STRUCTURAL SUPPORTS

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STATE OF THE ART

Structural support in a tunnel maintains a stable, usable, and economical underground opening and prevents settlement in the surrounding media or adjacent structures. Design of supports has depended to a great extent on the ability of the designer to convert meager geologic data into practical information for use by contractor and supplier. Existing design procedures still depend greatly on empirical data and the judgment of a knowledgeable designer. To design the required structural supports, the designer must consider

1. Media through which tunnel is to be driven,
2. Method of excavation,
3. Function of support (primary or secondary support or both),
4. Time of support installation, and
5. Method of load imposition (expansion, grouting, blocking, or other means).

Only when the total system of construction is considered can the proper structural support be provided. Some structural supports in use are discussed below.

1. Timber sets are used primarily today in mines and in locations where timber is plentiful. Steel rib sets have replaced timber sets in practically all other instances.
2. Pans (cast or ductile iron) were developed for use with shield-driven tunnels. Welding and improved manufacturing techniques, together with the use of flexible liners, have limited their use.
3. Roof bolts were originally developed for mine roof supports. The wedge type was first used, the expandable was then used, and now the chemically or cement grouted is used. Often used in conjunction with shotcrete or gunite, roof bolts provide an economical support for proper rock conditions.
4. Steel ribs are probably the most popular tunnel support system in use today. This system is adaptable to changing ground conditions and conformable to practically any shape or size of member.
5. Pressed metal plates, commonly referred to as liner plates, are used generally in small tunnels, soft ground, and hand-mined operations. They have been used in conjunction with shields. More recently, gasketed liner plates have permitted temporary linings to be installed watertight.
6. Fabricated steel pans were first used on the land approaches for the Detroit River vehicular tunnel. Improvements in fabrication procedures and development of waterproofing methods have made this type of support acceptable. It is used today in conjunction with tunnel boring machines as a final lining in rapid transit tunnels.
7. Shotcrete provides an economical support where ground conditions permit. It can be used either alone or in conjunction with roof bolts or steel ribs.
8. Precast concrete segments are used in conjunction with the tunnel boring machine, frequently as a temporary lining. Waterproofing methods are now available to permit their use as a final lining.

Because they can advance rapidly, tunnel boring machines in use today have reduced tunnel costs and made tunneling a more accepted construction mode. Their progress is usually impeded, however, by the backup systems such as muck removal and installation of structural supports. The development of improved support techniques should not be the sole responsibility of suppliers and contractors. If so, only slight improvements will likely be made in existing methods when large advances are needed in the areas of new materials and better design procedures.

Steel supports in tunnel (photo courtesy of Commercial Shearing, Inc.).

FUTURE RESEARCH

Geological Data

More accurate and complete data are needed to help eliminate underground surprises. Any support system must be adaptable to changing ground conditions. However, because of the time necessary to design, receive approval, fabricate, and install a support system, it cannot be changed from day to day. Research is needed to provide better or improved information for support design as well as to verify existing methods of design.

Demonstration of New Methods

Innovations in design methods and types of supports should be tried in a full-sized tunnel. A research program, part of a proposed tunnel system, could be the proving ground for support systems as well as the muck removal system. In addition to the testing of different support materials and concepts, the flexible or interaction design concept could also be verified to permit both primary and secondary supports to be designed more economically. Stimulus might thus be given to the increased use of tunneling as a construction mode.

Mechanical Loading of Explosives

One of the factors that increase labor costs in tunnel construction is the number of workers required to hand place and tamp the explosive charge. Machines to place the charges could result in significant savings in labor cost and loading time.

Hydraulic Drills

Manufacturers have recently introduced hydraulically powered drills and impact breakers that give great promise of success. Perhaps further experimentation with combinations of percussion drills and impactors of expansion breakers will lead to a new rock-breaking technique that will eliminate the need for explosives.

Smoother Excavation

One of the advantages of machine excavation is the elimination of overbreak. The removal of unnecessary material beyond the required excavation lines increases the cost for labor and ground supports and especially adds to the cost of concrete lining required to fill those unwanted spaces. Further research is needed in methods to permit better control of overbreak.

Faster Muck Removal

Little improvement has been made during the past 40 years in mucking machines. Faster production could undoubtedly be obtained by introduction of already known principles to tunnel excavation. Use of hydraulically powered and more compact shovels could result in faster and less costly handling of materials in underground excavation.

Labor Efficiency

A program of education and improved relations between employer and workers is needed to increase labor efficiency, improve safety, and reduce costs. An objective study should be made to determine the optimum number of workers required for various tunneling operations. Part of the high costs of underground excavation results from requirements of union management that more workers be employed than needed for efficient and safe operations with today's equipment.

Measuring Surface Vibrations

Vibrations at the surface of the ground are caused by blasting for rock tunnels. The character of these vibrations cannot now be accurately predicted, and a measurement method is needed, particularly when blasting occurs under densely populated areas.