A portable data acquisition system for the measurement of impact attenuation of playground surfacing

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ABSTRACT

Gone are the days when children’s playgrounds were erected on concrete and asphalt. Impact attenuating playground surfacing has been common place in most children’s playgrounds for many years. Unfortunately there is not a strong correlation between the expected reduction in the frequency and severity of playground injuries. Until recently testing of playground undersurfacing was restricted to the laboratory. This paper details the development and description of a portable data acquisition system for use in playgrounds.

BACKGROUND

In industrial safety there is a recognized hierarchy of hazard control measures based on the principle that risks need to be reduced to an acceptable level by engineering means. Risk management within the playground environment is more complex than industrial safety because the primary aim of a playground is to stimulate a child’s imagination, provide excitement and adventure and allow scope for children to develop their own ideas of play. Children are not little adults and the intervention strategies intended to protect children may differ from those intended to protect adults. Ideally playgrounds should encourage the development of motor skills and present the child with manageable challenges. A well designed playground is actually encouraging the child to take risks, but in a semi-controlled environment that protects a child from hazards he or she may be unable to foresee when using playground equipment as intended. A well-designed playground will also help the child to develop a sense of boundaries, a very important and often overlooked life skill. A well designed playground will also be designed so that risk involved in play is apparent and foreseeable by the child.

When the authors were growing up, they walked to school, rode bikes around the local neighborhood without any fear of abduction, they played in the local natural bushland, and breaking an arm or grazing an elbow was all part of growing up. The free use of the natural environment is no longer easily available to children; instead playgrounds now provide the main opportunities for healthy physical activity. Unfortunately in Australia, Councils are citing the high cost of litigation and insurance as the primary reason for removing playgrounds and/or stimulating playground equipment.

The Australian Bureau of Statistics has confirmed that Australian adolescent children are more obese than in previous generations. Approximately 15% of Australian adolescent children are now classified as overweight, while 5% are classified as obese. This obesity is blamed on a number of factors including the removal of stimulating playground equipment and playspace areas. Society has effectively created an environment that makes it harder for children to run around and play. It is well known that the enjoyment of being active, particularly in childhood, is a key factor in becoming and remaining active in later life.

PLAYGROUND SAFETY STANDARDS

The impact attenuating surfacing beneath playground equipment is known by a number of terms, including: playing surface system, surface system, softfall, impact absorbing playground surfacing, soft-surfacing, soft-pour, playground surfacing, and undersurfacing. It has been the focus of much attention within the playground industry particularly in recent years.

In 1996 an Australia and New Zealand Standard was published that specifically addresses the issue of playground undersurfacing impact attenuation and injury prevention associated with falls. This standard was the Australian and New Zealand Standard AS/NZS 4422 Playground Surfacing – Specifications, Requirements and Test Method (1996). There are similar standards in other countries, for instance ASTM F355 (2001) and ASTM F1292 (2004) are the impact attenuation Standards used in the United States, and EN 1177 (1998) is the equivalent impact attenuation Standard used throughout Europe. The common thread within all of these Standards is the requirement for the fall zone[1] (see Figure 1) to comply with a maximum deceleration of no greater than 200g and a HIC of no greater than 1000. Simply, the pass/fail requirements of AS/NZS 4422 are that the impact resulting from a fall must not exceed 200g and 1000 HIC[2] from any given piece of playground equipment. The surfacing material within the fall zone is determined according to the fall height from the equipment, currently referred to as the ‘free height of fall’.

It is worth pointing out that with all the above mentioned Standards the height and surface requirements are intended to reduce the risk of head injuries and not, as is widely assumed, injuries to other parts of the child’s body such as arm and leg fractures. It also all worth considering whether it is appropriate to base the surfacing requirements of children’s playgrounds solely on the risk of head injury data that was obtained for tests performed on adults, adult cadavers and animals (Stapp, 1955).

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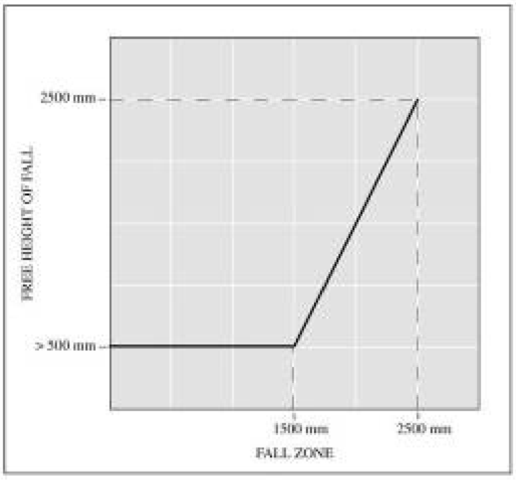
[1] The fall zone is the surface beneath playground equipment that may be hit by a child falling from that equipment. The line in Figure 1 represents the minimum extent of the undersurfacing for the corresponding adjacent equipment height.

[2] The HIC is the Head Injury Criterion.

As with industrial safety a balance must be found between risk and safety. The encouragement of risk-taking in children needs to occur without the child sustaining an injury that causes death or leaves the child permanently disabled or disfigured.

The testing of playground undersurfacing material has been available in Australia and New Zealand for approximately 9 years. Why is there no evidence of a reduction in the incident rate of accidents from playground equipment falls?

There are many reasons why both the frequency and severity of playground injuries are not reducing. Firstly, in many cases a very large number of playgrounds do not comply with the existing undersurfacing safety Standard. Random field audits of playgrounds by the author within the Sydney Basin Region have produced some quite alarming data. These audits show a very high rate of non-compliance with AS/NZS 4422. Other independent studies also provide evidence of non-compliance. A major study (Witheaneachi and Meehan, 1997) was conducted by Kidsafe NSW and NSW Health of 240 Council playgrounds. These playgrounds were assessed to determine the extent to which they complied with safety guidelines. Of the 723 pieces of equipment that required undersurfacing only 45.4% had the recommended type of undersurfacing while only 42 of the 723 pieces had undersurfacing to the required depth. When the fall height of the equipment was considered in addition to the undersurfacing only 1.8% of the 723 pieces of equipment simultaneously satisfied all the safety requirements. The author's experience suggests that, if a similar comprehensive study were repeated there would be many Local Government Authorities with similar statistics. Fortunately, there is a growing number of Local Government Authorities, such as Willoughby Municipal Council and Brisbane City Council, who are proactive with respect to playground safety compliance. A study of 25 Councils that was conducted by the Impact Testing Laboratory, Faculty of Engineering, University of Technology Sydney in 2000 (Howarth, 2001) into playgrounds and playground fall heights concluded that the main issue with playground safety was how to maintain compliant surfacing beneath the equipment.



Source: (AS 4865, 2004)

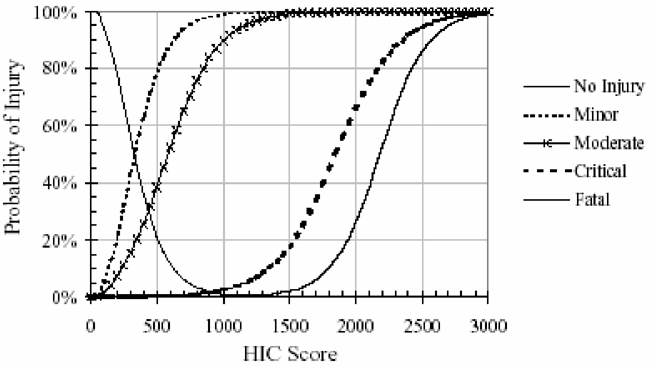
Figure 1 Minimum extent of fall zones

A major problem in manufacturing compliant surfacing is that undersurfacing material does not always perform as well as manufacturers and installers claim. Sometimes the impact attenuation rating of playground undersurfacing falls well short of what was expected or specified. There is a big difference between a material passing an impact test under ideal conditions in a laboratory and passing a test in-situ. The installer may have got the mix wrong. They may have installed the material to an inadequate thickness because of a genuine mistake or intentionally to shave more profit from the project. The weather may have been inclement, too hot, or the humidity levels high. The installer may have installed the product over poorly or inadequately prepared sub-base, or poured it around an old tree stump and in so doing reduced the cover thickness of impact attenuation material. The material that was certified in the laboratory may bear little or no resemblance to the material that was installed. This is a particular problem with natural material such as sand, bark and mulch.

A second reason for the lack of reduction in hospital accident and emergency admissions is that the existing standard was never written to prevent the majority of injuries. Yet, most people associated with playgrounds mistakenly believe that if a playground complies with AS/NZS 4422 there will not be any injuries from impacts or falls. This is not so. Figure 2 is a graph of the expanded Prasad / Mertz Curves and it shows that at a HIC score of 1000 there is a 99.5% chance that a person will suffer a minor head injury, an 89% risk of a moderate injury, and a 3% chance of a critical injury (Prasad and Mertz, 1986). It can be seen that if we want to lower the rate or severity of injuries we would need to lower the existing 200g/1000HIC threshold to 100g/500HIC.

Furthermore, the playground Standards are voluntary, except in the few cases where they are mandated by a particular stakeholder, as NSW Department of Community Services does with Early Childcare Centres throughout NSW. There is growing ground swell of opinion in the community to make playground safety Standards mandatory as is the case with particular Standards that apply to children's toys.

Inadequate maintenance or total lack of maintenance also contributes to the problem. Regular checking of depth of natural surfacing and making sure that it extends well beyond each piece of equipment is essential. Making sure that the undersurfacing is kept free of litter or objects that could harm children at play is also essential.



Source: (Prasad and Mertz, 1986)

Figure 2 Probability of specific head injury level for a given HIC score

Finally, the 200g/1000HIC criterion does not take into account all of the forces that are occurring during impact. The existing criteria limit the measurement of the impact forces to those associated with deceleration and ignore the forces associated with change in momentum. This simplification is fine when we have impacts that result in a near zero or *dead cat* type bounce where all the energy is absorbed by the undersurfacing material. However, when we have impacts that produce bounce a component of the energy in the undersurfacing is converted back into kinetic energy. As the bounce height increases, so do the forces associated with change in momentum until they reach a magnitude that equals the impulse forces associated with deceleration.

KINEMATICS OF IMPACTS

The reader may believe that a fall of a child onto a playground undersurfacing material is a simple matter when considering the forces involved. Nothing could be farther from reality. This simple fall would produce a large number of quite complex forces. If the fall was at an angle there would be horizontal components of the force to consider. When the child impacts upon the surfacing there is an equal and opposite force that impacts upon the child's body. An energy wave enters the child's body and travels through the body at a variety of velocities and frequencies and be absorbed and attenuated by the bones, organs and soft tissue to varying degrees. This energy wave is also reflected, refracted, dispersed, and dissipated by the bones, organs and soft tissue to varying degrees. It may excite and resonate components of the body that have natural modes of vibration at the same or harmonic frequencies to those of the energy wave. This is an example of only some of the forces acting immediately after the impact and does not take into account the complex interface forces flowing between the child and the semi-elastic undersurfacing material. The kinematics of falls and impacts is a very complex science.

PLAYGROUND UNDERSURFACING

Traditionally natural materials such as grass, pine-bark nuggets (the broken bark of conifers, grain size 20 mm to 80 mm), wood chips (mechanically broken wood with no wood based materials and without bark and leaf components, grain size 5 mm to 30 mm), sand (washed without silt or clay particles, grain size 0.2 mm to 2 mm) and gravel (round and washed, grain size 2 mm to 8 mm) have been used as a undersurfacing material. A major problem with natural materials is the high ongoing maintenance cost. This cost has two components, namely: the cost of regular topping up to maintain impact absorbing properties; the cost of grooming or racking to ensure that minimum depths are maintained; and the removal of broken glass and used syringes. There are other problems including the supply and use of appropriate high quality materials that exhibit energy absorbing properties. For example, sand that is used as a road-base is not suitable for use as an undersurfacing material. There are also problems associated with needle-stick injuries, splinters, ingestion, choking, and accessibility for people with mobility problems. Ideally all materials should be on-site tested and certified for compliance stating the playground undersurfacing depth and associated maximum free height of fall. Nominally a minimum depth of 200 mm to 300 mm is standard practice.

In recent years artificial or synthetic materials have progressively replaced natural materials as the preferred undersurfacing material within playgrounds. These synthetic materials include recycled ground soft-rubber and LDPE. A major reason for the change in usage is the lower ongoing maintenance costs and the perceived reduction in risk as the market perceives the synthetic material as a safer more reliable product that once installed will continue to provide a safe play space for many years.

Until relatively recently all playground undersurfacing energy absorption testing was confined to the laboratory. Recent technological advances have allowed the development of relatively low cost portable impact test rigs that can test in-situ in accordance with the relevant test methods and procedures. Previously all in-situ testing was limited to a visual inspection and measurement of depth (for natural materials).

Unless playground equipment is totally enclosed, children will continue to fall off this equipment. It is now generally accepted that undersurfacing material is a necessary component of good playground design for the purpose of reducing the severity of accidents. As the playground equipment height is increased the need for more effective undersurfacing and or other hazard reduction methods, such as: guardrailing, barriers, and total-enclosure increases.

IMPACT ATTENUATION CALCULATIONS

All the existing surfacing attenuation standards have a requirement for the entire fall zone to comply with a maximum acceceleration of no greater than 200 g and a HIC of no greater than 1000. It has been suggested by numerous researchers that the magnitude of these values is too high and needs to be lowered to reduce the injury rate and the severity of the injuries.

The HIC requires maximization of the following mathematical expression involving the time-average deceleration by varying the limits t_1 and t_2. It can be seen that the acceleration is weighted by the exponent 2.5, and therefore high accelerations for short time durations will contribute more to the integral than low accelerations for extended time durations.

$$\mathrm{HIC} = \left[\left(\frac{\int_{t_1}^{t_2} a \, dt}{t_2 - t_1} \right)^{2.5} (t_2 - t_1) \right] \max$$

where:

a	is the deceleration experienced by the headform expressed in g; and
t_2, t_1	two intermediate values of t (t is the time in seconds) between t_{start} such t_{end} between which the function for calculating HIC is maximized. Note this procedure is only valid for impact events with a total duration of more than 3 ms (AS/NZS 4422:1996).
t_{start}	is the time, at the start of the impact event, when the deceleration of the headform first equals or exceeds zero;
t_{end}	is the time, at the completion of an impact event, when the end deceleration of the headform first equals or falls below zero;

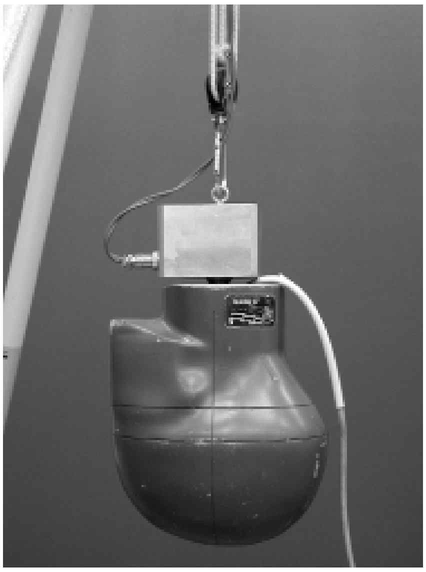
Eager and Chapman (2004) in a paper titled *Why bounce is bad* suggested that a third term called the Playground Injury Criteria or PIC be introduced to take account of the forces associated with the maximum rate of change of acceleration.

UTS IMPACT ATTENUATING TESTING SYSTEM

The UTS Impact Attenuating Testing (IAT) System is a rig that measures the impact attenuating characteristics of an impact-absorbing surface in accordance with the Australian and New Zealand Standard AS/NZS 4422 Playground surfacing - Specifications, requirements and test method. The measurement is made by dropping an instrumented headform onto the impact attenuation surface and recording the severity of the impact with a data acquisition system. For each impact the system displays the acceleration vs time curve, and calculates a number of parameters, including the maximum total acceleration (g_{max}) and HIC. By dropping the headform from a range of heights, the Critical Fall Height (CFH) of the surface can be extrapolated.

Source: (UTS:Engineering, 2005)

Figure 3 UTS Impact attenuating testing system



Source: (UTS:Engineering, 2005)

Figure 4 Headform and electromagnetic release mechanism engaged

The system consists of a number of components which will now be described.

Tripod

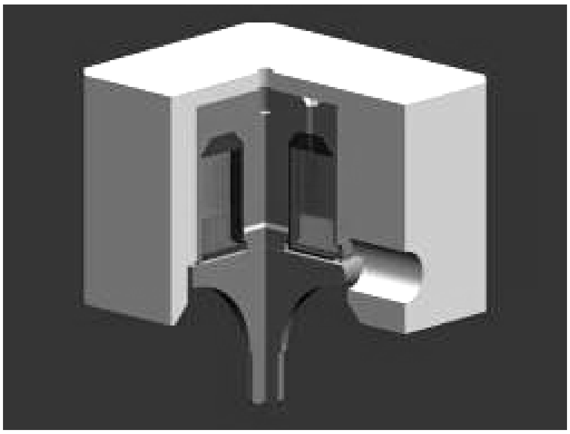
The tripod has been designed to be lightweight, to facilitate use in the field, robust, and to safely support the headform and electromagnetic release. The tripod weighs 5.3 kg and allows drops to be done from 0 to 3.0 m. The tripod consists of a machined aluminium head, a set of lightweight three stage telescopic legs, and screw-on machined aluminium feet to spread the load on soft surfaces. If drops from a greater height are required, the tripod legs can be extended by screwing on an additional set of legs to facilitate drop heights in excess of 4.9 m. At ground level, a rope triangle is used to stop the feet of the legs sliding outwards. The headform is raised using a 3:1 pulley system, and the pulley rope is secured in a cleat located on one of the tripod legs.

Electro-magnetic release mechanism

To release the headform in a safe, clean and reproducible manner, an electro-magnetic release was designed and manufactured. This mechanism incorporates a rare-earth permanent-magnet to suspend and hold the headform, and an electro-magnet to release the headform. This configuration is designed to be intrinsically safe so that when current is passed through the electro-magnet the magnetic field produced is in opposition to the field of the permanent-magnet, thus canceling the force holding up the headform and allowing the headform to fall under the influence of gravity. This arrangement has two advantages:

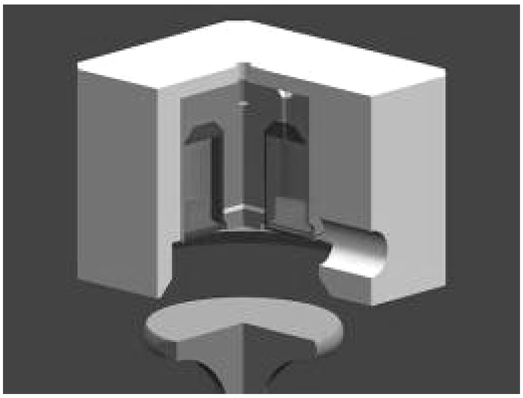
1. It is fail-safe in that power must be applied to the release to start the fall, not to prevent the fall. The release circuit can be broken when the headform is suspended and the headform will remain connected to the release mechanism.
2. Power is only required for a fraction of a second to initiate the fall. As soon as the headform has fallen a few millimetres the magnetic circuit is essentially broken and power is no longer required. This is a real advantage when operating in the field where everything is battery powered.

The electro-magnetic release is activated by the release control box, which has a release push button, a buzzer to provide audible feedback, and three D-size batteries for power. The release connects to the headform using a specially designed domed self-aligning headform connect that can screw into the top of the headform. A cross-sectioned isometric-view of the engaged and disengaged configurations is depicted in Figures 5 and 6 below.



Source: (UTS:Engineering, 2005)

Figure 5 Electromagnetic release assembly – Engaged position



Source: (UTS:Engineering, 2005)

Figure 6 Electromagnetic release assembly – Disengaged position

Headform

The system utilizes a standard J-type maganese alloy headform, shown in Figure 4. It is fitted with three accelerometers orientated to the X, Y and Z Cartesian co-ordinates. The headform also includes the data communication cabling and a special dome-shaped self-aligning headform connector that interfaces to the electromagnetic release. The total weight of the headform and components is 5.0 ± 0.1 kg. When conducting an impact attenuation test, the headform is aligned and released so that the headform crown impacts the impact-attenuating material (the test sample). As the headform descent is an unguided free fall, a vector sum is applied to the output from the three accelerometers aligned on mutually orthogonal axes to calculate the total acceleration.

Accelerometers

Three identical accelerometers are mounted at the centre of mass of the headform. They are arranged tri-axially, so that when the headform is suspended from the release with the headform crown pointing to the ground, (Figure 4) the X and Y-Channels are in the horizontal plane, and the Z channel is in the vertical axis. As seen in the acceleration graph in Figure 7, during impact the Z-channel acceleration maximum is considerably larger then the X- and Y-Channels. The software calculates the total acceleration by doing a vector sum on all three channels, and it is the total acceleration that is used for determining whether the surface has passed or failed the test. As can be seen from Figure 7, the total acceleration closely follows (and is higher than) the Z-channel data because the Z-Channel dominates the other channels in the vector sum.

The accelerometers are Endevco type 7264B-500. These are piezo-resistive, chosen for their DC response characteristics and simplicity of interfacing to the data acquisition card. Internally, they have a Wheatstone Bridge with two active elements and two reference elements. Thus they require a stable bridge excitation source and provide a millivolt differential output. They have a measuring range of ±500 g and have built-in stops to protect them against impacts of up to ±5000 g.

Accelerometer cable

The accelerometers are connected to the interface box via a single shielded cable, which carries power for the accelerometers and returns the three differential acceleration signals. The headform is exposed to repeated extreme high g-force impacts. Great care was taken when designing the way the accelerometer cable entered the headform and is terminated inside. All free loops of wire inside the headform are immobilized to prevent fatigue failures. The present configuration is a 3rd generation design iteration, and to date this design is holding up well to the rigours of impact testing in the lab and in the field, having already endured several thousand +200 g-force impacts.

Accelerometer interface box

An interface box has been constructed to connect the accelerometers to the data acquisition card. This Interface Box has several features, including:

1. It has a linear voltage regulator to regulate the 12 V battery supply voltage down to a stable 10.0 V dc supply voltage for the accelerometers.
2. For each acceleration channel, it has a low-pass anti-aliasing filter to attenuate unwanted high frequency components (>3 kHz) reaching the data acquisition card.
3. It can perform a 500 g-force calibration shunt check on the Z-Channel to verify calibration in the field.

It has additional connectors for diagnostic purposes.

Data acquisition card

The three acceleration channels are digitized in the data acquisition card. This is a National Instruments DAQ-Card 1200, which utilizes a PCMCIA slot in the laptop. The card has 12-bit resolution, and a sampling rate of 25 kHz is used for each of the three acceleration channels. The inputs are configured in differential mode with DC coupling. The card is also used to monitor the accelerometer battery voltage on a fourth channel.

SOFTWARE

The software has been written in LabVIEW Version 7.1 from National Instruments. There are two programs: Impact Attenuating Tester (IAT) v13 and Impact Attenuating Reader (IAR) v13. As the name implies, IAT is for impact testing impact-attenuating surfaces, and is also used for system calibration. IAR is used for reading and displaying the data previously collected by IAT. Both programs are deployed as an executable file on the laptop computer being used for field use, running Windows 2000 or Windows XP operating systems.

Impact attenuating tester v13

The user interface of IAT has five separate tabbed pages, namely: test result page;settings page; calibration page;time analysis page; and the frequency analysis page. These will now be described.

Test result page

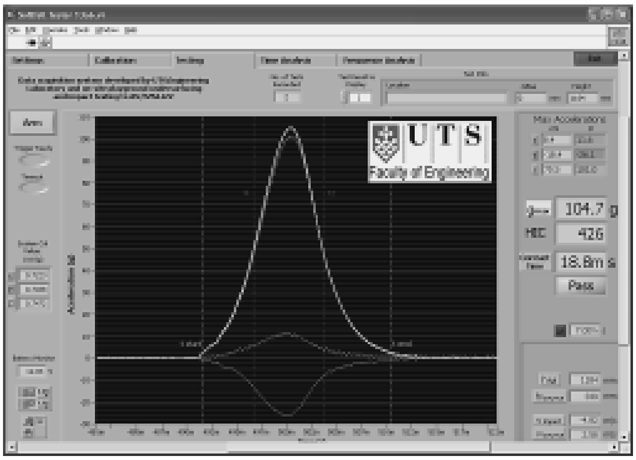
This is the main page (depicted in Figure 7) and is used for collecting the impact data and displaying the most commonly used measurement parameters. When performing an impact test, the user enables the system by pressing the arm button on this page, and then releases the headform using the electromagnetic release control box. Upon impact the system is triggered and captures the impact data which is displayed on the acceleration vs time graph. The Y-axis is normally set to auto-scale mode. The graph has four plots: X, Y, Z and Total acceleration. As mentioned previously, the Total acceleration is simply the vector sum of the X, Y, and Z accelerations. The graph also displays four time markers: t_{start}, t_{end}, t_1 and t_2. The start and end times of the impact event are delineated by t_{start} and t_{end}, respectively, and t_1 and t_2 are the limits of integration selected by the HIC calculation. The time axis is scaled in milliseconds, relative to the start of the headform fall. Both axes of the graph are auto-scaling and can be customised using the graph palette control on the lower left hand side of the Test Result Page.

Displayed to the right of the graph is the main measurement parameter group, consisting of the total acceleration maximum (g_{max}), HIC, contact time (t_{end} - t_{start}) and the pass/fail result. AS/NZS 4422 stipulates that for a test sample to pass this test, three requirements must be met, namely:

1. $g_{max} \leq 200$ g, and
2. HIC ≤ 1000, and
3. contact time ≥ 3.0 ms.

The software compares the measurements with these requirements and displays the pass/fail result.

Below the main parameter group is Δt (t_2 - t_1) being the time over which the HIC integration is maximized, the calculated estimate of the fall and bounce heights (h_{fall}, h_{bounce}), and the calculated impact and bounce velocities (v_{impact}, v_{bounce}). Above the main parameter group are the maxima of the individual acceleration channels, displayed as millivolts and g-force units.



Source: (UTS:Engineering, 2005)

Figure 7 Typical impact data display – Test Result Page

To the upper left of the graph are the Arm button and two trigger indicators. When the arm button is pressed, a number of checks are performed before the Trigger Ready indicator is lit. Firstly, the accelerometer interface box is checked to see that the accelerometer power supply is turned on and that the battery has sufficient voltage to run the accelerometers. If these conditions are not met, the user is notified by a pop-up dialog box and the arming sequence is terminated. If these conditions are met, the outputs of the accelerometers are then checked for the presence of abnormal DC and AC voltages. All piezo-resistive accelerometers will produce a small DC voltage, or zero offset, when at rest. If this measured offset voltage is larger than a chosen threshold, then it is likely that the accelerometer has been damaged or there is a cabling problem. If AC voltage is present (noise), this indicates that there may be a shielding problem (generally in the data communications cable) or that electro-magnetic noise is penetrating the system shielding. If any of these abnormalities are detected, the user is notified by a pop-up dialog box. If the system passes these checks, the system is armed and the Trigger Ready indicator is lit. These checks are conducted under the assumption that the headform is hanging motionless from the electromagnetic release. If this is not the case, a diagnostics problem may be falsely indicated.

When the system is armed, the system samples all three acceleration channels and continues to sample until the headform impact is detected. To prevent the system hanging-up if no impact is detected, a user specified time-out period is used, set at a default value of 15 s. If no impact is detected by the end of the time-out period, the system stops sampling and the Timeout indicator is lit.

Below the Timeout indicator is a display of the system calibration values being used (see description of the Calibration Page).

Below the system calibration display is the Battery Monitor. In addition to the arming battery check mentioned above, the system periodically checks the accelerometer battery voltage and displays it in the Battery Monitor. There are three battery voltage thresholds that the system uses to warn the user of any battery problems (these can be set on the Settings Page).

1. **Warning Threshold**: If the battery voltage falls below this level, the background of the Battery Monitor turns yellow to warn the user. However this is just a warning and the system can still function normally.

2. **Critical Threshold**: If the battery voltage falls below this level the software logic prohibits aiming and displays an appropriate error message as the accelerometers calibration is no longer valid and any recorded results would be suspect. This is because the voltage regulator in the accelerometer interface box can no longer provide a 10.0 V excitation for the accelerometers.

3. **Switched-On Threshold**: This is simply used to detect whether the accelerometer battery supply is turned on, an easy thing to overlook when doing the first test.

Each time the system is triggered by an impact, the data is immediately displayed on the graph and a dialog box pops up to give the user the choice of either keeping the data or discarding it if something has gone wrong. If the graphed data looks ok and the user decides to keep it, the user has the option of giving that particular data set a name. The data is then automatically saved to disk by appending it to an existing data file. This file is a text file formatted in such a way that it is easily imported into a spreadsheet or word processor, or it can be read by the Impact Attenuation Reader program.

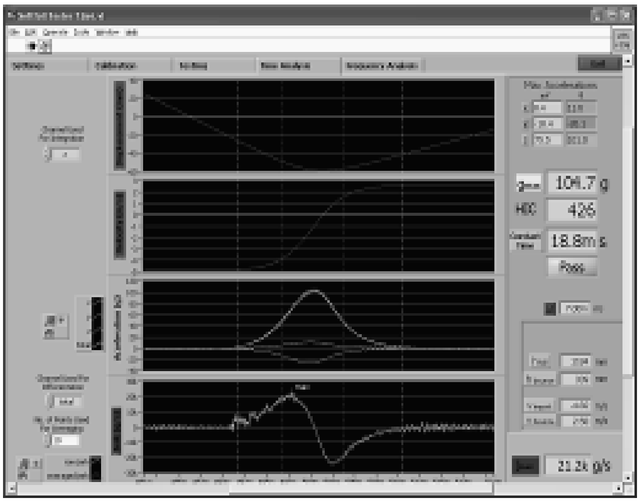
The Test Results Page can record data from multiple drops and allows the user to review data from previous drops with the Test Result to Display control at the top of the page. When a new drop is recorded, the display automatically switches to the latest test result.

Settings page

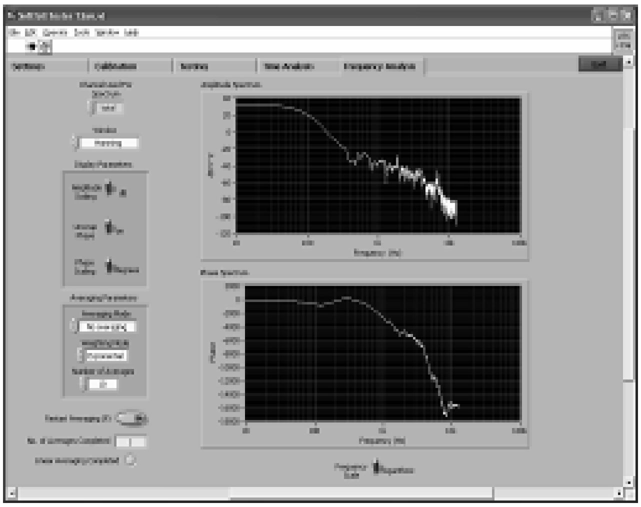
This page contains most of the settings that the user may want to change.

Calibration page

This page displays the filtered output from each of the three accelerometers, in real time. This is used when calibrating the system. The graph can display the accelerometer outputs as either raw millivolts or scaled to g's. Both axes of the graph are auto-scaling, which can be manually controlled. Field calibration is performed by way of a impact test onto a laboratory calibrated test sample. This is performed at the start and end of each group of test in a similar manner to that used when field calibration is performed with a Sound Level Meter. For quick field checking the operator can also use a 1 g inversion while using the Calibration page as a display.



Source: (UTS:Engineering, 2005)
Figure 8 Typical Time Analysis Page



Source: (UTS:Engineering, 2005)
Figure 9 Typical Frequency Analysis Page

Time analysis page

This page, shown in Figure 8, displays the impact data in different ways in the time domain. Starting with the acceleration graph, one of the acceleration channels can be selected (usually Z or Total) to be integrated once to provide a velocity plot, and then again to provide a displacement plot. For the Z acceleration, a positive signal corresponds to acceleration nominally vertically upwards. Hence the pre-impact velocity is negative, and the displacement during the impact is negative. The pre-impact velocity is calculated from the estimated fall height.

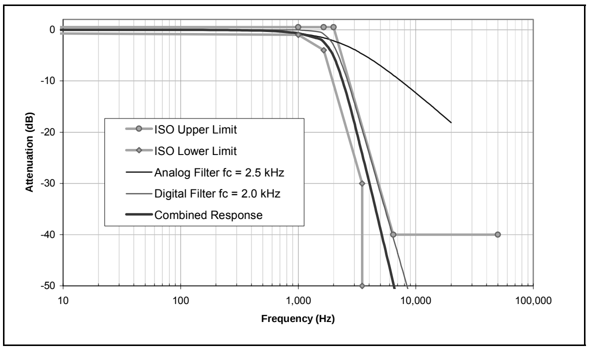
Below the acceleration graph is a graph of jerk, which is obtained by differentiating one of the acceleration channels. This graph contains two plots - the white one is the raw jerk, which is obtained by differentiating over two adjacent acceleration samples. Obviously this will be a noisy signal. The red plot is time averaged jerk, obtained by differentiating over more than two samples. The number of samples over which to differentiate can be selected by the control to the left of the graph. The maximum of the time averaged jerk is displayed on an indicator to the right of the graph, and the location of this maximum is displayed by a cursor on the graph.

Frequency analysis page

This page, shown in Figure 9, displays the impact data in the frequency domain, with two graphs: amplitude and phase. The channel to use for the spectral analysis can be selected, along with the type of window. For each axis linear or logarithmic scaling can be selected, along with phase wrapping and phase units.

FILTERING

The system uses two low-pass filters on the acceleration signals. The first is a first order analog filter located in the accelerometer interface box. This is an anti-aliasing filter that attenuates any frequency components >3 kHz. The second filter is a fourth order digital filter that makes the system comply with the requirements of ISO 6487 CFC 1000. The bandwidth requirements of CFC 1000 are shown in Figure 10, along with the responses of the analog filter, digital filter, and the combined system response.



Source: (UTS:Engineering, 2005)
Figure 10. Frequency response

CONCLUSIONS

The objective of this project was to design and construct a portable impact attenuating measuring system that conformed to the requirements contained within AS/NZS 4422. The resulting system has been used both in the laboratory and in the field to measure the impact attenuating properties of a variety of surfacing material. This has enabled further research in the effectivness of these material in making playgrounds safer for children

This paper presents the design detail of such as system.

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