3.5 IN-SITU STRESS EVALUATION

There are methods available for in situ stress determination,

- Hydraulic fracturing
- FLAT Jack testing
- Stress relief technique
- Strain recovery methods
- Borehole breakout method
- Indirect methods, fault slip data analysis, Kaiser effect, measurement of residual stresses etc.

3.5.1 Hydraulic fracturing

The objective of the hydraulic fracturing is to define the state of stress in the rock ambience at desired depth and requires lots of instrumentation. Codal provisions for the hydraulic fracturing tests have been given in IS 13946 (Part-1):1994. However, the technique used marginally modified using re-opening of pre-existing fractures.

![Figure 3.27: Schematic Representation of Hydro-Fracture (HTPF) Test](image-url)
Hydraulic fracturing involves the isolation of part of a borehole using an inflatable straddle packer (Figure 3.27) and the subsequent pressurization of the borehole until the pre-existing fracture opens. During a hydraulic fracture of preexisting fracture test, pressure versus time is recorded. The magnitude of the stress component normal to fracture plane can be determined desired on the analysis of time history of closing/opening of the pre-existing joint/fracture obtained through specially designed test. The magnitude of the major and secondary principle stress can be calculated from relationships involving the fracture re-opening pressure and the strength attributes of the tested rock joint. An impression packer is used to determine the orientation of the fracture in the borehole. This in turn, gives the orientation of the major secondary principal stress in the plane normal to the borehole axis. An impression packer consists of an inflatable element wrapped with the replaceable soft rubber film. When the packer is inflated, the film is extruded into the fracture.

The following equipment and accessories required for the test,

1. Packer elements: To seal the test section
2. Water pumps: To apply fracture opening pressure
3. Flow-meter: To record flow of water w.r.t. time
4. Pressure Transducers: to monitor pressure of fracturing fluid in test interval w.r.t. time.
5. X-T Recorder:
6. Borehole impression packer, to get the orientation of fracture
7. Geological compass
In calculating the insitu stresses the shut in pressure ($P_s$) is assumed to be equal to the minor horizontal stress $\sigma_h$. The major horizontal stress $\sigma_H$ is then found from the break down pressure ($P_c'$ or $PB$). In the calculation, the break down pressure has to overcome the minor horizontal principal stress (concentrated three times by the presence of the bore hole) and overcome the insitu tensile strength of rock, whereas, it is assisted by the tensile component of the major horizontal principal stress. The corresponding equations involved are mentioned below. Here, $P_r$ and $P_o$ respectively represent the fracture re-opening pressure and pore pressure respectively. Once the magnitude of the insitu stresses are determined, the direction of the same can be evaluated using impression packer units.

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\begin{align*}
\sigma_h &= P_s \\
\sigma_H &= 3 \sigma_h - P_c' - P_o + \sigma_t \\
\sigma_t &= P_c' - P_r \\
\sigma_H &= 3 \sigma_h - P_r - P_o
\end{align*}
\]
Figure 3.29: Major and minor principal stresses on a bore hole subjected to hydraulic fracturing.

Figure 3.30: Hydrofracturing control unit with Impression packer with impression of fracture captured (Courtesy: Aimil Ltd, New Delhi.)
3.5.2 Flat Jack Test

A flat jack is comprised of two metal sheets placed together and welded around their periphery. A feeder tube inserted in the middle allows the flat jack to be pressurized with oil or water. The flat jack method involves the placement of two pins fixed into the wall of an excavation. The distance ‘d’ is then measured accurately. A slot is cut into the rock between the pins. If the normal stress is compressive, the pins will move together as the slot is cut. The flat jack is then placed and grouted into the slot.

On pressurizing the flat jack, the pins will move apart. It is assumed that when the pin separation distance reaches the value it had before the slot was cut, the force exerted by the slot is the same as that exerted by the pre-existing normal stress.

Principle of this test is to relief of stress and its recovery by means of hydraulic pressure. A narrow slit (35-50mm) is cut. Prior to that deformation measuring pins are fixed into the narrow holes drilled into the rock. Due to construction of slot, stress relief takes place. A hydraulic flat jack (Figure 3.31) is inserted and inflated till the pins returns to the pre-slot values.

The main limitation of the Flat Jack test are

- minimum 6 number of tests to be required at different locations
- the size of the flat jack in relation to the size of the rock mass
- assumption of elastic recovery,
- error due to stress concentration/redistribution due to driving of tunnels and
- the test cannot be carried out at appreciable depth from rock surface.

Assumptions- Involves following assumptions

- The cutting of the slot causes change in stress distribution in the rock which in turn produces a corresponding strain or displacement at the gauge points.
- The strain and displacement produced by pressure in the flat jack at cancellation pressures equal and opposite to that developed as a result of cutting the slot.
The application of cancellation pressure by flat jack restores the initial stress field in the rock around the slot and the cancellation pressure is therefore equal the initial stress existing within the rock.

Values of the deformation modulus $E$ and Poisson's ratio ($\mu$) has been assumed to be the same in all directions.

Error due to stress concentrations due to driving of tunnels are negligible.

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**Figure 3.31:** Flat Jacks and flat jack test for insitu stress determination in a tunnel

**Figure 3.32:** Schematic diagram of FLAT jack testing
For the compressive stress system $S$ and $Q$ existing within the rock prior to slot cutting,

$$S = F_1 \cdot P + F_2 \cdot Q$$

where, $F_1$ and $F_2$ are constants and their values can be taken as 0.815 and 0.064 respectively, for a slot length $(2c) = 33\text{cm}$, flat jack length $(2c) = 30\text{ cm}$, slot width $(2y_o) = 4.0\text{cm}$, gauge length $(2y) = 25 \text{ cm}$ and Poisson’s ratio $(\mu)$ ranging from 0.15 to 0.25. The above equation involves two unknowns, namely, $S$ and $Q$ and as such the flat jack tests are carried out in two directions, normal to each other so as to formulate a set of two equations. These equations shall then be solved for the values of $S$ and $Q$. If $P_h$ and $P_v$ are the cancellation pressures in horizontal and vertical slot direction respectively, then,
In order to determine the principal stresses at least three tests shall be carried out at one site in three orthogonal planes. The test shall be carried out at the same site but in the zone not influenced by any previous test. For this, tests should be carried out at a distance of more than three times the length of the slot from the centre of the slot along its length.

3.5.3 Stress-relief technique

Stress relief technique, also known as over-coring or bore hole strain measuring technique. Using this, the magnitude and directions of the three principal stresses acting at a point can be known, which means an absolute stress measurement. In this method, the rock element containing the strain measuring device is relieved from the stress imposed by the surrounding rock and the resulting strains are measured which help in determination of stresses known by stress-strain relation (Figure 3.35). The basic instrumentation needed are electrical strain gages, bore hole deformation meter, bore hole inclusion stress meter and bore hole strain gauge devices.

(i) $Nx$ Bore hole drilled.

(ii) $EX$ Bore hole drilled at end of $NX$ hole and rosettes pasted.

(iii) $EX$ portion of the bore hole overcored by $NX$ coring crown.

(iv) Cylindrical hollow core removed.

Figure 3.35: Schematic diagram explaining stress-relief technique
3.6 SUMMARY

Insitu tests are essential component for any geotechnical design and provide the response of a larger mass under natural insitu condition. The extent of investigation could vary from a limited effort where the rock mass is very good to a very extensive and detailed where the rock mass is highly disturbed. Usually it is always advisable to carry out certain minimum number of insitu test to ensure that weak zones are not present in the site. The insitu site investigation is a costly affair and proper test location is necessary to optimize the number of insitu tests. Proper care is needed while conducting the tests to ensure good representative values for the site and estimate correct design parameters.