Measurement on the Pilot Bore for the Straight Creek Tunnel

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•THE MEASUREMENT of rock loads and ground movements associated with the excavation of underground openings had its beginnings approximately 25 years ago in Europe. Although there are earlier records of salt mine convergence measurements and of load measurements in Alpine tunnels (1920's), all these early measurements suffered from the lack of precision measuring devices. The early salt mine convergence measurements were obtained by determining the time to squeeze tight a steel plug in a drill hole. The Alpine tunnel load measurements were based on the observation of the crushing of wooden blocks placed in timber sets.

The availability of precise measuring devices has permitted a more accurate approach to measuring the response of rock to mining and construction operations. To date, the greatest application of available rock mechanics instrumentation has been in Europe. The reason for this early development in Europe was the need for information related to mining operations under difficult conditions and near populated areas. The problems of underground mining and construction in Europe became critical because of the necessity of making a maximum recovery from limited ore reserves. This problem has not been as severe in the United States or Canada because of the more abundant resources and the less dense population. In general, in the United States it is possible either to buy the surface above a mining operation if damage is anticipated or to forego mining deposits under populated areas.

The ability to measure the reaction of rock masses to mining operations has made it possible for Europeans to develop lower cost mining methods which permit ore recovery within permissible damage limits to surface structures.

Terrametrics, Inc., of Golden, Colorado, measured rock loads and ground movements in relation to the excavation of the Straight Creek Tunnel Pilot Bore. They were specifically measuring:

1. The relationship between the load imposed on the steel sets and the designed load,
2. The zone of influence around the tunnel where the ground is strained (stressed or de-stressed) as the result of the tunnel excavation,
3. The strain variation outward from the tunnel walls resulting from the tunnel excavation, and
4. The rate of decrease of overall ground strain rates with time and tunnel face advance.

Instrumentation stations were placed along the tunnel at intervals sufficient to obtain a statistical approximation of the rock loads and ground movements in relation to various parameters, i.e., rock type, joint spacing, overburden depth, faulting, alteration, and tunnel geometry.

A total of 44 instrumentation stations was installed. Figure 1 is a diagram of one of the primary instrumentation stations (PIS). This type of station is designed to:

1. Measure the rock load on the steel support;
2. Measure the overall radial deformation of the roof and walls of the tunnel; and
3. Permit the calculation of the rate of change of the rock strain rate as the tunnel face advances away from the station.

Paper sponsored by Committee on Soil and Rock Properties and presented at the 45th Annual Meeting.

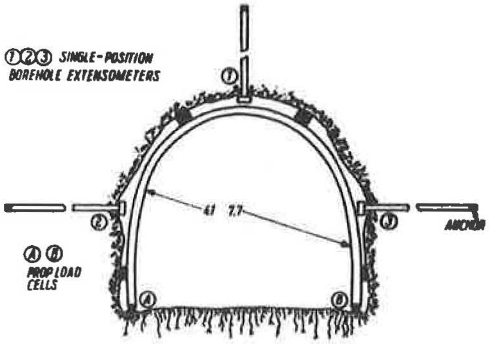


Figure 1. Primary instrumentation station (PIS).

Instrument stations were placed as close as possible behind the advancing tunnel face. The distance varied from 5 to 15 ft. Care was exercised to prevent blast damage to the instruments or their signal wires.

ROCK LOADS

Figure 2 is a typical vertical load history curve for PIS No. 6. These load measurements are directly related to the tunnel geometry, the steel set spacing, and the mass rock density. This permits the calculation of the rock load in pounds per square foot and the indicated rock arch-height in feet. The set spacing and rock density are dependent on the structural characteristics of the rock being excavated. The Straight Creek Pilot Bore is in a terrain of Precambrain granitic and metamorphic rocks.

The load history curve shown in Figure 2 demonstrates one of the phenomena measured in this tunnel—an extremely high-load zone which follows the tunnel face. Similar high loads were measured at every instrument station. The measured peak loads appear to be limited only by the yield strength of the steel or the crushing strength of the timber blocking.

This phenomenon closely follows the measurements made around several instrumented longwall coal faces in Europe. In coal mining, these loads are referred to as the abutment loads.

The apparent abutment load measured at Straight Creek can be explained by a modification of the theory used to describe the deformation of the rock roof behind an advancing longwall coal face. In brief, the hypothesis advanced is as follows (Fig. 3):

1. In between the face and the major rock section overhead is the near-roof beam, which may have considerable height in a nonstratified rock such as at Straight Creek.

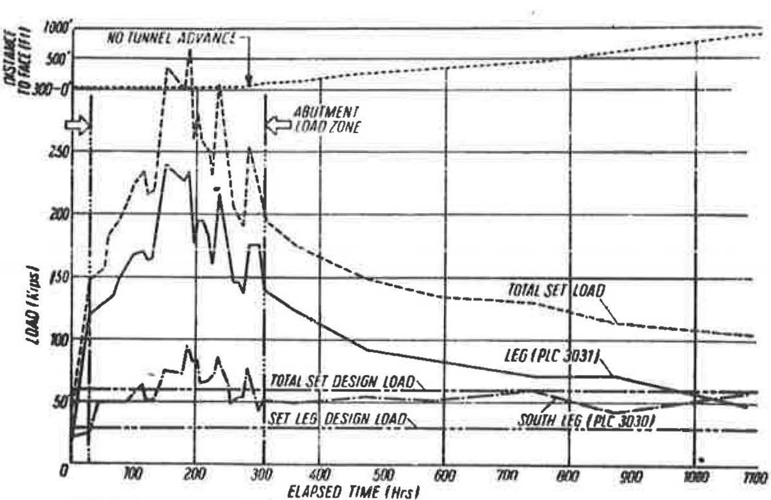
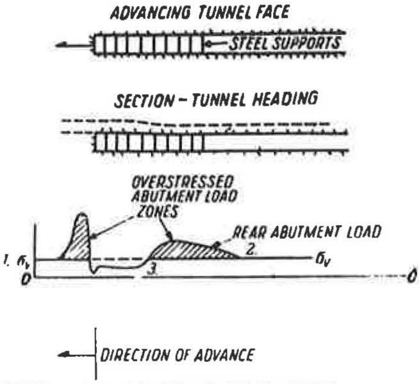


Figure 2. Typical vertical load history curve (PIS No. 6)



NOTES: 1. σ_v = BACKGROUND VERTICAL STRESS
2. REAR ABUTMENT ZONE DETERMINED BY LOAD CELLS
3. SMALL LOAD IN DESTRESSED ZONE RESULTS FROM BLOCKING OF STEEL SUPPORTS

Figure 3. Hypothesis for the loading phenomena.

2. This cantilevered near-roof beam is deflected downward as the tunnel face advances away from the instrumented station.

3. The deflection of the near-roof beam is resisted by the strength of the beam, the tunnel walls, and the steel tunnel supports.

4. The tunnel walls strain in response to the increased load; the near-roof beam deflects; and the steel supports are left attempting to support the vertical load previously supported by the rock excavated for the tunnel.

5. The measured peak loads (abutment loads) result from the attempted support by the steel sets of the total vertical load which is forcing the near-roof beam to deflect and the tunnel walls to strain.

6. The distance from the face of this apparent abutment load is determined by the stiffness or load-carrying capacity of the near-roof beam and tunnel walls, in conjunction with the steel support.

7. The steel support attempts to resist the deflection of the near-beam. The resistance of the steel is determined by the manner in which the blocking loads the particular steel set in question. The manner of the blocking is in turn determined by the geology and the construction technique.

8. Since the steel tunnel supports cannot support the entire load of the rock except in the case of a tunnel near the surface, either the steel or the blocking must be deformed so that the vertical load can be transferred to the tunnel walls, which are the major load-carrying structural units in any tunnel.

9. Once the rock has deformed sufficiently to establish stable conditions, the temporary set overloads will cease. When the rock deformation ceases, the steel set deformation will also cease. The stable loads measured on the steel tunnel supports are principally from the rock in the tension zone above the tunnel. A possible additional source of a portion of the stable set load may be some residual load from the

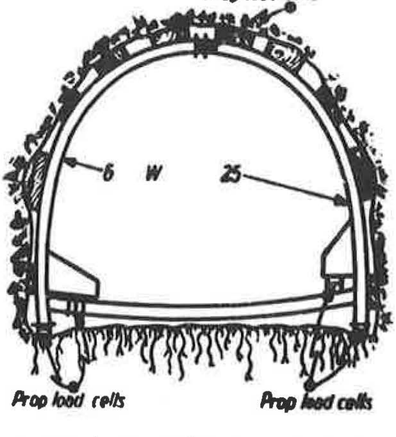


Figure 4. Special instrumented sets.

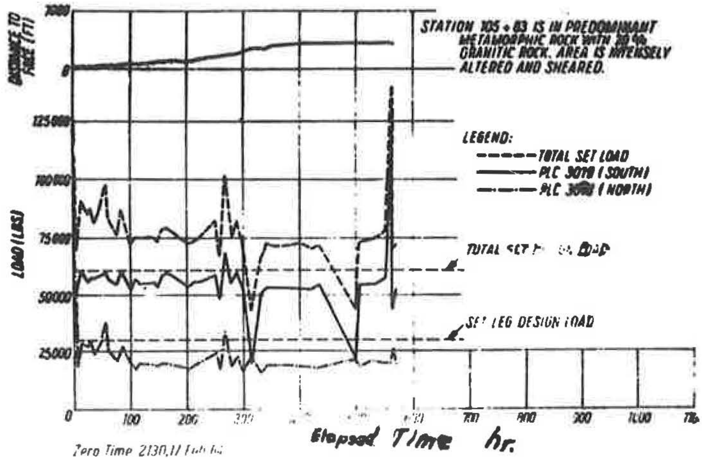


Figure 5. Load history, station 105 + 83: indequate steel size.

squeezed blocking and elastic deformation of the steel. This load should decrease with time as the wooden blocking ages and relieves this applied load.

Special load-measuring stations were installed in the two shear zones encountered in the Straight Creek Tunnel Pilot Bore. These stations were constructed to permit the measurement of the horizontal and vertical steel loads. Figure 4 shows how these special sets were constructed and instrumented. Knowledge of the loads on these special sets has permitted the calculation of a friction factor for sheared and altered material in the major shear zone.

In the sheared zone, the rock loads built up above the steel sets' (417. 7) design value, and thereby deformed excessively, necessitating replacement with a heavier steel

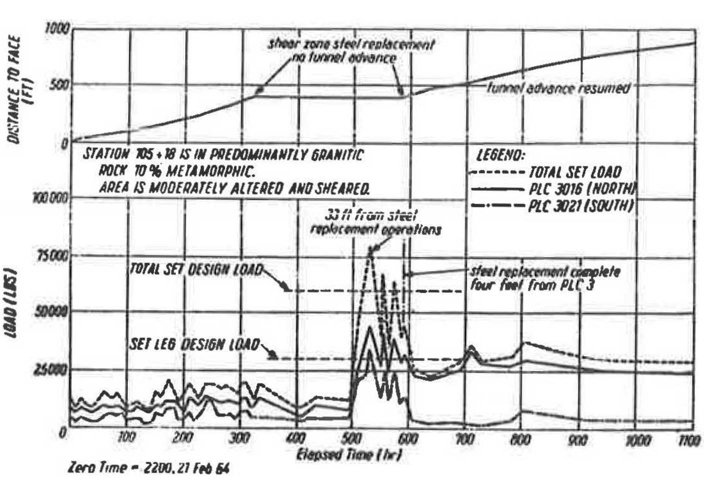


Figure 6. Load history, station 105 + 18: effect of steel replacement.

section (6H 25). The inadequacy of the original steel to support the rock loading in this shear zone can be seen in Figure 5.

When the new steel was substituted for the original lighter steel, the tunnel advance had to be stopped. During the course of replacing the steel supports in the major shear zone, a small amount of rock fell out in the shear zone. This action temporarily raised the loads measured on the instrumented steel sets adjacent to but not in the shear zone. Figure 6 shows the effect of the steel replacement on a nearby load-measuring station just outside the shear zone.

The measured stabilized rock load on the heavier steel after replacement was 6000 psf vertically and 4800 psf horizontally. Figure 7 is a graph of the total vertical and horizontal load histories of the two sets instrumented in this shear zone. The total design load for these two sets is approximately 500, 000 lb. Of particular interest is the instability of the loading and overloading during the first 100 hr after installation.

The selection of steel with a design load of 60, 000 lb appears rather good for this pilot tunnel, in respect to the stabilized loads. It is obviously not sufficient for the shear zone at Straight Creek.

GROUND STRAINS

Figure 8 is a typical borehole extensometer strain rate change plot at a primary instrumentation station (PIS No. 6). It demonstrates initial instability of the rock around the tunnel and the approach of stability with time and tunnel advance. The rock strain stabilized at the same time that the set loading stabilized. This can be seen by comparing Figure 2 with Figure 8.

Figure 8 demonstrates the ground strain (movement) phenomenon, which was typical in the jointed granitic and metamorphic rocks in the pilot bore. Figure 9 is a similar plot for an unsupported granitic tunnel section. Here the joint spacing was from 1 to 3 ft and the strain fluctuation effectively ceased in about 100 hr. The implication was that the joint spacing was the controlling variable in the duration of induced strains around the Straight Creek Tunnel Pilot Bore.

The ground (rock) strains have followed a definite pattern. This pattern appears to be the result of intermittent adjustments of the rock along predefined joint surfaces in response to stress changes associated with tunnel advance. These movements are somewhat erratic, with quiet (low-strain) periods separated by brief strain adjustments

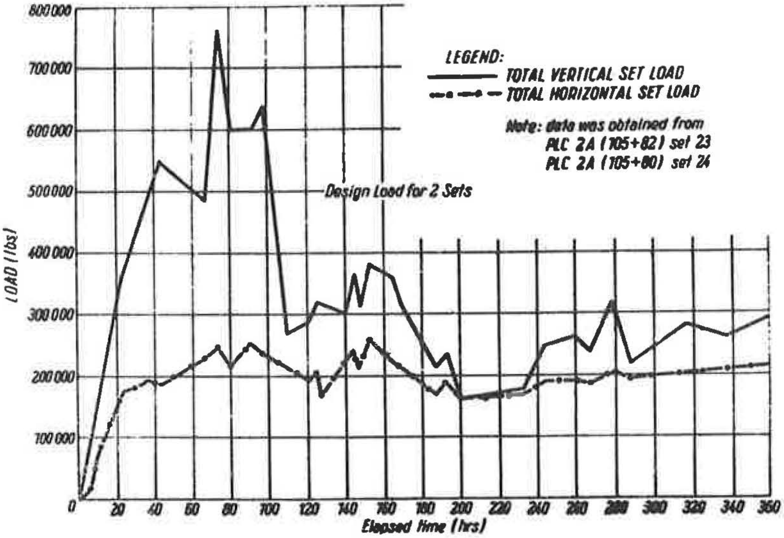


Figure 7. Total vertical and horizontal load histories for two sets in a shear zone.

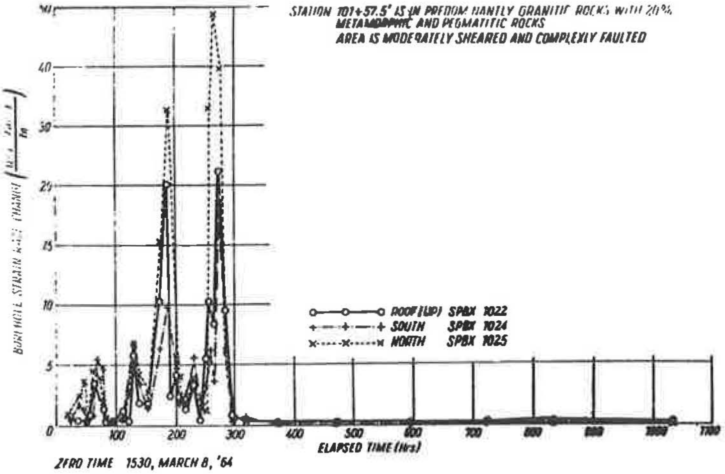


Figure 8. Strain phenomena typical of jointed granitic and metamorphic rocks.

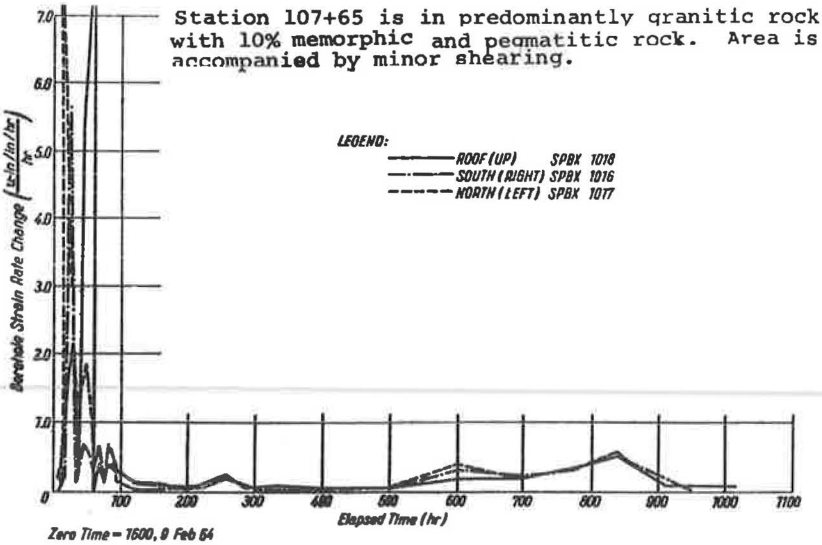


Figure 9. Strain phenomena for an unsupported basically granitic section.

of considerable magnitude. At all the stations instrumented, the magnitude and frequency of these adjustments decreased with time and the advance of the tunnel face away from the station. This pattern of decreasing strain rate is a primary indication of approaching stability.

Figure 10 shows a typical supplementary instrumentation station (SIS). The purpose of this instrumentation, in addition to providing all the information obtained by a primary station, was to permit the determination of the stress change outward from the tunnel in both the upward and the lateral directions.

The ideal elastic approximation of the strain and, therefore, stress distribution around an opening in brittle rocks, has been tested by the strain-measuring instrumentation at the Straight Creek Tunnel Pilot Bore.

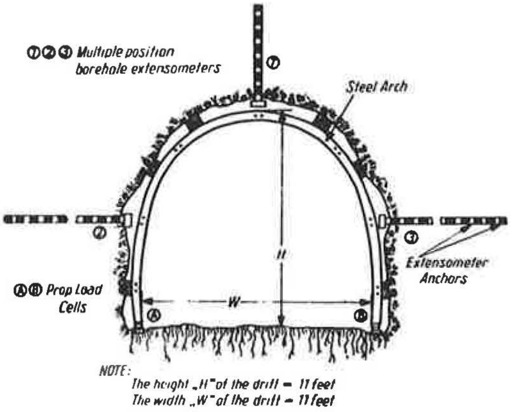


Figure 10. Typical supplementary instrumentation station (SIS).

The most interesting results were obtained from the up-hole instrumentation. Figure 11 is typical of the rock strain variation measured at one station. This figure is a schematic of the relative radial strains measured about the pilot bore. It shows that the general radial strain picture is similar to that anticipated on the basis of elastic theory. This schematic has been derived from curves of relative strain rates for randomly sampled time intervals along the various holes.

One of the immediate applications of this instrumentation is to design a preliminary roof bolting pattern both to support the rock load and to be of sufficient length to penetrate into the compression-optimum anchorage. The unknown is then the joint spacing which influences and controls the roof bolt spacing.

At station SIS No. 2, the indicated bolting pattern would be 6-ft-long bolts (minimum) on 4-ft spacing. The joint spacing was 0.5 to 1 ft, which would require wire mesh or

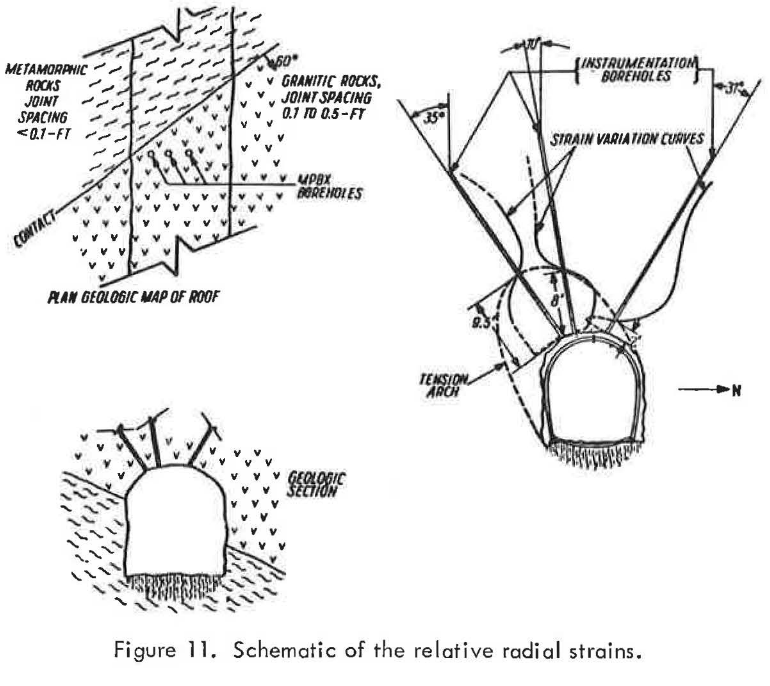


Figure 11. Schematic of the relative radial strains.

chain link fence between bolts. This pattern should both maintain the structural integrity of the tunnel and prevent blocks of rock which may become detached between the bolts from dropping into the tunnel.

CONCLUSIONS

1. The ability to accurately measure loads and rock strains makes it possible to rationally design supports to withstand the applied loads and accommodate the associated strains.
2. The determination of the safety of a rock structure need not be left to a nebulous experience factor. When support loads stabilize and rock strains cease or become negligible, we then have an effectively safe structure.
3. The ability to measure is the major step toward the ability to control.

ACKNOWLEDGMENTS

The investigations have been conducted with the full cooperation of the Colorado Department of Highways. The authors wish to thank the personnel of the Highway Department, in particular Adolph Zulian, engineer of plans and surveys; G. N. Miles, district engineer; and F. A. Mattei, project engineer.

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