SHOCK ABSORBING PROPERTIES

OF

NATURAL AND SYNTHETIC TURF SPORTS GROUNDS

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The worlds most popular games -- soccer football, field hockey, American football and baseball -- have in common a number of elements.

All are played on open fields -- traditionally covered with grass -- ranging in size from 6000 to 12,000 square meters.

All involve the management of some sort of ball which rolls and bounces on the surface of the playing field.

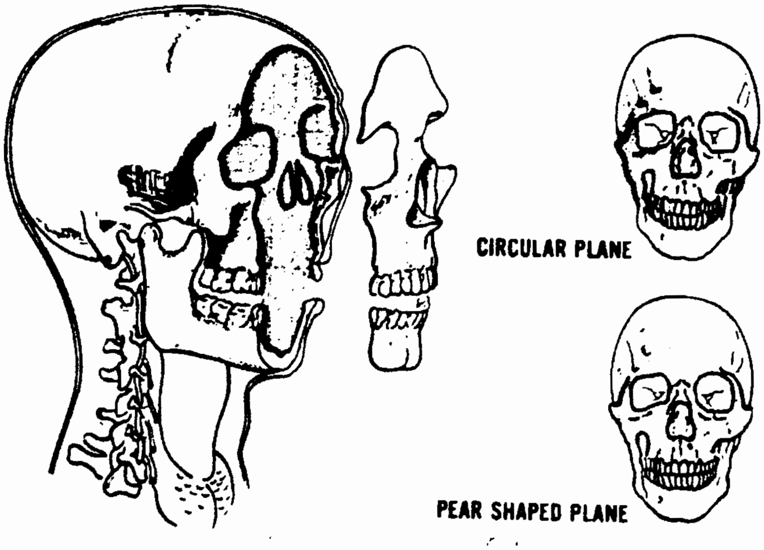
Players run in all of the games.

Players fall to the ground in all of them, either because of their own efforts or as a result of opposing player action.

In our work to define the requirements of synthetic turf playing surfaces we have regarded the running, falling and ball response properties of well maintained natural grass, under its best conditions, as an ideal to be matched by the synthetic materials. In the remarks to follow we will specifically address the shock absorbency of natural surfaces over the range of soil types and playing conditions normally found. Our objective was to characterize natural surfaces and then match or exceed them with synthetic ones in order to gain the synthetic turf benefits of increased usage, resistance to wear from such usage, resistance to weathering, and consistency of properties over a wide range of uses and climates. Put simply, natural turf at its best is the standard; but natural turf under heavy usage in less than ideal climates is seldom (if ever) at its "best".

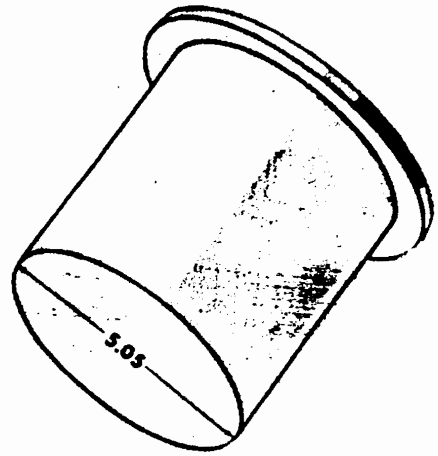
TEST METHOD

In the early 1970s, Committee F-8, "Sports Facilities and Equipment", of the American Society for Testing and Materials developed its standard method F-355 (Ref. 1) for measuring the impact attenuation properties of playing surfaces. The test had its foundation in work by Daniel of the U.S. automobile industry (Ref. 2). He proposed that the human head and neck weighed approximately 9 kg (20 lbs), and that the human facial plane had an area of roughly 129 cm^2 (20 in^2). He suggested that a flat impacting surface, like the human facial plane, gave a more appropriate measure of impact attenuation than the hemispheric surface used by earlier investigators.



Face contours compared to flat

Fig. 1



Face-form for testing load distributing crash padding plane

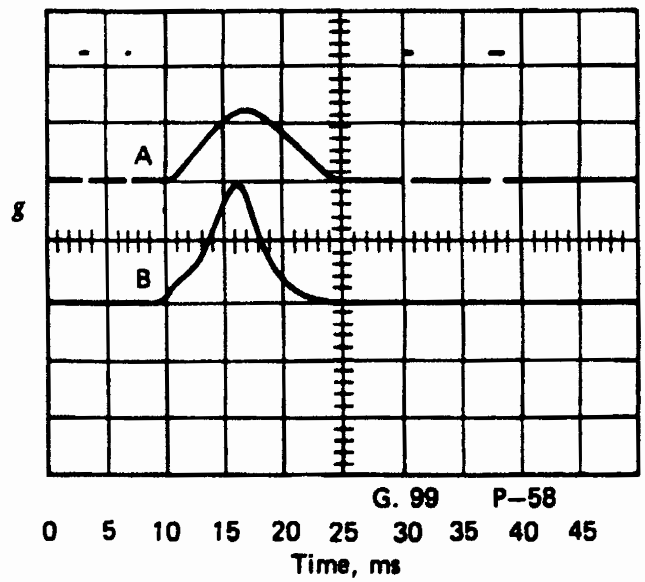
Fig. 2

In 1970 Stephen Reid (Ref. 3) attached accelerometers to the head of an American footballer, with radio transmitters to send the resulting electronic data to the side lines of the game. He reported that approximately 85 per cent of the impacts in American football were 54 Newton Metres (40 Ft Lbs) or less. With the equipment suggested by Daniel this is equivalent to the impact from dropping the 9 kg (20 lb) missile from a height of 60 cm (24 in). The ASTM method (Ref. 1) uses as its procedure "A" the Daniels missile geometry, with an impact velocity of 345 cm sec^{-1} (136 in sec^{-1}) as obtained from a free fall of 60 cm (24 in). The resulting test equipment consists of a free falling missile equipped with either strain gauge or piezoelectric accelerometers, connected through signal conditioning circuits to a cathode ray oscilloscope. A Polaroid camera is used to make a permanent photographic record of the force -- time trace from the accelerometer as it is displayed on the oscilloscope.

Fig. 3

Typical Force-Time and Penetration-Time Curves

(A is Penetration, B is Force in units of G)



In some test units provision is also made to measure the displacement of the missile during the initial impact and rebound period.

We have built portable impact testing equipment and carried it to a variety of well maintained grass playing fields to measure their force -- time deceleration properties during actual playing seasons.

In addition to measuring the impact response, we collected soil samples at the impact sites and submitted them to a commercial laboratory for measurement of moisture content, particle size distribution, plastic and liquid limits and soil type.

The same impact test method is used to routinely measure the impact properties of synthetic playing surfaces made by Monsanto and other suppliers.

INTERPRETATION OF FORCE TIME CURVE

The classic analog for shock absorbing systems is a combination of a dash pot and a spring. When the resulting force time curve, reported in multiples of G, the acceleration of gravity, is square, the average and maximum values for G are identical. While such a curve is ideal for minimizing impact damage to machinery, it moves to its maximum value instantaneously, giving a high "impulse" or slap factor which is uncomfortable to athletes.

For player comfort as well as protection, the trace should be more nearly sinusoidal -- keeping the maximum G value low but keeping the slope of the curve at onset to somewhat less than 10,000 G per second.

By analogy -- when driving your auto, you apply the brakes gradually rather than jamming them immediately to a maximum stopping rate.

The damaging potential of an impact is generally regarded to be related to an exponential function ofthe G/time history. The most commonly used factor is Gadd's "Severity Index" (Ref. 4), given as:

$$\text{Severity Index} = \int_0^t G^{2.5}\,dt$$

It follows readily that very high levels of G for even short periods of time are more damaging than moderate G levels for up to 30 or 40 milliseconds. Severity index values of 1500 to 1800 are generally regarded as severe, and to be avoided. The severity index can be obtained by graphical integration of the G-time curve, or can be electronically calculated by the test equipment itself if suitable circuits are built into it. For a given playing surface system, the correlation between $\log_{10} G_{max}$ and S.I. is usually very precise. Consequently, for field test work, most investigators simply rely on the maximum value of G for routine quality control analysis.

TEST RESULTS

1) Natural Grass

1.1 Ideal conditions

Lightly used areas of well grassed fields typically give maximum G values from 70 to 90. Such fields will have soil moisture contents ranging from 15 to 30 percent. There appears to be a strong relationship between soil type and ideal moisture content, as characterized by the "plastic limit" and "liquid limit" of the individual soil composition.

1.2 Wet and/or Muddy Grounds

As soil moisture increases to the point that the grounds are unplayable, the maximum G value from a standard impact falls to 60 to 65 G. We have not found any grass fields with G values below 60 for the standard test.

1.3 Frozen Grounds

At $-10^{\circ}C$ the playing field in Bloomington, Minnesota gave G values ranging from 150 to 275, and severity index values ranged up to 1400.

1.4 Compacted Clay

The "skin" areas of fields used for baseball are generally constructed of a hard packed clay base, covered with a compacted mix of clay, loam and sand. The total area is moistened and tamped before each game for maximum firmness. In tests at a number of Major League baseball parks in the United States we found infield Gmax values of 150 to over 250.

1.5 Engineered Sand Systems

Compacted wet sand covered with 2 to 5 cm of sod gave values significantly higher than those for grass in a normal soil medium -- ranging from 135 to 150 G. At first thought such high G values are surprising, since the normal idea is that sand is "soft". Upon reflection, however, one is reminded that the sand is "soft" when it is dry and unconfined. Its "softness" comes from its ability to yield or be displaced. Wet sand confined by a matrix of grass roots (or in some cases textile fibers) is not free to move on impact, hence is "hard" and unyielding.

2) Synthetic Surfaces

The shock absorbing properties of synthetic turf surfaces are generally derived from the combined effects of each element in the system. A typical synthetic turf surface consists of the following:

2.1 Pile Fiber

The "grasslike" appearance of synthetic turf results from its nylon or polyolefin pile fibers, typically 8 to 12 mm long and ranging from nearly vertical to tilt angles of 45 degrees or less. The nylon 6,6 fibers used for AstroTurf® surfaces are given a texturing process to produce a "coiled spring" configuration which functionally eliminates the "grain" or directionality found with earlier surfaces. Interestingly, the textured pile fiber contributes to the shock absorbency of the turf system, especially at elevated temperatures. Similar contributions are not found from polyolefin pile fibers after the first few impacts, as the olefin materials cold-flow and mat down under repeated foot traffic or other impacts.

2.2 Backing Fabric

Synthetic turf systems are generally assembled by the traditional carpet manufacturing techniques of knitting, tufting or weaving. The backing fabric serves to give structural integrity to the entire turf system. The backing fabric appears to make little contribution to the system's shock absorbing properties, although in some cases it may increase the effective area contacted by the impacting missile or player, providing a stiffer, less yielding cushion but lessening penetration of the turf/pad system to prevent "bottoming out," or impact with the non-yielding subbase of the system.

2.3 Underpad

The primary source of shock absorbency for most synthetic turfs is the layer of elastomeric padding beneath the fabric. For contact sports such as American football the most common underpads are closed cell foams of either poly(vinyl chloride) or crosslinked polyethylene. Foam thicknesses vary from 10 to 18 mm. Where contact is less severe the foam thickness may be as thin as 7 or 8 mm, and the foam itself may be open rather than closed celled. In some cases rubber crumb (shredded automobile tires) bonded with polyurethane adhesive may be used. Such pads tend to be less yielding than cellular ones.

2.4 Mineral Substrate

In order to provide uniform planarity, synthetic surfaces are installed over some sort of stable foundation — most commonly a layer of asphaltic concrete over crushed stone. Occasionally Portland cement concrete is used, and there have recently been a number of so-called "dynamic" subbases introduced. The "dynamic" bases involve various fibrous matrices infilled with either mineral or organic particles. In some cases they may contribute to the overall shock absorbency of the turf system, at the price of lessened planarity and dimensional stability.

Synthetic turf playing fields intended for American football and baseball games with frequent falls and body to body impact are normally designed to give impact values from 70 to 100 G at the time of installation, and ranging upward to 150-175 G after five or more years of heavy usage. Severity Index values may range up to 800 or 1000 for some systems, but values of 300-500 are more common. These values are maintained over the full range of weather conditions encountered in actual play.

Synthetic turf playing fields for softball, soccer football, and field hockey, where body impacts are less severe and frequent, are generally designed to give impact values from 110 to about 200 G reflecting the greater emphasis on running and less emphasis on falling in those games.

CONCLUSION

Using a standard test method derived from automotive and aircraft safety studies we have measured the impact attenuation (shock absorbing) properties of a number of well maintained natural grass, prepared earth, and synthetic turf sports grounds, illustrating the wide range of impact properties found on playing fields.

Measurements on synthetic turf surfaces show far less variability than those on natural grounds. The synthetic surfaces can be designed and built to provide the conditions needed for the sports to be played on each sports ground. Future emphasis will be on providing increased longevity, lower costs, and — with no sacrifice in player comfort and safety properties — ball management properties that more closely match those of traditional surfaces.

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