Dry density
Specific gravity
Void ratio
Water absorption
Lithology of laterites
Shear strength of lateritic soils
Methodology and Results
Correlation
Shear strength - specific gravity
Shear strength - compaction parameters
Cohesion - soil fraction below 0.002 mm
Angle of internal friction - chemical composition
Shear parameters of undisturbed lithotypes of lateritic profiles
Conclusion

Chapter VIII
Permeability and Textural Characteristics of Laterites and Lateritic Soils

Introduction
Permeability characteristics of laterites
Methodology and Results
Factors controlling permeability
Permeability characteristics of Lateritic soils
Methodology and Results
Correlations
Coefficient of permeability and optimum moisture content
Coefficient of permeability and optimum dry density
Coefficient of permeability and void ratio
Conclusion
Chapter IX

Classification of Lateritic Soils for Engineering Purposes 159 - 164

Introduction

Coarse grained (gravelly) lateritic soils
Fine grained (concretionary lateritic soils)

Conclusion

Chapter X

Use of Laterite Aggregate in Concrete 165 - 169

Introduction

Methodology and Results
Aggregate preparation
Concrete mix

Lithology of aggregates

Conclusion

Chapter XI

Competency of Reservoirs In Laterites 170 - 187

Introduction

Reservoir at Poip
Remedial measures

Reservoir at Osargaon
Remedial measures

Reservoir at Kelambe
Preventive measures
Remedial measures

Reservoir at Beni
Preventive measures

Reservoir at Vapholi
Reservoir at Panhala
Reservoir at Mahabaleshwar (Venna lake)
Chapter XII
Grouting In Laterites
Introduction
Geology
Grouting
Conclusion

Chapter XIII
Landslides in Lateritic Terrain
Introduction
Classification of landslides
Landslides in lateritic terrain
  Slope failure along cylindrical surface and earlier slide plane at Tillari power canal
Landslide along cylindrical surface at Patgaon
Slumping and rock falls at Vapholi
Rock falls and block slides at Panchgani
Block slides at Mahabaleshwar
Rock slide at Sangameshwar, Sakharpa and Patgaon, Parashuram
Creeps at Tillari Hydro Electric Project
Debris flow at Sangameshwar
Geotechnical properties of slide prone lithotypes
Chapter XIV

Cement Concrete Pavements In Lateritic Terrain

Introduction
Performance parameters
Field performance of concrete roads
Cracks, settlement and potholes in cement concrete road
Laterite profile along National Highway 17
Laterite profile along State Highway between Pali and Amba
Mechanism of cracks, settlement and potholes
Conclusion
LIST OF FIGURES

Fig. 1.1 Location map 6
Fig. 2.1 Mature laterite profile 10
Fig. 2.2 Immature laterite profile 10
Fig. 2.3 Immature lateritic soil profile 10
Fig. 2.4 Reworked laterite profile 12
Fig. 2.5 Induced laterite profile 12
Fig. 3.1 a Profile at Panhala : Gradation analysis curves 32
Fig. 3.1 b Profile at Chandoli : Gradation analysis curves 32
Fig. 3.1 c Profile at Pen : Gradation analysis curves 33
Fig. 3.1 e Profile at Poip : Gradation analysis curves 33
Fig. 3.1 f Gradation analysis curves : Gravelly lateritic soil 34
Fig. 3.1 g Gradation analysis curves : fine concretionary lateritic soils. 35
Fig. 3.1 h Gradation analysis curves : Lithomargic clay 35
Fig. 4.1 Variation of LL, PL, PI and SL with depth :
   (a) Profile at Panhala 71
   (b) Profile at Tillari Nagar 71
   (c) Profile at Chandoli 71
   (d) Profile at Pen 71
   (e) Profile at Vapholi 72
   (f) Profile at Poip 72
   (g) Profile at Kalamwadi 72
   (h) Profile at Hateri 72
Fig. 4.2 Extended plasticity chart to lateritic soil
   (after Vallerge et al, 1969) 73
Fig. 4.3 a X-ray diffractograms
   (Immature laterite profile at Pen) 86
   b X-ray diffractogram
   (Laterite profile at Chandoli) 87
Fig. 4.4 Relation of silica - sesquioxide ratio with plasticity parameters. 89
Fig. 4.5 Relation between liquid limit, plastic limit, plasticity index and grain size below 0.002 mm 96
Fig. 4.6  Histogram showing effect of air drying and oven drying on Atterberg limits  
Fig. 5.1  Relation of specific gravity with depth  
Fig. 5.2  Relation between specific gravity and petrification  
Fig. 6.1  Relation between optimum moisture content and optimum dry density  
Fig. 6.2  Moisture-density curves  
Fig. 6.3  Relation between specific gravity and optimum dry density  
Fig. 6.4  Relation between optimum moisture content and plasticity index.  
Fig. 6.5  Effect of compaction efforts on particle size gradation  
Fig. 7.1  Distribution of vesicles along cylindrical surface of laterite from Jangamhatti (samples MNO)  
Fig. 7.2  Stress - strain curves of saprolite from Patgaon  
Fig. 7.3  Lines of failures  
  a)  Gravelly lateritic soils  
  b)  Fine concretionary lateritic soils  
Fig. 7.4  Relation between shear parameters and specific gravity.  
Fig. 7.5  Relation between shear and compaction parameters  
Fig. 7.6  Relation between angle of internal friction and chemical composition.  
Fig. 7.7  Lines of failures (undisturbed litho units)  
Fig. 8.1  Important patterns of vesicles in laterites  
Fig. 8.2  Relation between permeability and compaction parameters  
Fig. 9.1  Extended plasticity chart after Vellerga et al (1969)  
Fig. 11.1  Position of reservoir in laterite profile - Poip  
Fig. 11.2  Graph showing reservoir water levels - Poip  
Fig. 11.3  Position of reservoir in laterite profile - Osargaon  
Fig. 11.4  Position of reservoir in lateritic profile - Kelambe  
Fig. 11.5  Geological conditions along foundation of the dam at Vapholi  
Fig. 11.6  Position of reservoir in laterite profile - Panhala.
| Fig. 11.7 | Position of reservoir in laterite profile - Mahabaleshwar. | 184 |
| Fig. 11.8 | Position of reservoir in laterite profile - Dhampur | 184 |
| Fig. 12.1 | Laterite section in grouted portion of the foundation | 189 |
| Fig. 12.2 | Grout hole pattern | 189 |
| Fig. 13.1 | Geological section along slided portion | 198 |
| Fig. 13.2 | Block diagrams showing ancient slide | 198 |
| Fig. 13.3 | Land slide showing slip circle | 200 |
| Fig. 13.4 | Relation of land slide with planation surface | 200 |
| Fig. 14.1 | Geological section along National Highway No.17 between Ratnagiri and Kankavali. | 209 - 211 |
| Fig. 14.2 | Cross section of cement concrete road | 211 |
### LIST OF TABLES

<p>| Table 2.1 | Mature laterite profile at Panhala over basalt | 13 - 14 |
| Table 2.2 | Mature laterite profile at Tillari Nagar over basalt | 15 |
| Table 2.3 | Immature laterite profile at Jangamhatti over basalt | 16 |
| Table 2.4 | Immature lateritic soil profile at Pen over basalt | 17 |
| Table 2.5 | Reworked laterite profile at Poip over induced laterite, sandstone and granulite | 18 |
| Table 2.6 | Reworked profile at Oni over sandstone (Kaladgi) | 19 |
| Table 2.7 | Induced laterite profile at Chandoli over basalt | 20 - 21 |
| Table 2.8 | Induced laterite profile at Kalamawadi over sandstone and shale (Kaladgi) | 22 |
| Table 2.9 | Induced laterite profile at Vapholi over granulite | 23 - 24 |
| Table 2.10 | Induced laterite profile at Hateri over mica schist | 25 |
| Table 3.1 | Grain size distribution | 27 - 31 |
| Table 3.2 | Textural and mineralogical characteristics | 40 - 52 |
| Table 4.1 | Plasticity parameters | 65 - 69 |
| Table 4.2 | Plasticity characteristics and geological factors | 74 - 82 |
| Table 4.3 | General trend of plasticity parameters with depth | 83 |
| Table 4.4 | Clay minerals and sesquioxide coating | 85 |
| Table 4.5 | Plasticity parameters and silica-sesquioxide ratio | 88 |
| Table 4.6 | Mineralogy of fraction below 0.425 mm of lithotypes of lateritic profiles | 90 - 93 |
| Table 4.7 | Plasticity parameters and clay content | 95 |
| Table 4.8 | Influence of drying procedure on plasticity characteristics | 98 |
| Table 5.1 | Petrification and specific gravity parameters | 102 - 105 |
| Table 5.2 | Geological features and degree of petrification | 107 - 109 |
| Table 5.3 | General trend specific gravity and petrification with depth | 111 |
| Table 5.4 | Specific gravity of different grain size fractions of lateritic soils | 112 |
| Table 6.1 | Compaction parameters and chemical composition of lateritic soils. | 116 |
| Table 6.2 | Influence of compaction efforts on grain size distribution | 123 |</p>
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Geotechnical properties of laterites</td>
<td>128 - 129</td>
</tr>
<tr>
<td>7.2</td>
<td>Shear and other related parameters of lateritic soils</td>
<td>138</td>
</tr>
<tr>
<td>7.3</td>
<td>Shear parameters of undisturbed lithounits</td>
<td>139</td>
</tr>
<tr>
<td>7.4</td>
<td>Shear parameters of lithotypes of mature laterite profile (undisturbed samples) at Tillari</td>
<td>140</td>
</tr>
<tr>
<td>8.1</td>
<td>Field and laboratory permeability and lithology of laterites</td>
<td>150 - 151</td>
</tr>
<tr>
<td>8.2</td>
<td>Permeability parameters of lateritic soils</td>
<td>155</td>
</tr>
<tr>
<td>9.1</td>
<td>Plasticity, shear and permeability parameters of lateritic soils</td>
<td>160 - 161</td>
</tr>
<tr>
<td>10.1</td>
<td>Compressive strength of concrete cubes of laterite aggregate</td>
<td>167</td>
</tr>
<tr>
<td>13.1</td>
<td>Classification of Landslides (adopted after Zaruba and MencI, 1969)</td>
<td>193</td>
</tr>
<tr>
<td>13.2</td>
<td>Corrective measures and alternatives with reference to slope movement and civil engineering structures</td>
<td>206 - 207</td>
</tr>
<tr>
<td>14.1</td>
<td>Lithologywise performance of cement concrete Road, National highway 17</td>
<td>215</td>
</tr>
<tr>
<td>14.2</td>
<td>Lithologywise length of cement concrete road</td>
<td>216</td>
</tr>
</tbody>
</table>
**LIST OF PHOTOGRAPHS**

<table>
<thead>
<tr>
<th>Plate</th>
<th>Photo</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>1</td>
<td>Mature laterite profile at Panchgani (Note rock falls)</td>
</tr>
<tr>
<td>2.1</td>
<td>2</td>
<td>Immature laterite profile at Gaganbavada.</td>
</tr>
<tr>
<td>2.2</td>
<td>1</td>
<td>Immature lateritic soil profile at Pen</td>
</tr>
<tr>
<td>2.2</td>
<td>2</td>
<td>Lithomargic clay showing banding simulating sedimentary beds</td>
</tr>
<tr>
<td>2.3</td>
<td>1</td>
<td>Relict spheroidal structure in laterite of the immature laterite profile at Jangamhatti</td>
</tr>
<tr>
<td>2.3</td>
<td>2</td>
<td>Horizon C in reworked laterite profile at Poip (Note the tail channel erosion)</td>
</tr>
<tr>
<td>2.4</td>
<td>1</td>
<td>Induced laterite profile at Chandoli</td>
</tr>
<tr>
<td>2.4</td>
<td>2</td>
<td>Horizon A of the induced laterite profile at Chandoli (Note large blocks of reworked laterite)</td>
</tr>
<tr>
<td>2.5</td>
<td>1</td>
<td>Horizon B and C of the induced laterite profile at Chandoli</td>
</tr>
<tr>
<td>2.5</td>
<td>2</td>
<td>Induced laterite profile at Vapholi over amphibolite (Note the tail channel erosion due to slumping and rock falls)</td>
</tr>
<tr>
<td>11.1</td>
<td>1</td>
<td>Box work laterite</td>
</tr>
<tr>
<td>11.1</td>
<td>2</td>
<td>A reservoir in laterite at Mahabaleshwar</td>
</tr>
<tr>
<td>13.1</td>
<td>1</td>
<td>Landslide in laterite at Tillari Power Canal</td>
</tr>
<tr>
<td>13.1</td>
<td>2</td>
<td>Landslide in laterite at Tillari Power Canal (Note the sliding plane at the base)</td>
</tr>
<tr>
<td>13.2</td>
<td>1</td>
<td>Rock slide in saprolite at Patgaon</td>
</tr>
<tr>
<td>13.2</td>
<td>2</td>
<td>Debris flow at Sangameshwar, but traces across the slope</td>
</tr>
<tr>
<td>14.1</td>
<td>1</td>
<td>Network of cracks sealed with asphalt in cement concrete road (National highway 17) over lateritic soil near Pali</td>
</tr>
<tr>
<td>14.1</td>
<td>2</td>
<td>Longitudinal and random cracks sealed with asphalt in cement concrete road (National highway 17) over laterite near Lanja</td>
</tr>
</tbody>
</table>

* * * * *
CHAPTER I
INTRODUCTION
Chapter 1

INTRODUCTION

Prologue:

In the changing context of recent techno-economical developments, Engineering Geology has assumed a vital role in the socio-economic progress of our country. The factor of safety of several civil engineering structures such as dams, power houses, highways, bridges, tunnels, multistoried buildings, airports, runways, etc. is being increased with new innovation in construction methods, refinements in designs and use of better construction material. An adequate knowledge of geological formations and of the behaviour of different rock types forming foundations of different civil engineering structures has become an absolute necessity, especially from point of view of their stability, durability and economics.

Construction materials form the major component of the cost of the structures. Judicious selection of construction material therefore results in considerable economy. High durability, strength and shape are some of the prime requisites of good construction material. Suitable rocks are used as rubble for masonry, face stones in buildings, protective cover of earth dams (rip-rap), aggregate of concrete, etc., while soils are used in embankments of earth dams, canals, sub-base of road ways, airport runways, etc. In such functions geology enters into soil mechanics in many ways. Interpretation and correlation of data on geology and soil mechanics generally results in considerable reduction of the number of field and laboratory tests which would otherwise be required.

Geotechnical studies can be divided into three groups, namely, (i) geotechnical studies for evaluation of foundations and tunneling problems, (ii) studies for suitability of construction materials and (iii) geotechnical studies for adopting preventive or remedial measures against the harmful events/activities like earthquake, coastal erosion, landslides, silting of reservoir, etc.

In India, field and laboratory tests on rocks and soils are presently carried out in several laboratories predominantly in connection with the river valley projects, highways, buildings, airports, sea-ports, etc. However, these laboratory studies are carried out just mechanically without adequate recognition to the particular geological conditions. The present work aims to examine these
two aspects together in case of laterites and lateritic soils, which are not much in vogue at present, but are likely to get impetus in the years to come.

**Laterites : Definition and Scope of the Term :**

The term 'Laterite' was introduced for the first time to the Geological parlance in India by Francis Buchanan in 1807, while describing a peculiar brick like rock used for building construction in Kerala State. He described it as indurated reddish ochreous and porous clays, which can be cut into bricks with ordinary pickaxe and which harden on exposure. This definition, however, did not hold good for long, because lithological, physical, chemical variations in the laterites are noticed from place to place. A short resume of the development of concepts on lateritization at this stage may be rather pertinent.

Mallet (1883) identified that the laterite is ferruginous and aluminous, while Bauer (1893) established its main chemical characteristics. Warth and Warth (1903), Fox (1923,1936) reported that some of the laterites of India contain small amounts of alumina but were rich in iron and vice-a-versa. This erratic behaviour was found to be a common characteristic in all parts of the world. As a result of these observations, Geologists very soon became interested in the possible value of laterite as an ore of aluminium, iron or in some cases, manganese. Fermor (1911), Richtofen (1886), Oldham (1893), Van Bammelen (1904), Chautard and Lemolne (1908), Arsadcan (1909), Harrison (1910), Lacroix (1913) tried to define laterites in chemical and mineralogical terms, but their efforts gave rise to much contravarsy, particularly in regard to the nature and relative proportions of the characteristic oxides.

By 1910 attempts at physical definition of laterites were practically abandoned in favour of chemical and mineralogical definition. Harrison (1910) widened the scope of the term still further by including unhardened iron and alumina rich earths. Lacroix (1913) took into account only the total content of hydrous oxides and he distinguished laterite into (i) true laterite, (ii) silicate laterite and (iii) lateritic clays.

Van Bemmelen (1904), Harrossowitz (1926) and Martin and Doyne (1927) suggested consideration of \( \text{SiO}_2 / \text{Al}_2\text{O}_3 \) ratio into definition. The use of the different ratios was favoured and was widely adopted. However, the value of these ratios has been disputed by Pendleton and Sharasuvana (1946), Robinson (1949), Van der Voort (1950) and Waegemans (1951 a,b) on the grounds that they result from a combination of alteration processes, different migrations,
neosyntheses and mechanical reworking (Maignien, 1966). Therefore they are indicative rather than absolute criteria.

Kellogg (1949) introduced the term 'litosols' and Sys (1958) used the term 'Kaolisol' to denote intertropical soils possessing the physicochemical characteristics of laterites. Kaolisols are defined as the intense kaolinitic neosyntheses characteristic of humid tropical climates. United States Department of Agriculture (1960) introduced the term 'Plinthite' to the laterite in Buchanan's sense and described as a sesquioxide rich horizon, poor in humus and mixed with heavily altered clays, quartz, etc. occurring as red mottles. The seventh USDA approximation (1960) introduced the term 'oxisols' to latosols and most of the soils covered by the term laterites.

Alexander and Cady (1962) gave the definition of 'laterite' as a highly weathered material rich in secondary oxides of iron, aluminium or both. It is either hard or capable of hardening on exposure to wetting and drying. Schellmann (1980) defined "laterites are products of intense subaerial rock weathering whose Fe and / or Al content is higher and Si content is lower than in merely kaolinised parent rocks. They consist predominantly of mineral assemblages of goethite, hematite, aluminium hydroxides, kaolinite minerals and quartz." Bardossay (1982) slightly modified this definition as, laterite is a product of intense subaerial tropical weathering with a higher Al and Fe and lower Si content than that of underlying saprolite/parent rock, and the characteristic minerals are mainly gibbsite, hematite, goethite, kaolinite minerals, anatase and at some places some quartz.

In literature, the term saprolite includes all lithologic units between laterite duricrust at the top and unaltered parent rock at the base. In present studies, however, the saprolite horizon has been divided into two sub-lithologic units, namely upper portion as lithomarge and lower one as saprolite. This was considered necessary due to variation in their lithological, mineralogical and textural characteristics, which in turn, reflect the geotechnical properties.

Previous Work:


**Scope of Present Work:**

Laterites, in general, cover about 50% of the total area of the western Maharashtra, but systematic work on the same from the geotechnical point of view is almost negligible. The present investigations on "Geotechnical studies of laterites and lateritic soils of western Maharashtra" embodies results of field and laboratory studies carried out during the period between September 1982 and May 1986.

Prediction of engineering response of lateritic soils to some of the engineering structures has been found to be most frustrating due to their complex nature and inadequate data. To that extent the subject has been almost virgin, as the following two aspects have not been studied in case of Indian laterites. The study was divided into two aspects, namely, the determination of index and engineering properties of laterites and lateritic soils with respect to their occurrence, geotechnical properties, lithological variations, chemical and mineralogical compositions, geomorphological conditions, and classification of lateritic soils for engineering purposes; and secondly, studies of aspects on (a) use of laterite as coarse and fine aggregate in concrete, (b) reservoirs in laterites, (c) grouting in laterites, (d) landslides and (e) behaviour of cement concrete pavements in lateritic terrain, etc. These applied aspects were studied with special reference to the geology and geomorphology. The basic objectives were:

(i) identification and classification of different types of laterite/lateritic soil profiles developed over different rock formations under different geological and geomorphological conditions.

(ii) determination of geotechnical properties of about 100 samples representing different lithologic units of different types of laterite / lateritic soil profiles developed over different rock types under different geological and geomorphological conditions.

(iii) evaluate the geological factors that influence index properties which are considered to form a basic information for classification of fine grained soils in Unified Classification System
(iv) investigate reasons of functional failures of some of the reservoirs and suggest preventive and / or remedial measures.
(v) to investigate the possibility of using laterites as low cost source material for aggregate in concrete.

**Area of Investigation :**

The present study is limited geographically to laterites and lateritic soils of western Maharashtra, where they principally occur on plateaux of Sahyadri range of hills and in the low lying areas on eastern and western sides of the continental divide. They are particularly developed in Kolhapur, Sangli, Satara, Sindhudurg, Ratnagiri and Raigad districts of Maharashtra. The area of study is included in Survey of India sheet No. 47 F,G,H,L and 48 I on scale 1" = 4 miles. The localities of the important towns and of the sampling sites are shown in the location map (Fig. 1.1). The coordinates of these sites / locations are given in Appendix A.

**Methodology :**

Both field and laboratory investigations were undertaken as part of the present investigation.

**Field studies :** During the course of field work, different types of laterite / lateritic soil profiles were identified, measured and samples representing different lithologic units of different types of profiles were collected from the point of view of different aspects of the present studies for laboratory tests. Field permeability of laterites at three localities was also carried out. Traverse geological mapping approximately covering about 250 sq km area was carried out for in cases of reservoirs in laterites, areas of landslides and cement concrete pavements. In case of one of the reservoirs, trial grouting was undertaken to prevent subsurface water seepage, an attempt was made to map the portion where grouting was done and to collect pertinent grouting observations.

**Laboratory studies :** Laboratory studies include different tests to determine grain size distribution, plasticity, self-stabilization, specific gravity, compaction, shear, and permeability characteristics of different lithologic units of laterite profiles. The compressive strength, permeability, specific gravity, density, water absorption tests were carried out on different types of laterites. In order to study suitability of laterite pieces as coarse and fine grained aggregate in concrete,
Fig. 1.1 Location map

the compressive strength of concrete cubes was determined. For correlation purposes, chemical and mineralogical analysis was also carried out in case of corresponding samples. Mineralogical analysis include identification of minerals in reflected light under microscope and also X-ray diffractograms wherever possible. These tests were carried out in Maharashtra Engineering Research Institute, regional soil testing laboratory of the Irrigation Department, National Chemical Laboratory, Pune and Mineral and Physics Division, Geological Survey of India, Calcutta. In the present studies, the test procedures to determine engineering properties were followed according to those prescribed in Hand Book on Quality Control Vol. I (1972) and Vol. II (1973) by Kapadia. The degree of petrification was determined according to the procedure laid down by Nascimanto (1964) and porosity and void ratio was determined as per formulas given in Earth Manual (1963).