4.1 Introduction

The effect of the characteristics of the green on the impact have not yet been discussed. However, the importance of the depth and shape of the pitchmark in the last chapter shows that the "hardness" of turf is an important factor in the impact. The ball would be expected to penetrate less on a green that is hard while the ball might "plug" into a surface that is very soft. The term "hardness" could have many different meanings, however. This chapter discusses the tests to measure the characteristics of the green. Each test is evaluated to determine its usefulness and its exact meaning. The complex relationships between different characteristics have to be understood in order to determine their exact effects on the ball/turf impact.

Golf courses were visited throughout the summer of 1987 and were chosen to give a variation in the construction and quality of greens and for their proximity to the Institute. One of the difficulties in carrying out research on golf greens was to arrange days during which play was minimal. Furthermore, the work had to be completed in a single day to avoid possible changes in the characteristics of the green. Some of the visits were aborted because of bad weather or because of equipment malfunction but, in total, 18 greens were tested, two of which were on the same course but on different days.

The tests described in Chapter 2 were carried out on each green. For convenience it is possible to separate them into three categories; the first contains tests to study directly the natural characteristics of the turf. These are the grass species composition, the moisture content, the organic matter content and the soil composition. The second and third categories contain tests on properties that are dependent upon these natural characteristics. These are the tests related to the hardness of the green (the Clegg Impact Hardness Tester, penetrometer, traction and ball bounce) and to the motion of the ball across the turf (surface evenness, stimpmeter and friction). For convenience, the first category will be referred to as Green Characteristics while the second and third categories will be referred to as Playing Quality Tests.

The results from each test are shown in Appendix G and the means shown in Tables 4.1 and 4.2. Some data points are missing due to equipment failure on the day or because the apparatus had not been developed when the tests were made. Table 4.1 contains tests concerned with the Green Characteristics and with the Playing Quality Tests related to the surface. Table 4.2 contains the results from the Playing Quality Tests related to hardness. The next section studies each test and examines and compares the measurement errors due
to the apparatus with the errors inherent in the surface. This is necessary to ensure that the methods of measurement are neither too accurate nor too inaccurate.

4.2 Results

(i) Ground cover and species composition
Twenty frames of five readings were examined using the optical point quadrat frame. The random points located using the frame were identified as dead, bare or as a species of grass and expressed as a percentage of the total ground cover. The most common grasses were *Poa annua* (annual meadow grass) and *Agrostis* (Bent). The percentage of *Poa annua* in the sward is shown in Table 4.1 and varies from 5 to 100%. The errors involved in this analysis can be estimated using the binomial distribution (Woolhouse, 1976). If 100 points are identified and the ground cover of a particular type is 50% then the error is approximately ±10%. This error decreases as the ground cover increases.

(ii) Soil moisture content, organic matter content, soil composition
The results for the moisture content is displayed in Table 4.1. The range was found to be 14 to 43%. The average standard deviation from all the sites was about 2%.

In order to determine the organic matter content and the soil composition, the 10 samples from each green were grouped together. There is therefore only one calculation of organic matter content and soil composition and consequently no error estimation. The mechanical analysis carried out on the soil defined the composition in terms of particle size. Clay, silt and very fine sand are collectively known as fines and have diameters less than 0.125mm. Thus a soil which has very few fines is sandy while one with a high percentage of fines is of a silt or clay type. The percentage of fines present in the soil from each green varied from 11% to 64% (Table 4.1). The overall textural designation is determined on the basis of mass ratios of the sand, silt and clay. In order of increasing particle size, the relative numbers of greens in each classification are, 2 sandy clay loams, 1 loam , 4 sandy loams, 5 loamy sands and 4 sands. For example, the soil from Hallowes was classed as a loam while the soil from Austerfield Park was classed as a sandy clay.

(iii) Surface evenness/roughness
The surface evenness/roughness was found using the profile gauge described in section 2.6. The standard deviation of the ten rod positions was found at ten positions on the turf and the mean calculated. The most level green had a mean standard deviation of 0.4mm while the roughest green had a value of 1.2mm. The average error in these values was found to be about 0.3mm. The highest and lowest values are, therefore, significantly different, but the range is not very large in comparison to the error. The deviations are
approximately the size of the largest sand grains. Together with the variation in the grass sward, this may be the cause of the irregularities producing the standard deviations. It is possible that these small scale irregularities could cause inconsistencies in the roll of the ball since a small deflection at the beginning of a roll would cause a large deviation.

(iv) Stimpmeter
The stimpmeter was used to roll a golf ball twenty times across the turf at each site. Two balls were rolled along the same path and the distances travelled and the distance between the final ball positions were measured. The latter measurement was used as a simple measure of the consistency of the green; the further apart the final resting points of the two balls the more inconsistent the green. Only two rolls were made along the same line since tracks started to appear if further rolls were made. The method above was repeated in the opposite direction to reduce the effects of minor slopes. The mean of the twenty rolls and the ten differences were calculated and expressed in metres. The consistency figures are presented as a percentage of the mean of the distance rolled under the column heading "% variation" in Table 4.1. Expressing the differences in metres would have been misleading since the balls rolled further on faster greens with a corresponding increase in the variation between rolls.

The slowest green had a "speed" of 1.8m while the fastest had a speed of 2.6m. The average standard deviation was 0.3m. The USGA green section has drawn up guidelines for stimpmeter readings (Radko, 1977) and the readings above fall in the categories "medium" to "fast" for regular membership play. Cochran and Stobbs (1968) found that, on a good green, a putting machine hardly ever missed putts of around 1.8m. The "% variation" in the stimpmeter readings above was essentially a measure of the distance between the final resting points of two similar rolls across a green. In Cochran and Stobbs' results, the maximum percentage error of this kind occurred if the the ball just reached either side of the hole; in both cases the ball would have dropped into the hole. The distance apart of these two points (i.e the diameter of the hole) was taken as the maximum error allowed in the putts of 1.8m. This distance is about 110mm and corresponds to about 6% of the distance rolled by the ball. Thus, it can be considered, arbitrarily, that a percentage variation of 6% or less indicates a fairly consistent green. This was found on seven of the sites tested.

(v) Sliding friction and traction
Preliminary tests using the sliding friction and the traction apparatus showed that some damage to the greens would occur. Tests were carried out at different locations to study the effect of altering the weight of the apparatus since a lighter apparatus produced less damage to the green. Figure 4.1 (a) shows that the surface traction values for two different sites increased proportionally with the weight of the apparatus. An increase in
the downwards force produced greater penetration of the half golf balls attached to the bottom of the test disc which increased the torque required to twist the disc through the surface. There was hardly any penetration of the surface using a weight of 10kg and therefore the torque required to twist the disc was negligible. Using the friction apparatus it was possible to vary the weight of the apparatus from 10 to 40kg (Figure 4.1 (b)). At two different sites, an increase in weight produced a corresponding increase in the force required to pull the sled along at a constant speed, probably due to the increased penetration of the golf balls on the test sled into the turf. As the relationships between the weight of the apparatus and the traction and friction readings were found to be linear, it was possible to use the lowest weights possible to keep damage to the turf to a minimum. For the traction apparatus this was 20kg and for the friction apparatus this was 10kg. Limiting the tests to five measurements further reduced the damage to the green.

FIGURE 4.1 (a)

FIGURE 4.1 (b)

FIGURE 4.1. The effect of increasing the weight of (a) the traction apparatus and (b) the friction apparatus at two different sites.

The results from the traction apparatus varied from 10.1 to 17.7Nm while the average standard deviation was about 1.1Nm. This is consistent with the accuracy of ±1Nm in the reading of the measurement from the torque wrench used to twist the test disc through
TABLE 4.1. A table showing the results of the tests used to describe the natural characteristics and four playing quality tests of sixteen golf greens and a test site at the Sports Turf Research Institute.

The range of values was large enough, compared to the average deviation, for the greens to be considered significantly different.

The highest value using the sliding friction apparatus was 93N and this indicated that it was difficult to pull the sled across the surface. The lowest value was 49N. The average standard deviation was calculated to be about 5N. This is consistent with the individual measurements from the newton meter used to pull the friction sled which were in discrete steps of 5N.

(vi) The Clegg Impact Soil Tester and the USGA penetrometer
Twenty measurements were made per green using each of the four indenters dropped from a height of 300mm. The mean is expressed in gravities (g) (Table 4.2). The measurements were taken in discrete steps of 10g so that a mean of 29g (for Austerfield...
TABLE 4.2. A table showing the results of the playing quality tests relating to hardness for sixteen golf greens and five test sites at the Sports Turf Research Institute.

<table>
<thead>
<tr>
<th>Name</th>
<th>CLEGG 0.5kg (gravities)</th>
<th>CLEGG RB (gravities)</th>
<th>CLEGG MB (gravities)</th>
<th>CLEGG 1.0kg (gravities)</th>
<th>PENETROMETER in METER</th>
<th>TRACTION (Nm)</th>
<th>BALL BOUNCE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austerfield Park</td>
<td>29</td>
<td>4</td>
<td>2</td>
<td>20</td>
<td>7.8</td>
<td>17</td>
<td>5.2</td>
</tr>
<tr>
<td>Bellfield</td>
<td>52</td>
<td>5</td>
<td>7</td>
<td>33</td>
<td>7.1</td>
<td>12</td>
<td>2.3</td>
</tr>
<tr>
<td>Bingley</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Birkenhead</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crewe</td>
<td>62</td>
<td>10</td>
<td>10</td>
<td>42</td>
<td>7.2</td>
<td>14</td>
<td>5.4</td>
</tr>
<tr>
<td>Formby</td>
<td>30</td>
<td>8</td>
<td>9</td>
<td>23</td>
<td>6.2</td>
<td>14</td>
<td>5.6</td>
</tr>
<tr>
<td>Ganton</td>
<td>73</td>
<td>22</td>
<td>17</td>
<td>48</td>
<td>7.0</td>
<td>13</td>
<td>4.1</td>
</tr>
<tr>
<td>Hallowes</td>
<td>83</td>
<td>20</td>
<td>17</td>
<td>56</td>
<td>7.7</td>
<td>15</td>
<td>5.5</td>
</tr>
<tr>
<td>Hill Valley</td>
<td>57</td>
<td>2</td>
<td>5</td>
<td>31</td>
<td>8.3</td>
<td>12</td>
<td>6.4</td>
</tr>
<tr>
<td>Keighley</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lindrick (1)</td>
<td>75</td>
<td>20</td>
<td>22</td>
<td>63</td>
<td>4.3</td>
<td>13</td>
<td>4.6</td>
</tr>
<tr>
<td>Lindrick (2)</td>
<td>60</td>
<td>12</td>
<td>15</td>
<td>44</td>
<td>5.7</td>
<td>15</td>
<td>4.1</td>
</tr>
<tr>
<td>Moor Allerton</td>
<td>66</td>
<td>7</td>
<td>8</td>
<td>43</td>
<td>9.8</td>
<td>13</td>
<td></td>
</tr>
<tr>
<td>Moor Hall</td>
<td>44</td>
<td>7</td>
<td>7</td>
<td>33</td>
<td>6.3</td>
<td>17</td>
<td>4.2</td>
</tr>
<tr>
<td>Moortown</td>
<td>48</td>
<td>5</td>
<td>8</td>
<td>34</td>
<td>7.6</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>Newcastle-u-Lyme</td>
<td>57</td>
<td>8</td>
<td>5</td>
<td>36</td>
<td>5.4</td>
<td>14</td>
<td>4.6</td>
</tr>
<tr>
<td>Sandmoor</td>
<td>56</td>
<td>6</td>
<td>6</td>
<td>35</td>
<td>8.9</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>STRI green</td>
<td>70</td>
<td>23</td>
<td>33</td>
<td>62</td>
<td>11.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sutton Park</td>
<td>61</td>
<td>2</td>
<td>9</td>
<td>39</td>
<td>6.3</td>
<td>14</td>
<td>4.6</td>
</tr>
</tbody>
</table>

Park for example) was composed of 10, 20 and 30g measurements. It was considered that the 0.5kg Clegg was the most suitable indenter to use since individual measurements gave the greatest accuracy. The average standard deviation for the 0.5kg indenter was found to be about ±10g which corresponds to the error in individual measurements. The average value for the Clegg 0.5kg indenter was found to be 57g. In Chapter 3 the accelerations from the high speed films were compared to the average value of the Clegg indenter above. It was found that the analogy of the impact as the motion of a mass on a spring was not correct. This was not surprising since there must be a damping component if the ball is to slow down during impact.

Twenty measurements were also made on each green using the USGA penetrometer and a range of 4.3 to 11.4 sixteenths of an inch was found. The lower value indicates a firm green where the penetration was low. The higher value indicates a green which was soft and therefore unresistant to penetration. In this case the penetration was almost the radius
of a golf ball. Individual measurements were read to an accuracy of ±1 sixteenth of an inch. The average standard deviation was 1.3 sixteenths of an inch.

(vii) Ball rebound resilience

A Titleist 384 tour wound golf ball was used for the ball rebound resilience tests as this was the type of ball used in the studies of golf ball impacts. A comparison was made, however, between the wound ball and a Pinnacle 384 solid golf ball, the constructions of which were described in Chapter 3. Ten drops of each ball were recorded at a single site and the rebound heights expressed as a percentage of the drop height. The mean and standard deviation of ten drops for the wound golf ball was 5.5 ± 0.4%. This corresponds to a rebound height of 28 ± 2cm. Using the solid golf ball, the mean and standard deviation was 5.2 ± 0.6%, corresponding to an average rebound height of 26 ± 3cm. If the means are compared using a t-test, it is found that there is no significant difference between the ball rebound resiliences for the two constructions of ball. Therefore, at this height, the rebound resilience depends upon the characteristics of the turf rather than the properties of the ball. This agrees with the tests in Chapter 3 in which it was found that the construction of the ball had little effect on the impact of the ball with the turf.

Using the Titleist wound golf ball, ten drops were recorded on each green and the mean of the values expressed as a percentage of the original drop height of 5m. The range of rebound heights found across the greens varied from 11cm to 41cm, corresponding to a rebound resilience of 2.3 to 8.1%. It was possible to measure the rebound heights to within approximately ±0.001cm which corresponds to an error in the ball rebound resilience of about 0.1%. It was found that the average of the standard deviations for all the greens was five times larger than this at approximately ±0.5 cm for the rebound height or 0.5% for the ball rebound resilience.

4.3 Analysis

(i) Introduction

The correlation matrix shown in Figure 4.2 contains correlation coefficients of the relationships between all the tests shown in Tables 4.1 and 4.2. A coefficient of zero indicates that there was no correlation between the variables while a value of plus or minus one indicates an exact linear relationship. The negative sign indicates an inverse relationship. The number of degrees of freedom in each correlation determines the level of significance of the relationship. For instance, it can be found using tables that a correlation with 20 occurrences and a correlation coefficient of 0.6 is significant at the 1% level of confidence. This indicates that there is a probability of only one in a hundred that this relationship occurred by chance. The values boxed in bold in Figure 4.2 are signifi-
FIGURE 4.1. A correlation matrix showing the relationships between the tests for playing quality and the natural characteristics of the green. Relationships that correlated well have coefficients near to plus or minus unity. Negative values indicate an inverse relationship. The values boxed in bold are significant at the 5% confidence level and those that are boxed and underlined are significant at the 1% confidence level.

FIGURE 4.2. A correlation matrix showing the relationships between the tests for playing quality and the natural characteristics of the green. Relationships that correlated well have coefficients near to plus or minus unity. Negative values indicate an inverse relationship. The values boxed in bold are significant at the 5% confidence level and those that are boxed and underlined are significant at the 1% confidence level.
-cant at the 5% level of confidence and those that are boxed and underlined are significant at the 1% level of confidence. As with Tables 4.1 and 4.2, the Playing Quality Tests and the Green Characteristics are grouped together.

All of the playing qualities described in the previous section depend to some extent upon the recent weather experienced by the green. A recent drought may cause the green to become very dry and hard while a heavy storm may cause an abnormally high moisture content. In some cases the construction of the green or past maintenance regimes may affect the tests. The correlations shown in Figure 4.2 were analysed in more detail using regression analysis. The results of this, and their graphical representations are given in the following sections.

(ii) Green Characteristics

The correlations involving the naturally occurring turf characteristics were considered first since they were, in effect, the independent variables measured by the other tests.

FIGURE 4.3. The relationships between (a) the moisture content and the percentage of fines in the soil composition and (b) the moisture content and the organic matter content of the soil from different golf greens.
The moisture content correlated with the percentage of fines present in the soil at the 5% level of significance. Figure 4.3 (a) shows that the moisture content increases as the percentage of fines increases.

It has been found (Buckman and Brady, 1971) that soil water drains from large pore spaces first and remains in small pore spaces longest. Clay soils have very small particles and the resultant pore spaces between them are also small. A smaller, additional factor is that the clay particles have surface charges which attract water molecules. Soils with a high amount of clay, therefore, tend to have higher moisture contents than soils with a high sand composition.

Figure 4.3 (b) shows that the moisture content is positively correlated with the organic matter content at the 1% level of significance. This, however, was not found in the correlation matrix since two spurious points were found either side of a central band and were consequently omitted. One of the occurrences was that for Moortown and at this green the drainage was very poor. It is possible that the poor drainage of the green affected the moisture content more than the amount of organic matter present in the soil to produce an abnormally high reading. The other occurrence was that for Austerfield Park. This green was constructed on an old waste site and it is possible that this caused the organic matter to be abnormally high. Excluding these two values increases the correlation coefficient to 0.81 at the 1% level of significance. If this is a true correlation then it suggests that a soil with a high organic matter content has a high soil moisture content. This could be caused by a number of factors and it is not clear which is cause and which is effect. Organic matter is very water absorbent, but wet soils hinder the breakdown of organic matter due to their anaerobic nature. This fact links high organic matter contents to high moisture contents. In Figure 4.3 (a) it was seen that high moisture contents occurred on soils with high clay and silt contents. Clay contains water molecules that are only released during the high temperatures experienced during loss on ignition (determination of organic matter content). This contributes to the organic matter content reading giving a larger value than might be expected. The relationships shown in Figure 4.3 (a) and (b) are, therefore, closely linked. Soils with a high percentage of fines tend to have high moisture contents and large organic matter contents. All three measures may be mutually dependent and so it is necessary to state the value of each when determining the characteristics of a turf.

The species of grass prevalent on the green also has an effect on the organic matter and moisture content. Two dominant species of grass were found on the greens visited, Poa annua and Agrostis. Poa annua prefers moist conditions while Agrostis is much more drought resistant and is able to live in drier conditions. Thus, where one predominates the
FIGURE 4.4. The relationship between the percentage of Agrostis in the total ground cover and the percentage of fines in the soil.

other is insignificant and, in most of the cases studied, the Poa annua and the Agrostis provided the total ground cover.

Figure 4.4 shows that the trend is for Agrostis to live on sandy soils. Since Agrostis is drought resistant, it is able to live on the free draining sandy soils where other grasses such as Poa annua would die. The Agrostis is therefore linked with the soils that have low clay compositions, low moisture contents and low organic matter contents. As with the graphs in Figure 4.3 (b), it is not clear which is cause and which is effect. It may be that the dominant species of grass present is not just an indicator of the characteristics of the green but also contributes to those characteristics.

FIGURE 4.5. The relationship between the 1.0 and 0.5kg cylindrical indenters used with the Clegg Impact Hardness Tester.

(iii) Playing Quality Tests relating to the hardness of the surface
As might have been expected, the correlations between the different indenters used with the Clegg Impact Hardness Tester were all significant at the 1% level of confidence (Figure 4.2). The relationship between the maximum decelerations measured using the
The measurements from the indenters are proportional to each other and this fact indicates that they are probably measuring the same property of the soil. There is little, if any, difference between the readings taken with the indenter with a metal golf ball shaped end and that with a real golf ball adhered to its end. As with the results from the ball rebound resilience earlier in this chapter, this implies that the elastic properties of the ball play a minor role in the impacts.

The 0.5kg Clegg and the amount of *Poa annua* present in the grass sward were correlated at the 1% level of significance with a correlation coefficient of 0.57 (Figure 4.6 (a)). The maximum deceleration of the indenter measured by the Clegg Impact Hardness Tester decreases as the amount of *Poa annua* in the sward increases. It is known that the above ground biomass is higher for *Poa annua* than for *Agrostis* mown at 25mm (Canaway 1983). This increase in biomass with an increase in *Poa annua* would cause the Clegg values to be decrease since the ground would be softer. An additional factor may be due to the fact that *Poa annua* prefers moist conditions and so tends to live on soils with a high clay and organic matter content where the soil is likely to be soft anyway. The 0.5kg
Clegg, therefore, indicates that the ground is likely to produce a lower deceleration when the amount of *Poa annua* in the sward is high.

The traction values were found to correlate positively with the percentage of *Poa annua* at the 5% level of significance, i.e. the higher the amount of *Poa annua* the harder it is to twist the disc through/ across the surface. This relationship could be caused by the nature of the soil reflected by the species composition. *Poa annua* prefers clay soils which are “heavy” and bind together well. Sandy soils, on the other hand, have little *Poa annua* on them and are easy to shear through. If soils with a high clay content are soft then the test disc on the traction apparatus is likely to penetrate into the soil. This would produce high traction readings. On a firm sandy soil, on the other hand, the test disc may not penetrate into the soil and may interact more with the top layer of grass and organic matter. This may result in a lower traction reading. Thus, Figure 4.6 indicates that a turf with a large amount of *Poa annua* in its sward reflects, and to some extent causes, conditions that are soft to a vertical impact but quite resistant to shear through the surface. Conversely, soils with a small amount of *Poa annua* are likely to be sandy and appear firm to a vertical impact but relatively weak to horizontal motion of a ball through the surface.

![Figure 4.7. The relationship between the friction of the surface and the percentage of fines in the soil.](image)

(iv) Playing quality tests relating to the surface characteristics

The percentage of fines present in the soil was negatively correlated with the friction of the soil at the 5% significance level, i.e. the friction of the surface tended to decrease as the percentage of fines increased (Figure 4.7).

The fines are particles less than 0.125mm in diameter and a golf ball sliding across a soil composed mostly of particles of this size would experience little resistance. The particles in a sandy soil, on the other hand, could be as large as 2mm and would resist the motion of the golf ball over the surface therefore increasing the frictional force measured by the friction apparatus. This hypothesis assumes that the test apparatus is sliding across the
bare soil and does not account for the effect of the the grass on the frictional force. Another possible explanation is that clay soils tend to have a higher moisture contents and that this affects the moisture on the surface. This moisture then produces surfaces that have a lower friction than their dryer counterparts.

The purpose of this section was to gain an understanding of the relationships between the different Green Characteristics and Playing Quality Tests. It is now possible to use them to determine their effect on the ball/turf impact. The relationships between the Green Characteristics and the impacts described in Chapter 3 are discussed in the following section.

4.4. The effect of Green Characteristics on Ball/turf impacts

It is useful to understand the effects of different characteristics of the green on golf ball impacts with the turf so that the effect of different maintenance regimes and constructions can be assessed. The relationships between the velocity, angle and spin of the rebounding ball and those of the incident ball were shown in Chapter 3. If Tables 3.6, 3.7 and 3.8 are reconsidered, for instance, it can be seen that the coefficients of the regressions for the velocity, angle and spin vary from one green to another. The most likely cause of these differences is the variation in the characteristics of the green. The following method compares regression coefficients with Green Characteristics. These relationships will be beneficial to our understanding of the ball/turf impact.

Consider again the regression coefficients in Tables 3.6 to 3.8. These coefficients were correlated with the results from the playing quality tests in Tables 4.1 and 4.2. For instance, the relationship between the spin coefficients for the rebound velocity in Table 3.7 and the penetrometer readings for each green had a correlation coefficient of 0.235. This was not significant at the 5% level of confidence and was therefore rejected.

Five significant relationships were found and each one is considered individually. Figures 4.8, 4.9 and 4.10 show the relationships between three regression coefficients and the percentage of fines in the soil. Figure 4.8 shows the relationship between the coefficient for the angle of incidence in the regression for the velocity after impact (Table 3.6) and the fines in the soil. This correlated at the 5% level of significance. It is important to realise that this relationship indicates that the percentage of fines influences the manner in which the angle of incidence effects the velocity after impact. There are only five points on the graph since the angle of incidence was varied on only five greens. The errors shown are the standard errors of the coefficients and can be found in Table 3.5.
At this stage the meaning of the relationship is fairly abstract. It can be explained, however, if Figure 4.8 (b) is considered. A pure sand has zero fines present in it and, using the equation in Figure 4.8 (a), the angle regression coefficient would be -0.3ms⁻¹ per degree. As the percentage of fines in the soil increases the angle regression coefficient also increases and reaches zero when the percentage of the fines in the soil is about 60%. Thus a soil with 60% fines would have zero slope while a pure sand would have a slope of -0.3ms⁻¹ per degree.

![Graphs showing the relationship between the angle coefficient in the regressions for the velocity after impact and the percentage of fines in the soil composition and the relationship this implies between the velocity after impact and the angle of incidence.]

FIGURE 4.8. Graphs showing (a) the relationship between the angle coefficient in the regressions for the velocity after impact and the percentage of fines in the soil composition and (b) the relationship this implies between the velocity after impact and the angle of incidence.

An increase in the angle of incidence on a sandy green, therefore, produces a large decrease in the velocity of the rebounding ball. An increase in the angle of incidence on a clay green, however, has little effect on the velocity of the ball after impact. It tends to have the same rebound velocity independent of the incoming angle. The intercept of the lines in Figure 4.8 (b) were found to decrease as the slope approached zero. The velocity of rebound on a clay green was, therefore, lower for most angles of incidence than on a sandy green.

Figure 4.9 (a) shows the relationship between the spin coefficient in the regressions for the spin after impact with the fines present in the soil. It was significant at the 5% level of significance and shows that, as the percentage of fines in the soil increases, the spin regression coefficient decreases. Thus, on a pure sand soil, the spin coefficient would be at its maximum. On a soil containing about 60% of the fines the slope is zero. These facts are translated onto Figure 4.9 (b). An increase in backspin (i.e a decrease in the positive spin, since backspin is negative) produces a large increase in the final backspin.
on sandy greens but has little effect on clay greens since the topspin of the rebounding ball remains approximately constant, independent of the initial spin.

If Figures 3.10 (c) and 3.11 (c) are reconsidered, it can be seen that the variation of the spin after impact with the incident spin is less for Austerfield Park than for Ganton. At Austerfield Park the spin of the rebounding ball is predominantly related to the rebound velocity. Thus, the spin after impact varies little with the incident spin. At Ganton, however, gross slip occurs and since the rebound spin is proportional to incident spin, the variation in the spin after impact is much greater. In effect, therefore, Figure 4.9 is stating that the ball will slip throughout impact on a green with a low percentage of fines and not on a green with a high percentage of fines. Further evidence for this will be shown in the next section.

During the analysis of the impacts, the energy loss of the ball during impact was calculated. This was done by summing the kinetic energy of the ball with its rotational energy before and after impact using,

\[
\text{Energy of ball} = \frac{1}{2}m v^2 + \frac{1}{2}I \omega^2 = \frac{1}{2}m v^2 + \frac{1}{2}(0.4m^2)\omega^2
\]

where \( m \) is the mass of the ball, \( v \) is its velocity, \( I \) is the moment of inertia, \( r \) is its radius and \( \omega \) is its spin. The calculation of the moment of inertia approximates the ball to a homogeneous solid. The effect of the percentage of fines in the soil on the energy lost during impact is considered in Figure 4.10. Figure 4.10 (a) shows that an increase in the percentage of fines in the soil composition produces an increase in the spin coefficient for the regressions for the loss of energy of the ball as it impacts with the turf. The spin coefficient is, therefore, low on sandy greens and high on greens with a large clay content. This is described schematically by Figure 4.10 (b) in which the energy lost by

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**FIGURE 4.9.** Graphs showing (a) the relationship between the spin coefficient in the regressions for the spin after impact and the percentage of fines in the soil composition and (b) the relationship this implies between the spin before and after impact.
the ball is little affected by a change in the spin on sandy greens. On a clay green, however, an increase in the initial backspin produces a large increase in the energy lost by the ball.

\[ C_\omega = 2 \times 10^{-6} + 5 \times 10^{-8} \text{Fines} \]
\[ r = 0.775 \]
\[ p = 0.05 \]

![Graph showing the relationship between spin coefficient in the regressions for the energy lost by the ball during impact and the percentage of fines in the soil composition](image)

![Graph showing the relationship between the energy loss and the spin before impact](image)

FIGURE 4.10. Graphs showing (a) the relationship between the spin coefficient in the regressions for the energy lost by the ball during impact and the percentage of fines in the soil composition and (b) the relationship this implies between the energy loss and the spin before impact.

The effects described by Figures 4.8, 4.9 and 4.10 can be explained by the differences found between clay and sandy greens found earlier in this chapter. Greens with a high clay content are often moist and tend to be unresistant to vertical forces but resistant to horizontal motion of the ball across the turf. Greens with a high sand content, on the other hand, tend to be dryer and much firmer. The result is that sandy greens are resistant to vertical forces and, since the pitchmark is much shallower, the forces opposing horizontal motion are less. On clay soils, there does not tend to be much difference between impacts since the ball rebounds with roughly the same low velocity and with the same amount of topspin regardless of the initial impact. Sandier greens are much more receptive to changes in the angle of incidence and the initial backspin since the pitchmark changes more in depth as the impacts vary.

4.5 The characteristics of greens that allow backspin to be retained

The basic characteristics of the greens on which slip is likely to occur can be determined if we redraw some of the graphs found earlier in this chapter. Figure 4.11 shows the information contained in Figure 4.3, the letter “s” indicates the greens on which the ball was likely to slip off the surface if the initial backspin was high enough. Table 3.10 shows the greens that were considered to allow backspin to be retained if the incident spin exceeded \(-350\text{rads}^{-1}\). It can be seen in Figures 4.11 (a) and (b) that these greens are
characterised by a fairly low percentage of fines, a low organic matter content and a low moisture content. If Figure 4.6 is also reproduced in Figure 4.12 it can be seen that the greens on which slipping occurred had fairly low percentages of *Poa annua* in their sward, high Clegg Impact Hardness Tester measurements and low traction values. Therefore, slipping occurred on fairly sandy greens that were well drained and had a low organic matter content. These were quite resistant to vertical impacts. Horizontal motion through the turf was fairly unimpeded.

![Figure 4.11(a)](image1)

![Figure 4.11(b)](image2)

**FIGURE 4.11.** Graphs to show the relationship between greens where golf balls are likely to slip when rebounding from the surface and the natural characteristics of the turf. These greens are indicated by the letter "s".

Using these graphs, limits of all the tests can be suggested to indicate the likelihood of the ball slipping at the end of impact on a particular green. For slip to take place, the upper limit for the percentage of fines and the moisture content of the soil should be about 30% while the maximum organic matter possible should be about 8%. Slip throughout impact is most likely to occur if the percentage of *Poa annua* in the sward is less than 60% and if the measurements using the Clegg Impact Hardness Tester (0.5kg indenter) are greater than about 50g. The lowest desirable traction value for slipping to occur throughout impact is about 15N.
FIGURE 4.12. The graphs from Figure 4.6 showing the greens on which the ball was likely to slip off the surface (indicated by the letter “s”).

These guidelines could be used by greenkeepers to determine whether impacts on a particular green would always roll off the surface or whether slip throughout impact would be possible. If the greenkeeper wanted the ball to retain some backspin then maintenance regimes could be implemented that would satisfy the conditions above. Although this would not guarantee the retention of backspin, it would make its occurrence more probable.

4.6 Summary

This chapter analysed the results of the tests to determine the characteristics of golf greens. Some tests were found to relate significantly to other tests while others were found to be relatively independent. Although the Stimpmeter had already been used in golf research, it did not relate to any of the other tests. The differences between greens showed up well, however, and the results agreed with previous Stimpmeter tests in this country (Downes 1982) which concluded that greens in this country were too slow for tournament play.
The ball rebound resilience was not found to correlate with any of the other tests. However, it was found that the construction of the ball played little part in impacts from this height. It is possible that balls dropped from 5m only interacted with a top layer consisting of grass and roots. Other tests, such as the Clegg Impact Hardness Tester, probably interacted with the soil layer beneath the grass.

It was found in this chapter that the soil composition, the organic matter content and the moisture content were all inter-related. A sandy soil is likely to be dry and have a low organic matter content. A clay soil is generally more moist and has a higher organic matter content. It is not clear whether it is the organic matter that retains the moisture or the moisture content that aids the build up of the organic matter. The species of grass present provides a good indication of the characteristics of the green since Poa annua tends to live on moist clay soils with a high organic matter content while Agrostis tends to live on dry sandy soils with a low organic matter content.

Results of some of the tests were found to vary significantly within errors between greens but were not found to relate significantly to any other tests. It is possible that more observations may have produced a significant correlation but it is equally possible that the differing physical nature of the tests caused the lack of significance. The three extra indenters developed for the Clegg Impact Hardness Tester were slightly disappointing because the readings obtained with them were in such large discrete steps. This caused the Tester to be inaccurate when taking individual readings. Once a more accurate indenter was used, however, differences between greens showed up clearly. It was found that the Clegg Impact Hardness Tester could be used to determine the effect of the green composition (soil composition, organic matter content etc.) on the vertical deceleration experienced by an impacting body. The traction readings showed the effect of the green composition on the forces in the horizontal direction.

The Clegg 0.5kg indenter was found to provide a realistic measure of the Poa annua present on the greens, the "softer" surfaces indicating higher Poa annua contents. The traction values were also found to correlate significantly and this highlighted an important characteristic of greens containing a lot of Poa annua, that is, that they are fairly unresistant to vertical impacts but are resistant to horizontal shearing through the surface.

The greens studied in this project were categorised in Chapter 3 into those on which the ball slipped throughout impact if the backspin was high enough and those on which the ball always rolled off the surface. The playing characteristics of the two types of green were determined and it was found that the greens on which gross slipping was possible were sandy in composition. These were characterised by low moisture and organic matter contents and Poa annua contents of less than 60%. As a consequence, these greens
tended to have high Clegg Impact Hardness Tester values and moderate to low traction values. It was possible, therefore, to suggest limits of these playing quality tests which could be used to determine the playability of a particular green. These could be used by greenkeepers to determine the correct maintenance regimes required for a certain type of green.

There was no significant difference between the rebound heights of two different constructions of golf ball. This agreed with earlier findings in Chapter 3 which showed that the construction of the ball played a minor roll in impacts. As stated earlier, this simplifies the model of impact considered in the next Chapter since the ball can be considered as a rigid solid.