# SHOCK ABSORBING SURFACES FOR CHILDRENS' PLAYGROUNDS

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## ABSTRACT

This research into impact absorbing surfaces has attempted to connect statistical surveillance data with impact absorption tests, and research into the biomechanics of impact. Playground injury surveillances systems have been analysed for injury patterns as well as dangerous types of equipment and surfaces under equipment. Tables have been presented of statistical data to show that the most frequent playground injury eventuating in a hospital visit is to the head as a result of falling from equipment to the surface below. Laboratory testing for impact absorption was carried out on various surfaces. Results from impact absorption testing of various surfaces in the playground were compared to the laboratory conditions.

## INTRODUCTION

During the past ten years there has been increasing public concern world-wide regarding injuries sustained by young children in playground accidents. As a result, much pressure has been exerted on play equipment manufacturers, play area providers, policy makers and standard setting bodies to help reduce the level of accidents sustained by young children in playgrounds.

National authorities throughout the world have been attempting to produce standards which specify safety requirements for play equipment and the surfaces beneath it. Numerous research bodies have been involved in work to determine the best type of surface to absorb the impact of a child's fall and thus minimise the levels of injury sustained in play areas.

The process of separating the contributing factors in an accident is very complex. Interelated variables such as equipment type, age of child, undersurfacing and type of accident (such as falling, being pushed, or being struck by moving equipment) ensure that researchers are restricted in scope of investigation. Hospital accident statistics however, may be scrutinised for causes of injuries and dangerous types of equipment identified. The general role of undersurface material characteristics in injury type and severity also may be investigated by use of hospital statistics.

## PLAYGROUND ACCIDENT STATISTICS

The use of injury surveillance data has been recognised as an important element of accident prevention programmes. Accident and Emergency Systems allow the identification of hazardous products and patterns of events which may be modified to enable injury reduction. Many recent developments which have linked surveillance with community based intervention projects have been exceptionally successful in reducing injury rates (Moller 1986).

surveillance with community based intervention projects have been exceptionally successful in reducing injury rates (Moller 1986). One such project is the Child Injury Surveillance System for Australia which has been in operation since 1987 (Moller 1986). Injuries presented to accident and emergency departments in the three cities of Adelaide, Brisbane and Perth are monitored and the accumulated data made available to researchers active in child accident investigation.

The seriousness of playground accidents is illustrated in a NSW report (Royal Alexandra Hospital for Children 1981). The report showed that a quarter of the children attending hospital for playground injuries were admitted for further treatment or observation.

## Causes of Childrens' Injuries

Studies carried out in Adelaide, Australia indicated that 12% of visits to childrens accident and emergency departments are related to injuries associated with playgrounds (Trestrail & Whitelaw 1981). Similar surveys in Northern Sydney showed that approximately 1% of all two to twelve year olds are treated in hospital each year for fractures and lacerations due to playground accidents (Jones 1984). The Health Commission of Australia suggests that 1% of all five to nine year old Australians experience playground accidents each year (Jones 1984).

The Australian statistics are typical for the western world, as is seen in Table 1 where a comparison is made between various countries. The estimated number of hospital attendances for playground injuries per 1,000 children per annum range from 10.0 in the United States to 11.2 in the United Kingdom. It is estimated that between one third and one half of these injuries are playground equipment related.

**Table 1 Estimated hospital attendances of playground injuries per 1000 children per annum (King & Ball 1989)**

| Country | All playground injuries | Equipment related injuries |
|---|---|---|
| Australia | 10.0 | 3.9 |
| New Zealand | x | 5.7 |
| U.K | 10.4 | 5.0 |
| Netherlands | x | 11.2 |
| Denmark | x | 7.0 |
| U.S | 8.9 | x |

x indicates that no breakdown for this figure was given

## Age Distribution of Children Involved in Playground Accidents

The determination of the average age of children involved in playground accidents is extremely important if adequate modelling of accidents is to be carried out. Head/surface impact biomechanics vary with children's ages due to head weight variations, differences in neck compliance and skull strength. Inadequate information leads to incorrect laboratory experimentation and false conclusions drawn from those experiments.

In a Sheffield (UK) study of 200 hospital attendances of playground related injuries the average age was found to be 6.3 years (Illingworth 1975). This age was similar to that established in a statistical survey in the United Kingdom carried out by the Leisure Accident Surveillance System (LASS). In the LASS study a total of 27,487 hospital treatments were analysed for the period April to October, 1987. A total of 1469 playground injuries were detailed in the survey, which accounted for 5.4% of all leisure related injuries. Of the 650 playground equipment related injuries, 494 were caused by falls from equipment while the remaining 156 were caused by collisions with equipment or other children, and by jumping from the equipment as graphically represented in Figure 1.

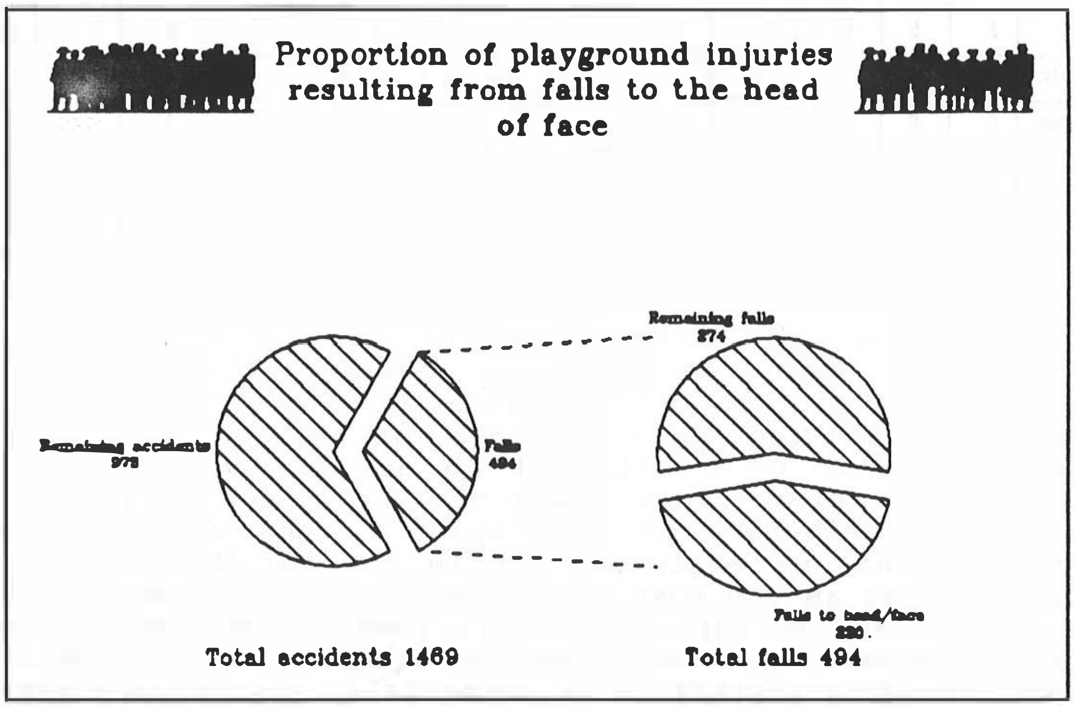

Figure 1

Analysis of this data by the authors has revealed that an average age of 7.3 existed for the 494 children falling from the equipment. For the remaining 156 children, the average age was calculated as 8.0 years. It may be expected that injuries caused by falls would correlate to a younger age bracket as equipment involving climbing requires a level of co-ordination often lacking in children of age seven and below. It is often the case that climbing equipment has been designed for older children (above 7 years) with bar spacing and steps being inappropriate for the younger group.

The establishment of 6 to 7 years as the predominant age involved in falling accidents suggests that modelling of child/surface impacts should utilise anthropometric data relevant to 6 and 7 year old children.

## The Role of Playground Equipment in Accidents

A major report was published in 1981 by the Child Safety Centre of the Royal Alexandra Hospital for Children in Sydney. The report contained data from 61 hospitals throughout New South Wales which monitored accidents over a three month period in 1980. This data is summarised in Table 2 and is grouped according to equipment type and age of child.

Table 2 Survey results from New South Wales
(Royal Alexandra Hospital for Children 1981)

| Type of equipment | Age of children | | | | | | | | | | | | Sum | % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | | |
| Climbing frame | 2 | 7 | 4 | 2 | 11 | 24 | 13 | 6 | 17 | 8 | 6 | 2 | 102 | 39 |
| Swing | 5 | 8 | 6 | 9 | 8 | 6 | 3 | 3 | 5 | 4 | | 1 | 58 | 23 |
| See-saw | 0 | 1 | 1 | 1 | 0 | 3 | 2 | 0 | 2 | 0 | 0 | 0 | 12 | 5 |
| Slide | 2 | 5 | 11 | 6 | 4 | 8 | 4 | 0 | 3 | 1 | 0 | 1 | 45 | 17 |
| Trampoln | 0 | 0 | 2 | 2 | 2 | 1 | 3 | 5 | 2 | 0 | 3 | 1 | 21 | 9 |
| Roundabt | 0 | 0 | 1 | 2 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 7 | 3 |
| Other | 0 | 1 | 0 | 2 | 1 | 3 | 4 | 0 | 0 | 0 | 0 | 0 | 11 | 4 |
| Total | 9 | 22 | 25 | 24 | 26 | 46 | 29 | 15 | 29 | 15 | 11 | 7 | 257 | |
| % | 3 | 8 | 9 | 10 | 17 | 18 | 11 | 6 | 11 | 6 | 4 | 3 | 100 | |

The survey results from NSW (Royal Alexandra Hospital for Children 1981) (Table 2) showed conclusively that the greatest percentage of accidents in playgrounds (39%) occurred on climbing frames. This is typified in the data for six year olds where it is seen that out of a total of 46 accidents over half (24) occurred on climbing frames. These statistics are not weighted to allow for distribution of time spent by the children on the individual items of equipment. It is not possible to identify climbing frames as the most dangerous type of equipment since it is possible that children spend far greater periods of time on climbing frames than other types of equipment. Climbing frames however, could be identified as potentially dangerous playground equipment items and in need of further attention.

In common with other studies such as Winter (1986), the NSW survey showed that most injuries for children aged between one and five years old were sustained on swings and slides. This again may simply be an indication that younger children spend most of their time on swings and slides. Such a time distribution would seem a logical conclusion as the other types of equipment mentioned in Table 2 are not as suitable for smaller children.

During 1981, Oliver et al. published a report of playground equipment injuries occurring in the Sydney region. Seven hospital accident and emergency departments were monitored around Northern Sydney during four, one week, surveys in June and December of 1978 and 1979. The data correlated well with the Royal Alexandra Study (1981). It was found that climbing equipment accounted for 29% of all accidents, followed by swings (25%), trampolines (14%) and slides (12%). The predominance of climbing frames in accident statistics was confirmed in a survey of Western Australia (Parry

1982) where it was found that climbing frames were involved in most injuries (28%), followed by slides (23%) and swings (15%).

**Head related Impact Injuries**

Between January 1981 and January 1982, the Home Safety Division of the National Council of Western Australia circulated a public appeal for notification of playground accidents (Parry 1982). Analysis of the collected data indicated that approximately 24% of total injuries were to upper limbs, 23% were to the head, and 16% were to the lower limb. This agrees well with other statistics from other researchers such as Watson and Tipp (1987), who claimed that approximately 30% of playground accidents result in head injuries.

Not all researchers agree with the approximate level of 30% suggested by Watson and Tipp (1987) and Parry (1982). King and Ball (1989) reported that head injuries (skull fractures, concussion and intracranial injuries) comprised of between 4%+ and 14% of all hospital attendances due to playground injuries. They found that upper limb fractures formed the highest proportion of playground injuries, ranging between 20% and 32%+. This survey however, mainly considered the more serious injuries such as concussion, fractures and intracranial damage when determining the 4%+ to 14% head injury statistics. If all playground injuries requiring hospital treatment had been considered by King and Ball (1989), it would have been seen that between 30% and 50% of accidents involved injuries to the head. The 30% to 50% range for head related injury correlates much better with the earlier findings.

**Table 3 Percentage of total hospital attendances due to playground equipment by type of injury (King & Ball 1989)**

| **Injury type** | **Bris.** | **Austr** | **Canada** | **US** | **UK** | **Neths** |
|---|---|---|---|---|---|---|
| Skull fracture | x | 0.3 | 1.0 | 0.2 | 0.0 | x |
| Concussion | 5.5 | 0.0 | 3.0 | 2.0 | 6.0 | 4.0 |
| Intracranial inj | x | x | 10.0 | 5.0 | x | x |
| Arm fracture | x | 32.0 | 21.0 | 20.0 | x | x |
| Leg fracture | 41.0 | 4.0 | 5.0 | 3.0 | 26.0 | 37.0 |
| Other fracture | x | 4.0 | 3.0 | 3.0 | x | x |
| **Total** | 46.5 | 45.0 | 43.0 | 33.0 | 32.0 | 41.0 |

**x indicates figure included with other fractures**
**z indicates figure included with concussion**

In the LASS survey mentioned earlier it was noted that 494 accidents (of the total number of 1469 playground accidents) involved falls from equipment, that is 34%. In these falls it was calculated that 220 injured their face or head at an incidence rate of 32%. Unfortunately, these figures gave no indication of the severity of injury. They did reveal however, that out of the 220 falls resulting in head injury, 97 had their injuries caused by the ground surface and 16 by the playground equipment while the remaining 107 did not specify the contact surface which caused their injuries. Further breakdown indicated that 55 of the 97 involved in ground impact related injuries specified the ground surface type. Ground surface type was indicated as 29 impacting on concrete, 10 grass, 6 tarmac, 6 gravel, 2 mud, 1 carpet and 1 woodchip (Figure 2). Such data indicates that modification of ground surface type would reduce severity of injury and cost to the community.

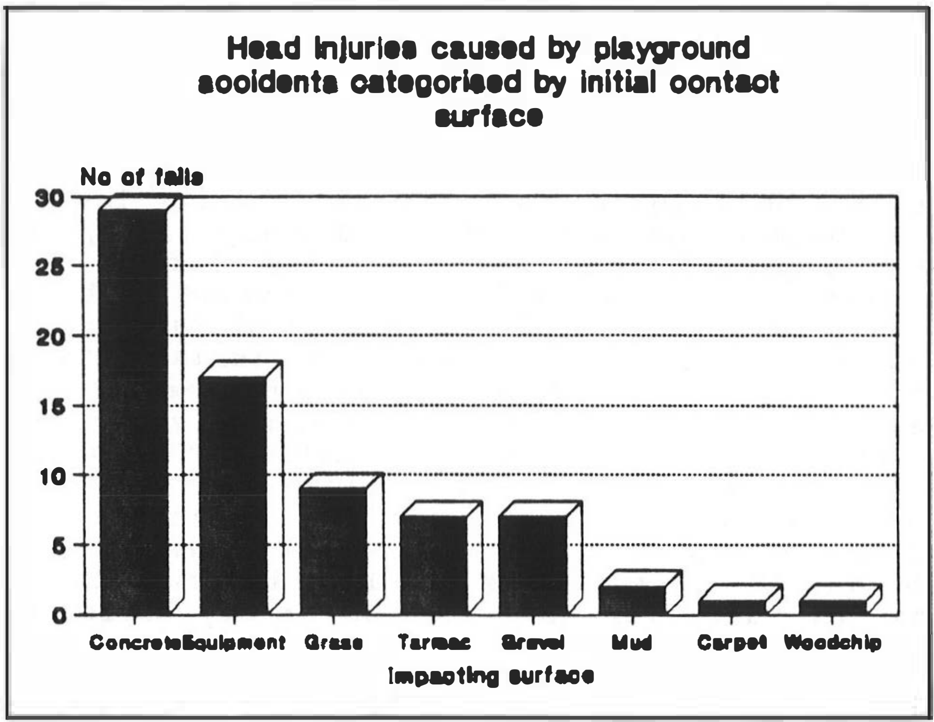

**Figure 2**

## HEAD IMPACT

### Biomechanical Considerations

It has commonly been assumed that head impact tolerance values for children are similar to those for adults. This assumption is incorrect as the head of a child is larger relative to the body and also differs in skull bone structure. The skull of an infant is thin and relatively flexible with mobile individual bones. The strength of a plate of bone is proportional to the cube of its thickness (Simpson 1985). The 2mm skull plate of an infant is thus much more likely to sustain damage than an adult skull plate of 6mm. The simple 3 to 1 thickness ratio translates a 27 to 1 strength ratio. For a child of 6, the stiffness of the skull has reached three quarters of that of an adult. An additional problem exists in that the brain of a child is still developing and long term effects of head injury to a child can be different to those of an adult (Mohan et al. 1979).

### The Effects of Deceleration at Impact

In the United States Mohan et al. (1979) reported that a conservative estimate of head injury tolerance limits for head impact falls of children were 200-250G peak deceleration ($G_{max}$) and 150-200G average deceleration ($G_{ave}$). These estimates were made by simulating falls of children using the Motor Vehicle Manufacturers' Association (MVMA) Two-Dimensional Crash Victim Simulator computer model and comparing them with actual incidents. They were calculated on the assumption that skull fracture is equatable to brain injury. The decelerations were indicative of the force needed to cause skull fracture despite the fact that permanent brain damage could be received well before slull fracture occurs.

To date these are the only relevant experiments involving children in free fall. It would seem fair to conclude therefore, that 200G is the best known tolerance limit for children in free fall. It should be noted however, that all the free falls which were observed in these experiments were onto hard surfaces such as concrete and tar macadam. It may be presumed therefore, that the duration of impact for each fall would be equal and similar. The duration of impact measured by Mohan was three milliseconds. Less resilient surfaces will involve longer pulse durations for deceleration and the 200G recommended by Mohan may not apply.

While testing childrens' playground surfaces in 1979, the Franklin Institute set $G_{max}$ at 60G (Jeavons 1984). A force of 60G was regarded as the maximum acceptable impact to avoid injury whilst 160G was estimated as a fatal blow. Mary Jeavons (1984) viewed 50G as the "often quoted level at which concussion or serious injury in children may occur". The work of Mohan (1979), however, was viewed as the acceptable criterion and 200 $G_{max}$ has since been used by the American Standard for impact absorption testing of playground surfaces (ASTM F355-86).

Other methods of specifying threshold levels of impact include the well known Severity Index (SI) and Head Injury Criterion (HIC). A maximum deceleration of 200G has an equivalent Severity Index of 1000 and Head Injury Criterion of 1000 (under certain impact conditions). These SI and HIC criterion have been set in the standards of the United Kingdom (BS 7188:1989) and New Zealand (NZS 5828: 1986) for the acceptable impact absorption levels of playground surfaces. A Severity Index of 1000 is also likely to become the testing criterion in the Australian Standard due to be published later this year.

### The Effects of Headform Weight on $G_{max}$

The mass of headform weight used during evaluation of undersurfacing materials varies between 3kg and 7kg. The limiting criteria of Gmax of 200G is frequently used in conjunction with a head form weight of 7kg. The study by Mohan et al. (1979) revealed that head impact tolerance values for children cannot be extrapolated from those of adults. As indicated previously a child's head is larger, relative to its body size, than that of an adult. The structure of the skull differs as well as the mechanical properties of the skull bone. It was found that in a head impact, the effective head mass of a child was equal to actual head mass. For adults, the effective head mass was found to be 2.4 times the actual mass for head first falls. This phenomenon occurs because the torso does not affect head loading in children as it does in adults due to neck compliance. In a report of impact absorption testing performed in the Netherlands (Kooi, Wismans & Versimissen 1988), it was stated that the mass of the headform should resemble that of a child's head as closely as possible. For a child aged 6, which is the average age of children involved in playground accidents as discussed previously, actual head weight is approximately equal to 3kg (Reynolds 1976).

It is obvious that the impact velocity will be similar for different weight headforms but that the impact momentum will differ greatly. The heavier the head, the deeper it will penetrate pliable surfacing and the longer the duration at impact. This would seem to suggest that although the time to maximum deceleration will be lengthened with a heavier headform, $G_{max}$ will be reduced. The lighter headform would have a shorter impact duration and a higher $G_{max}$ but would give more conservative Severity Index and Head Injury Criterion values.

## THE ROLE OF SURFACING MATERIALS

### Experimental Test Procedure

The test procedure commonly used throughout the world consists of dropping a headform onto a playground surface from various heights. Since playground equipment is normally built in a height range of 2.0 to 2.5 metres the headform is usually raised from 1.0 metres up to a maximum of 3.5 metres (to include an allowance of 1 metre for the height of the child) in approximately 0.5 metre steps. At each different height the headform is released between two and four times onto the surface depending upon the consistancy of the deceleration/time trace. The headform typically contains an accelerometer to obtain a trace of the deceleration curve which is recorded with the aid of a computer data acquisition system. The diameter of the various headforms used by different testing stations around the world is generally 165mm. This diameter is consistent with the anthropometric data of a 6 year old child (Snyder, 1977). which is considered the average age for a child sustaining a playground injury of the head/surface impact type.

### Typical test results

Typical results from testing carried out by the author in laboratory conditions are depicted in Figures 4 and 5. The lignum mulch data shown in Figure 4 demonstrates the spread of results which may obtained from different depths of the same material. When tested at depths of 100mm and 150mm, the mulch has safe fall heights of 1.8m and 2.8m respectively (for a limiting criterion of 200 $G_{max}$). If the material depth is increased to 200mm it is apparent from the plot that fall heights in excess of 4.0m may be tolarated. It should be noted that particulate materials such as these must maintain a minimum thickness of the surfacing material if they are to be effective. The practicalities of such a criterion would need to be scrutinized seriously when selecting a surfacing material.

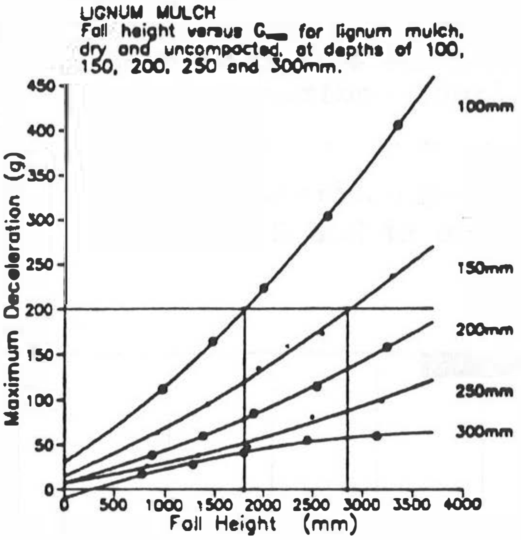

**Figure 4**

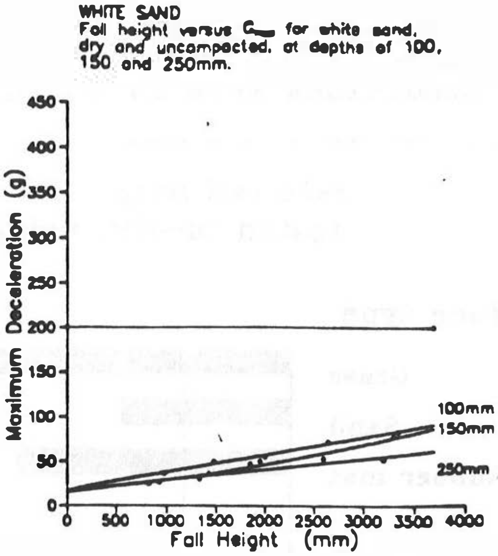

**Figure 5**

**Results of impact attenuation testing on sand and lignum mulch playground surfaces in laboratory conditions**

Test results from fine sand when tested dry and uncompacted in laboratory conditions (Figure 5) indicate that very little variation is obtained for safe fall height for various depths of material. All depths in excess of 100mm provided levels of deceleration of 100 G or less for fall heights up to 3.5 metres. Compaction of the sand however, with the standard table vibrator for 30 seconds, reduced the safe fall heights dramatically. The results indicated that the safe fall height for a 100mm deep, compacted sand layer was 1.8m (reduced from +3.0m for uncompacted sand). White Sand depths of 200mm and 300mm were found to provide adequate impact attenuation for fall heights up to 3.0m.

The safe fall heights were further reduced after the compacted sand had been saturated overnight and the excess water allowed to drain away. The safe fall height for 100mm of saturated sand was reduced to 1.0m while the safe fall height for 300mm was reduced to 1.3m.

The propensity for this type of sand to compact in field condition is high, especially when water has been allowed to drain through the material. It would appear that this type of sand has limited use as play equipment undersurfacing. This however, does not necessary apply to all sand types and some sands may provide a safe playground surface. In-situ testing of 100mm of a similar sand in a playground exposed to the elements resulted in a safe fall height of only 0.7m (for a limiting criterion of $200G_{max}$).

The safe fall heights of various surfaces tested in the laboratory as well as insitu are provided in Figure 6. It can be seen that woodchip, lignum mulch, sand and rubber/bark (50/50 combination) all perform excellently in the laboratory conditions. Sand and rubber matting however, have not performed as well in field studies as in the laboratory. Safe fall heights for well grassed undersurfacing in the playground were found to be superior to the sand and rubber matting tested under field conditions. It should be noted that materials such as sand under field conditions were in compacted, damp condition.

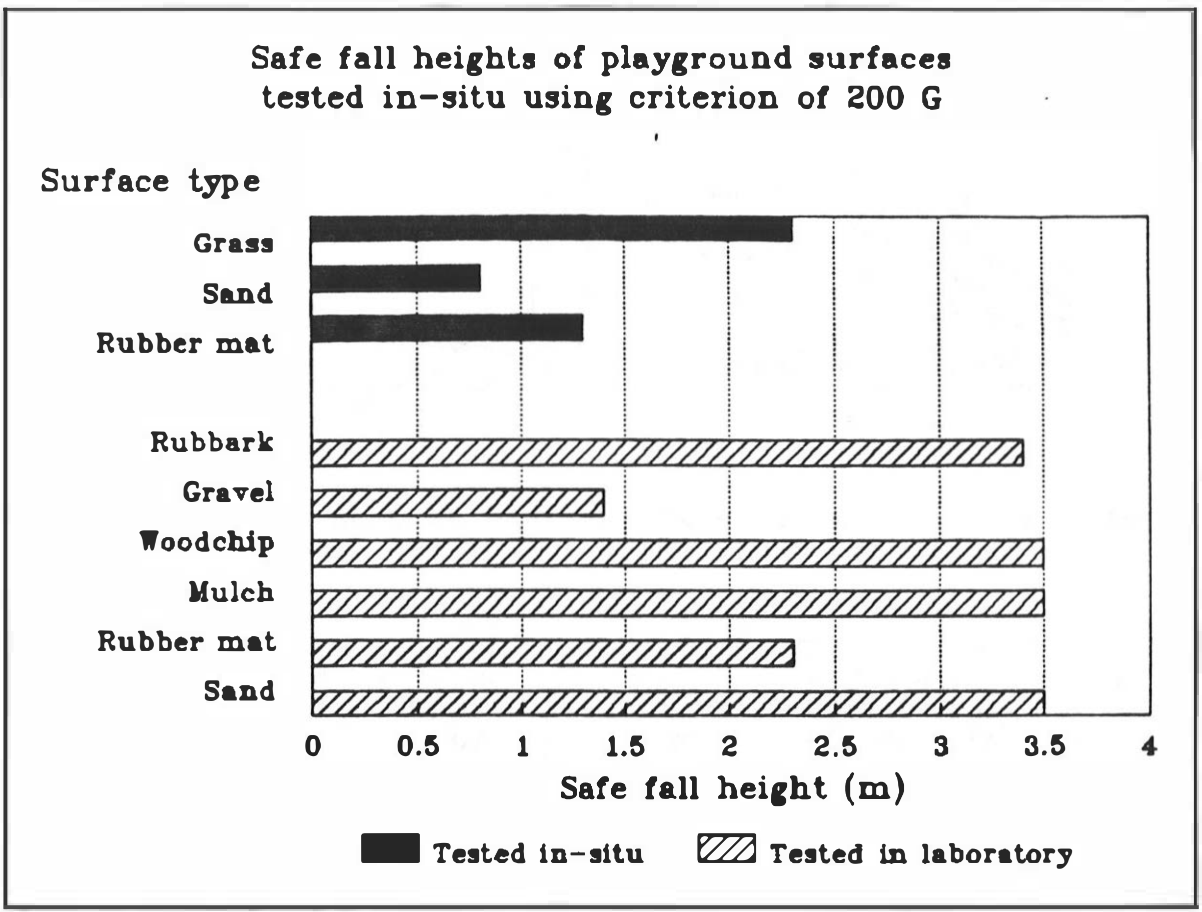

**Figure 6**

## CONCLUSIONS

Satistical surveys have revealed that the most frequent and dangerous playground injuries are those caused to the head by surface impact. It is a commonly held view that carelessness and lack of co-ordination are to blame for both limb and head damage. This view cannot be accepted as the child and his or her inherent abilites should be the main criterion for design of playground equipment. Such equipment design must include undersurfacing as an integral component if impact damage is to be minimised.

Injury surveillance must be utilised to give much needed insight into the cause and effect of playground injuries. Care however, must be taken in the analysis of statistical data since figures may indicate that a particular type of equipment is causing an unacceptably high percentage of accidents. Further investigation may reveal that the equipment type in question is receiving a disproportionately large amount of useage and that it is a relatively safe item on a user weighted basis. Surveillance statistics are extremely useful in revealling injury patterns which may be used in improving play area design.

The commonly used criteria (for head impact) for evaluation of undersurfacing materia is a $G_{max}$ value of 200G . The use of such a value does not appear conservative and may lead to poor design of undersurfacing in playgrounds. It is felt that a $G_{max}$ level of 100G would be more appropriate until the biomechanics of children falling onto impact attenuating surfaces is better understood.

In head impact accidents all medical data suggests that duration of impact is as critical as the maximum deceleration ($G_{max}$) in determining the severity of injury. Surfaces for playgrounds are impact absorbant and consequently give rise to pulse durations of up to 30 milliseconds. It would appear that the SI and HIC are far more useful than $G_{max}$ as they both take account of impact duration as well as $G_{max}$. Neither the HIC nor SI have been examined for head first, free falls of children and the authors question their use until correlation between SI, HIC and Gmax is established.

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