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A Comparison of the Mechanical Charatceristics of Natural Turf and Artificial Turf Football Pitches

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The aim of this study was to investigate the mechanical characteristics of football pitches such as hardness and traction. Field tests, including an impact hammer test and a traction test, were performed at 13 natural-turf pitches and eight artificial-turf pitches. Based on the field test data, differences between the natural-turf and artificial-turf pitches, and seasonal variations in their mechanical characteristics, and the influence of the presence or absence of turf-grass on traction characteristics are discussed. The main difference between natural-turf and artificial-turf is highlighted in the shape of a rotational resistance curve. Furthermore, the natural-turf pitch had significant seasonal variation in both hardness and traction, while that was not the case with the artificial-turf pitch.

Keywords: football pitch, natural-turf, artificial-turf, hardness, traction

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1. Introduction

To investigate the characteristics and performance of rugby pitches is of great importance for the safety of players and the quality of games. For instance, the surface hardness and slip resistance of pitches may play key roles in the safety of players when they fall or dive onto the pitch surface. The degree of traction between a shoe sole and the pitch surface has a great influence on running play especially when players change direction at speed. While rugby pitches themselves can significantly affect games there is little information on their actual playing performance characteristics (Ono and Mikami, 1986; Mikami et al., 1989; Ono et al., 1996). On the other hand, there have recently been attempts to use artificial-turf instead of natural-turf for football pitches (FIFA, 2005; IRB, 2006). To encourage such attempts, required performance criteria for such football pitches have to be established.

This study was carried out to find out the mechanical characteristics of football pitches. Field tests, including an impact hammer test and a traction test were performed at 13 natural-turf pitches and eight artificial-turf pitches, of which some pitches were used in the Japan Rugby Top League and/or the Japanese National Football League. The study mainly focused on exploring the differences in mechanical characteristics between natural-turf and artificial-turf pitches; how the change of seasons affects the mechanical characteristics of pitches; and, how the presence or absence of turf grass affects the mechanical characteristics of pitches, especially rotational resistance.

2. Field test method

2.1. Evaluation for pitch hardness

2.1.1. Impact hammer test

To investigate the hardness of football pitches, an impact hammer test was performed at 12 natural-turf pitches and eight artificial pitches. As shown in **Figure 1**, the impact hammer test apparatus consisted of a hammer with a mass of 5 kg or 10 kg and two accelerometers. The hammers were cylinders with a diameter of 10 cm. The striking surface of the hammer was flat. In the test the hammer was freely

Figure 1 Impact hammer test apparatus.

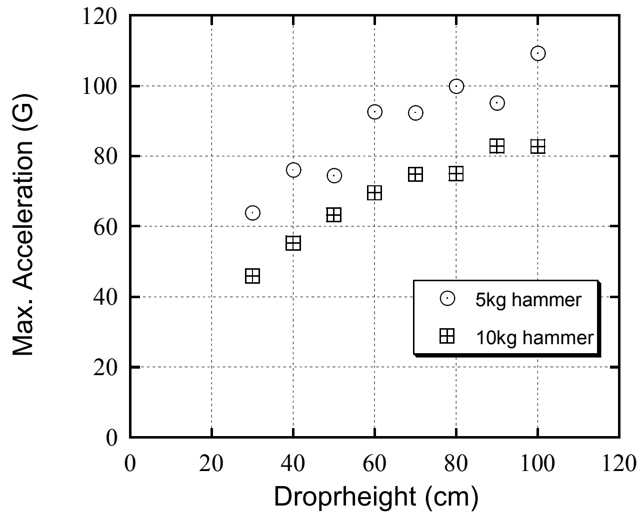


Figure 2 Typical impact hammer test result for natural-turf pitch.

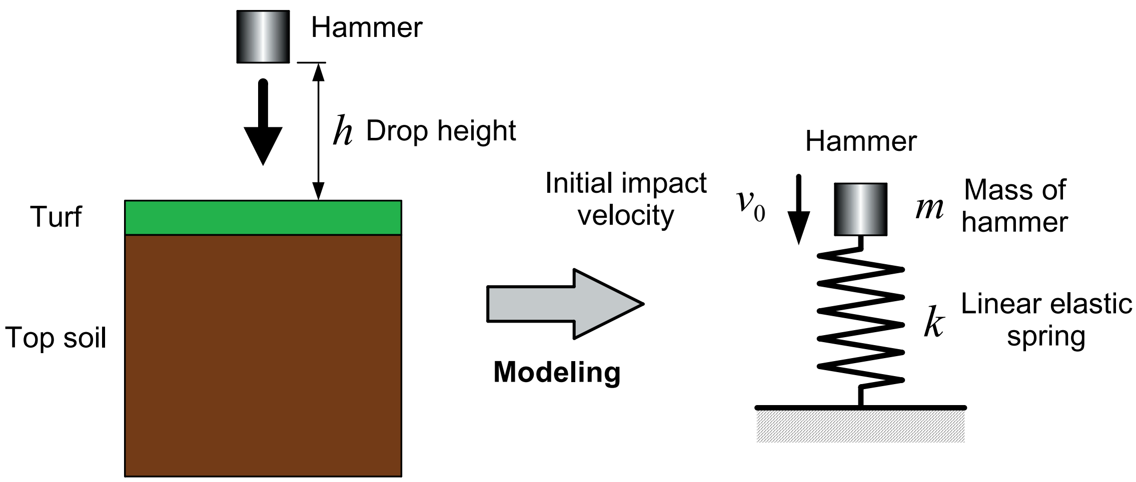


Figure 3 Linear elastic modeling for football pitch.

dropped from heights ranging from 30 to 100 cm in 10 cm intervals. The generated impact acceleration was measured by accelerometers fixed to the hammer.

In test methods previously used to investigate the hardness of football pitches, a rigid impact hammer was allowed to fall onto the pitch surface. The maximum force applied and the maximum surface deformation occurred were measured by a loadcell and a displacement transducer respectively (FIFA, 2005; IRB, 2006; Mikami et al., 1989; Ono and Mikami, 1986). The hardness of football pitches has previously been mainly discussed in terms of the maximum force applied and maximum surface deformation. As compared to those test methods, the test method employed in this study is simple and economical as it directly measures the generated impact acceleration with accelerometers.

2.1.2. Hardness index

Figure 2 shows the relationship between maximum acceleration and drop height. While the maximum acceleration increases with an increase in drop height, the relationship exhibits nonlinearity. It should be noted that from the same drop height a lighter hammer would achieve greater maximum acceleration.

Since the relationship between maximum acceleration and drop height generally included certain variations, it was difficult to evaluate the impact characteristics of a pitch with a maximum acceleration obtained at one constant drop height. Thus, a proper index was required to evaluate the impact characteristics of a pitch.

When a pitch is considered as a linear elastic body (**Figure 3**), the acceleration response of a hammer is

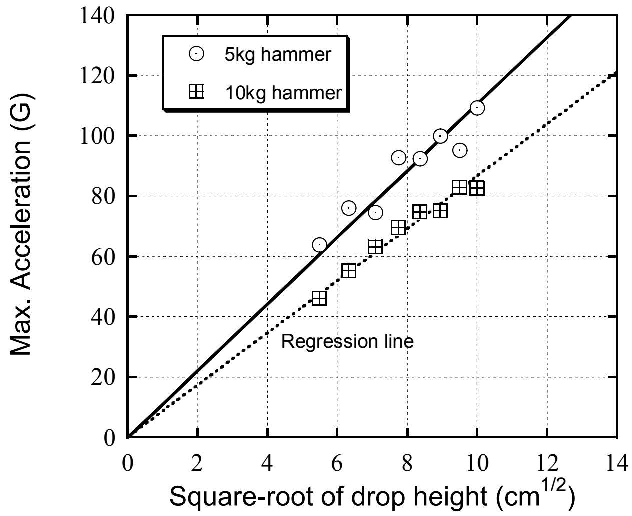


Figure 4 Relationship between maximum acceleration and square-root of drop height.

Figure 5 Traction test.

theoretically given as follows (Clough and Penzien, 1993):

$$a(t) = v_0 \sqrt{\frac{k}{m}} \sin\left(\sqrt{\frac{k}{m}} t\right) \qquad (1)$$

in which $a(t)$ = acceleration in time domain, t = time, v_0 = nitial impact velocity given as $v_0 = \sqrt{2gh}$, g = acceleration of gravity, h = drop height of hammer, m = mass of hammer, k = linear elastic spring constant.

Since m and k are constants in Eq. (1), the maximum acceleration can be simply given as:

$$\text{Maximum acceleration} = \alpha \times \sqrt{\text{Drop height}} \qquad (2)$$

in which α = a constant.

In the test results, a linear relationship was observed between the maximum acceleration and the square root of the drop height (**Figure 4**). In this study, the constant α was adopted as a hardness index for investigating the hardness of a pitch. It was determined by regression analysis with maximum accelerations obtained at several drop heights from 30 to 100 cm in 10 cm intervals. Since the units of maximum acceleration and drop height are G and cm, respectively, the hardness index has the unit of $G \cdot cm^{-1/2}$. In the subsequent impact hammer test, a hammer with a mass of 5 kg was used to evaluate the hardness index. The mass was determined to be 5 kg in consideration of the effect of topsoil which was up to approximately 200 mm in depth (Kinki Regional Development Bureau, 1996).

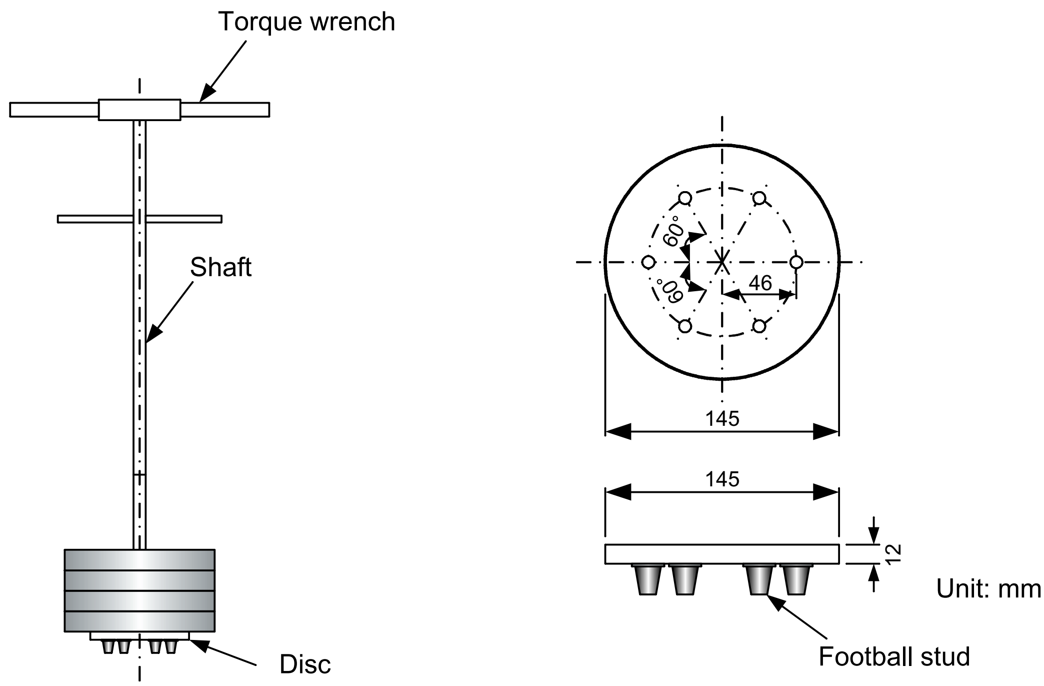
2.2. Evaluation of pitch traction

To investigate traction characteristics on the surface of turf, a traction test was executed at nine natural-turf pitches and eight artificial-turf pitches (**Figure 5**). In the traction test apparatus, six football studs were equally spaced on the bottom surface of a steel disc with a diameter of 145 mm (**Figure 6**). A two-handled torque wrench was attached to the top of the shaft. The total mass of the testing apparatus was 46 kg following the IRB standard (IRB, 2006). In the test, the apparatus was initially dropped from a height of approximately 60 mm. The apparatus was then rotated with the torque wrench with no application of vertical pressure until a rupture occurred. The maximum torque at the rupture was only measured in the IRB standard (IRB, 2006). In this study, however, both the torque and the rotational angle of the disc were measured with the torque wrench and the self-fabricated protractor until a rupture occurred. The traction test was performed a couple of times on the same pitch.

3. Field test results and discussion

3.1. Hardness characteristics of natural-turf and artificial-turf pitches

The hardness indexes obtained at each football pitch are shown in **Figures 7** and **8**. It is particularly



(a) Overall view (b) Disc detail

Figure 6 Traction test apparatus.

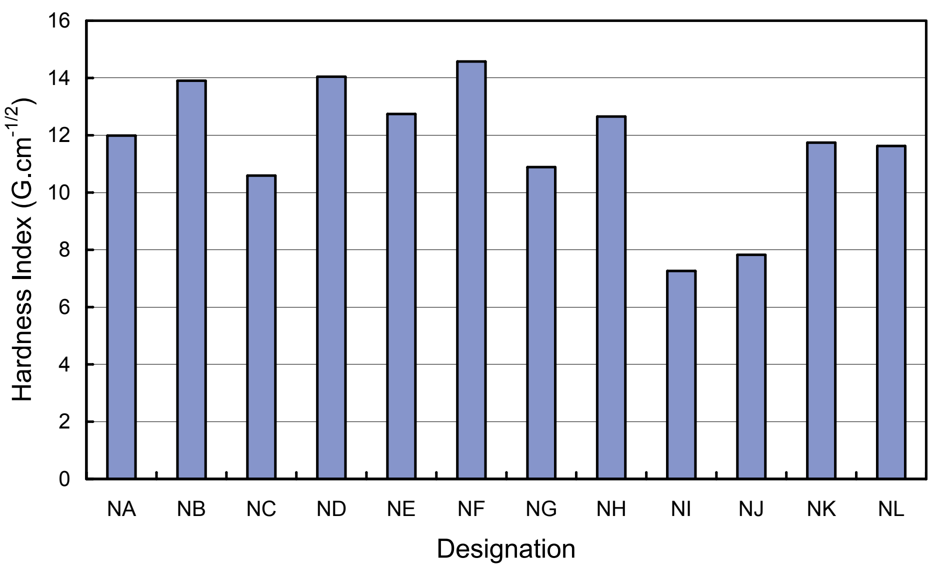


Figure 7 Hardness index for natural-turf pitches.

worth noting that the variation in hardness for the natural-turf pitches is larger than that for the artificial-turf pitches. The difference between the maximum and minimum hardness indexes in the natural-turf pitches was 7.3 $G \cdot cm^{-1/2}$, while that in the artificial-turf pitches was 2.7 $G \cdot cm^{-1/2}$. The average hardness index for the natural-turf and artificial-turf pitches was approximately 11.7 and 10.8 $G \cdot cm^{-1/2}$ respectively. For natural-turf pitches, increasing the frequency of use causes wear and tear of the turf, and the change of seasons will also affect the characteristics of the turf. Therefore, the frequency of use and the change of seasons might be the main factors affecting the hardness of natural-turf pitches, while they might have less effect on the hardness of artificial-turf pitches.

Figure 9 shows seasonal variations in the hardness index obtained at one natural-turf pitch, "NA", where an overseeding method is employed to keep the pitch green. As can be seen, the hardness index

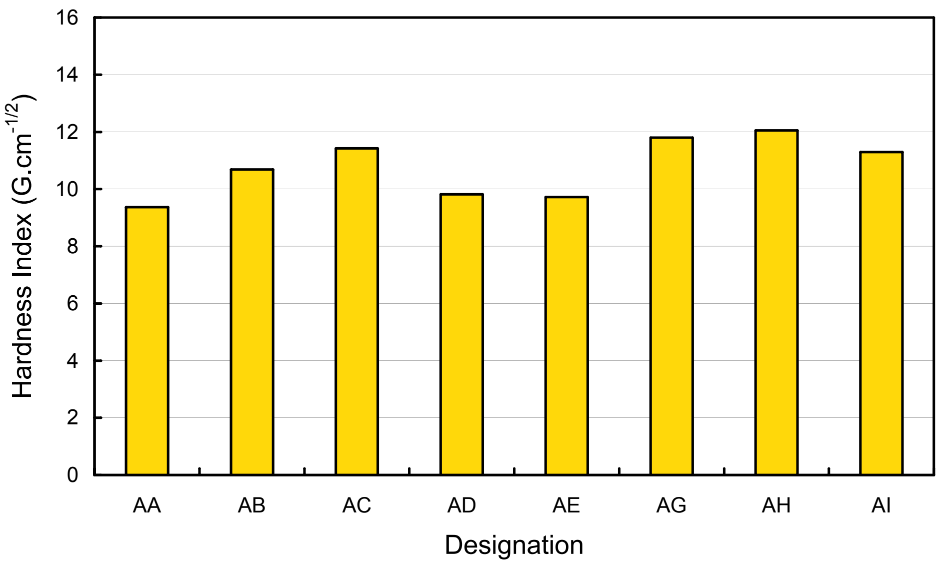


Figure 8 Hardness index for artificial-turf pitches.

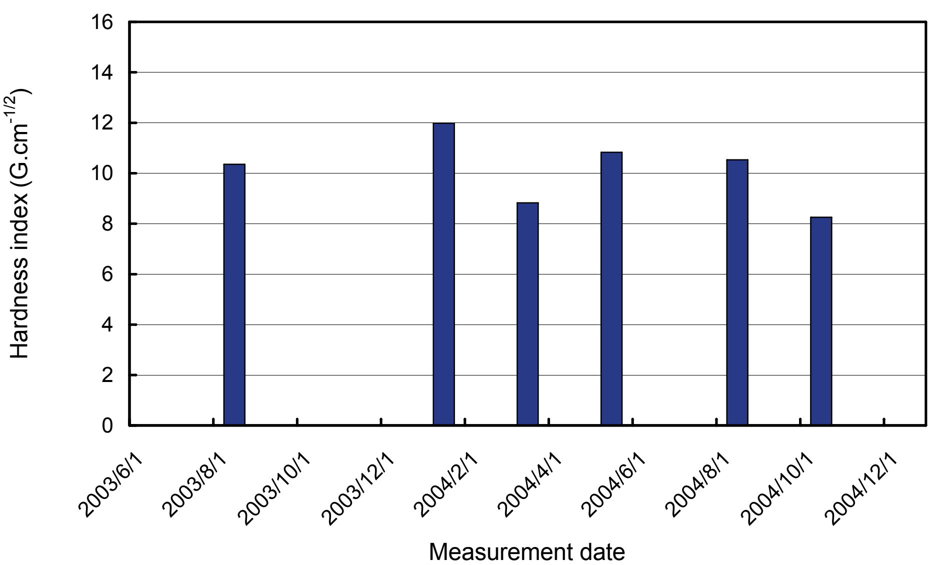


Figure 9 Seasonal variations in hardness index in natural-turf pitch “NA”.

varies with the seasons. It should be noted that since the difference between the maximum and minimum hardness indexes is approximately 4.0 $G \cdot cm^{-1/2}$, the seasonal variations in the hardness index are considerable. When discussing the performance and safety of natural-turf pitches, seasonal variations should be one of the main concerns.

The hardness index in March and October was lower than that in other months. March was a transition period from ryegrass to bermudagrass and October was an overseeding period which meant that the amount of turf was less. In addition, in both months an aeration process including coring, slitting and spiking (Puhalla et al., 1999) was performed to relieve compaction and allow air, water and nutrients to penetrate into the soil. We can conclude, therefore, that the amount of turf and the conditions of maintenance and climate are the main factors causing variation in the hardness index of natural-turf pitches.

3.2. Traction characteristics for natural-turf and artificial-turf pitches

The maximum rotational resistance obtained at various pitches is shown in **Figures 10** and **11**. In the natural-turf pitches, except for "NE", the maximum rotational resistance is in the range of approximately 40 to 60 N.m. Most of the artificial-turf pitches

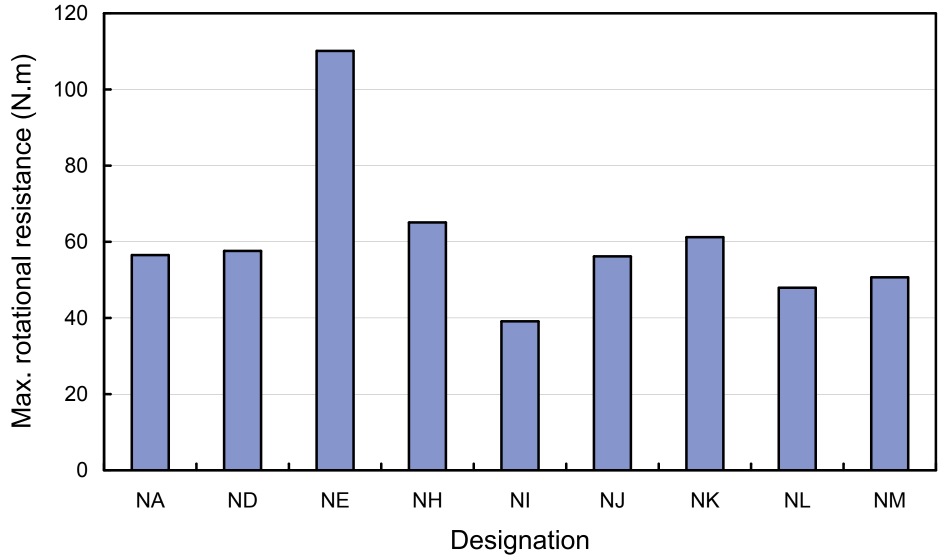


Figure 10 Maximum rotational resistance for natural-turf pitches.

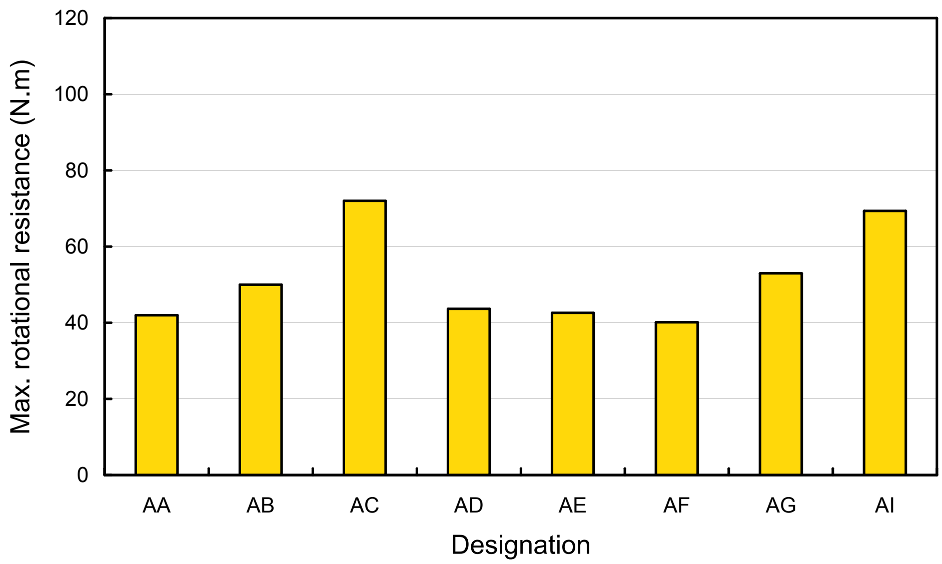


Figure 11 Maximum rotational resistance for artificial-turf pitches.

satisfied the IRB requirement (IRB, 2006), in which the specified maximum rotational resistance is 30 to 50 N.m. For both artificial-turf and natural-turf pitches, the longer the turf, the greater the maximum rotational resistance was observed.

Figure 12 shows seasonal variations in the maximum rotational resistance obtained at one natural-turf pitch, "NA", where bermudagrass was selected for the surface of the pitch while overseeding with ryegrass was executed in mid-September. As can be seen, the maximum rotational resistance varies with the seasons. It is also clearly recognized that the maximum rotational resistance is greater in the summer season and smaller in the winter season. This tendency seems to be closely related to the fact that bermudagrass grows well in the summer season and is dormant in the winter.

Figure 13 shows typical rotational resistance curves for natural-turf and artificial-turf pitches. The plural lines for each legend express several test results measured on the same pitch. Note that the variations near the maximum rotational resistance were due to little slips in between the disc of a traction test apparatus and the pitch surface. While the rotational resistance for the artificial-turf linearly increases with an increase in rotational angle, the curves for the natural-turf exhibit a parabolic shape in which a rather large torque is generated in the range

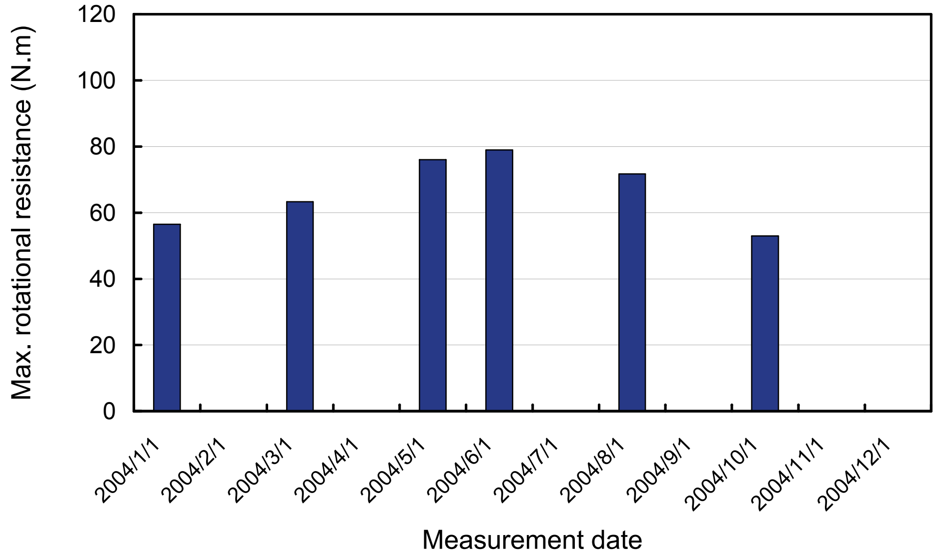


Figure 12 Seasonal variations in maximum rotational resistance in natural-turf pitch "NA".

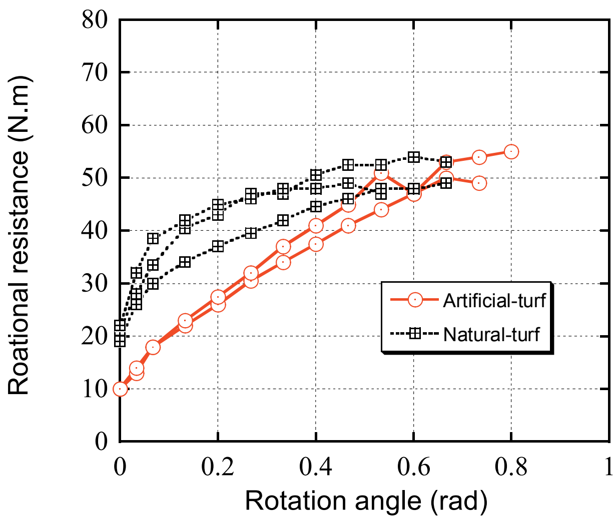


Figure 13 Typical rotational resistance curves for natural-turf and artificial-turf.

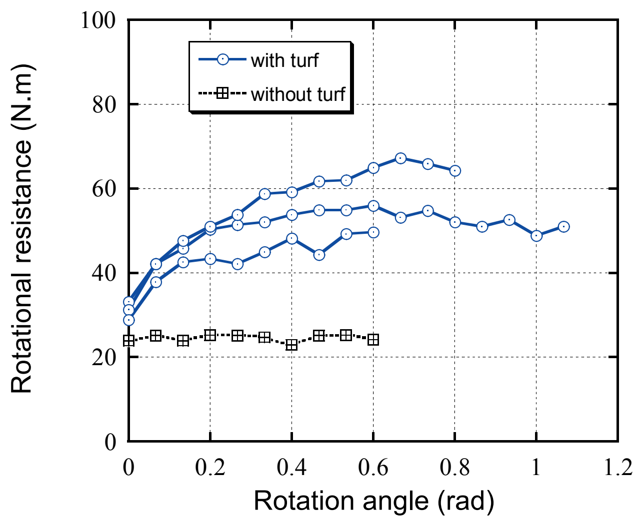


Figure 14 Rotational resistance curves with or without turf.

of a small rotational angle. These differences could be attributed to the different ways in which torque is generated on either natural-turf or artificial-turf. For the natural-turf, rhizomes and stolons spread horizontally below or on the soil surface which seems to significantly affect the initial torque generation. On the other hand, the torque generation for the artificial-turf seems to mainly depend on the frictional resistance of the synthetic fabric of the artificial turf itself. At the present moment, it is not known how these differences may affect player safety and performance.

3.3. Influence of the presence or absence of turf on traction characteristics

The traction test was performed under the same soil conditions except for the presence or absence of turf. The results are shown in **Figure 14**. The rotational resistance with turf increases with an increasing rotation angle, while that without turf has a constant regardless of the rotational angle. This may be a reason for the fact that players tend to get leg cramp more often on turf pitches compared to soil pitches.

4. Conclusions

In this study, field tests were performed to investigate the characteristics of 13 natural-turf and eight artificial-turf football pitches. Based on the results presented in this paper, the following conclusions can be drawn.

1. A hardness index was proposed to evaluate the hardness of a pitch.
2. The hardness index was affected by various factors for natural-turf pitches, such as seasons, maintenance and frequency of use. There was less variation for artificial-turf pitches.
3. The seasonal variations for the natural-turf pitches were significant in both the hardness index and the maximum rotational resistance.
4. The rotational resistance for the natural-turf and artificial-turf pitches increased with increases in the rotational angle, while the resistance for the pitches without turf was constant regardless of rotational angle.
5. The maximum rotational resistances for the natural-turf and artificial-turf pitches were virtually identical. However, the shape of the rotational resistance curve is significantly different between natural-turf and artificial-turf. Further research is required to investigate the possible effects of these differences on player safety and performance.

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