FOUNDATION ON ROCKS

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9.1 INTRODUCTION

Usually rocks are considered to be a good foundation material and strength is rarely an issue while designing any structure over rock. But, inherently rocks comes with weaknesses and that comes the real challenges for the design. Moreover, if the load is really very large such as in cases of heavy bridge piers or sky scrapers etc., the bearing capacity may need to be checked specially for rocks which rocks is weak or moderately strong. Sometimes, rocks may have defects, or inherently weak like chalks, clay shales or clay bands, friable sandstones, tuffs or porous limestones, or sometimes rocks may be highly weathered or fractured, such situations heavy foundation load may develop excessive deformation which is undesirable. Settlement of more than 20mm has also been observed with foundation pressure of even lesser than 10kPa (Sowers, 1977).

There are issues with the rock foundations specially if the rocks are decomposed, in karstic limestone which are soluble, rocks with faults, weathered rock with or without filling material, fractured/ fissured rocks etc. (figure 1). Figure 1(a) is an ideal condition for rock foundation construction as the rock is relatively strong with no fracture, having clearly defined bedrock surface and is smooth and horizontal. Figure 1(b-f) depicts different problematic rocks for foundation construction.

One of the example, where failure happens due to problematic rock below foundation is St. Francis Dam failure, California 1928. This concrete gravity dam constructed in 1926 and collapsed in 1928. Failed primary due to existence of weak rocks below. Rock was Schists and soft argillaceous conglomerate separated by a distinct fault. Its crushing strength was less than 4MPa. Conglomerate also did have veins of gypsum, a soluble mineral. Dam was founded on schist, not considered reliable founding rock. Conglomerate below the reservoir caused enormous leakage of stored water leading to the failure.
a) Ideal situation   b) Decomposed   c) Karstic limestone


d) Faulted rock   e) Weathered rock with residual soil   f) Fractured rock

Figure 9.1 : Different problematic rocks (Goodman, 1997)
Figure 9.2: Photograph of St. Francis dam, California, USA.
Many other dams across the world failed due to improper investigation, wrong planning and design of foundation. Definite for the safe design of any dam, one of the important aspect to be considered is rock mechanics principles and geology of the site.

9.2 FOUNDATION TYPES ON ROCKS

Different type of foundation may be constructed in rock, may be categorized in three groups,

- Shallow foundation
- Deep/Pile foundation
- Rock socketed piers

Failure in rock foundations may happen in a number of modes. Mode of hard, brittle rock may be totally different than the mode observed from weak rocks. More ever, if joints/fissures are present, same rock may again have a totally different mode of failure. Rocks are weak in tension and therefore the propagation of extension cracks leads to indentation of the loaded foundation on rock. Once the load reaches the tensile strength of the rock crack initiates, further loading may extends the crack and with still higher load, cracks coalesce and interfere leading to eventual failure. Foundation on rock masses undergoes additional permanent deformation due to the closure of the fissures, pores and cracks. Below shown figures different failure modes observed in rocks. (Goodman, 1989).
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(a) Footing on rock

(b) End bearing piles resting on rock
c) Rock socketed pier

Figure 9.4: Different type of foundations, a) Footing on rock b) End bearing piles resting on rock c) Rock socketed pier

9.3 BEARING CAPACITY

The bearing capacity of foundations founded on rock masses depends mostly on the ratio of joint spacing to foundation width, as well as intact and rock mass qualities like joint orientation, joint condition (open or closed), rock type, and intact and mass rock strengths. To perform satisfactorily, shallow foundations on rock must have two main characteristics. They have to be safe against overall shear failure in the rock mass that supports them. They cannot undergo excessive displacement, or settlement. Hence, there are two criteria for design, Sliding and shear failure and Settlement. Rock bearing capacity mentioned in various building codes are basically approximate values and it is advisable to go for the bearing capacity based on measurement of some particular parameters using insitu & laboratory tests.
Different failure modes are possible for a footing on rock (Ladanyi, 1972). Cracking happens, if the rock mass is relatively un-fractured. After crack initiates, further loading extend cracks, and at still higher load, cracks coalesce and interfere and eventually crush under additional increment of load. Due to dilatancy effect, cracked and crushed rock under the loaded area expands outward, eventually generating some radial networks of cracks (wedges) propagating upto surface. Additionally, in compressible seams or weakly cemented sedimentary rocks due to heavy load, irreversible settlement without cracking and wedging, known as punching failure.

Figure 9.3: Different failure modes for foundation on rock a) Cracking b) crushing c) Wedgeing d) Punching e) shearing
9.3.1 Ultimate bearing capacity

As per old US building codes, the ultimate bearing capacity (the load per unit area of the foundation at which shear failure/sliding in rock mass occurs).

- Soft rock: 1.4 MPa
- Medium rock: 2.4 MPa
- Hard rock: 4.8 MPa

Effect of fracture intensity on bearing capacity can be estimated using RQD,

- RQD >90%: No reduction
- %50 <RQD< 90%: Reduce by a factor 0.27-0.7
- RQD <50%: Reduce by a factor 0.25-0.1

If clay seems are found further reduction is made.

Allowable load will depend on many factors,

a) Occurrences During Excavation

- Undulating rock surface below a level ground;
- Heterogeneity of rock mass (the bearing capacity may vary up to 10 times in apparently the same rock mass because of presence of localized fractures/shear zones/clay gauge/clay
- weathering/alternate hard land soft beds, etc.
- Solution and gas cavities;
- Wetting, swelling and softening of shales / phyllite & expansive clays,
- Bottom heave;
- Potential unstable conditions of the slope and
- High in situ horizontal stresses.
b) Adjacent Construction Activities

- Blasting (Controlled blasting techniques such as line drilling, cushion blasting and pre-splitting are available if it is necessary to protect the integrity of the work just outside the excavation);
- Excavation
- Ground water lowering (excepting in highly pervious sedimentary rock, this phenomenon is rare in most of igneous and metamorphic rocks) and

c) Other Effects

- Scour and erosion (in case of abutments and piers);
- Frost action
- Flooding (only erodible rocks like slate and phyllite) and
- Undesirable seismic response of the foundation.