INTRODUCTION

Tunnels can be defined as underground passages constructed for transportation connections between two points. The tunnels can be described by:

1. Made into natural material (rocks or soils)
2. Empty inside
3. Carry the loads itself
4. Both ends are open to the atmosphere
5. Generally horizontal
6. The thick-walled structure looks like a cylinder

There are numerous tunnel classifications based on their purpose, geological location and condition, cross-sectional shape, and so on. Tunnels are classified according to their purposes as railway tunnels, metro system tunnels, highway tunnels, pedestrian tunnels, water tunnels, sewage tunnels, services tunnels, and storage tunnels (Fig. 1). Tunnels are classified into rock, earth, and submerged tunnels depending on their location. Finally, tunnels are classified according to their shape as rectangular, circular, elliptical, egg, horseshoe, or segmental (Fig. 2).

Fig. 1: Tunnels classification based on purposes.

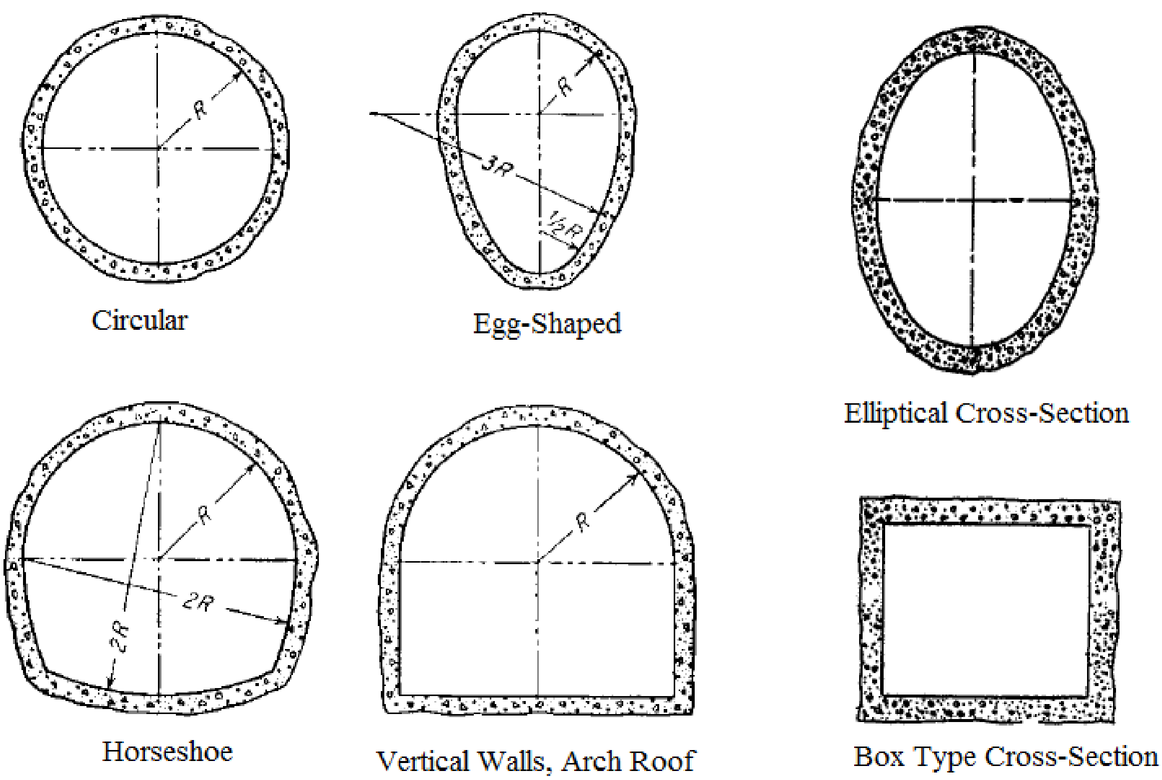

Fig. 2: Tunnels classification based on their shape.

Tunnels are one of many types of underground excavations, including adits, shafts, inclines, large chambers, subways or metros, underpasses, shelters, power plants, warehouses, stores, mines, and so on. The tunnel has nine elements, keystone, arch, wall, floor, bench, bench line or plane, top heading, invert, and unit (Fig. 3). Many factors influence the excavation of these structures, including the mineralogical composition of the rocks, texture or fabric, petrographic features, structure, rock mass, strike and dip of beds concerning the face of excavation, the intensity of tectonic disturbances, and the degree of weathering.

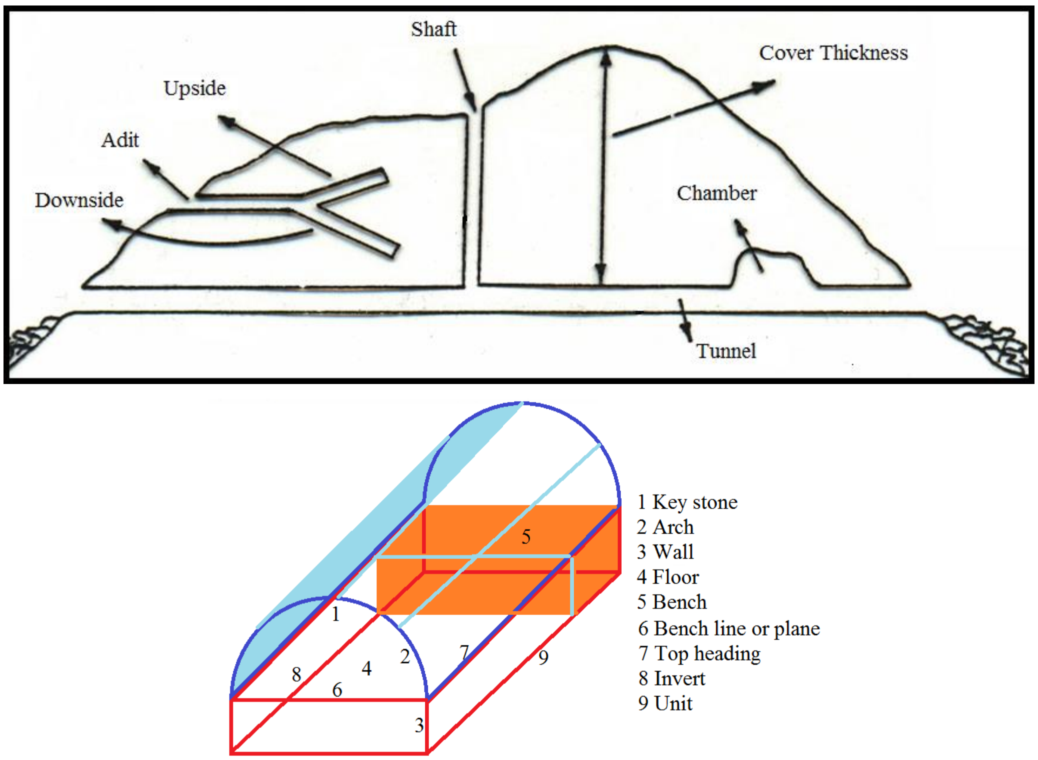

Fig. 3: Tunnels types and their elements.

Tunnels here include mainline haulage ways in mines and other important, semi-permanent underground passageways as well as conventional tunnels with surface portals at both ends. Like shafts, “tunnels” may be used for transporting personnel, underground supplies, waste rock, and for haulage of ore in mines. Like shafts, tunnels also serve as conduits for ventilation air and as pathways for compressed air and water lines. Because of their long service life, tunnels must be carefully designed and constructed with an adequate factor of safety. Tunnel support may be natural with only occasional rock bolting and screening. Support may also be in the form of a permanent, continuous concrete liner, discrete steel sets, or both. Large bolts placed on an engineered pattern may also be used for robust tunnel support. In the case of naturally supported tunnels, strength failure of the rock mass walls can be designed against using a stress concentration approach, with due consideration of joints. Indeed, in shallow ground tunnels, the fall of rock blocks defined by intersecting joints is often the primary threat to safety and stability (Fig. 4). In the case of parallel or multiple tunnels, pillars between tunnels may be designed using a moderate stress approach, again with due consideration of joints.

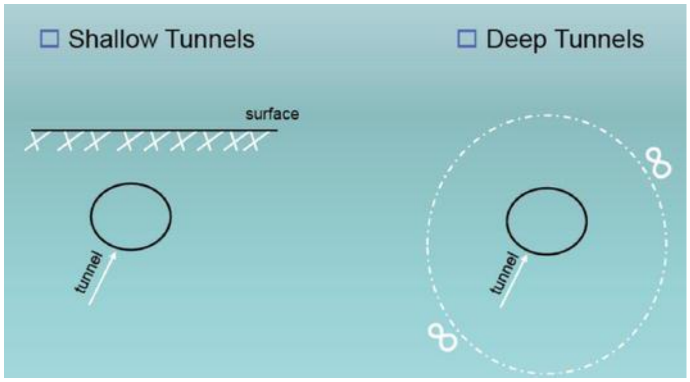

Fig. 4: Shallow and deep tunnels.

Where additional support or reinforcement is needed beyond that provided by the rock mass proper, difficulties arise that are absent in shaft support analyses. Lack of symmetry and circular sections in tunneling combine to make tunnel design more difficult. Although circular sections are sometimes used in tunneling, the pre-excavation principal stresses are not usually equal. Thus, the assumption of a radial "pressure" or support load is not generally justified, although in some special cases, for example, in "squeezing" ground, a radial pressure may be reasonable. In this regard, a reasonable estimate of the support load is a key ingredient to support design.

Naturally supported tunnels

The estimation of stress concentration for tunnels is similar to that for shafts. Thus, major features of the problem include

1 cross-section shape
2 aspect ratio
3 pre-tunnel stress field
4 orientation of the tunnel axis.

Nearly the entire discussion of stress concentration about single, naturally supported shafts applies to tunnels. The reason is that the mathematics of stress analysis does not distinguish between shafts and tunnels. For example, stress distribution about an elliptical tunnel or an elliptical shaft excavated in a hydrostatic stress field is the same and, as a consequence, so are stress concentration factors. The same is true for circular and rectangular sections. Figure 4 shows a comparison of stress distributions about circular, square, elliptical, and rectangular sections excavated in a hydrostatic stress field. The plots in Figure 4 indicate the magnitude of the tangential stress acting parallel to the tunnel wall by the length of a radial line extending from the tunnel outline; tension is plotted inside the tunnel and is considered negative, while compression is plotted outside (positive). No tensile stress appears in any of the distributions in Figure 4. The horizontal bar under the note K = 1 indicates the length of the line for a stress concentration of one. A circular section is preferable to a square in a hydrostatic stress field, and an ellipse is preferable to a rectangle of the same aspect ratio (a/b = 2) in a hydrostatic stress field when compared on a basis of peak stress (compression).

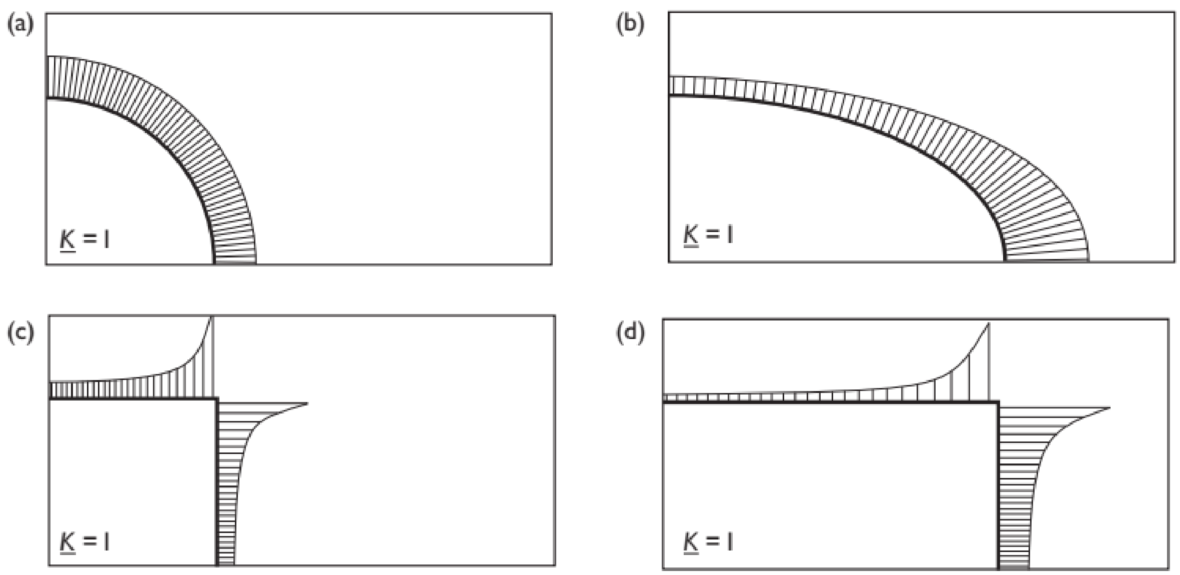

Figure 4 Stress distributions about (a) circular section, (b) elliptical section, aspect ratio = 2, (c) square section, and (d) rectangular section, aspect ratio = 2 excavated in a hydrostatic stress field (Sx = Sy = 1).

From a stress analysis view, any distinction between shafts and tunnels is simply one interpretation. Of course, an elliptical tunnel section would be even more difficult to excavate than an elliptical shaft. Indeed, elliptical shafts are rare and elliptical tunnels are almost unknown. Circular and rectangular tunnel sections are usually more practical. Indeed, tunnel boring machines (TBMs) often cut circular sections. Some boring machines used in mining result in rectangular sections with rounded corners that approach an ovaloid section, while some mechanical excavators (e.g. “continuous miners” used in coal mining) result in rectangular sections with relatively sharp corners. Mechanical excavation is preferred because of the low cost associated with a rapid advance rate, often several hundred feet per day in relatively soft ground that requires little temporary support. Because the machine dictates tunnel shape and often aspect ratio, orientation concerning the pre-excavation stress field is the only design parameter available for minimizing stress concentration. When the tunnel route is determined by other overall design considerations, then the orientation is also set.