Underground Construction in Soft Ground, Fujita & Kusakabe (eds) © 1995 Balkema, Rotterdam. ISBN 90 5410 536 4

Canadian national report on 'tunnelling in soft ground'

K.Y. Lo
Department of Civil Engineering, University of Western Ontario, London, Ont., Canada

R.P. Benson
Klohn Leonoff Ltd, Richmond, B.C., Canada

INTRODUCTION

To assess the current practice in the design and construction of underground structures in soft ground in Canada, the ISSMFE questionnaire was distributed to sixty-six (66) agencies. The list included individual consulting engineers and geologists, authorities of provinces and cities in the energy and transportation sectors, engineering companies working in the fields of mining, energy, transportation and water resources, as well as universities. The response to the survey, however, was not extensive. This report is based largely on the results of the survey, supplemented by the knowledge of the writers on the tunnelling activities in Canada. The report is not a definitive document but is believed to reflect a cross-section of the practice in Canada.

1. CONSTRUCTION METHODS

1.1 Construction methods for tunnelling in soft ground ranging from hand excavation to sophisticated closed-face earth-pressure-balanced tunnel boring machines have been used in Canada for ground conditions varying from weak, saturated soils to soft rock. Hand excavation is now seldom used, except in the case of unusual problems, as machine technology has improved dramatically, along with the ability of Canada's engineering and construction personnel to utilize such methods. It is generally expected that future soft ground tunnels will be excavated mainly by sophisticated TBMs, and that the EPB machine will be the preferred method for weak and saturated troublesome ground, especially for the large diameter tunnels. Microtunnelling is gaining acceptance and is expected to be used more often. In soft rocks and dense tills, the NATM type method is often employed with machine excavation.

1.2 The most widely used types of primary lining include pre-cast concrete segmental bolted lining and pre-cast concrete segmental expanded lining, shotcrete followed by in-situ concrete as well as steel ribs and lagging. The pre-cast concrete linings are commonly used in soft clays to clay tills. Shotcrete and steel ribs with lagging have been used in ground conditions ranging from clay tills to soft rocks. Cast-iron segmental bolted lining was used in older tunnels including the Toronto Subway, in dense silts and clay tills. These older techniques of bolted cast-iron or steel segments have been gradually replaced by modern bolted, gasketed, reinforced segmented concrete liners, and it is expected that this type of single-pass liner will develop broader usage in the future. Varieties of double-pass liner systems, including temporary liners of mesh-type systems reinforced by shotcrete and ribs as necessary, then followed by unreinforced or reinforced concrete are common.

2. EARTH AND WATER PRESSURES ON TUNNEL LININGS

2.1 Earth and water pressures exerted on tunnel linings are assessed for temporary and final loadings by a wide variety of methods. There are no specific Canadian standards, as designers utilize methods documented by previous investigators. Methods include hand calculations of loads based on gravity and estimated stresses that account for in situ soil stress prior to and subsequent to deformation caused by tunnel construction. Methods utilizing FEM, BEM and articulated elastic beam simulation are utilized especially for deep and/or large tunnels. Design analyses taking into account soil behaviour ranging from small strain behaviour to large plastic deformation are performed for specific problems.

2.2 The principal soil parameters required for the design methods vary, depending upon the complexity of the design, size of tunnel and overall strength and stiffness of the ground. Parameters normally required for soils include general index parameters for classification purposes, and shear strength parameters and deformation moduli for both undrained and drained cases. Undrained shear strengths are measured by both in situ (cone and vane-shear) and laboratory laboratory triaxial tests. Drained strengths are measured by laboratory triaxial tests. Values of K_0 are obtained by in situ pressuremeter and hydraulic fracture tests and laboratory directional consolidation tests.

3. GROUND MOVEMENTS

3.1 Design methods used to assess ground movements caused by tunnelling are based on both empirical and analytical approaches. The classical work of Peck, dating back to 1969, still appears to provide the basis on which most assessments of potential ground movement are made, at least for preliminary design purposes. Consideration of ground loss is given to the method of excavation, time-delay in liner placement and associated movement, as well as subsequent deformation of the final liner. Alternatively, the gap parameter method is sometimes used. Numerical methods such as FEM are also utilized with detailed parametric evaluation to assess complex problems in critical sections of the tunnel.

3.2 The principal soil parameters include undrained and drained shear strengths and consolidation behaviour of the soil surrounding the tunnel in association with anticipated groundwater behaviour, and are generally the same as those in 2.2.

4. MONITORING OF PERFORMANCE

4.1 Instrumentation of various types are utilized to monitor performance of the tunnel during and subsequent to construction. In addition, monitoring is included for assessment of behaviour of the tunnel itself, and the ground surrounding and above the tunnel, especially if critical structures may be affected.

Types of instruments include all kinds from direct hand survey measurement of surface or interior measuring points to electronic MPBX systems to measure deformation. Measurement of stress in temporary or final liners is also undertaken on larger or deeper tunnels utilizing load cells or flat jacks as applicable. Standard crack survey techniques for nearby or overlying structures is undertaken, especially when rapid transit tunnels or other types of tunnels are driven beneath populated areas. Piezometers of all types from simple standpipe to electronics readout are utilized depending on the type of soil or soft rock.

Performance measurements are normally undertaken during construction and may be continued for about one year after construction, unless other conditions warrant.

4.2 Probing ahead of the tunnel face during construction is undertaken on an if-necessary basis. Such conditions could include potential for weak or running ground, high pressure water, or gas. Such probing may be undertaken by the contractor or required by the engineer.

5. CODES OF PRACTICE

There are no general Canadian codes of practice for tunnelling. Standards and criteria are usually established on a project basis pertinent to the ground condition, construction method and lining system. General reference is made to ASTM and CSA for materials specifications. Reference to recommended practice norms established by ITA Working Groups are utilized by some Canadian designers. Canadian Building Codes are used where applicable and construction under the regulations of provincial Workmen's Compensation Boards are a safety requirement.

6. GENERAL REMARKS

Canadian experiences in tunnelling are usually recorded in the Canadian Geotechnical Journal and the Journal "Canadian Tunnelling Canadien", as well as in proceedings of the annual Canadian Geotechnical Conference and the annual Canadian Tunnelling Conference. The Canadian Foundation Engineering Manual is a reference commonly used. Some major projects that are underway or are about to start in the near future include

- The Edmonton Light Rail Transit Extension involving use of both TBM and the Sequential Excavation Method (SEM).
- The St. Clair Tunnel, a railway tunnel connecting Sarnia, Ontario and Port Huron, Michigan will involve the use of TBM through clay with shallow cover. The tunnel will be 1844 m long with a finished diameter of 8.3 m.
- Extension of the Toronto Subway System involving 10 km of twin tunnels with finished diameters of 5.2 m in glacial deposits.
- Twin tunnels of 13 m diameter and approximately 10 km long, each to be constructed in soft rock (shale) at Niagara Falls, Ontario.

ACKNOWLEDGEMENT

The writers wish to express their appreciation to the individuals and organizations for their time and effort responding to the questionnaire.