3. Geomechanical Properties of the rocks and stresses

3.1 Purpose

The rocks loaded by a structure undergo displacements and if overloaded they may crack and break. The possible effects of loads on rocks depend on the physical properties of these materials and should be known to the designer of a structure (Krynine and Judd 1957). The purpose of engineering design is to construct physical structure capable of withstanding the environmental conditions (loads) to which it may be subjected.

The design of dam or any civil engineering structure involves two-stage processes firstly, defining of the force field acting on the structural material and secondly, determination of the reaction of the material to that force field. The first stage involves an analysis of stresses acting within the structural members; the second involves knowledge of the properties of structural material. The proper knowledge of geomechanical (physico-engineering) properties of the rock material and of the rock mass and in-situ stresses are necessary for the evaluation of site for an engineering project. The more comprehensive this knowledge the more exact will be the design and more perfect will be the structure (Farmer 1968). Geomechanical properties of the foundation rocks and stresses can be obtained by various laboratory and field tests (Table 2 & 3).

3.2 Physico-engineering properties of Narmada dam foundation rocks

The physico-engineering (geomechanical) properties of the foundation rocks including specific gravity, water absorption, compressive strength, ultrasonic velocity, modulus of elasticity and modulus of deformation were determined. (Fig. 7 to 9)(Appendix-II).

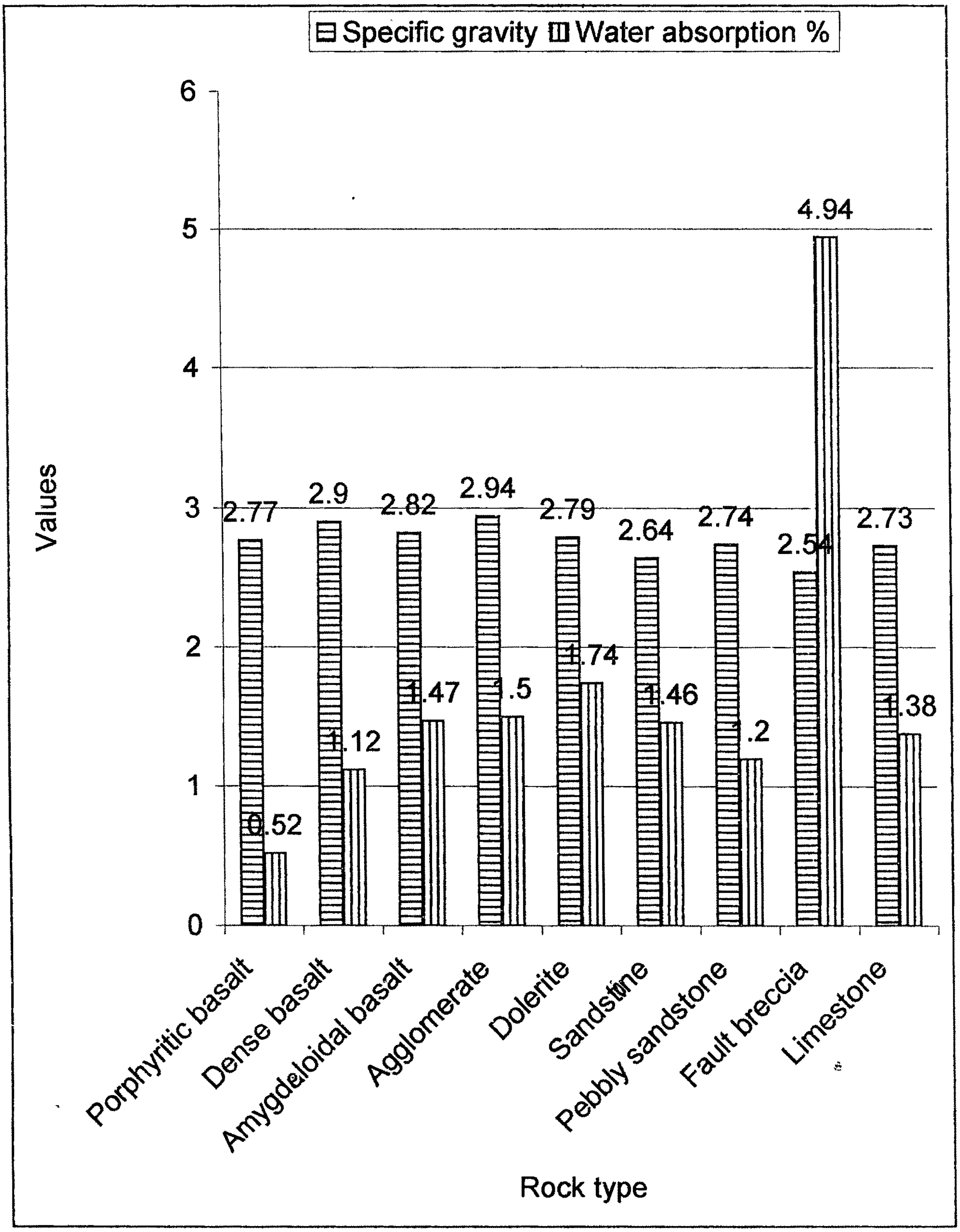
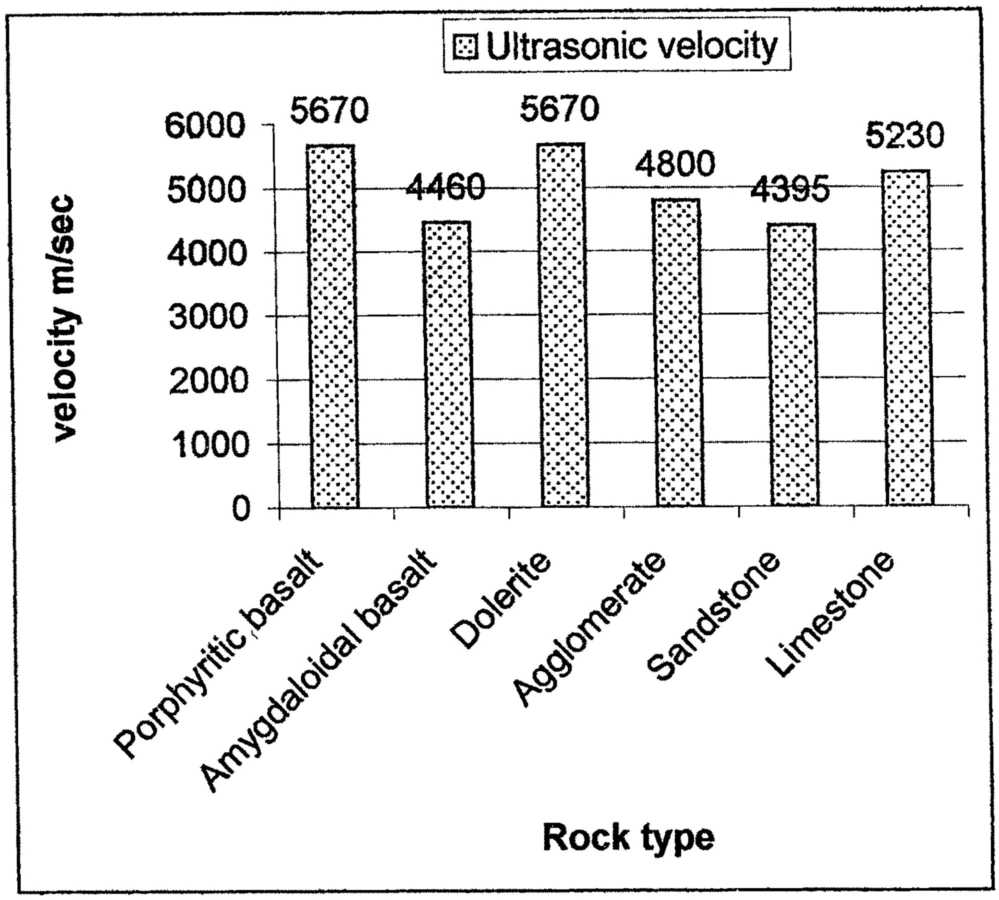
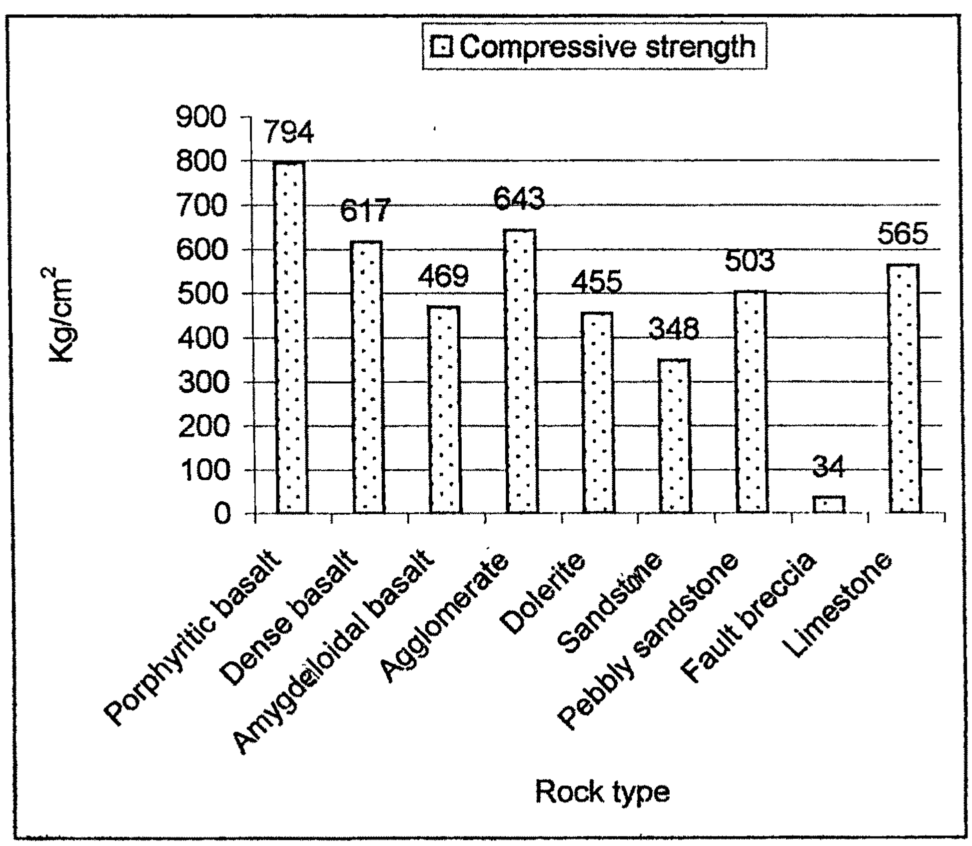


Fig. 7: Specific gravity and water absorption of the foundation rocks, Sardar Sarovar (Narmada) Project

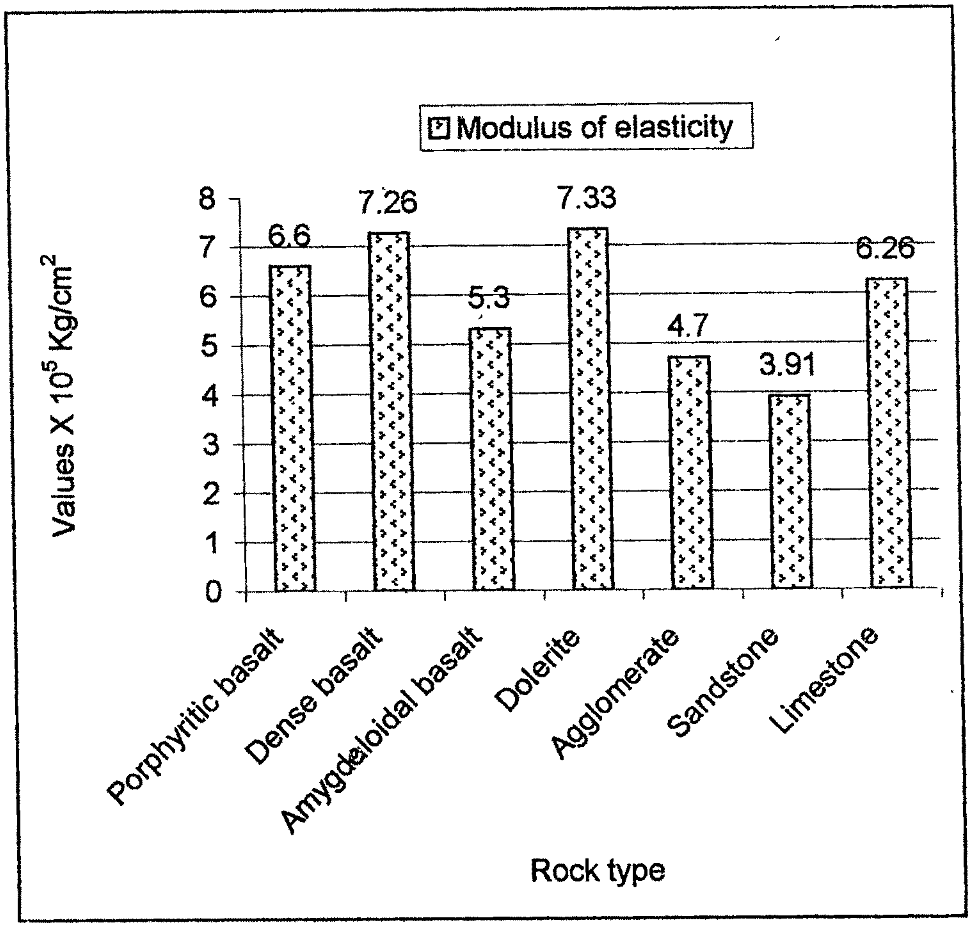


(a) Ultrasonic velocity of foundation rocks

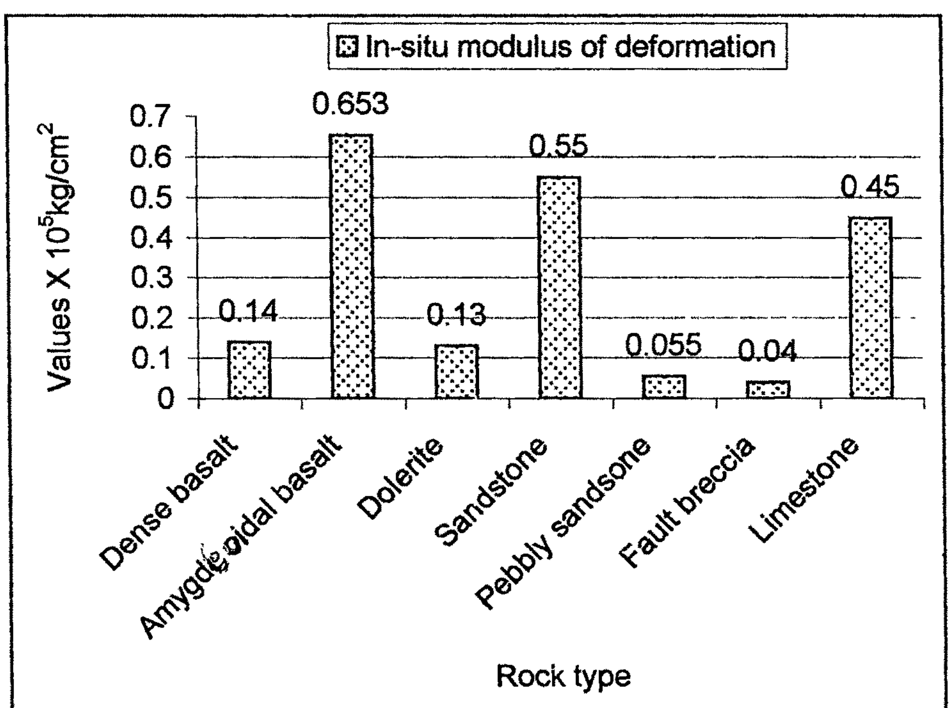


(b) Compressive strength of foundation rocks

Fig. 8: Ultrasonic velocity and compressive strength of foundation rocks, Sardar Sarovar (Narmada) Project



(a) Modulus of elasticity dynamic



(b) Modulus of deformation of rock mass

Fig. 9: Modulus of elasticity (dynamic) and in-situ deformation of modulus of rock mass, Sardar Sarovar (Narmada) Project

3.2.1 Physical properties of rocks

The foundation rocks are in general moderately strong. Test results indicated that compressive strength of rocks is mostly higher than 348 kg/cm^2 except of fault breccia (34 kg/cm^2) and ultrasonic velocity varies from 4395 to 5670 m/sec (Fig. 7, 8 & 11). Specific gravity of the foundation rocks varies from 2.64 to 2.94 and percentage water absorption from 0.52 to 4.94 (Fig. 7). The high percentage of water absorption (4.94) has been noticed only for the fault breccia which also show low values of compressive strength (34 kg/cm^2) (Prakash 1990).

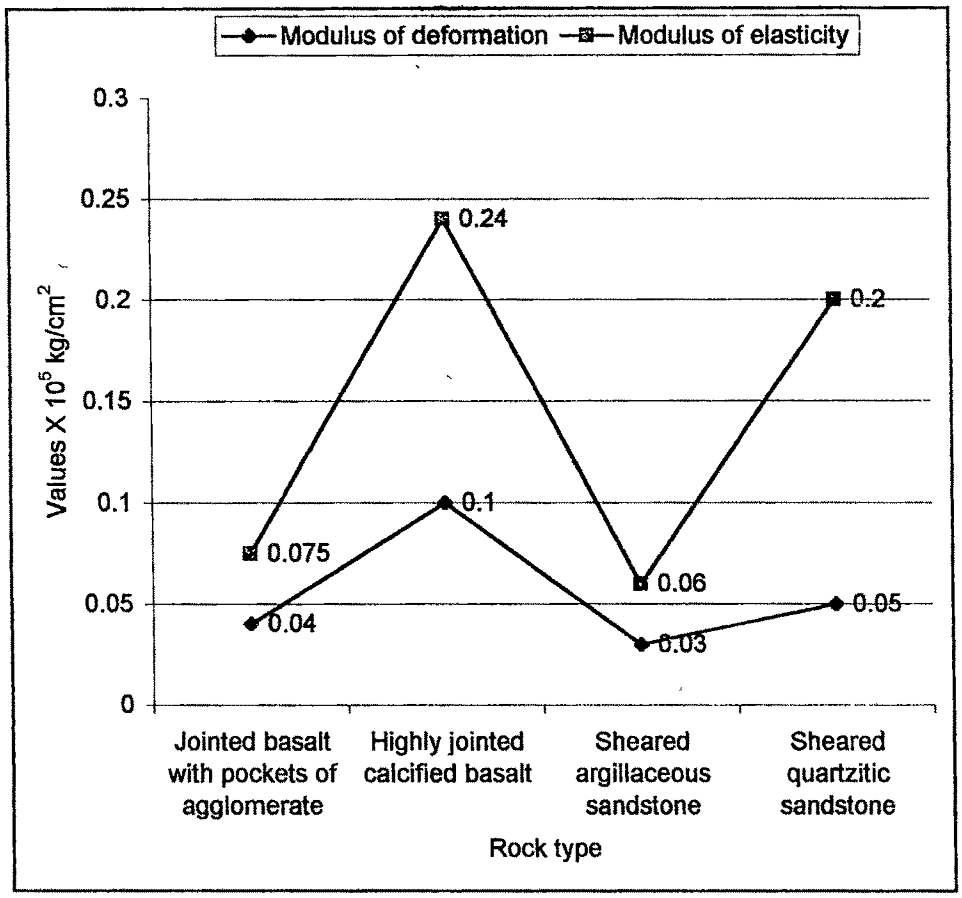
Rock Mass Rating (RMR) values of the foundation rocks were compared with the physical properties. In general RMR values of the foundation rocks are directly related with the Rock Quality Designation (RQD)% and Unconfined Compressive Strength (UCS) values (Fig. 11).

3.2. 2 Shear strength of foundation rocks

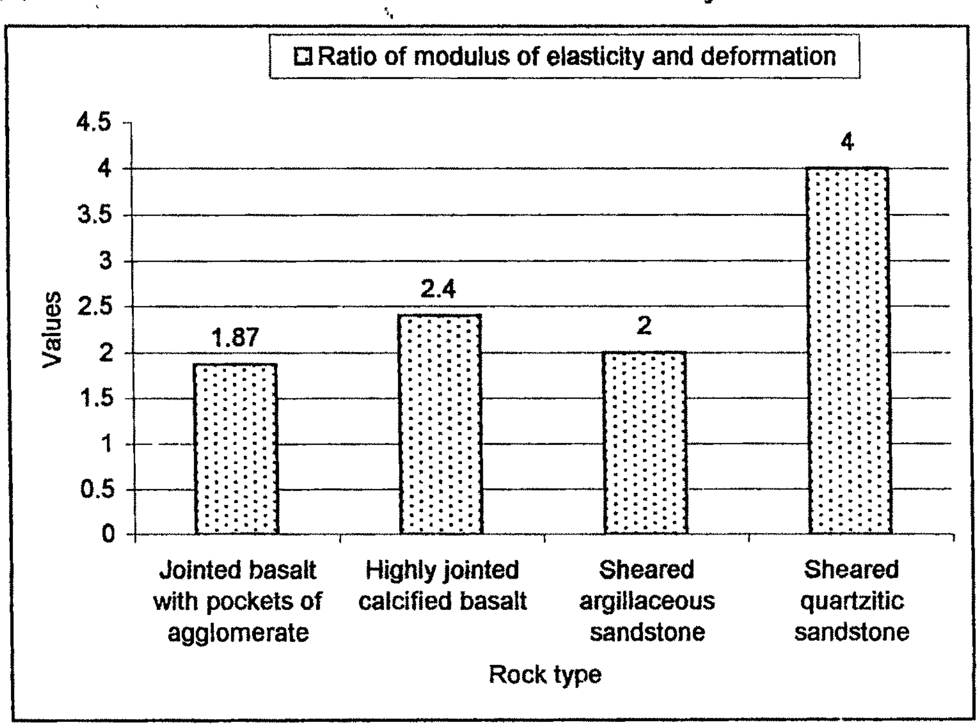
Shear strength of the foundation rocks was determined by the laboratory (Table 2) and in-situ tests (Table 3). Design parameters of the foundation rocks were evaluated based on these tests as summarised in the Table 19 (Thatte et.al. 1990).

3.2.3 Modulus of deformation values of fault zone and foundations rocks

In situ test results indicated low values of modulus of deformation for the fault zone (0.04 x 10^5 kg/cm^2) (Fig. 9). High values of modulus of deformation was obtained for the basalt (0.14 to 0.653 x 10^5 kg/cm^2) and sandstone (0.55x $10^5 kg/cm^2$). The ratio of average values of the modulus of elasticity and modulus of deformation of the basalt adjacent to fault zone vary from 1.87 to 2.4 (Fig. 10). This indicates weathered and or jointed nature of the rock mass. Sedimentary rocks adjacent to the fault zone are also highly jointed as indicated by high ratio



(a) Modulus of deformation and modulus of elasticity of foundation rocks



(b) Ratio of modulus of elasticity and deformation of foundation rocks

Fig. 10: In-situ deformability of sheared and jointed foundation rocks, shear zone/ fault zone, Sardar Sarovar (Narmada) Project

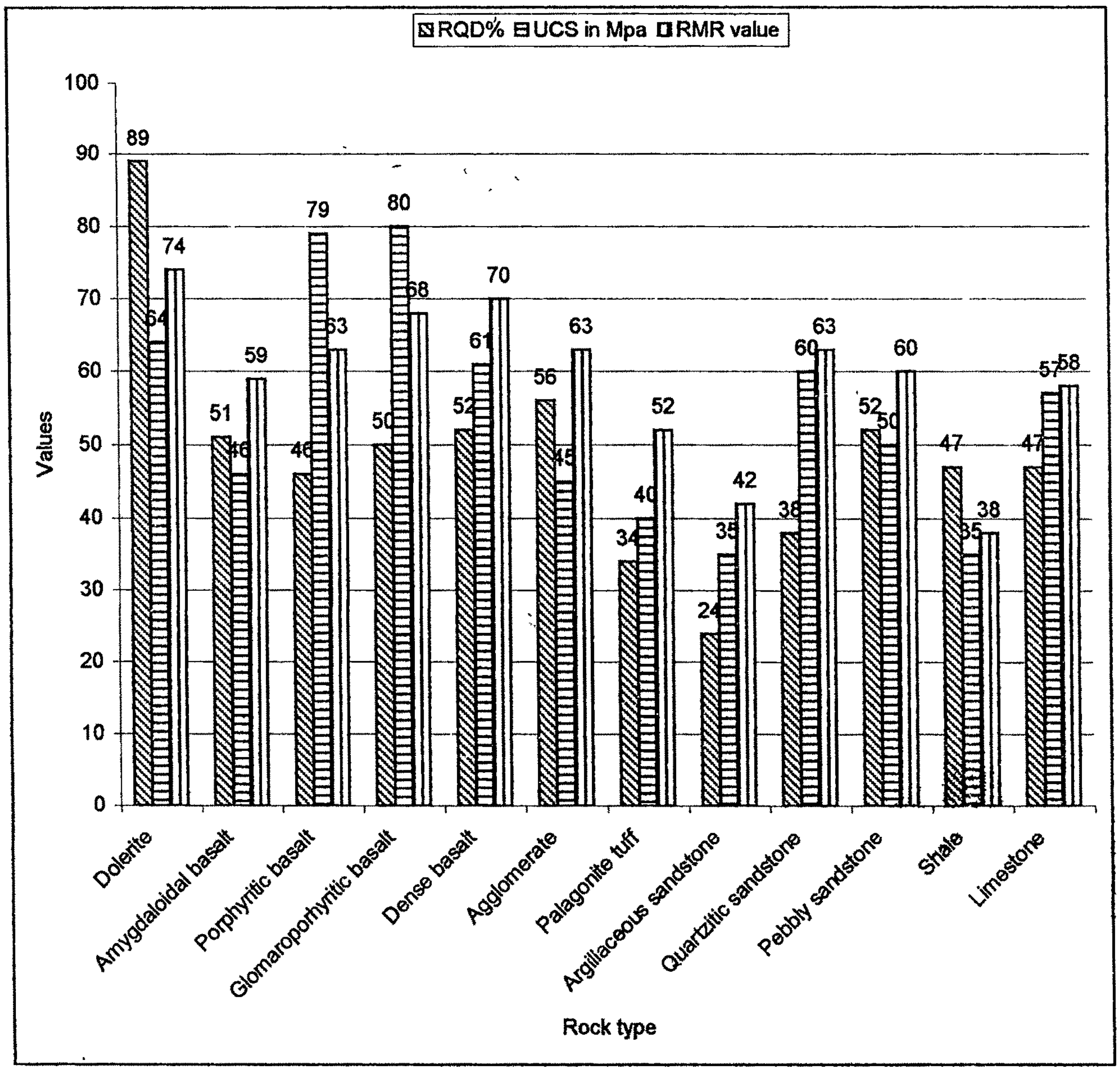


Fig. 11: Rock Quality Designation, Compressive strength and Rock Mass Rating of main dam foundation rocks, Sardar Sarovar (Narmada) Project

of two modulii (2 to 4). In view of the low modulus of deformation of fault zone and high modulus ratio of the abutment rocks of varying physico-engineering properties, problem of differential settlement in the foundations of riverbed blocks 41 to 44 was apprehended.

Table 19: Shear strength parameters of weak layers

No.	Rock/interface	Location	Shear strength	
			C MPa	ϕ degree
1	Intraflow layer	Left bank (Ch. 637 m)	0	39
2	Intraflow layer	Left bank (Ch. 1420 m)	0	28
3	Intraflow layer	Left bank (Ch. 1460 m)	0.25	11
4	Intraflow layer	Left bank (Ch. 1630 m)	0.14	13
5	Interflow layer (red bole)	Left bank (Ch. 1120 m)	0.08	17
6	Quartzitic sandstone	Right of riverbed fault	0	44
7	Argillaceous sandstone			
	(a) Without propping	-Do-	0	17
	(b) With propping	-Do-	0.20	28
8	Pebbly sandstone	-Do-	0	45
9	Contact of quartzitic sandstone with argillaceous sandstone	-Do-	0	11
10	Contact of argillaceous sandstone with quartzitic sandstone	-Do-	0	26
11	Contact of massive trap with conglomerate	-Do-	0	47
12	Concrete rock interface			
	(a) Dolerite rock	-Do-	0.71	53
	(b) Basalt rock	-Do-	1.02	66

3.2.4 Physico-engineering properties of chloritized and slaked dolerite rock

Petrographic analysis of slaked dolerite shows alteration of feldspar to sericite and augite/olivine to chlorite. A few cracks observed in these rocks are of branching type infilled with chloritic material. X-ray analysis revealed presence of saponite (Smectite group) as a major constituent in the slaked dolerite rock and chlorite as a minor constituent along joints (Prakash 1990).

a. Slaking test: Rock lumps of slaked dolerite were subjected to alternate wetting and drying cycles of 24 hours each in the laboratory. Chlorite flakes started separating along joint planes after two cycles. Rock lumps started crumbling after

5 to 16 cycles. Slaked rock crumbled into flakes or granular particles after exposing to air depending upon the nature and degree of alteration.

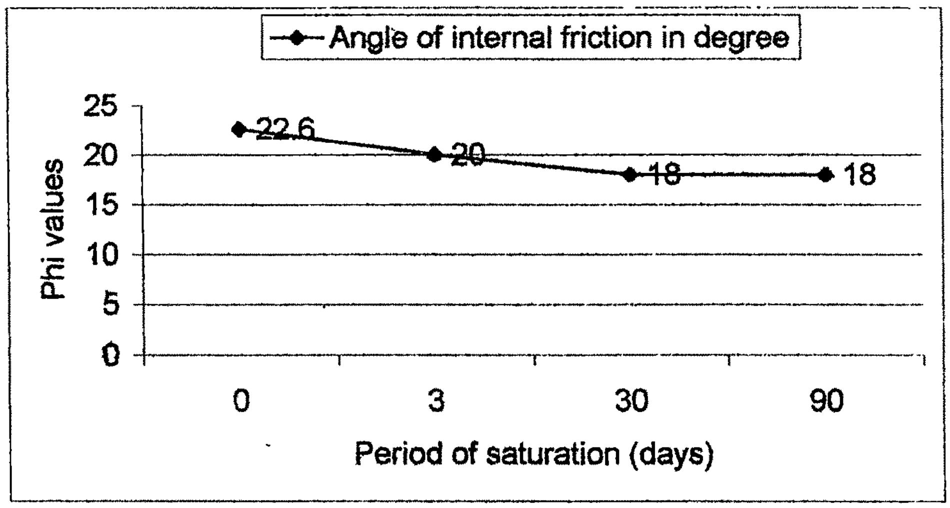
Mechanism of slaking can be explained by 'ordered-water' molecular pressure. Possibly repeated wetting and drying allows the water molecule to become increasingly ordered, assuming a quasi-crystalline nature and exerting expansive force that thrust against the confining walls (Ollier 1984).

b. Laboratory shear test: Laboratory shear tests of rock samples having chlorite coated slickensided joint surfaces gave the value of 'C' 0.20MPa and 'ϕ' 18°. Phi (ϕ) value remained unchanged even after 30 days of saturation (Fig. 12).

3.3 Physico-engineering properties of the Karjan dam foundation rocks

The physico-engineering properties of the foundation rocks including specific gravity, water absorption, porosity, permeability, unconfined compressive strength and tensile strength were determined (Fig. 13 & 14). The average values of water absorption percentage varies from 1.60 to 2.20, porosity 4.20 to 5.15, specific gravity 2.58 to 2.70, unconfined compressive strength 62 to 79 MPa, tensile strength 10 to 12.50MPa and permeability 0 to 2.73×10^{-9}cm/sec. These values are within the normal limit of fresh, moderate to good values of basalt.

In-situ shear tests carried out on weathered rock seams in the foundations of overflow blocks indicated value of cohesion 'C'=0 kg/cm^2 (low values of cohesion were neglected in the design hence stated as zero) and the value of angle of internal friction 'ϕ' =22° to 26° (Fig. 15). Low values of shear parameters have necessitated provision of concrete shear keys along the weak layers in the foundation of dam blocks to resist the sliding forces.



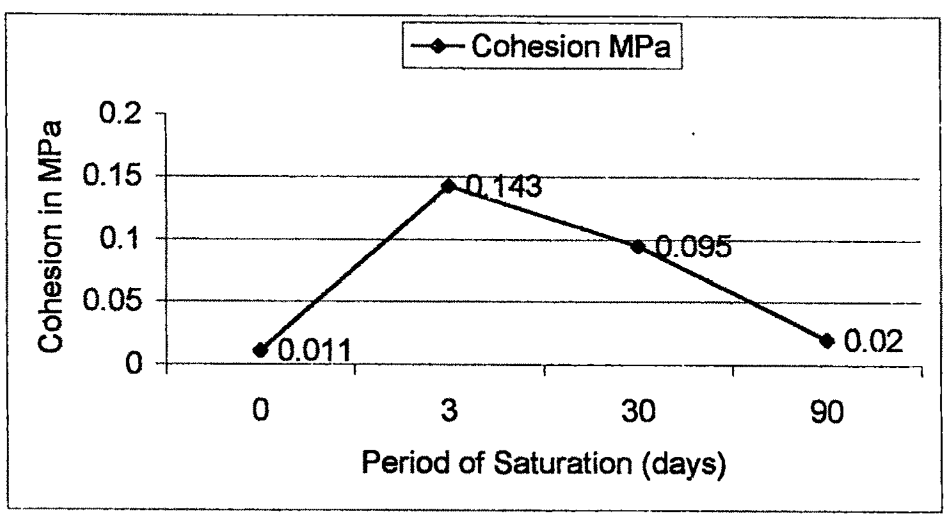


Fig. 12: Shear parameters of chlorite coated joints in the dolerite rock based on the laboratory tests, Sardar Sarovar (Narmada) Project

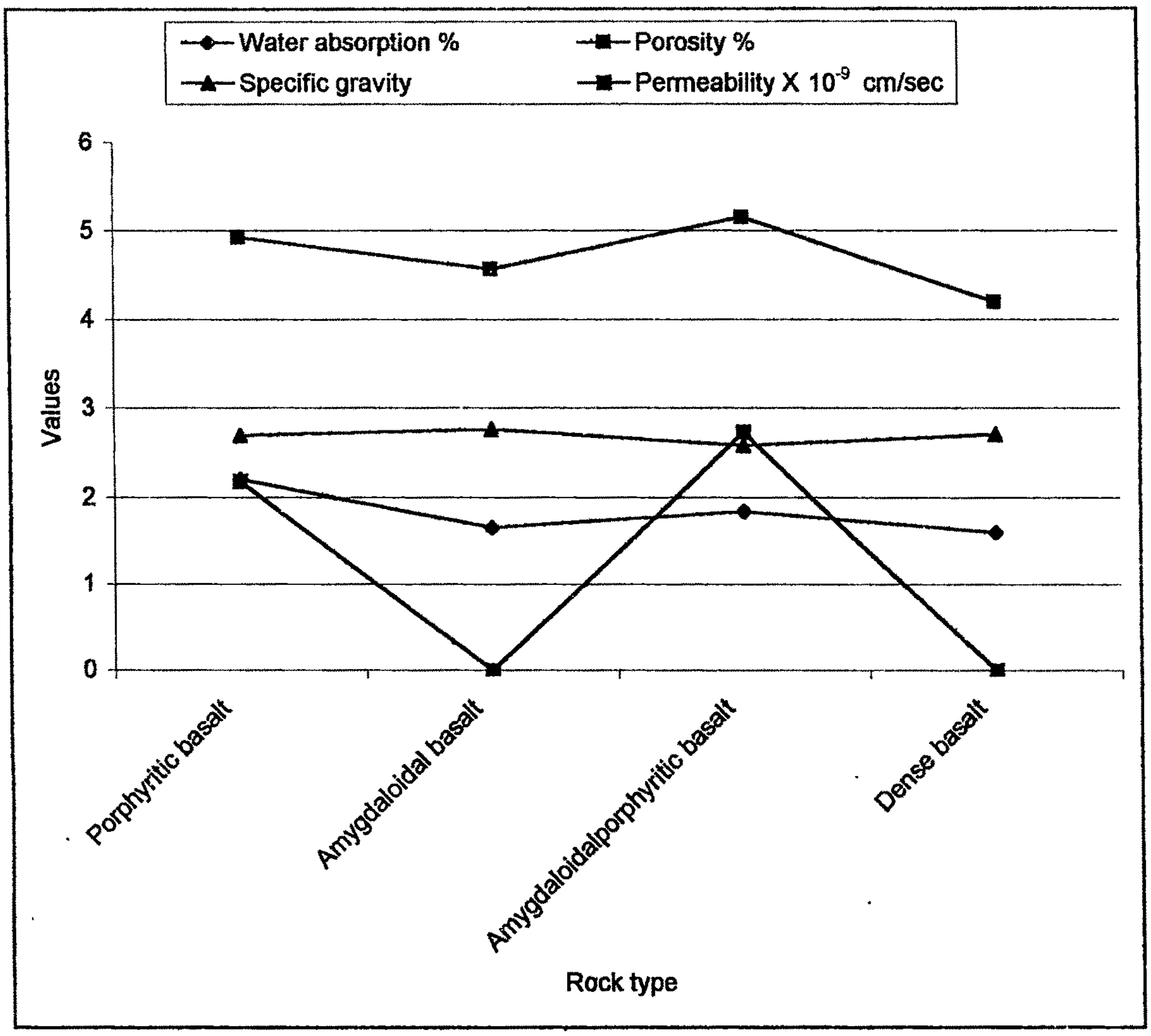


Fig. 13: Physical properties of foundation rocks, Karjan dam

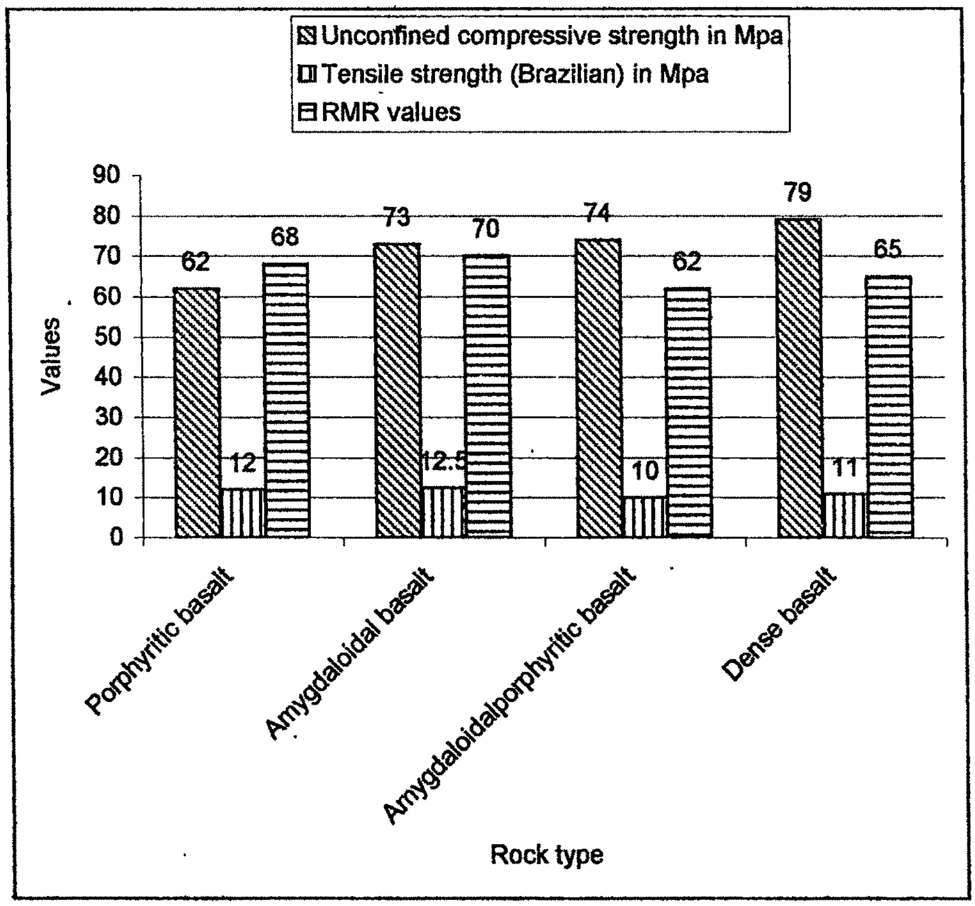


Fig. 14: Compressive, tensile strength and rock mass rating of foundation rocks, Karjan dam

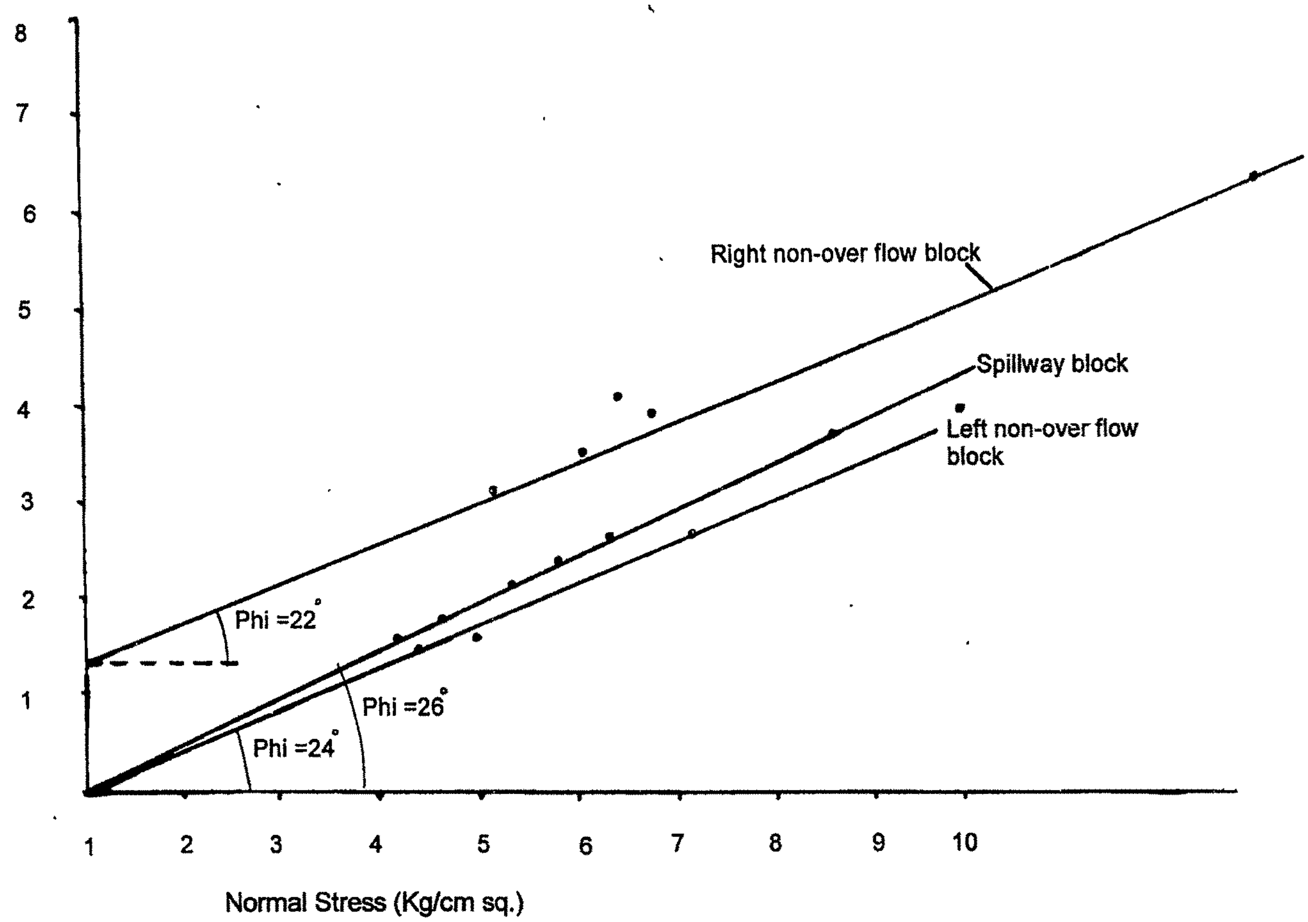


Fig. 15: Plot of in-situ shear tests on weathered rock seams at Karjan dam foundation

3.4 State of stresses in the rock mass in the powerhouse cavern

The in-situ stress field (i.e. internal stresses in the rock mass) in the powerhouse was measured by flat jack, over coring and hydro-fracturing methods (Table 20).

Table 20: Results of in-situ stresses at underground powerhouse site

Stress	Flat jack test (MPa)	Hydro-fracture test (MPa)	Horizontal to vertical stress ratio 'k'	
			Flat jack method	Hydro-fracture method
Vertical:	1.379	1.2	-	-
Horizontal:				
1. Parallel to longer axis	1.171	3	0.85	2.5
2. Perpendicular to longer axis	-	1.5	-	1.25

Note: Due to jointed nature of the rock mass overcoring tests failed, hence not mentioned.

The hydro-fracture tests indicated that minimum in-situ stress is vertical due to shallow rock cover and is equal to depth below surface times the unit weight of the rock (0.026 MN/m^3). The major in-situ stress is approximately 2.5 times the vertical stress and is parallel to the longer axis of the cavern axis. The intermediate principal stress perpendicular to the cavern axis is approximately 1.25 times the vertical stress. As the average cover over the cavern roof is only about 45m, the vertical stress is approximately 1.25 MPa and the horizontal stress acting perpendicular to the cavern axis is approximately 1.5 MPa. The direction of the maximum principal horizontal stress is North $\pm 5°$ (Prakash and Sanganeria 1992).

It has been noticed that horizontal stresses measured by flat jack tests in the exploratory drifts are different and less than evaluated by the hydro-fracture test. Similar observations have been made at Srisalam dam site (Tilak 1999). Further study is required to establish the relationship, if any, between flat jack and hydro-fracture tests.