compressor	0.80
240 air compressor	0.15
Fans	0.10
Eimco mucking machine	0.38

TABLE 16

Cost Estimates for Excavating the Greater Victoria Water Board Tunnel using the Mechanical Boring Machine

The Intermountain Construction Ltd. prepared the following contract estimate for the final testing of the Robbins boring machine, in August 1965, after having completed 2274 feet of tunnel with the mole.

	Estimated Total Cost		Cost Per Foot $
(a)	Mole cost $284,134. Probable footage to be bored 24000 ft.		
	Cost per foot $11.88. Recoverable value $1.67 per ft. Write off		10.21
(b)	Cutters and repairs to-date to machine	($53,921)	
	Estimated value of parts after 2274 ft of tunnel	(23,921)	
	Write off for 2274 ft	($30,000)	13.20
(c)	Expenditures in August 1965. Refitting bearing and transporting to tunnel face, duty, freight, repair parts, all fittings, etc.		
	Recovable over 1800 ft	($12,186)	6.77
(d)	Repairs and supplies to-date other than Robbins used in mole repairs and operation Jan-Aug 65. (cost for 2274)	($32,445)	14.27
(e)	Power plant operation Jan to Aug 31. cost for 2274 ft (7316)		3.21
(f)	Labour costs. Jan-Aug/65 on mole	(83,593)	
	Nov-Dec/64 on mole	(17,877)	
	Total (2274')	101,570	44.66
(g)	Equipment on rental purchase.	(80,404)	
	$8,000 per month 600 feet per month		13.33
(h)	Head Office, insurance, interest and travel		4.00
	Total		$109.65

In actual fact, costs would exceed this estimate. Two more bearings had to be replaced on the machine, heavy expenditures were required on ground control, and repairs to the machine continued to be necessary. Total footage bored was only about 3380 feet and it is understood that the Robbins machine was finally sold back to the manufacturer for some $20,000.

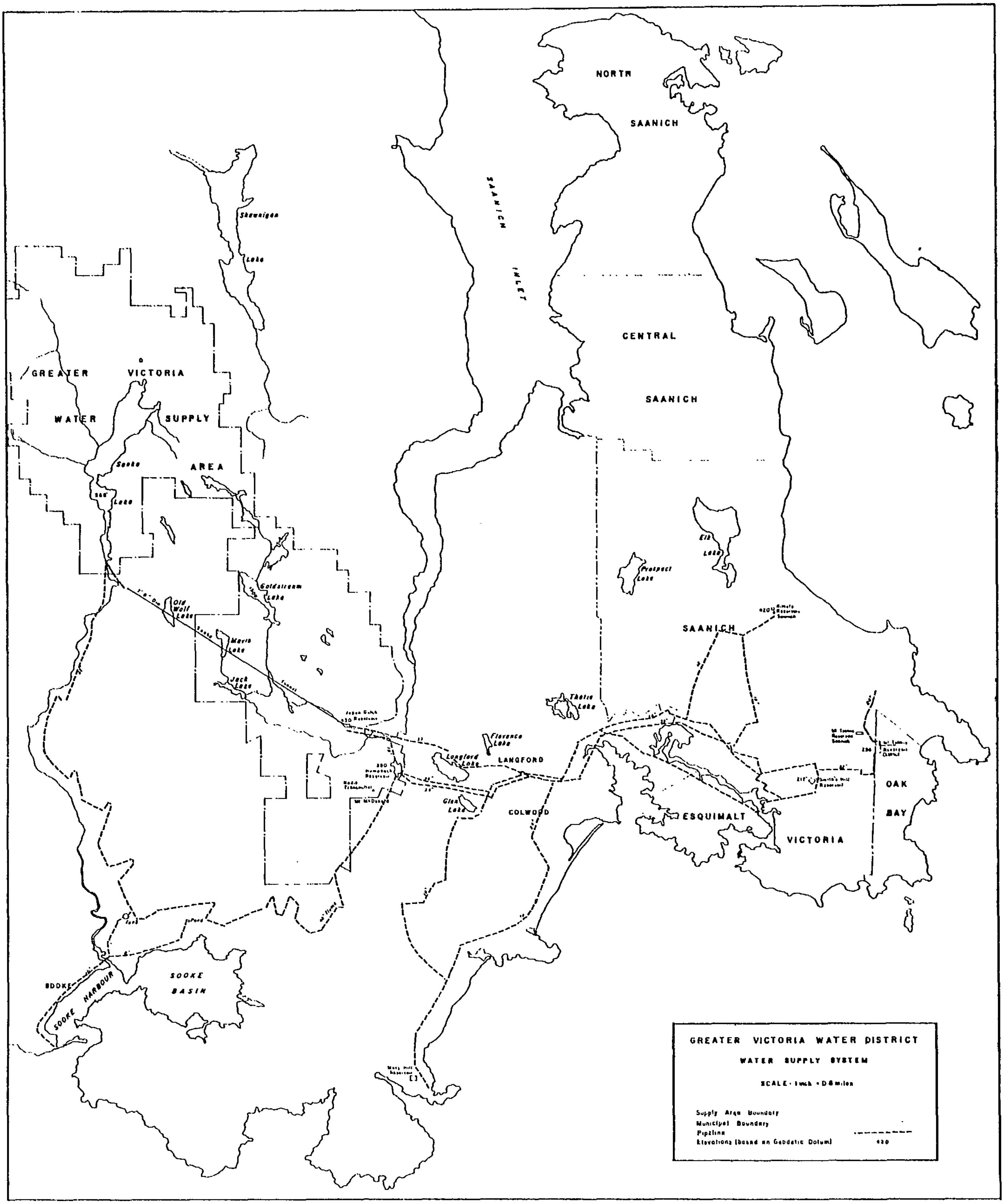

Figure 52: Location of Sooke Lake - Goldstream River Tunnel.

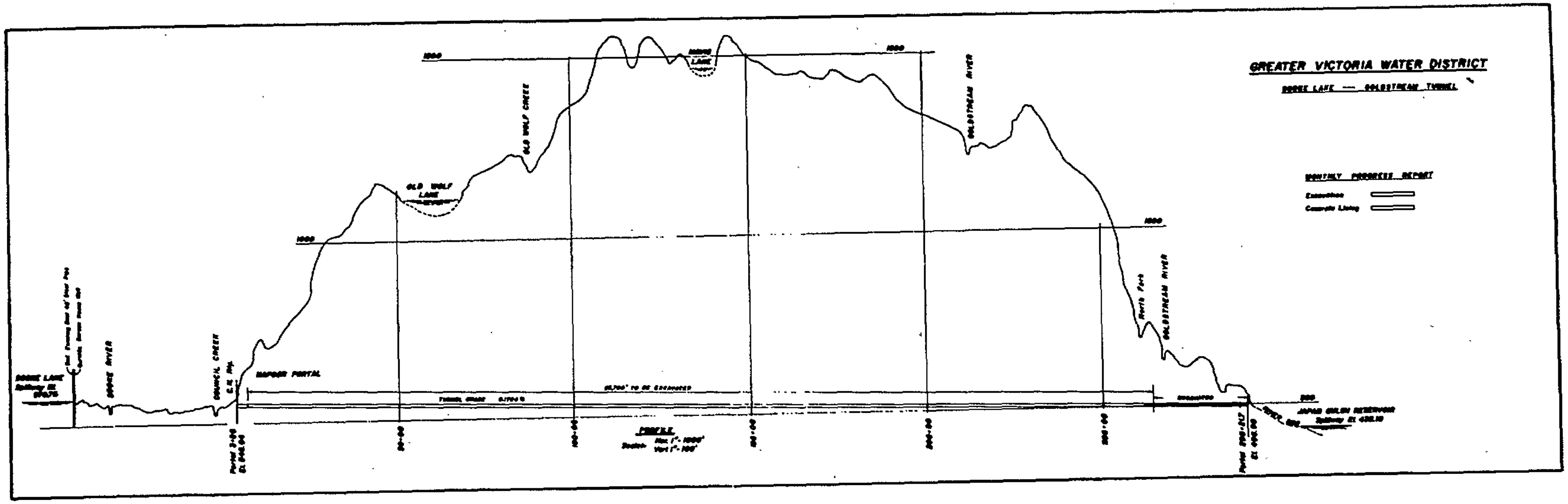

Figure 53: Profile of Sooke Lake - Goldstream River Tunnel.

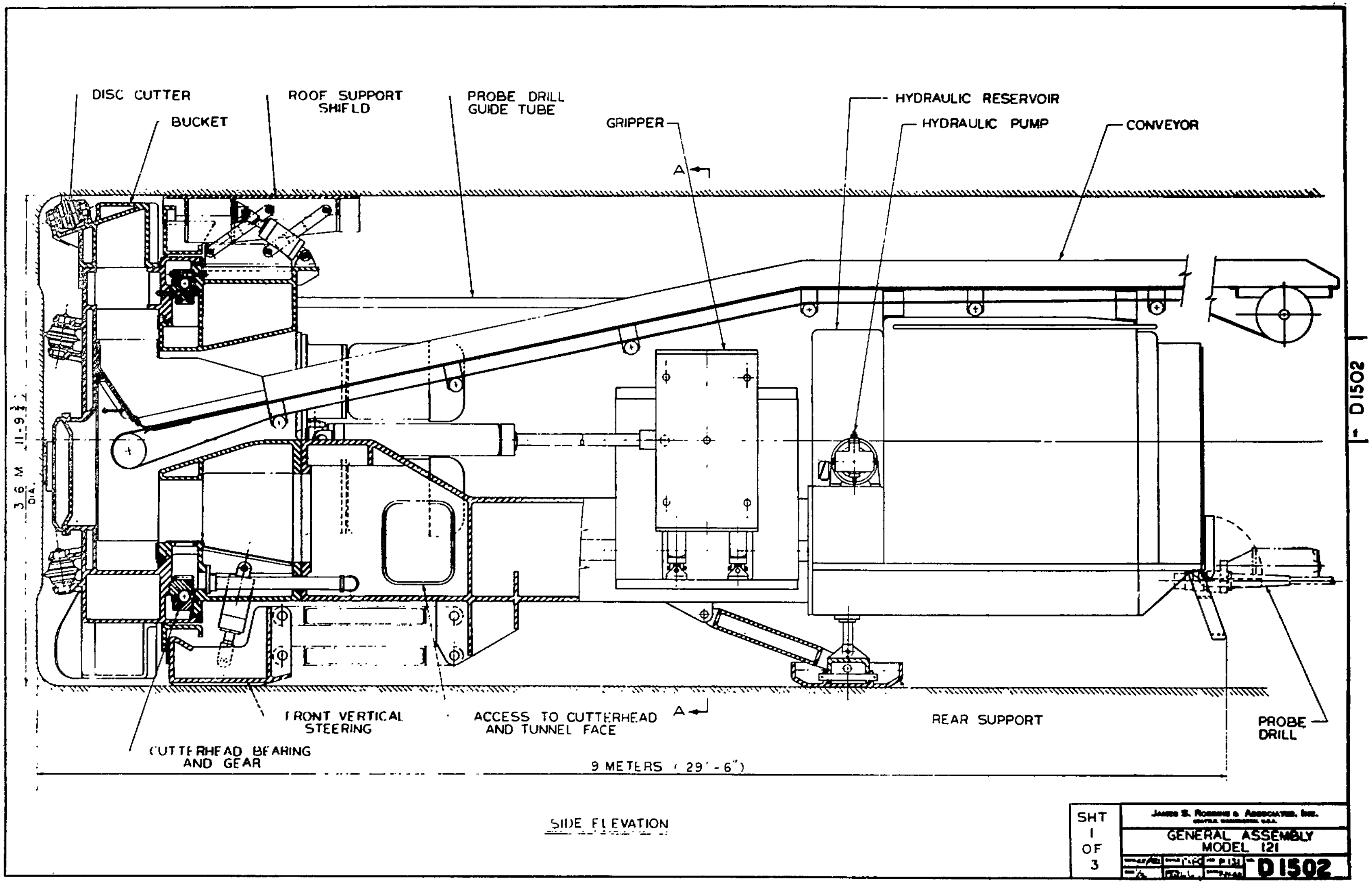

Figure 54: Side Elevation - Robbins Boring Machine, Model 121.

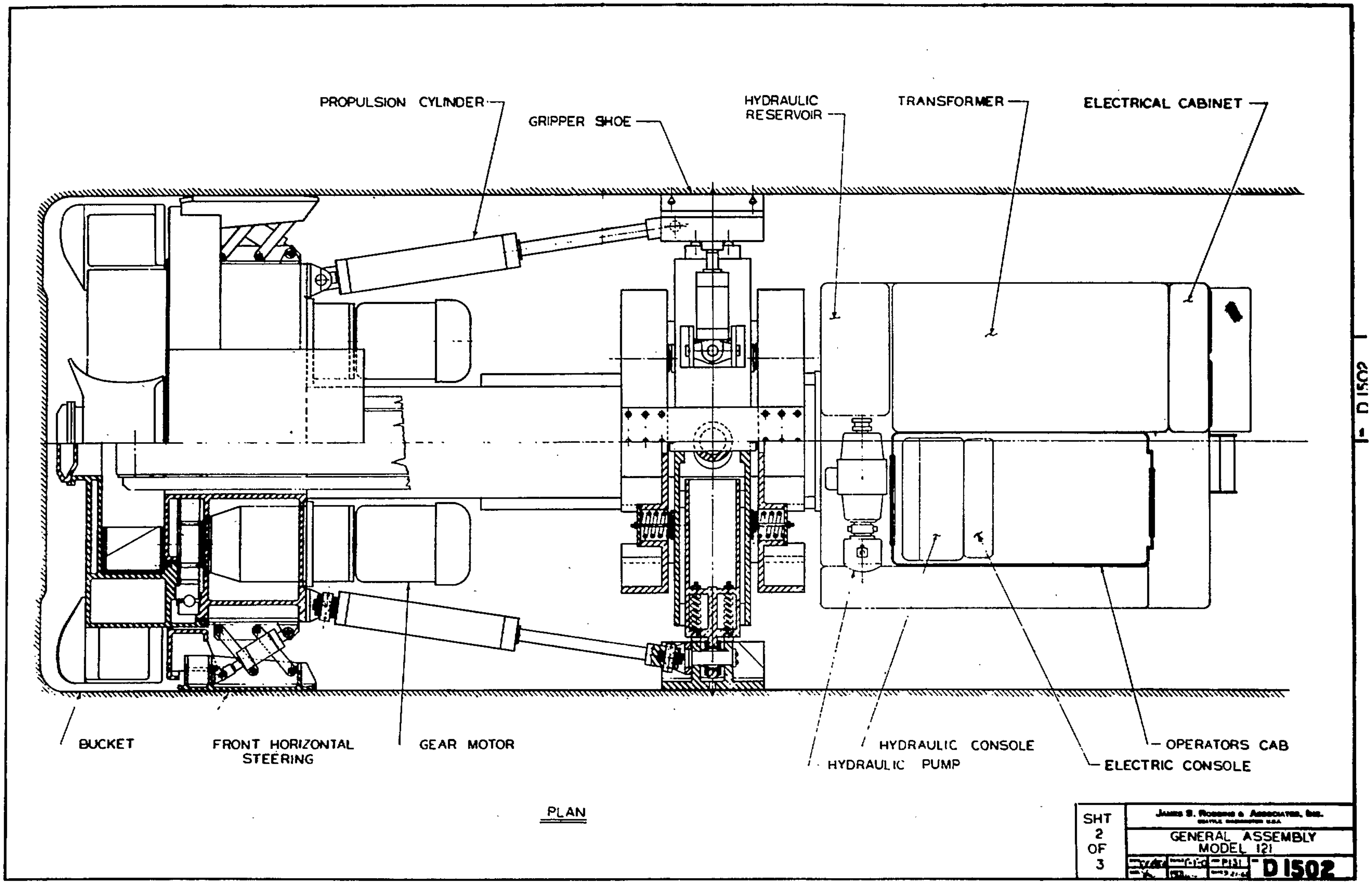

Figure 55: Plan View - Robbins Boring Machine, Model 121.

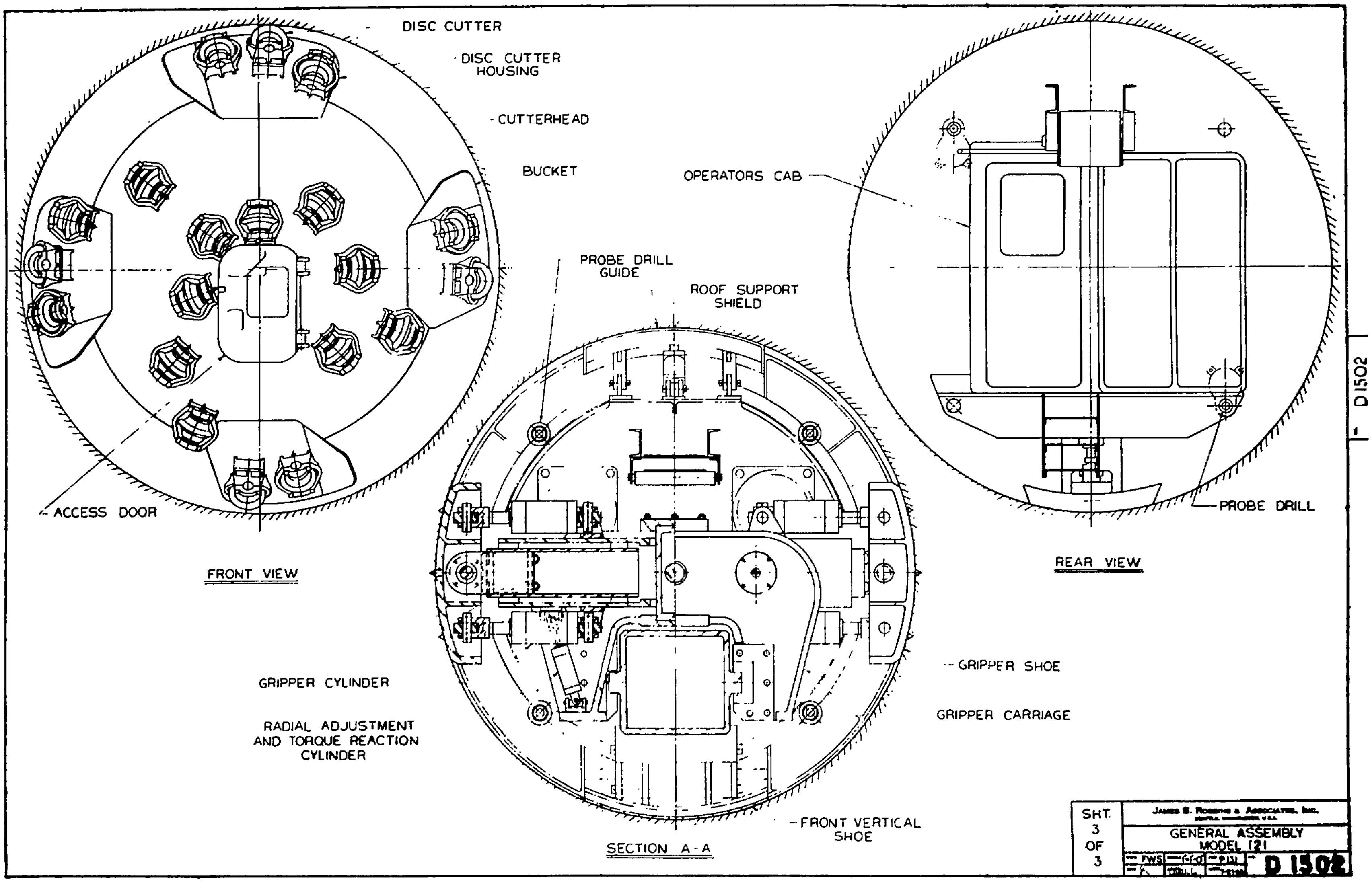

Figure 56: View of Cutterhead Assembly and Rear of Machine.

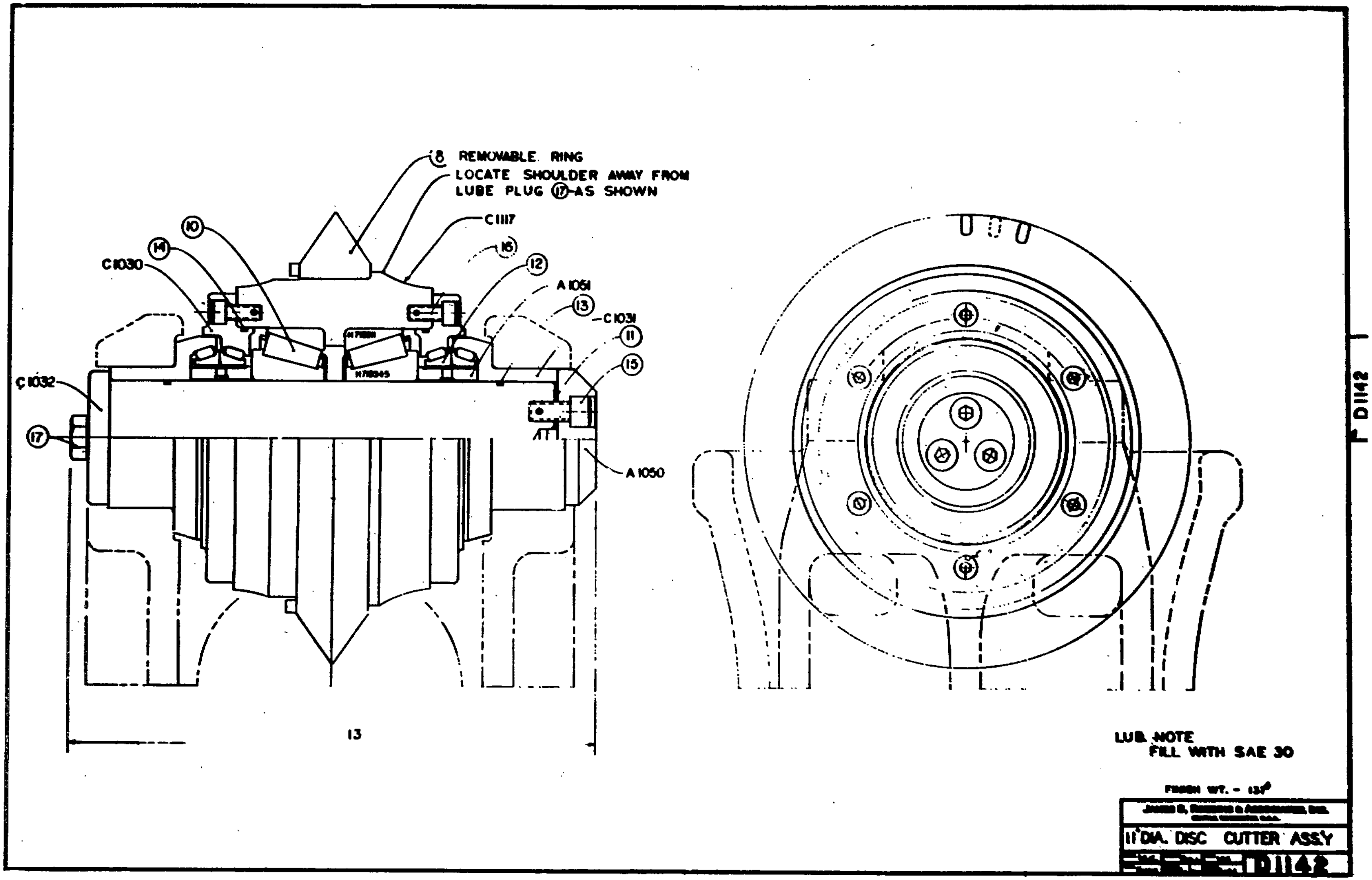

Figure 57: Details of Disc Cutter Assembly.