PHYSICAL, GEOPHYSICAL AND GEOTECHNICAL BEHAVIOUR OF LIMESTONES

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Abstract: Limestone is one of the three principal sedimentary rock and occurs prominently in India. Limestones are extensively encountered during various civil engineering construction activities, mining projects and tunneling operations. Hence a study of their characteristics is imperative in evaluating their response to various in-situ stress conditions. This paper presents data which briefly describes physical and geophysical properties and geotechnical characteristics of limestones collected from two locations namely Katni and Nayagaon from state of Madhya Pradesh. The study of physical properties included determination of specific, gravity, porosity and water absorption. The geophysical characteristics were assessed through compressional and shear wave velocities and Schmidt rebound hardness. The geotechnical characteristics were assessed through uniaxial compression, Brazilian and point load tests on dry as well as saturated specimens. The relationships between various properties are evaluated. The saturation is found to have a significant influence on the geotechnical characteristics.

1 Introduction

Sedimentary rocks occur predominantly in India. The three principal sedimentary rocks namely sandstone, limestone and shale account for about 75% of all sedimentary rocks. Limestones are extensively encountered during various mining, tunneling and civil engineering activities. Accordingly, the rational design and construction of structures related to civil, mining, tunneling and other engineering activities require a proper evaluation of their properties and realistic assessment of their engineering behaviour under varying field conditions. Hence a study of their characteristics is imperative in evaluating their response to various in-situ stress conditions

Among various in-situ factors which influence the strength and deformation characteristics of limestones, moisture is most significant parameter. It is well known fact that most of underground rocks contain moisture varying from less than one percent for some evaporates to over thirty five percent for highly porous rocks like sandstones. The presence of moisture is one of the most important in-situ parameters which influences geotechnical properties and performance of rock mass and influences underground working conditions and response of rock mass to loading. Thus, it is thus imperative that the influence of varying moisture on strength and deformation behavior of limestone is studied in detail.

In this paper an attempt has been made to evaluate physical, geophysical and strength and deformation behaviour of two limestones collected from the state of Madhya Pradesh in India. Towards this end an extensive experimental programme was systematically planned and meticulously executed and the results are presented and are analyzed to understand geotechnical response of these limestones. The paper also presents the effect of saturation on their geotechnical response.

2 Effect of Moisture on Rock Behaviour

A small amount of moisture can affect strength and deformation characteristics of rocks. Most of the studies to study the effect of varying moisture are concerned in the low moisture range. A number of investigators (Van Eeckhout; (1976), Rao et al.; (1985), Dobereiner et al.; (1990), Gokhale; (1994) and others have studied the effect of varying moisture (in terms of relative humidity, RH, or equilibrium moisture content, EMC) on strength and/or elastic constants of sedimentary rocks.

Rao et al. (1984) studied the variation of uniaxial compressive strength (σ_c) and deformation modulus (E) with varying moisture for Bath limestone and Bunter sandstone. They observed clear reduction in σ_c and E with increasing moisture and noted that their results are in line with those of earlier researchers. Their data indicate that the reduction in σ_c and E is marginal beyond the moisture content of about 2% (this value being around 20% of that of saturated moisture content). They attributed the reduction in σ_c to two factors viz. (i) a change in the surface energy or electrical force system and (ii) a change in pore water pressure (as the specimens were tested without confinement, the pore air pressure remains constant at atmospheric pressure).

Dobereiner et al. (1990) discussed the variation of σ_c and elastic modulus (E) with varying moisture contents for sandstones and observed that larger reduction in strength occurs at low moisture contents, in most cases below 1%. They reported that the reduction in strength due to an increase in sample moisture content must involve the usual variations in cohesion and friction of granular material.

A number of researchers also studied the effect of RH on reduction in Brazilian tensile strength, point load strength index and modulus of elasticity. Deshmukh and Gokhale (1990) studied the variation of σ_{tb} with RH for Pinoura sandstone.

In practice the moisture variation is still larger extremely ranging from dry to fully saturated condition. In most of the practical applications rocks are nearly saturated. Further the partially saturated rocks in practice have non-uniform moisture distribution. The literature study indicated that very little work has been done to study the influence of the full range of water content from dry to fully saturated on strength and elastic constants. The study conducted by Rao et al. (1985) on sandstone and limestone indicated that both σ_c and E_t decreases significantly at initial increase in moisture content (up to about 15% of that of fully saturated) over dry condition.

3 Experimental Investigation

In order to understand the strength and deformation behaviour and to evaluate the influence of saturation on strength and deformation behavior the limestones samples in the form of block samples were collected from two locations in Madhya Pradesh and were subjected to elaborate experimental investigation. From the block samples specimens as required were obtained and subjected to various tests. The Table 1 presents the details of locations of these rocks.

Table 1 Location of Rock Samples

Sr. No.	Location of Procurement		Latitude	Longitude	Symbol adopted
	Village	District			
1	Katni	Jabalpur	23.7N^0	80.3E^0	KJLS
2	Nayagaon	Mandsaur	24.5N^0	74.8E^0	NMLS

The physical characteristics of these two limestones were assessed both at microscopic and macroscopic level. In order to identify the rock forming constituents, mineralogy and petrography X- ray diffraction analysis, the studies of thin sections under microscope at magnification of x20, scanning electron microscopy and chemical analysis was conducted following conventional and standard procedure. The macroscopic physical properties such as specific gravity, dry & saturated unit weights, effective & total porosities and water absorption (saturated moisture content) have been determined in the laboratory following the ISRM suggested procedure Brown, (1981). Various index properties such as destructive axial point index, diametral point load index, non-destructive Schmidt rebound hammer index were determined for both dry and fully saturated conditions. In addition, second cycle slake durability index, void index and water evaporation index were also estimated. In order to assess the strength and deformation response various tests viz. uniaxial compression tests, Brazilian tensile strength test, Punch shear strength test, were conducted on dry and saturated specimens.

4 Result and Discussion

The typical experimental data are presented and analyzed so as to assess the nature and engineering behaviour and to evaluate influence of varying moisture on strength and deformation behaviour.

4.1 Mineralogy, Petrography and Chemical Composition

Geologically both limestones studied belongs to Upper Proterozoic geologic age with stratigraphic unit being Vindhyan super group and sub unit being Kaimor group for KJLS and Semri group for NMLS. The mineralogical and petrographical studies have been carried out using petrographical microscopy of thin sections, x-ray diffraction and scanning electron microscopy. The dominant mineral present in each rock type is identified on the basis of these studies and its approximate percentage is also obtained through petrographical study and chemical analysis is also performed. On the basis of the study of x-ray diffractograms, scanning electron micrographs and petrographical analysis following observation are made.

4.1.1 Katni-Jabalpur Limestone (KJLS): The colour of this limestone is white having brown-black speckled. It contains medium to fine grains with clear texture. The grains are compact and well locked with few alterations. At places grain boundaries are filled with iron minerals. The high cleavage and cross-hatching in grains has also been observed. This limestone which shows presence of calcareous cementing material also exhibits alteration of iron grains and presence of some opaque minerals. The calcite mineral in this rock is in crystalline form.

4.1.2 Nayagaon-Mandsaur Limestone (NMLS): The studies on this dark green-brown coloured limestone indicate that, it contains medium grained calcite minerals. Some grains are observed to be altered. It has_rombhohydrate structure with closely packed and well-locked grains, leading to very few voids. This rock having predominantly calcareous cementing material also exhibits the presence of argillaceous material and opaque minerals.

The summary of chemical composition of these two limestones is presented inTable 2. It can be seen from the data given Table 2 that both limestones have CaO as main constituent ranging between 45%-50%. The Loss on Initiation (LOI) ranges from 39.00% for NMLS to 43.60% for KJLS.

Table 2 Chemical Composition of Limestones Studied

Rock Type	Chemical Constituents, %								Predominant minerals
	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	LOI	Others	
KJLS	2.16	Traces	0.52	…	50.68	3.00	43.60	0.04	Calcite, Pyrite, Dolomite
NMLS	10.64	1.96	1.40	…	46.76	Traces	39.00	0.24	Calcite, Dolomite, Kaolinite

4.2 Physical Properties

The values of various physical properties viz. specific gravity (G), dry unit weight (γ_{dry}), saturated unit weight (γ_{sat}), total porosity (n_t), effective porosity (n_e) and water absorption (saturated moisture content, m_s) for the two limestones studied are reported in Table 3. In addition, Table 3 also presents the magnitudes of effective degree of saturation, S_{re} [$=(n_e/n_t)$. S_r] for the two limestones studied. It can be observed from the data given in Table 3 that both limestones have very low porosity with effective degree of saturation ranging from 15.81% for KJLS to 20.03% for NMLS.

Table 3 Physical Properties of Limestones Studied

Rock Type	G	γ_{dry}	γ_{sat}	n_t	n_e	m_s	S_{re}
		KN/m^3	KN/m^3	%	%	%	%
KJLS	2.79	26.84	26.88	1.95	0.27	0.10	15.81
NMLS	2.77	26.47	26.52	2.60	2.60	0.19	20.03

4.3 Geophysical and Index Properties

The average values of various geophysical and index properties obtained for these rocks are presented in Table 4. The table presents the average values compression wave velocity (v_p), shear wave velocity (v_s), non-destructive Schmidt rebound hammer index (I_{Sr}) for fully dry and saturated specimens. The Table 4 also presents the average values of second cycle slake durability index (I_{sd2}), void index (I_v) and water evaporation index (I_{we}) [Gokhale, (1999)]. The values of v_p, v_s and I_{Sr} presented in Table 4 indicates that saturation has very minimal influence on values in dry and saturated conditions for these two limestones, against general observation in literature that saturation has significant influence on properties of sedimentary rocks. The average values of second cycle slake durability index (I_{sd2}) given in Table 4 for both the limestones indicate that whereas value is quite closer to 100 for both KJLS and NMLS. As this index is basically devised and used for assessing rock weatherability very high values exhibited by the rocks studied indicate their high resistance to weathering/slaking. The values of I_{we} indicate that although the values for both limestones are very low, the value for NMLS is almost double of that for KJLS. Gokhale (1999) has described the usefulness of this index to understand pore size distribution.

Table 4 Index Properties of Sandstones Studied

Rock Nomenclature	v_p, km/s		v_s, km/s		I_{Sr}, No		I_{sd2}, %	I_v, %	I_{we}, %
Saturation Condition	Dry	Sat.	Dry	Sat.	Dry	Sat.	…..	…..	…..
KJLS	5.19	5.44	3.26	3.22	47	46	98.48	0.06	0.04
NMLS	5.76	5.94	3.78	3.67	50	49	99.45	0.10	0.07

4.4 Geotechnical Behaviour

The uniaxial strength behaviour of the two rocks was assessed in all three modes that is compression, tension and shear through determination of uniaxial compressive strength (σ_c), Brazilian tensile strength (σ_{tb}) and punch shear strength (τ_p). The values of rock strength in these three modes for both dry and saturated conditions are presented in Table 5. It is clearly evident that NMLS is little stronger than KJLS under all three types of stresses viz. compression, tension and shear.

Table 5 Strength Properties of Limestones Studied

Rock Type	σ_c, MPa		σ_{tb}, MPa		τ_p, MPa	
	Dry	Sat.	Dry	Sat.	Dry	Sat.
KJLS	64.54	59.80	7.55	5.96	10.93	10.20
NMLS	72.57	66.20	13.26	9.68	15.29	13.94

Further data presented in Table 5 also clearly isolate that there is minimal reduction (less than 10%) in strength in shear mode (6.68%-8.83%) and compression mode (7.34%-8.78%). The highest reduction in strength upon saturation is observed in tension mode of order of 21.06% for KJLS to 27.00% for NMLS, indicating a special attention when such rocks are subjected to tensile stresses.

4.4 Stress-Strain Behaviour

The stress-strain curves under uniaxial compression for KJLS and NMLS are presented in Fig. 1. It can be seen that the stress-strain curves for both the rocks studied are S-shaped; initially showing concavity upwards up to about quarter of failure stress (due to closure of micro cracks/voids) followed by nearly linear portion indicating elastic response within range. The stress-strain curves further show increasing nonlinearity with convexity upwards (inelastic yielding) as failure approaches. Qualitatively such behaviour is observed for dry as well as saturated conditions. The rate of change of diametral strain continuously increases with increasing stress until failure. Beyond half the failure stress large lateral deformations occur. The effect of moisture is observed to be more pronounced in case of diametral strain changes as compared to axial strains. On the basis of values of σ_c and tangent modulus of elasticity (E_s) both the rocks studied are classified as CM that is rock of medium strength and medium modulus ratio, on Deere and Miller (1966) classification system for intact rocks.

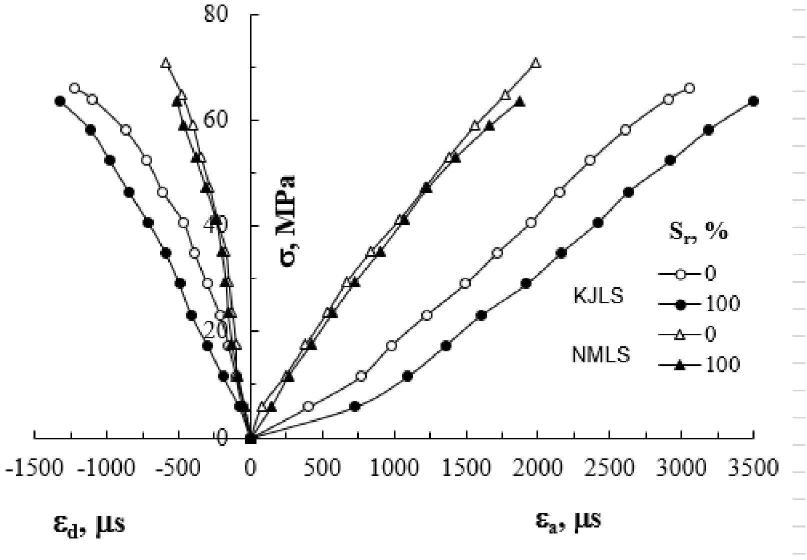

Fig. 1 stress-Strain curves for limestones studied under uniaxial Compression

4.5 Elastic Constants

The values of static elastic constants i.e. tangent modulus of elasticity (E_s) and Poisson's ratio (ν_s) determined at 50% of failure stress from stress-strain curves are presented in TABLE 6. The corresponding dynamic elastic constants E_d and ν_d obtained on the basis of compressional and shear wave velocity are also presented in Table 6. The values provided in TABLE 6 indicate that in general values of modulus of elasticity are higher for SAS while values of Poisson's ratio are higher or DSS both in static as well as in dynamic conditions. Under both dry and saturated conditions. Further upon saturation while values of modulus of elasticity are observed to decrease, the value of Poisson's ratio is observed to increases.

Table 6 Static and Dynamic Elastic Constant of Rocks Studied

Rock Type	E_s, GPa		ν_s		E_d, GPa		ν_d		E_d/E_s	
	Dry	Sat.	Dry	Sat.	Dry	Sat.	Dry	Sat.	Dry	Sat.
KJLS	24.00	23.20	0.22	0.25	68.49	70.25	0.17	0.23	2.85	3.03
NMLS	35.65	32.50	0.22	0.23	86.39	86.87	0.12	0.12	2.42	2.67

The data given in Table 6 indicates that whiles E_s is observe to decrease marginally on saturation, in contrast E_d is observed to increase marginally on saturation. The comparison of static and dynamic values of modulus of deformation indicates that dynamic values are about 2.42 to 2.85 times the static values in dry condition. This ratio of E_d/E_s for saturated condition is observed to be between 2.67 to 303. The data for Poisson's ratio presented in Table 6 also illustrate that for both dry and saturated conditions poisons ratio values are lower in dynamic condition as compared to static condition.

5 Conclusions

This paper presents the results of experimental investigation conducted on two limestones to understand the physical, geophysical and geotechnical behavior and effect of saturation on strength and deformation behavior. The following major conclusions arrived at on the basis of above experimental results.

- Geologically both limestones studied belong to Upper Proterozoic geologic age with stratigraphic unit being Vindhyan super group.
- Both limestones have CaO as main constituent ranging between 45%-50%. The Loss on Initiation (LOI) for the limestones studied ranges from 39.00% to 43.60%.
- The two limestones studied have very low porosity with effective degree of saturation ranging from 15.81% to 20.03%.
- Both the rocks studied indicate their high resistance to weathering/slaking.
- The results of present study clearly isolate that while reduction in strength is less than 10% in both compression and shear mode, it is moderately significant in tension mode having an order of 21%-27%, indicating a special attention when such rocks are subjected to tensile stresses.
- The stress-strain curves under uniaxial compression for limestones studied are observed to S-shaped; initially showing concavity upwards up to about quarter of failure stress (due to closure of micro cracks/voids) followed by nearly linear portion indicating elastic response within range. The stress-strain curves further show increasing nonlinearity with convexity upwards (inelastic yielding) as failure approaches.
- Dynamic elastic constants are observed to be higher than respective static elastic constants for rocks studied
- The comparison of static and dynamic values of modulus of deformation indicates that dynamic values are about 2.42 to 2.85 times the static values in dry condition.

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