IMPACT ABSORBING SURFACES: INJURY PREVENTION IN PLAYGROUNDS

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ABSTRACT

Every year, some 46,000 children receive medical attention in the Netherlands as a result of accidents occurring in playgrounds. Compared with the total population of 14 million people, this is a relatively high proportion of accidents. About 70% of the injuries are known to involve children falling and making contact with the ground. As a result, the use of protective surfacing materials in playgrounds is thought to offer considerable potential for reducing the incidence and severity of such injuries. A study has therefore been made of how best to evaluate this group of materials.

The first phase of the investigation involved making an inventory of the existing regulations and test methods governing playground surfaces. Three different test procedures were identified in the literature, which are currently in use. It was, however, readily apparent that none of these methods makes use of the biomechanical data that have been generated over recent years. Since the most serious and common injuries that occur in playgrounds affect the head, a special test method has been developed in which a free falling weight is used to simulate the type of impact that occurs when a child's head hits the underlying surface. In order to assess the impact absorption of various surfaces, the Head Injury Criterion (HIC) has been adopted. Following laboratory experiments in which the test method was thoroughly evaluated and calibrated, the impact absorption of various surfacing materials such as sand, wood chips and rubber mats were measured in playgrounds.

A detailed description of the test method is presented in this paper along with a summary of the results obtained. In addition, recommendations are given for the type of surface that should be used in relation to the height of the equipment in the playground.

INTRODUCTION

Playgrounds in streets often only consist of one piece of equipment whereas those in parks tend to have a wide variety of different facilities. Such amenities can be managed by public authorities or owned by private companies or individuals. All have one thing in common: the large number of children that are injured when using such facilities. Current accident statistics indicate that some 46,000 children receive medical treatment in the Netherlands each year because of playground accidents. These data are collected as part of the Home and Leisure Accident Surveillance System (PORS) operated by the Dutch Consumer Safety Institute. Accident data are recorded for the PORS system in a representative sample of hospital casualty departments [1].
Additional enquiries are made about the cases of accidents and injuries which enables a database to be maintained that can be used to identify dangerous products and high-risk activities.

On being made aware of the appreciable accident rate associated with playgrounds, the government requested that safety criteria be developed to be incorporated in standards controlling the use of playground equipment. It was also decided to prepare a specific standard for the surfacing materials applied under playground equipment, since a relatively high proportion of accidents (69%) involve falls.

In 1985, a working group was convened to establish safety criteria to be incorporated in standards goveming the surfacing materials used under playground equipment . The working group consisted of representatives of the owners of playgrounds, manufacturers and consumer organizations. It was agreed that the necessary technical specifications would be established by two institutes of the Netherlands Organization of Applied Research (TNO). The Road-Vehicles Research Institute was asked to concentrate on the impact attenuation capacity of surfacing materials including the formulation of test methods and related requirements. The Institute of Building Materials and Building Structures was given the task of addressing some of the other aspects affecting the performance of these materials e.g. the installation and maintenance of surfacing materials and the safety requirements relating to surface finish. The results of this preliminary study have now been reported [2] and will serve as the basis for future Dutch safety standards conceming playground equipment.

An outline of the requirements for the impact attenuation of surfacing materials is given in the present paper, in addition to discussing the existing test methods used to assess surfacing materials. The shortcomings of these methods are reviewed and the reasons for developing a more appropriate test procedure given. A detailed description of the proposed test set-up is provided and the results obtained with different types of materials are discussed. Recommendations are made for acceptable heights of fall above specific surfaces.

INVENTORY OF EXISTING TEST METHODS

A literature survey has shown that three different test methods are currently in use for evaluating the impact attenuation of playground surfaces. These tests involve dropping a weight from a given height above the surface and are based on work carried out by:

a. the Polymetric Material Group in the United Kingdom, PMG [3];
b. the Consumer Product Safety Commission in the United States, CPSC [4];
c. the Technische Überwachungs-Verein in the Federal Republic of Germany, TÜV Bayern [5].

The researchers involved in designing these tests claim that the dropped weight simulates the impact made by the head of a child falling onto the surface. However, the weights used (4 to 7 kg) are considerably higher than that of a child's head. The specifications of the different test methods are compared with the test procedure developed by TNO in Table 1. The headforms used in the three existing tests were conventional types of standard weights, which were not specially designed for evaluating the impact attenuation of surfacing materials. The injury criteria on which these tests are based relate to peak accelerations or the Severity Index. In two of the test methods the headforms are released along a guided rail while in one of the tests, the free-fall principle is used. The test method developed by TNO is described in the following section.

Table 1. Overview of the test methods used to assess the impact attenuation of playground surfaces.

	a. PMG [3]	b. CPSC [4]	c. TÜV [5]	d. TNO [2]
Headform	metal ASTM F355 - ca. 7 kg	metal FMVSS 218 ANSI 'C' ca. 4 kg	wood DIN 7926-2 ø 240 mm 5 kg	wood - ø 165 mm 3 kg
Criterion	SI = 1000	peak g = 200	peak g = 150-200	HIC = 1000
Guidance	Double rail	monorail	free fall	free fall
Height (max.)	2.5 m	3.0 m	3.5 m	3.5 m

EQUIPMENT DEVELOPMENT

Special equipment and testing procedures including an associated injury criterion have been developed for evaluating the impact attenuation of surfacing materials. The requirements for the test method and a detailed description of the equipment that has been developed are given below.

General requirements for impact attenuation testing

In order to be able to select the most suitable protective materials for playgrounds, it is essential that the seriousness of the injuries that could be caused to children can be assessed by simulated impacts with such materials. The injury criterion that is adopted must serve as a basis for judging the acceptability of particular heights of fall for given surfacing materials. Moreover, it is important that the test method should be highly reproducible. Further requirements are that the equipment should be transportable, easy to install and that it can be used to test different types of surfacing materials both in the laboratory and in actual playground environments. It must also be possible to process results immediately after the tests have been performed in order to allow preliminary evaluations to be made on the spot.

Description of the test equipment

Analyses carried out on data collected from playground accidents have shown that, of all the parts of the body, the head tends to be injured most frequently and most severely [6, 7]. It was therefore decided to develop a test method that would allow the severity of the injuries occurring during a child's fall onto a typical playground surface to be assessed. In common with the three test methods described above, it was concluded that the severity of head injuries could be determined using a headform. To make the test as realistic as possible, the weight of the headform should correspond closely to that of a child's head. It has been assumed that the neck compliance does not affect the acceleration in impacts of such short duration.
In the test procedure developed by TNO, a free-falling headform has been chosen to represent the head of a six-year-old child[1]. The mass of the headform used is 3 kg[2], the diameter is 165 mm[3]. The headform is made of wood. A steel insert is added to obtain the correct weight. Three piezoresistive accelerometers are mounted in the X, Y and Z directions at the centre of gravity (Figure 1).

A transportable frame was constructed from three detachable aluminium parts, which allows the headform to be dropped from various heights. A simple hoisting mechanism is used to adjust the height of fall, which can be varied from 0.1 to 3.5 m. The associated measurement hardware is installed on a trolley and as such is easily transportable (Figure 2).

Data processing

The signals generated during the tests are amplified and filtered before being stored on a transient recorder. A pulse, which is triggered at the instant the headform touches the surface is used to initiate the recording. Throughout the test, the recorder is controlled by a personal computer. This allows plots to be made on a matrix printer before the signals are stored for post-processing purposes. In this way, preliminary conclusions can be drawn about the tests conducted in a given playground without having to wait forthe post-processing stage to be completed on a VAX 11/750 computer. Time histories of the resultant acceleration signals derived from the three accelerometers can be plotted and meaningful assessments made in relation to the injury criterion adopted.

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1) Surveys show that six-year-old children are frequently involved in many of the accidents occurring in playgrounds [7].
2) As is equivalent to the head of the TNO P6 dummy. The anthropometry of the dummy is based on data taken from Reynolds [8].
3) The diameter is based on data collected by Snyder [9].

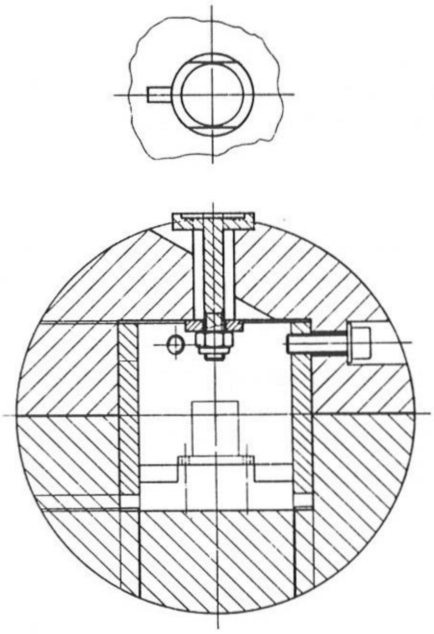

Figure 1. Headform simulating the head of a six-year-old child.

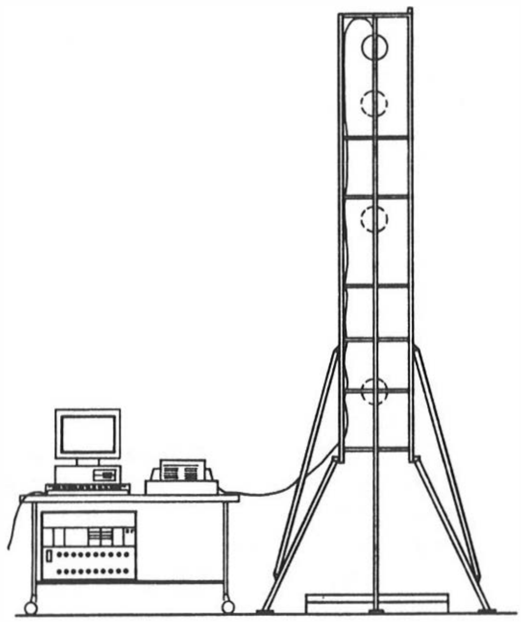

Figure 2. Test apparatus for impact attenuation.

Injury criteria and biofidelity

In the absence of a comprehensive data set on which to base injury criteria for children, it was decided to used the Head Injury Criterion adopted for the Part 572 dummy (50th percentile male Hybrid II). The critical HIC value defined in this criterion is 1000 [10]. In order to judge the biomechanical response of the headform in a drop test, the equipment was calibrated using the procedure specified for the head of the Part 572 dummy [11]. This involves a drop test onto a rigid surface carried out from a height of 254 mm. The resulting acceleration signal must lie within a prescribed corridor. It was shown that the acceleration traces from the headform that had been selected met this condition and that the calculated HIC value (645) was almost identical to that previously obtained for the Part 572 dummy (626).

Test method Evaluation

Various types of surfacing material were tested with the newly developed equipment at a range of different heights in order to assess the reproducibility of the results. The time histories of the acceleration traces for two materials are given in Figure 3. In the case of the rubber tile, the level of agreement between the minimum, mean and maximum signals show that the reproducibility is extremely good. However, the repeatability for sand is less good, which is thought to be due to variations in density. The two materials evaluated in these experiments clearly show different responses. In the case of sand, the traces are long and flat, whereas short, peak-like signals are generated with rubber.

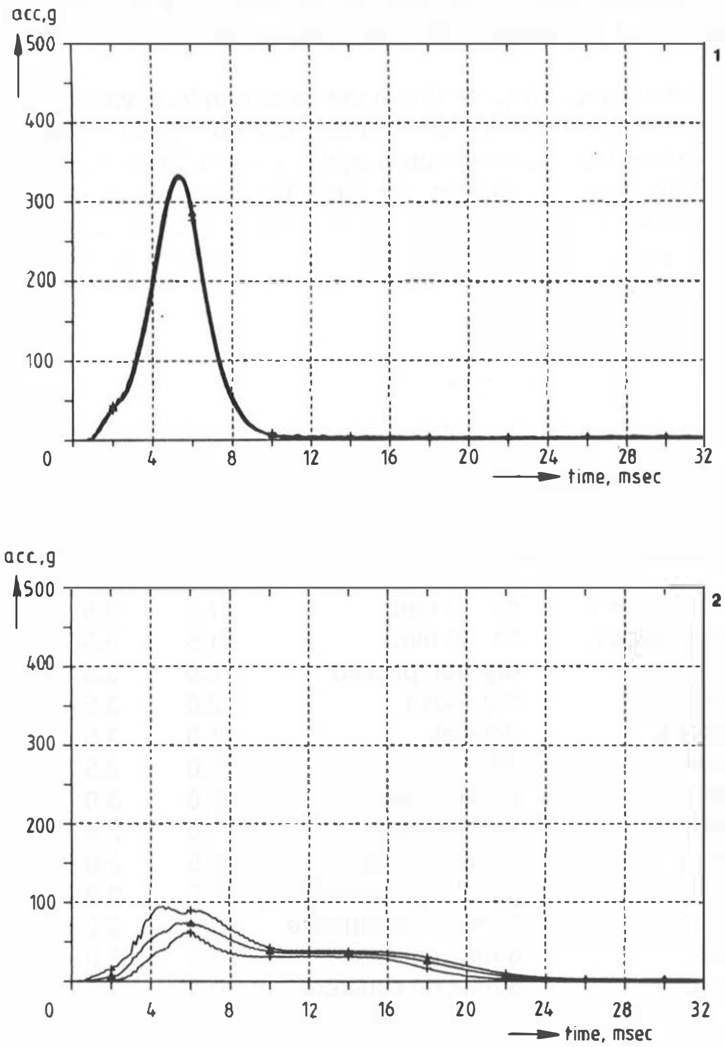

Figure 3. Time histories of acceleration signals from tests conducted at a height of 3.0 m above a rubber tile (1) and above sand (2). Maximum, minimum and mean values are plotted.

On the basis of these findings, it was concluded that the general requirements concerning the reproducibility of the test method had been met and that this procedure would be suitable for incorporation into future safety standards. It was also recognized that the use of a personal computer to calculate HIC values improves the reliability of the evaluation process [12].

TEST PROGRAMME

A test programme was drawn up to evaluate various surfacing materials in the laboratory and at four outdoor locations. A representative selection of the test performed and the surfaces investigated are summarized in Table 2.

Attempts were made, within the confines of a limited test programme, to assess as many different conditions as possible and to include the materials most commonly found in playgrounds in the Netherlands. The outdoor tests were performed on different days during the summer of 1987. Some of these tests were conducted after a relatively dry period and some after a relatively wet period. The resilient tiles or mats were tested on a subsoil of sand or on concrete tiles supported on a sand foundation. Various types of loose materials were tested in a range of different thicknesses.

Each of the surfacing materials was impacted with the headform from various heights. The critical height was estimated from the plots as the point at which the HIC value reached 1000. The materials were tested at heights of fall beginning at the minimum heights given in Table 2 and increasing in subsequent increments of 0.05 - 0.5 m. After each test, the equipment was moved so that the impact was performed on an untested section of material. In order to derive more information about the factors that affect the impact attenuation of grassed areas and the likely degree of variation, additional tests were conducted at several different locations on a particular playing field.

Table 2. Summary of the test programme.

Category	Surfacing materials Type	Specification	Heights (m) Min.	Max.	Increments	Code
Loose materials	Wood chips 1	ca. 70 mm	1.5	3.5	0.5	W1
	Wood chips 2	ca. 30 mm	1.5	3.5	0.5	W2
	Sand 1	dry/wet, packed	2.0	3.5	0.5	Sd1
	Sand 2	dry, loose	2.0	3.5	0.5	Sd2
Natural surfaces	Grass 1	dry/wet	1.0	3.5	0.5	G1
	Grass 2	dry	1.0	2.5	0.5	G2
	Soil 1	packed, wet	1.0	3.0	0.5	Sl1
	Soil 2	packed, wet	1.0	2.5	0.5	Sl2
Rubber materials	Tiles 1	40 mm; on sand	0.5	2.0	0.5	T1
	Tiles 2	40 mm; on concrete	0.5	2.0	0.5	T2
	Tiles 3	20 mm; on concrete	0.5	2.0	0.5	T3
	Mat 1	8 mm; on sand	0.5	2.0	0.5	M1
	Mat 2	8 mm; on concrete	0.5	1.5	0.5	M2
Paved surfaces	Concrete 1	tiles; on sand,	0.10	0.50	0.1	C1
	Concrete 2	floor	0.05	0.15	0.05	C2
	Asphalt	--	0.15	0.20	0.05	A

RESULTS

The HIC values calculated from the tests are given as a function of height of fall in Figure 4. The plots presented are linear approximations of the measured HIC values. To facilitate comparison with the four categories of surfacing materials the same scale has been used in all graphs. The results obtained for each type of material are analysed below.

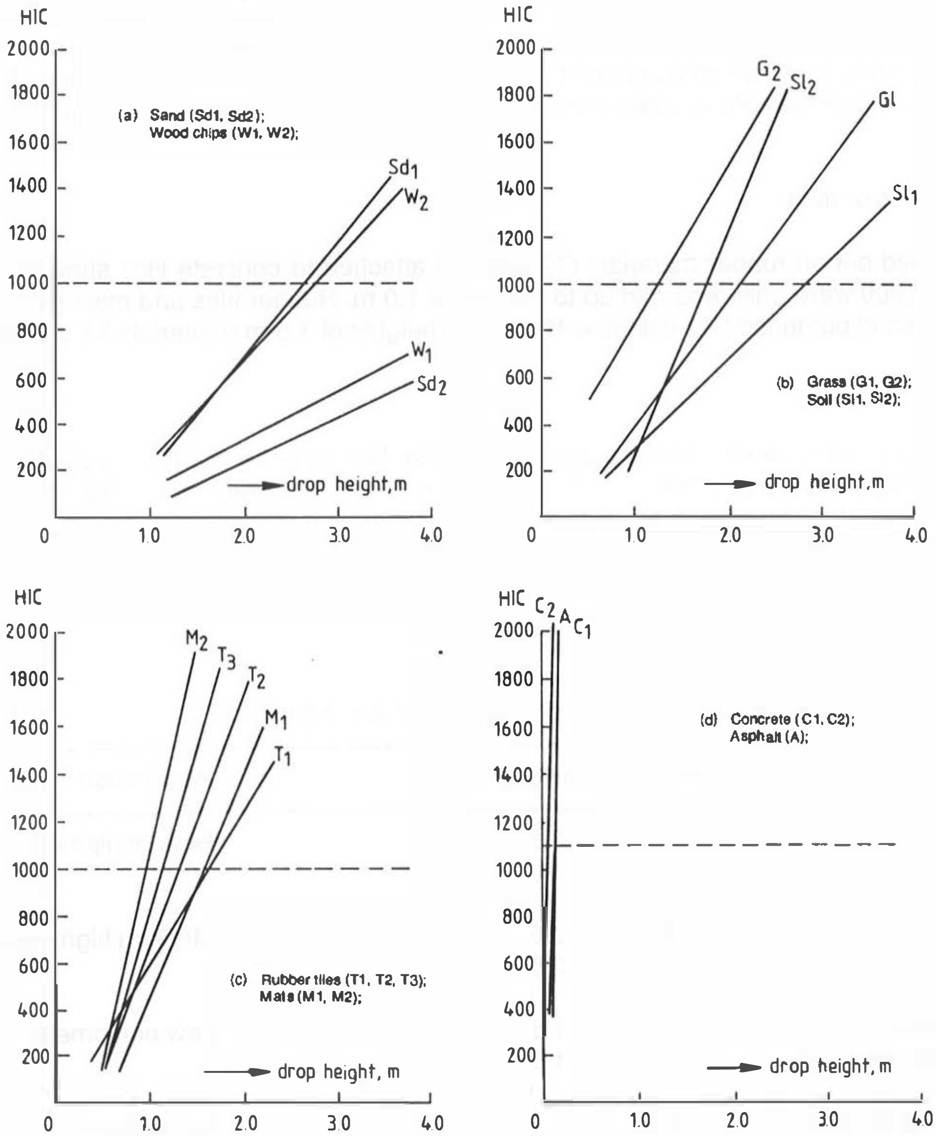

Figure 4. Test results obtained on loose materials (a), natural surfaces (b), resilent tiles and mats (c) and paved surfaces (d) (see Table 2 for specifications).

Loose materials

The HIC values measured on the thicker layers of wood chips (7 cm - materials W1) were found to remain below 1000 up to heights of 3.5 m. For layers of wood chips of about 3 cm thick (material W2) HIC values < 1000 were obtained up to heights of 2.5 m. In general, loose sand (material Sd2) was shown to produce very low HIC values. Extrapolating the HIC characteristic obtained for this material showed that the critical value of 1000 would only be reached at heights of over 5 m. In contrast, the HIC values calculated for packed sand (material Sd1) were found to be generally higher than those for loose sand and only remained below the 1000 level up to heights of 2.5 m.

Natural surfaces

Significant variations in the HIC values obtained on grassed surfaces were noted during the trials as is illustrated by traces G1 and G2 in Figure 4. HIC values of less than 1000 were observed at heights of up to 2.0 m on material G1. In the case of the other type of grassed surface (G2), HIC values < 1000 were only found up to a maximum height of 1.0 m. Tests performed on different sections of the same grassed area showed considerable variations in HIC values (e.g. minimum 908, maximum 1174 at a height of 1.5 m).

Resilient tiles or mats

Tests carried out on rubber materials (T2 and T3) attached to concrete tiles showed that HIC values of less than 1000 were only recorded up to heights of 1.0 m. Rubber tiles and mats positioned directly on a subsoil of sand produced HIC values < 1000 up to heights of 1.5 m (materials T1 and M1).

Heights of fall

A summary of the maximum height ranges over which HIC values < 1000 were obtained is given in Table 3. The heights indicated for the various materials are given in increments of 0.5 m and can be regarded as a guide for the type of surface that should be installed under playground equipment of a particular height. The upper height limits are recommended to be used under favourable circumstances such as with loose sand or thick layers of material whereas under less favourable or unknown conditions the lower height limits should be adopted.

Table 3. Maximum heights for materials installed on a sand subsoil.

Surfacing materials	Maximum heights (m)	Application
Wood chips	2.5 - 3.5	High equipment
Sand	2.5 - 3.5	
Grass	1.0 - 2.0	Medium high equipment
Soil	1.5 - 2.5	
Rubber tiles	1.0 - 1.5	Low equipment
Rubber mat on sand	1.0 - 1.5	
Rubber mat on concrete	0.50	Not suitable
Asphalt	0.15	
Concrete	0.10	

DISCUSSION AND CONCLUSION

A new method of assessing the impact attenuation of the surfaces under playground equipment has been developed and evaluated. It has been shown that the results obtained can be used to determine the impact attenuation of a wide range of surfacing materials. A list of recommended protective materials that can be used for different heights of fall has been prepared. It is concluded that the test method which has been developed is suitable for incorporation into Dutch safety standards.

Test method

The injury criterion that has been used to select appropriate surfacing materials requires that the HIC values should always be less than 1000. The precise definition of this limit is, of course, open to discussion since there is a general lack of biomechanical data concerning children's head injuries. Adopting this criterion results in acceptable HIC values for equipment with heights of up to about 1.0 - 3.5 m, dependent on the type of surfacing material used. A sensitivity analysis was conducted to determine how significant changes in the absolute level of the HIC criterion would be. It was shown that a ± 25% change in the HIC criterion would only modify the recommended height for packed sand, grass, soil and thin layers of wood chips by about 0.5 m. In contrast, no changes in the recommended heights would be expected in the case of loose sand, rubber materials and thicker layers of wood chips. It was therefore concluded that this method was perfectly adequate to compare and classify different types of surfacing materials.

Aspects that affect impact attenuation

It has been shown that the thickness of surfacing materials combined with the underlying subsoil can significantly affect impact attenuation properties. The type of subsoil is especially important with relatively thin materials such as rubber mats. For instance, the performance of the 8 mm thick rubber mats placed on a concrete surface was regarded as 'unsuitable', whereas on sand, the same mats were considered to be perfectly satisfactory under equipment with heights of up to 1.0 - 1.5 m. The effects of density and moisture levels are particularly important in the case of loose materials and for natural surfaces. However, extra tests are needed, to investigate these aspects in detail. Tests performed at outdoor locations showed substantial variations between the results obtained on different samples of the same material. This suggests that it is advisable to conduct several tests, preferably under both dry and wet conditions. This will allow average values to be calculated which will probably serve as a better basis for determining critical heights.

Recommendations

Loose materials such as sand and wood chips are recommended for use under relatively high pieces of equipment in playgrounds. In contrast, rubber surfacing materials were found to generate rather high HIC values under certain conditions. This was rather unexpected since rubber is traditionally known for the degree of protection it offers. Rubber tiles on concrete only gave acceptable HIC values up to heights of 1.0 m whereas rubber tiles fitted on a sand base were found to be suitable for heights of up to 1.5 m. The use of (thin) rubber mats on concrete surfaces as well as asphalt and concrete paving is not recommended under high playground equipment.

Comparisons with other test methods

The results obtained in the present study cannot be compared directly with those of other testing institutes because of differences in the test conditions and materials used. It can however, be stated that the recommended heights prescribed by TÜV and the CPSC are broadly in line with those put forward by TNO. The PMG were known to have tested a large variety of rubber or rubber-like materials and produced far higher recommended heights of up to about 3.0 m. The conclusions drawn by TÜV in regard to the differences observed on grassed surfaces conflict with those of TNO. No correlation was found with the thickness (greenness) of the grass as had been suggested by TÜV. In some of the TNO tests, dense grass surfaces appeared to behave more rigidly than those with a sparser covering. This tends to contradict the hypothesis put forward by TÜV that grass surfaces with a thinner covering produce more severe impacts. On the whole, the natural surfaces, such as grass and soil, seemed to be more rigid in dry periods than after periods of appreciable rainfall, which supports the conclusion reached by the CPSC concerning most loose materials (sand, chips etc.).

FUTURE WORK

The preliminary study reported in the present paper was finished at the beginning of 1988 and was subsequently passed on to the Dutch Standardization Office (NNI). The requirements and recommendations formulated during this study will be incorporated by the NNI in a series of safety standards being prepared for children's playgrounds [13]. The Dutch Ministry of Welfare, Health and Cultural Affairs is currently involving in coordinating attempts to provide a legal framework for these standards [14].

It is clear that, in order to be able to improve the impact attenuation of surfacing materials more data are required regarding the effect of factors such as density and moisture levels. However, it is already apparent that the impact attenuation of the types of rubber material that are currently being used needs to be improved. The test equipment that has been designed for the present study could be usefully employed in developing better protective surfacing materials.

The biofidelity of the headform used in the present study was defined on the basis of the Part 572 calibration requirements. Improvements in this design could be introduced if new data become available. Information relating the head injury criteria for children to head impact performance are of particular interest in this respect. However, it is not expected that the general recommendations outlined in this paper will be modified as a result of improved headform design.

Detailed accident analyses must be performed on a regular basis in order to judge the effectiveness of the protective measures taken. Changes in the severity and incidence of head injuries in relation to other injuries should be noted as a matter of course. Moreover, additional requirements might have to be introduced in respect of other injuries. Nevertheless, these requirements, when taken together, should not only contribute to safer playgrounds but should also facilitate the design of more attractive amenities for children.

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