Laboratory Package Drop Testing

Over-testing In the Name of Probability

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Abstract

Numerous field studies conducted by many parties, including Westpak, Inc., have shown that the probability of a "design drop height" event during distribution is very small, on the order of 5% or less during any particular shipment. Yet the majority of laboratory package drop test procedures typically call for 10 impacts from the design drop height on different faces, edges, or corners of the package system. Does this not constitute a substantial over-test? This paper will examine the nature of package drop testing, why it evolved in its current format, and the significance on package performance and optimization.

Introduction

When studying the distribution environment to determine typical package drop heights, it becomes apparent very quickly that the vast majority of the data is rather boring in that most impacts are at a relatively low level. For a very few number of impacts, however, the drop height can be significant, certainly significant enough to cause potential damage to a packaged product. But these less than 5% of the total recorded impacts most of the time, the vast majority of studies report only one impact from this "higher" drop height. In fact, most environmental data recorders, so-called "ride recorders", are often set up to reject data below a certain drop height because the amount of data collected would be very difficult to analyze based on the large number of very minor impacts. Thus, from a statistical standpoint, it's very difficult to even determine the percentage of "total" drops simply because much of the data from lower drop heights is not even collected.

It is also worth noting that the environmental data bears very few patterns such as the orientation of the impacts. Most studies show that the package base will receive a majority of the measurable impacts. The remaining impacts, typically two-thirds or more of the measured data, are scattered randomly through different orientations including top down, side down, end down, corner impacts, or edge impacts. A 2005 study conducted by HP monitored dummy packages during 57 one way "2nd day express" shipping through multiple destinations in Europe. The obtained data gives a picture of the typical impacts seen during a shipment. (See Fig. 1 and 2)

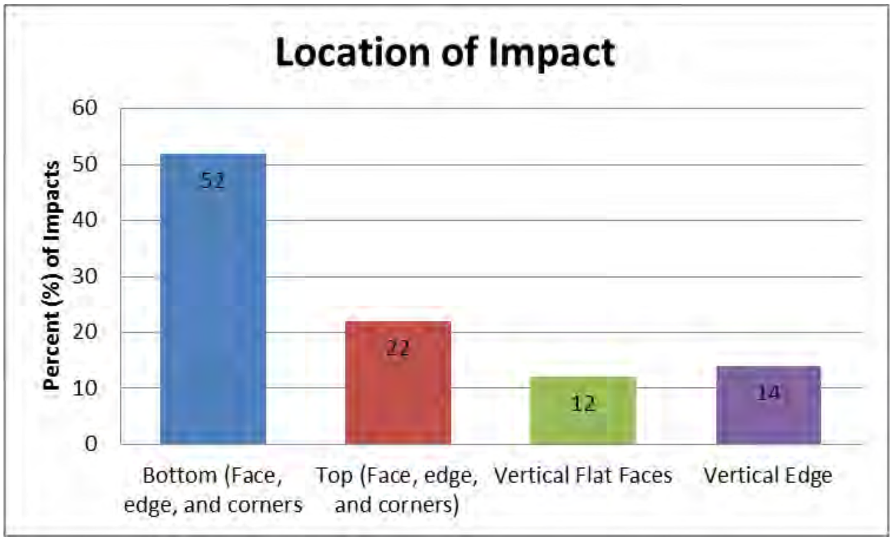


Figure 1- Location of Impacts

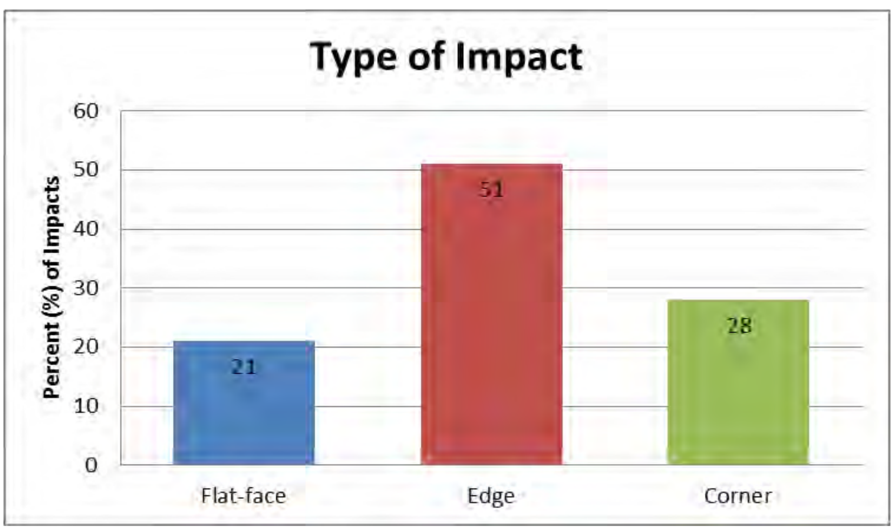


Figure 2 – Type of Impacts

Source: European Express Shipping Drop/Impact Study

When the field data is brought into the laboratory, an attempt is made to determine a "rational" drop height and impact orientation for the package. Most studies attempt to determine the drop height above which less than 1% of impacts will occur. This is the normal "target value" and the drop height chosen is normally referred to as the *"design drop height"*. This is the value used to determine the amount and thickness of cushion placed around a fragile product to help guarantee successful delivery more than 99% of the time. In this manner, the drop height used to test the packaged product in the laboratory is fixed from the field data.

It is the orientation of the impact(s) that causes some consternation when translating this data into a test specification. Since the base down orientation tends to be more predominant in the field data, this orientation is almost always selected for laboratory testing. If a packaged product is more sensitive in another orientation other than base down, then it is likely to receive damage during shipment because a significant number of impacts will occur in other than the base down orientation. Therefore, a real dilemma exists.

Most specifications resolve this issue by calling for a number of impacts at the design drop height. This number varies from 6 to approximately 26 depending on the specification. The problem is, of course, that a test spec requiring 26 impacts from the design drop height is an entirely different matter from the field environment which will subject the packaged product to perhaps one impact from that design drop height and only 1% of the time.

The nature and reason for this over-testing in the laboratory will now be examined.

Collecting Field Drop Height Data

Most package drop height data is collected by using a ride recorder (a device that will measure and record the acceleration versus time signal resulting from an impact to the package) during distribution. *It's important to recognize that the ride recorder does not record drop height directly.* Rather, it records a deceleration versus time pulse. In order to obtain the drop height from this data, the pulse must be integrated *twice*. The difficulty here is that the pulse contains both input *and* rebound data while we are looking for IMPACT data only. Thus, the integral of that pulse may be substantially larger than the impact data alone would dictate. The difference between the impact and the impact plus rebound data, is referred to as the "*coefficient of restitution*" (e) of the package and is a measure of the momentum (think of it as energy) stored during the impact (resulting in a rebound) vs. that dissipated during the impact alone. The following equation applies:

$e = V_r/V_i$ [Coefficient of Restitution equals the rebound velocity divided by the impact velocity]

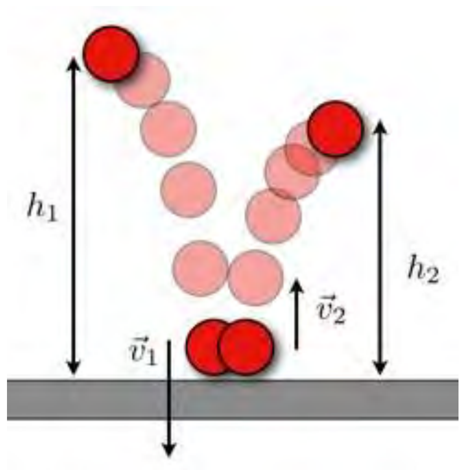


Figure 3: Coefficient of Restitution Visualized

Source: http://www.wired.com/2011/04/modeling-a-bouncing-ball/

Data recorders are now equipped with very handy software wherein the user can determine the coefficient of restitution of a package system by means of laboratory test data. This coefficient can then be programmed into the data recorder allowing the unit to more accurately record actual drop height from a deceleration versus time pulse. The problem that occurs is that the coefficient of restitution of a cushioned package will likely vary depending on its orientation and it may vary a significant amount depending on whether or not the impact is flat, predominantly on the corner of the package, or predominantly on an edge. Again, with some diligent laboratory work, an average coefficient of restitution can be established that will accurately display drop height data within a reasonable tolerance.

When reviewing field data of drop heights experienced by package systems, it becomes apparent that the mass or weight of a package has an influence on the data. The theory is that impacts during distribution are primarily a function of manual handling which is largely a people-related function. Since people don't like to pick up heavy objects very high, it is assumed that heavier packages will experience lower drop heights. Some studies have shown that there may be a problem with this assumption. However, it can be safely assumed that once a package system exceeds perhaps 65 kg (150 lb.), most of the impact data will occur by means of mechanical handling including forklift handling, diverter plates in sorting facilities, or similar. In addition, environmental studies from developing countries show that a relatively common method of moving larger package systems involves *rolling the package* end over end or side over side using a number of individuals in order to achieve the desired result. Also, package systems tossed off the end of a truck or those that fall from a material handling vehicle will likely experience random orientations of the impacts at a higher level than would be dictated by the weight of the package system itself.

Fig 4: Rolling of heavy packages and improper handling can be observed in the distribution environment

Data Analysis

Once the data is collected, it will normally be assembled into a format that is easier to use in the laboratory for package design and testing purposes. The first thing that is apparent is that the data must be analyzed for each individual trip separately. That is to say for any one shipment cycle, a single design drop height data point above which 1% of the data exists is determined. Simply amassing a large number of data points from multiple shipments will result in erroneous conclusions. Thus, the data for each shipment should result in a single "three sigma" data point, that is, the drop height above which less than 1% of the impacts occurred *for that shipment*. Three sigma data points can then be averaged or in another way assembled to produce a "mean 99% drop height" which becomes the "design drop height" for the package system as well as the test drop height for package performance evaluation.

Fig 5: In-lab Drop Test

The data collected in this manner will often show a near linear relationship between the drop height experienced and the weight of the package system. While the volume or cube of the package system may also have some significance in terms of the experienced drop height, this relationship is not as distinct as that between weight and drop height. Most studies also conclude that labels on packages such as "*Fragile Handle With care*", or "*This Side Up*" have little influence on either the drop height or the impact orientations experienced.

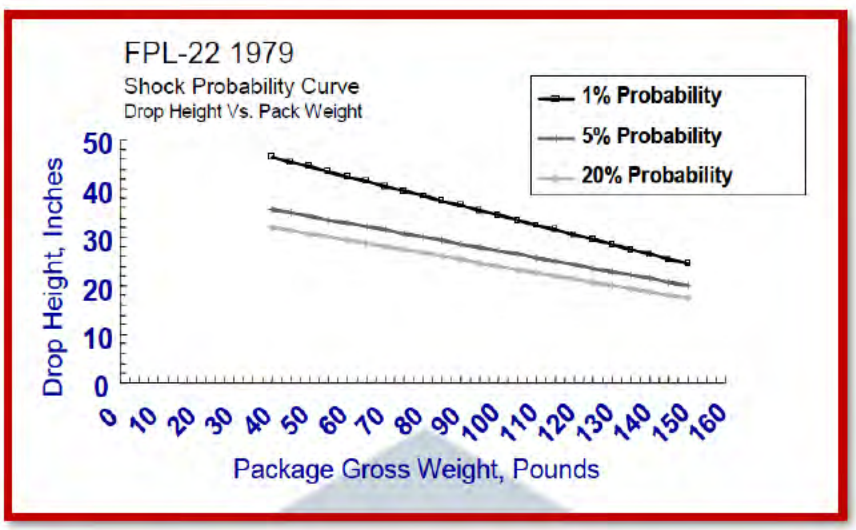
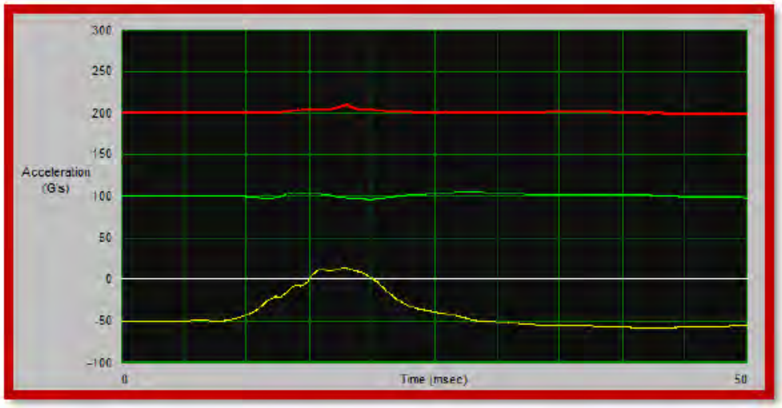


Fig 6 Drop Height vs. Package Weight from FPL-22 1979

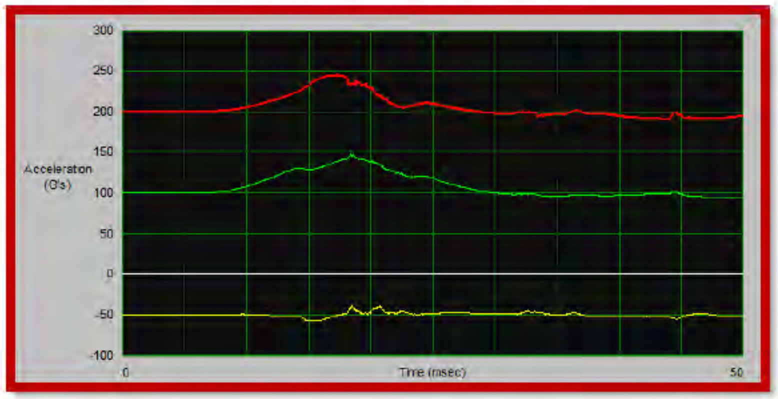
(Source: European Express Shipping Drop/Impact Study)

Package Test Specification Development

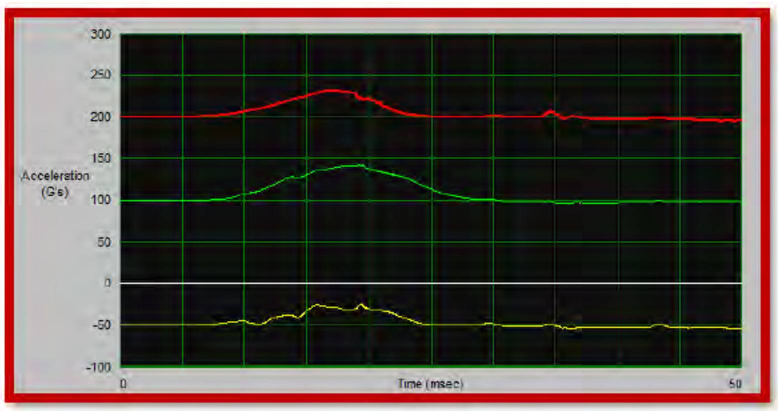
After the drop height of the package is well established, (likely based primarily on the package weight), several factors must be taken into consideration. The fragility of the product, its sensitivity to various orientations, and the overall size of the package system are all important factors in determining the test specification. The only unresolved item remaining is the number and orientations of the impacts. Recall that the environmental data collected normally seeks to identify the drop height above which only 1% of the impacts occur, the so-called "three sigma" or design drop height. Also recall that this height of impact normally occurs only once per shipment. Since there is, on average, about a one-third probability that this impact will occur on the base, the base down orientation is normally chosen as a beginning point for the test specification. The remainder of the flat package faces (5 remaining faces) are normally selected for impact tests based on the fact that these other faces may also contain product identification or shipping information which may result in a default "up" orientation based on the ability of someone to read that information. In addition, it is thought that the flat orientation of the package normally constitutes the highest transmitted deceleration level for a given impact level (drop height). The theory is that all of the energy from a flat impact is dissipated in one axis (primarily) whereas an impact on a package edge will dissipate the energy in two axes or a corner impact in three axes.



Flat Impact – Energy dissipated in one axis



Edge Impact – Energy dissipated in two axes



Corner Impact- Energy dissipated in three axes

Fig 7: Plots Showing Dissipation of Energy in Various Impact Orientations

Thus, most package test specifications will include all 6 impact surfaces from the design drop height as a starting point for a package drop test specification. The environmental data also suggests, however, that truly flat impacts (within 5° of flat) are very rare. Most impacts occur randomly on surfaces, corners or edges of a container system. Thus, the specifications normally include some number of corner or edge impacts in order to cover that likely event. It is also known that while flat impacts may be more severe from a transmitted deceleration standpoint, corner or edge impacts tend to be more severe from a package integrity standpoint, that is, the ability of the package to hold together when subjected to the stresses of a corner or edge impact. The splitting of a cushion system or buckling of the outside container is a very common occurrence with corner or edge impacts as well.

What often emerges from this wealth of seemingly conflicting data is one of two types of tests using the following philosophies:

Philosophy A

This philosophy dictates that if we cannot predict the orientations of the impacts, let's just *test them all to be sure*. On a typical rectangular package, that amounts to a total of 26 impacts (including those counted as the flat faces of the package). This is easy to determine by simply counting up all the corners, edges, and flat faces on a typical rectangular container system.

Philosophy B

The far more common approach is to simply select a corner and designate it as the "most vulnerable" impact corner of the container system. If it is impossible to determine a most vulnerable corner impact location, then the base corner of the package that includes the manufacturer's joint of the container is selected. In addition to a single corner impact, the edges radiating from that impacted corner are also often selected for testing resulting in a total of 10 impacts (1 corner, 3 edges, and 6 flat faces). This would represent a “moderate” test from a package integrity viewpoint.

Some specifications duplicate this procedure (single corner and 3 radiating edges) on the diagonally opposite corner of the package system. This will result in a total of 14 impacts on the container (2 corners, 6 edges, and 6 flat faces). Other test protocols are used but by far the most common test procedure is 10 impacts from the design drop height. In addition, accepted test protocols for drop testing of a package (such as ASTM D5276) will require that the orientation of a package for flat impacts be within 2° of flat and that the impact surface be a solid and non-rebounding surface typical of steel or concrete.

Putting the Final Spec Together

Regardless of the actual specification that results from this analysis, it’s fairly obvious that the test procedures will result in a substantial over-test of the package system from a design drop height standpoint as well as an over-test in the quantity and orientation of the impacts. The field data clearly points out that the package will likely receive only one impact from a design drop height and only 1% of the time. Yet a typical drop test procedure will require 10 impacts – or more - from the design drop height in a specified number of orientations. Some of the realizations that can be reached from this finding are as follows.

Point 1. Most protective package designs are very conservative from an impact standpoint. Those who claim that we may be wasting large amounts of money on protective packaging that is not needed may have a good point.

Point 2. The data also suggests - and many others have often pointed out - that shipping to third world countries will result in a substantially higher number of impacts due to the greater degree of manual handling experienced in those environments.

Point 3. Evaluation of the results of a package drop test in the laboratory must be evaluated in light of the substantial over-test potential of most common test specifications for package drop testing. This is to suggest that a minor amount of damage or non-standard product appearance may be acceptable in light of the conservative and perhaps even severe nature of the test inputs.

Point 4. Note that the test procedures themselves will tend to favor package cushion designs with cushions that are rebounding or totally resilient in their format over those that are crushable or non-rebounding. While the data clearly suggests that these cushion designs might be perfectly acceptable in the distribution environment, the test procedures with multiple impacts will likely be less favorable toward non-rebounding cushion designs. Since resilient package cushion designs tend to be more expensive, the test procedures can be viewed as building in more expensive package systems.

Conclusion

It has been shown that the nature of the package test specifications, especially in terms of the orientations and number of impacts, is conservative by its nature and will likely lead to more expensive and over-designed package systems from a shock mitigation standpoint. Where multiple impacts on a product-package system are desired for a package drop test sequence (and the authors certainly believe that that is the case), perhaps these additional impacts should be conducted using a fresh package system for each orientation. It may also be feasible to use one package for several drop orientations where a crushable package system, for example, will still offer adequate protection. In this manner, a fresh package impact orientation could be maintained with as little as 3 or 4 package prototypes during the test protocol in the laboratory.

Substantial improvement in package optimization and reduction in package cost – along with better sustainability overall – can be anticipated if and when this topic comes under more scrutiny by package test specification writers.

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