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Impact absorption, new and old AstroTurf at West Virginia University

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ABSTRACT. Because of a subjective observation that the surface "hardness" of West Virginia University's Mountaineer Field, covered with Monsanto's AstroTurf, has progressively increased since its installation five years ago, impact absorption studies were carried out. Surfaces tested for comparison were new AstroTurf, five year old AstroTurf, a well kept grass field, and asphalt. Four impact parameters of each surface were measured; stopping time, total impact duration, peak acceleration and average acceleration. Sod was found to have the most superior impact absorbing qualities, followed closely by new AstroTurf. Five year old AstroTurf was found to have considerably less ability to absorb impact force, apparently due mainly to changes in the grass-like surface layer. A method of measuring impact absorbing capacity of athletic playing surfaces is described.

ARTIFICIAL PLAYING SURFACES, HARDNESS, DETERIORATION WITH USE AND EXPOSURE

INTRODUCTION

The physical characteristics, playing qualities and injury statistics of West Virginia University's AstroTurf surfaced Mountaineer field were observed through five complete seasons. During this span it has been a subjective observation by players as well as by the authors, that the field has increased in "hardness." Certain physical alterations in the surface were also noted, the most significant of which has been progressive compression of the grass-like surface layer (Figure 1a).

Initially, the nylon fibers projected upward from the mat into which they are woven a distance of 1 cm. These fibers no longer project vertically upward but rather lie over to the extent that the surface layer height is now ½ cm (Figure 1b). This change is irreversible and we have felt this alone was enough to increase the "hardness" of the field.

Surface hardness can be expressed in terms of impact absorption parameters. We therefore investigated the impact absorption capability of our AstroTurf field and did similar studies on sod and asphalt for comparison.

In August of 1973 several strips of new AstroTurf were laid down on the playing surface during major maintenance repair. The underpad was not involved. We thus were afforded the opportunity to perform impact absorption studies on five year old AstroTurf and new AstroTurf, each on the same five year old underpad. Any significant difference in impact absorption could then be attributed to alterations in the grass-like surface layer.

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INVESTIGATION

Preliminary Analysis. When two objects such as an athlete and his playing field collide, the impact is not easy to analytically formulate. Some straight-forward analysis based on elementary physics leads, however, to a few key parameters which engineers commonly use in comparing one impact with another.

Consider a test body of mass m which falls from a height h and strikes the earth. Before the fall its potential energy was

$$P = mgh \qquad (1)$$

where g is the acceleration of gravity. At the moment of impact all of its energy will have been converted to kinetic energy, K, which can be expressed as

$$K = \tfrac{1}{2} mv^2 = P \qquad (2)$$

where v is the velocity of the mass. Combining equations (1) and (2), one finds that

$$v = \sqrt{2gh} \qquad (3)$$

at impact.

It is also known that

$$-mv = \int_{\Delta t} F\,dt \qquad (4)$$

where $\int_{\Delta t} F\,dt$ is the stopping impulse acting on the mass during the stopping time Δt. Here, F is the force acting on the mass at any time. This may be written as

$$v = \int_{\Delta t} \frac{F}{m}\,dt \qquad (5)$$

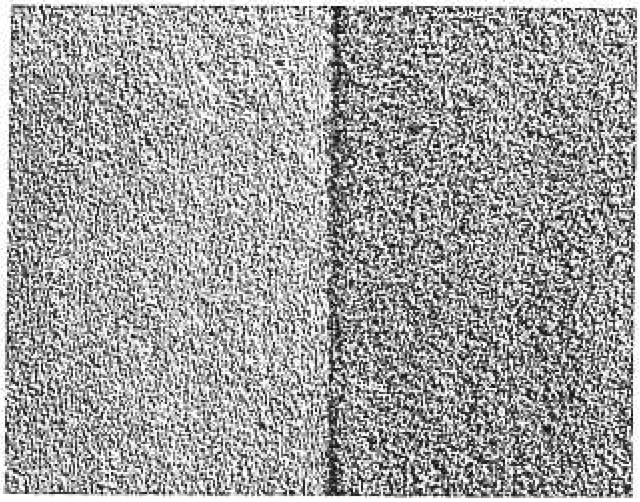

Figure 1a — Photograph of present surface on Mountaineer Field showing strip of new surface layer on right, compared with compressed 5 year old layer on left.

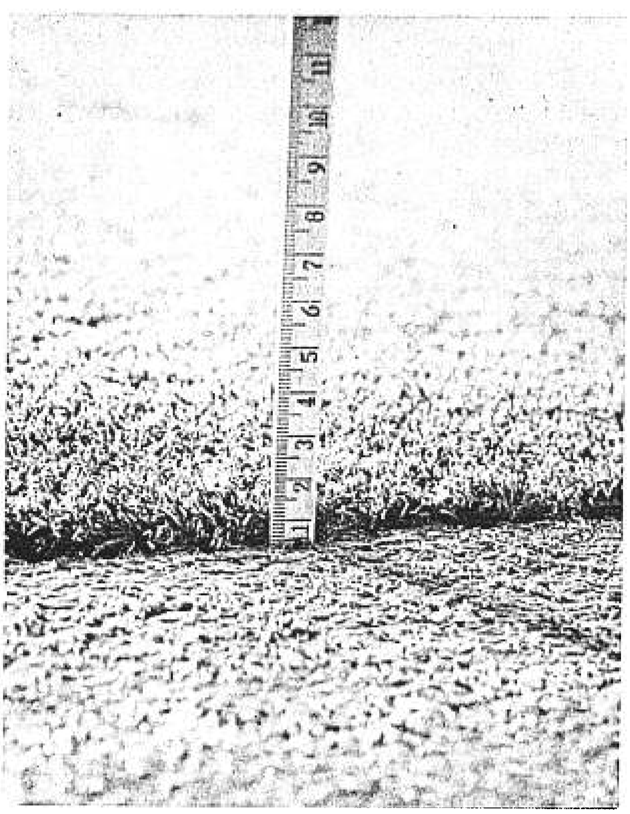

Figure 1b — Photograph of present surface on Mountaineer Field showing difference in height of new surface layer, 1 cm, in background, and 5 year old surface layer at ½ cm in foreground.

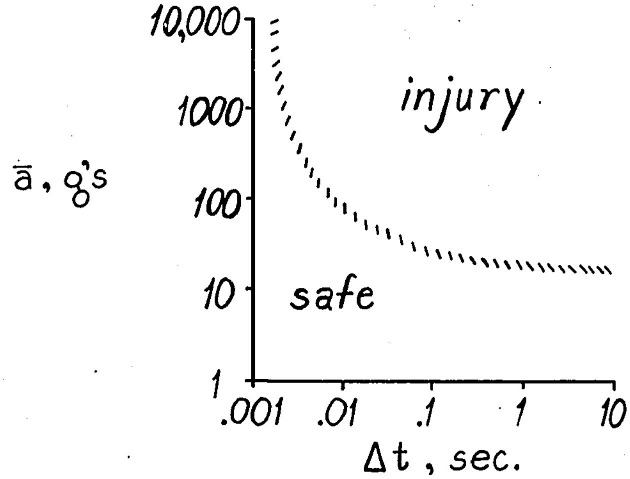

Figure 2 — Wayne State Tolerance Curve.

In terms of the average force $\overline{F}$ acting on the mass during impact, (5) becomes

$$v = -\frac{\overline{F}\Delta t}{m} \qquad (6)$$

$\overline{F}$ may be called the "average stopping force" experienced by the mass during the impact.

Engineers commonly measure and speak of accelerations (a) in an impact rather than forces. The two are directly related by the mass of the body:

$$F = ma \qquad (7)$$

Therefore (6) may be written also as

$$v = -\bar{a}\,\Delta t \qquad (8)$$

where $\bar{a}$ is the average acceleration (or "decceleration") experienced by the mass while being stopped.

Taken together, $\bar{a}$ and Δt give a good description of an impact. It is clear that a given impact velocity can be dissipated by having $\bar{a}$ large and Δt small, or vice versa, or some compromise between the two.

In terms of human injury, it is known that high average accelerations can be endured only short times without trauma, while lower accelerations can safely last much longer. Figure 2 shows the well-known Wayne State tolerance curve (1,2), which elicits the relationship of injury to a graph of $\bar{a}$ versus Δt. When various impact experiments were plotted on this graph, it was found those above the curve produced injury while those below did not. The graph, therefore, represents a standard, though crude, means of determining how dangerous an impact may be.

Finally, it should be noted that $\bar{a}$ can be calculated from Δt and h by combining equations (3) and (8):

$$-\bar{a} = \frac{\sqrt{2gh}}{\Delta t} \qquad (9)$$

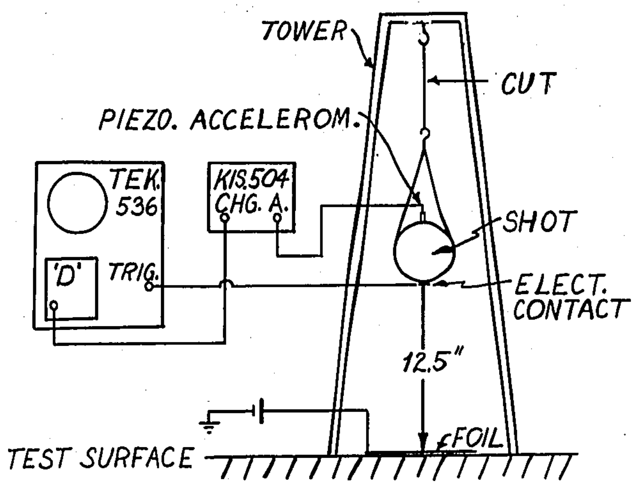

Figure 3 — Schematic diagram of impact test apparatus.

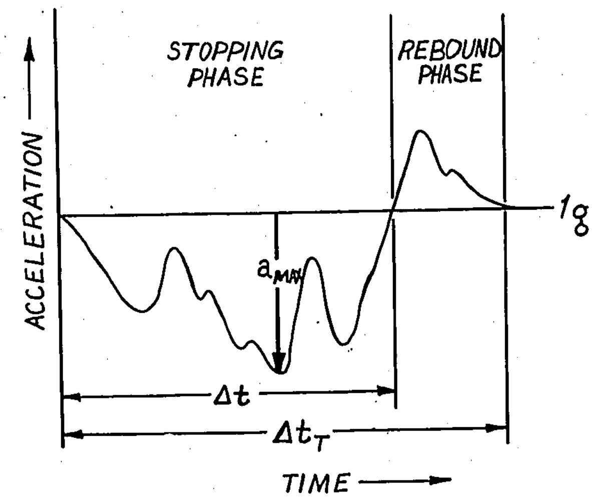

Figure 4 — Typical accelerometer response.

METHODS

The apparatus used for the impact test is shown schematically in Figure 3. The impacting mass was a 16 pound indoor shot put consisting of a homeogeneous, rubber-like ball five inches in diameter. A Kistler Model 808A piezoelectric accelerometer was mounted on a two inch stud screwed into the shot normal to its surface. This arrangement was suspended as shown, 12.5 inches from the playing surface, by four shroud lines, a release line, and a small tower. When the release line was cut, the shot fell squarely to the playing surface. The accelerometer output was amplified and photographed with an oscilloscope camera. The sweep function was triggered when a contact point at the bottom of the shot struck a piece of aluminum foil spread over the playing surface.

A typical accelerometer response is shown in Figure 4. It consists of two distinct phases: the stopping period, in which the acceleration is negative, and the rebound period, in which the acceleration is positive. If the rebound acceleration is great enough, the shot will bounce; otherwise it remains in contact with the surface. In either case, only the initial impact is of interest here. In order to quantify the impact, four important parameters were measured for the accelerometer response.

Total duration, Δt_T, is the time required for both the stopping and rebound phases of the initial impact.

Stopping time, Δt, is the time required for the stopping phase only.

Peak acceleration, a_{max}, is the maximum acceleration experienced in the stopping phase, as seen on the accelerometer response.

Average acceleration, $\bar{a}$, is the average acceleration during the stopping phase as calculated using $h = 12.5$ inches and the measured Δt in equation (9).

Since the rebound forces might also contribute to injury the total duration is included as noteworthy. Likewise the peak acceleration during stopping is noted since an extremely high peak could conceivably cause trauma despite a modest average value. It should be remembered that longer times (both Δt and Δt_T) and smaller accelerations ($\bar{a}$ and a_{max}) are advantageous for a safe playing surface.

The testing was done on four surfaces in or adjacent to W.V.U.'s Mountaineer Field during two days in early November of 1973.

1. *Sod:* a flat surface of a natural dry field covered with Kentucky blue grass approximately 1½ inches high.
2. *New AstroTurf:* this consisted of a replacement strip of new AstroTurf surface glued down onto the five year old underpad when maintenance work was done during August of 1973.
3. *Old AstroTurf:* this consisted of the original AstroTurf surface and underpad installed during the summer of 1969. This combination comprises the vast majority of the present playing surface of Mountaineer Field.
4. *Asphalt:* the asphalt walkway bordering the playing field was also tested since it represents the underlying surface of the field and a baseline which deterioration should never exceed.

At the time of testing the surfaces were dry or slightly damp but definitely not moist or wet. The air temperature was 40-44° F during one test series and 70-72° F during the other. No discernable temperature effects were encountered.

RESULTS

Effect of repeated impacts—When four successive drops were made within five minutes at the same location, the impacts became progressively worse. Stopping time typically decreased from 8.8 to 8.0 milliseconds; peak acceleration increased about 75%.

TABLE 1. Experimental results.

Surface	Stopping Time msec	Total Duration msec	Peak Accel. g's	Average Accel. g's
Sod	14.5	20.9	150	17.6
New AstroTurf	11.4	17.6	122	22.4
Old AstroTurf	7.6	10.8	286	33.6
Asphalt base	6.1	8.1	5500	41.8

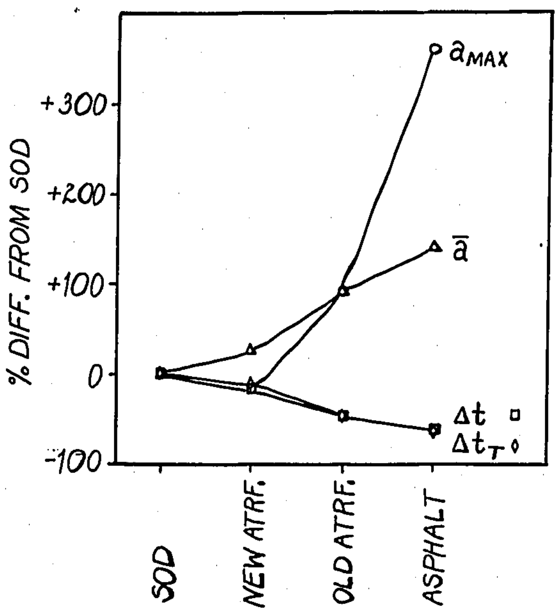

Figure 5 — Impact test results expressed as percent difference from sod. a_{max} is peak acceleration, $\bar{a}$ is average acceleration, Δt is stopping time, and Δt_T is total duration of the impact.

Variations over the field—When eight drops were made at various locations (four spaced between the hash marks on one ten yard line, four on the left hash mark of the 15, 20, 25, and 30 yard lines) the maximum variation in stopping time was 15% of the mean. The peak acceleration was always within 30% of the mean.

Surface variations—Table 1 shows the results of testing the four different surfaces. It is seen that except for its peak acceleration, sod is superior in every respect to each of the other three. Because this peak acceleration typically occupied so little of the stopping time, the average acceleration must be considered more important, and it was lower in sod. It should also be noted that old AstroTurf is significantly deteriorated with respect to new AstroTurf in all four categories of impact measurement. This is shown more clearly in Figure 5. It shows how the four surfaces compared in regard to $\bar{a}$, a_{max}, Δt, and Δt_T. Note that five year old AstroTurf has deteriorated significantly towards asphalt from the new turf-old pad level in all categories.

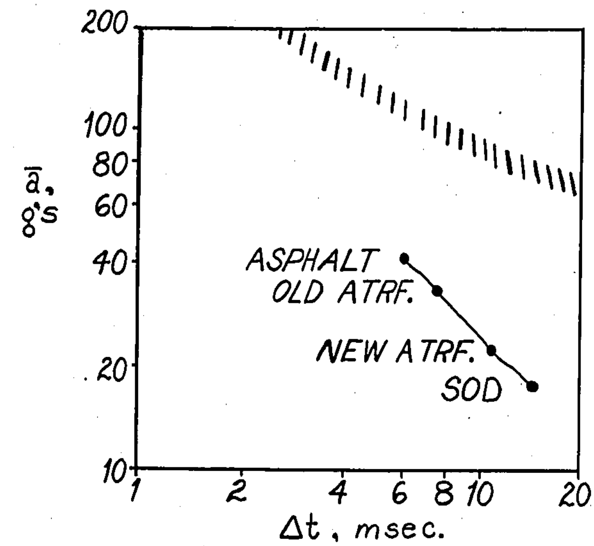

Figure 6 — The results of plotting average acceleration and stopping time for typical impacts on the four tested surfaces in a standard severity format. The curve at upper right is the Wayne State Tolerance Curve. Closeness to the curve is an approximate indication of the biological hostility of the surface.

Finally, in Figure 6 the results from each surface tested are plotted on the Wayne State tolerance curve. Since the test body was not a biological subject and no damage was sought, there should be no illusions that this graph has any direct medical meaning. It clearly shows, however, that the relative positions of the surfaces with respect to the type of injury criterium represented in the Wayne State method of evaluation. Impacts of the same initial energy are seen to be significantly closer to the tolerance curve when they occur on asphalt or old AstroTurf than when sod or new AstroTurf is involved.

It should be pointed out that recently *peak* acceleration has received more emphasis as a trauma parameter at the expense of average acceleration. Certainly the situation is not well understood and has many difficult variables, including the shape of the acceleration pulse, but whether one looks at a_{max} (Figure 5) or $\bar{a}$ (Figures 5 and 6), there is a significant deterioration of the AstroTurf at Mountaineer Field. The only debate would be over the severity of the problem.

DISCUSSION

When the testing of the two AstroTurf surfaces is considered, the variables were age, use, and exposure to weather conditions. Age had no significant effect. Unused and unexposed segments of the original AstroTurf layer were tested in the laboratory and the results were similar to those of new AstroTurf. Therefore, use and exposure to variable weather conditions were the factors most responsible for the alterations in the material tested.

Our field has been used extensively. Most football practice sessions and all varsity and junior varsity home games are played on it. Additionally, soccer games, physical education classes, intramural sports and band practices take place on the same field.

In northern West Virginia a rather broad spectrum of weather conditions is experienced. The five year old surface has been exposed to temperatures ranging from below zero to near 100° F, frequent water saturation, direct sunlight and snow cover. The new layer when tested had been down for three months during which it was exposed to direct sunlight, rain and temperatures from the 30's to the 90's.

Initially, the nylon ribbon used in AstroTurf surfaces has a molecular weight of about 30,000. Under ultraviolet exposure the molecular weight begins to drop in the portions of the fiber actually seen by the radiation. When the molecular weight drops below seven or eight thousand, it becomes brittle and flakes off. (Personal Communication—Ed Milner, Director of Products Technology, Recreational Surfaces Enterprise. Monsanto Company). This results in loss of a certain amount of mass of each fiber exposed and is demonstrated by a "green dust" which collects on the field. Our field is cleaned by a vacuum machine four times a year. Each time the "dust" accumulated approximates twenty-five pounds.

Our impact severity studies clearly indicate that our five year old AstroTurf and underpad has significantly less ability to absorb impact force than the new layer and five year old underpad. The study further reveals that our new layer approximates, but does not equal, a grass field in this regard.

CONCLUSIONS

1. Our new AstroTurf surface approximates, but does not equal a grass field in impact absorption capability.
2. Our five year old AstroTurf surface has significantly decreased ability to absorb impact compared to the new AstroTurf layer.
3. Replacing the AstroTurf surface layer significantly improves the impact quality of our field; therefore the diminished impact absorbing quality of our field appears to be directly related to the alterations in the grass-like surface layer secondary to continued use and exposure to atmospheric conditions.

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