Seasonal Variations in Properties of Expansive Soils along a Railway Corridor in Western India

Sanjay Gupta
Ravi Sundaram
Sorabh Gupta
Cengrs Geotechnica Pvt. Ltd., A-100 Sector 63, Noida, India
E-mail : sanjay@cengrs.com;ravi@cengrs.com;sorabh@cengrs.com

ABSTRACT: The properties of expansive soils at shallow depth are influenced by moisture variations due to seepage of water into the soils during rains. The paper presents a case study in western India along a railway freight corridor. Testing on samples collected from boreholes drilled in the pre-monsoon and post-monsoon periods indicate substantial variations in moisture content, undrained shear strength and swell pressure to about 3-3.5 m depth. Below this depth, these properties show insignificant change. This confirms that the active zone, the geotechnically unstable zone in expansive soils that undergoes swelling-shrinkage due to moisture variations extends to about 3.5 m depth.

Keywords: *expansive soils; seasonal variations; active zone: moisture variations; undrained shear strength; swell pressure*

1. Introduction

A major Railway Corridor covering a distance of 1483 km is planned which shall connect Dadri (near Delhi) to a port near Navi Mumbai. It is being built for the movement of heavy freight by rail.

The paper presents results of investigations in a 57-km stretch in the Vadodra-Bharuch section in Gujarat.

A vicinity map of the project area showing the alignment of the railway freight corridor in Gujarat is presented on Fig. 1.

Fig. 1 Vicinity map

2. Project Alignment

In general, the railway freight corridor runs parallel to the existing railway track with a few detours in areas where there were space constraints. A map showing the investigations done in the Vadodara-Bharuch section is presented on Fig. 2.

Expansive soils of the Deccan Trap are encountered in this section of the railway corridor. Due to the hot summer season typically experienced in western India, followed heavy rains during monsoon, there is substantial moisture content variation over the year.

To assess the seasonal variations in the soil properties, boreholes were drilled along the alignment in the pre-monsoon and post-monsoon periods. This paper is based on the work done by the authors in this stretch in the year 2012.

Fig. 2 Project alignment in the vicinity of Vadodara

3. Meteorological Data

The climate in the area is sub-tropical and has three well defined seasons – summer from April to June, monsoon from July to December and mild winter from October to March.

As per the meteorological department (Kaur & Purohit, 2013),the rainfall during Jan-Dec 2012 was about 928 mm of out of which nearly than 95% occurred during the monsoon period (July-Sep). The year experienced normal rainfall (within ±20% of the annualized average rainfall).

The maximum temperature in the pre-monsoon period (May-June) is generally around 37 to 41˚C. In July-September period, the maximum temperature comes down to 31-33˚C. Post-monsoon temperatures are around 32-36˚C in October-December.

4. Geological Setting

The close of the Mesozoic Era was marked by the outpouring of enormous lava flows which spread over vast areas of western, central and southern India (Krishnan, 1982). They issued through long narrow fissures in the earth's crust from a large magma basin. The lavas spread out far and wide as nearly horizontal sheets. The flows are called "traps" because of their step-like or terraced appearance of the rock-outcrops.

The Deccan Traps cover a large tract of central and western India, extending over large parts of Madhya Pradesh, Gujarat and Maharashtra. The basalts, upon weathering, form a clay / loam which is deep grey to black in color to 2-3 m depth below which it is brown colored due to iron content. These clays are usually rich in the clay mineral montmorillonite. These clays exhibit swelling behavior on coming in contact with water and shrink upon drying.

5. Investigation Program

In the section between Vadodara and Mumbai (approx.400 km), about 166 boreholes were drilled to 5-10 m depth in the pre-monsoon period (April-May 2012) to assess the distribution of expansive soils (black cotton soils) along the alignment. This was followed by 32 boreholes to 5 m depth in the post-monsoon season (September-October).

The boreholes drilled in the post-monsoon period were used to assess the change in properties due to the seepage of rainwater into the ground.

In the 57-km stretch between Chainage 74 and 131 km (0 km taken at the port), 22 boreholes were drilled in the pre-monsoon period and 9 boreholes were drilled post-monsoon. Data from these boreholes have been analyzed to assess the trend of variation in soil properties along the alignment in the pre-monsoon and post monsoon periods.

6. Soil Characteristics along the Alignment

6.1 Physiography

Geographically, the area belongs to the western coastlands of the Deccan Peninsula. In general, the area gently slopes towards the west. The topography is primarily plain with moderate to deep cutting river valleys and occasional hillocks.

6.2 Stratigraphy along Alignment

In general, the soils along the corridor to about 10 m depth consist of expansive silty clay / clayey silt of high to medium plasticity. The clays are generally very stiff to hard in consistency. Typical borehole profiles for four boreholes along the alignment are presented on Fig. 3.

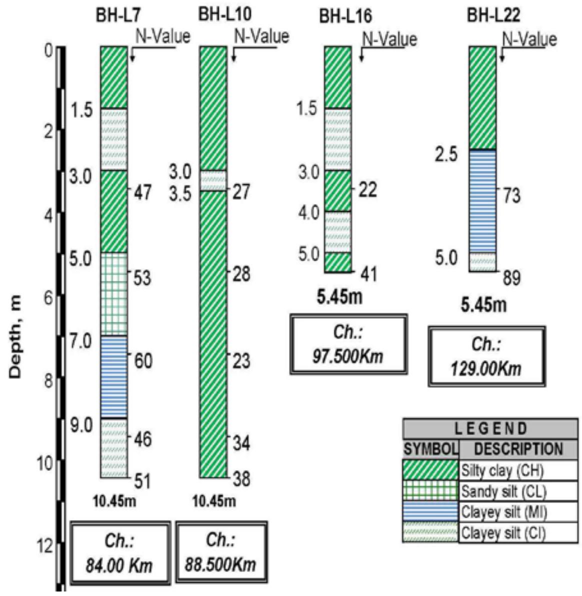

Fig. 3 Typical borehole profiles along the alignment (pre-monsoon)

6.3 Soil Properties

In general, the soils are highly plastic at shallow depth and medium to highly plastic at deeper depths. To illustrate the soil properties along the corridor and with depth, plots of various soil properties have been prepared along the alignment at 2 m depth and at 5 m depth. Data from all boreholes drilled along the railway corridor have been considered in the analysis (22 boreholes pre-monsoon and 9 boreholes post-monsoon).

Liquid Limit: The liquid limit along the corridor determined in accordance with IS: 2720 (Part 5)-1985ranges from 47 to 72% at about 2 m depth and from 35 to 70% at 5 m depth.

Plastic Limit: The plastic limit determined as per IS 2720 (Part 5)-1985 ranges from 23 to 34% at 2 m depth and from 22 to 29% at 5 m depth. The liquid limit and plastic limit profiles along the alignment at 2 m depth and 5 m depth are presented on Figs. 4 and 5, respectively.

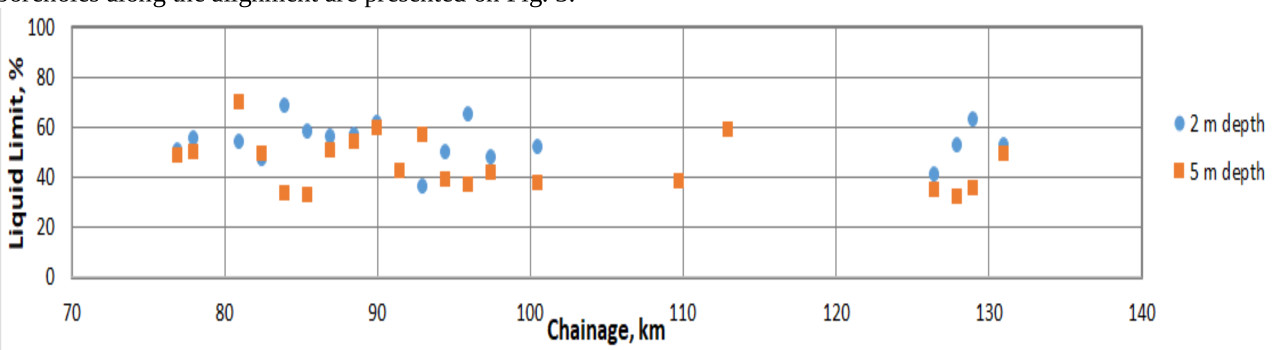

Fig. 4 Variation of liquid limit along the railway corridor at 2 m and 5 m depths

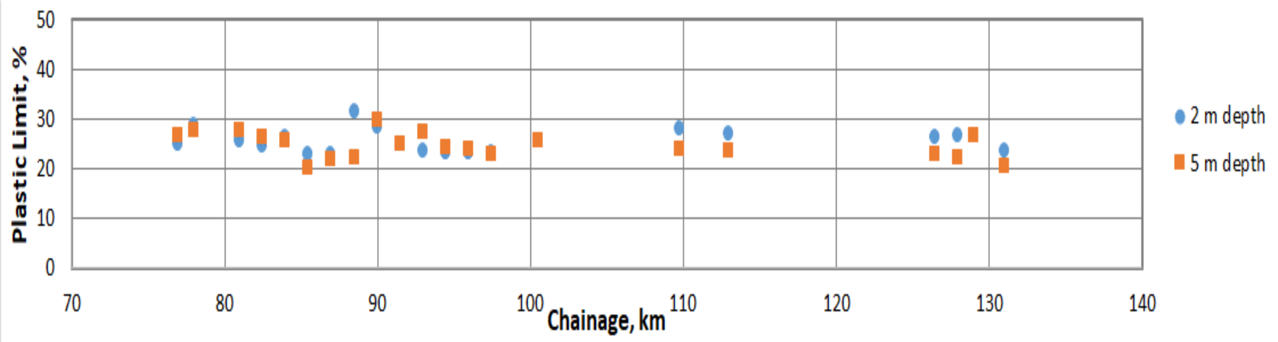

Fig. 5 Variation of plastic limit along the railway corridor at 2 m and 5 m depths

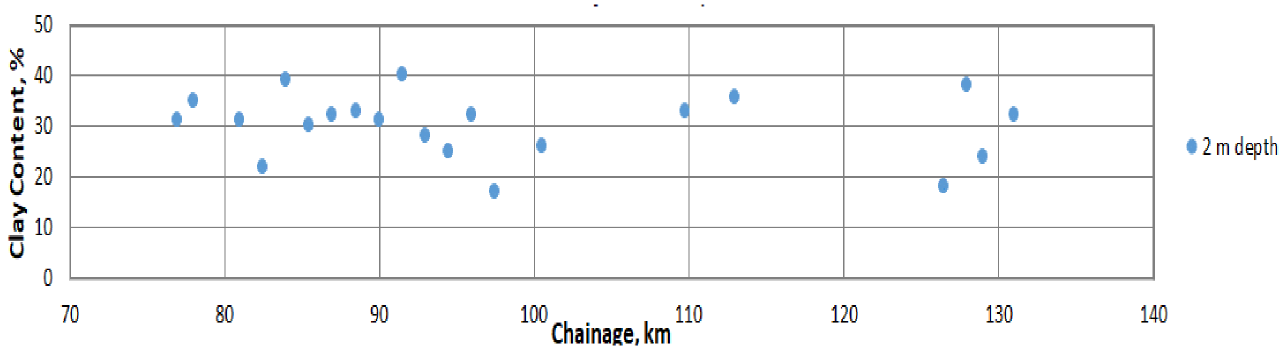

Fig. 6 Clay content (particle size ≤ 2 μm) along the railway corridor at 2 m depth

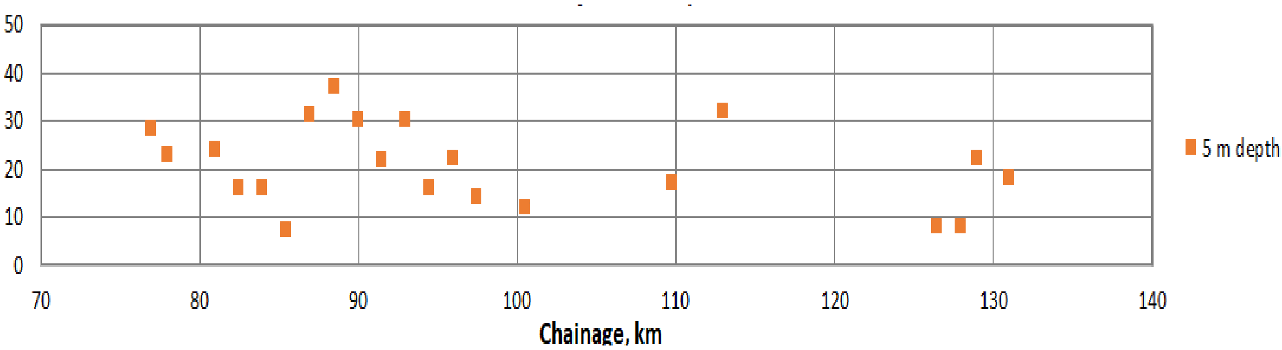

Fig. 7 Clay content (particle size ≤ 2 μm) along the railway corridor at 5 m depth

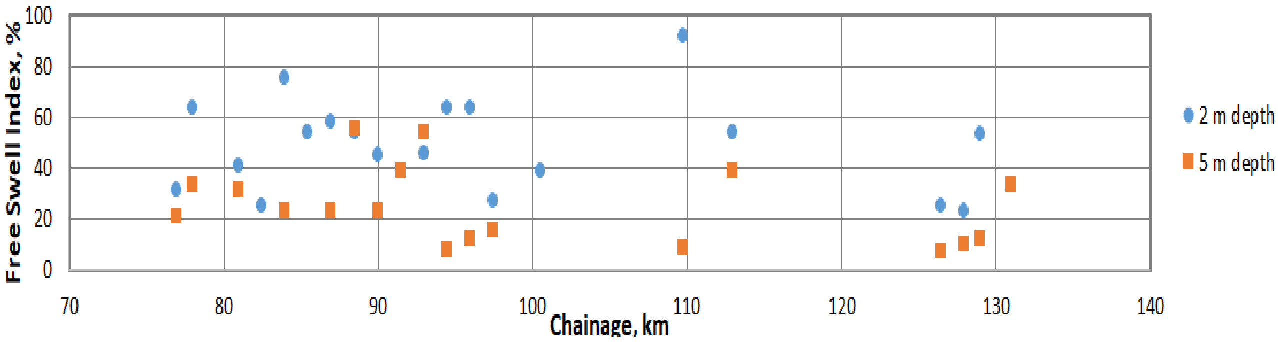

Fig. 8 Variation of free swell index along the railway corridor at 2 m and 5 m depths

Clay Content: The clay content [≤ 2 micron size particles (as determined by hydrometer analysis as per IS: 2720 (Part 4) -1985] along the alignment generally ranges from 24 to 40% at 2 m depth and from 16 to 32% at 5 m depth (see Figs. 6 and 7).

Free Swell Index: The free swell index computed as the difference in volume of 10 g of soil soaked in water and in kerosene for 48-72 hours (till volume change in water stabilizes) is an indicator of the swelling nature of the soil. The free swell index, determined in accordance with IS: 2720 (Part-40) -1977, ranges from 41 to 92 at 2 m depth and is generally below 30 at 5 m depth. The profile along the alignment is illustrated at 2 m depth and 5 m depth on Fig. 8.

7. Seasonal Variations

The rainy season in most parts of India usually lasts for three months (June/July to August/September) followed by generally dry season for the balance nine months.

During the summer months (April-June), moisture content in the top few meters reduces substantially due to evaporation and transpiration. The moisture lost is replenished during the rains in the monsoons.

To assess the variations in soil properties before and after monsoon, boreholes were drilled before monsoon during April-May (pre-monsoon) and later in September-October (post-monsoon). Undisturbed samples collected from the boreholes were tested in the laboratory to determine moisture content, undrained shear strength (q_u) and swell pressure. These post-monsoon parameters were compared with the pre-monsoon values to assess the change in soil properties with depth.

Figs. 9 to 12 present the profile of moisture content, undrained shear strength (q_u) and swell pressure with depth at four typical boreholes along the alignment. All these tests were conducted on undisturbed samples. These four boreholes, widely spaced along the alignment, have been selected to demonstrate the overall trend of variation in the soil properties.

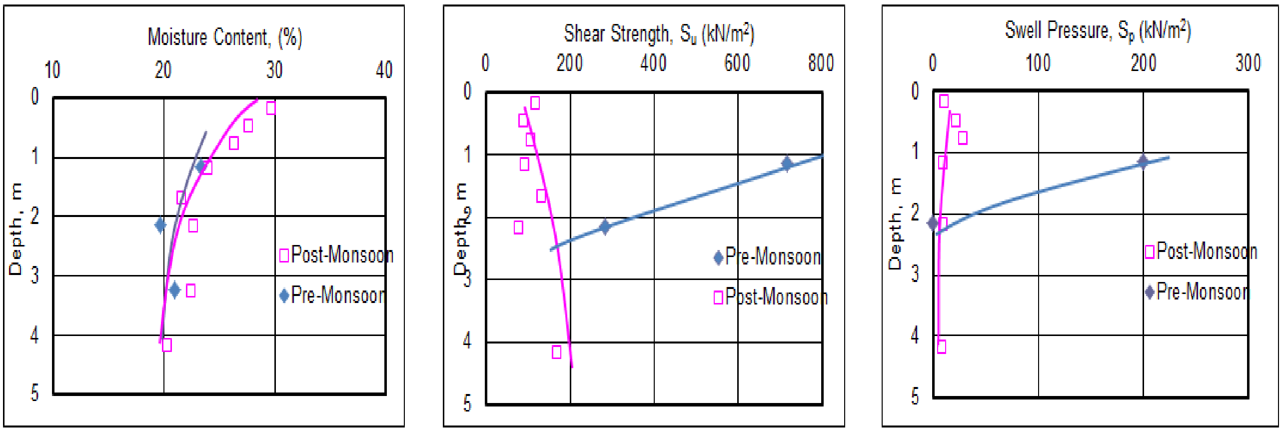

Fig. 9 Moisture content, undrained shear strength and swell pressure versus depth - Borehole L7 at Chainage 84.0 km

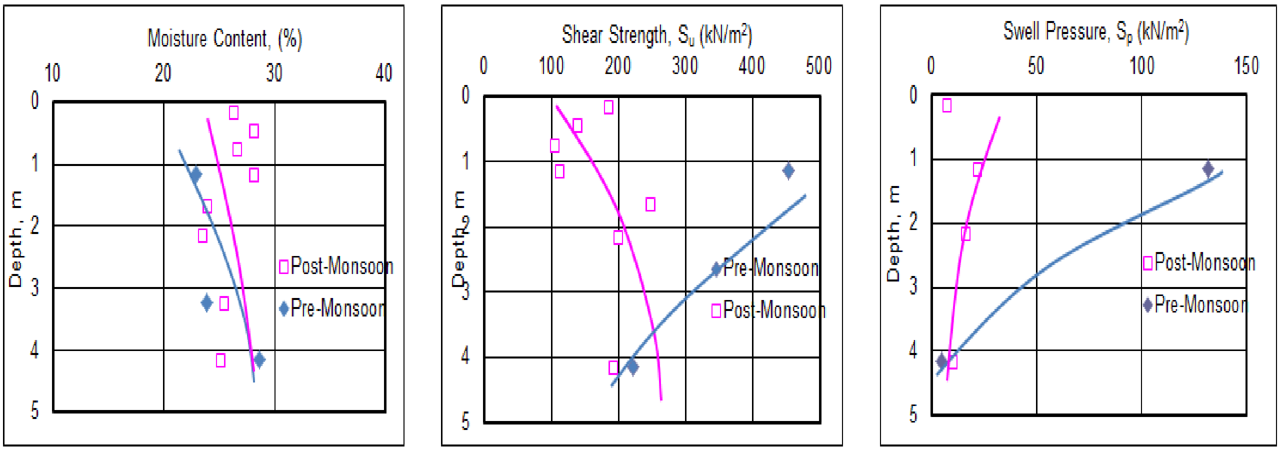

Fig. 10 Moisture content, undrained shear strength and swell pressure versus depth - Borehole L10 at Chainage 88.5 km

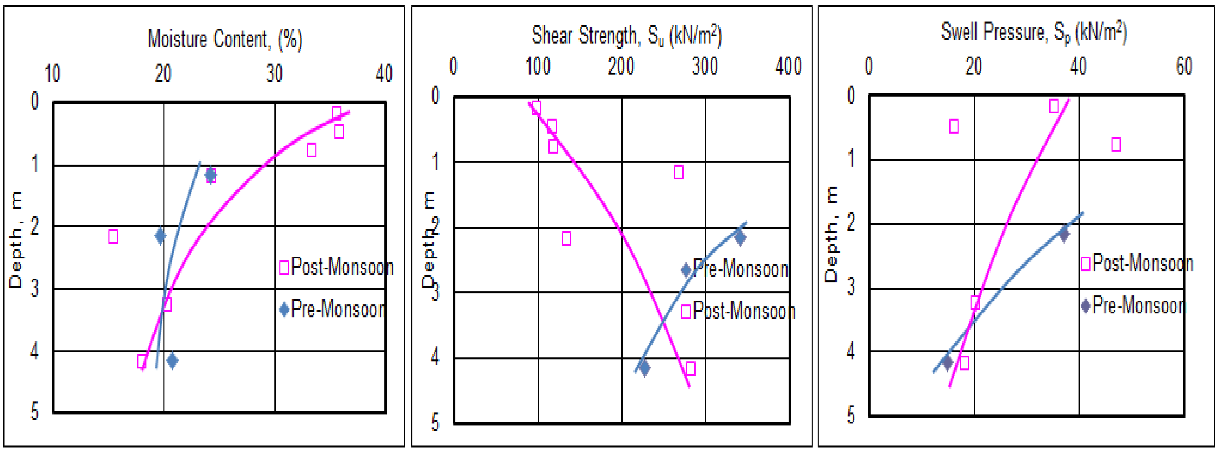

Fig. 11 Moisture content, undrained shear strength and swell pressure versus depth - Borehole L16 at Chainage 97.5 km

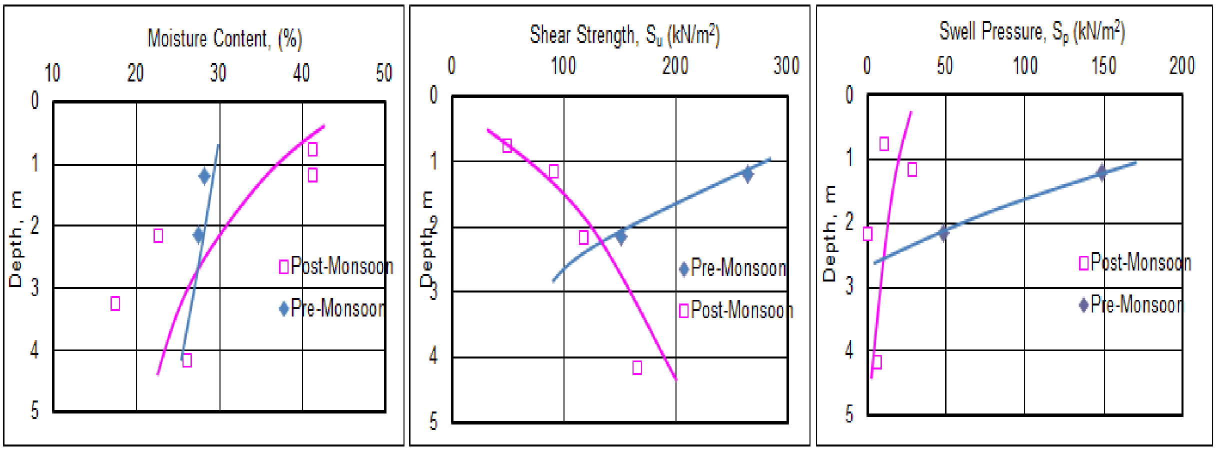

Fig. 12 Moisture content, undrained shear strength and swell pressure versus depth - Borehole L22 at Chainage 129 km

The above plots clearly illustrate the influence of water seepage during the rainy season and variation of the properties with depth. These are explained below:

Moisture Content: The moisture content, determined in accordance with IS: 2720 (Part 2)-1973, increases post-monsoon at shallow depth. The maximum increase is near the ground surface and the change in moisture content decreases with increasing depth. The increase at 2 m depth is about 40-55%. The change in moisture content is insignificant below about 3.2-3.5 m depth. The pre-monsoon and post-monsoon moisture content profile along the corridor at 2 and 5 m depths are presented on Figs. 13 and 14, respectively.

Undrained Shear Strength: The undrained shear strength [IS: 2720 (Part 11)-1993] on undisturbed soil samples reduces post-monsoon at shallow depth with insignificant change below 3-3.5 m depth. The reduction in undrained shear strength at 2 m depth is about 55 to 65%. The variation of undrained shear strength in the pre-monsoon and post-monsoon periods along the corridor at 2 and 5 m depths are presented on Figs. 15 and 16, respectively.

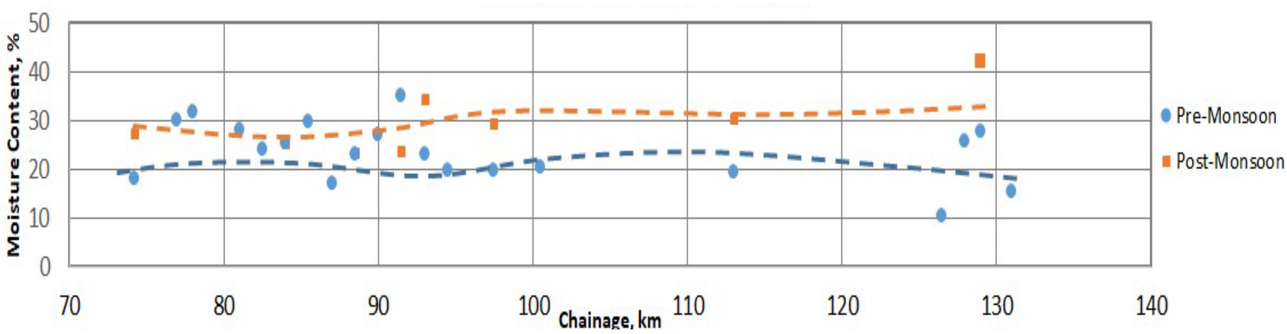

Fig. 13 Pre-monsoon and post-monsoon change in moisture content along the alignment at 2 m depth

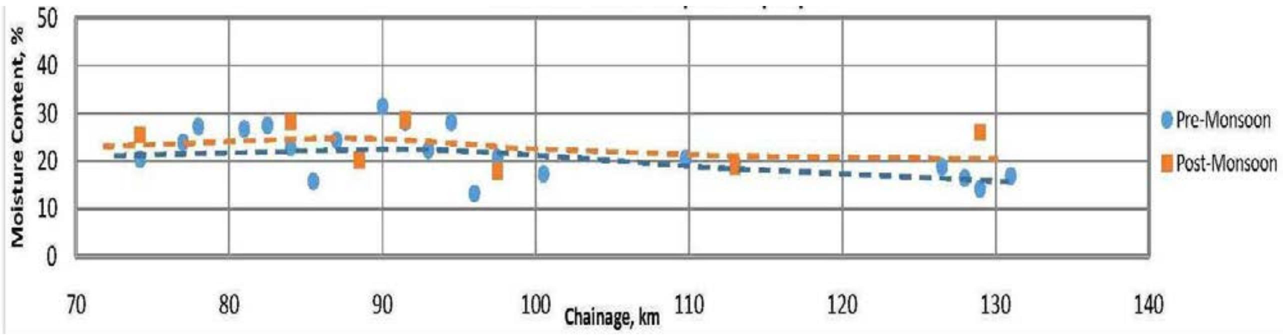

Fig. 14 Pre-monsoon and post-monsoon change in moisture content along the alignment at 5 m depth

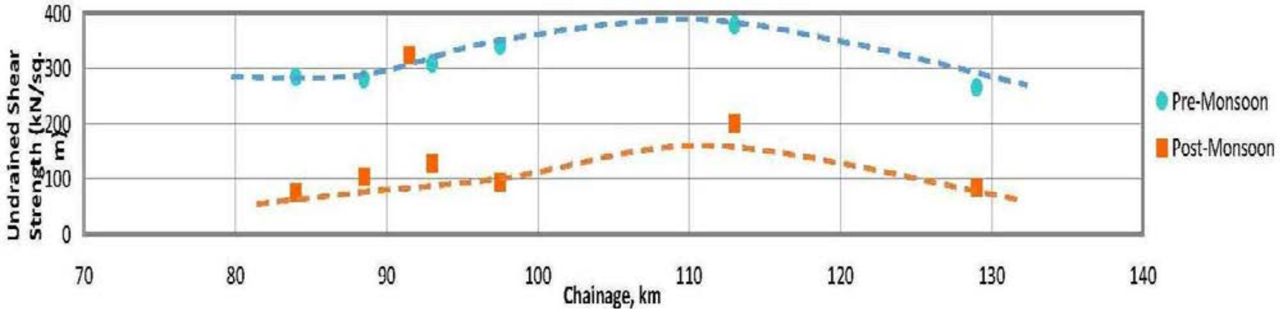

Fig. 15 Pre-monsoon and post-monsoon change in undrained shear strength along the alignment at 2 m depth

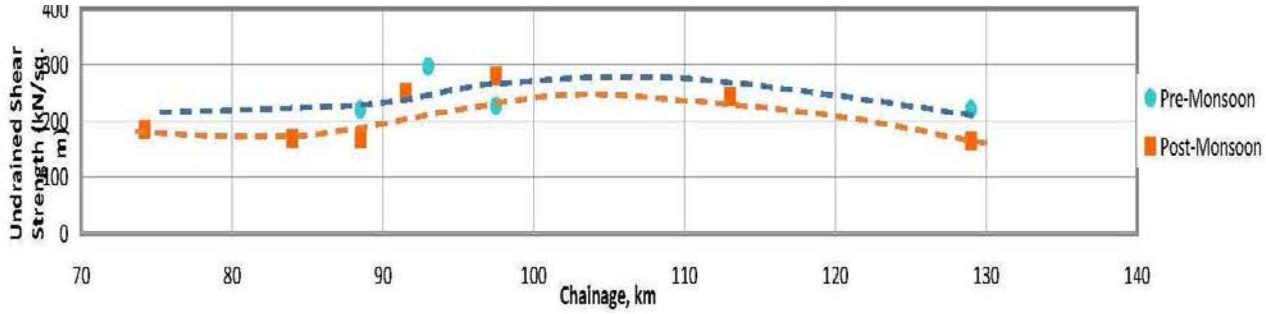

Fig. 16 Pre-monsoon and post-monsoon change in undrained shear strength along the alignment at 2 m depth

Swell Pressure: The change of swell pressure in the pre-monsoon and post-monsoon periods along the corridor at 2 and 5 m depths are presented on Figs. 17 and 18, respectively. From Fig. 17, it can be seen that the swell pressure at 2m depth on undisturbed soil samples at in-situ moisture content samples decreases during the rainy season, largely on account of the increase in moisture content at shallow depths (Fig. 13). The swell pressure values at 5 m depth (Fig. 18) are typically low on account of the lower void ratios and higher moisture content values. The change in swell pressure below 2.5-3.5 is insignificant. The pre-monsoon swell pressure at 2 m depth is about 75 to 115 kPa and less than 35 kPa in the post-monsoon period. At 5 m depth, the swell pressure post-monsoon is generally low.

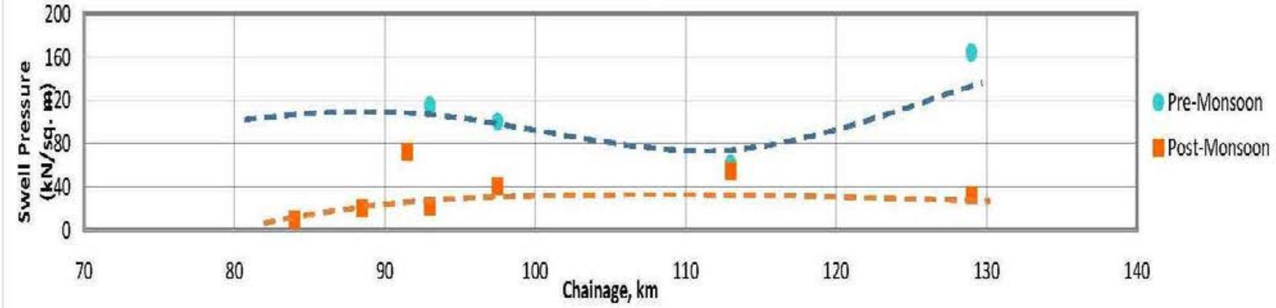

Fig. 17 Pre-monsoon and post-monsoon change swell pressure along the alignment at 2 m depth

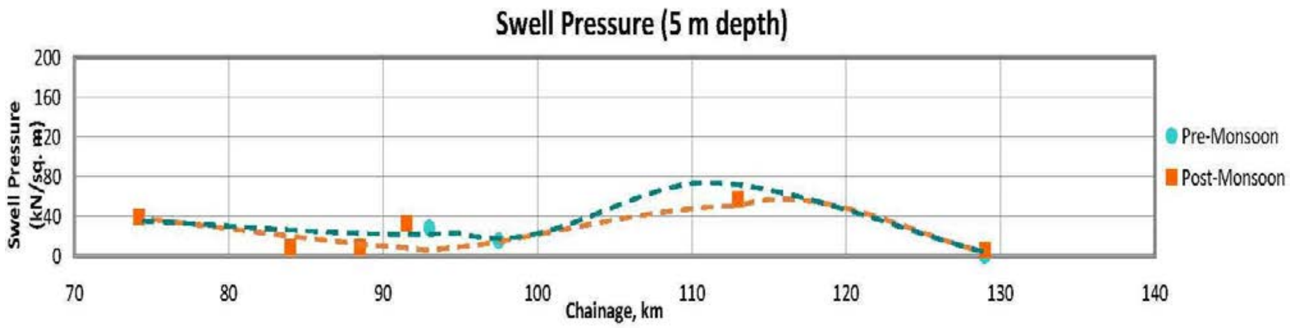

Fig. 18 Pre-monsoon and post-monsoon change in swell pressure along the alignment at 5 m depth

8. Active Zone

The active zone (Chen, 1975, Katti, 1978) in a deposit of expansive soil is the zone which is subject to swelling and shrinkage on account of variations in moisture content. In the active zone, there is a potential for variation in moisture content due to seepage from surface sources, precipitation, evaporation, variations in groundwater level etc.

The seasonal moisture changes in these expansive soils leads to volume changes and vertical movements of the soil mass in the active zone. The moisture content is usually constant throughout the year at some depth below the ground level.

Thus, the active zone is a geotechnically unstable zone in which foundations may experience heave / settlement due to swelling / shrinkage of the soils.

The moisture changes in these soils occur due to the capillary forces set up by evaporation. Due to the extremely low permeability of the soils, the hydraulic gradient caused by the groundwater level fluctuations is insufficient to reduce or increase the moisture content of such clays. The change in moisture content is mainly due to the suction forces created by thermal gradients.

In general, shrinkage/expansion below the groundwater level is negligible. However, all along the stretch investigated, water table is below 10 m depth.

Based on the data collected by various researchers in different parts of India (Mohan & Rao, 1965, Ramaswamy& Abu-Naser, 1984), the active zone in most areas of India is usually on the order of 2.5 to 3.5 m below the ground surface.

The current study reconfirms the trends reported in literature. As per the data collected, the active zone in this stretch of the railway corridor is about 3-3.5 m deep.

9. Conclusions

Geotechnical investigation was performed along a 57 km long stretch along a railway corridor in Gujarat in western part of India. To investigate the seasonal variation in soil properties, boreholes were drilled in the pre-monsoon period (May-June) followed by boreholes in the post-monsoon period (September-October).

The study revealed that the moisture content of the soils increases in the top 3-3.5 m depth, below which the change in moisture content is insignificant. There are corresponding reductions in undrained shear strength and swell pressure in the top 3-3.5 m depth zone.

The active zone in which the soil properties are sensitive to moisture content variations extends to about 3.5 m depth in this part of Gujarat. Foundations in the active zone may experience swell / shrink behavior.

It is essential to assess the extent of the active zone so as to take adequate precautions in the design of the railway track and foundations constructed along the route.

10. Acknowledgements

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