Geotechnical Aspects of Bounce Index of Cricket Pitch

A thesis by

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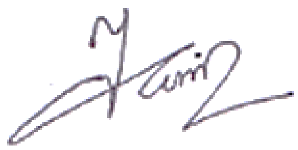
It is hereby declared that except for the contents where specific references have been made to the work of others, the studies contained in this thesis are the result of investigation carried out by the author under the supervision of Dr. Md. Zoynul Abedin, Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology. No part of this thesis has been submitted to any other university or other educational establishments for a degree, diploma or other qualifications (except for publication).



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ABSTRACT

Good bounce on a cricket pitch is one of the most desire properties of pitch in world cricket. In Indian subcontinent generally pitches are low bouncy and do not provide good contest between bat and ball. The study was carried out to correlate the bounce index with different geotechnical properties of pitch soils especially with the stiffness of pitch. To serve this purpose, bounce meter and pin-point penetrometer were designed and fabricated. Total fifteen miniature pitches were prepared with different top layer compositions (five different combinations of 2:1 clay and fine sand) where, vertical layers were constructed with proper engineering judgments. Among these pitches one third was prepared with vegetation crack control system (grasses on the top of the pitches), one third was prepared with artificial crack control system (geotextile sheet provided 75 mm beneath the pitch surface) and remaining was kept without any crack control system. To protect the top soil of pitches from lateral infiltration and efflorescence plastic sheet was provided surrounding the top soil of pitches. After proper curing, the rebound height on the pitches was measured by bounce meter for different height of free fall. The stiffness of the pitches was measured by pin-point penetrometer. In addition, other properties of pitch soils such as, crack width, moisture content and field density were also measured. The correlations were established between the bounce index and other properties of pitch soils for different crack control systems.

It was found that, from bounce and stiffness point of view, vegetation and no crack control system performed consistently with linear relations between parameters like clay content, crack width, moisture content, soil stiffness and bounce index, whereas, for artificial crack control system bounce index and the stiffness initially was found to decrease and beyond a certain (approximately 60%) clay content both stiffness and bounce index was found to increase. Regarding crack width control, artificial crack control system followed the similar linear pattern of other two control system. All these relations are proposed in terms of equations with good correlation coefficients.

Keywords: Bounce Index, Crack Control Systems, Stiffness, Pin-Point Penetrometer.

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LIST OF SYMBOLS AND NOTATION

Symbol	**Description**
b	Horizontal reading in bounce meter
C_1	First combination of stone chips and Sylhet sand
C_2	Second combination of stone chips and Sylhet sand
C_3	Third combination of stone chips and Sylhet sand
C_4	Fourth combination of stone chips and Sylhet sand
C_5	Fifth combination of stone chips and Sylhet sand
CB_1	First combination of bentonite and fine sand
CB_2	Second combination of bentonite and fine sand
CB_3	Third combination of bentonite and fine sand
CB_4	Fourth combination of bentonite and fine sand
CB_5	Fifth combination of bentonite and fine sand
CC	Clay content
C_c	Coefficient of curvature
C_u	Coefficient of uniformity
C_w	Crack width
CS	Compressive Strength of pitch soil cube
D_{10}	Diameter of 10% finer
D_{30}	Diameter of 30% finer
D_{50}	Diameter of 50% finer
D_{60}	Diameter of 60% finer
e	Coefficient of restitution
FM	Fineness Modulus
F_x	Horizontal component of force
F_y	Vertical component of force
g	Acceleration due to gravity
H	Height of fall
h	Rebound height
I_B	Bounce Index
MDD	Maximum Dry Density
m	Mass of ball
OMC	Optimum Moisture Content

r	Coefficient of regression
S_n	Stiffness
V_i	Incoming velocity
V_o	Outgoing velocity
V_{yi}	Vertical component of incoming velocity
V_{yo}	Vertical component of outgoing velocity
V_{xi}	Horizontal component of incoming velocity
V_{xo}	Horizontal component of outgoing velocity
V_f	Final velocity
w	Moisture content
Δt	Time difference
μ	Coefficient of friction

Chapter 1
INTRODUCTION

1.1 General

The area in between two sets of stumps at the center of a cricket ground is known as cricket pitch. The quality of this surface is the prime concern of the players and all other concern people. As per as ICC operation manual 29.1 preparation of pitch is very complex and needs great skills. The favourable conditions for fast, bouncy and consistent pitches may vary considerably from country to country, venue to venue and even from match to match depending upon prevailing weather conditions and that this will have an impact on the nature of pitches produced (Sing 2014) e. g. in Indian subcontinent, pitches are slow and low bouncy (Kawamoto and Nawagamuwa, 2014) whereas, pitches in Australia and South Africa are fast and good bouncy. The performance of a pitch depends on many factors. The grounds staffs have relatively high degree of control over some factors such as, soil moisture content, compaction etc. (James et al, 2004). However, the do not have any idea about some factors such as, soil textures, clay minerals, organic matter, salt contents, pH value etc. consequently grounds men are preparing pitches by following thumb rules (James et al, 2004).

One of the mostly desirable properties of cricket pitch, especially in Indian subcontinent is bounce. If a cricket ball pitched up more than 28 inch above the pitch when it reaches to the batsman, the pitch is considered as a bouncy pitch. In Australia and South Africa pitches are prepared with a huge amount of clay (50% to 80%) which have a high swelling properties (Taiton and Klug, 2002) whereas, in Indian subcontinent, pitches are prepared be clay with low swelling properties. Most interestingly, in England pitches are prepared with less than 33% clay for bouncy pitch (Adams, 2004), which indicates that the properties of cricket pitch depend on so many factors.

1.2 Background of the Present Research

A cricket pitch is construction by using different layers of particulate materials including a cover layer of highly plastic clay soil. Pace, bounce and consistency indicate the properties of a good pitch (James et al, 2004). Factors like; moisture content, temperature, humidity, compaction, soil texture and composition, organic matter, grasses etc. affect the properties of a pitch (James et al, 2004; Taiton and Klug, 2002; ESPN 2014). Hence preparations of pitch vary from location to location and even match to match depending upon the prevailing weather conditions (Taiton and Klug, 2002; ESPN 2014; Sing, 2014). The geotechnical properties of pitch soils play a great role in controlling the bounce and pace of a good pitch. It is seen that, not only the clay percentage but also the type of clay minerals are significantly responsible for fast and bouncy pitch (Taiton and Klug, 2002; Sing, 2014; Ekwue et al., 2006; Kawamoto and Nawagamuwa, 2014). Moreover the plasticity of pitch soil should allow remolding and compaction by rolling to provide a smooth surface (Sing, 2014). The degree of compaction is also an important aspect for bouncy pitch and that is to be ensured by compaction test (Sing, 2014; Kawamoto and Nawagamuwa, 2014). However, it is apparent that these sciences behind the art of pitch preparation in most of the instances are ignored. Traditionally, pitches are prepared by feel, based on the experience of curators (James et al, 2004, Taiton and Klug, 2002; Ekwue et al., 2006) and pitch properties are forecasted only on the basis of experience. As a consequence, the pitches may be slow, low and dusty as like as Indian subcontinent's pitches (Kawamoto and Nawagamuwa 2014).

On the other hand, deep rooted uniform grass covering full pitch, ensure the consistency of a good pitch (Taiton and Klug, 2002,). However, the accumulation of grass roots in the pitch increases organic content in pitch. As a result, the bouncing capacity of the pitch becomes low (Taiton and Klug, 2002). Hence, for a good bouncy pitch the optimization of the various aspects as mentioned is required.

Geotechnical Engineering solutions may play a great role to achieve the desired properties of good pitches (Sing, 2014). This calls for carrying out proper research to develop fast and bouncy pitches with adequate scientific explanations.

1.3 Objectives of Research

The present study principally constitutes an investigation on geotechnical aspects of cricket pitch relating to its bouncing effect. The main objectives of this study are:

(a) To study the geotechnical factors of a cricket pitch related to bounce index.

(b) To study the formation and functions of different layers of cricket pitches.

(c) To identify a proper composition for cricket pitch with good bounce index.

(d) To compare the effect of grass and geo-textile in controlling the cracks.

(e) To introduce a pin-point penetrometer to detect the bounce index of a cricket pitch.

1.4 Scope of Work

This research focused on the geotechnical governing factors of a bouncing cricket pitch. A correlation between the absorbed energy, stiffness and the bounce index of a cricket pitch was developed. By using this correlation, the bounce index of any pitch can be determined. This research also discusses the functions of different layers of cricket pitch.

1.5 Outline of the Research

A detailed report of the content of this thesis is organized sequentially into chapters, sections and subsections.

Chapter One contains the introduction, objectives, scope of the work and the background of this research. To fulfill the objectives described in this chapter the study goes forward.

Chapter Two holds the previous literatures those have been studied as a guideline of this thesis work such as – some technical terms, formation and functions of different layers of cricket pitch, geotechnical properties of pitch soil related to bounce index, effect of grasses in pitch, uses of geo-textile for crack controlling, bounce measuring process, some field test procedures etc. Mainly the technical terms related to this study are clarified.

Chapter Three discusses briefly all the working processes that have been performed to make the research work fruitful. This chapter also discusses the assumptions of prevailing conditions, selection of materials for different layers and the physical properties of the materials, crack pattern observation prior to construct the real pitches, cyclic effect of watering and drying the pitch, the design and fabrication of bounce meter and pin-point penetrometer. The calibration of pin-point penetrometer is also discussed in this chapter.

Chapter Four explains all the findings of the entire thesis work. This chapter also discusses the limitations of this research including laboratory and field.

Chapter Five discusses the findings of research program. This chapter also includes scopes for future researches with specific recommendations.

Chapter 2
LITERATURE REVIEW

2.1 General

The main objective of this study is to improve the pitch condition so that proper bounce can take place over pitches. This chapter presents the basic concept of cricket pitch, the geotechnical properties of cricket pitch, pitch construction process in different continents and the available literature related to bounce index of a cricket pitch especially the past studies on cricket pitch improvement.

This chapter also discusses about the governing factors those influence the bounce index of a cricket pitch such as; the formation of different layers of pitch, stiffness of pitch, clay contents, effects of grasses, effect of moisture content, effect of cracks, compaction process, top dressing, watering, presence of organic substances etc.

In addition, this chapter gives the emphasis on the performance, maintenance and drainage process of a cricket pitch. The performance of a cricket pitch is discussed as a result of Bounce Index.

2.2 Cricket Pitch

The center area of cricket ground between two sets of stumps is known as cricket pitch. Figure 2.1 shows a typical view of a cricket pitch. Generally, the length of a cricket pitch is 22 yards (20.12 m). A good cricket pitch should provide a fare contest between bat and ball.

Figure 2.1: Typical cricket pitch

Depending on the use, pitches are prepared with different conditions. For example; for a four or five days match the properties of pitch varies with time. At first day pitch provides seam but at day four it becomes spin friendly (Taiton and Klug, 2002). Whereas, for limited over match pitches are prepared as batsmen friendly (Sing, 2014). Different features of a cricket pitch are sequentially illustrated below;

2.2.1 Four or five day pitch

For a five day pitch the pitch do not behave same throughout five day. It varies day to day. The behaviour of a five day pitch in different days is described below;

(a) Day one: The pitch should be quite moist with some greenish grass on the surface (although someone opposes grass on pitch). A greenish grass allows lateral movement of the seam. The pitch should have consistent pace and seam on first day on match.

(b) Day two and three: The pitch will have dried out and should become more bouncy and it should quicken up (provided it does not crack, crumble or dust-up badly by drying up quickly). It will have lost some of its greenness and so should not seam around much. The ball should come nicely onto the bat and now the pitch should be ideal for batting.

(c) Day four: The surface should start to powder and/or crumble and the cracks will start to open up as the pitch wears and the pitch dried further. This roughness will slow the pitch down. It will become less bouncy, the bounce will become inconsistent and it will start to take spin.

(d) Day five: The fourth day’s condition will be accentuated as the pitch wears further.

2.2.2 One day limited over pitch

As per ICC recommendations, for a limiter over one day match the preference is given to the pitch which favours the batsmen (Sing, 2014). As such the ideal would be to produce a pitch equivalent to that on the second or third day of a five day game but of course without the wear and with less grass on the surface. This suggest that water should be withheld for one to two days longer than for a five day game to allow it to dry out for a day or two longer. In general also it would probably be wise to leave somewhat less grass on the pitch. To achieve this, the grass should be thinned out at the start of preparation and much of what is left should be rolled into the pitch while it is still wet.

2.2.3 Characteristics of pitch

In addition to the above mention ideal conditions, in different levels of cricket, the cricket pitch soil should have the following important characteristics,

(a) Should have a plasticity which allows remolding and compaction by rolling, thus giving a smooth surface (Sing, 2014).

(b) Should have a deeply dried hard surface so the ball is manifested and preferably allows turn of the ball. Because a hard clay surface is itself elastic (Sing, 2014) and an elastic surface provides good bounce for the fast bowlers and turn for the spinners.

(c) Should have the vertical stability that prevents differential change in elevation of parts of the surface, lifting out of crumbling or powdering. There should not be any break at depths causing plating, or the surface to flake.

(d) Should have an ability to recover from the compaction, brought about during the preparation, so that the soil structure and the grass can regenerate after the play. The soil must be cracking clay (Sing, 2014). When the soil cracks it de compacts itself and allow air and water to enter into the root zone of the grass.

(e) The pitch soil should neither crack excessively nor have excessively wide cracks.

(f) Should have sufficiently high permeability when wet, to ensure reasonable rate of water movement. A suitable pitch soil should have a reasonable hydraulic conductivity so that the water can move slowly right through the profile.

(g) Should have a completely uniform grass cover, preferably with couch grass prior to the final preparation, with uniformity of root penetration to an appreciable depth usually 100 mm (Sing, 2014). This is essential to give uniform moisture levels and rates of drying of the surface and top 100 mm.

(h) Should be rich in nutrients, available essential minerals and humus basically in colloidal state (Sing, 2014).

Four different terms are used in cricket in order to describe the behavior of pitch, they are described in below

(i) Pace: Pace describes as to how fast a delivery will come at the batsmen after bouncing. It depends on horizontal velocity component of the ball and the higher the horizontal velocity retained after bouncing greater will be the pace of the pitch.

(ii) Bounce: Bounce describes the steepness of the path of a delivery after bouncing. The main factor which governs bounce is the vertical velocity component gained by the ball after the impact with the pitch.

(iii) Spin: Spin describes the affinity of a delivery to undergo lateral movement after bouncing due to the rotational motion of the ball. A friction between the ball and the pitch is the governing factor for spin with high coefficient of friction likely to produce greater lateral movement.

(iv) Consistency: Consistency may be considered as the most important among all pitch characteristics. It describes the variation of each of the above factors of a pitch. If the pitch characteristics change greatly from one area to another on the same pitch, the surface becomes unsuitable to play. The nature of a match depends very much on the consistency of a pitch as a high level of consistency means batsmen is better able to predict the path of a delivery and thus will find batting easier. Likewise, a lower level of consistency will help bowlers and make batting harder. Highly inconsistent pace and spin will make batting almost impossible while inconsistent bounce will be dangerous for batsmen. Thus a certain minimum level of consistency is mandatory for a proper game of cricket to be played.

2.2.4 Factors affecting the pitch performances

The pitch is said to be performed well when it makes a fair contest between ball and bat. The performance of a cricket pitch indicates pace, bounce and consistency (James et al., 2004) However, this research is aimed to study the pitch performance in terms of bounce. Hence, the performance of a cricket pitch in term of bounce defends on many factors including but not limited to, bowler’s factors (bowler’s height, bowling speed and angle), geotechnical factors (composition of soil, moisture content, compaction, drainage, vertical layers, etc.), grass. The contributions of bowler’s factors for the performance of pitch in term of bounce are omitted for this research. However, the geotechnical and all other environmental (rain fall, sun light, humidity etc.) factors affecting the pitch performance in terms of bounce index are included in this research.

2.2.5 Different pitch layers

A pitch consists of different layers of various granular particles. Every layer has individual functions. As described before, pitches are prepared on the basis of experience rather adequate judgments. As a results pitches are constructed with multiple layers (5 to 7 layers) in different regions (Kawamoto and Nawagamuwa, 2014, sing, 2014) whereas, researches have proved that, 2 or 3 layer pitches are economic and prudent to get the best pitches (sing, 2014). There are generally 3 layers, such as; Compacted Bed, Base and Bulli. Figure 2.2 shows a typical cross section of a cricket pitch.

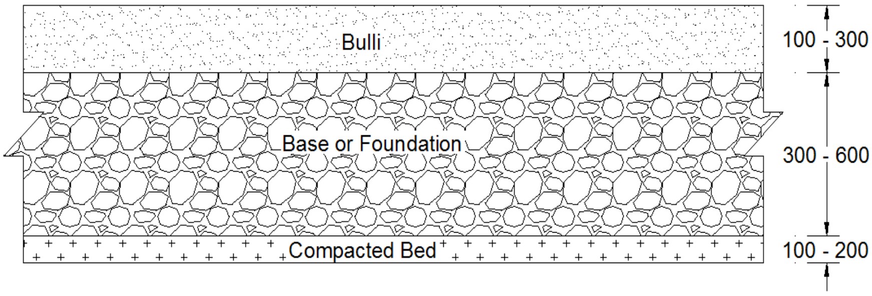


Figure 2.2: Typical cross section of pitch; usually for one-day match (All dimensions are in mm, Taiton and Klug, 2002)

Compacted bed is a layer of granular soil generally river washed sand which is around 100 to 200 mm (Sing, 2014). It works as like as improved sub-grade. Compacted bed provides a uniform bed for foundation. Base is the foundation of the pitch. It provides the support to the top layer and drain out excess water. It works as like as base layer of road. It consists of natural crushed gravel and sand and compacted to the maximum density with heavy rollers of 6 to 8 ton capacity. The height of base varies from 300 to 600 mm. The top layer of pitch is named bulli. It is the very vital part of the cricket pitch. It consists of combination of clay, silt and fine grain sand. The behavior of the pitch mainly depends on the performance of this layer. It provides relatively plane surface to play. The depth of bulli may vary from 100 to 300 mm.

The thickness and the sequence of layers vary according to the type of match and the type of maintenance work during performance. For a junior cricket match, where the bulli thickness could be as minimum as possible and generally 100 to 150 mm (Taiton and Klug, 2002, Sing, 2014). In this case a fine grain (intermediate coarse sand layer) filter layer is provided in between shallow bulli and base of coarse gravel, it acts as a filter for fine clay particles.

Figure 2.3 shows the cross section of a junior school match where pitch maintenance work is poor (pitch cover is not available, inadequate top-dressing, poor thatch maintenance etc.).

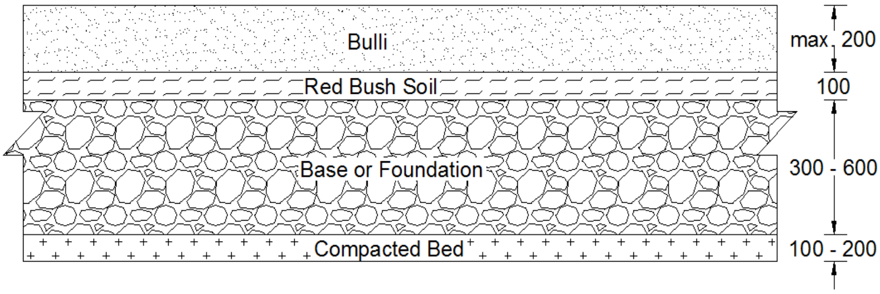


Figure 2.3: Cross section of a pitch where maintenance is poor, usually for Junior school pitch (All dimensions are in mm, Taiton and Klug, 2002)

On the other hand, in a test cricket match the pitch has to be dried up very slowly. Rapid drainage is prohibited for a test match pitch. That is why a red bush soil layer of low swelling properties (usually a composition of 1:1 clay) is provided to slow down the drainage beneath the bulli. Figure 2.4 illustrates the cross section of a test match pitch.

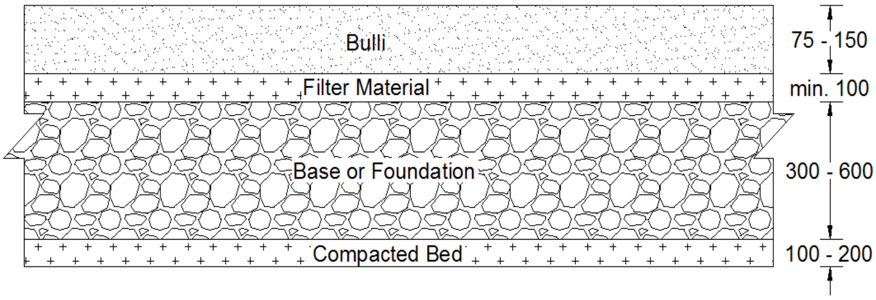


Figure 2.4: Cross section of slow drainage pitch, usually test match pitch (All dimensions are in mm, Taiton and Klug, 2002)

Another important component is plastic sheet which may be provided surrounding the bulli. Plastic sheet resists lateral infiltration (water from outfield towards pitch). It also reduce efflorescе (coming out salt to the surface) of the pitch (Taiton and Klug, 2002). However, plastic sheet makes difficult to dry up the bulli, so plastic sheet could be used where the pitch maintenance is done with great care.

2.2.6 Composition of bulli

The top layer of a cricket pitch over which the ball pitched up is termed as "Bulli". The nature of the Bulli determines the maximum pace and bounce that can be achieved on a pitch. In Australia and South Africa the soil of Bulli is to have strong swelling and shrinkage (i.e.

Bulli which swells quite appreciably when it is wetted and shrinks when it dries) properties. Pitches made of these materials are able to provide pace and bounce. These characteristics are brought about by a highly content of 2:1-type clay (Sing, 2014). These clays have a high binding strength and set hard and firm when dry (these characteristics are closely related with bounce and pace - "the greater the binding strength and the firmer the Bulli, the greater the potential pace and the higher the bounce"). If the clay content of the Bulli is too high the excessive crack became a major problem. The crack may become permanent i.e. the crack may not be able to close up when wetted. The problem becomes more serious when dead grasses fall into the cracks. However, the extent of cracking is not only depending on the clay content but also to a large extent on the type of clay mineral dominating in the Bulli, "the greater the proportion of smectite clay, the greater the degree of swell and shrinkage, and so greater the amount of cracking when the Bulli dries".

Organic material in the Bulli will have a damping effect in both pace and bounce. It weakens the Bulli and so it limits compaction, provides sponginess and has the effect of encouraging earlier dusting-up and crumbling at the surface.

On the other hand, a high sand content in the Bulli provides grip to the ball when it comes to the contact with the pitch. Hence, it reduces the bounce and pace of the ball and allows greater turn which is not expected in cricket. Therefore, it becomes complicated to prepare a strong bulli. The compositions of Bulli in different cricket stadiums are shown in Table 1.

Table 2.1: Composition of bulli at different test venue (Taiton and Klug, 2002)

Test Venue	City	Clay (%)	Silt (%)	Very fine sand (%)	Fine sand (%)	Medium sand (%)	Coarse sand (%)
Kingsmead	Durban	54	33	3.4	2.8	2.0	1.2
Wanderers	Johannesburg	53	36	7.9	1.2	0.6	0.6
Super Sport Part	Centurion	56	30	4.6	3.8	4.2	1.7
Newlands	Cape Town	74	19	1.9	2.6	1.2	0.4
SCG	Sydney	34	58	2.4	1.5	2.5	1.0
MCG	Melbourne	39	45	4.6	4.3	4.0	2.7
WACA	Perth	45	38	2.3	4.6	5.4	3.7
Harare Sports	Harare	56	22	6.2	5.2	4.3	5.9
Queens Club	Bulawayo	49	33	7.6	4.1	2.7	4.1
Average		51	35	4.6	3.3	3.0	2.4
Note: *clay < 0.002mm; silt = 0.002 – 0.05mm; very fine sand = 0.05 – 0.125mm; fine sand = 0.125 – 0.25mm; medium sand = 0.25 – 0.5mm; coarse sand = 0.5 – 2.0mm*							

According to Handreck & Black (1994), the following characteristics of pitch soils should be considered during pitch construction

(i) The pitch soil should not contain more than 5% organic matter, calcium carbonate and exchangeable cations in the form of exchangeable sodium (Sing, 2014).

(ii) The exchangeable magnesium: calcium ratio of pitch soil should be less than 1.

(iii) The pH value should be in between 6 and 7.

(iv) The soil should have a hydraulic conductivity at 5 hours of less than 2 mm/hr.

(v) Total dissolved salts should not exceed 200 ppm.

(vi) Linear shrinkage ratio of the soil should be within the range of 0.08 – 0.15, with 0.1 as ideal (Sing, 2014).

(vii) Smectite clays should comprise at least 50% of the total clay.

This is to be noted that the pitch soil contains high levels of calcium carbonate, calcium sulphate and salinity, will tends to crumble during play (Sing, 2014, Taiton and Klug, 2002). Moreover, poor clay cannot produce a good cricket pitch.

2.2.7 Depth of bulli

The bulli should be sufficiently deep to create a hard-bound surface but not so deep while drying becomes difficult. Heavily deep bulli behaves inconsistently whereas, shallow bulli dries rapidly and unfavourable for grass growth. Depending on uses and importance of pitches, depth of bulli may vary from 70 to 150 mm (Taiton & Klug, 2002) but not more than 300 mm (Sing, 2014). The longer the pitch has to last, the deeper bulli should be provided. If the selected depth is smaller than 200 mm then it is better to use 2:1 clay. For greater than 200 mm the bulli should constructed with two compositions. The top layer should be constructed by 2:1 clay (Smectite) and the bottom layer should be constructed using 1:1 clay (Kaolinite). Else, ndulation will be seen on the pitch (Taiton & Klug, 2002). Thick layer of pitch soil more than 300 mm creates a pitch layering and acts as a source of perched water table (Sing, 2014). The differences between kaolinite and smectite are given in Table 2.2.

2.2.8 Compaction

Compaction is an important factor which controls the performance of pitch. The greater the compaction of the pitch, the higher is the bounce, and the faster the pitch. At least 100 mm depth should be compacted at least 80% of the maximum potential to maximize these two properties. The maximum compaction can be achieved by rolling with roller at the optimum moisture content of pitch soil. It is very difficult to implement this condition in practice. The achieved density may differ from the desire value at same moisture content due to different energy level (weights of rollers). When a light weight roller is used the optimum moisture content is higher than would be the case when heavy roller is used, as illustrated in Figure 2.5. It shows different energy levels (roller weight from light to heavy, E-1< E-2< E-3< E-4) produce different optimum moisture contents and different maximum densities.

Table 2.2: Comparison between kaolinite and smectite (Murray, 2007)

Properties	Kaolinite	Smectite
Plasticity	Low	High
Drying shrinkage	Low	High
Cracks	Low	High
Compressive strength	Low	High

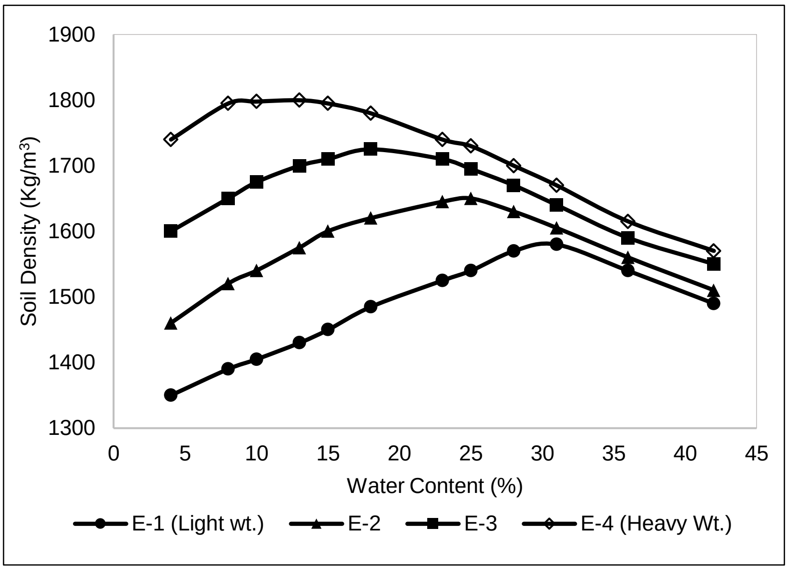


Figure 2.5: Compaction curves at different energy levels (after Van Deventer, 1995)

Compaction is then achieved by rolling regularly as the pitch dries. A frequent recommendation is to start rolling with a light weight roller and increase the weight of roller during rolling procedure. Light weight roller create the surface seal and early light rolling is sometimes used to roll the grass into bulli while it is too wet to carry a heavy roller (Taiton and Klug, 2002). Heavy rolling on dry surface or the use of vibratory roller are not recommended. Both are responsible for the generation of horizontal cleavage on bulli and may also damage the root system of pitch (Taiton and Klug, 2002). Horizontal cleavage may also the result of over rolling. It is seen that, more than five consecutive roller passes may cause horizontal cleavage (Taiton and Klug, 2002).

2.2.9 Moisture Content

Moisture content is one of the most important governing factors of pitch performance. Moisture content should maintain properly during pitch construction. Preferably, the pitch should have reasonably even moisture content down to at least 75 mm and deeper since the nature of bulli throughout this depth will affect the pace of the pitch. The moisture content tends to increase slightly (two to five percent) with depth (Taiton and Klug, 2002).

Deep drying requires a well-developed root system and depends on the active leaf. The water extracted from the lower layer in the profile is by root uptake and transpiration through the leaf system. Evaporation cannot effectively dry out the lower layer because the capillary action is very slow and any lateral crack completely disrupts the flow.

During preparation it may be necessary to reduce moisture loss from the surface by covering the pitch with hessian or shade cloth (or by spreading grass clippings over areas which are not well grassed – more of this latter). Alternatively, the pitch can be syringed (wetted with fine spray) at intervals during the day or in the evening before the covers go on, to moisten the surface. Syringing in the evening is probably preferable as it allows time for the water to soak into the surface layers of the pitch. Syringing needs, however, discontinued in time to allow the surface to dry out to the appropriate moisture content. It is most important to note that, slow and deep drying is preferable than rapid and surface drying.

The pitch should be constructed with uniform deep-watering for that, water should apply at a slow rate. A recent Australian recommendation is to apply water at a rate of 1 mm/hour for two days to wet bulli uniformly (Taiton and Klug, 2002). Rapid evaporation during day could lead the accumulation of salt at surface, for that reason it is preferable to wet the pitch during night. According to Baker (1998) the bounce of a pitch increase as it dries from some very wet state to some intermediate moisture content. When the increase in bounce slows down as it dries further and the surface roughens. The moisture content at which the change in bounce takes place varies with the nature of the bulli. Figure 2.6 shows the typical relation between moisture content and bounce of a pitch. This relationship was buildup by Van Deventer in 1995 on a clay sample for a 20 day period test under laboratory controlled condition. The drop height was 4.9 m. It can be seen that, there is a range of critical moisture content, where only 2% decrease in moisture content can make the bounce height around double.

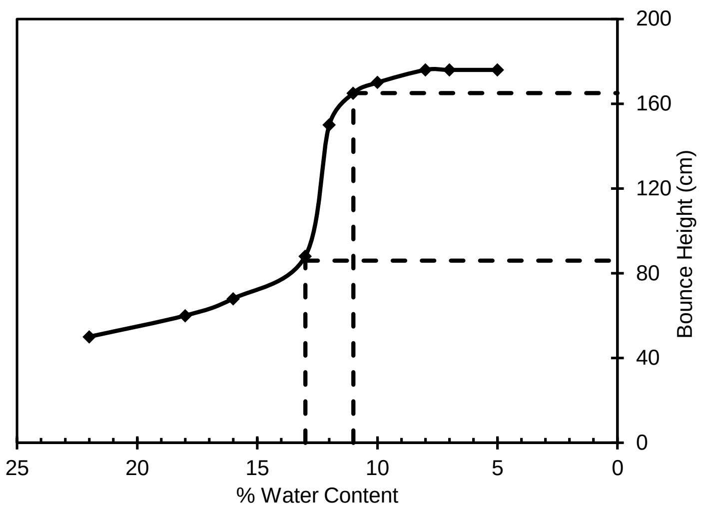


Figure 2.6: Typical relationship between moisture content and bounce for a pitch soil (after Van Deventer, 1995)

For four and five days matches, the pitch at the start of play should usually be at a moisture content greater than that which gives maximum pace and bounce so that pace initially speed up with further drying. It may continue to speed up through the duration of the match, depending on the extent to which the surface roughens as the bulli cracks, crumbles or powders. For one-day limited over match, the pitch moisture content should be near at which is gives maximum bounce (Taiton and Klug, 2002).

2.2.10 Thatch

Thatch results from the build-up of organic matter at the surface although the material derived from dead roots is also referred to as thatch. Thatch build up should be avoided at all costs. Whether, it lies on the surface or within the profile it acts to cushion the impact of the ball and will slow the pace. Whenever it takes place within the profile (where it often forms an organic matter sandwich as it accumulates in the cracks in the pitch profile), it might give rise to independent layers of bulli. This has severely negative impact on pace and bounce of the pitch and is considered to be the main cause of low and uneven bounce on otherwise well-prepared pitches. Thatch accumulation is therefore to be avoided at any cost. For that, dead surface material should be removed before applying any top dressing. As the dry organic material increases, the strength of bulli decreases (Taiton and Klug, 2002). It is seen that, any organic material, including dead or living roots in the profile reduce the soil strength as a consequence, it reduces, pace and bounce of the pitch. Although living roots in particular should help to hold the pitch together and prevent the cracks from opening up too much as it dries (Taiton and Klug, 2002).

2.2.11 Top-Dressing

Top-dressing is a term which related with the maintenance works of a pitch. When the pitch losses its evenness of the top surface then the top dressing is required. Top-dressing material should always have similar swell/shrink characteristics to the underlying soil because different materials will not bind well (Taiton and Klug, 2002). Such layering is then often exaggerated when grass roots follow the horizontal cracks between the layers of different material or when surface thatch settles or is washed into these cracks. It is important, therefore, to top-dress with material which has similar swell/shrink characteristics to the pitch bulli. If the top surface is smooth then it should always be scored until rough to allow for good bonding between the topdressing and the underlying soil (ESPN 2014).

2.3 Pitch Performance

2.3.1 Effect of cracks on pitch performance

As a pitch dries, the bulli shrinks and so vertical cracks develop. A pitch is not allowed to dry out to the extent that cracks become so large that they extend right through the bulli or reoccur in the same place so often that they become permanent (easily identified by grass growing more vigorously along the cracks). Cracks reduce the bounce and pace (Taiton and Klug, 2002, Sing, 2014) and increase variability in the bounce, particularly if the blocks being to rock or the edges of the blocks begin to crumble. Cracks may increase the amount of spin that a pitch will take. However, excessive turn in a badly cracked pitch is likely to be inconsistent. Severe cracks which makes the blocks of bulli unstable is clearly undesirable. This occurs if a horizontally layer exist close to the surface of the pitch or if the bulli below the surface crust is not well compacted.

Crack patterns also influence the behavior of pitch. For a consistent pitch, a pattern of many fine cracks is preferable to one in which there are few large cracks (Taiton and Klug, 2002).

A strongly rhizomatous grass (i.e. a grass with strong horizontal underground stems) is preferable to a surface grower as the rhizomes can be extremely effective in holding the pitch together (Taiton and Klug, 2002).

2.3.2 Powdering and crumbling effects on pitch performance

If a pitch powders or crumbles (as it dries) its surface becomes rough. Which allow the ball to grip when it pitches and so the ball may take excessive turn. The pitch may become inconsistent for pace and bounce. The lower the clay content of the bulli, the greater will be its tendency to powder and crumble as it dries, and so the grater the tendency for the pitch to take spin. Any accumulation of salt in the pitch also accelerates crumbling of the pitch (Taiton and Klug, 2002).

2.3.3 Deterioration of bulli

Deterioration describes the length of time a pitch is likely to maintain a certain level of pace and bounce. All pitches lose pace and bounce with time due to wear and tear of the surface. Actually three things are likely to be happen to the pitch as it ages;

(a) Different layers develop either because of layers of dead leaf material are incorporated into the pitch or because different types of bulli are used as top-dressing.

(b) Organic matters accumulate from the dead roots and poor thatch management which weakens the bulli and make the pitch spongy.

(c) Salts may accumulate at the surface and between layers in the bulli or indeed throughout the profile of the bulli either from firtilizers or from irrigation water. Salts are commonly seen as white crystals in the pitch profile and they seriously reduce the ability of the bulli to bind and hold together.

Careful management can control the buildup of thatch and the accumulation of salts at the surface, but there is nothing much can be done about build-up of root organic matters. Therefore, it is required to replace the pitch after a certain period of time. However, if pitches are prepared with sufficient scientific judgments then it may lasted around 15 years with some temporary treatments (Taiton and Klug, 2002, Sing, 2014).

2.3.4 Pitch geometry

Generally, pitch length should be orientated to lie true north to south. The minimum length of established strips should be 24 m. A slightly longer pitch (26 m) has advantages for bowlers' delivery strides. However, the recommended practice of shifting the crease along the length from match to match to avoid having to play on the same deteriorated areas often leads to unacceptable inconsistency in bounce and pace between the two ends of a pitch. Each individual strip should be 3.05 m wide.

The pitch should be as flat as possible. However, for drainage purpose small slope may be provided. The slope of the pitch itself should not exceed 1% in any direction (Taiton and Klug, 2002), and the slope should fall in all directions from the center. The amount of fall should not exceed 300 mm across a 3.05 m (along width) or 200 mm along its length (Taiton and Klug, 2002). The edge of the pitch should be about 50 mm above the level of outfield to ensure drainage off the pitch (Taiton and Klug, 2002).

2.3.5 Pitch performance analysis

Many studies were carried out to identify factors that affecting the performance of pitch. Stewart and Adams (1968) conducted a series of tests on cricket pitch immediately following the close of actual first class matches. They have postulated the measured rebound height of a ball dropping from 4.88 m (16 ft) on to the pitch provide a good prediction of pitch performance (James et al, 2004). It is said that, if the rebound height is below 1 ft then the pitch is considered as low bouncy pitch, whereas, the pitch is considered as a bouncy pitch if the rebound height is 1.5 ft (450 mm). Some places in UK this test is used in modified form, i.e. the drop height is changed to 3 m and named as 3 m drop test (Adams et al, 2004). However, Stewart and Adams were unable to simulate the actual scenario of the performance of a pitch. Figure 2.7 shows the 3 m ball drop test.

A clegg impact hammer was used to investigate the performance of first class cricket pitches in Australia (James et al, 2004). The device measures the hardness of the surface by recording the acceleration of a falling mass as it impacts on the surface. Generally a 2.25 kg Clegg hammer dropped from 450 mm to measure the acceleration (Adams et al, 2004). Figure 2.8 shows the arrangement of Clegg hammer test. Lush found that, the impact hammer correlated well with the results from ball drop test (Jems et al, 2004). Combining the findings with Stewart and Adams (1968) it was postulated that, impact hammer could provide a quick and easy measure of the pitch performance. Clegg hammer correlated with few variability of soil. According to Adams et al. (2004) for a reliable assessment of variability a large number of readings are required.

In New Zealand, McAuliffe and Gibbs (1997) collected measurements on the pace and bounce of first class cricket pitches. They used a crossbow-type ball launcher to project cricket balls onto prepared pitches and measured the rebound trajectory with an array of laser diodes (James et al, 2004). Correlations were found between grass cover and pace. The age of the ball was also shown to be of importance. However, the methods were failed to correlate the pitch performance with the assumptions of players and ground staffs.

Figure 2.7: Three meter ball drop test

Figure 2.8: Arrangement of Clegg hammer test

Carré et al. (1999) used an artificial bowler to project cricket balls onto simulated cricket pitch plots and employed stroboscopic photography to analyze the oblique impact. Differences were found between the simulated pitches, and soil and grass types were attributed to performance characteristics.

The rebound angle and the rebound speed govern the “pace and bounce” of a pitch. James et al (2004) first attempted to prepare a mathematical model to simulate the performance of a pitch (Kawamoto and Nawagamuwa, 2014). James et al (2004), showed that a correlation between the rebound speed and a combination of the coefficients of friction and existed when incorporated in to a Newtonian model. Essentially the Newtonian impact model allows for no deformation of either the surface or the ball and calculates the ball rebound dynamics using a combination of friction and restitution measurements (James et al, 2004). Even though the rotation and the angular momentum have been included in original model it is neglected to simplify the model. Figure 2.9 shows the mechanism of impact between ball and surface.

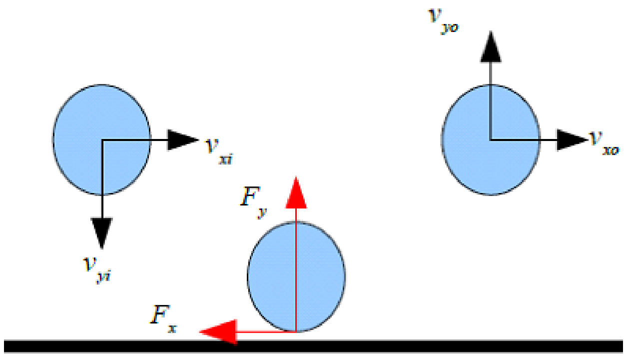


Figure 2.9: Impact between ball and surface

F means force, v represents velocity. Subscripts ‘x’ and ‘y’ denote the direction and ‘i’ and ‘o’ indicate incoming and outgoing velocity. The governing equations for this model are in below

From the second low of newton’s it can be written as,

$$\uparrow \int F_y dt = m(v_{yo} + v_{yi}) \quad (2.1)$$

$$\rightarrow - \int F_x dt = m(v_{xo} + v_{xi}) \quad (2.2)$$

If μ is coefficient of friction then,

$$F_x = \mu F_y \quad (2.3)$$

Coefficient of restitution is ‘e’ which relates the vertical component of incoming and outgoing velocity as followed

$$v_{yo} = e v_{yi} \quad (2.4)$$

From the above equations it can be derived that,

$$v_{xo} = v_{xi} - \mu v_{yi}(1 + e) \quad (2.5)$$

From equations 2.4 and 2.5 the outgoing velocity components can be found if ‘μ’ and ‘e’ are known. If v_{xo} and v_{y0} are known, the complete path of the ball can be defined and thus the behaviour of the ball can be predicted.

It has been seen that pace and bounce have different relationships with the coefficients of friction and restitution. High ‘e’ values help both the pace and the bounce of a pitch but the effect of ‘μ’ is not as straightforward. Lower ‘μ’ values will make a cricket pitch faster while higher ‘μ’ values will make the pitch bouncy. This higher bounce is due to the decreasing of the horizontal velocity component which makes the gradient of the path of the rebounding ball steeper. High bounce based on high ‘μ’ values is not recommended for cricket pitches as it causes high loss of pace making the pitch non-conducive for stroke-play. The process of measuring ‘e’ and ‘μ’ is discussed in the following Sections.

2.3.6 Coefficient of restitution test

For this test a ball is allowed to fall from a certain height and the rebound height is measured. If the ball is dropped from a certain height of “H” and the rebound height “h” is measured. This is illustrated in Figure 2.10. Three meter ball drop test may use to calculate the coefficient of restitution test. From simple mechanics of kinetics, it can be written that,

$$v_i = \sqrt{2gH} \qquad (2.7)$$

$$v_o = \sqrt{2gh} \qquad (2.8)$$

$$e = \frac{v_o}{v_i} \qquad (2.9)$$

$$e = \sqrt{\frac{h}{H}} \qquad (2.10)$$

Where,

v_i = velocity of ball before drop (i.e. falling velocity)

v_o = velocity of ball after drop (i.e. rebound velocity)

H = falling height

h = rebound height

e = coefficient of restitution

2.3.7 Coefficient of friction

The coefficient of friction can be found out by measuring the frictional force acting on a sled when it is been dragged across a cricket pitch. The surface of the sled in contact with the pitch should be similar to that of a cricket ball. James et al (2004) had used a friction sled made by clamping three cricket balls between two triangular metal plates in such a way that the balls protruded through holes in the plates.

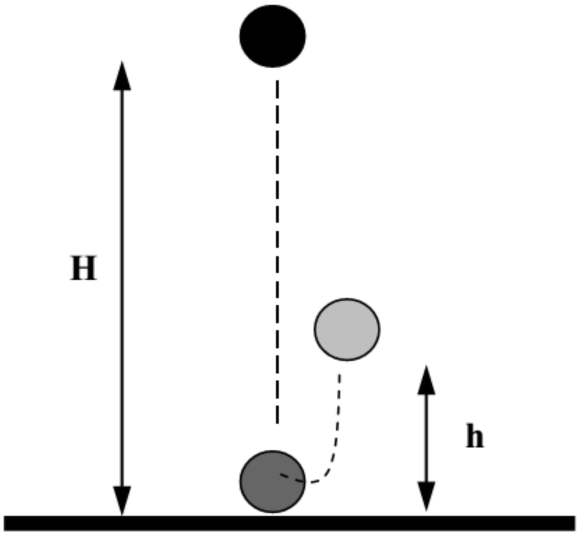


Figure 2.10: Measuring the rebound height

2.4 Concluding Remarks

Study on geotechnical aspects of cricket is suggesting that a few and negligible amount of work has been done worldwide on this interesting topic of the cricket pitch. The present study is expected to find some valuable information regarding the most unpredictable bounce characteristics of cricket pitch. Thus it was felt necessary to carry out a study on this important aspect of geotechnical conditions and crick pitch behavior

Chapter 3
TEST PROGRAMME, PROCEDURES AND FABRICATION OF EQUIPMENT

3.1 General

The present research was aimed to study the formation of cricket pitch, its performance and to correlate the bounce index with the pitch characteristics such as stiffness, cracks and moisture content. To fulfill the principal objectives of this study, laboratory and field works were done simultaneously. The methodology that was followed to complete this study is discussed in this chapter. This chapter also focuses on the selection of materials for pitch, procedure of pitch preparation, design and fabrication of bounce meter and pin-point penetrometer and the calibration of pin-point penetrometer.

3.2 Research Methodology

After an adequate literature review, different materials were selected for different layers of pitch on the basis of engineering judgments and availability. For compacted bed coarse grain sand (Sylhet sand), for base or foundation material ¾ inch down grade stone chip and Sylhet sand, for Bulli fine grain sand (river dredged sand) and bentonite (locally available montmorillonite) were selected and collected from local market. Laboratory tests such as; combined grain size analysis, Atterberg limits test, specific gravity test, California Bearing Ratio test (for base materials) etc. were conducted to identify the physical properties of pitch materials. Total five different compositions (at different percentage of bentonite) were selected for bulli preparations. Miniatures of all compositions were prepared in buckets to observe the crack pattern. A bounce meter was designed and fabricated to measure the rebound height of a free fall cricket ball from a certain height. Fifteen small scale pitches (450 mm × 450 mm) were prepared with three different crack control conditions. Among them one third consist of vegetation crack control condition i.e. grasses on top layer of bulli, one third consist of artificial crack control condition i.e. geo-textile at the middle of pitch's top layer and the remaining pitches were made with no control system i.e. top surface was exposed to the environment. Each crack control system consists of previously selected five individual compositions. A pin-point penetrometer was calibrated to measure the stiffness of the pitches. The rebound heights were measured by Digital Digitizer software from the video, captured while performing bounce meter. Stiffness of these pitches were measured by the pin-point penetrometer. Finally the rebound height and the stiffness were correlated and optimum composition was selected. The research methodology that was followed in this research is explained in Figure 3.1.

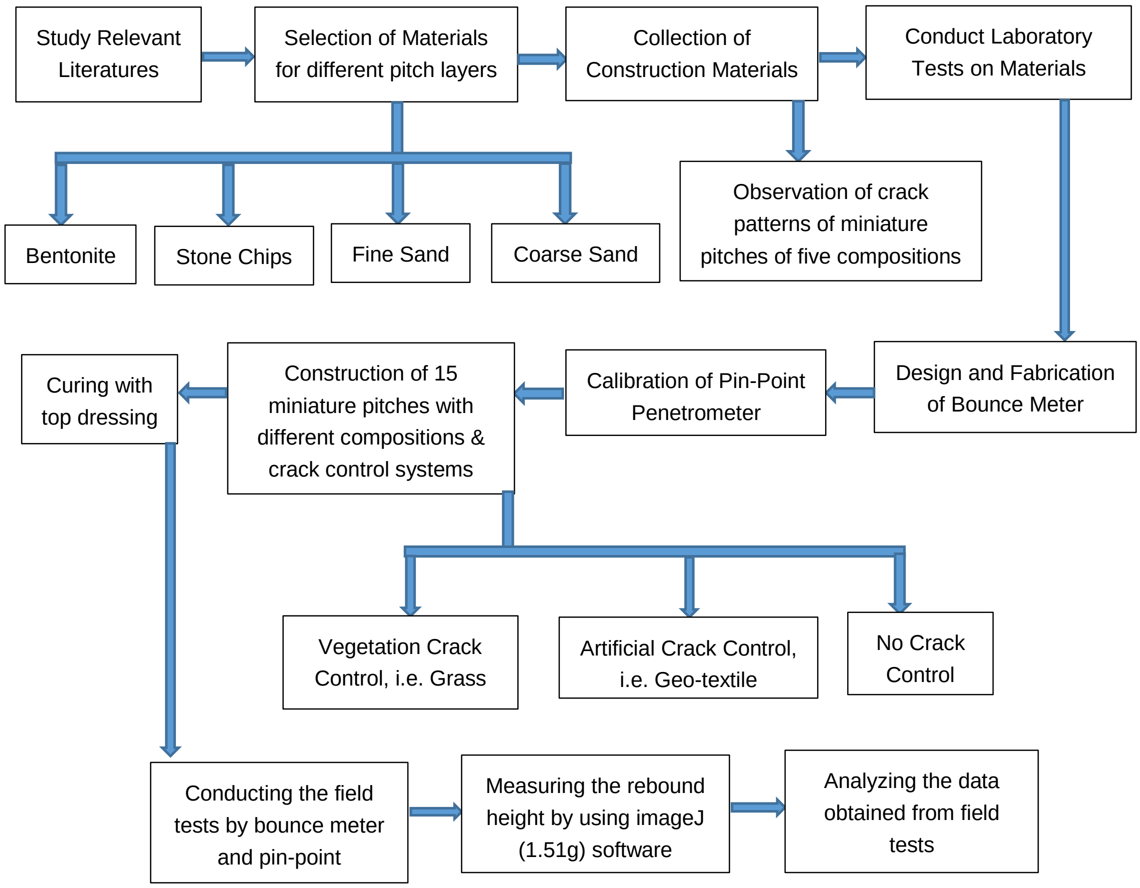


Figure 3.1: Flow chart of research methodology

3.3 Layout Plan

To fulfill the objectives of this research fifteen miniature pitches (with an individual dimension of 450 mm × 450 mm) were constructed in the BUET playground and the bounce was measured by bounce meter. Five pitches of five different combinations of pitch soils (as mention earlier) were in each row. Each row has different crack control system. First row has no crack control system, second row contained vegetation crack control system (i.e. grass at the top) and the third row contained artificial crack control system (i.e. geo-textile at 75 mm beneath the top surface). There was a working zone of 450mm width in between two rows, along the row length. Figure 3.2 illustrates the detail layout plan. The bottom layers were extended by 150 mm in all around to accommodate the roller. Figure 3.3 shows the section A-A of layout plan.

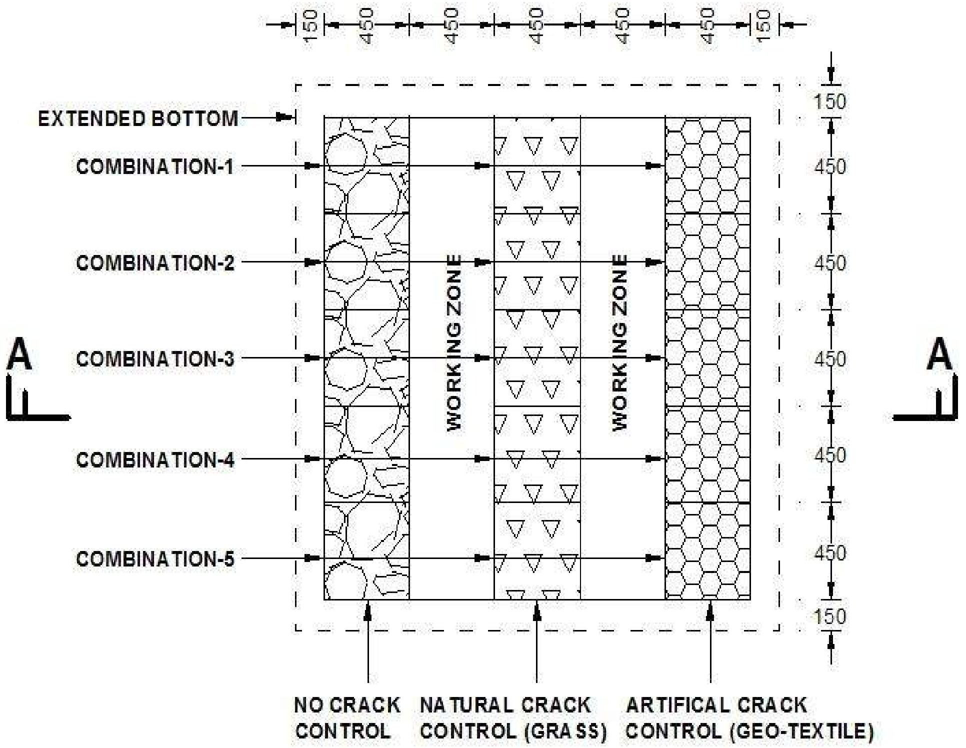


Figure 3.2: Detail layout plan (all dimensions are in mm)

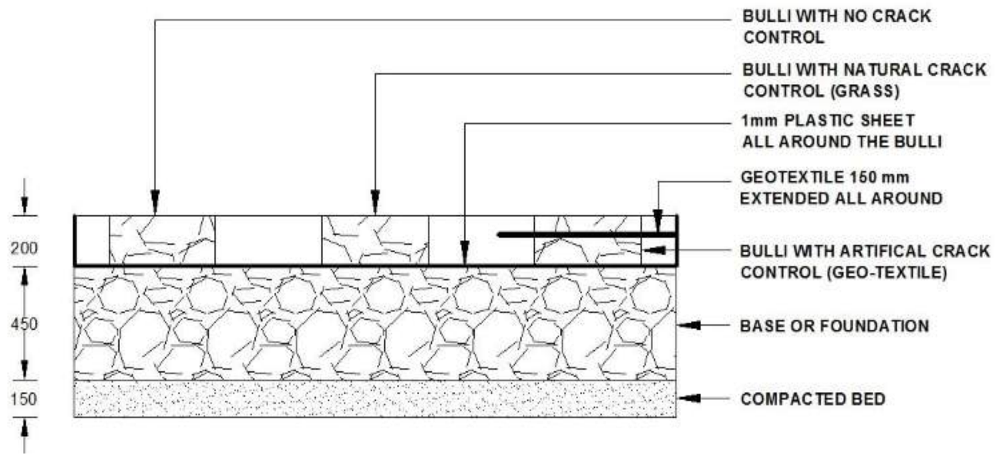


Figure 3.3: Section A-A of layout plan (all dimensions are in mm)

3.4 Properties of Selected Materials

As it is discussed earlier, pitch consists of different layers with different functions and strengths. On the basis of function and other conditions pitch layers varies. For this study, prior to preparation of pitches some prevailing conditions were assumed such as, the top soil maintenance will be done properly, the pitch should be longer lasting, test playing conditions will be the predominating condition of pitch etc. Depending on these assumptions three pitch layers were selected such as, compacted bed, Base or foundation and Bulli. Each layer consists of different materials. The properties of the materials are described as under.

3.4.1 Properties of compacted base material

Coarse grain sand, locally available Sylhet sand was selected for compacted bed and base construction. The physical properties of coarse sand such as, specific gravity, grain size distribution, minimum and maximum density etc. are discussed in below;

(a) **Gradation:** According to ASTM D-422 (2007) grain size analysis was conducted on selected coarse sand. The selected sand was poorly graded with the following parameters; D_{60} = 0.9, D_{30} = 0.5, D_{10} = 0.3, Cu = 3 and Cc = 0.926. Figure 3.4 shows the gradation curve of selected coarse sand.

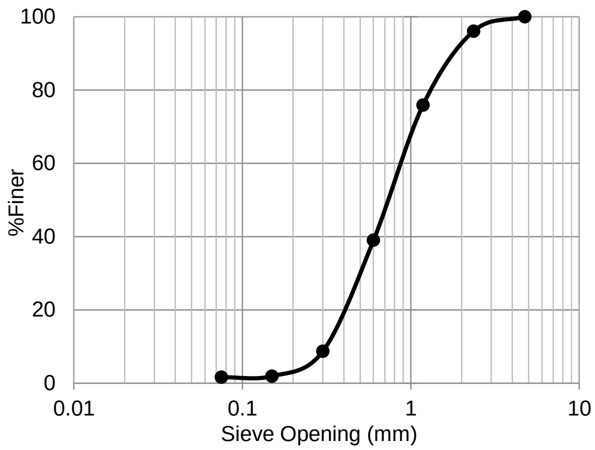


Figure 3.4: Grain size distribution curve of Sylhet sand

(b) **Specific Gravity:** According to ASTM D-854 the specific gravity of Sylhet sand was measured and was found as 2.81.

(c) **Minimum and Maximum Density:** Generally compaction test is good indicator of density. However, for coarse grain soil sometimes it becomes difficult to find out the maximum dry density at certain optimum moisture content (as, the water can be drained out). As such, maximum and minimum densities are measured to calculate relative density. For Sylhet sand the maximum and minimum density were calculated as per ASTM D-4253 and D-4254 respectively. The minimum and maximum density of selected coarse sand was found 14.7 kN/m^3 and 17.1 kN/m^3 respectively.

(d) **Maximum Self-Compaction Height:** When aggregates are fallen from a certain height they get some compaction due to their own weight. Generally degree of compaction supposed to be increased with the increase of falling height. However, with the increases of falling height air entrap into the aggregates which reduce the degree of compaction. Hence, there is a certain height beyond which, degree of compaction does not increase. This height is known as maximum self-compaction height. The maximum self-compaction height also varies for various aggregates.

In this study the maximum self-compaction height of Sylhet sand was measured by air pluviation method. The sample was allowed to fall in a mould of known volume, from different heights. Figure 3.5 shows the arrangement of maximum self-compaction height test. The test was performed by allowing the sample to fall from eight different heights at an interval of 6 inch (150 mm).

The sample was passed through No. 4 sieve and collected into a CBR mould (150 mm in diameter and 175 mm in height). By weighing the mould the density of the sample was measured. From the plot of density vs. falling height, the optimum height of fall (corresponding to the maximum density) was measured. The maximum self-compaction height of sand was 900 mm. Figure 3.6 shows the density-height of fall relationship.

Figure 3.5: Arrangement of maximum self-compaction height test

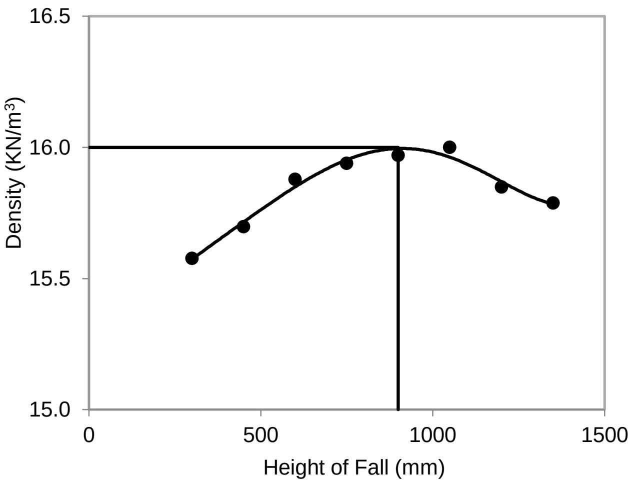


Figure 3.6: Density vs. height of fall

3.4.2 Properties of base materials

For base materials ¾ inch down grade (maximum size of aggregate is ¾ inch) stone chip and Sylhet sand were selected. For base construction stone chips and Sylhet sand were mixed with each other. The physical properties of Sylhet sand has been discussed earlier. In this Section the physical properties of stone chips are discussed.

(a) **Gradation:** The gradation was done as per ASTM C-136. Figure 3.7 shows the gradation curve of the selected stone chip with the parameters D_{10} = 8, D_{30} = 14, D_{60} = 20, C_u = 2.5 and C_c = 1.225.

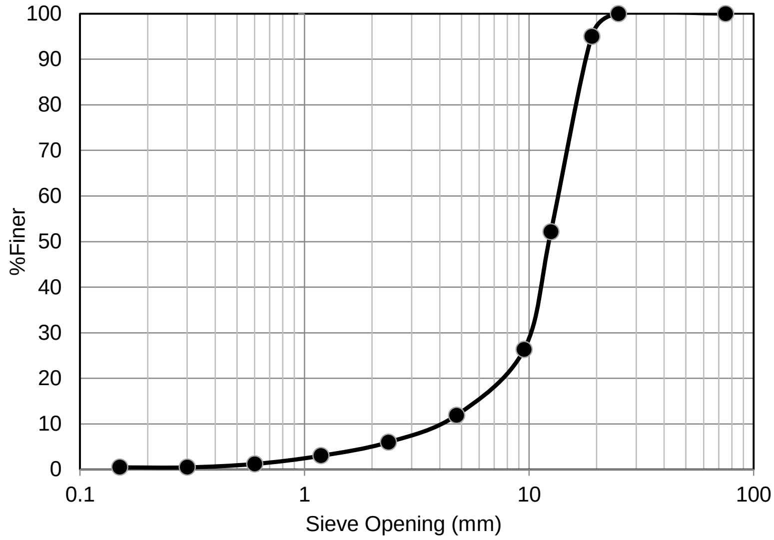


Figure 3.7: Gradation curve of stone chips

(b) **California bearing ratio test (CBR):** the stone chips and the Sylhet send were to be mixed. However, which proportion would give the maximum stiffness was to be sort out. For this purpose 5 combinations, Table 3.1, of sand and chips were selected and CBR was performed as per ASTM D-1883. Figure 3.8 shows the relationship between the soaked CBR and percent stone. The summary of CBR test is shown in Table 3.2. It was found that, the combination of 90% stone chips and 10% sand gave highest CBR value and as such combination 5 was selected for base construction.

(c) **Maximum self-compaction height:** After CBR test combination No.5 was selected for base preparation. As discussed before in Article 3.4.1 (b), the maximum self-compaction height varies for various aggregates. Before construction of pitch the maximum self-compaction height was measured. For this test the sample was prepared by random mixing of 90% (by volume) stone chips and 10% (by volume) coarse sand. Afterward, the samples were let to fall from a certain height to a known volume bucket

(15 L). Then by weighing the bucket the density was measured. The falling height was increasing by 150 mm until the weight of bucket reduced. Figure 3.9 shows the arrangement of maximum self-compaction test. Figure 3.10 illustrates the outcomes of maximum self-compaction test for combination No 5. From the graph it can be seen that the maximum self-compaction height for combination No. 5 was found as 900 mm.

Table 3.1: Combinations of stone chips and Sylhet sand

Combination No.	Stone chips (%)	Sylhet sand (%)
C_1	50	50
C_2	60	40
C_3	70	30
C_4	80	20
C_5	90	10

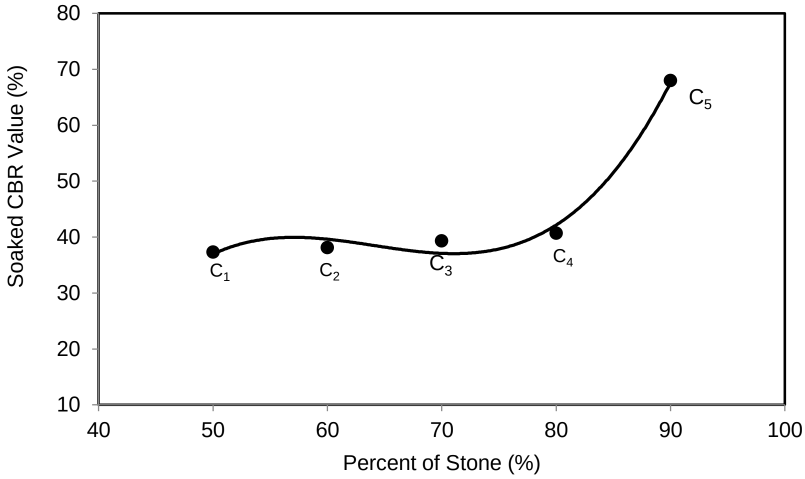


Figure 3.8: Comparison of CBR for different combinations

Table 3.2: Summary of CBR test for different combinations

Combination No.	Stress to penetrate 0.1 inch	Stress to penetrate 0.2 inch	CBR for 0.1 inch penetration (%)	CBR for 0.2 inch penetration (%)	CBR value (%)
C_1	240	560	27	37.3	37.3
C_2	280	572	28	38.1	38.1
C_3	290	590	29	39.3	39.3
C_4	300	610	30	40.7	40.7
C_5	510	1020	51	68.0	68.0

Figure 3.9: Arrangement of maximum self-compaction height test for combination 5

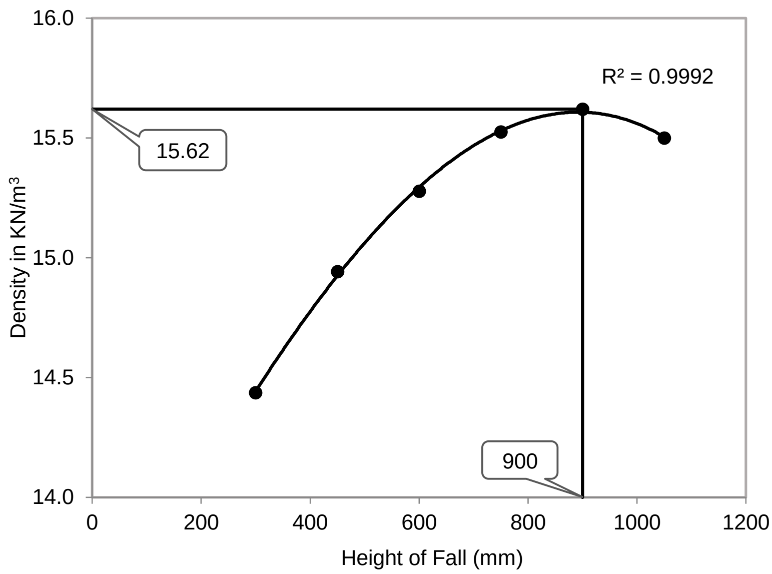


Figure 3.10: Maximum self-compaction height for combination 5

3.4.3 Properties of bulli's materials

For bulli construction fine grain sand (river dredged sand) and bentonite (locally available montmorillonite) were selected. The engineering properties such as, Atterberg limit, specific gravity, combined grain size analysis, specific gravity etc. of bentonite and river dredged sand are discussed in the sub-sequent articles. For bulli construction total five combinations of fine sand and bentonite were selected. The combinations are listed in Table 3.3. The combined properties are also discussed in the sub-sequent articles.

Table 3.3: Combination of bentonite and fine sand

Combination No.	Bentonite (%)	Fine sand (%)
CB_1	60	40
CB_2	70	30
CB_3	80	20
CB_4	90	10
CB_5	100	0

(a) **Specific gravity of bulli's materials:** Specific gravity of both fine sand and bentonite were measured as per ASTM D-854. The specific gravity of fine sand and bentonite was found 2.68 and 2.55 respectively.

(b) **Grain size analysis:** A close look at soil will clearly indicate that the makeup of the mineral portion is quite variable. The soil is composed of small particles. These small particles are the result of massive rocks of different mineralogy that have weathered to produce smaller rock fragments and finally soil particles. Soil particles vary in size, shape and chemical composition. Some are so small they can be seen only with a microscope. In most of the cases the characteristics of a soil composition depends on the particles gradation. In this articles the gradation of the combinations are discussed. As the combinations were done among fine particles (Bentonite and fine grained sand), combined sieve and hydrometer analysis were conducted as per ASTM D-422. Figure 3.11 shows the grain size distribution curve for bentonite. From the physical observation, it has been seen that the bentonite procured for pitch preparation consisted of clay, silt, fine sand etc. Therefore, sieve analysis was conducted on particles retained on #200 sieve after wash. Hydrometer test was conducted on particles passed through #200 sieve. From the grain size analysis, it was found that, the bentonite (which was locally available) contained 4.3% sand, 8.3% silt and 79.3 % clay (finer than 0.002 mm). The parameters were D_{60} = 0.0005 mm, D_{50} = 0.0003 mm, D_{30} = 0.0001 mm.

However, for fine grain sand (dredged sand) the combined grain size distribution is shown in Figure 3.12. The details of combined grain size analysis for fine sand is given below; It was found that, the dredged sand contained 89.3% sand, 10.5% silt and 0.1% clay (finer than 0.002 mm). The parameters were, D_{60} = 0.2034 mm, D_{50} = 0.1800 mm, D_{30} = 0.1298 mm, D_{10} = 0.0734 mm.

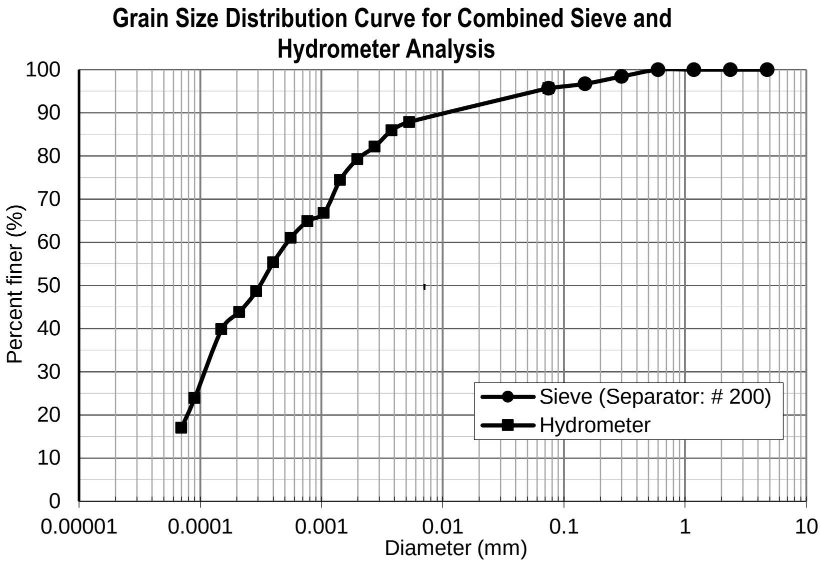


Figure 3.11: Grain size distribution curve of bentonite

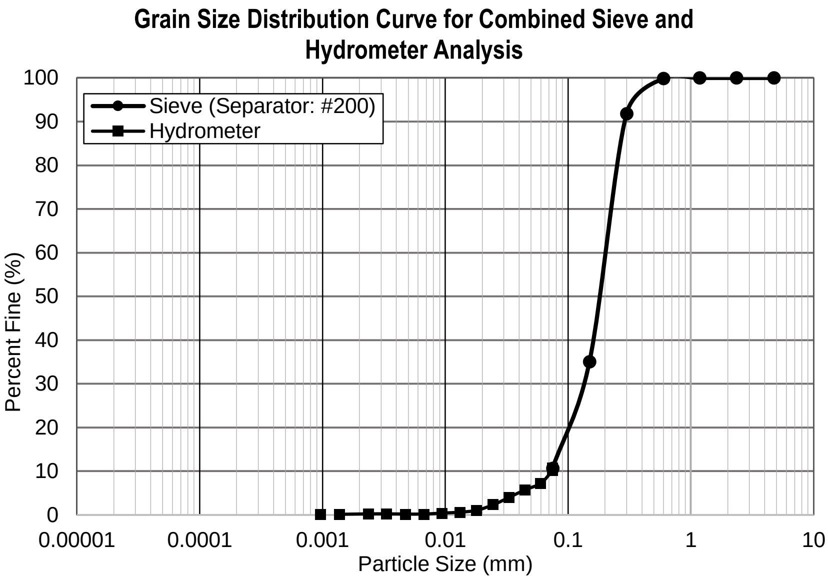


Figure 3.12: Grain size distribution curve for local sand (dredged sand)

(c) Atterberg limit: Plasticity is a property of the fine-grained portion of a soil that allows it to be deformed beyond the point of recovery without cracking or changing volume appreciably. All clay minerals are plastic and can be rolled into thin threads at certain moisture content without crumbling. For bulli construction total five combinations of bentonite and fine sand were selected. The plasticity of these combinations was measured as per ASTM D-4318. Generally, Atterberg limit tests are performed on the sample which passes through #40 sieve (0.425 mm sieve). However, in this case to compare the bentonite, Atterberg limit test was performed on bentonite at three different conditions such as, bentonite as it is purchase, bentonite passing #40 sieve and Bentonite passing #200 sieve (0.075 mm sieve). Table 3.4 shows the results of limit tests for different combinations. Burmister (1949) classification system was followed to classify the soil compositions in terms of plasticity. Figure 3.13 shows the relationship of liquid limits of different combination. Figure 3.14 shows the relationship between the plasticity indexes of different combinations.

Table 3.4: Summary of Atterberg limit tests

Combination	Liquid limit (%)	Plastic limit (%)	Plasticity index	Remarks
CB_5	106	19	87	Very high plasticity
CB_4	95	20	75	Very high plasticity
CB_3	82	18	64	Very high plasticity
CB_2	73	14	59	Very high plasticity
CB_1	62	15	47	Very high plasticity

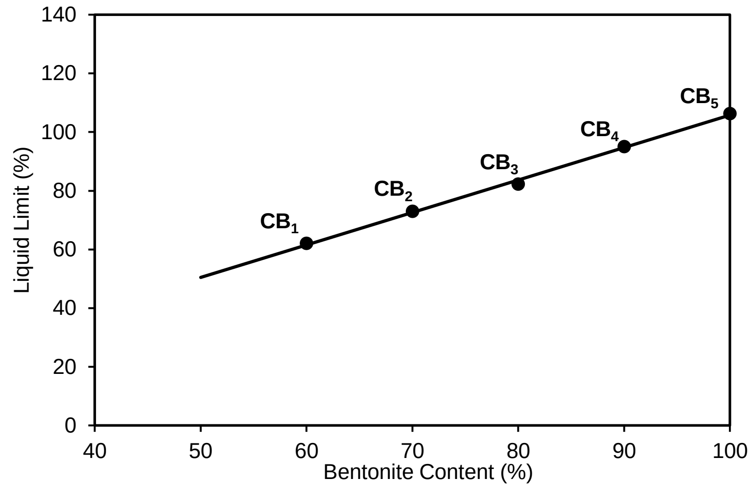


Figure 3.13: Relationship between liquid limit and bentonite content

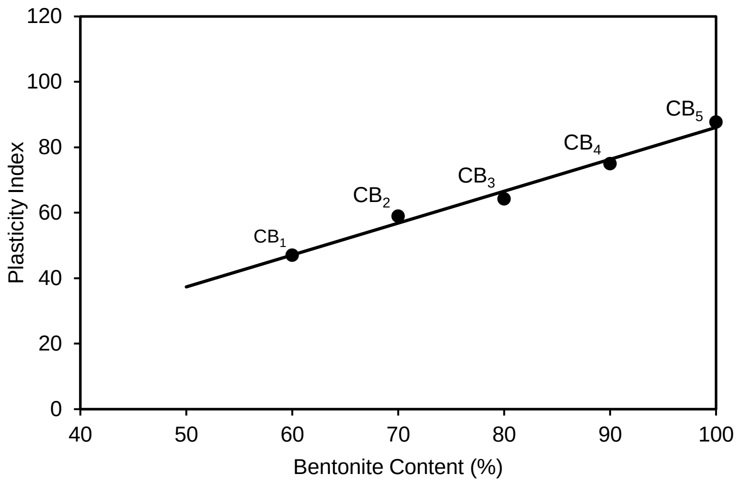


Figure 3.14: Relationship between plasticity indexes of different combinations

(d) **Proctor test:** The Proctor compaction test is a laboratory method of experimentally determining the optimal moisture content (OMC) at which a given soil type will become most-dense and achieve its maximum dry density (MDD). The OMC and MDD varies with the variation of soil type and plasticity. In this research it was essential to determine the optimum moisture content of those selected five combinations before construction of bulli. To obtain the required optimum moisture contents of the selected combinations, standard proctor test was conducted for all five combinations as per ASTM D-698. Table 3.5 shows the results of Proctor test.

Figure 3.15 shows a linear correlation between percent bentonite and optimum moisture content. It is observed that, as the percent of clay content increases the optimum moisture content also increases, that is, when the plasticity increases the optimum moisture content also increases. It is because, any increment in fine contents increase the surface area, which increase the water held capacity of particles. Figure 3.16 shows the correlation between percent bentonite and maximum dry density. It is seen that, with the increase of clay content the maximum dry density decreases. Initially with the increase of clay content the decrease in maximum dry density is high. However, beyond 80% of clay content, any increase in clay content decreases the maximum dry density at a lower rate.

Table 3.5: Standard proctor test results

Combination No	Optimum moisture content (%)	Maximum dry density (kN/m^3)
CB_5	16.7	16.9
CB_4	17.2	16.4
CB_3	21.0	15.1
CB_2	21.4	14.9
CB_1	24.3	14.9

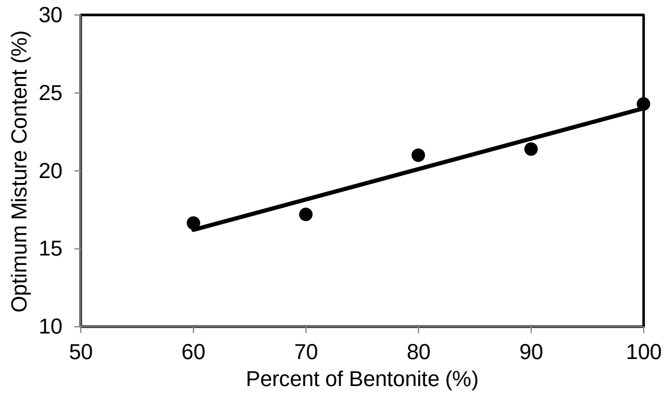


Figure 3.15: Correlation between OMC and percent bentonite

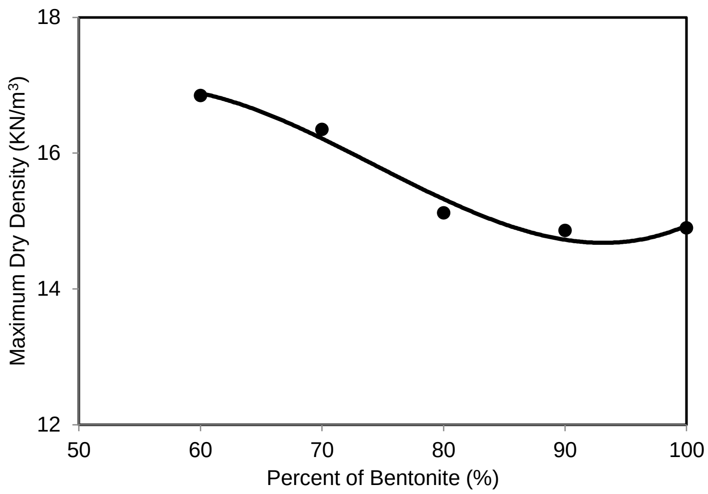


Figure 3.16: Correlation between percent bentonite and maximum dry density

3.5 Observation of Crack Pattern

As the bulli is the most important part of pitch, the characteristics of pitch mostly depends on bulli. Among these characteristics, crack pattern is most the important one. To observe the crack patterns, prior to construction, 10 miniature pitches (for each combination 2 miniatures) were prepared into plastic bucket with a dimension of 0.3 m × 2.0 m × 1.0 m. The miniatures were exposed to sun light that provides air dry condition.

Figure 3.17 shows the natural drying process of miniature pitches. A total 7 days' data were collected. During these days the miniatures were exposed to sun light even during night time. They were kept expose to the environment to simulate the exact scenario of pitches. Every day the crack width was measured. The first crack was developed earlier in 60% bentonite and 40% fine sand composition. The development of first crack did not follow any general rules. The atmospheric details (as obtained from Accuweather.com for Dhaka, Bangladesh) were also collected during those days. Table 3.6 shows the atmospheric details during the observation period. Table 3.7 shows the crack width details. It is seen that, crack width is maximum for maximum clay content (i.e. 100% bentonite). However, crack width did not follow any gradual pattern i.e. for 100% bentonite the crack width was found maximum; for 60% bentonite the crack width was not minimum among all combination (in 60% bentonite the clay content is minimum among all the compositions). For 70% bentonite the crack width was the minimum among all the combinations.

Figure 3.17: Typical crack pattern of different composition of bulli

Table 3.6: Atmospheric details during the observation period

Date	Day	Max. Avg. Temperature (^{0}C)	Min. Avg. Temperature (^{0}C)	Humidity (%)	Dew Point (^{0}C)	Cloud Cover (%)
29-04-2015	Day-1	30	25	78	22	35
30-04-2015	Day-2	33	25	73	20	85
01-05-2015	Day-3	33	24	74	24	40
03-05-2015	Day-4	35	27	68	22	35
04-05-2015	Day-5	36	26	70	23	48
05-05-2015	Day-6	35	27	65	24	39
06-05-2015	Day-7	38	27	68	25	45

Table 3.7: Crack width details for different bulli compositions

Container ID	A	B	C	D	E	A″	B″	C″	D″	E″
Bulli Compositions										
Bentonite (%)	100	90	80	70	60	100	90	80	70	60
Fine Sand (%)	0	10	20	30	40	0	10	20	30	40
Crack Width (mm) on Different Dates										
29-04-2015	2-4	2-6	1-2	1	1-5	2-4	1-5	1-5	1-3	1-6
30-04-2015	1-6	1-8	2	2	2-7	2-6	1-5	1-7	2-5	1-7
01-05-2015	3-8	2-10	2-5	1-7	1-9	1-8	3-8	4-12	2-8	1-9
03-05-2015	2-12	4-12	6-9	10-11	8-12	5-11	2-12	6-12	7-12	5-11
04-05-2015	3-17	2-14	4-12	3-13	9-14	2-15	1-13	7-14	12-13	2-12
05-05-2015	2-20	11-14	9-12	5-12	9-15	10-19	2-17	10-15	12-16	3-13
06-05-2015	3-20	4-15	6-13	6-13	9-15	15-20	2-15	10-15	6-16	5-13
First Crack Developing Sequence	3rd	2nd	4th	5th	1st	Similarity was also found for second group in developing the first crack.				

3.6 Observation of Cyclic Watering and Drying Effects

A cricket pitch is generally exposes to the weather. Evaporation and evapotranspiration are the common mechanisms which take place during a cricket match. On the other hand, water is provided to the pitch at a regular interval. Evaporation and evapotranspiration propagate cracks on pitch, whereas, water reduce the cracks on the pitch (Taiton & Klug, 2002). This propagation and reduction of cracks may have fatigue impact which may implies a negative impact on the strength of soil. To observe the effect of watering and drying some laboratory investigations were done. Total 15 no of 50 mm cubes were prepared for this purpose, Figure 3.18 (a). Three cubes for each combination (bentonite and fine sand) of bulli. Adequate amount of sample was prepared for each combination into the miniature boxes and mixed at dry condition, Figure 3.18 (b). Water was added to each sample up to the optimum moisture content of each combination and mixed at wet condition, Figure 3.18 (c). Before casting, the cube moulds were lubricated as illustrated in Figure 3.18 (d), so that the adhesion between soil and metal was reduced. Then the cubes were filled by the samples and compacted into two layers by a six inch (150 mm) plunger (cross section 12.5 mm × 25 mm). Thirty two (32) blows were provided in each layer to compact the sample into the cube as illustrated in Figure 3.18 (e). The smoothness of the top surface of cubes were ensured by a plastic straightedge, Figure 3.18 (f). Afterward the miniature boxes were kept to sunlight for dry up as shown in Figure 3.18 (h). However, the cubes filled with samples were kept into room temperature (because if the cube samples were kept in sunlight there might be a probability of developing cracks in cube samples, which ought not be accepted for strength test), Figure 3.18 (g). The samples in the miniature were taken again into the laboratory and added water again (up to the optimum moisture content of each sample) for the second trial. Similarly the cubes were filled again by samples and kept at room temperature for second trial. Total three trials were conducted at an interval of seven days. Table 3.8 shows the compression test result (Compressive Strength, CS) for cube samples.

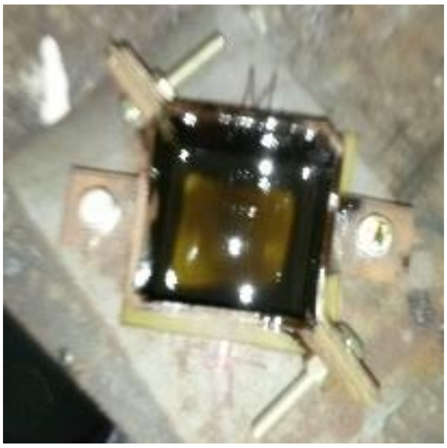
Figure 3.19 illustrates the cyclic watering effects on the shear strength of the soils at different combinations. From Figure 3.19, it is seen that, the shear strength of the soil was reducing due to the cyclic watering and drying effect. It is found that, Combination 2 (i.e. 70% bentonite and 30% fine sand) gave higher shear strength than other combinations up to second watering.

Figure 3.20 shows the Comparison between the shear strength of different combinations of soils at three cycles of watering and drying. It can be seen that, for combination 2 the shear strength reduction rate is highest than others. For combination 4 this reduction rate is lowest.

(a) 50 mm leak proof cube

(b) Dry mix sample in miniature box

(c)Wet mixing of sample in miniature box

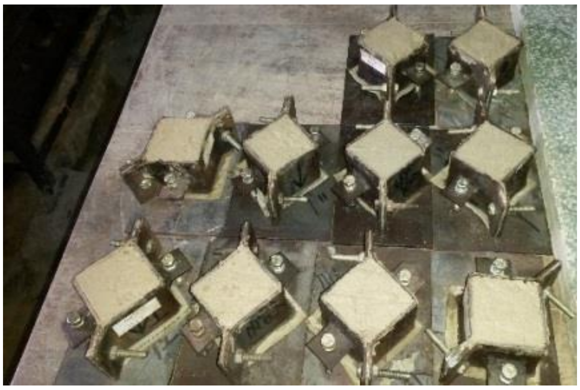


(d) Lubricating the cube

(e) Compacting the sample into the cube

(f) Ensuring smoothness of top surface

Figure 3.18 (a to f): Sequence of sample preparation and compression test


(g) Air dry the cubes at room temperature


(h) Drying-up the samples in miniature boxes


(i) Collection of cube samples after 7 days


(j) Measuring actual dimensions


(k) Conduction of CS test


(l) Ignoring excessively cracked samples

Figure 3.18 (g to l): Sequence of sample preparation and compression test

Table 3.8: Details of compressive strength test at different stage of watering

Watering Cycle	Combination No	Test No	Corresponding strain (%)	Compressive Strength (kN/m^2)	Avg. Compressive Strength (kN/m^2)
1st	CB_1	1	15.0	33	87
		2	15.0	142	
	CB_2	1	15.0	110	113
		2	15.0	115	
	CB_3	1	15.0	91	80
		2	15.0	69	
	CB_4	1	15.0	72	70
		2	15.0	67	
	CB_5	1	15.0	67	59
		2	15.0	50	
2nd	CB_1	1	15.0	62	84
		2	7.6	95	
		3	9.2	96	
	CB_2	1	15.0	103	101
		2	15.0	94	
		3	10.1	106	
	CB_3	1	14.5	65	65
		2	15.0	60	
		3	15.0	69	
	CB_4	1	15.0	61	60
		2	15.0	60	
		3	13.0	60	
	CB_5	1	15.0	63	55
		2	15.0	52	
		3	13.0	49	
3rd	CB_1	1	15.0	34	28
		2	11.6	18	
		3	15.0	33	
	CB_2	1	15.0	26	30
		2	15.0	31	
		3	11.9	33	
	CB_3	1	15.0	20	24
		2	15.0	39	
		3	15.0	14	
	CB_4	1	15.0	10	23
		2	15.0	36	
		3	15.0	23	
	CB_5	1	15.0	15	19
		2	15.0	23	

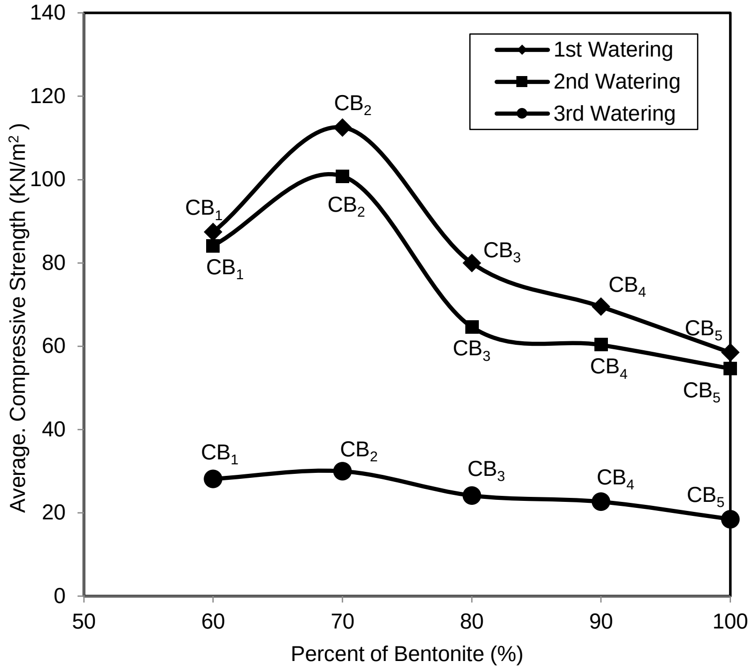


Figure 3.19: Effects of cyclic watering on the shear strength of soils at different combination

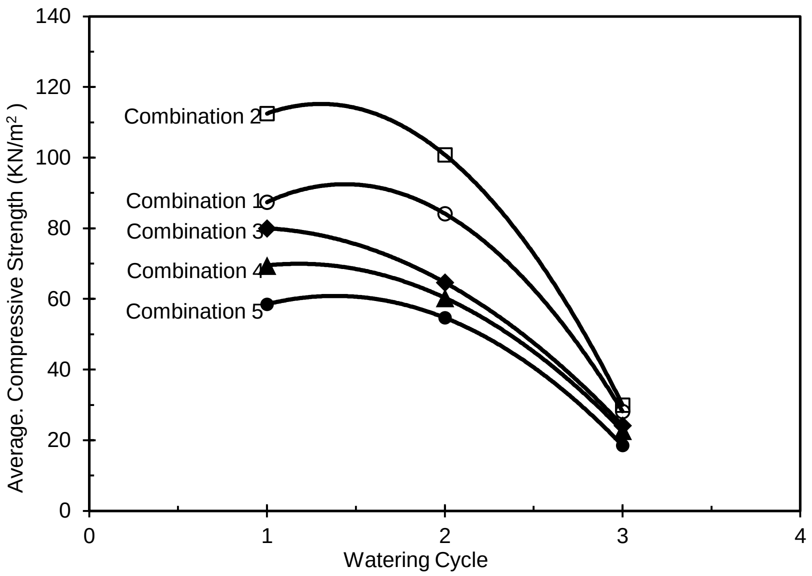


Figure 3.20: Comparison between the shear strength of different combinations of soils at different cycles of watering and drying

3.7 Pitch Preparation

For preparation of pitches some prevailing conditions were assumed such as, the top soil maintenance will be done properly, the pitch should be longer lasting, test playing conditions will be the predominating condition of pitch etc. Depending on the assumptions pitches were prepared by following some steps, which are illustrated in subsequence articles.

3.7.1 Excavation

From the prevailing conditions, the depth and position of different layers were determined. As it was assumed that, the top maintenance will be done properly (i.e. water will not allow to penetrate into the pitch), the filter material is not required (Taiton & Klug, 2002). As it was desired to produce test playing conditions the bulli thickness must be higher than 150 mm (Taiton & Klug, 2002 and Sing, 2014). For a longer lasting cricket pitch the base should be more than 300 mm. Thus three layers were selected for pitch construction, they are, Bulli, Base and compacted bed. The thickness was designed as 200 mm bulli, 300 mm base and 150 mm compacted bed. Hence total depth of pitch was 650 mm. the excavation works was done up to 600 mm so that the pitch top could be 50 mm higher than the outfield to allow the pitch slightly above the outfield level (Taiton & Klug, 2002). The required width and length of the layout plan 2250 mm (7.5 ft) however, to accommodate the roller extra 150mm was also needed to excavate from all sides. Hence, the volume of the trench was 2400 mm × 2400 mm × 600 mm. A gentle side slope was maintained on one side to ensure the easy movements of the rollers. Before excavation the layout was given in the field and ensured the level using a water level, Figure 3.21 (a). RL of layout line was measured, Figure 3.21 (b), so that the depth of excavation could be controlled and the finished level of total layout would be perfectly horizontal. Figure 3.21 (c) shows the excavation work. After excavation the layout was given again and the RL was checked so to ensure the depth. Figure 3.21 (d) shows the side slope provided for easy handle of roller.

3.7.2 Compacted bed casting

The compacted bed was constructed using coarse grain sand (F.M. 2.78). After excavation, RL different points were checked to ensure the desired depth. Adequate amount of water was added with the materials (15% water). The materials were then let to fall into the trench from the maximum self-compaction height (i.e. 900 mm for the Sylhet sand). The trench was filled by selected bed materials into two stages (i.e. 75 mm in each stage). After each stage, the sand layer was compacted using both hand compactor and manually operated roller. After preparation of compacted bed the field density was measured as per ASTM D-1556 to obtain the relative density. The relative density was found as 75.5%, indicating dense compaction (Das and Sobhan, 2010). As the base materials stand on the compacted bed, key in between two layers (compacted bed and base) was required to provide lateral rigidity (Taiton & Klug, 2002). Holes of 50 mm dia were made arbitrarily in compacted bed, Figure 3.22 (a), using a 1200 mm long 50 mm dia re-bar, falling free from a height about 900 mm, Figure 3.22 (b).

(a) Layout check

(b) Measuring RL. Of layout line

(c) Excavation work

(d) Side slope provided for roller

Figure 3.21 (a to d): Excavation work for cricket pitch

(a) Shear key on compacted bed

(b) Rebar used to generate shear key

Figure 3.22 (a & b): Arrangements and tool for shear key

3.7.3 Base or foundation construction

As mentioned earlier in article 3.4.2 (b), for base construction the combination of 90% stone chips (¾ down grade) and 10% coarse sand (Sylhet sand) was selected. As like as compacted bed, first of all the RLs of different points were checked, Figure 3.23 (a). The materials were mixed in volumetric proportion. Figure 3.23 (b) shows the mixed materials. Adequate amount of water was added, Figure 3.23 (c), for wet mixing (as the optimum moisture content was not determined 10% moisture was added to the mixture). The materials were let to fall in to the trench above the compacted bed from a maximum self-compaction height of 900 mm for a selected material, Figure 3.23 (d). The trench was filled by base materials by 300 mm in four stages of 75 mm each. After completion of each stage the materials were compacted by both hand compactor and manually operated rollers. Figures 3.23 (e) and 3.23(f) show the hand compaction and roller compaction of base, respectively. Two manually operated rollers were used. One was one ton's concrete roller another one was two ton's steel roller.

(a) Checking of Reduced Level(RL)

(b) Heap of mixed materials

(c) Addition of water

(d) Max. Self-compaction height

(e) Compaction by hand compaction

(f) Compaction by manual roller

Figure 3.23 Contd. (a & f): Pictures illustrating construction of pitch foundation

3.7.4 Infiltration Resistance

The most important part of a pitch is the top soil of the pitch which is known as bulli. Most commonly seen that, in spite of proper top maintenance the pitch become unfit to play due to lateral infiltration e.g. the second match of Bangladesh vs. South Africa test series in July 2015 was abandoned (ESPN Crickinfo), because of lateral infiltration the pitch became unfit to play. On the other hand, due to cyclic watering and drying effloresce may occur if the materials of subsequent layers are contaminated by saline water (Taiton & Klug, 2002). Both of these actions are harmful and deteriorate the life of bulli. To get rid of these problems, in this study infiltration resistance was provided beneath the bulli. This resistance was provided by using 1 mm thick plastic sheet (trade name celluloid sheet). First of all, the thickness was measured by slide calipers, Figure 3.24 (a). Afterward, pasting was provided to join the sheets to form a desire shape, Figure 3.24 (b). Figure 3.24 (c) shows the placement of plastic sheet. The sheet was anchored with side soil by a pin shape nails, Figure 3.24 (d).

(a) Ensuring thickness of plastic sheet

(b) Using glue to adjust the size

(c) Placement of plastic sheet above base

(a) Anchoring of plastic sheet by pin shape nails (in circle)

Figure 3.24 (a to d): Providing infiltration resistance to bulli.

3.7.5 Bulli Construction

The fortune of a match is mostly depends on the performance of the pitch, specially the top layer of the pitch i.e. bulli. As such, it should be constructed with great care and consciousness. The bulli should provide adequate pace and bounce, which mostly depends on the properties of pitch soils. In this study, a total of five combinations of bentonite and fine sand were selected. The combinations were prepared in the field by dry and wet mixing of bentonite and fine sand. For wet mixing water was added to each combination according to its optimum moisture content. Figure 3.25 (a) and Figure 3.25 (b) show the dry and wet mixing respectively. These five combinations were placed as per layout plan into four stages (each stage consists of 50 mm). To ensure the dimension of the pitches (i.e. 450 mm × 450 mm) a steel framework was provided, Figure 3.25 (c). Figure 3.25 (d) shows the casting of bulli inside the steel framework. After construction of each stage working zones were filled by ordinary soil and the steel framework removed. Figure 3.25 (e) shows the bullies without steel framework and in between rows the working zones filled with ordinary soil. Afterward, the compaction was done by both hand compactor and manually operated rollers. Figure 3.25 (f) shows the hand compactor. Figures 3.25 (g) and 3.25 (h) show concrete roller and steel roller respectively. For middle row of layout plan the natural crack control system was selected, and grasses were planted for controlling the cracks on the pitches of the middle row. The Bermuda grass (Cynodon dactylon) was selected to plat at a spacing of 75 mm in each direction as shown in Figure 3.25 (i). In third row, the artificial crack control system was selected using a geotextile sheet (roofing membrane) along the length of row at 75 mm beneath the top level. The geotextile was extended by 150 mm in all sides to provide anchorage with side soil, Figure 3.25 (j).

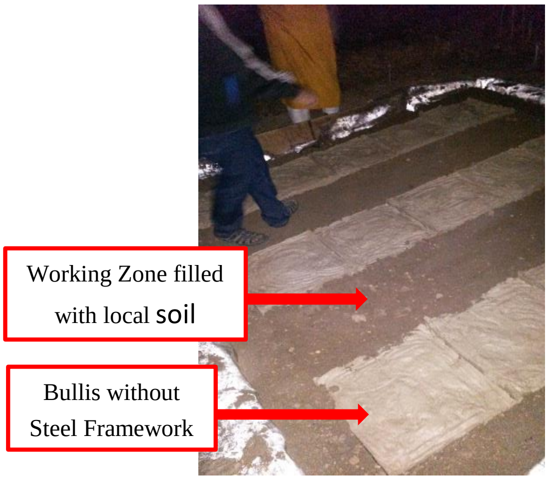
(a) Dry mixing of bentonite and fine sand

(b) Wet mixing at OMC

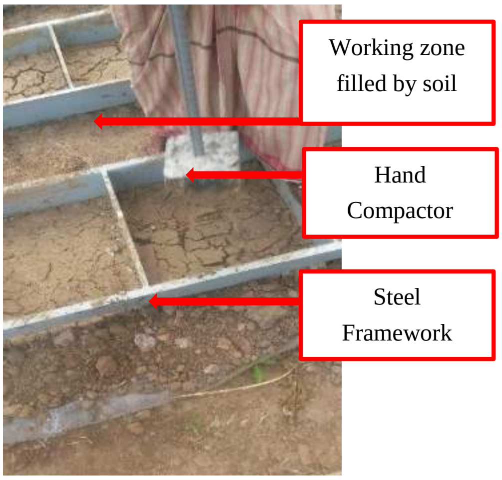
Figure 3.25: Pictures showing construction stages of bulli

(c) Steel casing on plastic sheet

3.25 Casting of bulli inside Steel casing



(e) Bulli after 1st stage construction



(f) Hand compactor

(f) Rolling by one ton concrete roller

(h) Rolling by two ton steel roller

Figure 3.25 (Contd.): Pictures showing construction stages of bulli

(i) Planting grass in the middle row

(j) Providing the geo-textile in third row

Figure 3.25 (Contd.): Pictures showing construction stages of bulli

3.8 Curing of Pitch

The hardness of a pitch depends on the process of preparation and the curing that is done during construction. If the soil is too dry then segregation (too dry soil separated from relatively moist soil) may takes place on the pitch (Taiton & Klug, 2002). On the other hand the grasses on the pitch required water to grow up. During curing of pitch watering was done regularly to the pitches, so that, no segregation occurs and grasses get adequate water. Figure 3.26 (a) shows the watering to the pitches. After certain growth (when the root systems were strong enough) the grasses were cut beyond 10 mm (Taiton & Klug, 2002) height. Figure 3.26 (b) shows the cutting of grass on the pitches.

(a): Watering to grass

(b) Cutting the grass after growth

Figure 3.26: Curing of pitch

During curing cracks form on the surface and air entrap into the cracks which reduce the density of bulli (Taiton & Klug 2002). As a consequence, the pitch loses its properties of pace and bounce. Lowly compacted pitch behaves inconsistently (Shipton and James, 2009). To avoid this effect during curing, in this research the pitches (fifteen pitches in three rows) were rolled by maintaining a proper procedure. When the surface is too dry it is difficult to compact the soil to a desire level, because the soil is very hard at dry condition. Water is needed to compact the soil because, water helps to weaken the soil (Shipton and James, 2009). On the other hand, it becomes impossible to compact the soil when the air void is just about five percent of total void (Shipton and James, 2009), because neither soil solid nor water are compressible. That is why, adding too much water is not always give a good compaction. Therefore, after few passing of roller it would be wise to allow the pith to dry (Shipton and James, 2009) so that, further compaction could be done. In this research work for curing purpose, adequate amount of water was applied to the pitches. Afterward rolling was done until the settlement due to rolling became negligible. Figure 3.27 shows the rolling over the pitches (jute mattresses were used to soak extra water on the surface and to provide smooth surface). After rolling the pitches were allowed to dry up for further rolling. Repeating this phenomenon of rolling the bulli was transferred to a compacted solid mass.

Swiping is also a part of pitch curing. Due to the activity of rolling and drying some sharp edges of cracks may divide into several parts and produce powders on the pitch. This powders are not allowed to patch on the pitch. Moreover, thatches may also accumulate on the pitch which reduce the properties of pace and bounce. That is why the thatch and powders are to be removed from the surface of the pitch by swiping. Vacuum suction is the best option for this purpose (Taiton & Klug, 2002). Figure 3.28 shows the swiping of the pitches.

After all this curing works the pitches became ready for experiment. Prior to experiment the segregation marks in between pitches and working zones were provided. The colour of the marks was white and the width of marks was limited to 1 inch (New Zealand Cricket Umpires and Scorers Association, 2010). Figure 3.29 shows the fifteen (15) miniatures of pitch ready for field test.

3.9 Design and Fabrication of Equipment

To fulfill the objectives and the field requirements of this research work, bounce-meter and pin-point penetrometer were used in the field. Bounce-meter and pin-point penetrometer were specially designed for this research work and fabricated them locally. The details of this equipment are discussed in the subsequent articles. The calibration of the pin-point penetrometer is also discussed in this part.

Figure 3.27: Rolling over pitches during curing period

Figure 3.28: Swiping the pitches

Figure 3.29: Miniatures of pitch as per layout plan

3.9.1 Bounce-meter

It is the equipment which was used to determine the rebound energy (bounce) of a ball after falling from different heights. This equipment was designed according to the requirement of this study. The dimension of bounce-meter was chosen as 900 mm × 900 mm. The falling height could vary from 1500 mm to 3000 mm at an interval of 300 mm. Figure 3.30 shows the pictorial view of bounce meter and its components are described below.

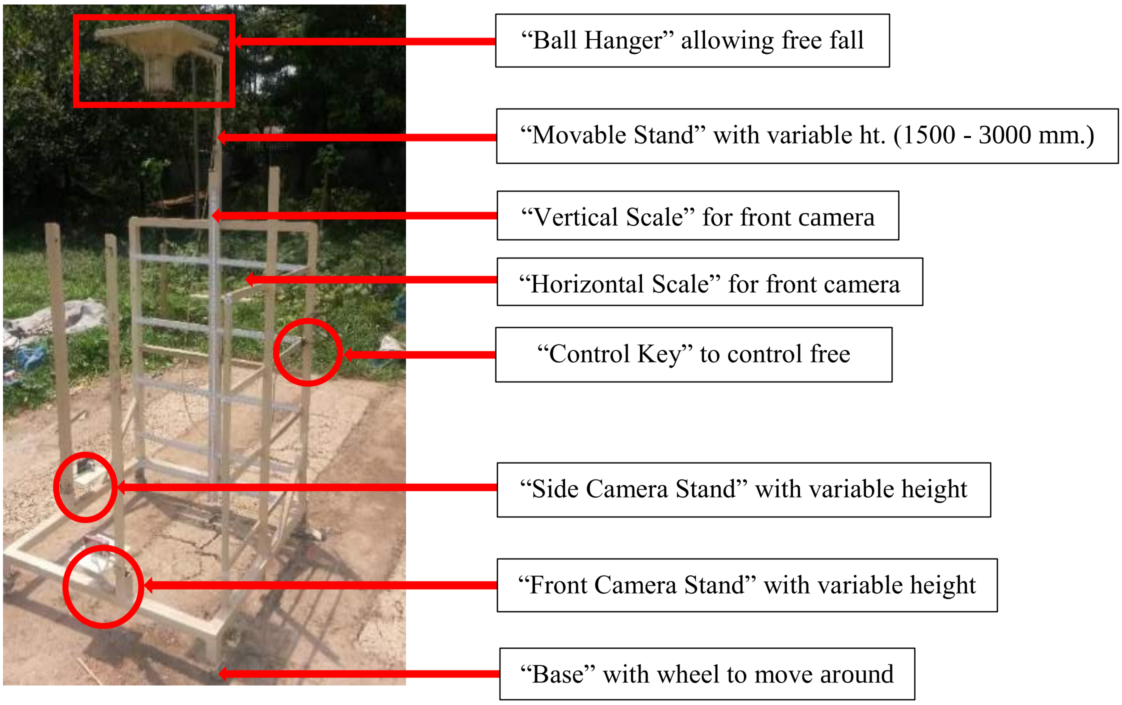


Figure 3.30: Pictorial view of bounce meter

(a) **Ball hanger:** this is a hanger on which the ball is placed before falling. This is consists of two parts top part is a square (300 mm × 300 mm) catchment area where the ball is thrown. And a cylindrical (height 75 mm and diameter 100 mm) guide-way through which the ball can be placed at the center of the bounce-meter. At the bottom of the guide-way there is a lock, on which the ball rest before fall (as shown in figure 3.31). The lock is controlled by the control key. The falling height is maintain from the bottom of the guide-way to the base of the bounce-meter

(b) **Moving stand:** This is a vertically movable stand which holds the ball hanger and keeps it at the center of the bounce-meter. It can move vertically from 1500 mm to 3000 mm at an interval of 300 mm. By using this stand falling height can be adjusted.

(c) **Camera stand:** when a ball fall from the ball hanger and get bounce on the pitch the motion need to be captured from both front and side. Therefore, two cameras can be placed in this bounce-meter. One from front side and another from left side. These cameras are facilitated on flat and vertically movable (50 mm in vertical direction) stands, which are termed as camera stands. Figure 3.32 shows the camera stand. This stand can be rise up to 1200 mm above the bottom level of the base.

(d) **Vertical scale:** To measure the vertical rise of the ball after bounce there are two vertical scales adjusted in front of both camera stands (the distance between camera stand and vertical scale is 900 mm. in both directions). A total height of 1500 mm (from the bottom of the base) can be measured using this vertical scale. The vertical scales are attached in such a way that each focus of a camera coincides with the vertical scale in front of it.

(e) **Horizontal scale:** There is a facility in bounce-meter to measure the horizontal distances using horizontal scales. There are also horizontal scales in front of each camera (the distance between camera stand and horizontal scale is 900 mm. in both directions). The horizontal scales are attached in both leftward and rightward from the center (at a vertical interval of 300 mm.) in front of both camera stands. 18 inch either left or right from the center can be measured by horizontal scales in front of both cameras. Figure 3.33 shows the details of horizontal and vertical scale

(f) **Control key:** A control key is attached to the bounce-meter at a corner. It is connected with the lock of guide-way through a cable. By the control key the guide-way can be unlocked. Figure 3.34 shows the control key.

(g) **Base:** The base is the foundation of the bounce-meter that carries total load of the equipment. The base consists of four stands and a square frame with a dimension of 900 mm × 900 mm. Beneath each of the stands there is a wheel to move around the bounce-meter. The height of the base is 7 inch. Figure 3.35 shows the base of the bounce-meter.

Figure 3.31: Ball rest on the lock

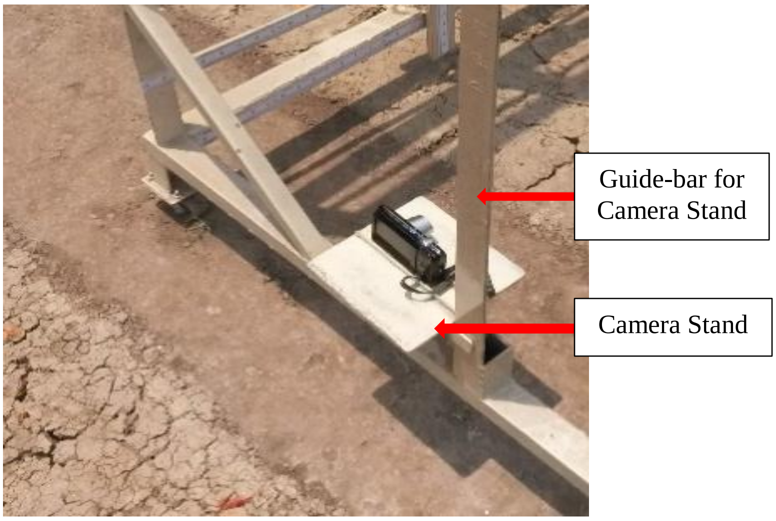


Figure 3.32: Camera stand attached with guide-bar

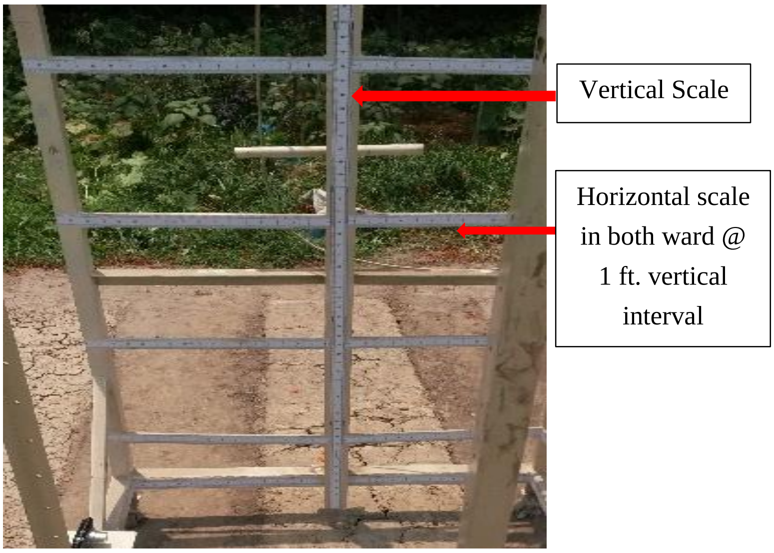


Figure 3.33: Vertical and horizontal scales

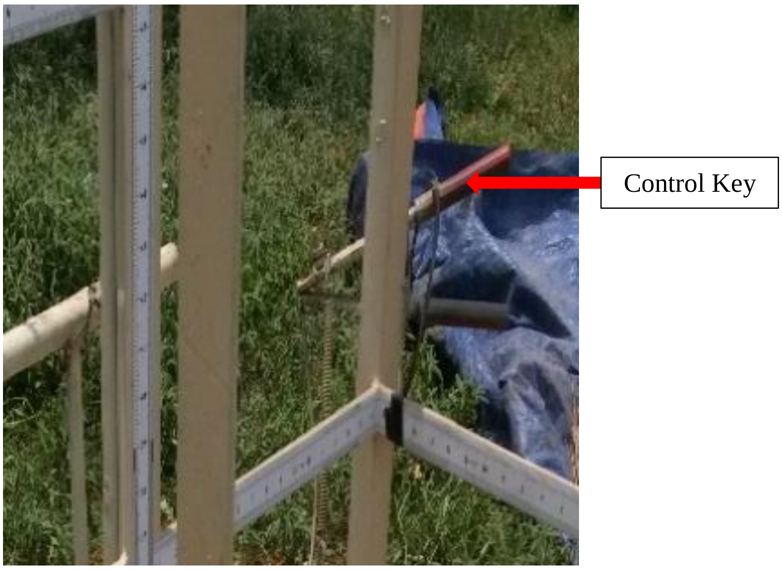


Figure 3.34: Control key

Figure 3.35: Base of the bounce-meter

3.9.2 Pin-point penetrometer

To correlate the bounce energy with the in-situ shear strength, it is necessary to measure the in-situ strength of soil. In this research it is done by using a pin-point penetrometer. It is the modified format of pocket penetrometer. Generally a pocket penetrometer is used to determine the unconfined compressive strength of cohesive soils in ton per sq. foot or kilogram per sq. centimeter. The load is applied by a spring. It has a piston of ¼ inch diameter which needs to penetrate to a certain level usually ¼ inch or 6.25 mm (ELE operational manual). Figure 3.36 shows the pocket penetrometer. If the soil strength is low, an external Adapter Foot of 1 inch (25 mm) diameter has to be attached with it to obtain the unconfined compressive strength.

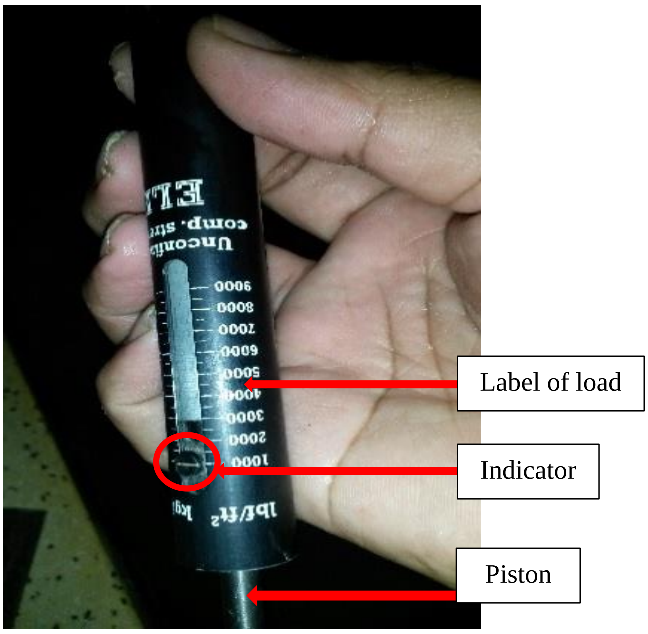


Figure 3.36: Pocket penetrometer

However, in case of pitch soil, soil is very stiff and hard to penetrate the piston of ¼ inch diameter. Therefore, the piston diameter is needed to be reduced so that it could easily be penetrate into the pitch soils. For this research work, the piston diameter was replaced by using cylindrical rods of 2 mm and 3 mm diameters. These rods were attached by using a bruss socket (as shown in figure 3.37). As the diameter of the penetrometer was modified to very small, it is termed as pin-point penetrometer.

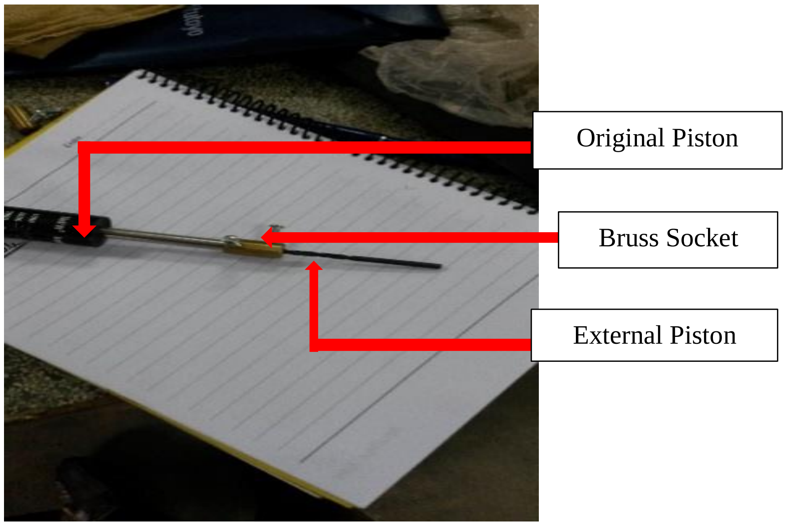


Figure 3.37: Pin-point penetrometer

3.9.3 Determination of nominal spring constant

A ELE pocket penetrometer was used to determine the stiffness of the pitch. As mentioned earlier that, in pocket penetrometer the load is applied by a spring. This article discusses the process of determination of nominal spring constant of the spring. First of all the deflections of indicator were measured by slide calipers for different loads (labeled on the penetrometer) as shown in Figure 3.38. Afterward, a load vs. deformation curve was plotted. The slope of this curve is the nominal spring constant. Figure 3.39 shows the load vs. deformation curve for the penetrometer. The spring constant of the penetrometer was found as 0.3431 N/mm.

3.9.4 Calibration of pin-point penetrometer

While changing the diameter of the piston it became necessary to calibrate the equipment with the known values. Two questions had to be solved through calibration. (i) how much the pin-point penetrometer to be penetrated, and (ii) how the load value (indicated on the penetrometer label) will be converted for pin-point penetrometer (both 2 mm and 3 mm dia).

Figure 3.38: Determination of spring constant

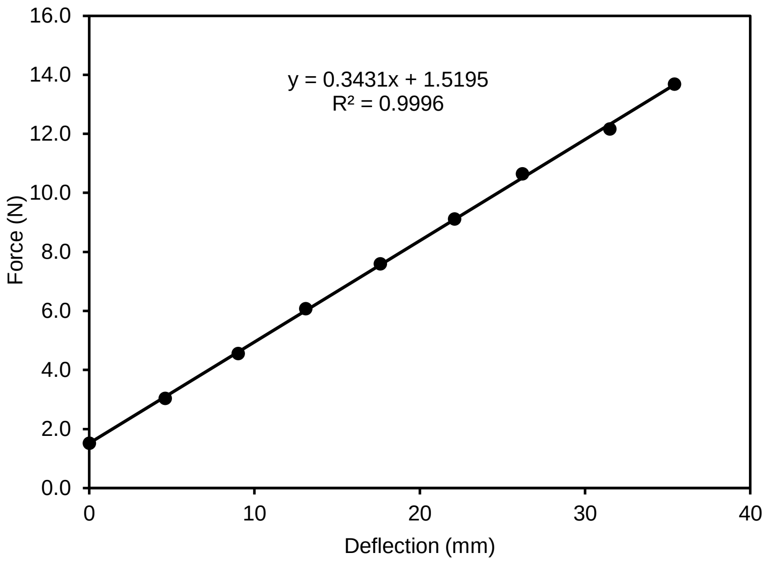


Figure 3.39: Load vs. deformation curve

Figure 3.40: Reading on miniature pitch by penetrometer

To calibrate the pin-point penetrometer five miniature buckets were filled with five different combinations of soils. After drying few days at room temperature the penetrometer readings were taken on all these miniatures (as shown in figure 3.40). Afterward by using the spring constant value, for each corresponding reading of penetrometer (labeled reading on the penetrometer) on specific miniature the deflections of indicator were calculated (for both 2 mm and 3 mm diameter). Table 3.9 gives the detail calculation of deflections for both 2 mm and 3 mm steel rod. In Table 3.9 average penetrometer readings are shown in third column. It is also seen that, the average pressure measured by penetrometer for two miniatures were same it may occurred because of non-uniform mixing and drying of soils in the room.

Figures 3.41 and show the pressure in penetrometer (for ¼ inch diameter piston) vs. deflection of indicator for 2 mm and 3 mm respectively. It is seen that, both graphs provide a linear relationship between the pressure of penetrometer (¼ inch piston) and the deflection of the spring. Knowing the deflection of a 2 mm or 3 mm diameter rod, the pressure on the penetrometer of ¼ inch (6.25 mm) could be calculated from the relationships shown in Figures 3.41 and 3.42.

After that pin-point penetrometer readings (for both 2 mm and 3 mm diameter rods in each miniature) were taken, Figure 3.43 (a). During observation, the rod (modified piston) was allowed to penetrate until the indicator of penetrometer reached the calculated deflection. Then marking was provided to the rod up to the penetrated level, Figure 3.43 (b). Then the pin-point penetrometer was removed and the penetration length was measured by a slide calipers. Figure 3.43 (c) shows the penetration depth of pin-point penetrometer. For 3 mm diameter rod, the average penetration was found 24 mm. However, for 2 mm diameter rod the whole length of the rod was penetrated but did not reached the specific deflection. If the length of 2 mm diameter rod increased, buckling may occur while pushing into soil.

Hence it can be said that, for only 3 mm diameter rod can be used as a replacement of ¼ inch (6.25 mm) diameter piston. 24 mm is to be penetrated into the soil. The correlation between penetrometer pressure and the deflection of the spring is;

$$\text{Penetrometer Reading}\left(\frac{\text{kN}}{m^2}\right) = 48.539 \times \text{Deflection in indicator (mm)} - 6 \times 10^{-14}$$

Table 3.9: Calculation of deflections for both 2 mm and 3 mm diameter rod

Sample ID	Spring constant (N/mm)	Penetrometer reading (N/m^2)	For 2 mm diameter rod		For 3 mm diameter rod	
			Required force (N)	Deflection (mm)	Required force (N)	Deflection (mm)
1	0.343	72003	0.23	0.66	0.51	1.48
2	0.343	72003	0.23	0.66	0.51	1.48
3	0.343	96004	0.30	0.88	0.68	1.98
4	0.343	96004	0.30	0.88	0.68	1.98
5	0.343	264011	0.83	2.42	1.87	5.44

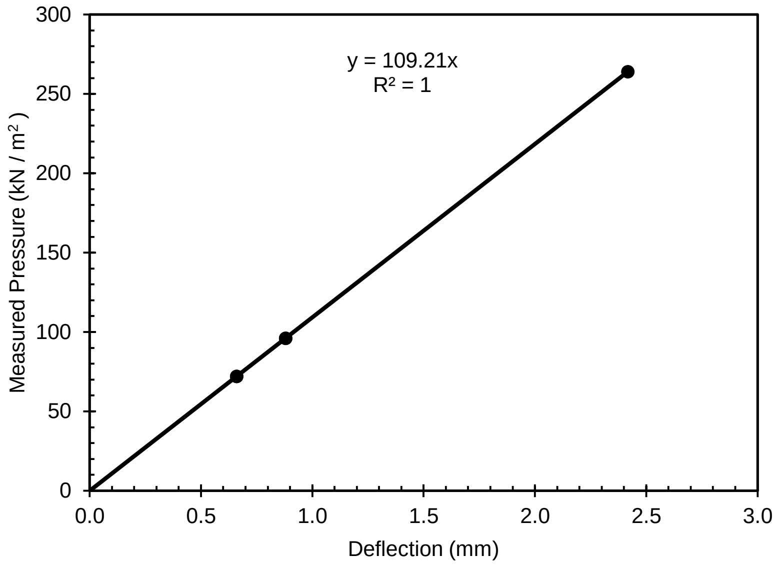


Figure 3.41: Pressure vs. deflection curve for 2 mm diameter

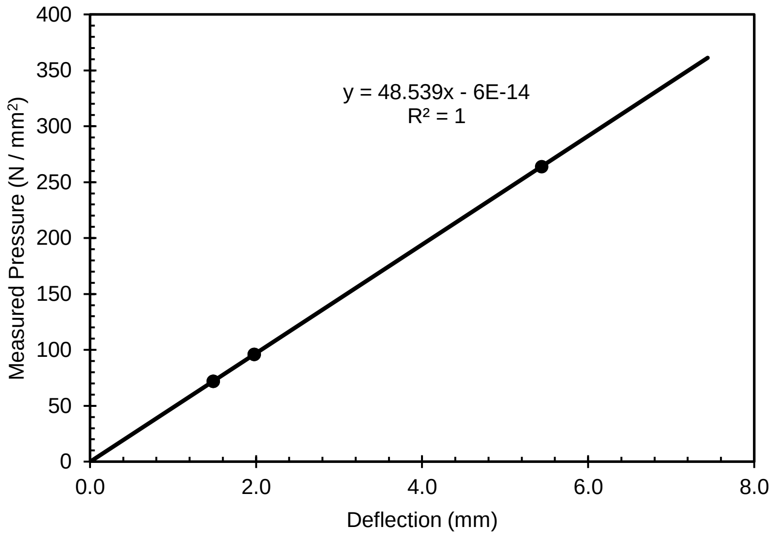
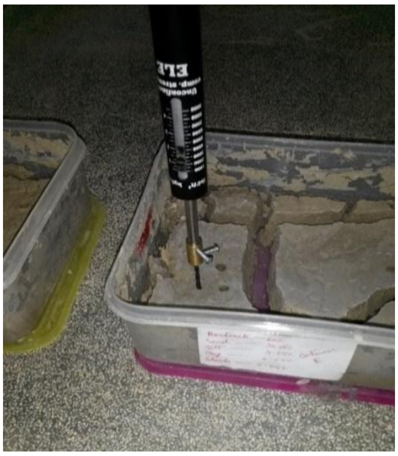


Figure 3.42: Pressure vs. deflection curve for 3 mm diameter



(a) Pin-point penetrometer reading (b) Marking the rod up to penetrated level

(c) Penetration depth of pin-point penetrometer

Figure 3.43 (a to c): Pin-point penetrometer operation

3.10 Field Test

After completion of pitch preparation and equipment calibration, field tests were conducted on the pitches. Measurement of bounce, crack width, stiffness of pitches, field density and moisture content were included in field tests. The tests are described as under.

3.10.1 Bounce measurement

Measuring the bounce height on a pitch while a ball was falling from a certain height was done using bounce meter. At first, the bounce meter was placed on the pitch in such a way that the center ball hanger of bounce meter and the center of the pitch were in the same vertical line. The level of the bounce meter was adjusted by water level, Figure 3.44. Then two cameras were set on the movable camera stand. Panasonic SZ1 with 16.1 megapixel was set as front camera to focus the X-axis (local horizontal axis with respect to bounce-meter) and Z-axis (global vertical axis). A Nikon COOLPIX S2600-14 megapixel was set as a side camera to focus on the Y-axis (local horizontal axis with respect to bounce-meter) and Z-axis. Movable stand of the bounce meter was moved to a desire height. Afterword a trial test was conducted to adjust the height of camera stand. The setup became ready for bounce test.

On every pitch for each specific height 6 specific heights, ball was dropped 10 times. The specific falling heights were maintained between 5 ft. to 10 ft. (1500 mm to 3000 mm). Figure 3.45 (a) shows the arrangement of bounce test. After every 10 drops for a certain height the video backups of both cameras were collected to the computer as shown in Figure 3.45 (b). Simultaneously, similar procedure was followed for all the pitches. The bounce tests were performed in two successive days (on 29 April and 30 April, 2016) to observe the consistency of pitches.

Figure 3.44: Leveling the bounce meter by water level

(a) Arrangements of bounce test

(b) Collection of video backup from cameras

Figure 3.45: Arrangements of bounce test and video backup

(a) Rebound height calculation

To fulfill the objective it became necessary to find out the rebound height of the ball after bounce on the pitch. The rebound height was calculated from the velocity of the ball after bounce. The velocity is a function of distance with respect to time. Therefore, the velocity can be measured by knowing different positions of moving object (ball) at different times. For this purpose the collected videos from the field tests, were transferred into still pictures by Adobe premierePro cc 2015. Each video file was converted into still pictures in a manner that, 60 frames (still pictures) generated per second. The rebound velocity of the ball was measured by using "imageJ 1.51 g" software after analyzing the frames which were found from the field tests video. From the frames for a specific pitch and specific height of falling, two different frames were selected at a time interval of Δt. First of all in the first frame three base points of known position were selected to find out the scale factor of the frame. Then the top most point of the ball was selected to know the horizontal and vertical position (coordinates) of the ball with respect to the origin (in imageJ 1.51 g upper left corner is the default origin). Figure 3.46 (a) shows the selection of first frame. Let L_{x1} and L_{z1} are the horizontal and vertical positions respectively with respect to the origin. Afterward in the second frame same base points were selected to find out the scale factor. Then the top most point of the ball was selected which showed the vertical and horizontal position of the ball with respect to the origin, Figure 3.46 (b). Let L_{x2} and L_{z2} are the horizontal and vertical positions respectively with respect to the origin.

Then the horizontal velocity component (captured in the front camera) was calculated as,

$$V_x = \frac{(L_{x2} - L_{x2})}{\Delta t} \quad (3.2)$$

The vertical component of velocity (captured in the front camera) was calculated as,

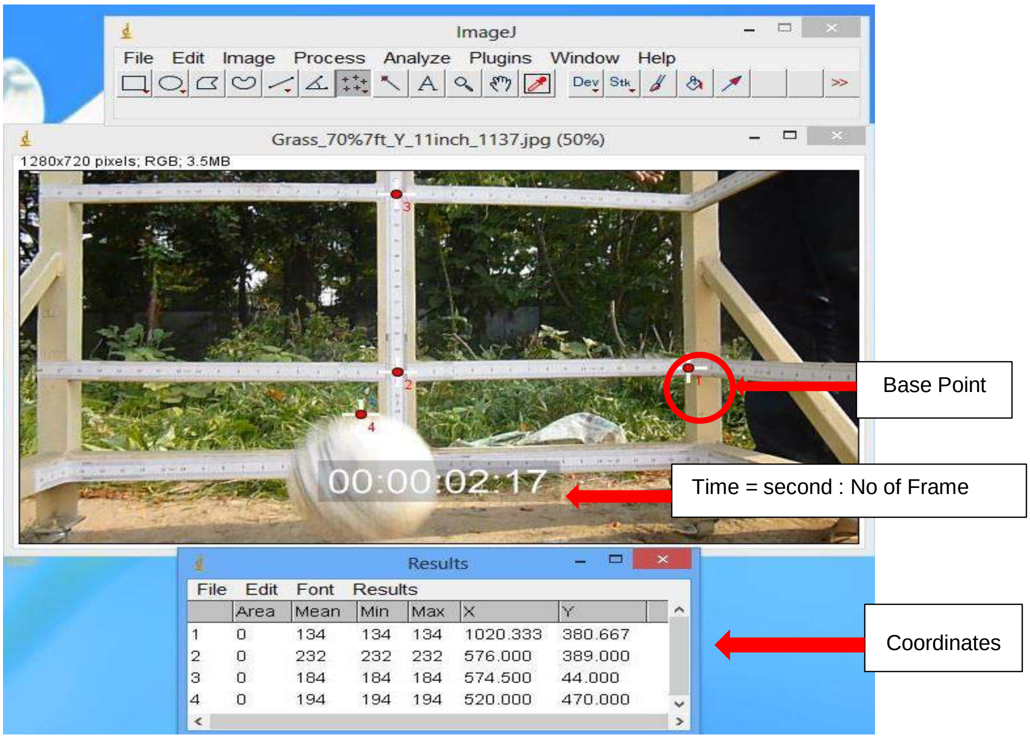
$$V_z = \frac{(L_{z2} - L_{z1})}{\Delta t} \quad (3.3)$$

V_x and V_z were calculated from the video of captured in the front camera. Similarly for the same pitch and same height of fall the V_y (horizontal velocity component) and V_z (vertical component) were calculated from the video captured in side camera. The equations of the horizontal component (captured in side camera) is,

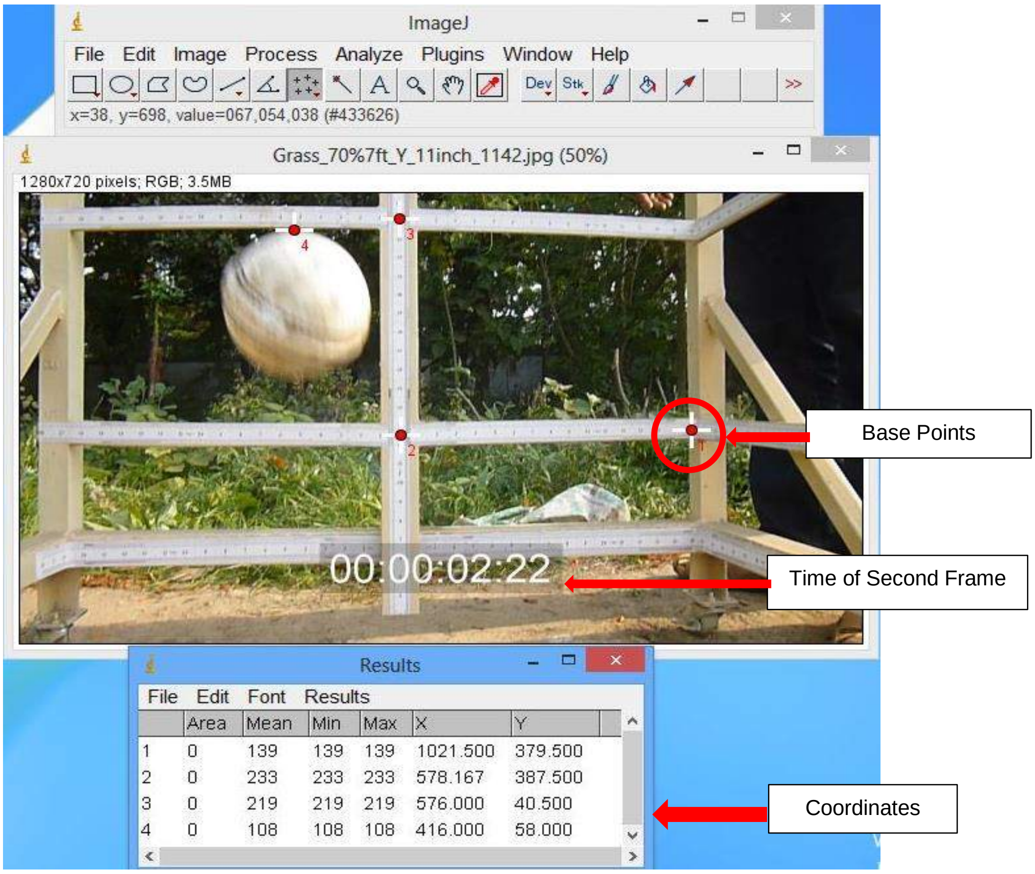
$$V_y = \frac{(L_{y2} - L_{y2})}{\Delta t} \quad (3.4)$$

The vertical component of velocity (captured in the side camera) is,

$$V_z = \frac{(L_{z2} - L_{z2})}{\Delta t} \quad (3.5)$$



(a) Coordinate of the ball in the first frame



(b) Coordinate of the ball in the second frame

Figure 3.46: Coordinates of the ball in different frames

It is seen that, both front and side camera gave the vertical component of velocity which are actually same. That is why, only one the horizontal component was taken from the side camera. Afterward, the velocity was calculated from the following equation,

$$V = \sqrt{V_x^2 + V_y^2 + V_z^2} \qquad (3.6)$$

Frome the basic equation of motions,

$$V_f^2 = V^2 - 2gh$$

$V^2 = 2gh$ [as the final velocity become zero when the ball reach its maximum height]

$$h = \frac{V^2}{2g} \qquad (3.7)$$

Taking V value from Equation (3.6), the rebound height was measured from Equation (3.7).

(c) Correction of parallax error

There were two scales (one horizontal and another vertical) in front of each camera at a distance of 3 ft (900 mm). The ball hanger was centered at middle of the bounce meter. Therefore, when the cameras (both front and side camera) focused on the ball the scale was 1.5 ft (450 mm) behind the actual position of the ball. As a result the reading showed in the scale was slightly deflected and correction was done for both vertical and horizontal scale. Figure 3.47 illustrates the details of vertical scale correction. For vertical scale if the camera height is "h" and the vertical scale reading is "H" then the actual vertical reading would be

$$L_z = \frac{(H-h)}{2} \qquad (3.8)$$

Similarly, in horizontal plane the camera focus slightly deflected due to the distance of focus object and the scale. Figure 3.48 illustrates the details of horizontal scale correction. If the horizontal scale readinsg is "b" then the deflection was adjusted by the following equation.

$$L_x \text{or } L_y = \frac{b}{2} \qquad (3.9)$$

3.10.2 Ball used in bounce test

A cricket ball plays a great role in a cricket match. The weight, seam, age, diameter etc. are also the controlling factors of bounce on a pitch. An old ball with roughly tearing surface can provide a lower bounce than a new ball remaining all other factors constant. In this research for bounce test a new white ball of 156.7 gm. (5.53 ounce) weight was used. The average maximum diameter of the ball was found 72.8 mm. Moreover, the average minimum diameter of the ball was found 72.0 mm.

3.10.3 Measurement of stiffness of pitches

In mechanics, stiffness is the load per unit deformation (unit is load per displacement). However, in soil mechanics the modulus of sub-grade refers to the stiffness of subgrade (TxDOT, 1999). In the present study, the pin-point penetrometer (3 mm dia) used measured the pressure (kN/m^2) per 24 mm penetration, which is similar as subgrade reaction. Thus, the results obtained from pin-point penetrometer are referred to stiffness of the surface soil and the unit of stiffness is written as kN/m^2.

While performing the bounce test in the field, at the same time the calibrated pin-point penetrometer readings were collected for all of the pitches. Figure 3.49 (a) shows the collection process of pin-point penetrometer readings. By measuring the deflections of the indicator the pin-point penetrometer readings were converted in to actual penetrometer readings. Figure 3.49 (b) shows the measuring the deflection of indicator. Table 3.10 shows the stiffness of all pitches.

3.10.4 Measurement of crack width

Prior to the bounce test the average maximum crack width was measured by slide calipers. Figure 3.50 shows the crack width measuring procedure. Table 3.11 gives the details of average crack width for different crack control system. Figure 3.51 gives the comparison graph of average crack width for different crack control systems. It is seen that, as the percent of bentonite increases the average crack width also increases for no control and vegetation crack control pitches. Whereas, for artificial crack control pitches this relationship follows a polynomial pattern. For a specific percentage of bentonite, the average crack width for no crack control system is higher, whereas, the average crack width for both natural and artificial crack control system are mostly same (except two clay content).

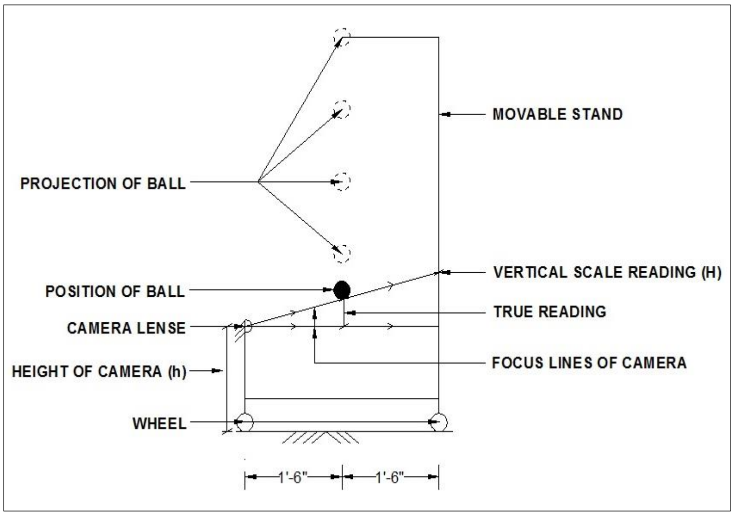


Figure 3.47: Section in the vertical plane of bounce meter

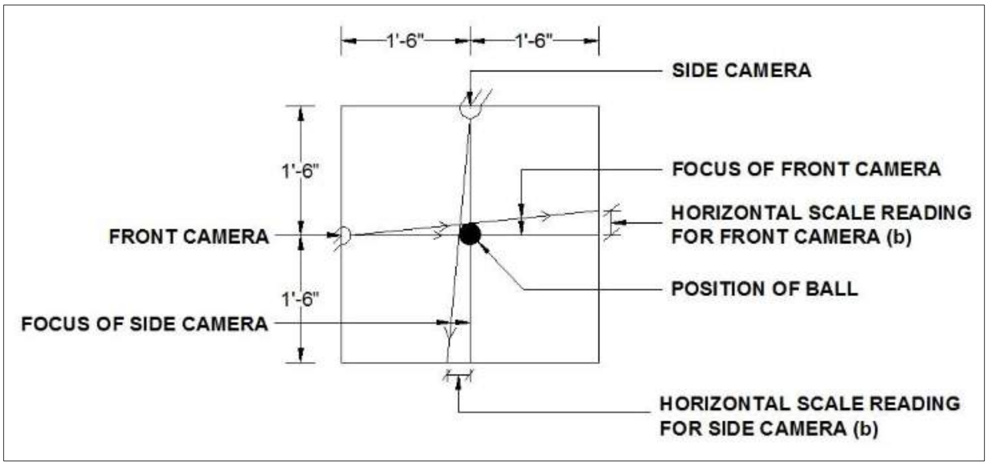


Figure 3.48: Section in the horizontal plane of bounce meter

(a): Measuring the stiffness of pitch

(b): Measuring the deflection of indicator

Figure 3.49: Measurement of pitch stiffness using indicator

Table 3.10: Summary of stiffness of pitches

Combination No	No crack		Vegetation crack control		Artificial crack control	
	Deflection (mm)	Stiffness (kN/m^2)	Deflection (mm)	Stiffness (kN/m^2)	Deflection (mm)	Stiffness (kN/m^2)
CB_1	22.2	1078	22.4	1087	27.5	1334
CB_2	26.0	1261	24.9	1208	25.4	1232
CB_3	29.5	1431	26.5	1286	22.3	1082
CB_4	32.5	1577	28.6	1385	37.6	1822
CB_5	38.4	1860	30.0	1455	43.9	2130

Figure 3.50: Measuring the crack width

Table 3.11: Crack width at different crack control system

Combination No	Average crack width (mm)		
	No crack control	Vegetation crack control	Artificial crack control
CB_1	10.2	8.2	13.0
CB_2	15.7	14.3	10.2
CB_3	19.3	17.9	7.8
CB_5	25.6	19.2	16.5
CB_5	28.9	23.1	21.8

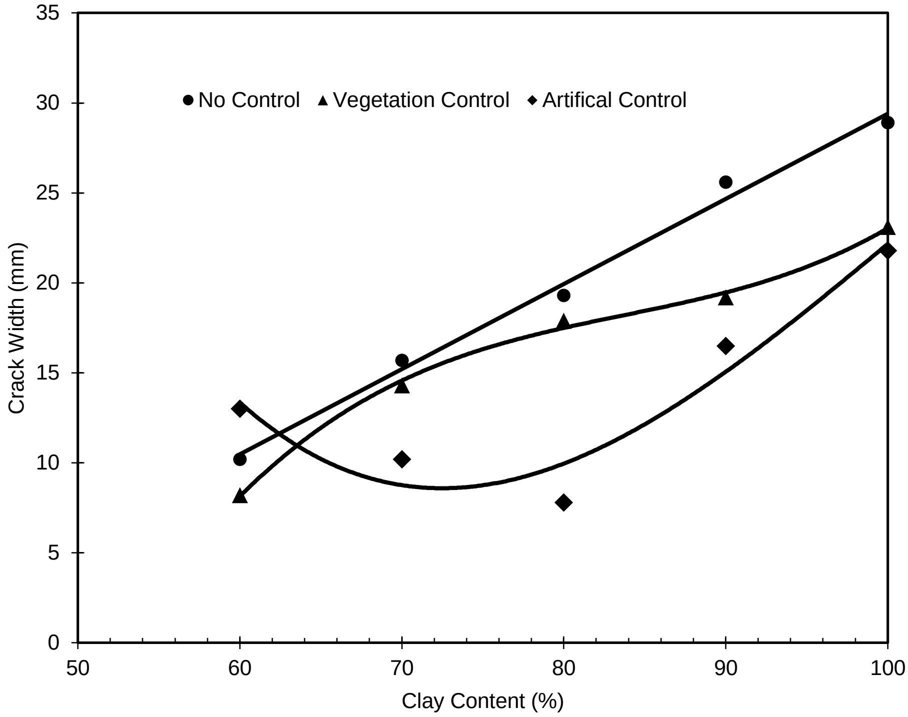


Figure 3.51: Comparisons of crack width for different crack control system

3.10.5 Field density measurement

On completion of bounce test, field density test was performed on the bulli of each pitch following the procedures of ASTM D-1556. Figure 3.52 shows the field density test of bulli.


Figure 3.52: Field density test of bullis

There were fifteen miniatures bullies of five different combinations (three bullis contain same combination) and five tests were performed for different combinations. It was considered that, due to same combination and same optimum moisture content the density would be same. Test results are presented in Table 3.12.

Table 3.12: Field density test results for different combinations of bulli

Combination	CB_1	CB_2	CB_3	CB_4	CB_5
Percent Bentonite (%)	60	70	80	90	100
Maximum Dry Density in Lab (kN/m^3)	17.0	16.2	15.1	14.9	14.9
Field Density at Dry condition (kN/m^3)	16.9	16.2	16.8	16.4	15.5
Relative Density (%)	99.4	100.0	111.3	110.1	104.0

3.10.6 Determination of moisture content of the pitches

In-situ moisture content has a great role in stiffness and even in bounce height. Therefore, the in-situ moisture content was measured after completion of bounce test. Table 3.13 shows the field moisture content after the completion of bounce test. The dry up rate of pitch decreases with the increase of the depth. Therefore, the moisture contents were measured at two different layers (top and bottom). It can be seen that, there were a difference between the top and bottom layer water content. However, these differences were high for artificially crack controlled pitches. The top soils were almost dried, whereas, the bottom soils were contained huge amount of moisture. Probably the geotextile may physically have segregated the pitch soils in to two layers. Due to this the stiffness of the pitches (artificial crack control system) gave non-linear relationship with respect to clay contain of the pitch soils compositions.

Table 3.13: Moisture content of different pitches

Crack control system	Bentonite content (%)	Layer	Moisture content (%)	Difference between two layers moisture content (%)
No Crack Control	60	Top	13.1	4.1
		Bottom	17.2	
	70	Top	13.4	4.6
		Bottom	18.0	
	80	Top	12.4	4.3
		Bottom	16.7	

Crack control system	Bentonite content (%)	Layer	Moisture content (%)	Difference between two layers moisture content (%)
	90	Top	12.1	4.4
		Bottom	16.5	
	100	Top	11.5	5.8
		Bottom	17.3	
Vegetation Crack Control	60	Top	15.3	2.2
		Bottom	17.5	
	70	Top	13.5	1.9
		Bottom	15.4	
	80	Top	14.1	3.4
		Bottom	17.5	
	90	Top	12.1	2.8
		Bottom	14.9	
	100	Top	11.2	3.1
		Bottom	14.4	
Artificial Crack Control	60	Top	13.3	5.0
		Bottom	18.3	
	70	Top	13.8	5.8
		Bottom	19.6	
	80	Top	14.7	5.9
		Bottom	20.6	
	90	Top	12.4	6.8
		Bottom	19.2	
	100	Top	11.8	7.2
		Bottom	19.0	

Chapter 4
RESULTS AND DISCUSSION

4.1 General

This study was aimed at establishing relationships between bounce characteristics and geotechnical parameters of cricket pitch soil, so as to forecast the bounce index. To fulfill the objectives field and laboratory tests were carried out on specially prepared model pitch using purpose built bounce meter, and data were obtained for rebound height, stiffness of the pitch, crack width and moisture content.

The present study was conducted on three types of pitches; (i) no crack controlled pitches, (ii) vegetation crack controlled pitches, and (iii) artificial crack controlled, with geotextile, pitches. Cricket pitch bullies were prepared using various proportions of clay (bentonite) content. Rebound height of the cricket ball was measured using photogrammetric techniques and by dropping the ball from desired heights of a specially prepared bounce meter. A special stiffness measuring tool was designed and fabricated to measure the stiffness of the pitch bulli. The width of cracks developed due to drying of the bulli was measured using calipers. In this study the bounce index was defined and proposed as Equation (4.1).

$$\text{Bounce Index} = \frac{h}{H^{0.5}} \qquad (4.1)$$

Where, h is the rebound height in mm and H is the falling height of the ball in mm.

The rebound ht. for different pitches are given in Table 4.1. Table 4.2 and Table 4.3 present the bounce index values and the coefficient of restitution for different crack control systems. Clay content, crack width, moisture content, soil stiffness and bounce index values are plotted in various combinations. The relations obtained are presented in the following Sections. This is worth mentioning that the present study uses a pitch moisture content of 10 to 15% and clay contents of 40 to 80% content (by volume), and all the analyses of data and results are valid for the ranges of moisture content and clay content as mentioned.

4.2 Effects of Clay Content on Crack Width

Cracks were found to develop on the pitches when the fine particles of the pitch released water due to drying up of the pitch. As crack width increases it affects the stiffness and the rebounce height of the pitch. Thus, the crack width is an indication of bounce index. Crack widths of the pitches were measured and listed in Section 3.10.3. As mentioned earlier in

Section 2.3.1 that excessive and large crack width is not allowed for a cricket pitch. As such, pitches having large cracks (more than 20 mm) were ignored. The effects of clay content on crack width for different crack control systems are discussed in the sub-sections.

Table 4.1: Rebound height (mm) for all pitches

Crack Control System	Combination No	Percent of Clay (%)	Falling Height					
			1500 mm	1800 mm	2100 mm	2400 mm	2700 mm	3000 mm
			Average Rebound Height (mm) on Different Pitches for Different Height of Fall					
No Crack Control	CB_1	48	223	238	256	272	289	306
	CB_2	56	247	263	284	301	319	337
	CB_3	63	279	301	311	329	347	366
	CB_4	71	350	372	391	414	438	462
	CB_5	79	405	417	453	477	499	528
Vegetation Crack Control	CB_1	48	214	231	249	265	284	303
	CB_2	56	240	258	277	296	316	334
	CB_3	63	267	286	306	324	345	363
	CB_4	71	339	361	380	400	423	444
	CB_5	79	383	405	426	450	471	496
Artificial Crack Control	CB_1	48	397	420	441	462	487	512
	CB_2	56	244	263	279	298	316	334
	CB_3	63	221	238	253	270	286	306
	CB_4	71	372	391	411	432	453	477
	CB_5	79	552	575	603	628	653	683

Table 4.2: Bounce Index for all pitches

Crack Control System	Combination No	Percent of Clay (%)	Falling Height					
			1500 mm	1800 mm	2100 mm	2400 mm	2700 mm	3000 mm
			Average Bounce Index of Different Pitches for Different Height of Fall					
No Crack Control	CB_1	48	0.33	0.32	0.32	0.32	0.32	0.32
	CB_2	56	0.36	0.35	0.35	0.35	0.35	0.35
	CB_3	63	0.41	0.40	0.39	0.38	0.38	0.38
	CB_4	71	0.51	0.50	0.48	0.48	0.48	0.48
	CB_5	79	0.59	0.56	0.56	0.55	0.55	0.55

Crack Control System	Combination No	Percent of Clay (%)	Falling Height					
			1500 mm	1800 mm	2100 mm	2400 mm	2700 mm	3000 mm
			Average Bounce Index of Different Pitches for Different Height of Fall					
Vegetation Crack Control	CB_1	48	0.31	0.31	0.31	0.31	0.31	0.31
	CB_2	56	0.35	0.35	0.34	0.34	0.35	0.35
	CB_3	63	0.39	0.38	0.38	0.38	0.38	0.38
	CB_4	71	0.50	0.48	0.47	0.46	0.46	0.46
	CB_5	79	0.56	0.54	0.53	0.52	0.52	0.51
Artificial Crack Control	CB_1	48	0.50	0.48	0.47	0.46	0.46	0.45
	CB_2	56	0.36	0.35	0.35	0.35	0.35	0.35
	CB_3	63	0.32	0.32	0.31	0.31	0.31	0.32
	CB_4	71	0.58	0.56	0.55	0.53	0.53	0.52
	CB_5	79	0.81	0.77	0.75	0.73	0.71	0.71

Table 4.3: Coefficient of restitution for all pitches

Crack Control System	Combination No	Percent of Clay (%)	Falling Height					
			1500 mm	1800 mm	2100 mm	2400 mm	2700 mm	3000 mm
			Average Bounce Index of Different Pitches for Different Height of Fall					
No Crack Control	CB_1	48	0.38	0.36	0.35	0.33	0.32	0.32
	CB_2	56	0.40	0.38	0.36	0.35	0.34	0.33
	CB_3	63	0.43	0.41	0.38	0.37	0.36	0.35
	CB_4	71	0.48	0.45	0.43	0.41	0.40	0.39
	CB_5	79	0.52	0.48	0.46	0.44	0.43	0.42
Vegetation Crack Control	CB_1	48	0.37	0.36	0.34	0.33	0.32	0.32
	CB_2	56	0.40	0.38	0.36	0.35	0.34	0.33
	CB_3	63	0.42	0.40	0.38	0.36	0.35	0.35
	CB_4	71	0.47	0.44	0.42	0.40	0.39	0.38
	CB_5	79	0.50	0.47	0.45	0.43	0.41	0.40
Artificial Crack Control	CB_1	48	0.47	0.44	0.42	0.40	0.39	0.38
	CB_2	56	0.40	0.38	0.36	0.35	0.34	0.33
	CB_3	63	0.38	0.36	0.34	0.33	0.32	0.32
	CB_4	71	0.51	0.48	0.45	0.43	0.42	0.41
	CB_5	79	0.60	0.56	0.53	0.51	0.49	0.47

4.2.1 Crack width for no crack controlled pitches

Data of clay content and crack width are plotted in Figure 4.1. Figure 4.1 it is evident that crack width is linearly proportional to the clay content of the pitch. Crack width increases with the increase of clay content. Statistical analysis of the data reveals that there exists strong linear correlation, with a correlation coefficient (r^2) of 0.9918, between clay content (CC) and crack width (C_w), and the relationship may be expressed as:

$$C_w = 0.5977CC - 18.004 \tag{4.2}$$

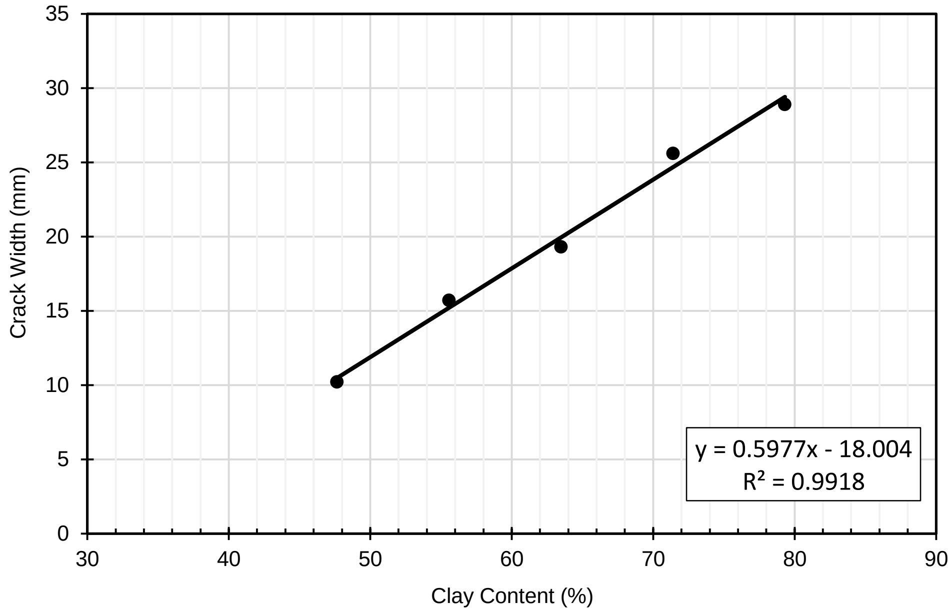


Figure 4.1: Crack width vs. clay content for no crack controlled pitches

4.2.2 Crack width for vegetation crack controlled pitches

Figure 4.2 shows the relationship between clay content of the pitch and the average crack widths for vegetation crack control pitches. It can be seen that, Figure 4.1, the crack width increases with the increase of clay content by maintaining a linear relationship with a coefficient of correlation of 0.9516. The relationship may be expressed as:

$$C_w = 0.4385CC - 11.296 \tag{4.3}$$

It was also observed that, for same composition of pitch soil, crack width for a vegetation crack control pitch was smaller than a no crack control pitch. It may have taken place because of the moisture held in the root zone of the grasses and the lateral rigidity provided by the strong rhizomes of the grasses on the pitch.

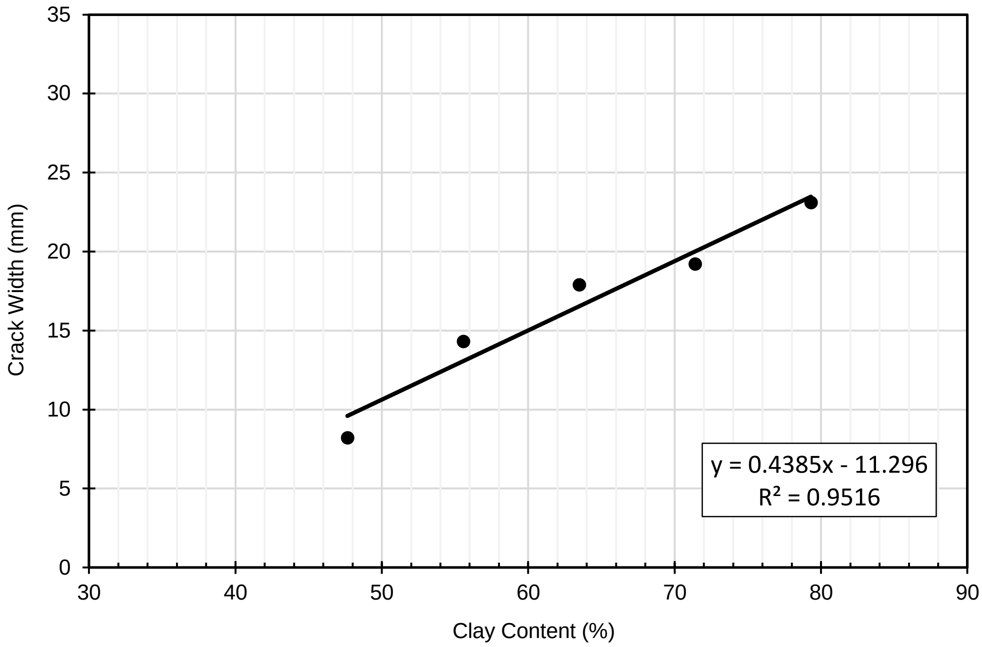


Figure 4.2: Crack width vs. clay content for vegetation crack controlled pitches

4.2.3 Crack width for artificial crack controlled pitches

Figure 4.3 shows the relationship between the clay content of the pitch and the average crack width for artificial crack control pitches. It can be seen that, for artificial crack controlled pitches the crack width maintained two linear relationships with clay content of the pitch. It was also found that, up to about 60% clay content the crack width decreases linearly with the increase of clay content and then increases also linearly. It was also seen that, the average crack width for artificial crack controlled pitches was smaller than both of no crack controlled pitches and vegetation crack controlled pitches. It may have happened because the geotextile sheet (provided inside the artificial crack controlled pitches) provided a uniform lateral resistance. The relationship may be expressed by using two Equations 4.4(a) and 4.4(b).

$$C_w(in\ mm) = -0.3285CC + 28.59 \quad (4.4a)$$

$$C_w(in\ mm) = 0.8845CC - 47.787 \quad (4.4b)$$

4.3 Effects of Moisture Content on Crack Width

As the fine particles released the moisture, the soil body shrinks and the crack developed in the pitch. In this study, moisture contents at the top layer of different pitches were considered to investigate the relationship between moisture content and crack width. The effects of moisture content on crack width for different crack controlled pitches are discussed in the following sub-sections.

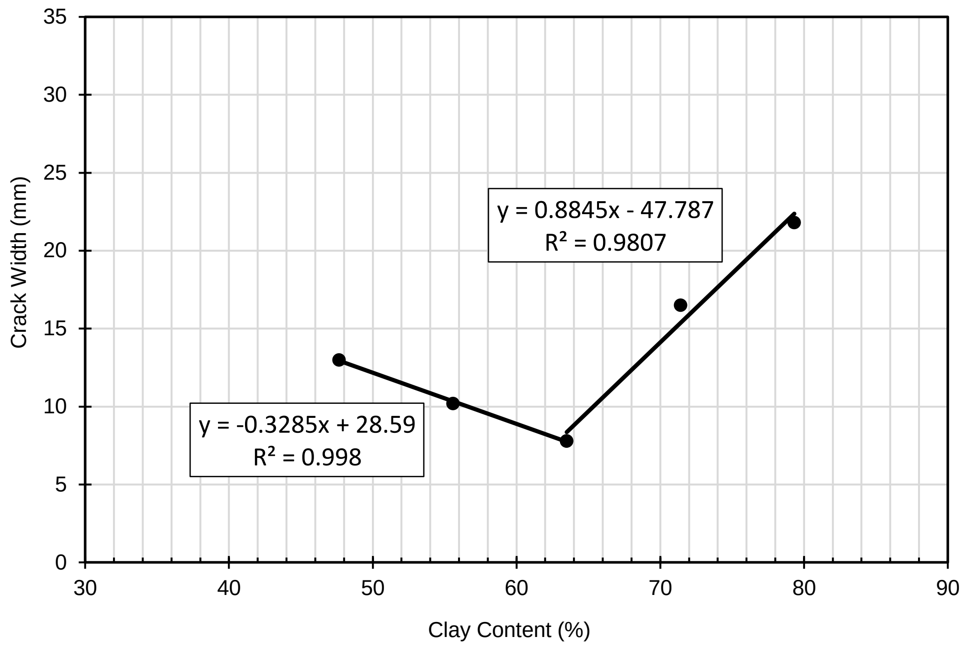


Figure 4.3: Crack width vs. clay content for artificial crack controlled pitches

4.3.1 Moisture content and crack width for no crack controlled pitches

Moisture content and crack width data are plotted in Figure 4.4. It was found that, crack width was inversely proportional to the moisture content at the top layer of the pitch for no crack controlled pitches. Crack width, C_w (in mm) decreases linearly with moisture content (w %) and their relationship may be expressed using Equation (4.5).

$$C_w = 117.87 - 0.7.749w \qquad (4.5)$$

4.3.2 Moisture content and crack width for vegetation crack controlled pitches

Figure 4.5 shows the relationship between crack width and moisture content of the pitch for vegetation crack controlled pitches. Similar to no crack control pitches, the crack width was found inversely proportional with the moisture content (w%). Their relationship may be expressed using Equation (4.6).

$$C_w = 61.315 - 3.3806w \qquad (4.6)$$

4.3.3 Moisture content and crack width for artificial crack controlled pitches

Figure 4.6 shows the relationship between crack width and moisture content at the top layer of the pitch for artificial crack controlled pitches. It is found that, a linear relationship exists between the crack width and the moisture content at the top layer of the pitch. Crack width decreases with the increase in moisture content for artificial crack controlled pitches. The polynomial relationship may have happened because, the geo-textile sheet provided a uniform lateral resistance against crack width, whereas, the moisture content was not varied uniformly. Similar to other types of pitches, the crack width was found inversely proportional with the moisture content (w%). Their relationship may be expressed using Equation (4.7).

$$C_w = 76.081 - 4.71136w \tag{4.7}$$

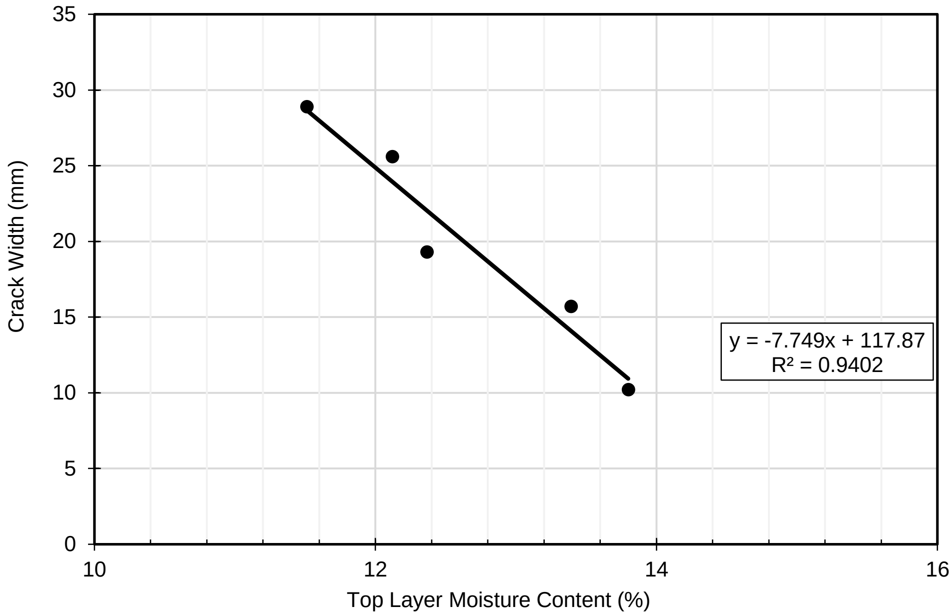


Figure 4.4: Crack width vs. top layer moisture content for no crack controlled pitches

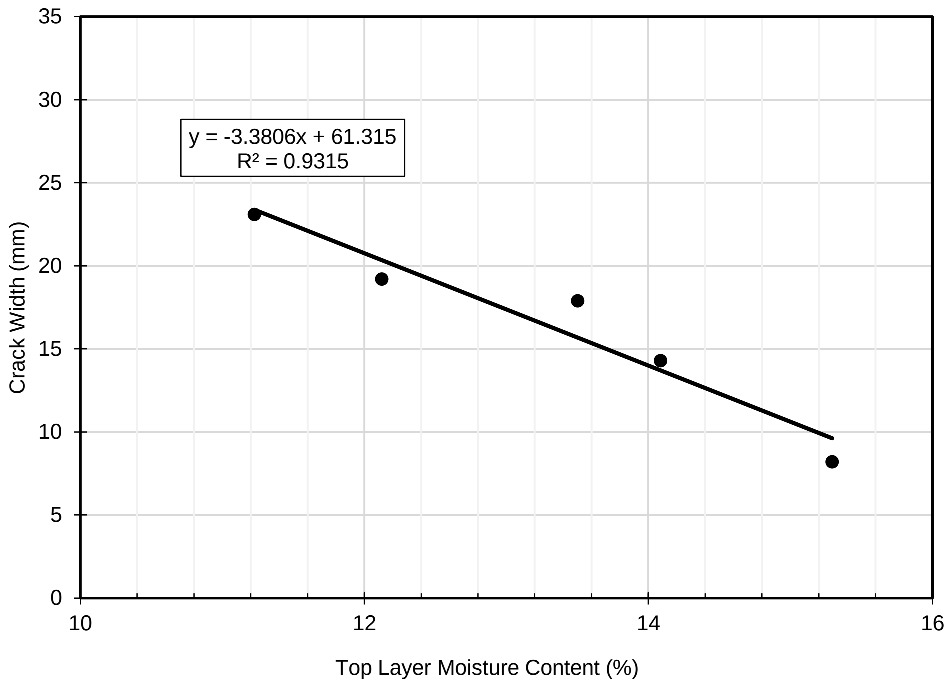


Figure 4.5: Crack width vs. top layer moisture content for vegetation crack controlled pitches

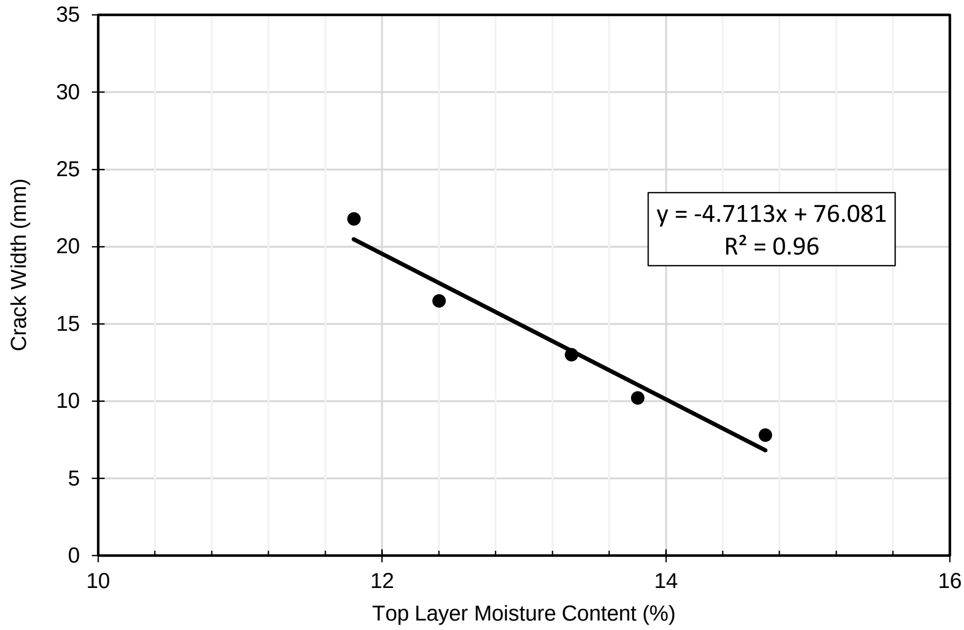


Figure 4.6: Crack width vs. top layer moisture content for artificial crack controlled pitches

4.4 Effects of Clay Content on Stiffness of Pitch Soil

As mentioned earlier in the Section 2.2.3, a smooth elastic hard surface is badly required for good bouncy pitch. The shrinkage properties of the pitch soils give a hard surface to play. In this study, pitches were prepared with clay dominating soil composition and compacted at their optimum moisture content. As high amount fine particles presence in the pitch soils high amount of water could be held in the soil body during construction. During curing period high amount of water released from the particles surface. As a result, the soil mass shrink and become hard. Hence it can be seen that, the stiffness of a soil mass depends on the moisture content and moisture content depends on the amount of clay content. The effects of clay content on the stiffness of pitch are discussed in the subsequent articles.

4.4.1 Clay content and stiffness of pitch soil for no crack controlled pitches

Figure 4.7 shows the relationship between the clay content and the stiffness of pitch for no crack controlled pitches. It was found that, the stiffness (S_n in kN/m^2) of the pitch increased linearly with the increase of clay content of the pitch for no crack controlled pitches.

$$S_n = 23.759CC - 66.89 \quad (4.8)$$

4.4.2 Clay content and stiffness of the pitch soil for vegetation crack controlled pitches

Figure 4.8 shows the relationship between the clay content and the stiffness of the pitch for vegetation crack controlled pitches. From Figure 4.8, it can be seen that stiffness of the pitch is linearly proportional with the clay content of the pitch, with strong correlation coefficient. The relationship may be expressed using the Equation (4.9).

$$S_n = 11.554CC + 550.54 \quad (4.8)$$

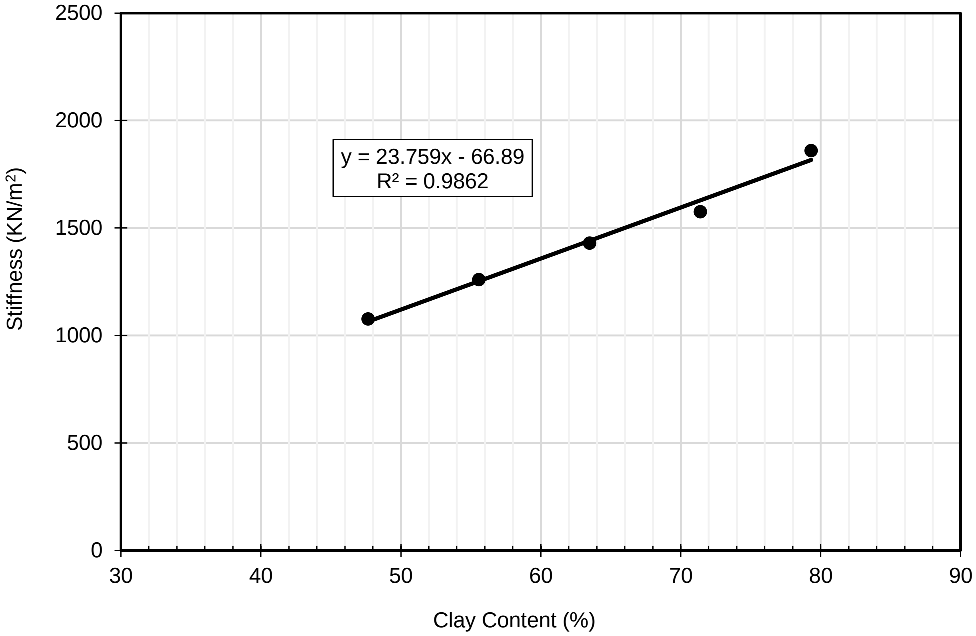


Figure 4.7: Stiffness vs. clay content for no crack controlled pitches

4.4.3 Clay content and the stiffness of pitch soil for artificial crack controlled pitches

Figure 4.9 shows the relationship between the clay content and the stiffness of pitch for artificial crack controlled pitches. It is seen that, there is an optimum clay content up to which stiffness of the pitch decreases with increasing clay content, beyond that stiffness increases with increase in clay content. The optimum clay content is approximately 60%, and the increase and decrease of stiffness may be illustrated by the following Equations.

$$S_n = -15.937CC + 2101.7 \quad (4.9a)$$

$$S_n = 66.2CC - 3049.1 \quad (4.9b)$$

4.5 Effects of Moisture Content on Stiffness of Pitch

Moisture content influences the stiffness of fine soil. If moisture exists in clay soil, it becomes soft and loses its hardness. The effects of moisture content on the stiffness of the soil for different crack control system are discussed in the following sections.

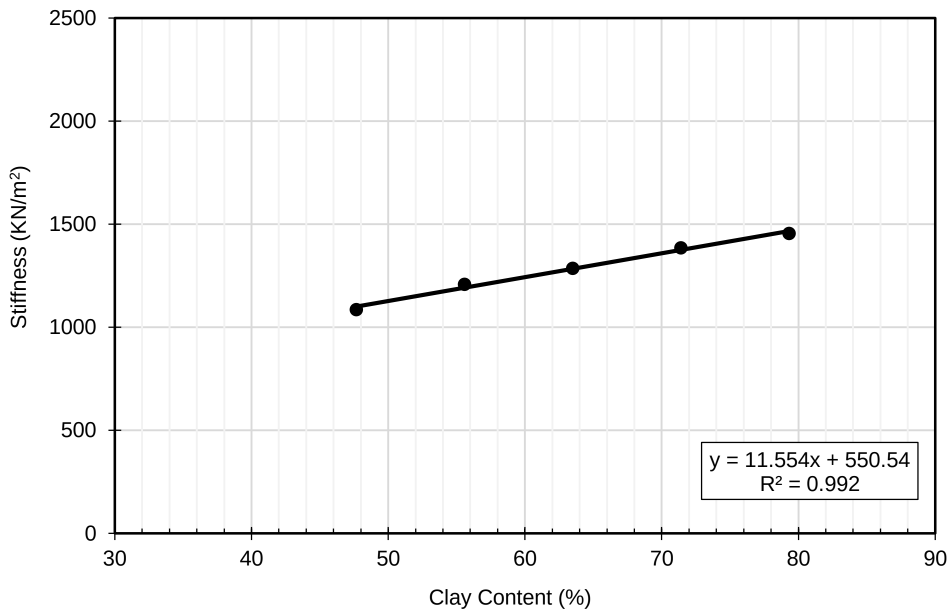


Figure 4.8: Stiffness vs. clay content for vegetation crack controlled pitches

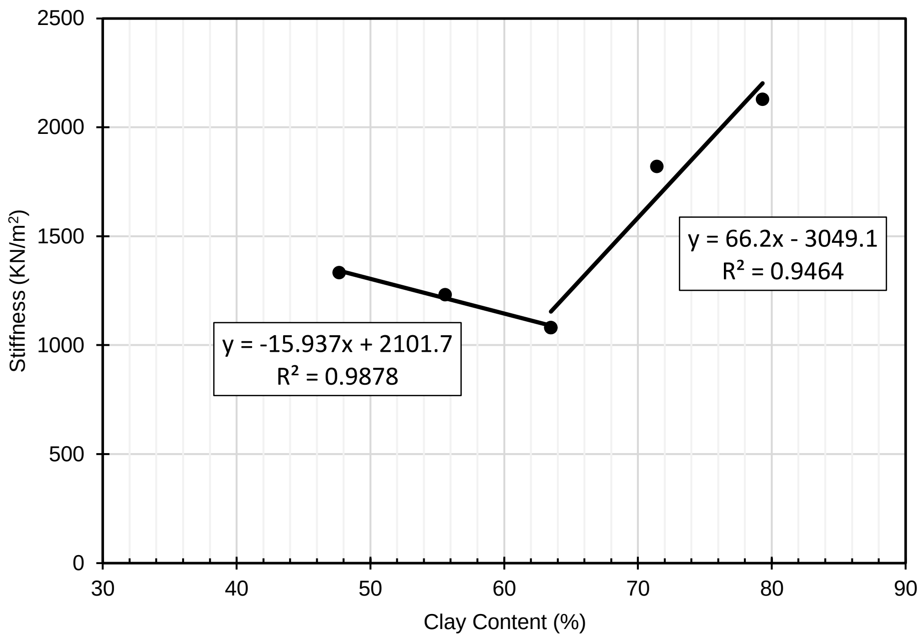


Figure 4.9: Stiffness vs. clay content for artificial crack controlled pitches

4.5.1 Moisture content and stiffness of pitch for no crack controlled pitches

Figure 4.10 shows the relationship between moisture content at the top layer of pitch and the stiffness of pitch for no crack controlled pitches. From the Figure it can be seen that, the stiffness (in kN/m^2) of the pitch soil is inversely proportional to the moisture content at the top layer of the pitch for no crack controlled pitches. The relationship may be expressed as:

$$S_n = 5369.2 - 310.79w \quad (4.11)$$

4.5.2 Moisture content and stiffness of pitch for vegetation crack controlled pitches

Figure 4.11 shows the relationship among the moisture content at the top layer of pitch and the stiffness of pitch for vegetation crack controlled pitches. From the Figure it can be seen that, stiffness (in kN/m^2) of the pitch soil is inversely proportional to the moisture content at the top layer of the pitch for vegetation crack controlled pitches.

$$S_n = 2475.2 - 89.929w \quad (4.12)$$

Comparing Figures 4.10 and 4.11, it is seen that stiffness of both no crack controlled and vegetation crack controlled pitches decreases with the increase of moisture content. However, the change in stiffness for no crack controlled pitches is larger than for vegetation crack controlled pitches for the same amount change in moisture content. This may have occurred as the rhizomes of grasses held the pitches together and formed a relatively uniform surface.

4.5.3 Moisture content and stiffness of pitch for artificial crack controlled pitches

Figure 4.12 shows relationship between moisture content of pitch and stiffness for artificial crack controlled pitches. Similar to other pitches, strong linear relationship exists between stiffness of the pitch and moisture content for artificial crack controlled pitches. As the moisture content at the top layer of the pitch increases the stiffness of the pitch decreases. The relationship may be expressed as:

$$S_n = 6445.1 - 372.93w \quad (4.13)$$

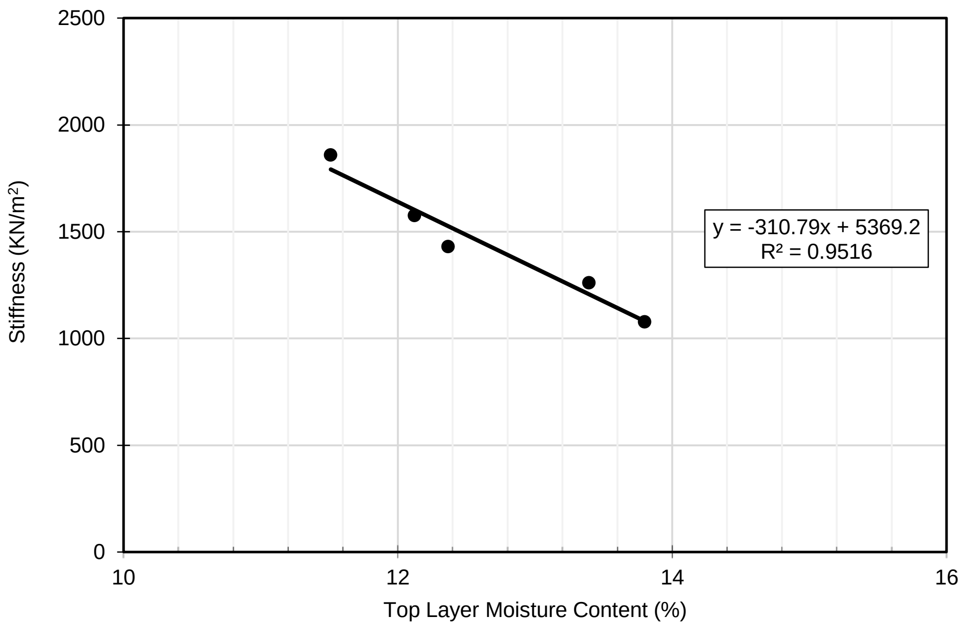


Figure 4.10: Stiffness vs. moisture content at top layer for no crack controlled pitches

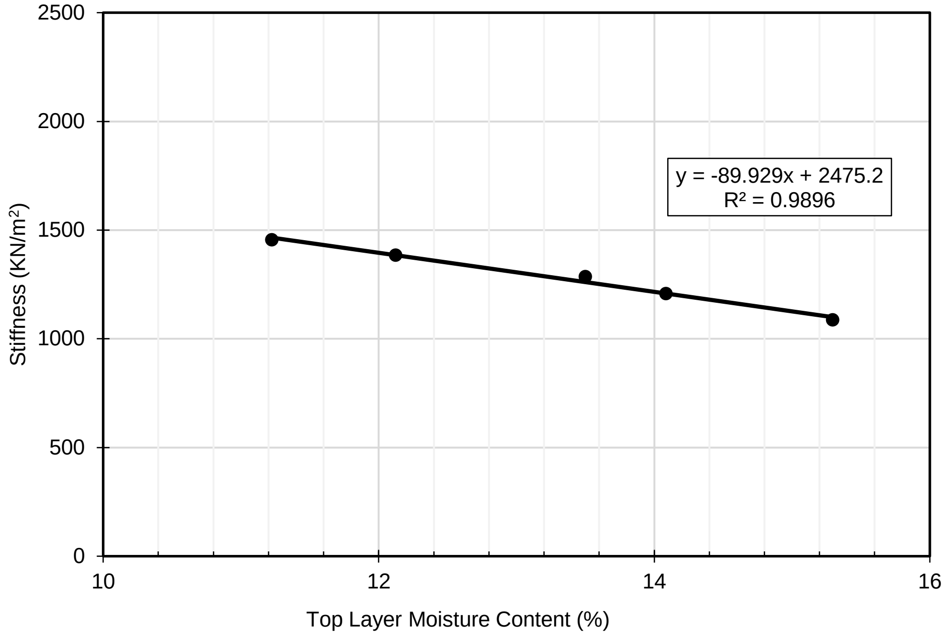


Figure 4.11: Stiffness vs. moisture content at top layer for vegetation crack controlled pitches

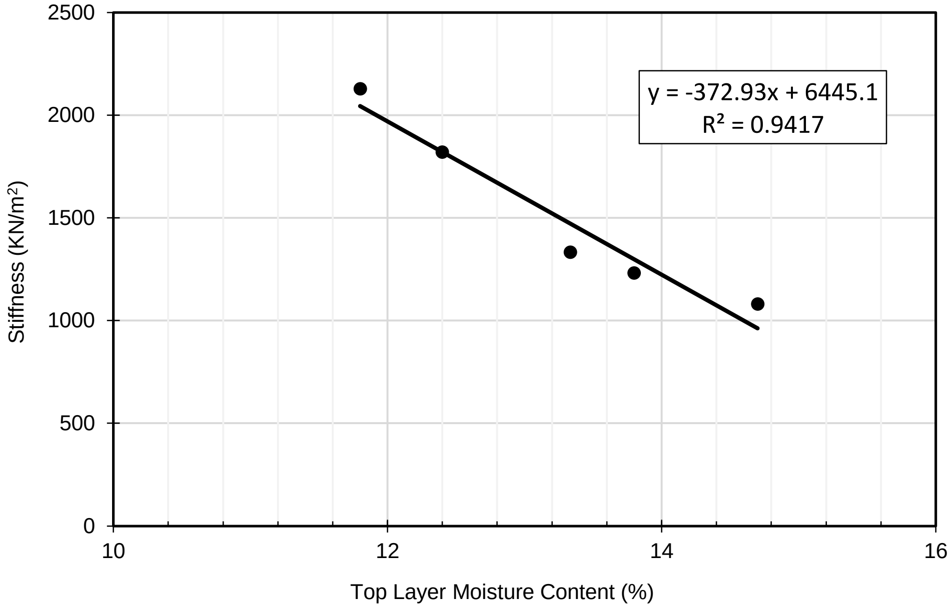


Figure 4.12: Stiffness vs. moisture content for artificial crack controlled pitches

4.6 Effects of Crack Width on Stiffness of Pitch

As the crack develops on the pitches the clay soil shrinks by losing water and gets hardness or stiffness. It indicates that crack width mostly depends of the amount of clay and moisture content. The effects of crack width on the stiffness of pitch for different crack control systems for the specific range of clay content and moisture content are discussed in the following Sub-sections.

4.6.1 Crack width and stiffness of pitch for no crack controlled pitches

Figure 4.13 shows the relationship between crack width on the pitch and the stiffness of pitch for no crack controlled condition. Figure 4.13 indicates that the stiffness of pitch linearly increases with the increase of crack width. Crack width, C_w (in mm) and stiffness, S_n (in kN/m^2) relationship may be expressed by using Equation (4.14).

$$S_n = 25.377Cw + 864.35 \quad (4.14)$$

4.6.2 Crack width and stiffness of pitch for vegetation crack controlled pitches

Relationship between crack width and the stiffness of pitch for vegetation crack controlled pitches is plotted in Figure 4.14. From the Figure it can be seen that, the stiffness of the pitch is linearly proportional to the crack width of the pitch. Crack width, C_w (in mm) and stiffness, S_n (in kN/m^2) relationship may be expressed by using Equation (4.15).

$$S_n = 25.377Cw + 864.35 \quad (4.15)$$

4.6.3 Crack width on stiffness of pitch for artificial crack controlled pitches

Figure 4.15 shows the relationship between crack width on the pitch and the stiffness of pitch for artificial crack controlled pitches. The plot of Figure 4.15 suggests a strong linear correlation between stiffness of the pitch and the crack width for artificial crack controlled pitches. Crack width, C_w (in mm) and stiffness, S_n (in kN/m^2) relationship may be expressed as Equation (4.16).

$$S_n = 78.641Cw + 829.88 \quad (4.16)$$

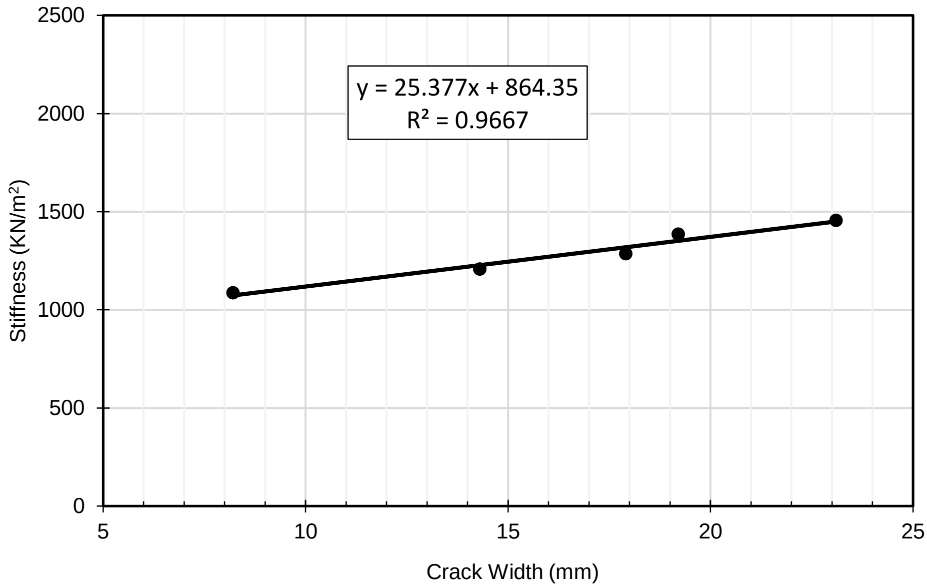


Figure 4.13: Stiffness vs. crack width for no crack controlled pitches

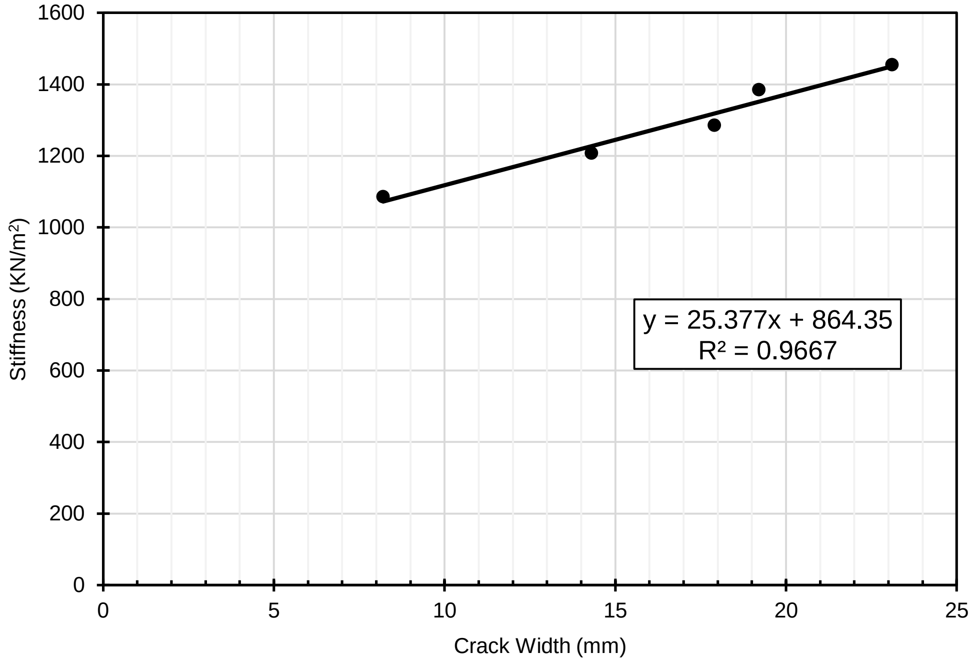


Figure 4.14: Stiffness vs. crack width for vegetation crack controlled pitches

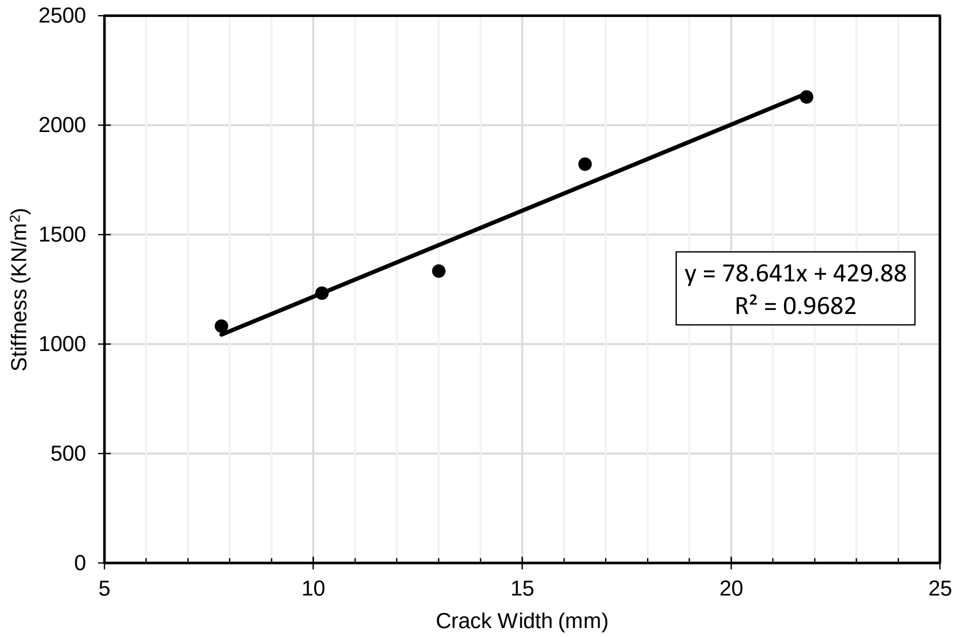


Figure 4.15: Stiffness vs. crack width for artificial crack controlled pitches

4.7 Effects of Clay Content on Bounce Index

To achieve the objectives of the present research, the rebound height was measured on all pitches for different falling heights. Table 4.1 shows the rebound height on the pitches for different crack control systems. It is seen that the rebound heights on no controlled pitches were slightly higher than naturally crack controlled pitches. On the other hand, rebound heights on artificially crack controlled pitches were higher than no crack controlled and naturally crack controlled pitches except combinations 2 and 3.

As discussed in Section 2.2.6, clay content (finer than 0.002 mm) has a great influence in controlling the properties of the pitch. Clay controls the governing factors which influenced the bounce height.

4.7.1 Clay content and bounce index for no crack controlled pitches

Figure 4.16 shows the relationship between the clay content and the bounce index for no crack controlled pitches. Figure 4.16 indicates that, the bounce index (I_B) is linearly related to clay content (CC) for no crack controlled pitches within the limit of clay contents of 35% to 80%. The relation may be expressed as per Equation (4.17).

$$I_B = 0.0096CC - 0.0922 \quad (4.17)$$

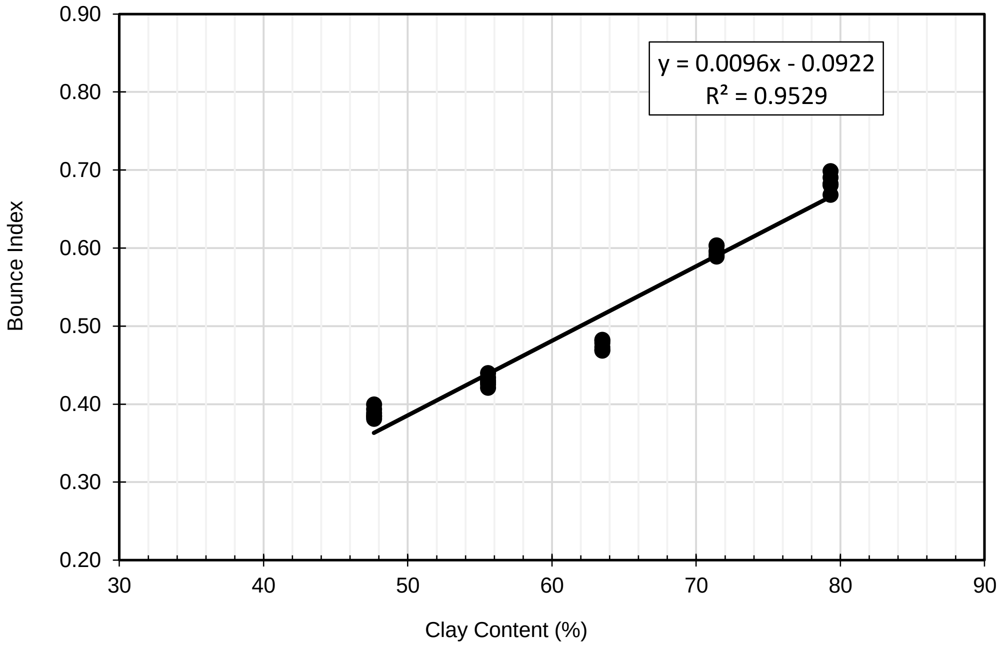


Figure 4.16: Bounce index vs. clay content for no crack controlled pitches

4.7.2 Clay content and bounce index for vegetation crack controlled pitches

Figure 4.17 shows the relationship between clay content and bounce index for vegetation crack controlled pitches. Similar to no control cases, bounce index also increases with increase of clay content linearly, Equation (4.18) with coefficient of correlation, r^2 of 0.95.

$$I_B = 0.0072CC - 0.0461 \quad (4.18)$$

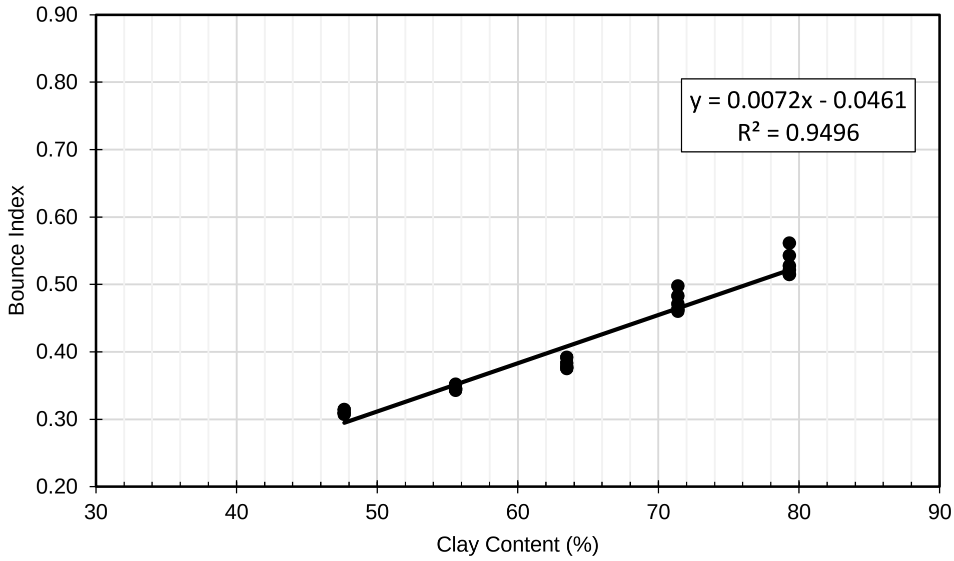


Figure 4.17: Bounce index vs. clay content for vegetation crack controlled pitches

4.7.3 Clay content and bounce index for artificial crack controlled pitches

Figure 4.18 shows the relationship between the clay content and the bounce index for artificial crack controlled pitches. It is observed that, initially the bounce index decrease with the increase of clay content up to 64%, then the bounce index increases with the increase of clay content. The relations may be expressed using Equations (4.19a) and (4.19b).

$$I_B = -0.0096CC + 0.9096 \quad (4.19a)$$

$$I_B = 0.0272CC - 1.4036 \quad (4.19b)$$

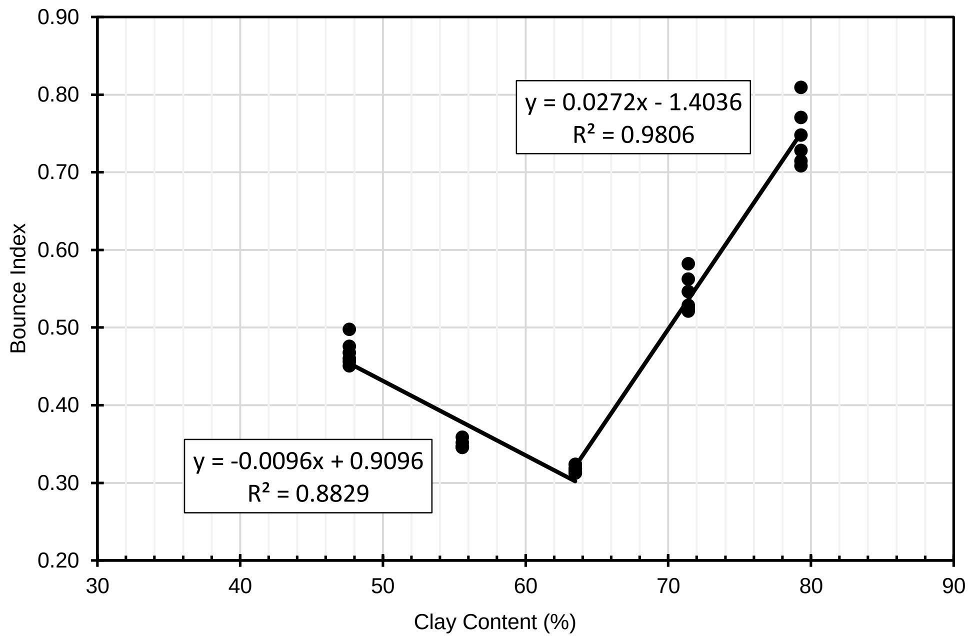


Figure 4.18: Bounce index vs. clay content for artificial crack controlled pitches

4.8 Effects of Stiffness on Bounce Index

Pitch stiffness has great impacts on rebound height. Generally, as the ball bounce on a hard surface the rebound height would be high. For a certain rebound height, a minimum stiffness of the pitch is required. The effects of stiffness on the bounce index for different crack controlled pitches are discussed in below.

4.8.1 Stiffness and bounce index for no crack controlled pitches

Relationship between stiffness of pitch and bounce index of the pitch for no crack controlled pitches is presented in Figure 4.19. It is seen that a linear relationship exists between bounce index and stiffness of the pitch for no crack controlled pitches.

The bounce index increases with the increase of stiffness for no crack controlled pitches and the relationship may be expressed as Equation (4.20).

$$I_B = 0.0003S_n - 0.0508 \quad (4.20)$$

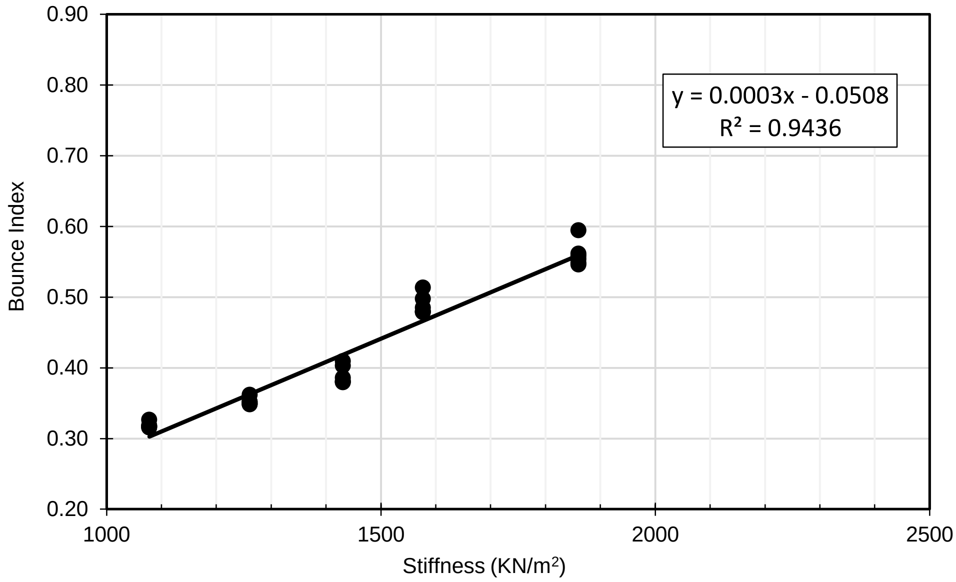


Figure 4.19: Bounce index vs. stiffness for no crack controlled pitches

4.8.2 Stiffness and bounce index for vegetation crack controlled pitches

Figure 4.20 shows the relationship between the stiffness of pitch and the bounce index of the pitch for vegetation crack controlled pitches. Figure 4.20 suggests that a relationship exists between the bounce index and the stiffness of the pitch for vegetation crack controlled pitches. The bounce index increases with the increase of stiffness and can be related as:

$$I_B = 0.0006S_n - 0.3748 \quad (4.21)$$

4.8.3 Stiffness and bounce index for artificial crack controlled pitches

Figure 4.21 shows the relationship between the stiffness of pitch and the bounce index of the pitch for artificial crack controlled pitches. It can be seen that a linear relationship exists between the bounce index and the stiffness of the pitch for artificial crack controlled pitches. The bounce index increases with the increase of stiffness and may be expressed as:

$$I_B = 0.0004S_n - 0.0926 \tag{4.22}$$

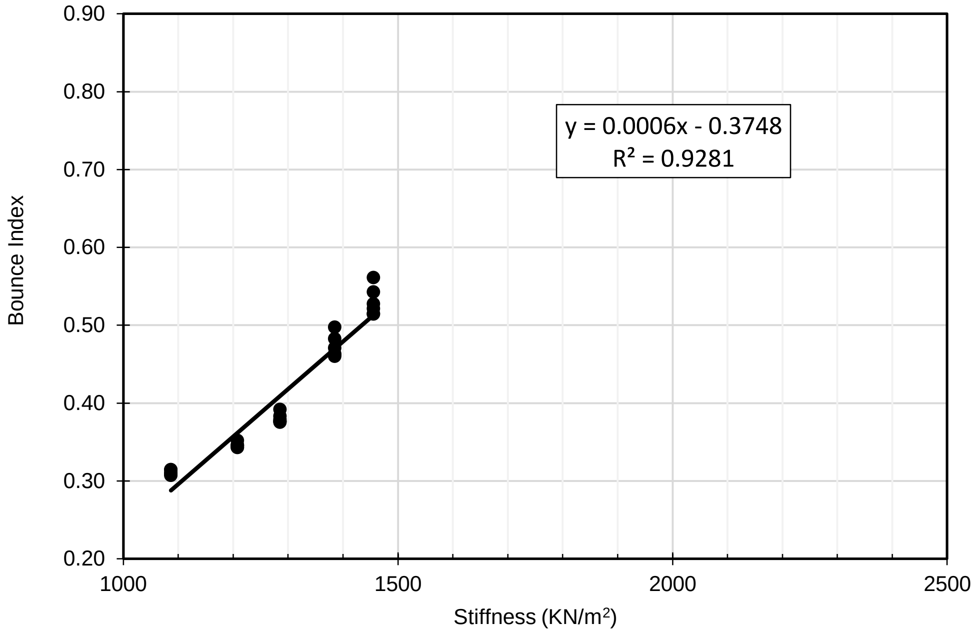


Figure 4.20: Bounce index vs. stiffness for vegetation crack controlled pitches

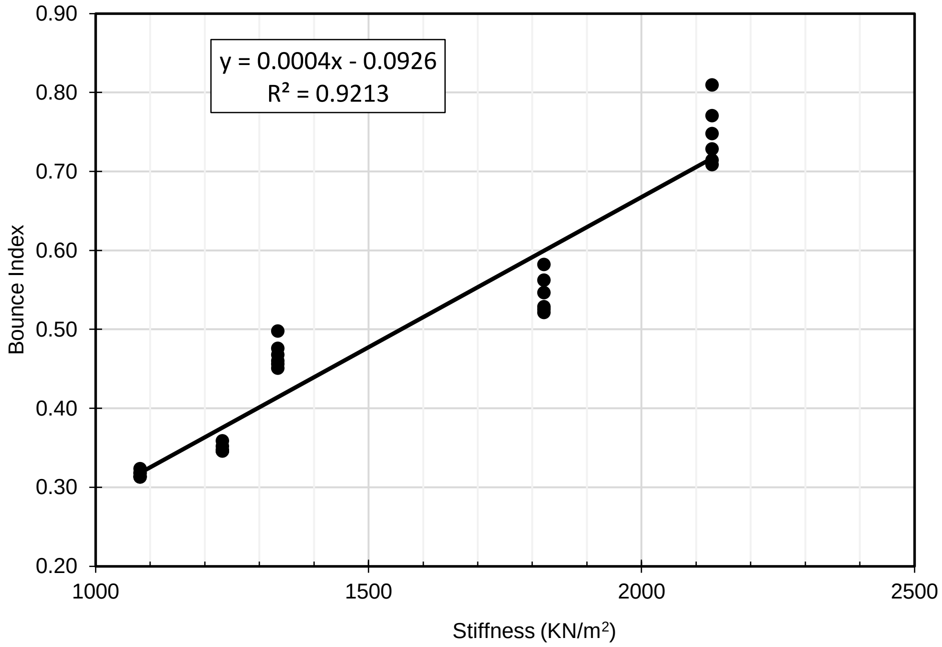


Figure 4.21: Bounce index vs. stiffness for artificial crack controlled pitches

4.9 Effects of Moisture Content on Bounce Index

The relationship between the moisture content and the bounce index of the pitch for different crack controlled pitches are discussed in the following Sub-sections.

4.9.1 Moisture content and bounce index for no crack controlled pitches

Figure 4.22 shows the relationship between moisture content and the bounce index for no crack controlled pitches. It is observed that the bounce index decreases with the increase of moisture content for no crack controlled pitches. Van Deventer (1995), Figure 2.6, proposed a relationship between the bounce height and the moisture content of the pitch. According to him, there is a transitional moisture content range (13% – 12%) and the moisture content smaller this range yields a rapid increase of bounce height. Close scrutiny of the plot of Figure 4.22 supports the proposal of Van Deventer (1995). However, the moisture content bounce index relation can be reasonably expressed linearly by the Equation (4.23).

$$I_B = 0.1005S_n + 1.6919 \quad (4.23)$$

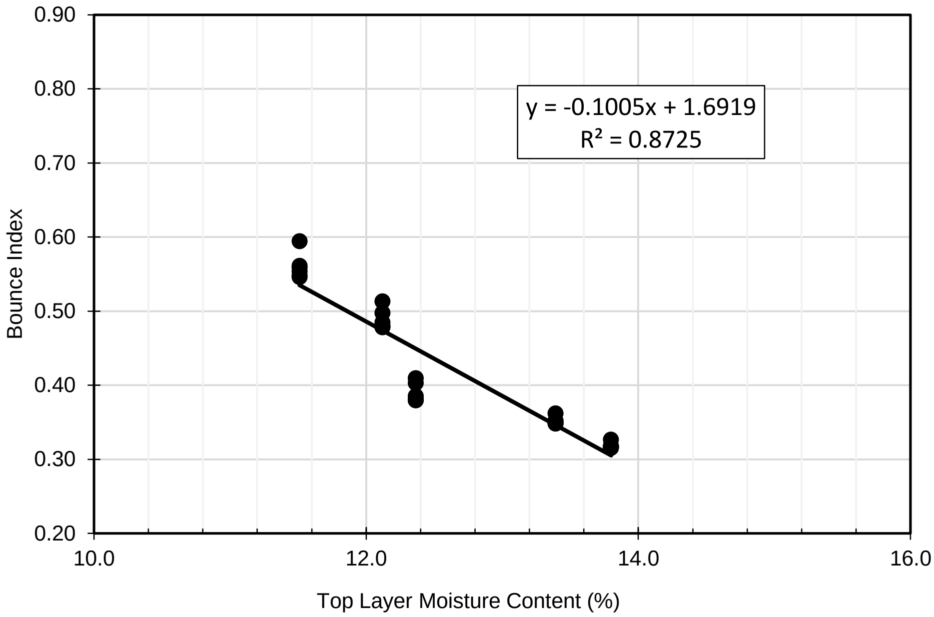


Figure 4.22: Bounce index vs. top layer moisture content for no crack controlled pitches

4.9.2 Moisture content and bounce index for vegetation crack controlled pitches

Relationship between moisture content and the bounce index for vegetation crack controlled pitches is presented in Figure 4.23. From the Figure it can be seen that, there exists a linear relationship between the bounce index and moisture content for vegetation crack control pitches. The bounce index decreases with the increase of moisture content at the top layer of pitch for vegetation crack controlled pitches. The relationship may be expressed as:

$$I_B = 0.0561S_n + 1.1514 \quad (4.24)$$

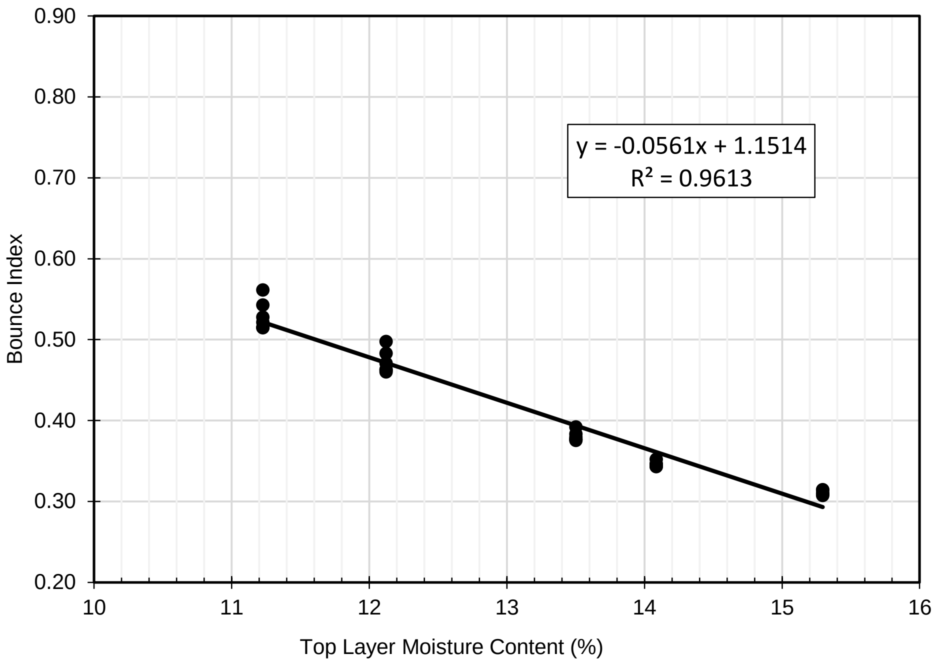


Figure 4.23: Bounce index vs. top layer moisture content for vegetation crack controlled pitches

4.9.3 Moisture content and bounce index for artificial crack controlled pitches

Figure 4.24 shows the relationship between moisture content and the bounce index for artificial crack controlled pitches. It can be seen that, there exists a linear relationship between the bounce index and moisture content for artificial crack control pitches. The bounce index decreases with the increase of moisture content for artificial crack controlled pitches and the relationship may be expressed by Equation (4.25).

$$I_B = 0.1435S_n + 2.3796 \quad (4.25)$$

4.10 Effects of Crack Width on Bounce Index

Fine soil particles of the pitch hold water on its surface. Due to evaporation or evapotranspiration (occur on pitch where vegetation is used) soil particles released the water, at that instant crack develops on the pitch. As the soil particles release water, they become stiffer affecting bounce index. The effects of moisture content on bounce index are presented in the subsequent articles.

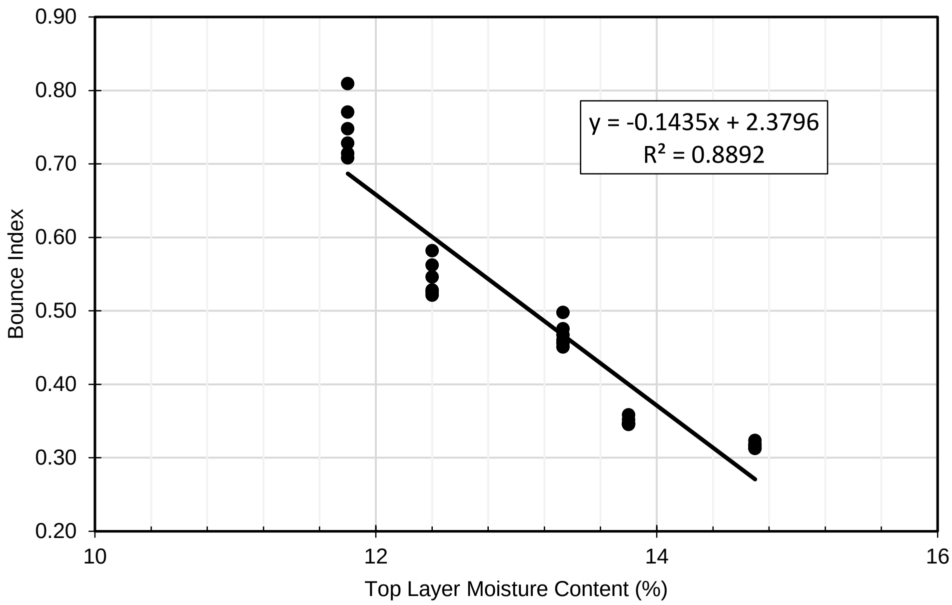


Figure 4.24: Bounce index vs. moisture content for artificial crack controlled pitches

4.10.1 Crack width and bounce index for no crack controlled pitches

Figure 4.25 shows the relationship between crack width and the bounce index for no crack controlled pitches. It is observed that, Figure 4.25, the bounce index is related to crack width in a linear form. The bounce index increases with the increase in crack width and relation may be expressed as:

$$I_B = 0.0131C_w + 0.1617 \tag{4.26}$$

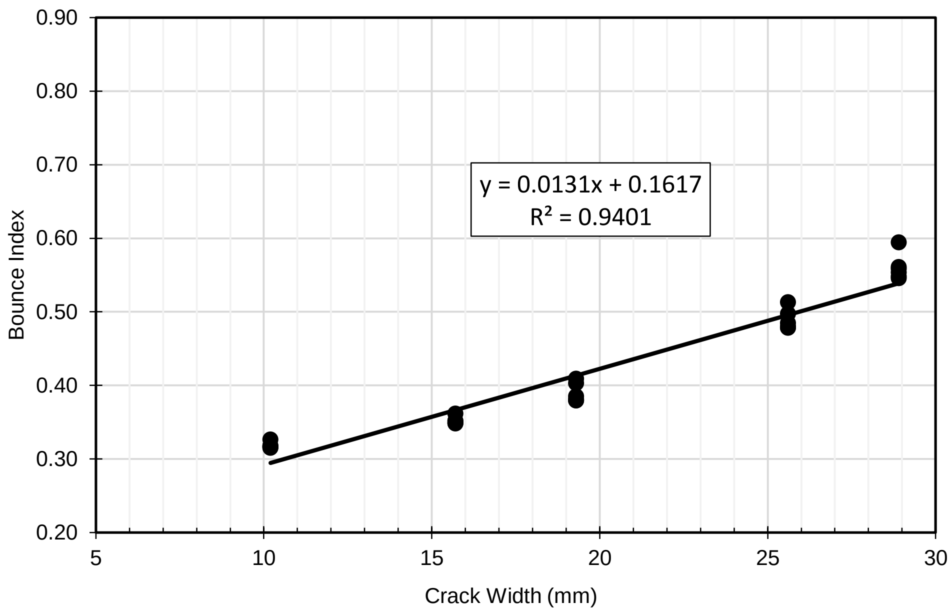


Figure 4.25: Bounce index vs. crack width for no crack controlled pitches

4.10.2 Crack width and bounce index for vegetation crack controlled pitches

Figure 4.26 shows the relationship between crack width and bounce index for vegetation crack controlled pitches. The bounce index is to be related to crack width in a linear form. The bounce index increases with the increase of crack width obeying the following equation within the range of crack width of 8 mm to 23 mm.

$$I_B = 0.0149C_w + 0.1614 \qquad (4.27)$$

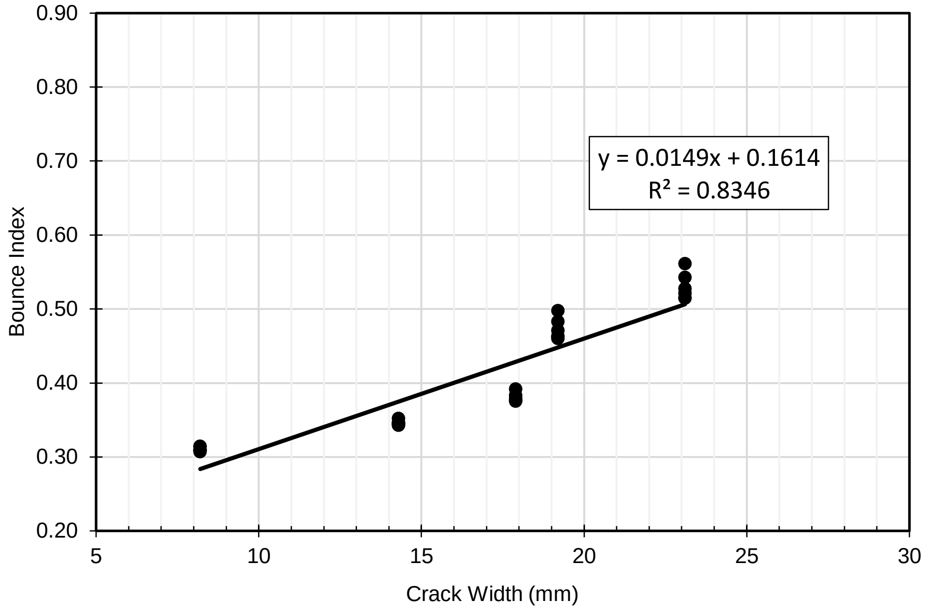


Figure 4.26: Bounce index vs. crack width for vegetation crack controlled pitches

Close scrutiny of the data and Figure 4.26 indicates that up to 11 mm crack width bounce index varies slowly. Beyond 11 mm crack width, bounce index increases rapidly. It may have happened because of the fact that after 11 mm crack width the evaporation surface increases and rapid ventilation took place. As a consequence, the soil released moister rapidly and gets stiffness. Figure 4.14 (stiffness vs. crack width for vegetation crack controlled pitches) also shows that beyond 10 mm crack width the stiffness of the pitch increases rapidly.

4.10.3 Crack width on bounce index for artificial crack controlled pitches

Figure 4.27 shows the relationship between crack width and the bounce index for artificial crack controlled pitches. Over here, the bounce index is also linearly related to crack width. The bounce index increases with the increase of crack width and the relation may be expressed as:

$$I_B = 0.0312C_w + 0.0531 \qquad (4.28)$$

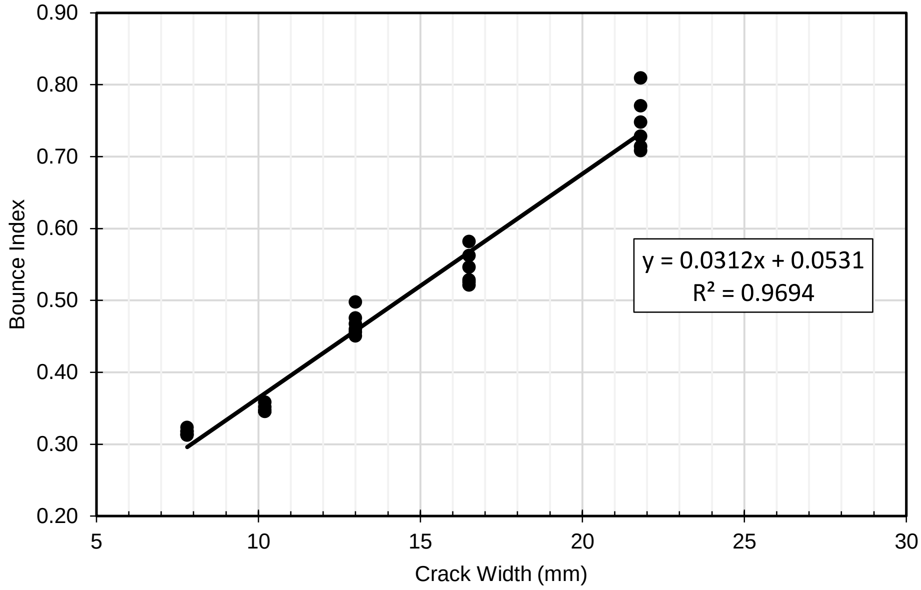


Figure 4.27: Bounce index vs. crack width for artificial crack controlled pitches

4.11 Effect of Stiffness on Energy Ratio

The ratio of rebound energy to impact energy is a function of stiffness. As the surface absorbs portion of impact energy the rebound energy ought to be smaller. Thus, the rebound height would also be low. Thus absorb energy has adverse impact on rebound energy. Generally, stiff surface absorbs very little energy rather than a soft surface. The effect of stiffness on energy ratio for different crack control systems are discussed in the following articles.

4.11.1 Effect of stiffness on energy ratio for no crack controlled pitches

Figure 4.28 represents the relationship between the energy ratio, E_r and the stiffness, S_n of the pitch, for no crack controlled pitches. The energy ratio is linearly proportional to the stiffness of the pitch. The energy ratio increases linearly with stiffness by obeying the following equation.

$$E_r = 0.0001S_n - 0.0014 \tag{4.29}$$

4.11.2 Effect of stiffness on energy ratio for vegetation crack controlled pitches

Figure 4.29 represents the relationship between the energy ratio and the stiffness of the pitch for vegetation crack controlled pitches. For vegetation crack controlled pitches, the energy ratio is also linearly proportional to the stiffness of the pitch. The relationship may be expressed as:

$$E_r = 0.0002S_n - 0.0975 \tag{4.30}$$

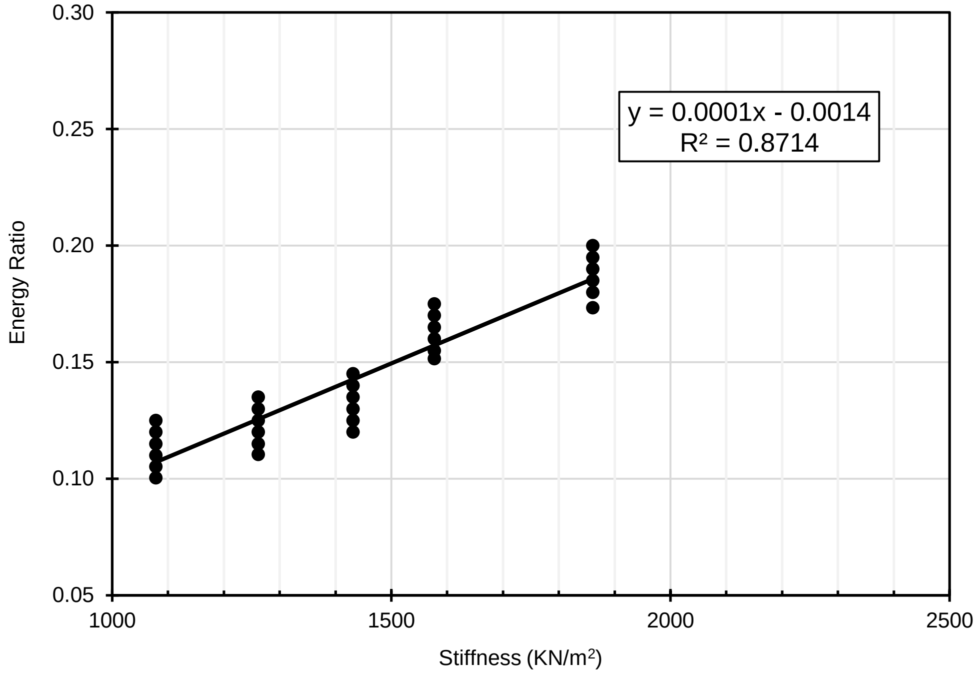


Figure 4.28: Energy ratio vs. stiffness for no crack controlled pitches

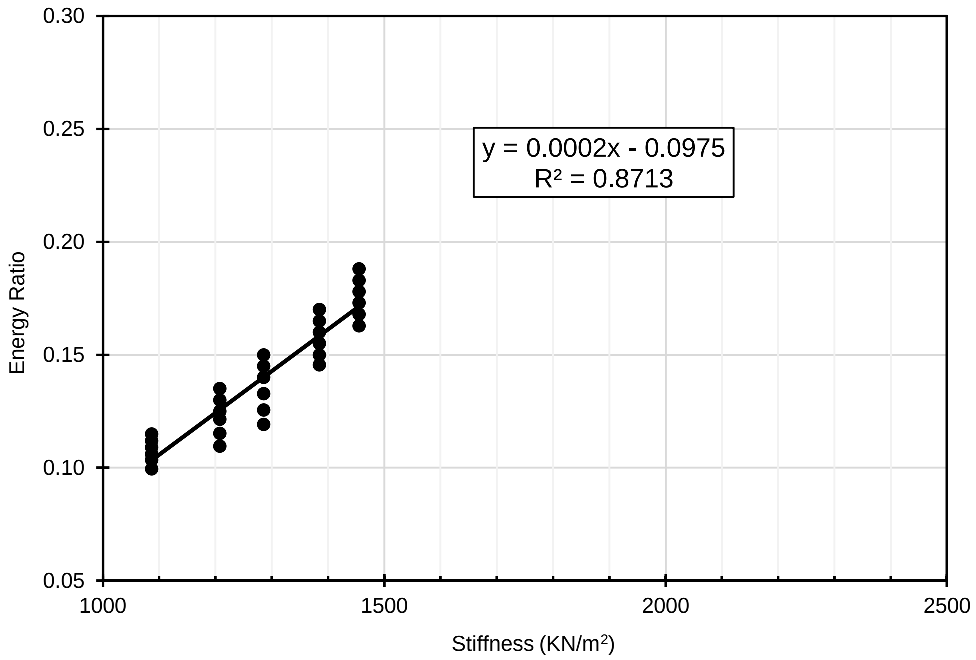


Figure 4.29: Energy ratio vs. stiffness for vegetation crack controlled pitches

4.11.3 Effect of stiffness on energy ratio for artificial crack controlled pitches

Figure 4.30 represents the relationship between the energy ratio and the stiffness of the pitch for artificial crack controlled pitches. For artificial crack controlled pitches, the energy ratio is linearly proportional to the stiffness of the pitch. The relationship may be expressed as:

$$E_r = 0.0001S_n - 0.0058 \quad (4.31)$$

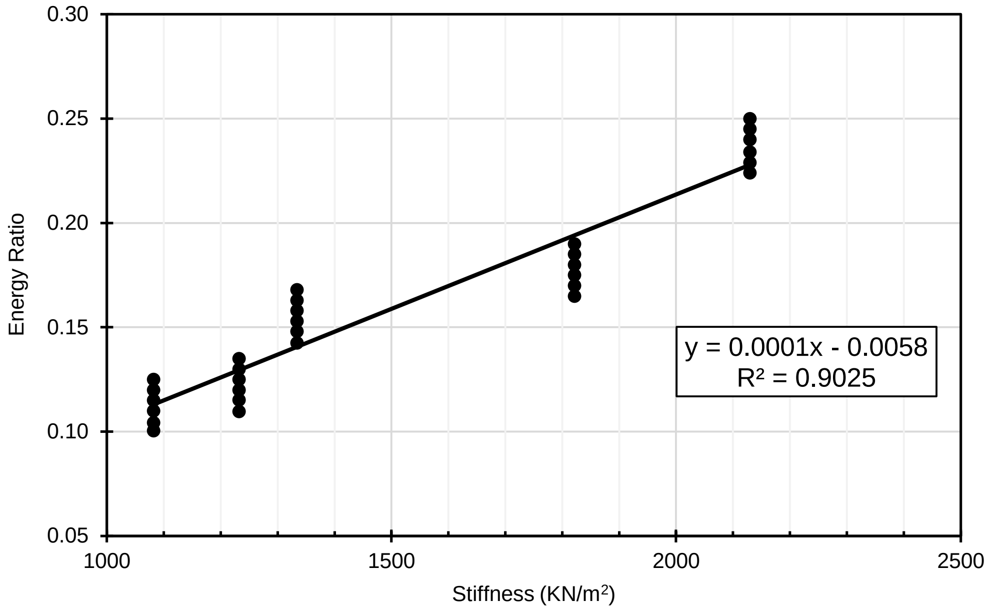


Figure 4.30: Energy ratio vs. stiffness for artificial crack controlled pitches

4.12 Forecasting of Bounce Height in Real Cricket

The principal objective of this research work was to correlate the bounce characteristics of cricket pitch with the geotechnical parameters of the pitch forming soil so that the bounce height in real game could be estimated. In this study the rebound height was measured for a ball falling vertically. However, using the correlations of pitch stiffness and energy ratio as stated in Section 4.11, and the assumptions given by James et al. (2004) the bounce height in the real game could be predicted measuring the stiffness of the pitch by pin-point penetrometer. A dynamic analysis was conducted by James et al. (2004) on the trajectory of a cricket ball during the game as shown in Figure 4.31. The trajectories of 3000 balls were analyzed, mathematically. It was seen that, before impact the ball on the pitch due to the high speed of the ball, the ball followed a linear path. Whereas, after bounce the ball losses its energy and follows a polynomial path. It was also found that for a maximum valid impact angle α of 11.9^0 for a real cricket game, the rebound angle β was 8.4^0.

Numerical examples are shown in Appendix-A, where for a particular bowler, knowing the stiffness (measured by pin-point penetrometer) of a pitch the estimated bounce height is provided.

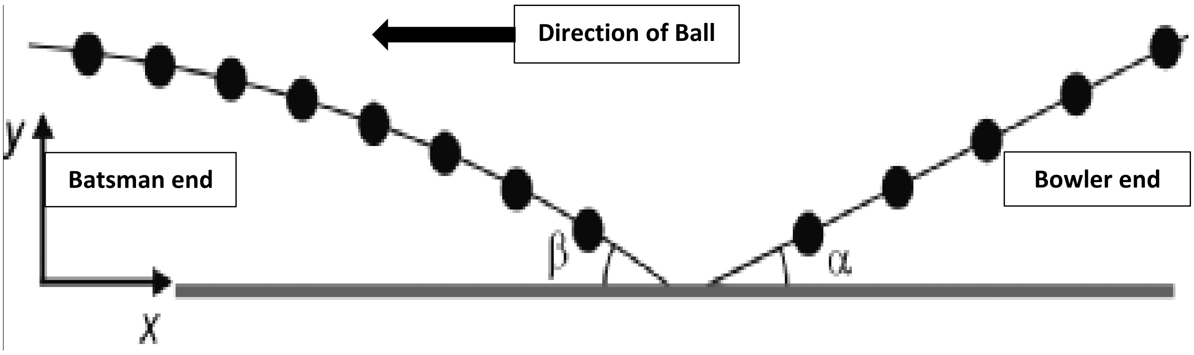


Figure 4.31: A schematic of the trend line fitting used to determine ball trajectories, James et al. (2004)

4.13 Crack Pattern of Bulli Compositions

To fulfill the objective of this research, the crack pattern was observed and the details of crack patterns are presented in Table 3.6. Among all compositions the sequence of first crack formation is given in Table 4.4. It was found that the latest crack forms for the combination of 70% bentonite where percent of clay content was 56%. Moreover, the minimum crack width was found for combinations of 70% and 80% (i.e. 63% clay content) of bentonite. As such, from the view point of delaying crack formation, the combination of 70% bentonite and 30% fine sand (dredged river sand) could be the best combination for pitch preparation.

Table 4.4: Summary of crack observation in the miniature box

Percent Bentonite (%)	Percent Clay (%)	Sequence of First Crack Formation	Average Crack Width (mm)
60	48	1st	9-15
70	56	5th	6-13
80	63	4th	6-13
90	71	2nd	4-15
100	79	3rd	3-20

4.14 Cyclic Watering and Drying Effect on Bulli Compositions

In the present study, the cyclic watering and drying effects on the bulli compositions (five combinations) were observed as stated in Section 3.6. Moreover, the compressive strength of 50 mm cubes was also measured for three cycles of watering and drying. The average compressive strength of 50 mm cubes are listed in Table 4.5. It can be seen that, for first watering cycle the maximum compressive strength was found for 70% bentonite (56% clay content). For the second and third cycle of watering the compressive strength of cube was also determined for 70% bentonite content. Therefore, from compressive strength (and hence the stiffness) point of view, the combination of 70% bentonite and 30% fine sand (dredged river sand) could be the best combination for pitch preparation.

Table 4.5: Compressive strength of cube for different cycle of watering

Bentonite Percent (%)	Clay Content (%)	Compressive Strength of Cube (kN/m^2)		
		1st Cycle	2nd Cycle	3rd Cycle
60	48	87	84	28
70	56	113	101	30
80	63	80	65	24
90	71	70	60	23
100	79	59	55	19

4.15 Effect of Crack Control Systems on Moisture Content

As discussed earlier in Section 2.2.9, moisture content may slightly vary throughout the depth from two to five percent. From Table 3.13 it can be found that, the variation of moisture content between top and bottom layers for no control pitches were high even more than five percent. This might have happened because of the presence of infiltration resistance (1 mm plastic sheet) beneath the pitches. On the other hand, variation of moisture content for vegetation crack control pitches was found low. This might be because of deep root system that helped evapotranspiration. The root zone might hold water near the pitch surface, and as a consequence, the moisture content at the top layer of vegetation crack control pitches was higher than those for other two crack control systems. In addition, along with infiltration resistance geotextile resistance was provided in artificial crack control pitches that interrupted the evaporation process. As a result, the moisture content at the bottom layer for artificial crack control pitches was higher than those for other two crack control system pitches. Thus, for the same composition of bullis (each composition contained three pitches) the moisture content of pitches was found to be varied in different crack control systems.

4.16 Effect of Infiltration Resistance

The function and the installation process of infiltration resistance are previously discussed in Section 3.7.4. The moisture content at the bottom layer of no control and artificial crack control pitches were high due to this infiltration resistance. However, for vegetation crack control pitches the moisture content at top and bottom layers were nearly uniform. Therefore, vegetation crack control system should be adopted while infiltration resistance provided. Moreover, infiltration resistance provides the drainage only due to evaporation (downward drainage is not allowed) as a consequence the pitch needs extra time to dry up after construction. Generally, the curing period of a pitch is two to three month (Silva, 2014). In this study, the curing period was 4 months (25th December 2015 to 30th April, 2016). In spite of this limitation, infiltration resistance protects the pitch from the deterioration by efflorescence and downward drainage. It also makes the pitch workable against lateral infiltration.

Chapter 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 General

The present study investigated the relationships between the rebound height of a ball dropped on a cricket pitch and the geotechnical properties of pitch soils for three different crack control systems. Laboratory and field investigations were done, and were obtained and analyzed. The crack patterns for different composition of bulli were observed in miniature boxes. The cyclic watering and drying effects on bulli compositions were observed and the compressive strength of cube samples was measured.

In the field 15 model pitches were constructed in five different compositions of bulli. For each composition, three different crack control systems were adopted; (i) no crack control; (ii) crack control with vegetation; and (iii) artificial crack control by geotextile. The stiffnesses of the pitches were measured by a calibrated 3 mm diameter pin-point penetrometer. The rebound height was measured by the bounce-meter and photogrammetric techniques. The average crack widths and the in-situ moisture content of the pitches were also measured after the bounce test.

Test data obtained for various soil compositions and physical conditions were analyzed to obtain some conclusive verdict. However, this study mainly focused on the geotechnical aspects on the rebound height, where, only the static energy against the gravity was considered. The empirical relationships developed are valid for some specific range of moisture content (10 to 15%) and clay content (50 to 80% by volume) of pitch soils. The construction of a good bouncy pitch is an art and that depends on many factors. Most of the factors are independent, as the pitches exposed to the weather. Most interestingly, the standard of pitch is also variable depending on the prevailing conditions. To generalize the research apprehensions, further studied should be carried out. In the following sections, conclusions from the studies are summarized and recommendations made to carry out further research.

5.2 Conclusions

The study suggested the following conclusions:

(i) Clay content of pitch bulli increases the crack width of the pitch linearly for both no control and vegetation control pitches. However, for artificial crack control measures with geotextile imparts a different phenomenon; crack width initially decreases with increasing clay content up to 60% and then increases. Analyses of the data yield clay content – crack width relations as proposed by Equations (4.2) to (4.4).

(ii) Clay content of the pitch bulli also increases the stiffness of the pitch and hence the bounce index in a similar fashion of crack width. Both stiffness and bounce index of pitch can be estimated using the Equations proposed in Sections 4.4 and 4.7.

(iii) Increase of moisture content of the pitch bulli decreases the crack width linearly for all the crack width controlling systems of the bulli. Moisture content affects the stiffness and bounce index in a similar nature. Crack width, stiffness and bounce index can be estimated using the proposed Equations of Sections 4.3, 4.5 and 4.9.

(iv) There exist linear relationships between crack width and stiffness, stiffness and bounce index, crack width and bounce index, energy ratio and stiffness and rebound energy and rebound velocity. These interrelated parameters may be estimated using the proposed Equations of Sections 4.6, 4.8, 4.10, 4.11 and 4.12.

(v) Minimum crack width was found to take place at 50% to 60% clay content. The maximum compressive strength against cyclic watering and drying effect was found at approximately 50% clay content.

(vi) To use geotextile for crack control, clay content should be more than 60% otherwise the geotextile will affect the properties of pitch soil. Maximum bounce would be achieved for 80% clay content. However, at that clay content excessive crack was also found to notice. Hence, 50 to 60% clay content might be preferable for pitch preparation.

(vii) The designed device for measuring stiffness of cricket pitch can be used to measure the stiffness effectively. Thus, using the device, bounce height of any pitch for any fast bowlers can be forecasted.

(viii) Performance of no crack controlled and vegetation crack controlled pitches appeared to be consistent. In spite of maintaining a minimum crack width, geotextile showed inconsistent behavior. However, to minimize the crack width a thin geotextile layer (0.5 mm) may be placed in the mid depth of the bulli.

5.3 Recommendations for Further Study

The following recommendation may be made to continue the present study.

(a) The main focus of this study was limited to the bounce index of a pitch only. The study may be extended for pace, swing and consistency of the pitch.

(b) The study was limited to the correlation between bounce index and geotechnical parameters of pitch soils. The study may be continued with other influencing factors related to bounce such as speed and inclination of ball, bowler height, spin of ball, rebound angle, bounce location etc.

(c) The present research was limited to the effects of infiltration resistance. Further study may be carried out on the chemical analysis of the pitch soils to justify the use of infiltration resistance.

(d) Temperature had great influence in the pitch soil properties. The present research work was conducted only at the atmospheric temperature. The study may be continued at various controlled temperatures to observe the behavior of pitch.

(e) The present research was conducted only at in-situ moisture content. The research may be continued to observe the pitch behavior at various moisture contents.

(f) The present study was limited to using the bentonite clay (montmorillonite clay). The study may be continued using various types of clay, especially local clay.

(g) Numerical model may be developed to simulate the complexities involved in the dynamic behavior of ball, thus addressing the problem in a refined manner. Provisions may be kept in the model to vary any or all the parameters involved in the phenomenon of bounce, pace, swing and consistency.

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APPENDIX-A

Calculation of Bounce Height Considering the Real Scenario

Table A-1 illustrates the details of a real ball trajectory and the calculation of the bounce height of Player-P1, for vegetation crack controlled pitch. Figure A-2 shows the schematic diagram of the ball trajectory on vegetation crack controlled pitches for Player-P1.

Table A-1: Bounce details of player-P1 for vegetation crack controlled pitch

Items	Value	Remark
Wt. of Ball (gm.)	156.7	Measured
Name of the bowler	Player-P1	Assume
Impact angle (degree)	11.9	James et al. (2004)
Bowling speed (km/hr)	160	Assume
Bowler height (cm)	187	Assume
Extra height of bowling (cm)	30	Assume
Energy of the ball (J)	154.8	
Trajectory before bounce	Linear	James et al. (2004)
Stiffness of the pitch (kN/m^2)	2000	Can be measured by pin-point penetrometer
Crack control system	Vegetation crack control	Assume
Energy Ratio for the Stiffness	0.303	Correlations of section 4.11
Rebound Energy (J)	46.8	
Rebound Velocity (m/sec)	24.4	
Rebound Angle (degree)	8.4	James et al. (2004)
Trajectory after bounce	Polynomial	James et al. (2004)
Length of the pitch (m)	20.12	Fixed
Distance of bounce (m)	10.30	
Remaining distance to travel (m)	9.82	
Batsman height (m)	1.8	Assume
Type of delivery	Good length to the batsman	
Ball height at batsman position (m)	0.65	
Ball height at stump position (m)	0.64	

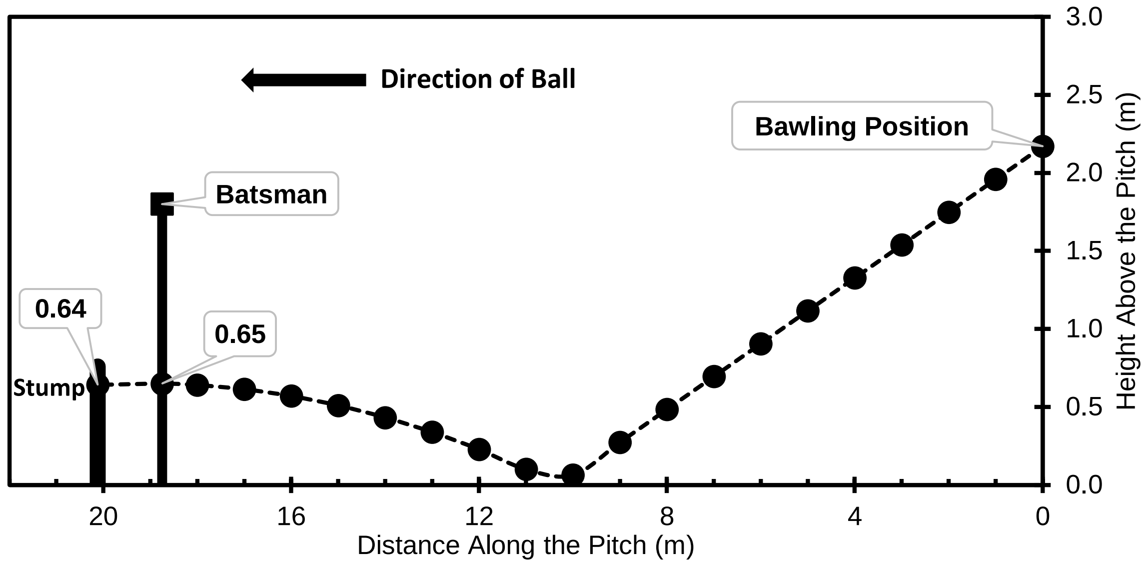

Figure A-1: Schematic diagram of the ball trajectory on vegetation crack controlled pitches for Player-P1