Playground Safety: Relationships Between Surface Impact Attenuation, Fall Height, & Surface Depth

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INTRODUCTION

Over 200,000 children visit an emergency room each year for traumatic brain injuries (TBI) sustained on playgrounds, with falls being the leading cause[1]. Playground surfacing is the main method of attenuating the impact of these unintentional falls. Good impact attenuation performance of these surfacing materials is critical for injury prevention.

There are a variety of surfacing materials used on playgrounds across the country, ranging from natural to synthetic products, both loose fill and solid. The surfaces assessed in this study are sand, pea gravel, wood chips, wood mulch, engineered wood fiber, rubber tile, and poured-in-place (Figure 1). Each surfacing material performs differently in the field based on fall height and depth of material[2].

PURPOSE

The intent of the study was to evaluate the surfacing materials impact attenuation performance – the playground industry acceptable threshold being HIC <1000[3]. Specifically, the study examined the relationships between fall height & impact attenuation and fall height & surface depth.

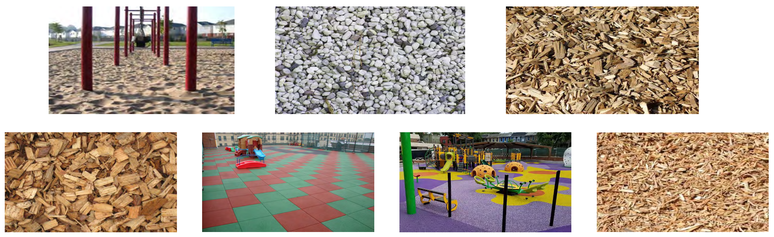


Figure 1: Various playground surfaces (from left to right starting with top left: sand, pea gravel, wood mulch, wood chips, rubber tile, poured-in-place, and engineered wood fiber).

METHODOLOGY

Following ASTM F1292[3] field testing provision procedures, 3,453 impact attenuation drops occurred on sand, pea gravel, wood products, and unitary surfacing. For relating fall height & surface depth, a fall height surface depth (FHSD) ratio was calculated:

$$FHSD = \frac{Fall\ Height\ (in.)}{Surface\ Material\ Depth\ (in.)}$$

In order to create a guide regarding what surface depths are needed at what fall heights, plots regarding HIC of the average of impact test drops 2 & 3 vs. the FHSD ratio were created. A vertical red line represents recommended surface depths for given fall heights based on an existing guideline related to determining surface depth to fall height[4] (Figure 2).

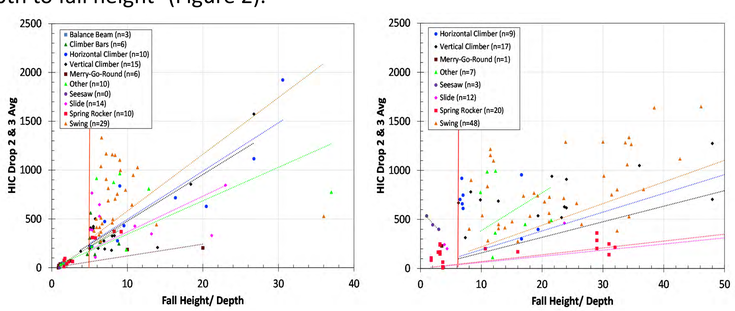


Figure 2: Representative plots comparing the average HIC of drops 2 & 3 and the FHSD ratio for sand and pea gravel. The vertical red line represents the current FHSD guide from CPSC.

RESULTS

Table 1 captures the recommended loose-fill surface depths corresponding to different fall heights. These depths increased at different rates based on the surface's impact attenuation performance. Sand requires the most surface depth, while engineered wood fiber requires the least surface depth at a given fall height to appropriately attenuate an impact. For example, at a fall height of 14 feet, sand requires 34 inches of compressed loose fill to attenuate impact safely, while pea gravel requires 28 inches, wood chips and wood mulch require 19 inches, and engineered wood fiber requires 14 inches. Table 2 illustrates the effect that fall height has on the impact attenuation of the surfacing materials. **Overall, loose fill products experienced a sharp decrease in impact attenuation compliance at heights above 9 ft., while unitary products experienced a sharp decrease in performance at heights above 6 ft.**

	Sand	Pea Gravel	Wood Chips	Wood Mulch	Engineered Wood Fiber
*CPSC FHSD**	*5.3*	*6.7*	*13.3*	*9.3*	-
New FHSD	*5*	*6*	*9*	*9.3*	*12*
Fall Height (ft)	**Recommended Compressed Surface Depth (in)**				
1	3	2	2	2	1
2	5	4	3	3	2
3	8	6	4	4	3
4	10	8	6	6	4
5	12	10	7	7	5
6	15	12	8	8	6
7	17	14	10	10	7
8	20	16	11	11	8
9	22	18	12	12	9
10	24	20	14	13	10
11	27	22	15	15	11
12	29	24	16	16	12
13	32	26	18	17	13
14	34	28	19	19	14

** based on the CPSC Public Playground Safety Handbook*

Table 1: Fall height, surface depth (FHSD) guide for loose-fill surfacing material comparing the findings of this study to the recommended fall heights & depths from CPSC. Unitary surfacing material is not included because the depths of the unitary surfacing (rubber tile & poured-in-place) for this study were unknown.

Fall Height	Sand (n=306)	Pea Gravel (n=351)	Wood Chips (n=1131)	Wood Mulch (n=63)	Engineered Wood Fiber (n=1188)	Rubber Tile (n=108)	Poured-in-place (n=306)
0-3 ft	63 (100%)	63 (100%)	204 (99%)	--	198 (100%)	9 (100%)	108 (100%)
3-6 ft	27 (100%)	60 (95%)	261 (100%)	18 (100%)	304 (99%)	18 (100%)	63 (70%)
6-9 ft	166 (88%)	123 (80%)	567 (97%)	36 (100%)	633 (98%)	72 (89%)	63 (58%)
9-12 ft	20 (74%)	35 (65%)	67 (83%)	9 (100%)	27 (100%)	--	--
12+ ft	--	9 (50%)	--	--	3 (33%)	--	--
Total Test Locations < 1000 HIC	**276 (90%)**	**290 (83%)**	**1099 (97%)**	**63 (100%)**	**1099 (98%)**	**99 (92%)**	**234 (76%)**

Table 2: Amount and percentages of test location sites below 1000 HIC based on 5 fall height ranges. Amount of total test locations <1000 HIC are also reported for each of the 7 surfacing materials.

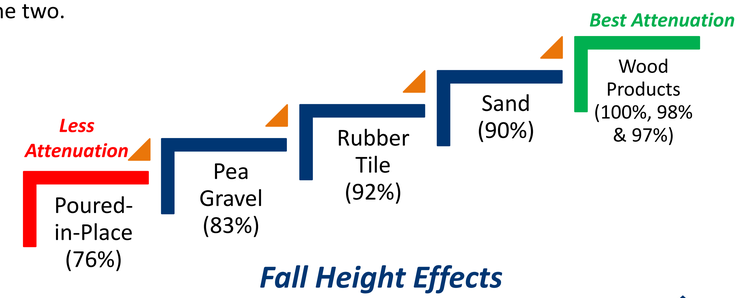
REFERENCES

1) *Cheng, T. A (2016). Pediatrics 137(6).*
2) *Gunatilaka AH (2004). Injury Prevention 10:174-179.*
3) *ASTM Standard F1292 (2013).*
4) *CPSC (2010). Handbook for Public Playground Safety.*
5) Olsen HM (2018) National Study of Public Playground Equipment and Surfacing.

DISCUSSION

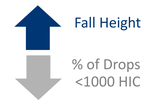
Fall Height & Surface Depth Guideline: Study vs. CPSC

The CPSC guide presents higher FHSD, representing higher fall height and shallower surface depth than the guide from this study's result. A lower FHSD represents lower fall height and thicker surface depth, which fosters better impact attenuation. The CPSC guide from their *Playground Safety Handbook* is based on "compressed" loose-fill conducted in a lab, following ASTM F1292[3] lab procedures. This study's data is from field-test results on existent playgrounds across the nation. Therefore, limitations may arise with the comparisons between the two.



Fall Height Effects

At higher fall heights, effective impact attenuation becomes compromised. For instance, pea gravel changes from ***65% to 50%*** compliance, while engineered wood fiber decreases from ***100% to 33%*** compliance from fall height category 9-12 ft. to 12+ ft.



Sand, wood chips, and wood mulch were not installed beneath equipment with fall heights higher than 12 ft. Rubber tile and poured-in-place were not installed beneath equipment with fall heights higher than 9 ft.

CONCLUSIONS

Guidelines informing manufacturers or operators may be updated based on this mini study and future studies regarding fall height and recommended surface depth. **If equipment height increases without maintaining the correct depth, surface impact attenuation will be poor.**

Compared to an existing CPSC guideline developed from lab testing, **this study's field-test data suggests that increased surface depth is needed at each fall height**. The relationship between HIC and fall height is useful to inform playground owners and maintenance staff about which materials are best for certain heights or how much upkeep is required to maintain certain depths of surfacing materials.

Acceptable fall heights may need to be lowered in order to have more surface material compliance. At 12+ ft., more than half (pea gravel: 50%, engineered wood fiber: 67%) of the test locations did not comply with HIC <1000.

Future Work

Future studies may benefit from analyzing the relationship between unitary surfacing materials' fall height and surface depth to add unitary products to the FHSD guideline.

Acknowledgements

The national sampling of playground dataset was funded by the U.S. Consumer Product Safety Commission, CPSC-S-16-0061.