Engineering Properties of Major Soils Used in Cricket Pitches in Trinidad

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The physical and engineering properties of major soils used in cricket pitches in Trinidad were measured in the laboratory. The study was undertaken to identify suitable soils for use in cricket pitches, as well as to provide advice on how to manage the pitches where these and similar soils are used. The properties assessed were soil texture, Atterberg limits, swelling characteristics, density-water relations, penetration resistance, shear strength and compressibility. Values obtained for the parameters were consistent with those expected for soils with high clay content (46%–80%). The soils exhibited liquid limits that were both high and quite variable, ranging from 58%–91%. Maximum bulk densities of the soils subjected to 5, 15 and 25 Proctor compaction blows ranged from 1.26–1.55 Mg m⁻³.
Peak penetration resistance of the soils obtained after the three Proctor compaction efforts varied from 2.21–6.44 MPa. Shear strengths of most of the soils exceeded 130 kPa, particularly at high compaction levels. The compression index obtained from a standard confined compressibility test upon compaction varied from 0.60–0.77. Generally, the soil properties that affect the performance and preparation of cricket pitches are consistent with the high clay content of the test soils.
Results indicate that some of the soils are ideally suited for use in cricket pitches. However, further measurement or monitoring of these measured properties in actual or simulated cricket pitches are recommended.

Keywords: Soils, cricket, strength, stress.

1. Introduction

It is well known that good cricket can only be played on good pitches. In the late 1970s, red sand was used in the construction of most cricket pitches in Trinidad. The sand was wet and rolled to allow compaction and then matting was placed on the surface of the pitch. These were called sand wickets, unlike the turf wickets, which have clay on the surface. With the growing popularity of the sport locally, regionally and internationally, turf wickets are now becoming very popular and these require proper management to promote their performance.

Ground managers and curators have usually chosen 'cane land' soil for cricket pitches in Trinidad. Princes Town Clay is the most common soil type used today. Sevilla Clay was very popular in the 1980s. Princes Town Clay is mainly found in Princes Town, Ste. Madeline, Indian Walk and areas in the vicinity of the Cipero Road. This soil has been described by **Brown** and **Bally** [1] as a calcareous vertisol, a dark grey-black soil which is high in humic content. The soil is alkaline, has impeded drainage and is high in carbonates [2], as well as being extremely plastic [3]. The Sevilla Clay is more sparsely distributed in Trinidad. It is found in Felicity, Chaguanas, Couva, California, Gasparillo, Bonne Aventure, Cipero Road and Ste. Madeline. The soil has been described as a relatively neutral vertisol, developed from calcareous shales and marls of Central and Southern Trinidad [1]. These two soils exist

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in the sugarcane belt in Trinidad. A third soil, Integrade Clay, which is a mixture of the two, was identified by **Gumbs *et al.*** [3]. Not many properties of this latter soil have been identified, except for the work done by the authors. The soil is moderately high in clay and silt and is highly plastic [3]. These authors have recommended this soil and it is indeed now being used in the prestigious Queen's Park Oval in Port of Spain. Another soil commonly used in cricket pitches in Trinidad is Frederick Clay. This soil is slightly acidic, contains moderate amounts of nutrients and displays considerable swelling and shrinkage in response to wetting and drying [4].

The performance of cricket pitches in Trinidad and in the Caribbean region generally can best be described as erratic and unreliable. This unpredictable behaviour of the pitches was emphasised during the two Test matches played in Trinidad as part of the 1998 Test Series of England vs. West Indies. Upon conclusion of the series, the West Indies Cricket Board was asked to submit a report on the state of its pitches by the International Cricket Council. A similar incident occurred at the Queen's Park Oval in January 2002, where during a match organised to select the National team, the match was called off because of the unpredictable bounce which posed severe threats to batsmen.

Ground curators always prepare cricket pitches by feel. Surveys conducted as a part of this study revealed that throughout Trinidad, curators depend on their senses to determine when a pitch has sufficient water and has been rolled enough to achieve a good result, which includes a durable pitch that allows for good bounce and pace of the ball. Scientific measurements of moisture content, compaction, infiltration rates and other parameters are not used in the preparation of cricket pitches. Presently, the game demands a fair, precise, durable and sometimes predictable pitch in order to achieve a successful match for both batsmen and bowlers. The need for the detailed study of soil properties used in cricket pitches is very important in order to help in advising curators in their preparation and maintenance of pitches. From literature, only **Gumbs *et al.*** [3] and **Ahmad** [2] have carried out work on the soils used in cricket pitches in Trinidad. Ho ver, these works are a bit limited since they only emphasised the physical and chemical properties, leaving out the soil engineering properties, e.g., strength enetrability, compactibility and compressibility. These engineering properties greatly influence the performance of cricket pitches [5]. The work by these latter authors in South Africa provides useful guidelines on the preparation of cricket pitches and particularly on how soil engineering properties affect the performance of cricket pitches. They reported that an ideal cricket pitch should have 50–60% clay, less than 10% coarse sand, less than 5% calcium carbonate and sodium levels, a linear shrinkage of 0.08–0.15 and less than 5% organic matter content.

This paper reports the results of the study of the physical and engineering properties of soils commonly used in cricket pitches in Trinidad and uses the paper by **Tainton *et al.*** [5] and others to make inferences on the suitability of these soils for use in cricket pitches, as well as offer advice on the management of Trinidad's cricket pitches. These inferences are appropriate in Trinidad's conditions since in the West Indies, cricket is mostly played during the dry season which corresponds to the summer period in South Africa.

2. Materials and Methods

Six samples of soils (**Table 1**) were collected from different locations in Trinidad (**Figure 1**) and used in this study. The soils represent five of the most important soils used in cricket pitches in Trinidad, while another one, Talparo Clay was chosen for comparison with the others. Talparo clays are the most widespread soils in Central and South Trinidad. The soils were collected from 0.3 m–0.6 m below the soil surface, air-dried and ground to pass a 5-mm sieve. Particle-size distribution (**Table 2**) was performed using the hydrometer method [8]. To determine the maximum bulk density and soil strength after compaction for each soil, the standard Proctor compaction test [8] was adopted. **Ekwue *et al.*** [9] described details of the experimental procedure used for the compaction test. For each soil, compaction was done at different water contents (ranging from 11–43% by weight, dry basis) using 5, 15, and 25 blows in three layers from a standard Proctor hammer in cylindrical moulds. The water contents for compacting the soils were selected so as to be less and greater than the plastic limits (**Table 2**) determined using the method described by **Lambe** [8]. Proctor optimum water contents do not normally exceed plastic limits [10,11]. After compaction, the mould with the soil was weighed to determine the dry bulk density and then the penetration resistance test was conducted using a

TABLE 1: *Sampling and Classification of the Cricket Pitch Soils*

Sample Name	Sample Location	Soil Number	Clay Minerology[a]	Soil Classification[b]
Frederick Clay	Felicity Section, Felicity, Chaguanas	409	Mixed	Vertic Tropaquolis
Queen's Park Old Soil	Queen's Park Oval Grounds, POS	Mixed	Mixed	Mixed
Sevilla Clay	Buen Itento Cane Field, Princes Town	335	Montmorillonite	Aquentic Chromuderts
Talparo Clay	Cedar Hill, Princes Town	177	Mixed	Aquentic Chromuderts
Princes Town Clay	Usine Ste. Madeline Cane Land	474 L	Montmorillonite	Aquentic Chromuderts
Integrade Clay	Harmony Hall, Gasparillo	Mixed	Mixed	Mixed

[a] Clay minerology identified by [6]

[b] Classification according to USDA Soil Taxonomy System [7]

TABLE 2: *Some Properties of the Cricket Pitch Soils*

Sample Name	Sand (2 - 0.05) mm (%)	Silt (0.05 - 0.002) mm (%)	Clay (< 0.002) mm (%)	Shrinkage Limit (%)	Plastic Limit (%)	Liquid Limit (%)	Plasticity Index (%)	Swell (%)
Frederick Clay	5.0	15.0	80.0	19.7	34.0	82.2	48.2	35.0
Queen's Park Old Soil	11.5	19.5	69.0	18.2	29.0	69.8	40.8	20.4
Sevilla Clay	6.8	25.5	67.7	33.5	29.4	70.8	41.4	20.5
Talparo Clay	14.3	23.4	62.3	33.3	26.6	57.8	31.2	21.0
Princes Town Clay	3.4	39.5	57.1	26.9	27.8	91.2	63.4	39.0
Integrade Clay	5.6	48.6	45.8	28.3	33.7	70.4	36.7	36.0

Coefficients of variation of the results ranged from 2 to 13%.
Two replicate samples were used for each test.

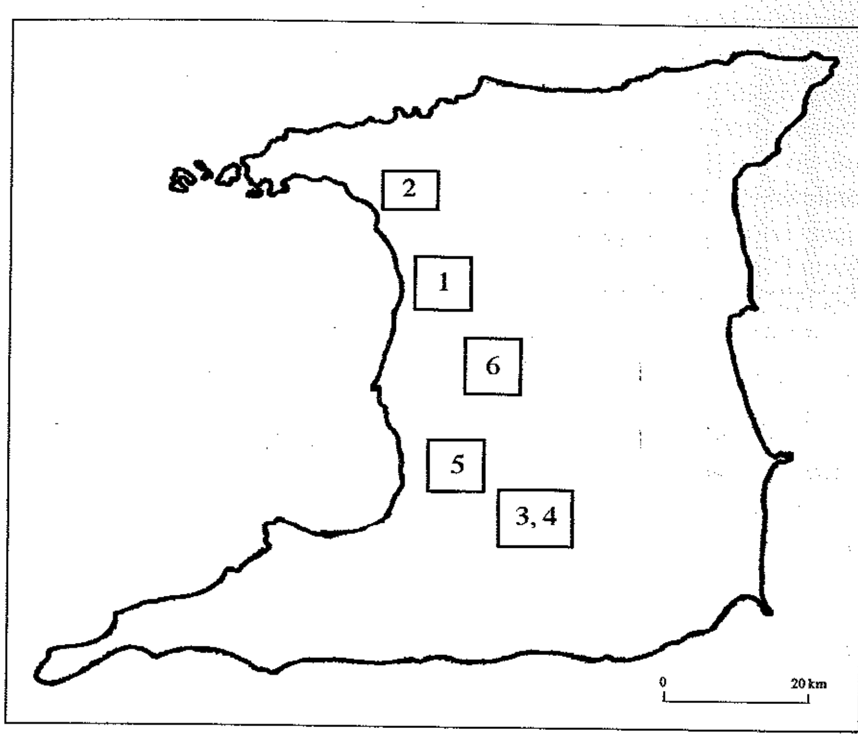

FIGURE 1: ***Map of Trinidad showing the Sampling Positions. (1- Felicity, Chaguanas; 2- Queen's Park, Port of Spain; 3,4- Princes Town; 5- St. Madeline and 6- Gasparillo)***

spring-type, Proctor penetrometer [12] with a probe diameter of 6.4 mm. Four penetration resistance readings were taken on the surface and averaged to obtain the mean penetration resistance. Shear strength measurements were also made for soils compacted with the 5 Proctor blows using a shear vane whose vane size was 19 mm. One shear strength reading was taken at the top 5-cm depth of each sample. Shear strength readings for the 15 and 25 blows could not be taken for five of the soils because the soil strength at these compaction levels exceeded the limit (130 kPa) of the shear vane. Two replicate soils were used for each test. For each soil and compaction effort, the mean values of bulk density, penetration resistance and shear strength were plotted against corresponding water contents to obtain maximum bulk density, peak penetration resistance and peak shear strength and the corresponding water contents. Liquid limits and shrinkage limits were also determined using the methods described by **Lambe** [8]. The plasticity index (**Table 2**) is the difference between the liquid limit and the plastic limit. The swell test of the soils immersed in distilled water was done using the method described by **Bowles** [13].

The compressibility of each soil was determined with a standard compression machine using the procedure earlier described [9, 14]. The soils were all tested at their Proctor optimum water contents for maximum compaction to ensure that they were at similar compaction states before testing. The soils were loosely packed into a cylinder 15.2 cm in diameter and 11.6 cm high and weighed to determine the initial dry bulk density. This loose condition simulates the freshly placed layer of the soil in cricket pitches. The soils were then placed in a compression machine which applied confined uniaxial static compression at the rate of 2 mm min^{-1}. Because the soils were confined during testing, there was no lateral strain and the axial strain was exactly equal to the volumetric strain [15]. Values of applied stress were monitored for every 2.5 mm compression until a stress of 1000 kPa was reached. Values of bulk density, volumetric strain and void ratio at any applied stress were computed using the formulae derived by **Stone & Ekwue** [14, 16]. In addition, the compression index, C_c [15] based on void ratio, and popular in Civil Engineering literature was computed using the following equation derived by **Stone & Ekwue** [14].

$$C_c = \frac{\rho_s(\varepsilon_2 - \varepsilon_1)}{\rho_i \log(\sigma_2 / \sigma_1)} \quad \text{........(1)}$$

where ρ_s is the particle density of the soil assumed as 2.65 Mg m^{-2}; ρ_i is the initial bulk density of the soil before compaction; $\varepsilon_1, \varepsilon_2$ are strains at two compressive stresses σ_1 and σ_2, respectively.

3. Results

3.1 Soil Physical Properties

All the soils had high clay content with the Frederick Clay with 80% content having the greatest amount (**Table 2**). The high clay contents are consistent with previous results [9] which showed high clay contents for many soils in Trinidad. The high clay soils are likely to be related to the pedology of the soils and the climate in Trinidad. With the high clay content in the Frederick Clay, it is likely to have the ability to withstand a long game duration without considerable surface deterioration. Interviews done at the Calcutta Cricket Ground in Couva and the Invaders Ground in Felicity; the two major cricket grounds which presently use this type of clay, revealed that players were happy with the consistent pace and bounce which the pitch delivered during a match. The Princes Town Clay, a soil which was recently requested by Trinidad and Tobago Cricket Board of Control (TTCBC) to relay a number of cricket grounds throughout Trinidad revealed its relatively lower clay content (57.1%) which is, however, within the 50–60% content suggested for cricket pitches [5]. The concern for this soil is its high silt content, which would increase the air spaces in the soil, leading to a pitch of slow pace and short bounce. Appreciable level of silt in a soil makes the pitch deteriorate fast, resulting in low and unpredictable bounce, slow pace and loss of hardness of surface. However, this provides greater turn which is preferred by spin bowlers. Visits to Pierre Road Recreation Ground in Charlieville and Sir Frank Worrell Cricket Ground in Couva – the two grounds that use Princes Town clay, revealed that players complained of the slowness of the pitch and the low bounce. They also noticed the surface becoming dusty and cracking during a game.

The Sevilla Clay seems ideal for a cricket pitch with its 67.7% clay content. It has just enough clay to allow good consistent pace and bounce, not too much silt which will prevent pitch deterioration and a little sand content (6.8%) which may barely assist with drainage of water. If used on a cricket pitch, this soil is expected to give consistent results of pace, bounce and spin. The Queen's Park old soil has been in use in this cricket ground for a number of years. The soil is not a uniform mixture, as interviews with ground curators revealed that different soils were used at different times to repair the pitch. The constant rolling and repair may have led to this soil becoming deteriorated and discarded. However, although the clay content of the soil (69%) appears favourable, the high percentage of sand (11.5%) is a major concern. A large sand content encourages looseness in soil structure, hence, the pitch may not withstand a long game duration. The inconsistent mixture of this soil would result in the pitch playing unpredictably, as well as being dangerous on occasions with inconsistent bounce and pace. All these are features of the Queen's Park Oval pitch before the soil was discarded.

The Integrade Clay or the Queen's Park new soil is the new soil being re-laid on the Queen's Park Oval pitch. This soil has much less clay content (45.8%) and much more silt (48.8%). These two factors make for a slow, spinning pitch. The consistency of the mix is important and since the clay-silt contents are almost 50:50, the pitch may very well play consistent with respect to pace and bounce [3]. The pace may, however, have to be generated by the bowler rather than the pitch.

The Talparo soil shows a good percentage of clay (62.3%) and is slightly above the content recommended by **Tainton *et al.*** [5]. The latter authors reported that too much clay content of the soil leads to considerable cracking of the soil. The relatively low content of silt in this soil (23.4%) may mean that this soil should at least be tried in future cricket pitches in Trinidad. However, it has the greatest sand content (14.3%) which is a major concern.

Table 2 shows the values of the Atterberg's limits of the soils. The shrinkage limits vary from 18.2% in Queen's Park old soil to 33.5% for the Sevilla Clay. The former soil would undergo the most shrinkage during drying, leading to surface cracks in the pitch. The Frederick Clay has a similar value of 19.7% for its shrinkage limit. This is also an indication that this soil would undergo severe shrinkage during drying. The surface of such a pitch will be expected to have small and numerous cracks, perhaps even large cracks in some areas. This could lead to dangerous and unpredictable pitches. Despite its low shrinkage limit, the high percentage of clay in this soil (80%) could assist in holding the surface together without much dust and deterioration. Sevilla Clay has the highest shrinkage limit. In terms of cricket, this is a suitable value. One would not want to see a pitch crack while drying. Cracking reduces the bounce and pace of the ball and increases variability of the pitch [5]. It also increases the spin that a pitch will take. Although cracks may form, they would be small and ineffective as well. This soil is likely to develop the least cracks compared to all the other soils. Talparo soil will also have the same property. Princes Town Clay and the Integrade Clay has close values which would suggest similar surface appearance with respect to cracking during drying.

The swell test values (**Table 2**) reveal that Princes Town Clay has the most swell when placed in distilled water. Swelling of this clay soil can affect the characteristics of a cricket pitch. This property will affect the durability of the pitch. During a match, if the pitch gets wet due to rainfall or otherwise, the soil will begin to swell and crack. This will introduce air spaces into the soil and make it less compact and spongy. This will cause the pitch to absorb impact energy, resulting in low pace and bounce. Sevilla clay had the least swell characteristics and is consistent with the values of its shrinkage limit. Frederick Clay displayed the second largest swell property, probably as a result of its large clay content.

All the soils have relatively high liquid limits, except for Talparo clay, which has a value of 57.8%. Princes Town Clay has a high value of 91.2%. This shows that it is capable of holding large amounts of water before saturation and that drainage could be difficult. Its plastic limit of 27.8% is the second lowest value and means that the Princes Town Clay has a good tolerance for water. It does not become saturated or behave plastically too quickly as well. Frederick clay has the highest plastic limit and with its low shrinkage limit, this clay has the greatest friable zone. Hence, the soil can be manipulated easily and is considered workable.

Princes Town clay displays the greatest plasticity index. Plasticity is due to the presence of significant clay content or organic materials [17]. Liquid limit is particularly an indirect index of soil strength [18]. This would indicate that Princes Town Clay is the strongest of all the soils.

3.2 Soil Capability

Dry bulk density, penetration resistance and shear strength were used as indices of soil compactibility. Soil compactibility is the maximum density or strength achieved by a soil upon compaction. The plots of the dry, bulk density and penetration resistance vs. gravimetric water content for the six soils each compacted with 5, 15 and 25 Proctor compaction blows are shown in **Figures 2** and **3**. For each soil, these soil compaction parameters increased with increasing soil water content, until peak values occurred. After this, as expected, the values decline with further increases in water content. Results show that all of the six soils are highly compactible, with the Talparo soil achieving the highest soil bulk density on compaction.

Table 3 summarises values of maximum bulk density, ρ_{max}, peak penetration resistance, R_m and peak shear strength, T_m, as well as the corresponding values of the water contents at which these peak values occur. Because of the high plastic and liquid limits (**Table 2**) in these soils with higher clay contents, the soils have high moisture contents at peak strength values. As expected, values of P_{max} and R_m increase with increasing compaction effort. Moreover, in line with previous work on soil compaction [19], the water content corresponding to P_{max} decreases with increasing compaction effort. As compaction effort increases, less water is required for lubrication to achieve maximum bulk density and strength [19]. This means that for a given soil, heavy rollers are likely to damage the soil particularly if it is dry and hard. It does this by introducing cracks on the surface and widening the ones that may already exist [20]. In addition, horizontal cleavage may also occur and severely damage the root system of the turf grass on the pitch [5].

These values in **Table 3** are very significant for cricket pitch preparation. The greater the compaction, the higher the bounce and the faster the pitch [5]. The authors suggest that to maximise the two, compaction of the pitch down to a depth of 100 mm should be at least 80% of the maximum density of the soil. Such compaction is best achieved

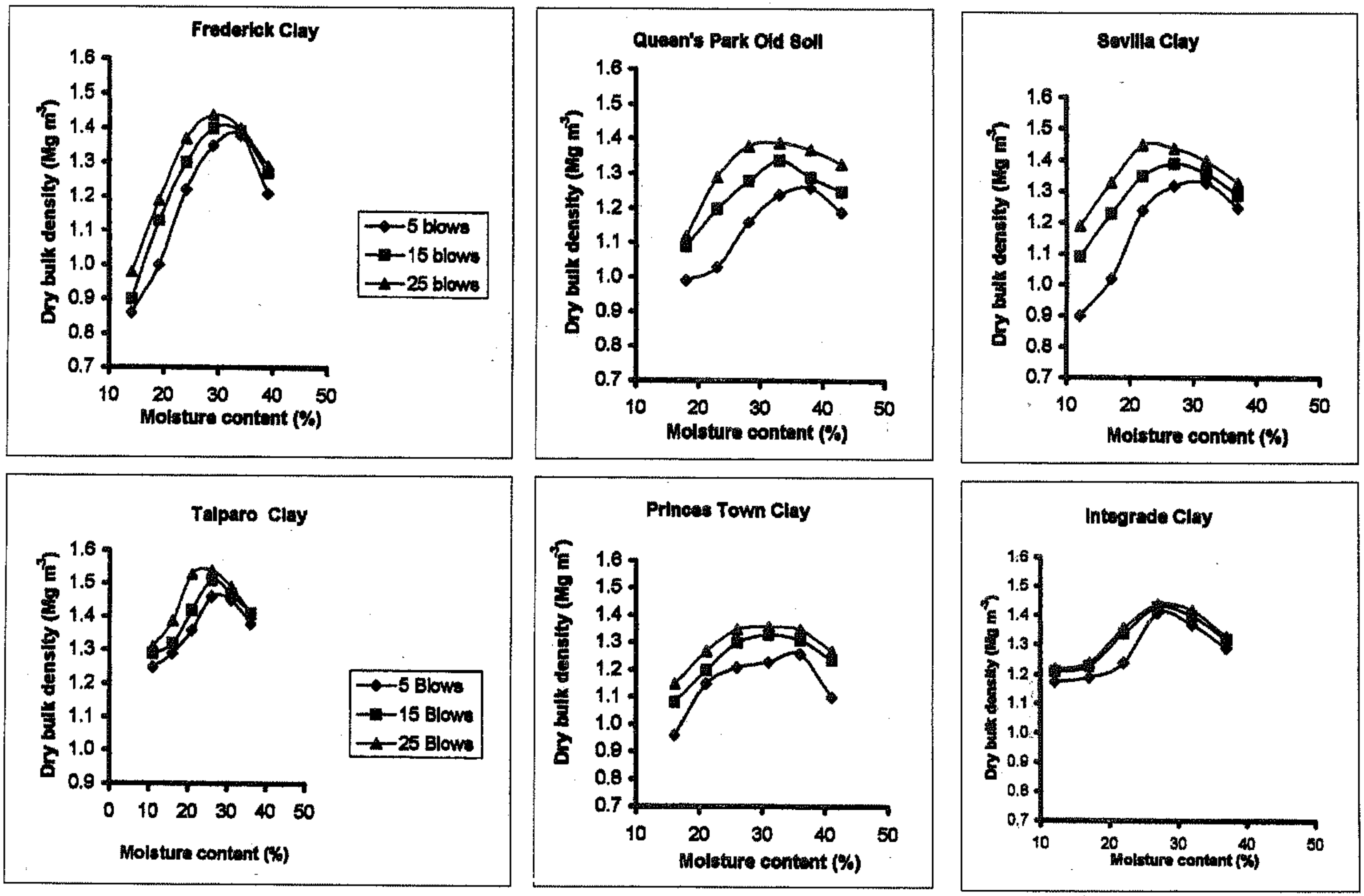

FIGURE 2: *Density-moisture Relations for the Six Soils tested at Three Compaction Levels*

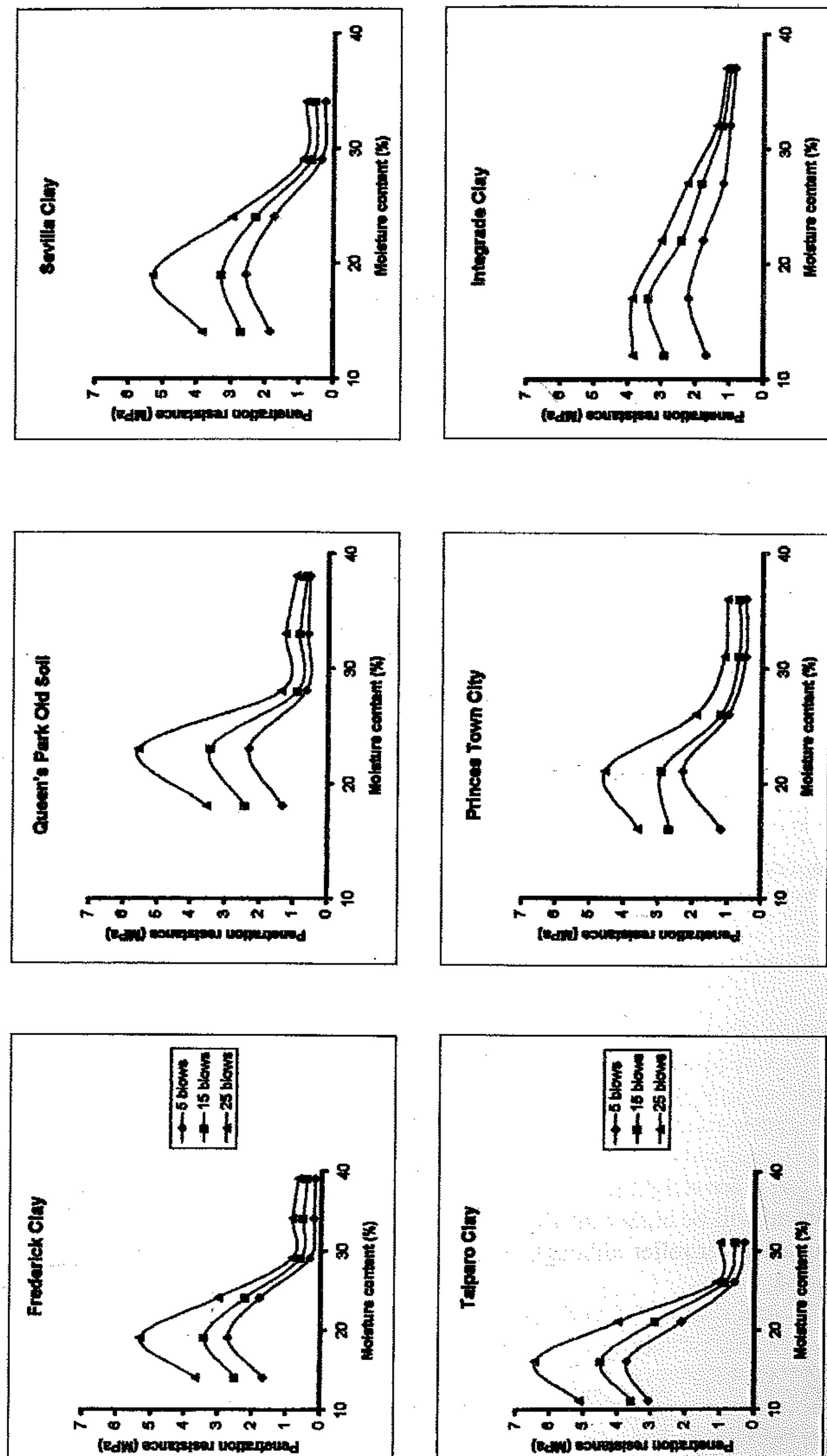

FIGURE 3: *Penetration Resistance-moisture Relations for the Six Soils tested at Three Compaction Levels*

TABLE 3: *Values of Maximum Bulk Density, Peak Penetration Resistance, Peak Shear Strength of the Soils and the Corresponding Water Contents*

Sample Name	Compaction Level (Proctor blows)	Maximum Bulk Density, ρ_{max} (Mg m^{-3})	Peak Penetration Resistance, R_m (MPa)	Peak Shear Strength, T_m (kPa)
Frederick Clay	5	1.39 (32.5)*	2.72 (19)	120 (19)
	15	1.41 (31.0)	3.40 (19)	nm**
	25	1.44 (30.0)	5.33 (19)	nm
Queen's Park Old Soil	5	1.26 (36.5)	2.60 (23)	62 (23)
	15	1.34 (33.0)	3.42 (23)	80 (23)
	25	1.39 (29.5)	5.54 (23)	110 (23)
Sevilla Clay	5	1.32 (29.5)	2.57 (19)	88 (19)
	15	1.39 (27.0)	3.28 (19)	nm
	25	1.43 (23.5)	5.32 (19)	nm
Talparo Clay	5	1.48 (28.0)	3.74 (16)	68 (16)
	15	1.52 (26.5)	4.51 (16)	nm
	25	1.55 (23.5)	6.44 (16)	nm
Princes Town Clay	5	1.27 (34.5)	2.28 (21)	nm
	15	1.33 (31.0)	2.90 (21)	nm
	25	1.37 (28.5)	4.58 (21)	nm
Integrade Clay	5	1.36 (30.0)	2.21 (17.0)	nm
	15	1.42 (29.0)	3.38 (17.0)	nm
	25	1.44 (28.0)	3.87 (17.0)	nm

* Values in parenthesis are optimum water contents and water contents (%) at peak penetration resistance and peak sheer strength. Coefficient of variation values ranged from 4 – 10%.

** Not measured because the shear strength values exceeded the shear vane measuring limit of 130 kPa.

by rolling with a roller of appropriate weight at the optimum moisture content, hence the need to obtain the value of this moisture content for soils used in cricket pitches. **Figure 2** shows the different densities achieved using different compaction blows (energy levels). Results imply that when a light roller is used, the optimum water content will be higher than would be the case while using a heavier roller, although one would not achieve the same density.

Tainton *et al.* [5] suggested that pitch preparation should start with uniform deep-wetting of the pitch. Since the rates of infiltration of the soils are slow as a result of high day contents, it is advisable to apply water very slowly over a long time. Compaction is then achieved by rolling regularly as the pitch dries. During the initial stages of preparation (two days before the match), the pitch may be assumed to be around the density comparative to that at five blows. Therefore, at this stage, a greater amount of water is needed to achieve maximum compaction. If less water is added than required, then the soil structure could be damaged and lead to desiccation of the clay. On the following morning, the pitch has now been rolled and may be comparative to the soil state at 15 blows or 25 blows depending on the amount and roller load applied to the pitch. At 25 blows, compaction effort is where the state of the pitch at the morning of the match should be – compact and moist; the two necessary conditions for a durable consistent pitch. It is critical that the moisture content does not exceed the optimum water content.

Penetration resistance is a very significant value for the measurement of soil strength. Many items and pieces of equipment like bowlers' shoes, bats and

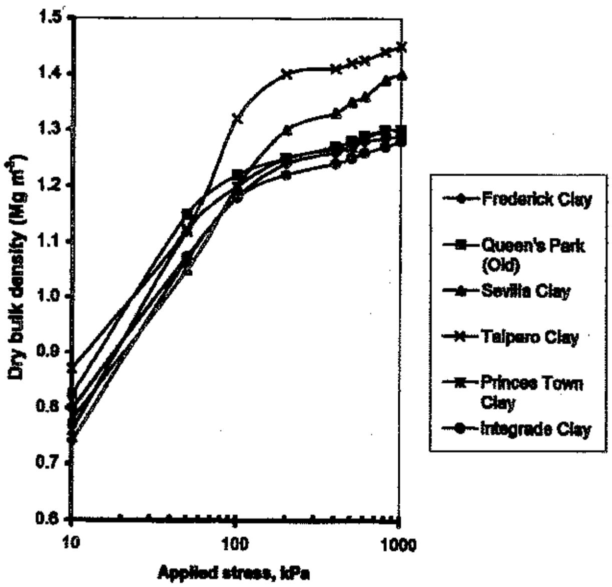

FIGURE 4: *Dry Bulk Density Versus Applied Stress*

balls, which are in contact with the pitch surface can cause damage to it. Consider the impression of a ball when bowled on the surface of the pitch. A standard cricket ball weighs about 0.16 kg and makes a circular print on a hard surface. The print would represent the contact surface for a ball on the pitch. The diameter of the contact surface, obtained by actual field measurements was found to be 1.2 cm or 0.012 m corresponding to an area of 0.0001131 m^2.

Fast bowlers can achieve a maximum speed of 40 m/s at a maximum, horizontal trajectory angle of 14.5° [21]. Therefore, the vertical component of velocity at which the ball strikes the ground is 40 sin 14.5° which is 10 m/s. Assuming a conservative value of 0.60 for the vertical coefficient of restitution for the ball into the pitch, the impact impulse (mass of the ball multiplied by the change in the vertical component of velocity) is equal to 0.16 (10 - 0.6 x 10), which is 0.64 kg m/s. Assuming a minimum duration of impact of 0.0017 s [21], the force exerted on the surface of the pitch is 0.64/0.0017, which is 376 N. The corresponding pressure exerted on the pitch's surface is therefore 376/.0001131 = 3.3 MPa. This means that the pitch should have at least 3.3 MPa penetration resistance so that considerable damage will not be done to the pitch. Luckily, cricket matches are played when the soil is relatively dry and values from **Figure 3** show that for all the soils, this 3.3 MPa penetration resistance could be attained as long as the soil is compacted with maximum effort at close to the optimum moisture content. All the soils would maintain high levels of strength when compacted.

Table 3 shows that at the compaction levels of 15 and 25 blows, the peak shear strength of most of the soils was more than 130 kPa. This means that the overall trafficability (the ability of a soil to bear traffic load without structural damage) of these soils are good. Rolling on the soils is not likely to damage them.

3.3 Soil Compressibility

Soil compressibility is defined as the ease with which a soil decreases in volume when subjected to a mechanical load [22]. **Figure 4** shows the compression curves of the soils representing the plots of dry bulk

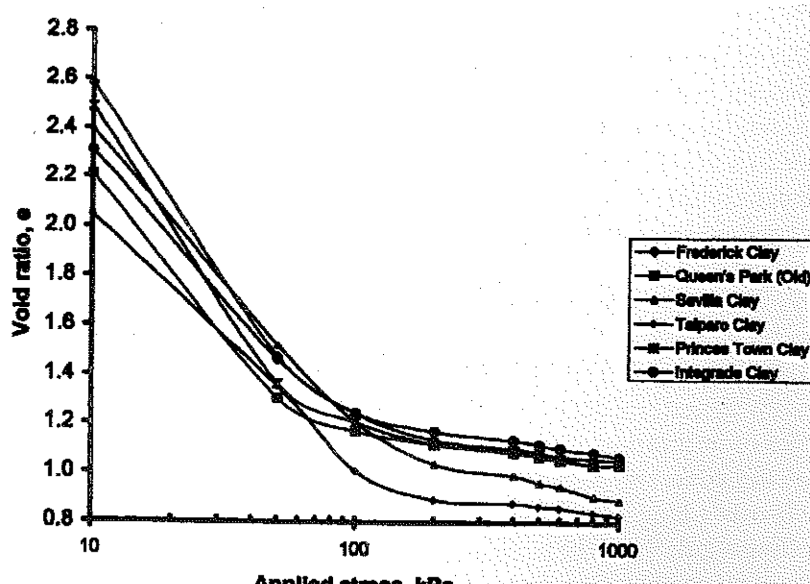

FIGURE 5: *Void Ratio Versus Applied Stress for the Soils*

TABLE 4: *Values of Initial Bulk Density, Particle Density, Strain Parameters and Compression Index of Soils*

Sample Name	Initial Bulk Density (Mg m^{-3})	Particle Density (Mg m^{-3})*	Strain Differences*	Compression Index, C_c
Frederick Clay	0.65	2.65	0.38	0.77
Queen's Park Old Soil	0.64	2.65	0.29	0.60
Sevilla Clay	0.66	2.65	0.38	0.76
Talparo Clay	0.75	2.65	0.34	0.60
Princes Town Clay	0.64	2.65	0.35	0.72
Integrade Clay	0.65	2.65	0.30	0.61

* Strain values at 1000 kPa minus that at 10 kPa. Values of particle density are assumed. Coefficient of variation values ranged from 4 – 13%. Two replicate samples were used.

density vs. the log applied stress. **Figure 5** shows the plots of void ratio vs. log applied stress for the test soils. Void ratio (e) is defined as the ratio of the volumes of voids and the solid phase [15]. It differs from porosity, which is the ratio of the volumes of the voids and the total soil. Void ratio can be expressed as:

$$e = \frac{\rho_s}{\rho_b} - 1 \qquad \text{........(2)}$$

where ρ_s is the particle density, defined as the ratio of the mass and volume of the soil solid phase and ρ_b is the dry bulk density at any given applied stress. As was obtained in a previous study [14], the plots for the clay soils were not straight lines indicating that the void ratios did not decrease linearly as the applied axial stress increased to 1000 kPa. For all the soils, the major losses in the void ratios occurred in the 10 to 100 kPa range. This can be mainly attributed to the initial loose packing of the soils. The decrease of void ratio with increased applied stress was expected since during compression, the volume of soil solids remains constant whereas the voids volume decreases [15] mainly due to the expulsion of air.

The plots of void ratio vs. log applied stress (**Figure 5**) is indeed very applicable to cricket pitches. It gives an indication of the amount of voids (air spaces) present in the cricket pitch soil when a certain stress is being applied. **Figure 5** showed that at the applied stress of 10 kPa, Frederick Clay and Talparo clay had the highest and lowest void ratios respectively. As the applied stresses increased, the void ratios diminished indicating that the soil became denser. A pitch would need to have a low void ratio in order to have a hard, compact nature. Air spaces will make the pitch spongy or absorb impact energy and reduce pace and bounce of the ball. Voids will also encourage swelling upon drying and hence decrease the durability of a cricket pitch. The Sevilla and Talparo soils particularly lost most of the voids at high applied stresses.

The common index of compressibility [14] is the compression index, C_c, which is the slope of the plot of void ratio vs. log-applied stress. C_c values varied from 0.60 in the Talparo Clay to 0.77 in the Frederick Clay (**Table 4**). This range of C_c values is within the range of 0.76 – 0.97 obtained by **Ekwue *et al.*** [8] for wetland soils in Trinidad. However, values are less than 1.0 which may be expected for clay soils, but more than 0.5 value that may be obtained for most natural clays [18].

The compression index determines the level of settlement of soils when exposed to mechanical loads. This implies that the Frederick and the Sevilla Clay, which has the highest compression indices will be most easily compressed by rollers during pitch preparation.

4. Summary and Conclusion

Results of the study have so far showed that the properties of the soils used as cricket pitches in Trinidad vary widely. **Table 5** summarises the results of all the measured soil properties and attempts to produce an overall ranking of the soils by obtaining the ranking of each soil for each soil behaviour. For instance, because of the properties described, Sevilla Clay was declared the best when the relative proportion of sand, silt and clay (texture) is considered. The description for each of the six soils is given below in the decreasing order of their preliminary overall ranking.

4.1 Sevilla Clay

Sevilla Clay has a good clay content and yet little swelling characteristics. Its liquid limit and plasticity index are high, indicating good soil-binding strength. Its high Atterberg limits enable the soil to be compacted to a high density and its high compressibility means that the cricket pitch can be compressed easily without leaving out pockets of air that could reduce the bounce of the ball. A pitch of good pace and even bounce is expected. The pitch would be durable for at least a two-day and three-day game. The high shrinkage limit means that there would be limited cracking. Based on the soil properties measured, this soil has been declared the best, with an overall ranking of one. This soil deserves more use in present day cricket pitches.

4.2 Princes Town Clay

Apart from the Integrade soil, its clay content is the lowest but is well within the limits desirable for cricket pitches. The high silt content could lead to surface deterioration of the pitch. The high plasticity index indicates a strong binding strength and although its surface may crumble and become dusty, the soil mass could still maintain its strong appearance. This will lead to low bounce and spin and slow pace of the ball. The soil has very good tolerance for water and will not become saturated too rapidly. However, the high swelling and cracking behaviour observed during the testing could lead to the pitch absorbing the impact energy of the ball. The pitch may last for one day or two with slow pace. As stated in Sections 1 and 3 of this paper, this soil is the most popularly used in cricket pitches in Trinidad and the TTCBC has made a good decision to relay many cricket pitches with this soil. The soil has been found to be the second best soil based on the soil properties measured.

4.3 Frederick Clay

This soil has a very high percentage of clay. Its strength, compactibility and compressibility are adequate and the high plasticity index indicates good binding strength. The swelling property is adequate but because of the high clay content and its low shrinkage limit, cracking could occur easily, but this may not cause

TABLE 5: *Preliminary Ranking of the Soils using the Measured Parameters**

Measured Soil Property	Comparative Ranking of the Soils for Each Measured Soil Property					
	Frederick Clay	Queen's Park Old Soil	Sevilla Clay	Talparo Clay	Princes Town Clay	Integrade Clay
Soil Texture	5	4	1	6	2	3
Shrinkage	5	6	1	2	4	3
Atterberg Limits	2	5	3	6	1	4
Swelling	4	1	2	3	6	5
Compactibility	2	3	4	1	5	6
Shear Strength (Trafficability)	5	6	3	4	2	1
Compressibility	1	6	2	5	3	4
Total Numbers	24	31	16	27	23	26
Overall Ranking of the Soils	3	6	1	5	2	4

* 1 is considered best while 6 is the worst for each measured soil property and the overall ranking.

serious pitch deterioration. The soil, being a swamp clay, has a high tolerance for water. The soil possesses all the desired properties and will make for a durable, fast-paced pitch, as well as one with an even bounce and good binding strength. This soil is ranked third.

4.4 Integrade Clay

The Integrade Clay which was previously mentioned as a mixture of Princes Town and Sevilla Clays has high soil shear strength which would withstand high trafficability. However, based on the percentage of clay and silt, this soil does not seem durable for a cricket pitch, may not hold much water because of low clay content and more tests would need to be carried out to determine its suitability for use in cricket pitches. Its plasticity index is low suggesting a weak soil. The soil has modest swell-shrink characteristics and despite its high shear strength and trafficability, could not be compacted to a high density. Also, its compressibility is modest.

4.5 Talparo Soil

This soil is not popular for use in cricket pitches. It is widely an agricultural soil. The percentage clay and silt seem adequate for cricket pitches but its high sand content could introduce soil looseness. Its low plasticity index indicates low binding strength and, therefore, a weak soil. It will not swell appreciably. It responds well to compaction and compressibility and should be further studied for use in cricket pitches.

4.6 Queen's Park Old Soil

The soil seems the worst of those tested. The clay content appears adequate but the percentage sand may be too high leading to soil looseness and uneven moisture distribution. Its low plasticity index means that its binding strength is low and the pitch may not be durable. Its shear strength was also the lowest, making it less trafficable. Though the soil has moderate compactibility and low amount of swell, its low compressibility could lead to significant air voids in the soil resulting in slow pace and low bounce of the ball. In fact, this behaviour was observed when the soil was used at the Queen's Park Oval and the decision of the authorities at the cricket ground to replace the soil was a good one.

The overall ranking given to these soils, however, should be regarded as preliminary. Future work should now concentrate on placing these soils on actual or simulated cricket pitches and wetting and preparing them using the measured optimum water contents and scientifically measuring or observing their behaviour in terms of bounce, pace and spin of the ball using cricket bowling machines and bounce meters.

Also, the other laboratory measurements such as compressibility, compactibility, swelling characteristics and pitch durability should be monitored in actual cricket pitches. The work done so far is, however, a good first step in the right direction, since it has provided valuable data that would guide future research efforts.

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