RTH 305-80

LOAD CELLS

1. Scope

1.1 This method deals with load cells and their application in the field of rock mechanics and includes descriptions of various types, their construction, readout procedure, and data reduction.

2. Apparatus

2.1 Load cells have been utilized for a wide variety of engineering applications. Such uses include tunnel support, rock bolt, and tieback load monitoring. The data obtainable from load cells can be used for safety monitoring and as an engineering aid for support design. Some of the more common types of load cells used in rock mechanics applications utilize one of four basic types of measurement systems: (1) hydraulic, (2) mechanical, (3) strain gage (this includes bonded foil, vibrating wire, and unbonded wire gages), and (4) photoelastic. Although the strain gage type load cell is the most commonly used, all types of load cells have certain advantages depending on their application.

2.1.1 Hydraulic Load Cells - Hydraulic load cells are basically a fluid-filled deformable chamber connected to a pressure gage or an electric pressure transducer. The load is transferred to the fluid by means of a piston, or in the case of the flat jack, deformation of the fluid confinement chamber (Fig. 1). Hydraulic load cells allow the user to preload the load member, such as rock bolt tiebacks, by applying an initial pressure to the fluid. It is often desirable to posttension rock bolts and tiebacks due to anchor slippage or shifting load distributions. Although most hydraulic load cells are of rugged construction, their application has been limited due to their physical size, poor load resolution, and temperature sensitivity. Hydraulic flat jacks have had the greatest application as earth pressure cells and concrete stress cells. Flat jacks have also been used in conjunction with other apparatus on radial jacking tests and in situ stress measurements.

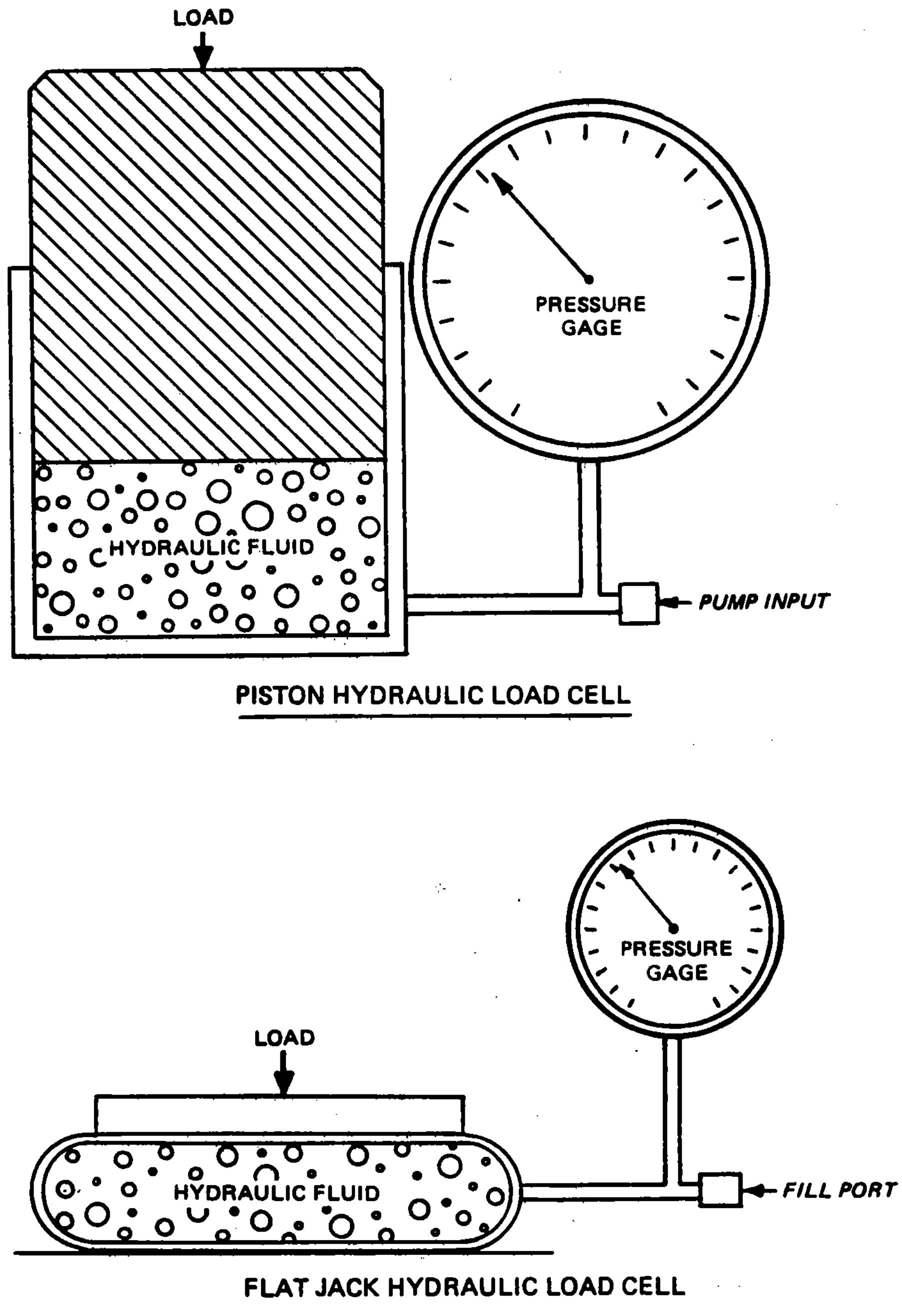


Fig. 1. Hydraulic load cells.

2.1.2 Mechanical Load Cells - The proving ring is the most common type of mechanical load cell but, due to its construction, has had very little application to field uses. The most commonly used mechanical load cells consist of an elastic disk element sandwiched between two plates. The disk deflects under load, changing the distance between the plates. The deflection is measured with a dial gage or suitable electronic transducer (Fig. 2). Although this type of load cell is relatively inexpensive to manufacture, it has had limited use because of its nonlinear calibration curve and restricted application. (This type of cell is generally designed to be used on rock bolts or tieback tendons.)

2.1.3 Strain-Gaged Load Cell

2.1.3.1 The strain-gaged load cell is by far the most commonly used for both field and laboratory applications. This type of cell is manufactured by a large number of geotechnical instrumentation suppliers. Most strain-gaged load cells consist of a metal cylindrical column. The column is loaded axially and the axial strain is measured with a suitable strain gage (Fig. 3). Bonded foil strain gages are used by most cell manufacturers because of their simplicity and availability, but the vibrating-wire and unbonded gages have also been proved to have distinct advantages. The bonded strain gage is a resistive element that undergoes a change in resistance when subjected to an axial strain. The gages are generally bonded to the load cell's cylindrical wall and connected together to form a Wheatstone bridge. The bonded gages are oriented in such a way as to cause a linear resistive imbalance proportional to the strain in the load cell. The unbalanced signal is amplified and observed on a galvanometer. Most strain gage readout equipment contain resistive balancing circuits that allow the operator to null the unbalanced signal with a potentiometer connected to a digital indicator. The load cells are calibrated to read load in pounds per readout digit (Fig. 4). The main advantages of the bonded strain-gaged load cells are simplicity of construction, relatively small physical size to load capacity ratio, direct reading requiring no summing, averaging or

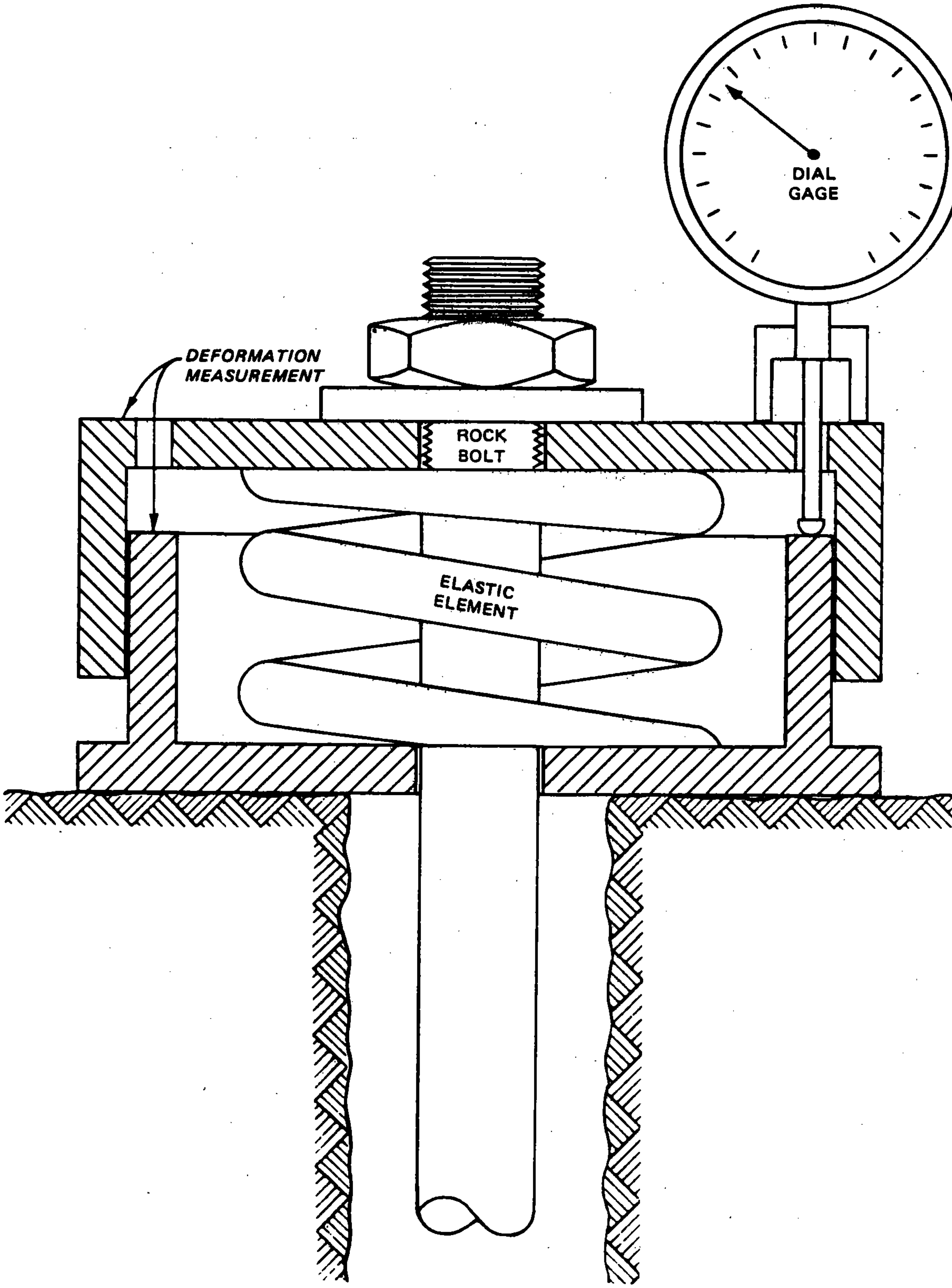
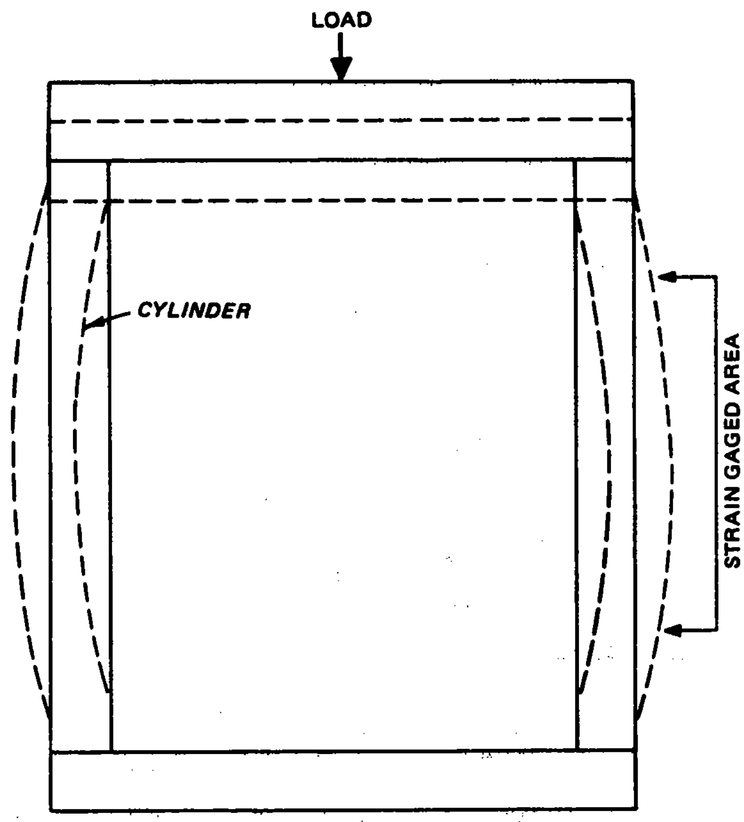


Fig. 2. Mechanical load cell.



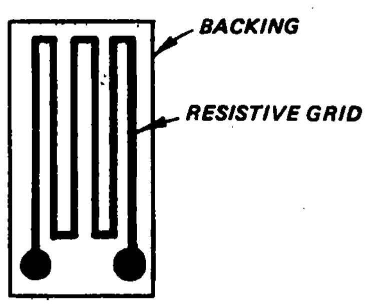


Fig. 3. Cylindrical column load cell.

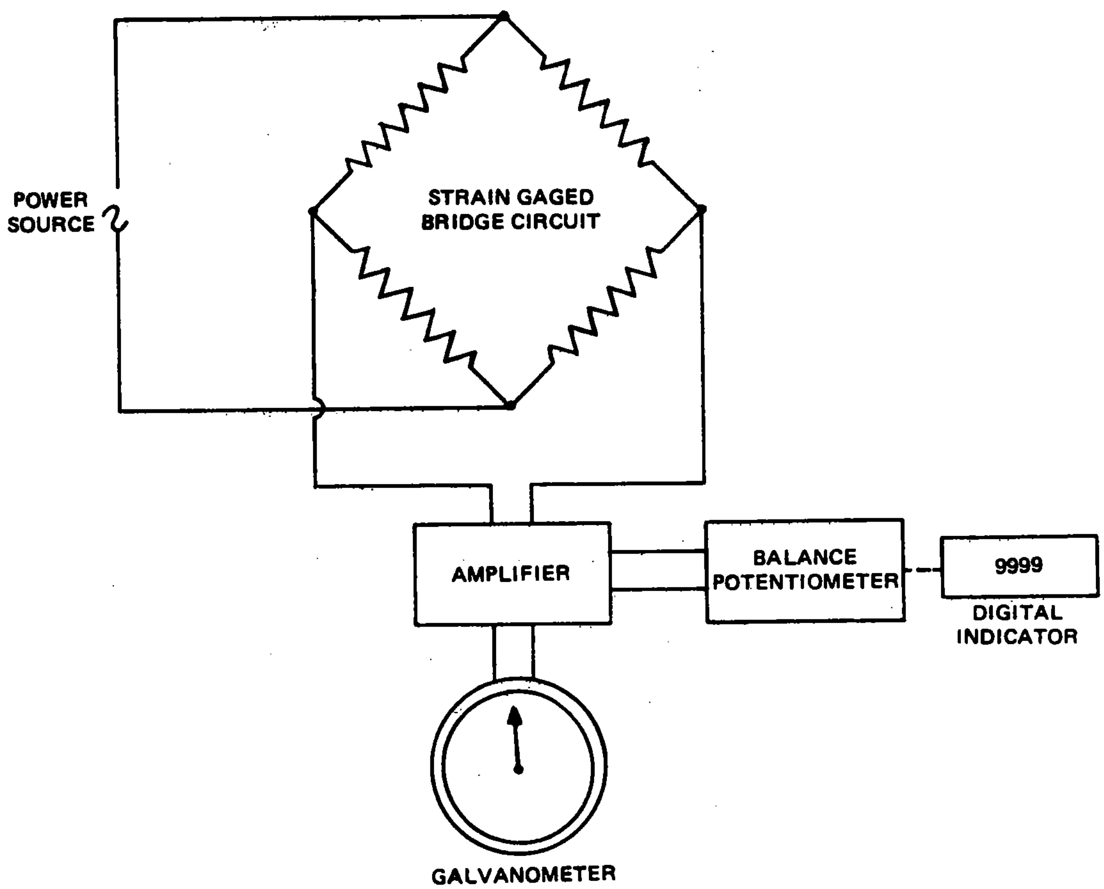


Fig. 4. Typical strain gage readout unit.

correction factors to obtain true load readings, and good temperature stability over a wide temperature range, thus allowing the load cells to be used in changing environmental conditions. The readout equipment is small, compact, and generally suitable for field use. The disadvantages of the bonded strain-gaged load cells are the extreme care required in waterproofing to prevent electrical leakage in the gaged circuit, the gage bonding technique required to assure long-term stability of the load cell, and the recalibration required when changing cable lengths due to lead wire load resistance changes and parasitic electrical signals.

2.1.3.2 The vibrating-wire load cell is generally constructed similar to the bonded strain gage cell. The load cells differ in the method of measuring the axial strain of the cell body. The vibrating-wire strain gage consists of a length of steel wire stretched between two posts extending from the cylinder wall (Fig. 5). The wire is pre-tensioned below its elastic limits when installed on the cell body. An electromagnet is placed near the wire, providing a method of plucking the wire when an electrical pulse excites the magnet. This pulse causes the wire to vibrate over the magnetic coil. The vibrating wire induces an electrical current in the electromagnet coil with a frequency equal to the frequency of the vibrating wire. The signal is then amplified by the readout unit and the frequency is determined by a frequency counter. As the load cell is subjected to load, the strain in the cylinder body reduces the tension on the vibrating wire, changing its frequency. This change in frequency per unit load is used to calibrate the load cell. Most load cells contain at least three vibrating-wire transducers placed at 120 deg around the periphery of the cell body. The vibrating wires are read separately and the readings averaged. This method of reading reduces errors caused by eccentric loading of the load cell. Some advantages of the vibrating-wire load cell are that the loads are read as a frequency, thus reducing the problems caused by ground leakage and poor signal cable condition. Long signal cables should not effect the frequency readings as long as the signal is not attenuated beyond the sensitivity of the readout equipment. The vibrating-wire load cell could also be read through radio telemetry systems, eliminating the need for an analog to frequency converter. Some of the disadvantages of the vibrating-wire load cells are their physical size, cost of manufacturing, poor temperature compensation, expensive and complicated readout equipment, and vulnerability to shock damage, causing zero shifts in load cell readings.

2.1.3.3 Load cells utilizing the unbonded strain gage have not found wide usage in load cell manufacturing. The unbonded strain gage employs the same principle as the bonded gage in that it consists of a wire made of a resistive material that, when strained, changes its resistance in proportion to the strain. The unbonded strain gage has more commonly been used in soil and concrete stress meters such as manufactured by the Carlson Company. The gages are mounted similar to the vibrating-wire gage and are generally employed in a bridge utilizing the same readout principles as the bonded gage (Fig. 6).

2.1.4 Photoelastic Load Cell - The photoelastic load cell consists of a cylindrical steel column with a hole drilled through its center diameter. A photoelastic element (optical glass) is inserted in this hole and locked in place. When polarized light passes through the optic glass, interference fringes can be observed if viewed through a polarizing filter. The number of fringes observed depends on the amount of stress in the optic glass. The load cell is calibrated by counting the interference fringes produced by a given load. Although this type of load cell is quite rugged and is a comparatively simple device, limited use has been made of it due to its coarse calibration and inability to be read from a remote location.

2.1.5 Manufacturers - Although there are a large number of companies manufacturing load cells for various applications, most of this equipment is not suitable for rock mechanics instrumentation.

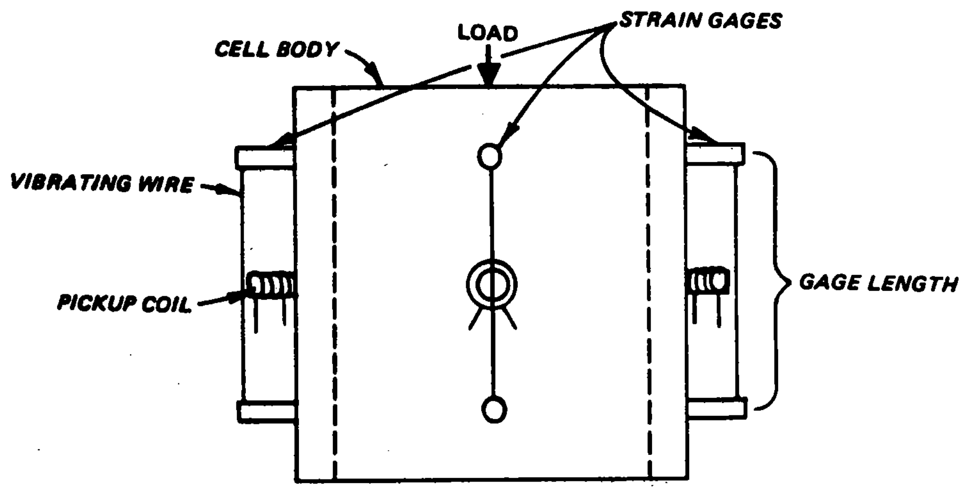


Fig. 5. Vibrating-wire load cell.

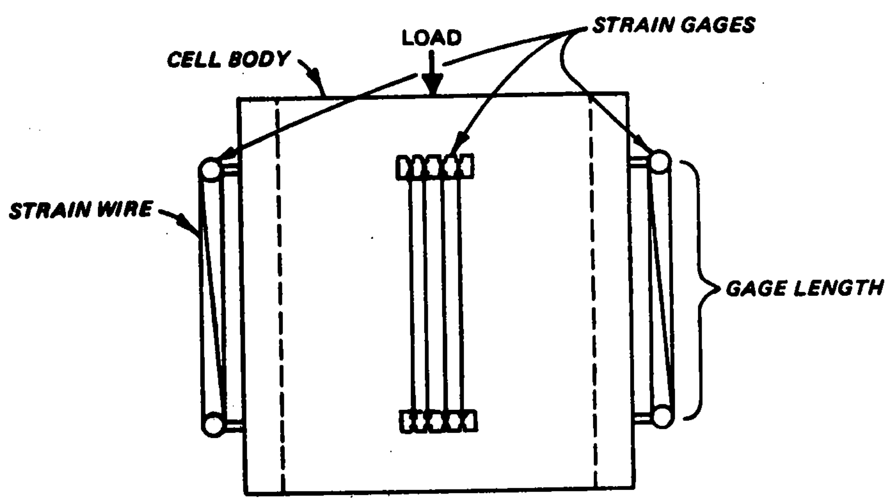


Fig. 6. Unbonded strain gage load cell.

The following is a partial list of geotechnical instrumentation suppliers that deal with the various types of load cells previously described:

<u>Hydraulic load cells</u>

Terrametrics, PJJ Machine Co., Interfels

<u>Mechanical load cells</u>

Terrametrics, Interfels, Norseman, Procep, Doboku Sokki, Strain sert

<u>Strain-gaged load cells</u>

Terrametrics, Soil Test, Telamac, Maihok, Geonor, Remote Systems

<u>Photoelastic load cells</u>

Terrametrics, Stress Engineering

3. <u>Procedure</u>

3.1 Although load cells have been employed for many diversified applications, the primary function in the field of rock mechanics has been for tunnel support load monitoring and rock bolt tension measurements. The following uses and methods of installation are typical for most applications.

3.1.1 <u>Steel Arch Tunnel Support Instrumentation</u> - The structural steel arch support set is the most commonly used tunnel support system. Measurements of the compressive loads actually being supported by the arch support provide a direct means of comparing actual loads with assumed support design loads. Load cells are generally installed under the base plates of arch-type sets; however, at times, it is desirable to include a crown load cell. In areas of squeezing or swelling ground invert struts may be used with load cells placed in them to measure the side loads. Close attention to the placement of blocking should be observed to assure proper load distribution on the arch supports (Fig. 7). The load cells should be installed on the set at the time of the set placement. It is desirable to place the instrumented sets as close to the blasting face as practical to measure the entire load history. Care must be taken to afford blast protection for the load

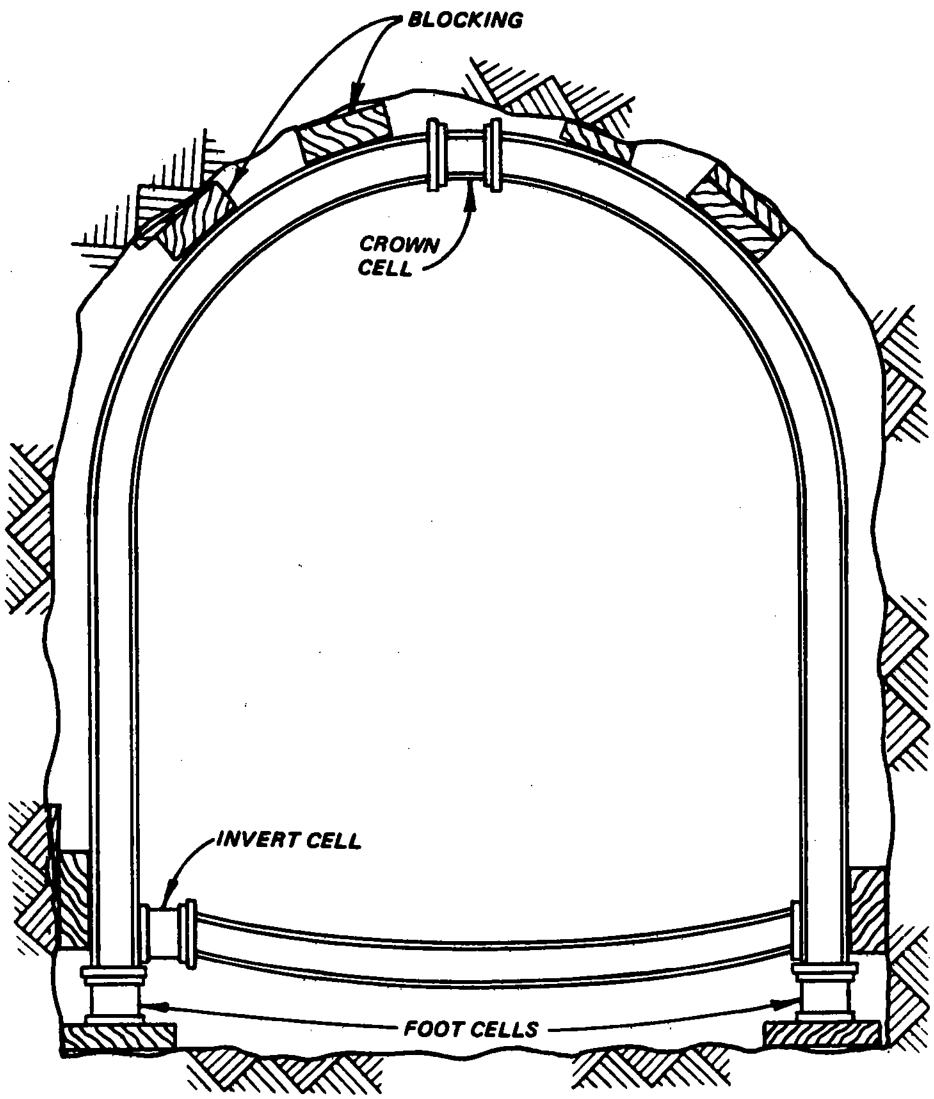


Fig. 7. Arch support load cell placement.

cells and signal cables when used near the blast face. This can be accomplished by running the signal cable inside the set flange facing away from the tunnel face. Steel shrouds can be welded to the sets to protect the load cells from fly rock (Fig. 8). The load cells selected should have a capacity greater than the yield strength of the arch supports. It is generally desirable to instrument at least three consecutive sets to reduce errors caused by anisotropy of the rock mass or nonuniform blocking on individual sets. Provisions should be made for the removal of the load cells after their portion of the tunnel has stabilized. This allows the load cells to be reused in a leap frog fashion, resulting in considerable instrumentation savings. Methods for removal of load cells on arch and circular sets are shown in Figs. 9 and 10. The load values obtained during a systematic instrumentation program provide a quantitative basis for reviewing the structural tunnel lining requirements for the final tunnel bore.

3.1.2 <u>Rock Bolts and Tieback System Instrumentation</u> - Rock bolts and tiebacks are often used to stabilize subsurface and surface excavations. In either case, the system usually incorporates steel rods or cables anchored at the base of a drill hole and tensioned to produce a compressive load along the axis of the drill hole. The actual loads acting on the bolt can be monitored (Fig. 11) by using a hollow core load cell acting as a washer at the collar of the bolt assembly. Calibrated torque wrenches have been widely used in rock bolting to produce the desired tension in the anchor tendon. Extensive tests have proven that such torque measurements can produce errors in the bolt tension as much as one to two times the indicated load. This variation can be caused by the condition of the threads on the bolt or anchor, dirt, rust, bending of the bolt, or anchor misalignment. Hydraulic jacks are often used in place of the torque wrench, especially in bolts or cables requiring high tensile loads. This system, where applicable, is far superior to the torque wrench but requires the use of specialized equipment for its adaptation. Actual loads can be monitored, using load cells, at the

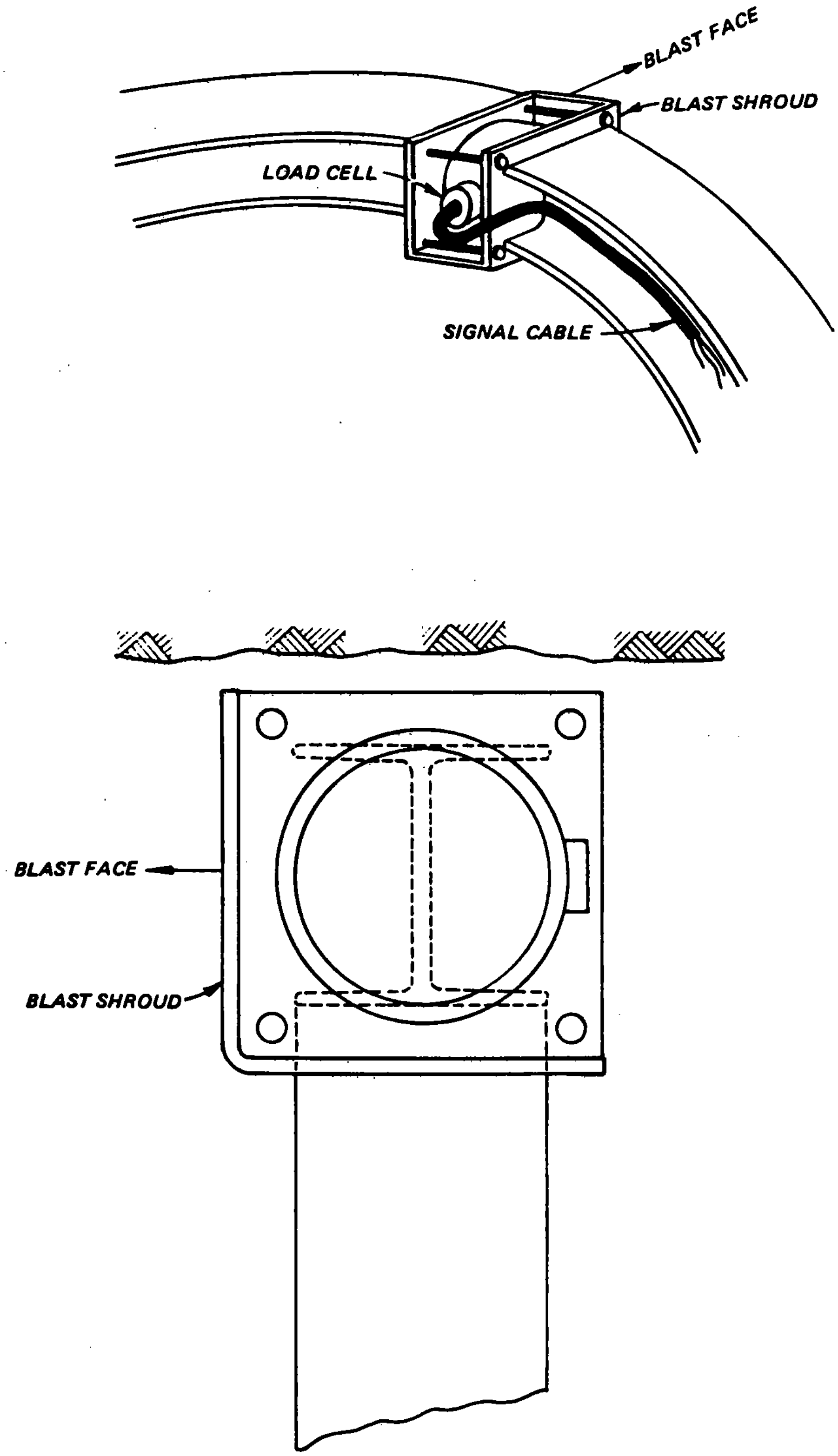


Fig. 8. Crown load cell blast protection

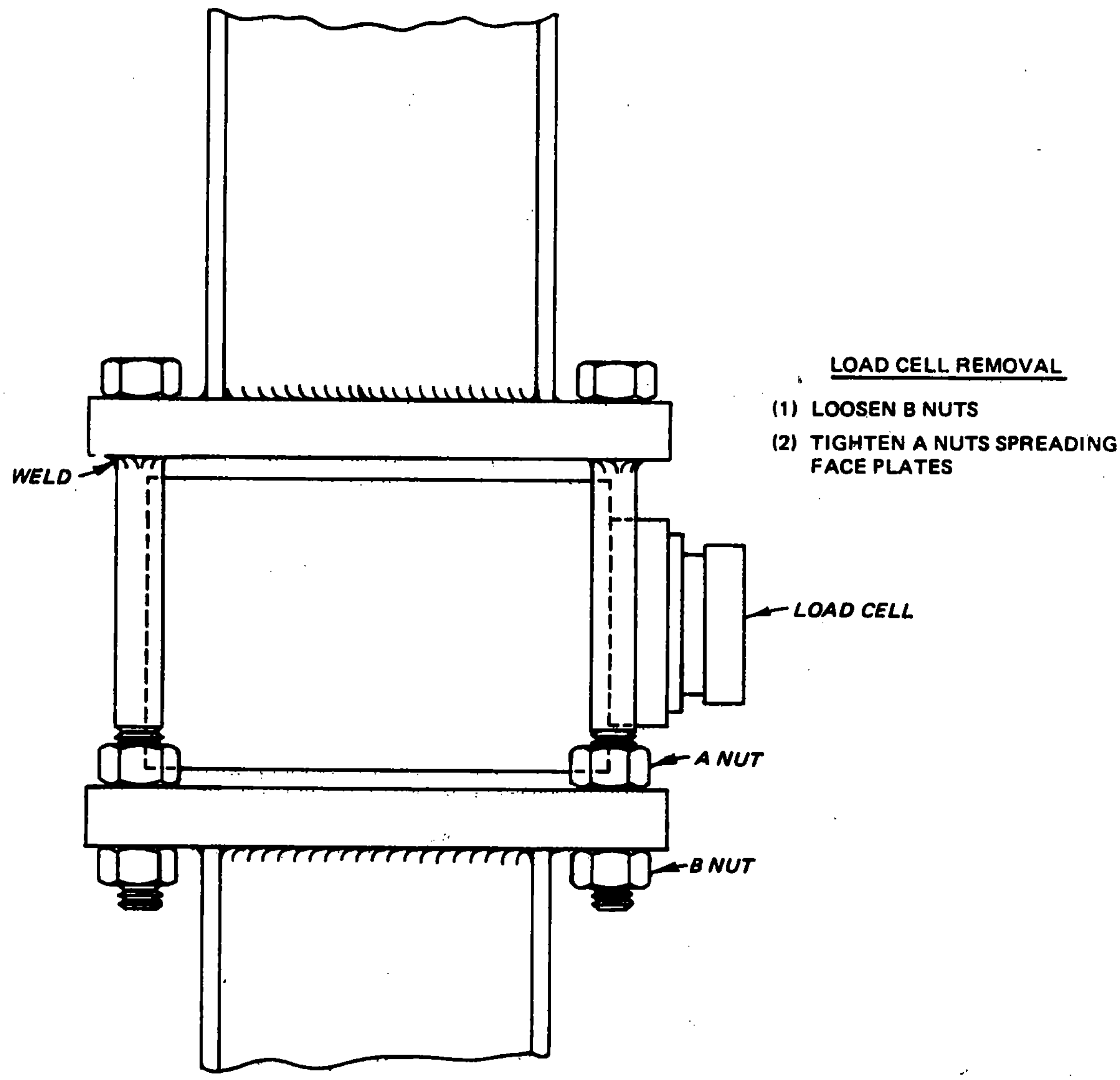


Fig. 9. Crown or springline load cell removal.

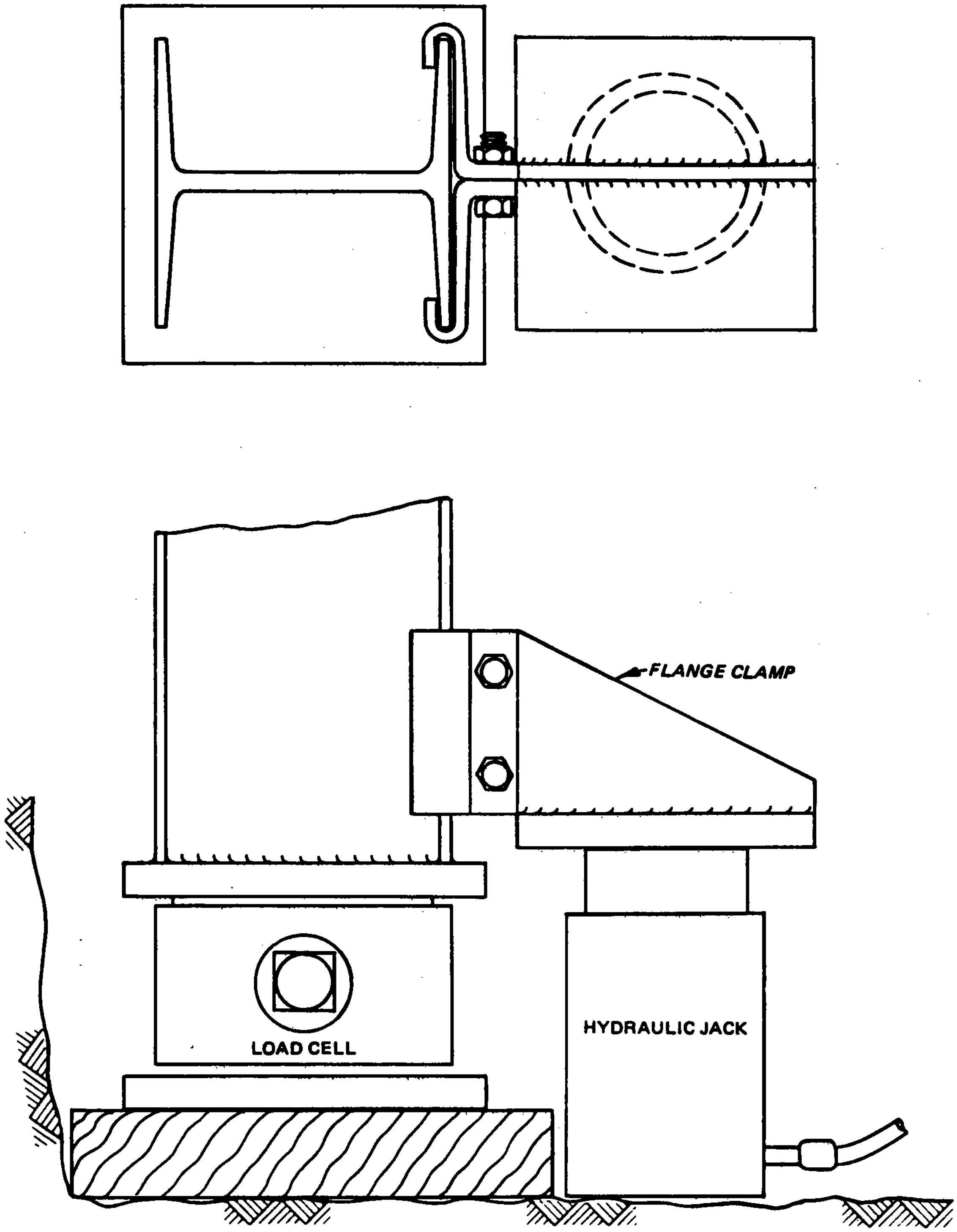


Fig. 10. Foot load cell removal.

time of installation and thereafter to plot the load history of the bolt system. It is desirable to use a number of load cells over a tunnel length equivalent to 2-1/2 tunnel diameters to obtain the average load being supported by the rock bolts. The load cell capacity should be greater than the yield strength of the rock bolts because the strain induced into the bolts at the time of blasting often exceeds their yield point. After tunnel stabilization the load cells can be removed and reused as the tunnel advances. The cells should be removed one at a time and the bolt retensioned to maintain stability of the tunnel section.

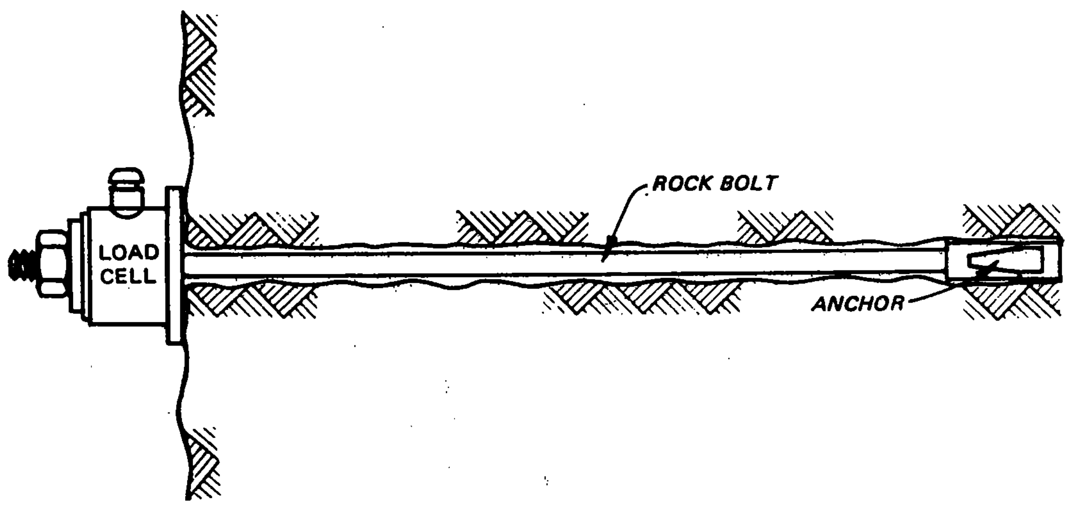


Fig. 11. Rock bolt load cell installation.

4. Data Reduction

4.1 Steel Arch Supports - As the tunnel excavation advances, the load normally being supported by the rock or soil removed in the excavated section is redistributed into the side walls and support system. At some point in time, depending on the tunnel advancement rate, material strength, and support system, the tunnel reaches a point of equilibrium. Support loads should be monitored during this stabilization period to determine support adequacy and future requirements.

Fig. 12 is a typical plot of load versus tunnel advancement. Note the decreasing frequency of readings as tunnel heading advances away from the load cells. The load is generally highest two to three diameters behind the tunnel face because the load has not stabilized or shifted to the side walls at this time. In this example the peak loading occurred when the tunnel heading was at station 130 (20 ft (6 m) or 2 tunnel diameters beyond the instrumental set) and equilibrium at station 110 was essentially achieved when the tunnel heading reached heading 148. A blocking diagram is often included with the data plot to help explain the stress distribution on the support member. A load versus time plot may also be used in some instances where varying time lags exist between tunnel heading advancements.

4.2 Rock Bolts - Rock bolt load data may be plotted in the same manner as the data for the arch support load cells; however, the indicated load should not decrease with time or tunnel advancement. By the use of the load plot the engineer can readily recognize anchor slippage, i.e., load loss or overload. A certain amount of anchor slippage is generally observed with bolts located near the blast face. When this occurs, the bolts should be retorqued to design specifications. The load plot will indicate stabilization versus tunnel advancement and can be used to determine a bolt torquing program for noninstrumented tunnel sections.

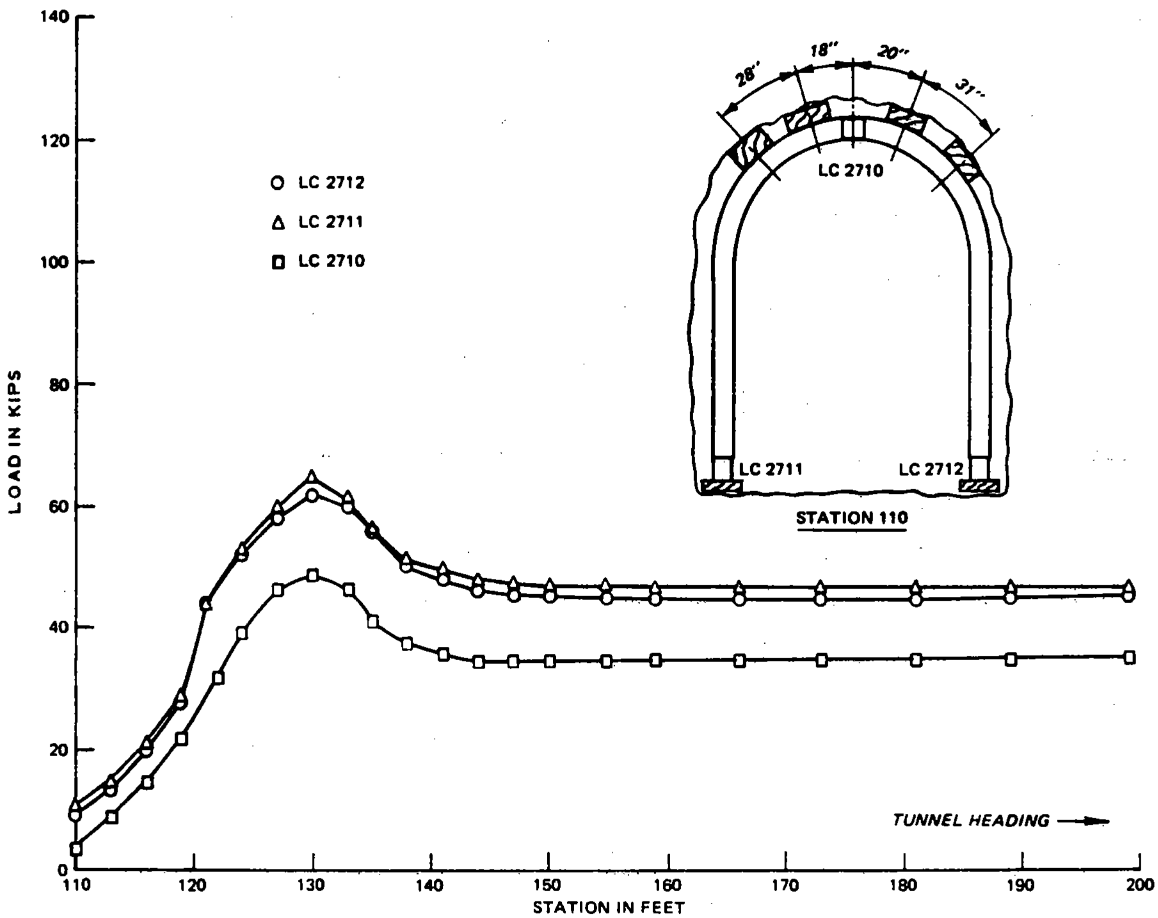


Fig. 12. Typical plot of load versus tunnel advancement.

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