

A Study of Shock Characterization for Protective Packaging Design

S.W. Lye, M.Y Teo, and S.C. Lew

Cushioning buffers made of expandable polystyrene, a white polymeric granulated material, are commonly used to protect goods from damage. Current design practices tend to be simplistic and general, resulting in either overdesigned buffers or inadequate product protection. The objective of this paper is to identify the main parameters affecting shock absorption so that products can be better protected. An investigative study reveals that the types of impact surfaces, material densities, geometric features, and configurations contribute significantly to the amount of shock that a product experiences.

Keywords
polystyrene, shock protection

1. Introduction

DURING transportation, goods generally encounter such hazards as accidental drops, mishandling, road bumps, and other vibrations involving abnormally high impact and shock loads. Goods also experience high compressive loads caused by product stacking during storage. Cushioning buffers made of expanded polystyrene (EPS), a white polymeric granulated material, are commonly used to protect goods from damage. The design of these cushioning buffers often involves adherence to a set of heuristic rules, including the use of tables, figures, and formulas. Such design practices vary from company to company and are closely guarded trade secrets. Figure 1 shows a typical set of procedural activities involved in the design of protective packaging. There are five main activities—namely, identifying the item that requires protection, specifying the variables and conditions for protection, sizing and arranging the cushioning features, providing a detailed buffer drawing, and performing a product drop test. For novices interested in protective packaging, these design procedures are well documented (Ref 1-3) and offer valuable insight into the subject.

Nevertheless, information obtained from published design rules tends to be simplistic and general, resulting in either overdesigned buffers or inadequate product protection. For the final design solution to be commercially viable, additional iterative steps are necessary to rework, remold, and retest. The problem is further compounded by the absence of tangible and effective rules to handle areas of failure and weakness. This study into the relationships between shock characterization and cushioning features was made with the objective of providing useful data to better guide designers.

S.W. Lye, M.Y. Teo, and **S.C. Lew,** School of Mechanical and Production Engineering, Nanyang Technological University, Singapore.

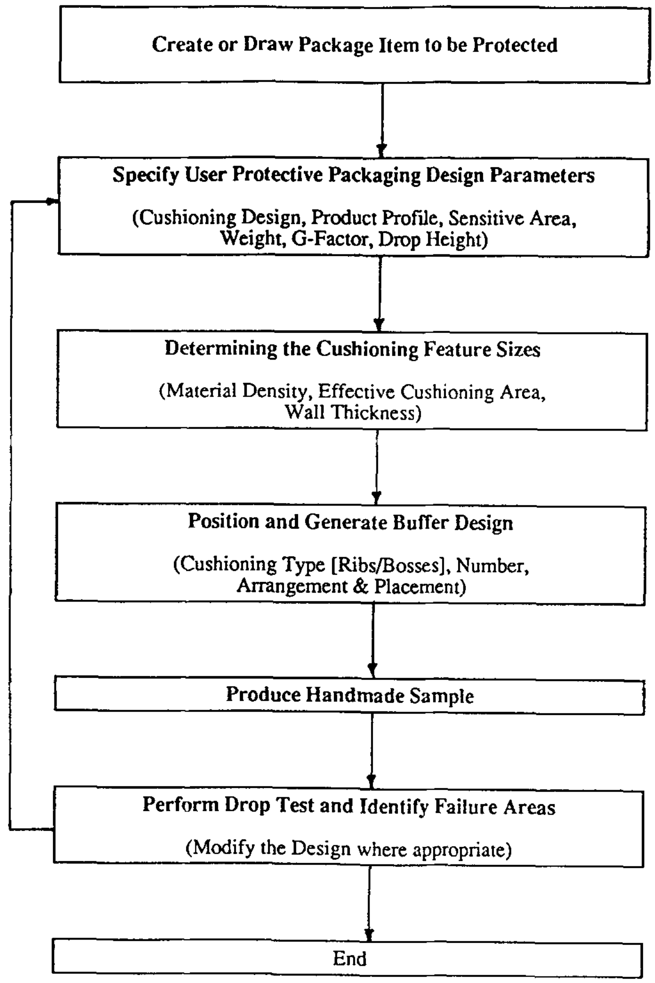


Fig. 1 A typical set of procedural activities involved in the design of protective packaging

2. Experimental Setup

Figure 2 shows the experimental setup. It consisted of a Lansmont (Schmidt Scientific Ltd. Singapore) shock test ma-

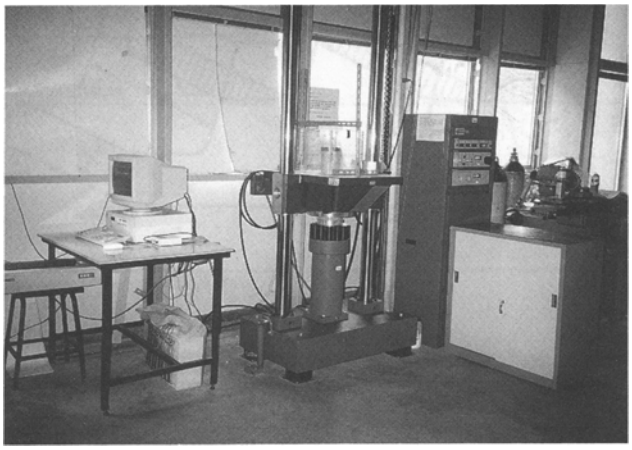
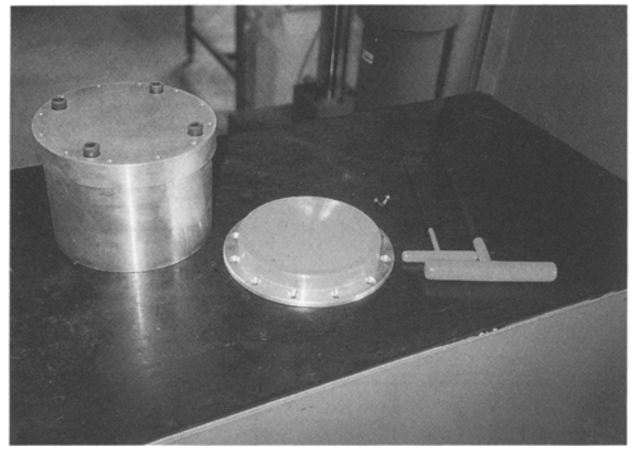


Fig. 2 Experimental setup



(a)

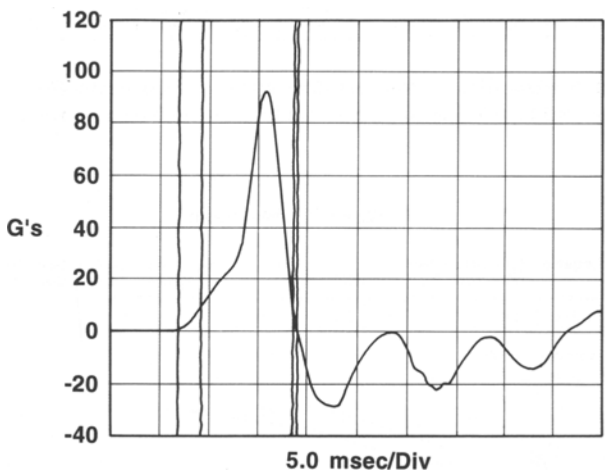
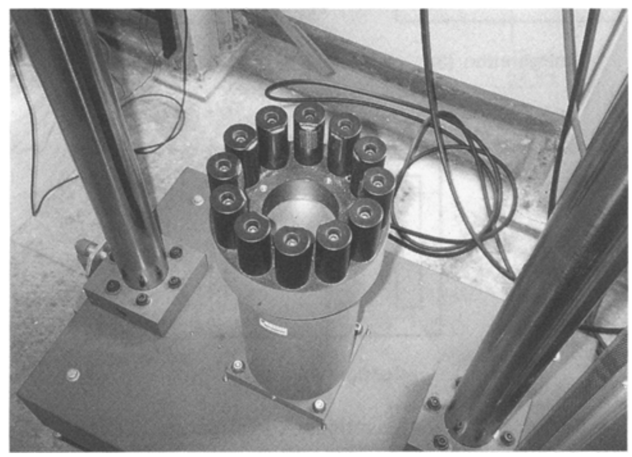


Fig. 3 Typical example of the impact shock pulse. The vertical axis is acceleration in terms of *G* units. One *G* unit is 9.8 m/s^2 (32.16 ft/s^2).



(b)

Fig. 4 Types of shock programmers. (a) Elastomer module programmers (soft impact surface). (b) Hard plastic programmers (hard impact surface)

chine (model 65/81), with a 420 kg machine table. The test specimen was 12 kg aluminum cylindrical block enclosed in an acrylic box, mounted with a single-axis accelerometer and placed on the machine table. The accelerometer registered the shock signals generated upon impact of the table onto a reaction base. The signal was transmitted to a computer via a signal conditioner with an interface module. A safety bracket prevented the specimen from bouncing off the test area. A software program called "Test Partner" was then used to filter and analyze the shock signals obtained. A sample of the shock characterization is shown in Fig. 3.

3. Experimental Tests

A parametric study into the shock absorption behavior pattern of a cushioned product was conducted and involved four different tests, whenever appropriate, based on ASTM D 3332 (Ref 4). This work studied the peak acceleration or *G* value, a common measurement used to determine the fragility or allowable shock level before damage occurs to a product. The following parameters for fragility or shock were investigated:

- Impact surface
- Positioning of the cushioning features
- Material density of the cushioning features
- Geometric sizes and ratios of the cushioning features

In the first set of tests, two types of shock programmers or cushion pads were used to act as the soft and hard impact surfaces onto which a product might fall. They included 5 to 13 mm thick elastomer module programmers and hard plastic programmers (Fig. 4).

For the second set of tests, sample blocks having the same effective cushioning features and area per face were prepared. The features, however, were arranged in five different configurations with respect to the center of gravity. Figures 5 and 6 illustrate the geometric cushioning dimensions and the different feature configurations.

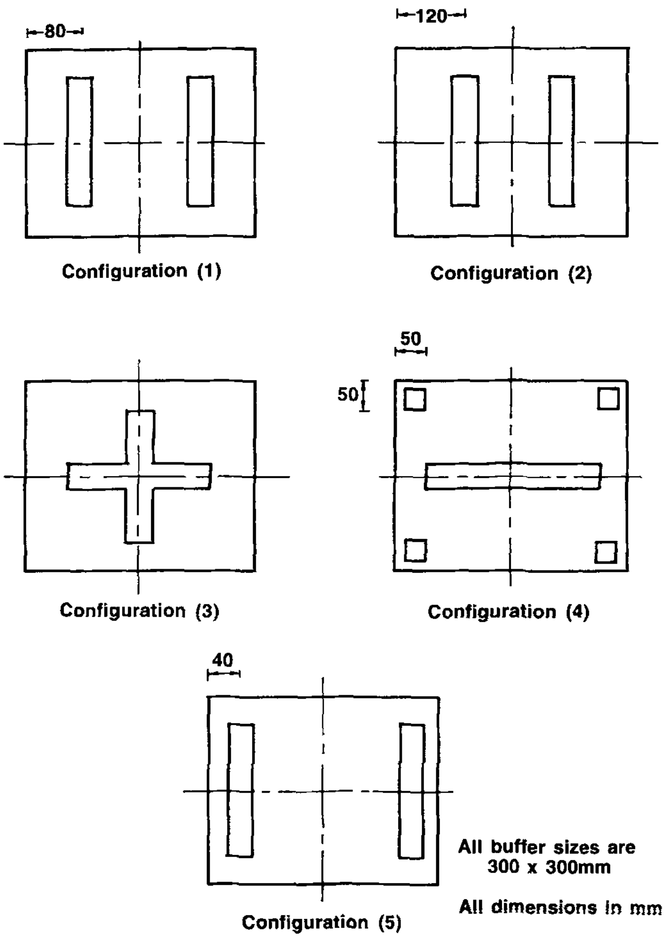
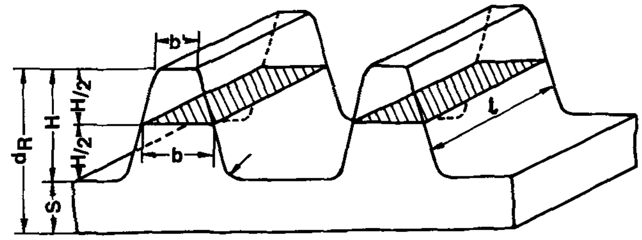


Fig. 5 Various rib configurations. All buffers are 300 by 300 mm. All dimensions are given in millimeters.



Experiment Description	Buffer Feature and Material Data					
	Mat. Density (kg/m^3)	L (mm)	d_r (mm)	H (mm)	b (mm)	b'(mm)
Effect of Rib Configuration	20	200	50	25	42	36
Effect of Materials	20,32	200	50	30	42	36
Effect of Rib Length and Height	20	200-300	50	12.5-25	42	36
Effect of Wall Thickness						
-same Mat.Den.	20	200	50	25-40	42	36
-varied Mat. Den.	20,32	200	50	35	42	36

Fig. 6 Experimental test data showing the effect of buffer features and material density on the study of shock characterization

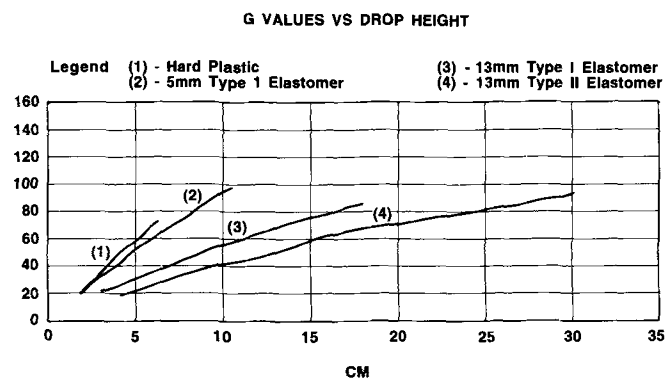


Fig. 7 Relationship between G value and drop height for four different types of impact surfaces. (1) hard plastic; (2) 5 mm type I elastomer; (3) 13 mm type I elastomer; (4) 13 mm type II elastomer

The third set of tests investigated the effect of material density on shock absorption. Samples were prepared with cushioning features produced using material densities of 20 and 32 kg/m^3 based on the geometric dimensions shown in Fig. 6. The cushioned specimens were then subjected to single and multiple drops.

In the final set of tests, the height, length, and buffer wall thickness of the cushioning features were varied. The geometric dimensions of these features are shown in Fig. 6.

4. Results and Discussion

4.1 *Effect of Impact Surfaces*

Figure 7 shows the relationships between the average G (peak acceleration) values and the drop heights of the tests conducted on four different types of impact surfaces: 5 mm type I, 13 mm type I, and 13 mm type II elastomer module programmers, and hard plastic programmers. Type I and type II elastomer programmers differ in that type I has a higher hardness value. For each data point, five drop experiments were conducted. Figure 7 shows that for a certain drop height, the G values obtained for the different impact surfaces varied significantly (in ascending order): 13 mm type II, 13 mm type I, 5 mm type I, and hard plastic programmers. This means that the harder the impact surface, the higher the G value. The results also revealed the experiments to be repeatable and linear, a reflection of the elastic behavior of the programmer materials used.

Another observation was the shorter pulse duration or signal waveform registered for hard surfaces; there was less elastic deformation on the impact surface made by the product, resulting in quicker rebound. Based on the findings, when specifying the appropriate G value for product protection, the designer must consider not only the likely drop height but also the impact surface on which the product is likely to land. This factor

Table 1 Effect of rib configuration on peak*G* values

Configuration	Peak *G* value First reading	Second reading	Third reading	Average
1	61.82	63.17	59.73	61.57
2	46.06	49.31	46.55	47.31
3	48.01	53.69	46.74	49.48
4	74.79	70.26	75.11	73.39
5	92.45	98.68	93.48	94.87

Table 2 Effect of material density on peak*G* values

Material density, kg/m^3	Peak *G* value First reading	Second reading	Third reading	Average
20				
First drop	22.5	27.26	25.71	25.16
Second drop				31.94
	30.48	36.12	29.21	
32				
First drop	21.31	22.42	23.94	22.56
Second drop				25.77
	26.98	25.56	24.77	

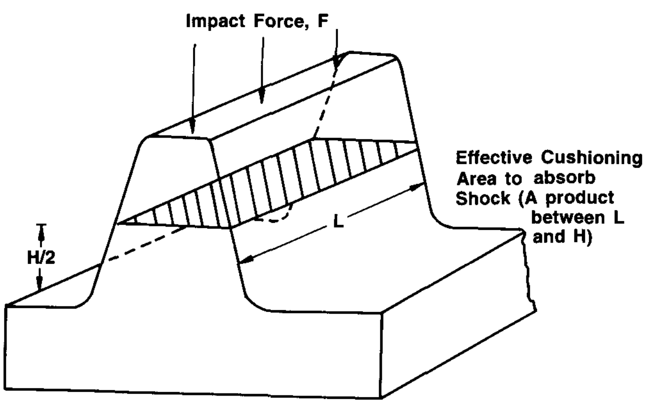


Fig. 8 Effect of cushioning area on shock absorption

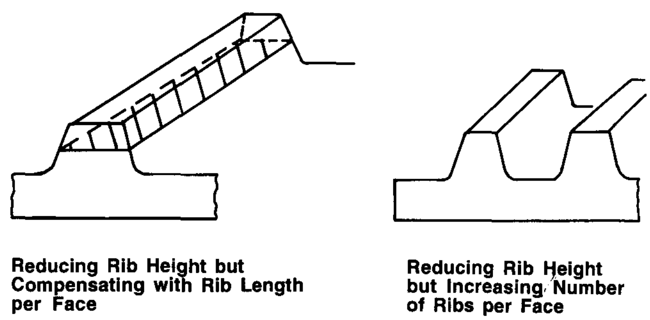


Fig. 9 Compensation of the effective cushioning area by extending rib length or adding ribs

must be built into any protective packaging design. This will lead to more appropriate use of cushioning materials, resulting in greater cost savings.

4.2 *Effect of Cushioning Configurations*

Table 1 presents results of the effect of buffer, or rib, configuration on shock absorption. Five different configurations having the same effective cushioning area per face were investigated (Fig. 5). At a drop height of 30 cm, the *G* values varied between 47 and 95 for the five configurations. Rib configurations 2 and 3 registered lower *G* values than configurations 4 and 5. Cracks were even observed in configuration 5. Although each face had the same effective cushioning area, in configurations 2 and 3 the ribs apparently absorbed most of the shock, with the product experiencing less shock.

The findings indicate that reinforcement and positioning of the ribs should be made near high-fragility regions and the center of gravity in order to both provide better support to the product and reduce the amount of shock transmitted to the product. Empirical studies are currently under way to determine their explicit relationships.

4.3 *Effect of Material Density*

Cushioning samples with material densities of 20 and 32 kg/m^3 and the features shown in Fig. 6 were prepared. The samples, along with the specimen, were then dropped from a height of 20 cm. The results show that the heavier buffer density offered about 10 and 20% better product protection in the first and second drops, respectively (Table 2). This is probably due to the compactness of the beads (higher material density), contributing to better rib durability. Current practice is based on a "single-drop" design and makes use of the lower material den-

Table 3 Effect of rib features on peak *G* values

Rib feature, mm		Peak *G* value			
Length	Height	Firs treading	Second reading	Third reading	Average
200	12.5	92.43	95.65	93.55	93.88
	19.0	43.13	45.1	46.71	45.0
	25.0	22.98	28.16	27.54	26.23
300	12.5	70.3	88.9	75.84	78.35
	19.0	31.92	35.34	33.25	33.5

Table 4 Effect of wall thickness on peak *G* values

Wall thickness,	Peak *G* value		
mm	First reading	Second reading	Average
10			
First drop	25.7	25.5	25.6
Second drop	40.8	38.7	39.8
25			
First drop	24.7	23.1	23.9
Second drop	36.3	39.8	38.1

sity in order to cut costs. For marginal failure cases, it may be more economical to use a higher-density material than change the design. This may call for the design of a composite cushioning buffer in order to optimize costs and make use of the increasingly diverse applications of EPS products.

4.3 *Effect of Cushioning Features*

Two series of experiments were conducted to investigate the effect of rib geometry and buffer wall thickness. In the first set of experiments, the rib height and length were varied. Table 3 shows the peak *G* values obtained at a drop height of 20 cm for rib lengths of 200 and 300 mm with height variations of 12.5, 19, and 25 mm. It can be seen that at a lower rib height for the same rib length, the peak *G* value was greater although not linearly related. For a constant rib height, the longer the rib length, the lower the *G* value. An increase in *G* value indicates that the product experienced a greater amount of shock; in other words, less shock was absorbed by the rib buffer. This is because the amount of shock to be absorbed by the rib is dependent on the effective cushioning area (Fig. 8). Decreasing the rib size effectively reduces the cushioning area.

The results also show that, to minimize transportation and storage costs, the overall size of the package should be reduced. This can be done either by minimizing the rib height and compensating with its length, or by using more ribs while maintaining the same effective cushioning area per face. This is illustrated in Fig. 9. Nevertheless, it should be noted that, for manufacturing reasons, the rib height cannot be reduced too drastically. A critical minimum rib height limit equal to that of the buffer wall thickness is typically observed.

The second series of tests investigated the effects of buffer wall thickness and its related material density on shock absorption. Cushioning samples with buffer wall thicknesses of 10 and 25 mm were prepared with rib configurations and features similar to those shown in Fig. 6. Table 4 shows that for the two buffer wall thicknesses, the *G* values differed slightly. The results indicate that the buffer wall does not offer much protection to the product; most of the shock is absorbed by the cushioning ribs. This means that, except for containment and structural reasons, the buffer wall thickness should be kept to a minimum.

The material wall densities were then varied as shown in Table 5. It was found that the difference in *G* values was negligible for the first drop by increased for the second. One explanation is that, in the first drop, the buffer ribs absorbed most of the shock, whereas in the second drop, the rib may have cracked or disintegrated, leaving the buffer wall to function as a "weak" cushioning medium. In view of the marginal protection offered, it is inappropriate to design a buffer wall using a denser material for economic reasons.

5. Conclusion

An investigative study into the effects on shock absorption of impact surface, rib configuration, material density, and geometry of the cushioning buffers was conducted. Higher *G* values with shorter pulse durations were typical for hard impact surfaces. Cushion design should be based on the likely type of surface on which the product might land.

Rib configurations positioned near to or at the area of interest registered lower *G* values. Rib designs should be incorporated and arranged according to regions of high fragility and the center of gravity of the product.

Denser buffers register lower *G* values and are particularly suitable for use in "multiple-drop" designs. For marginal failures, the use of a denser buffer may be preferred, whereas strengthening of particularly weak areas may call for design of a composite cushioning buffer (if economically justifiable).

Rib length and height affect *G* values. The larger the cushioning feature, the greater the amount of protection offered. To achieve a compact design package, results show that it is more economical to minimize the rib height and compensate for the difference with its length, or to have more ribs on that face. The buffer wall thickness does not offer significant protection to the product.

This work provides a useful platform from which further empirical studies and theories (currently in progress) can be formulated to establish parametric relationships between shock characterization and cushioning features.

Table 5 Effect of material density on peak G values for similar wall thickness

Material density, kg/m^3	Peak G value: First reading	Second reading	Third reading	Average
20				
First drop	22.99	25.18	24.87	24.35
Second drop	35.71	35.00	38.21	36.31
32				
First drop	26.17	22.38	25.85	24.8
Second drop	33.07	30.82	32.17	32.02

Acknowledgments

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