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Original Article

Simplification and Transformation of ASTM F1292 Measurement Procedure for Fall Accident Injury Criteria

Maki KATO[1*], Yoshie SHIMODAIRA[2], Takeshi SATO[3] and Hiromi IIDA[4]

[1]Faculty of Human Sciences, Waseda University, Japan
[2]Nagano Prefectural College, Japan
[3]Jissen Women's University, Japan
[4]Nihon Taiiku Sangyo Co., Japan

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Abstract: Protecting children from injuries caused by fall accidents from playground equipment is important. Therefore, measures toward minimizing the risk of fall accident injuries are required. The risk of injury can be evaluated using ASTM F1292. In this test, G-max and the HIC are used to estimate the risk of injury. However, the measurement procedure is too complicated for application to a large number of installed equipment. F1292 requires simplified by reducing the number of phases, even with a small risk of loss in accuracy. With this in mind, this study proposes a shortened measurement procedure and a transformation equation to estimate the risk as same as F1292. As the result of experiments, it was revealed that G-max and the HIC values for both procedures linearly increase with drop height. The differences in outcomes between the regression equations of the standardized procedure and those of the shortened procedure can be used as a correction value. They can be added to the value measured by the shortened procedure. This suggests that the combination of the shortened procedure and transformation equation would be equivalent to F1292, with the advantage of being more easily and efficiently applied to the evaluation of installed playground equipment.

Key words: Fall accident, Playground equipment, ASTM F1292, HIC, G-max, Regression analysis

Introduction

Injury and death of children from playground equipment

Over 15,000 people are accidentally killed in daily life in Japan every year. The number of victims of traffic accidents has been decreasing over the last decade. However, the number of victims of accidents in daily life is greater than those caused by traffic accidents. One of such "daily life" accident is the fall accident. Statistics for 2012 show that 6,414 people were killed by traffic accidents, while 7,761 people were killed by daily life accidents involving fall accidents[1)]. Overall, the majority of the fall accident victims are elderly people, many of whom trip over in flat places. However, children are more likely than elderly people to fall from tall structures, especially from playground equipment such as slides, climbing frames and swings. Therefore, it is necessary to protect children from fall accidents in playgrounds.

The problem of accidents involving playground equip-

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*To whom correspondence should be addressed.
E-mail: macky@waseda.jp

ment is serious not only in Japan, but also in many other countries. One of the most serious examples can be observed in the United States, where over 200,000 children are treated for injuries that occurred in public playgrounds each year[2–4]. The average numbers of injured children in the United States during the 10 yr period from 1996 through 2005 is 213,700. Injury and death of children under the age of 2 are also reported. Estimated numbers of injury cases tend to increase from 2 yr-old aged children. Approximately half of the children under the age of two had head or facial injuries and 41 percent of them were injured with public playground equipment[5]. Incidentally, numbers of injuries of 6 yr-old aged children are the highest[6]. Details of children's accidents can be found in pediatric records. Mapping of the place where the accidents occurred, which is based on the records in local hospitals, is effective to determine the risk of accidents in a residential area. So a survey of pediatric records reveals the locations of the accident risk in playgrounds[7].

Necessity of playground equipment for children

Once an accident involving playground equipment occurs, caretakers often remove the equipment in order to prevent future fall accidents. Similar accidents are not likely to occur without the same accident-involved playground equipment. This countermeasure is more economical than compensation for loss. However, this approach is not always appropriate. Generally, children need many different kinds of experiences while growing up. Awareness of the risk of fall accidents is one of the most important lessons for protecting them from hazardous situations. Therefore, playground equipment should be structured to maintain safety, even when children fall from it. For example, adding loose fill materials on the ground, which is an effective countermeasure, could keep them safe. Ideally, all items of playground equipment should be evaluated in terms of safety. That is to say, appropriate loose fill surface and reliable evaluations are necessary to protect children from injury and death by fall accidents from playground equipment.

Attenuation of impact by loose fill surface

Some types of loose fill surface are installed to attenuate the impact of fall accidents. For example, the levels of injury and death in sports are also so serious that numerous studies have focused on the attenuation of impact[8–10]. In a study of an indoor playground surface study, the critical fall height on many types of surfaces was measured. The lowest value was approximately 30 cm or less[11]. In another study, tanbark was tested as one of the attenuation materials for outdoor playgrounds. It was concluded that the depth of tanbark should be 8 cm or more[12]. In addition, Sand has also been tested as another attenuation material for outdoor playgrounds. It was concluded that the sand depth should be 16 cm or more[13].

Evaluation method of risk of fall accidents

The evaluation methods for the two criteria for fall accidents are standardized in the Standard Specification for Impact Attenuation of Surfacing Materials within the Use Zone of Playground Equipment, ASTM F1292[14]. G-max and Head Injury Criterion (HIC) are adopted as the criteria of injury risk with attenuation material on the ground for children aged from 3 to 14 yr old. G-max is defined as the maximum acceleration of a missile during an impact, expressed in G units. The HIC is defined as a specific integral of the acceleration-time history of an impact, adopted to determine relative risk of head injury. The fatal limit of G-max is defined to be 200 G and that of the HIC is 1,000. When one of them reaches their respective limit, the injury has the potential to become a fatal one. Although it was said that F1292 should be improved in the past study[15], the specification has been conventionally applied as the standard evaluation method for loose fill materials for a long time and it was renewed in 2013. Thus, F1292 can be considered reliable. Incidentally F2373 defines a standard method of evaluation for children who are under the age of two[16]. As this study's objectives are children over the age of two, F1292 is adopted to estimate the risk of fall injury. However, the F1292 evaluation method requires some preparation and three trials for one measurement. Since this approach is time consuming, it is often not appropriate for the evaluation of large numbers of playground equipment installed in residential areas. Therefore, a shortened procedure should be adopted for mass evaluation, which would enable early evaluation of risk of injury from playing equipment. In this study, a shortened procedure and transformation equations are suggested as applicable methods.

Methods

Measurement device and loose fill surface

Figure 1 shows a one-package device "missile" (MicroStone Corp.) to measure G-max and HIC, which was developed for the evaluation of the impact attenuation of playground surfacing materials[17]. The missile specification meets the ASTM F1292 standards. The missile is used

Fig. 1. One-package equipment to evaluate impact attenuation[17].

in two procedures, a standardized procedure in accordance with F1292 and a shortened one. There were six levels of drop heights; 60, 100, 150, 200, 250, and 300 cm. The surfaces at the impact point were the bare ground or loose fill surface. The materials of the loose fill surface were a mixture of 0.25–2.0 mm size sand and 2.0–4.75 mm size gravel, which meet the definition in the JGS0051 standards[18]. There were six levels of sand depths; 6, 8, 10, 12, 14 and 16 cm. The drop height and the sand depth were defined by referring to a past study about the attenuation of sand[13].

Standardized procedure in ASTM F1292

Two measurement procedures are defined in ASTM F1292. One is a critical drop height test in a laboratory. Another is a test of the installed surface performance of playground equipment. They include administrative phases such as obtaining permission from the caretakers of the playground. However the administrative phases are not the objective of this study from the viewpoint of shortening procedures in the physical operation. The procedure for the installed surface performance test should be compared with the shortened procedure. The procedure for the installed surface performance test defined in F1292 is as follows[14]: 1) The surface shall be prepared with the loose fill materials in a square boundary of at least 5.1 cm width and 5.1 cm length. 2) The surface temperature shall be confirmed to be within a functional range of at least from −7 to 54 degrees centigrade. 3) The loose fill surface shall be conditioned before measurement by impacting tamper, whose shape is a square of 25 cm width and 25 cm length. The tamper has a mass of 7 ± 1.1 kg and shall be dropped four times from a height of 60 ± 2.5 cm. 4) The missile shall be dropped three times to the same impact point on the surface. G-max and HIC scores shall be recorded for each drop test. 5) The average of the second and third scores shall be used as the evaluation scores.

Shortened procedure

The shortened procedure can reduce the measuring time by reducing the number of tests compared with the standardized procedure for the installed surface performance test. In the place of the removed phases, the transformation calculation phases after measurement is added. The shortened procedure is as follows: 1) The phase of preparing the loose fill surface is the same as that for the standardized test. The phases of measuring the temperature on the surface are also similar. 2) The phases of conditioning by the impacting tamper are omitted. 3) The missile, the same device used in the standardized procedure, shall be dropped to the loose fill surface just once. G-max and HIC scores shall be recorded as temporal scores. 4) The evaluation scores of the impact shall be estimated by calculating with the transformation equations, which are suggested in this study. In this study, the scores of a previous study[19] were used as a part of the score by the shortened procedure. These shall be compared with the results of the standardized procedure.

Comparing standardized procedure and shortened procedure

The standardized procedure was compared with the shortened procedure, using regression analysis. Because the scores obtained by the shortened procedure are smaller than those obtained by the standardized procedure, the scores must be appropriately transformed. The regression equations between G-max and drop height of the standardized procedures and those of the shortened procedure were compared to obtain transformation equations. Correction values calculated by the transformation equations were added to the scores of the shortened procedure to estimate the evaluation scores. The HIC was also processed in the same manner as G-max.

Result

Impact attenuation on the loose fill surface

Figure 2 shows the variation of acceleration at the moment of impact. The surfaces at the impact point in Fig. 2 were bare ground and check-pad for specific confirmation. G-max at 60 cm height was 94.4 G at 3.875 ms, at 100 cm height was 145.3 G at 4.15 ms, and at 150 cm height was

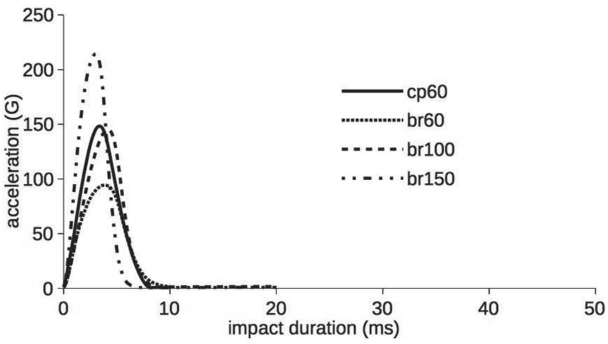


Fig. 2. Variation of acceleration of impact attenuation on the bare ground surface (cp: check pad for confirmation of the missile, br: bare ground; numbers signify drop height (cm))[19].

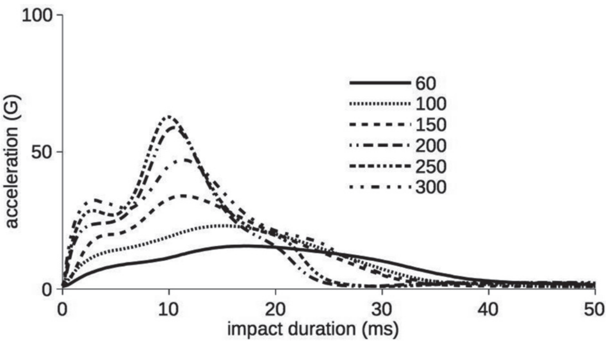


Fig. 3. Variation of acceleration of impact attenuation on the surface with 16 cm depth sand; numbers signify drop height (cm)[19].

214.3 G at 3.025 ms. As indicated, G-max, represented by the peaks of the wave, increased with drop height. The time to converge acceleration at 150 cm height was shorter relative to the other heights. Figure 3 shows the variation of acceleration at the moment of impact on the surface of 16 cm depth of sand as loose fill material. G-max at 60 cm height was 15.7 G at 17.05 ms, at 100 cm height was 23.1 G at 15.25 ms, at 150 cm height was 32.8 G at 11.2 ms, at 200 cm height was 54.5 G at 10.45 ms, at 250 cm height was 62.7 G at 9.95 ms, and at 300 cm height was 47.0 G at 11.375 ms. As indicated, G-max, represented by the peaks of the wave, which mean G-max, also increased with the drop height, except at height 300 cm. The time to converge acceleration decreased as the drop height increased, except at height 300 cm. One of the difference between the wave on bare ground and that on the loose fill surface was the shape of the waves. The waves on 16 cm sand depth at over 250 cm height had two peaks, and the bends of the waves became smaller as drop height decreased.

Regression equations of standardized procedure and those of shortened procedure

Figure 4 shows the results of regression analysis for G-max of the standardized and shortened procedures. The scores of both procedures increased with drop height. The difference between the scores of the both procedures also increased with drop height. This can be said for all levels of sand depth. In addition, G-max decreased as the sand depth increased. The coefficients of the regression equation for G-max also decreased as the sand depth increased. Figure 5 shows the result of regression analysis for the HIC of the standardized and shortened procedures. The variation of the HIC had the same features as those of G-max. The difference between the two procedures increased with drop height as same as in the case of G-max. The coefficients of the regression equation for the HIC also decreased as the drop height increased.

Transformation equitation to estimate evaluation scores

Figure 6 shows the coefficient difference of the regression equation for G-max and the HIC between the standardized and shortened procedures. The variation of the coefficient differences of G-max was unsteady; whereas, the coefficient differences of the HIC decreased as the sand depth increased. As the results show, the G-max difference between the two procedures depends not on the sand depth, but on the drop height. Generally, acceleration at the impact point is dependent on maximum speed. The speed at the moment of impact is determined by drop height. On the other hand, coefficient difference for the HIC depends on both of the drop height and sand depth. The correction value to be added to the temporal score can be estimated by the transformation equation as follows.

$$\text{G-max } e = x + 0.2\ h \qquad (1)$$

$$\text{HIC } e = x + (0.08d + 2.4)\ h \qquad (2)$$

x: temporal score, h: fall height (cm), d: sand depth (cm)

Note that the unit cm is used in the transformation equation so that the evaluation and transformation can be applied to practical use.

Discussion

Attenuation by loose fill material

Variation of acceleration at the moment of impact depends on the drop height and sand depth. The peak of

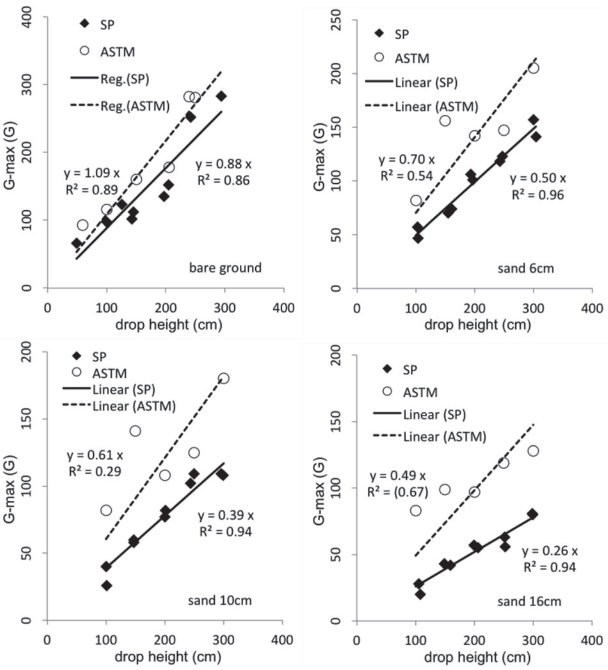


Fig. 4. G-max and regression equation on the bare ground and loose fill surface.

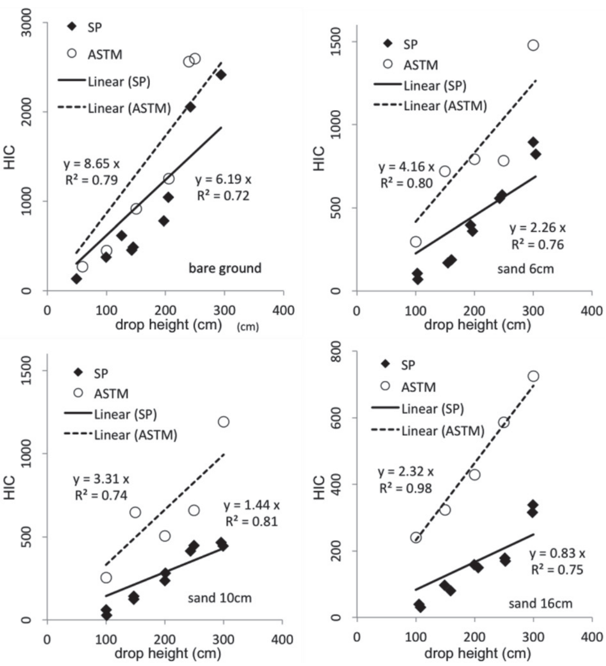


Fig. 5. HIC and regression equation on the bare ground and loose fill surface.

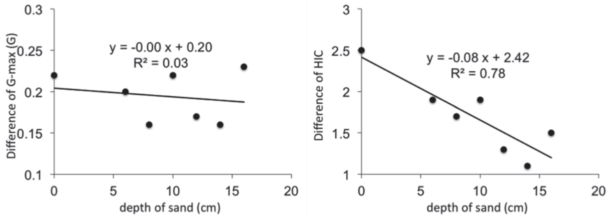


Fig. 6. Coefficient of differences between the standardized and the shortened procedures for G-max and HIC.

the wave, which represents G-max, became larger with the drop height. In addition, G-max became larger as the sand depth became shallower. Comparing the variation of impact acceleration on the bare ground with that in 16 cm sand depth at 150 cm drop height, it concluded that the sand decreased the score to one-seventh. The waves on the sand have two peaks because there were two types of impacts. The first peak of the waves was measured at the moment of touching the surface of the sand. The second peak was measured at the moment of stopping at the bottom after diving into the sand. It is conceivable that the sand increases the time until the missile stops and attenuates the impact. The measurement procedure in Figs. 2 and 3 is a shortened one, which is the first drop after preparing the surface without conditioning by the impacting tamper. The results using the standardized procedure would be larger.

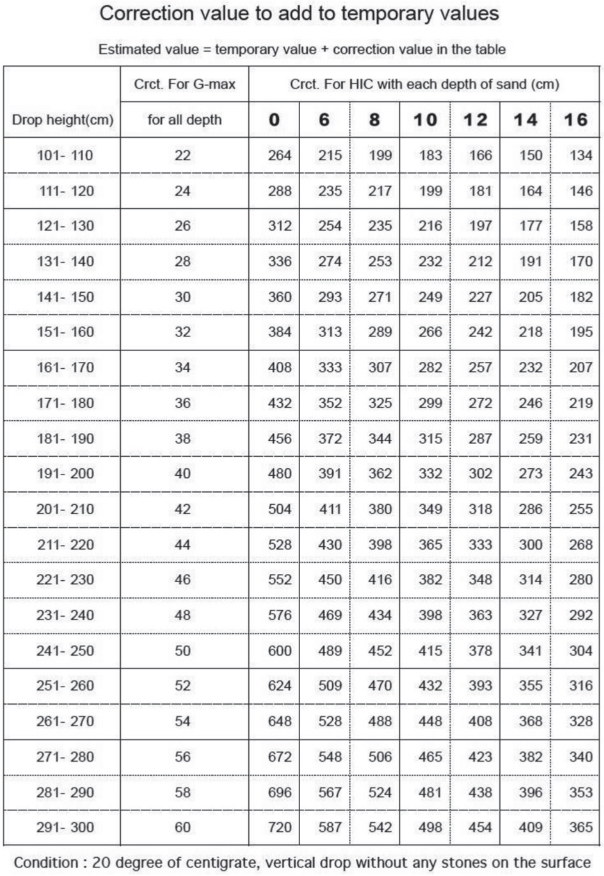
Difference between the two procedures

As shown in Fig. 4, the results of measurement tend to increase linearly with drop height. And they tend to decrease linearly as the sand depth increased. Determinations of coefficients in the results seem to indicate that the analysis is sufficiently reliable. G-max by the standardized procedure is larger than that by the shortened procedure because of the effect of the impacting tamper and repeats of trials. A surface conditioned by impacting tamper became harder than the initial surface. In addition, the first drop to the surface would make a crater and harden the surface, therefore the average of the second and third scores become larger. On the other hand, the surface of the shortened procedure is so soft that G-max does not become large. The effect increases with sand depth. This can also be said for the HIC as shown in Fig. 5. However the difference of the coefficient of the regression line in Fig. 5 tends to increase with the sand depth. This tendency in the HIC is larger relative to G-max. The variation of the coefficient differences of the regression line for G-max between the two procedures, which are shown in Fig. 6, seems to have little correlation with sand depth. On the contrary, that for the HIC tends to decrease as sand depth increases. This means that different transformation equations are needed for G-max and HIC to estimate the evaluation scores from the temporal scores by the shortened procedure.

Effect of declining of accuracy of shortening procedure

As seen from the results of the regression analysis, the measurements in both of procedures have a range of error. The variation of acceleration of 16 cm sand depth at 300 cm drop height in Fig. 3 is one such example. The homogeneity of loose fill materials are not easy to maintain although they are conditioned before the drop tests. This can be also said regarding the description of the standard method in ASTM F1292. In fact, the score can be estimated only by statistical procedure, because G-max and the HIC are calculated from the second and third scores. The standardized procedure can estimate more exactly than the shortened procedure, however, this specification cannot prevent all injuries and deaths[14]. Therefore the shortened procedure could be applied practically even though the accuracy declines. It is not easy to reveal the reliability of applying transformation equation, because the estimation by the standard procedure of ASTM F1292 includes the measurement error range. Comparing the estimated value with the measured one, the error range of G-max was 17%, and that of HIC was 19% respectively. However, the transformation equation can be applied to reveal the potential risk of injury, because the coefficients of the shortened procedure are stronger than those of standard procedure. On the other hand, easy and familiar methods will enable researchers to efficiently investigate multiple items. The shortened procedure can be used to identify equipment, which is risky. However, it is not as appropriate for strict measurement, compared with the standardized procedure. Therefore, measurement using the standardized procedure should be conducted to confirm precisely the risk of the equipment identified by the shortened procedure and the transformation equation. That is, after an observer obtains temporary G-max and HIC value using the shortened procedure, the observer adds a correction value calculated from the transformation equation. Then the observer would be able to use the predetermined transformation as shown in Table 1 to simplify the measurement. When a risky playground equipment is noticed by the shortened procedure, the observer would be able to obtain accuracy of the standardized procedure. The suggested shortened procedure and the transformation equation would enable easy measurement. However, this study used only sand as the loose fill material. When the other types of loose fill materials are used for attenuation in future studies, other transformation equations would be required.

Table 1. Predetermined transformation table



Correction value to add to temporary values

Estimated value = temporary value + correction value in the table

	Crct. For G-max	Crct. For HIC with each depth of sand (cm)						
Drop height(cm)	for all depth	**0**	**6**	**8**	**10**	**12**	**14**	**16**
101- 110	22	264	215	199	183	166	150	134
111- 120	24	288	235	217	199	181	164	146
121- 130	26	312	254	235	216	197	177	158
131- 140	28	336	274	253	232	212	191	170
141- 150	30	360	293	271	249	227	205	182
151- 160	32	384	313	289	266	242	218	195
161- 170	34	408	333	307	282	257	232	207
171- 180	36	432	352	325	299	272	246	219
181- 190	38	456	372	344	315	287	259	231
191- 200	40	480	391	362	332	302	273	243
201- 210	42	504	411	380	349	318	286	255
211- 220	44	528	430	398	365	333	300	268
221- 230	46	552	450	416	382	348	314	280
231- 240	48	576	469	434	398	363	327	292
241- 250	50	600	489	452	415	378	341	304
251- 260	52	624	509	470	432	393	355	316
261- 270	54	648	528	488	448	408	368	328
271- 280	56	672	548	506	465	423	382	340
281- 290	58	696	567	524	481	438	396	353
291- 300	60	720	587	542	498	454	409	365

Condition : 20 degree of centigrate, vertical drop without any stones on the surface

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