TUNNELS & TUNNELLING

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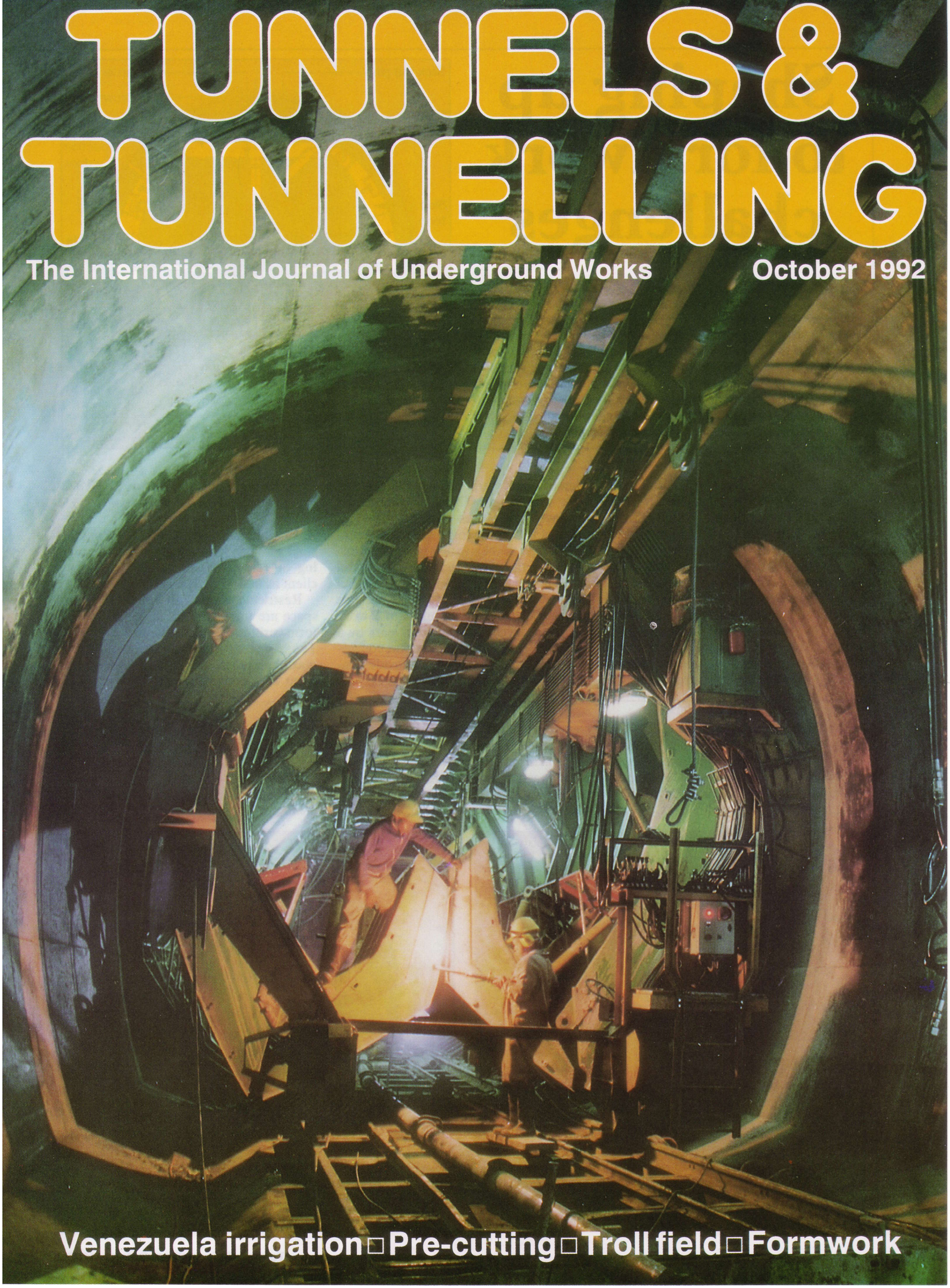


Venezuela irrigation □ Pre-cutting □ Troll field □ Formwork

Shaping up to formwork challenges

Ed Brady, Tunnel Manager, EFCO, Iowa, US

Steel forms for the tunnelling industry have developed swiftly over the past 50 years, although the steel form industry itself began at the turn of the century when the patent for the steel cantilever type form was issued. The rapid development of TBMs, together with pressure exerted by the environmental lobbies, has enabled local government agencies to design for tunnels instead of open cut constructions.

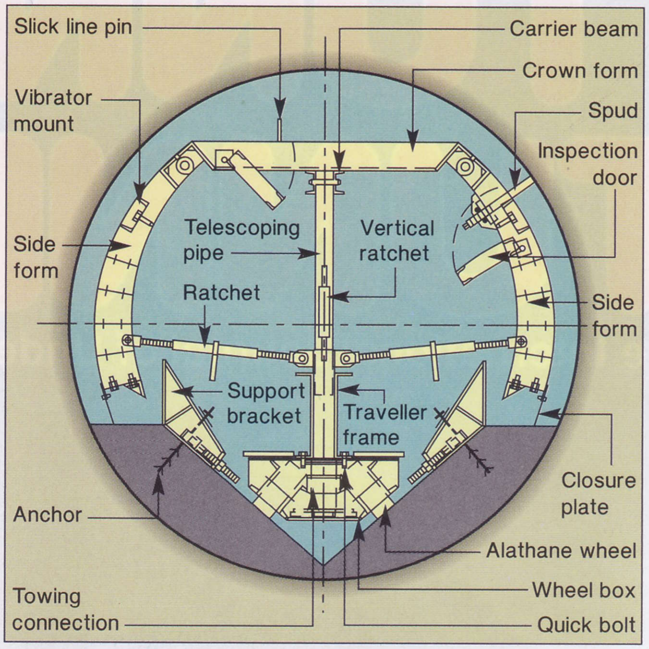


Fig 1. Forms in pouring position, New York City Bureau of Sewers, Staten Island.

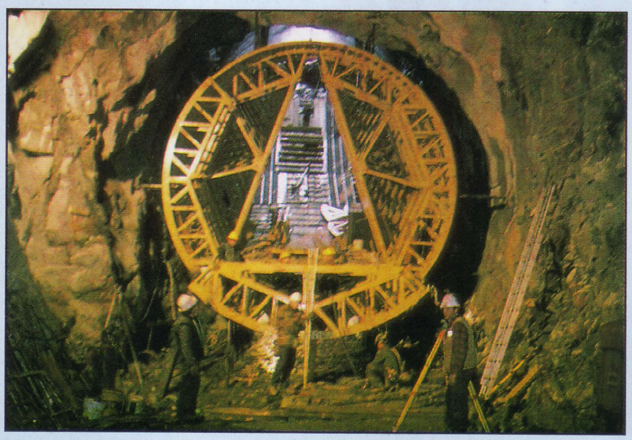
Before the advent of TBMs, most tunnels were excavated by pick and shovel in soft ground and by drill+blast in hard rock. Although the pick and shovel method is rarely employed today, drill+blast is still used under certain conditions.

In the past, most tunnels were formed by ribs and lagging with brick linings. The forms could be handled by brute strength. Concrete was placed behind the forms by shovel. As time went on, manual labour was replaced by carriers or travellers and wheels, jacks, turnbuckles and the like were introduced. These, together with improved hydraulics and the development of telescopic formwork, made possible longer tunnels with larger diameters.

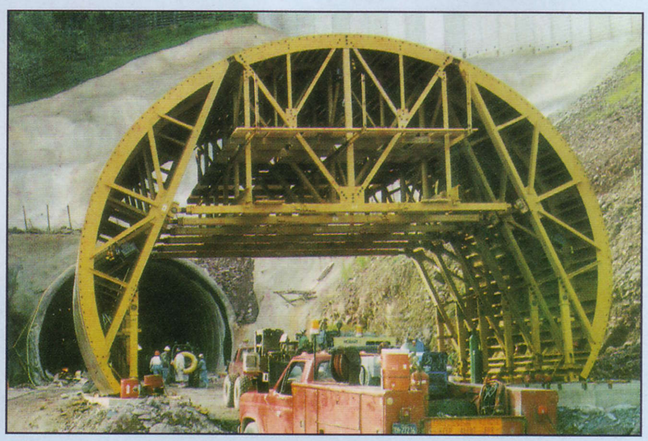
Placing the concrete lining in a tunnel demands considerable study and careful planing. Most of the multi-purpose formwork used for shaft and tunnel work has been developed over the years by a few form design and fabrication companies. These companies can provide contractors with precise information on proven forming arrangements at the bidding stage and can follow up by either supplying or renting forms to the successful client as and when required.

Restricted access and limited working space are major factors in the design of formwork for underground structures. The form designer must provide for maximum re-use and mobility and minimum bulk consistent with the specified

Economy Forms Corporation (EFCO) has been in the concrete forming business for over 55 years and therefore is very experienced in design, innovation and invention of steel forms for all types of concrete construction. EFCO's all steel, custom built tunnel forms are designed to form tunnels of every shape and size. Forms are manufactured full round with hinged or single pieced invert, invert first, invert last, screeded or western style with curve. The company's expertise covers continuous, telescopic or non-telescopic tunnel forms and the way in which the form is handled, whether by a straddle or non-straddle traveller, with a rolling or fixed needle beam, or no needle beam, or if it is to be power driven.



Full round conical shaped form assembled for the James Bay hydro project in Quebec. EFCO supplied 5200ft^2 of special all steel forms to Spino Construction Co to form the 6300ft long penstock tunnels. These forms were used to cast the 80ft long interior elbow. Because of its conical shape, EFCO manufactured 17 trussed sections located on 4ft centres with increasing diameter to adjust from the bottom 22ft diameter to the top 26ft diameter.



The crown and side forms for the Lehigh Tunnel on the Pennsylvania Turnpike are pre-assembled outside the tunnel. The tunnel was constructed by the Newburg/Walker/Rogers JV using EFCO tunnel formwork. This tunnel is 36ft 6in wide x 26ft 5in high. EFCO furnished two 30ft long units of all steel non-telescopic arch and side wall forms for this project. The arch and side wall forms were handled by an all steel, automated, rail mounted traveller.

concrete placing procedures. Today, highly developed basic form arrangements are readily adaptable to the vast majority of individual job requirements.

Tunnels are usually circular or horseshoe in cross section depending on their function and the type of ground through which they are driven. Regardless of the cross section, they are usually divided into invert and arch sections for concreting or full round 360°. The arch section is sometimes further divided into side wall sections which are cast separately from the upper part of the arch. Separate curbs may also be cast before the invert is concreted. The sequence for tunnel lining is to place the curbs first and then the invert, which will serve as a base for machinery and travellers; then the walls and arch are formed. In other cases, rails for travellers and machinery are positioned on excavated rock and the arch is concreted ahead of the invert.

The steel travelling form has largely replaced all other types of form for tunnel lining except the rib-and-lagging or precast concrete segment required for lining soft ground tunnels. There are several types of travelling forms. Some proceed on wide gauge track; others are moved by a traveller, in effect a carriage which moves along on the same track as the concrete trains. Some concrete lining procedures permit use of non-telescopic forms. In all types, the sections must be hinged to permit collapsing in order to break away from the concrete; they must be equipped with jacks for bracing and aligning; and they must be rigid and strong enough to resist distortion.

The invert may be placed with or without curbs. On larger tunnels, invert forming and placing is usually undertaken as a continuous process with the aid of a travelling bridge from which the side form handling concrete placing and, when required, track related jobs, are done.

The main structural frame for arch forms is made up of circumferential ribs and longitudinal stringers conforming to the required tunnel cross sections. Arch forms are partially collapsed and moved forward, usually on their own specially designed jumbo or traveller as the arch concreting advances. Forms that can be collapsed sufficiently to move forward within an adjacent form section which remains in place are described as telescoping arch forms.

Non-telescopic forms are those which collapse enough for stripping, then are moved forward beyond the just completed tunnel section to be set in place for concreting the next section of the tunnel. The arch forms are supported on the tunnel invert and are held in place by clamps attached to anchor bolts in the previously placed invert concrete.

Placing the full tunnel section monolithically in one operation is restricted to full circular tunnels with forms in relatively short lengths. On most jobs, the forms are erected above ground to insure proper fitting of parts when the units are taken under ground. The choice of materials for underground formwork is usually based on the shape, degree of re-use and mobility of the forms and the magnitude of pump or pneumatic pressure to which they are subjected. Usually tunnel and shaft forms are made of steel.

Most tunnels before 1941 were of the invert first arch construction. With the completion of the Lawrence Avenue sewer in Chicago in the '60s, most tunnels - sewer, water or metro - have been of the full 360° monolithic type. These projects include the American River Tunnel, the San Francisco Subway, New York water tunnels, and the Rochester sewer system (WMATA), Baltimore.

With the ability of the TBM to excavate large hard rock tunnels in excess of 33ft diameter as a full circle, steel form technology had to evolve to match. The development of the full round design type of form has permitted the contractor to form any size tunnel from 5ft in diameter to 36ft in diameter as a full round telescopic type of operation.

The design of the full round either with a hinged or single piece invert with the needle beam traveller can be designed to adjust to all conditions that arise in tunnel construction. In addition, the forms are designed to keep up with advances in the concrete placing industry. □

References

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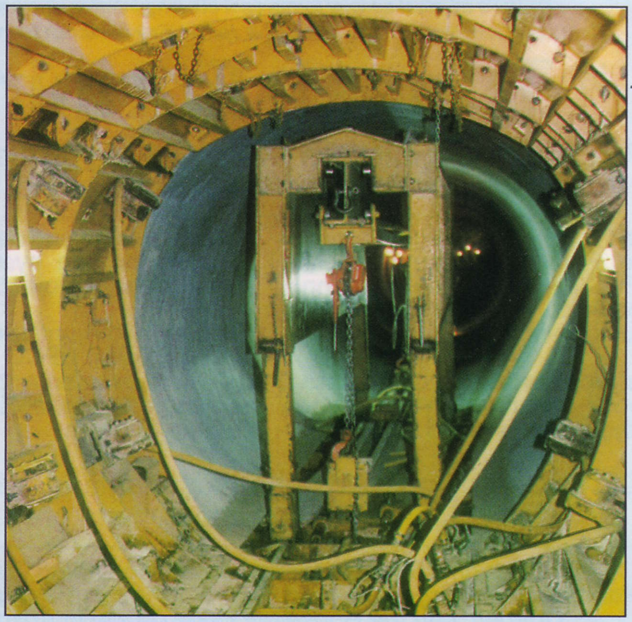
2. Engineering handbook. Edited by Bickel, J O and Kuesel, T R. *Published by Van Nostrand Reinhold.*
3. Formwork for concrete, fifth edition. Hurd, M K. *Published by the America Concrete Institute.*

The picture shows the 4m diameter, 14m long. 290 tunnel form built by EFCO for the deviation tunnel which is part of the El Diluvio Dam near the city of Maracaibo in Venezuela. The tunnel was constructed by Conintur, sub-contractor to the Seana-Omycca consortium. The 4m diameter, 14m long, 290ft form and its carrier were designed, built, and delivered from EFCO's Venezuelan factory.



Two Heber City, Utah, tunnels were built by Granite Construction using EFCO tunnel forms. The traveller pictured was designed to adjust for non-telescopic and telescopic uses. One tunnel is 7ft in diameter x approx. 700ft long and the other, 9ft 6in diameter x approx. 1800ft long. EFCO designed a traveller which would move the 7ft diameter form in a non-telescopic manner, then have the capability to move the 9ft 6in form in a telescopic manner.