PRESHIPMENT TESTING STRATEGIES FOR GLOBAL DISTRIBUTION

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ABSTRACT

Preshipment tests of packaged products can generally be categorized into three types: integrity testing, general simulation, and focused simulation. While the simplest approach, integrity testing, has served reasonably well for many years in the U.S., today's realities of global distribution and competition, varying transport conditions worldwide, and increasingly stringent environmental requirements often call for a more thorough approach. This paper will discuss the three test categories, their strengths and shortcomings, and the effectiveness of each vis-à-vis the demands of global distribution.

PRESHIPMENT TESTING

The benefits of preshipment transport package performance testing are well known and proven. It is said that the biggest step a manufacturer or shipper can take, in terms of securing those benefits, is to undertake a preshipment testing program – any program – where previously there was none. Guidelines published by the International Safe Transit Association (ISTA) state "Even a simple lab test used wisely is preferable to trial and error…" [1]. But once the decision has been made to perform preshipment tests, the question arises of what testing protocol is the most efficient and effective in a given situation.

The typical goal of preshipment testing coupled with a packaging development process is obviously to confirm design adequacy by passing the laboratory tests. But if the tests do not well match field hazards, levels and conditions, then the designs cannot readily be optimized. For example, if the tests are too severe or extensive, the packaging may perform well in the field but will likely be over-designed, excessively costly, and environmentally wasteful. If the tests are too gentle or critical hazards are omitted from the protocol, passing designs may still exhibit excessive field damage.

But passing a realistic series of tests does not in itself guarantee the best package. In addition, the tests must be passed with minimum practical margin to avoid over-packaging and waste. So the old approach of “redesign if necessary until the tests are passed” might change to “if the tests are passed, redesign with less material and test again”. It is a combination of proper tests and careful design which leads to packaging optimization.

Packaging optimization is not only good practice from the technical, business, and environmental viewpoints, it is sometimes required by law or regulations. Section EN13428 of the European Packaging Directive, for example, requires demonstration “that the minimum adequate amount of weight and/or volume of the finished packaging has been reached…” [2]. Other regional, national, and international regulations may contain similar requirements.

THE TESTING HIERARCHY FROM SIMPLE TO COMPLEX

ISTA places its testing protocols into three primary categories: integrity testing, which challenges the strength and robustness of the product-package combination without necessarily attempting to replicate actual transport occurrences; general simulation, which is designed to broadly model the damage-producing forces and conditions of the transport environment; and focused simulation, which bases laboratory tests, intensities, and conditions on actual field-measured hazards and levels. Although the “integrity, general, focused” nomenclature is ISTA’s, package testing protocols from other organizations can be categorized in much the same way.

The test types – integrity, general simulation, focused simulation – form a hierarchy of cost, complexity, and effectiveness. There is little question that the more advanced tests will lead to more accurate assessments of the ability of packaged-products to survive the transportation/distribution environment. But it does not necessarily follow that all situations demand or warrant use of the most sophisticated protocols. Many factors should be considered: cost and time requirements of testing; product fragility, value, and shipment quantities; packaging costs and environmental impacts; direct damage costs and intangibles; the extent and complexity of distribution; market issues such as time-to-market demands, customer satisfaction, and competition; liability exposures; regulatory requirements, etc. Proper protocol selection achieves the optimum balance of all these factors for the particular situation.

INTEGRITY TESTING

Description

Integrity testing is the simplest and lowest-cost approach to preshipment package performance evaluation. In its most basic form, it typically requires only free-fall drops and fixed-displacement vibration, using equipment similar to that shown in Figure 1 on the following page. Other than item weight, little or no consideration is given to product or package configuration, construction, value, shipment quantities, etc. The same protocols are used without regard to transportation modes and distribution means. Tests are conducted at lab ambient atmospheric conditions, and pre-conditioning of test specimens is generally not required. Test levels are not correlated to real-world occurrences and tend to be relatively severe. For example, only one fairly high drop height is specified for all drops for each weight range, whereas it's well known that in typical distribution there are usually many low drops and few high drops. Also, the vibration is a fixed-displacement test which doesn't attempt to simulate the motion of real vehicles, and is run for an arbitrary time or number of cycles not related to transport distance. Good examples of integrity test protocols are the ISTA 1-Series [1].

Packaging standards from many organizations include protocols which could be categorized as integrity tests. A number of the leading worldwide carriers include integrity-like tests in their basic recommendations and requirements. And ISTA estimates that its simplest integrity tests (Procedures 1A and 1B) have been conducted over 500,000 times since 1948 [3]. So there is no question that the basic approaches are used widely and successfully.

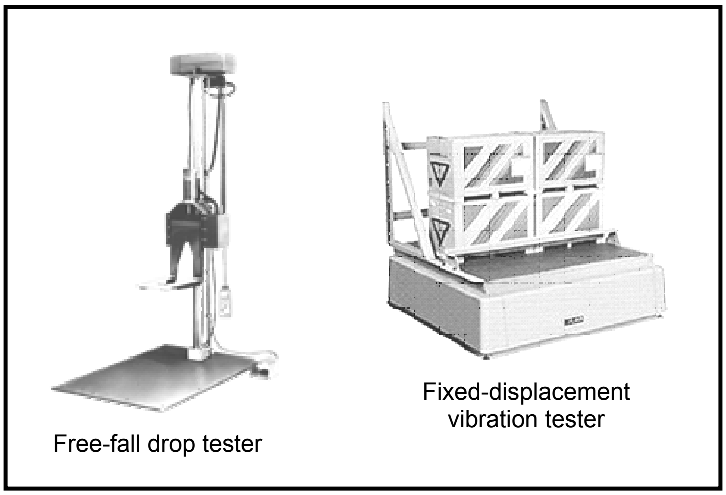

Figure 1 Typical equipment used for basic integrity testing

Effectiveness of Integrity Testing

For organizations where no preshipment testing is being currently conducted, institution of an integrity test program is an enormous step forward. Almost any testing is better than no testing, and can serve to screen out at least basic product and package design problems. In cases where product fragility is not particularly an issue, integrity testing can often do a good job of assessing the package performance – its ability to withstand abuse and continue to properly contain and identify the product.

When simple integrity tests "work", defined as leading to the design of packaging which successfully protects products in large-scale shipping situations, they probably err on the side of over-protection and over-performance. This is because the rational response to a lack of information or lack of consideration to real-world situations is to configure "worst-case" test intensities, and this is the essential approach of integrity testing. Of course some hazards (compression, atmospheric) may not be covered, but perhaps in many instances it happens that severe tests of just a few types will compensate for tests that are omitted altogether. Regardless, if the specimens pass these severe tests, they are probably overly-robust, at least with respect to those types of inputs.

When simple integrity tests do not work, it's probably because damage is caused by hazards for which a test was not included. For example, if damage is caused by compression during warehousing but there is no compression test, or by high humidity when all the tests are conducted at lab ambient conditions, the protocol's simplicity results in a major shortcoming. The tests are passed, but field performance is unsatisfactory – a sure sign that the tests are somehow improper for that situation.

In many situations, simple integrity tests can serve well. But even when they "work" and are passed with minimum margin, they can still lead to over-packaging because of the severe test levels. Therefore these tests are a poor tool for optimizing packaging costs, performance, and environmental impacts in a global market. They are not well suited for demonstrating compliance with regulations like the European Packaging Directive.

GENERAL SIMULATION

Description

General simulation is an attempt to realistically model the damage-producing elements of transportation and distribution in the laboratory, using broad-based depictions of the intensities, sequences, and conditions. Test levels and other parameters are contained within the testing protocols, corresponding to generalizations drawn from diverse compilations, industry consensus, calculation, and "conventional wisdom". Requirements typically include varying drop heights, additional types of impacts, compression based on generalized top loads and stack heights, simple shaped random vibration which broadly simulates actual vehicle motions, atmospheric conditioning, and combined hazards such as compression and vibration simultaneously. Tests are tailored to some extent based on package type and construction, and some degree of consideration is given to product value and shipment quantities. Different basic modes of transportation are taken into account (including multi-mode situations), and a generalized attempt is made to put the lab tests into a sequence similar to that expected during actual distribution.

Compared with integrity testing, general simulation typically requires an increased investment in laboratory equipment and facilities. More types of test systems are needed, and their complexity and sophistication is greater. See Figure 2 on the next page for representative examples of equipment. Since there are more variables to be considered, configuration of test plans typically requires more thought, understanding, and planning. In addition, general simulation tests are more extensive, involved, and time-consuming to run. Good examples of general simulation tests are ASTM (American Society for Testing and Materials) Practice D 4169 [4], ISO (International Organization for Standardization) Standard 4180 [5], and the ISTA 3-Series tests.

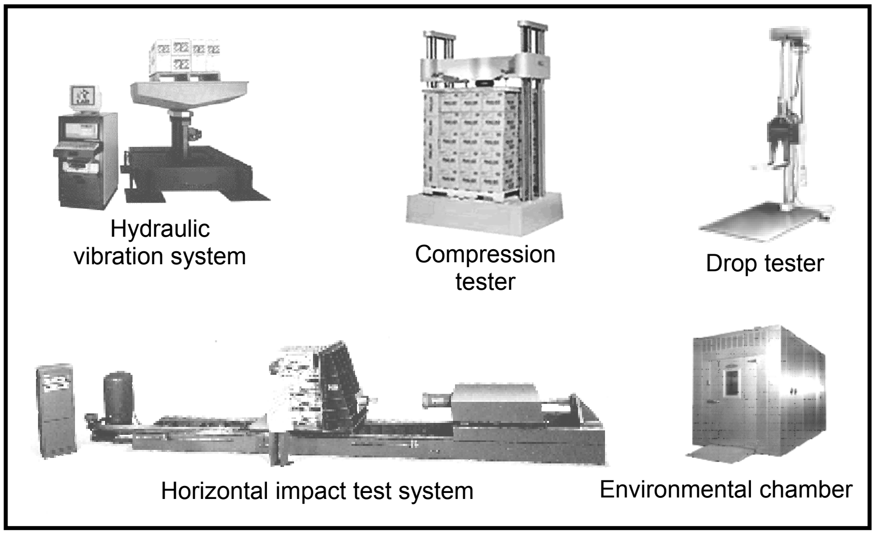

Figure 2 Range of equipment required for general simulation tests

Effectiveness of General Simulation

General simulation protocols are the approach of choice for many organizations. When product/package values and shipping quantities (or both) are moderate-to-high, the economic and environmental benefits to be derived from a more thorough preshipment testing program can be readily justified. If product fragility is an issue, general simulation can often uncover hidden damage as it might occur in actual distribution.

General simulations typically require that the user be able to identify, at least in broad terms, the character of the target distribution system. One is asked to describe the types of carriers, vehicles, generalized distribution channels, package type that defines the mode, or something that allows determination of the hazards and an approximate sequence. For example, if shipment is to be by “individual-package small-parcel carrier” a general test plan consisting of handling tests (representing pick-up), vibration (transport to hub), impacts (sorting operations), stacked vibration (long-distance transport), and handling (delivery) might be indicated.

Test intensities are based upon some rough assignment of product value, shipping quantities, hazard extremes, or combinations. There are usually only two to four different intensity levels, with little or no accommodation for “in between” or special situations.

As might be expected, general simulation works well when there is a good match between the actual transportation/distribution environment and the selected laboratory tests, sequences, and intensities. ASTM D4169 and the ISTA 3-Series tests have shown good correlation with actual field performance in the U.S., Canada, and Western Europe.

Problems can arise, however, when there is not a good match. Test intensities which are too high relative to the actual transport environment can lead to over-packaging. Or if a hazard is included in the tests but does not actually occur in the field, over-packaging can result. Conversely, test intensities which are too low, or the omission of a hazard which actually does occur, can lead to excessive damage. There is growing evidence that the correlation with ASTM D4169 and the ISTA 3-Series of tests is not so good for Mexico, many parts of Asia, and Eastern Europe.

If there is good correlation to actual transport conditions, general simulations can produce well-optimized designs, assuming packages pass the tests with minimum margin. In these situations they can be effective in attaining compliance with requirements like the European Packaging Directive.

FOCUSED SIMULATION

Description

Focused simulation is the most powerful approach presently available for preshipment package performance testing. It is also the most demanding in terms of prior knowledge, test preparation, equipment and facilities, and test time/complexity. Test levels and other parameters are not contained within the testing protocols; in fact, there aren't protocols per se, only guidelines and recommendations about how to construct them.

In its most complete form, focused simulation starts with development of detailed knowledge about the means and modes of distribution for a particular packaged-product or product line: the in-plant hazards, the handling and sorting operations, the transportation vehicles and their loadings, the warehouse and other stacking situations, atmospheric profiles and extremes, etc. This information is then organized into a specific "distribution description" outlining the potentially damage-producing hazards along with the sequences and combinations in which they occur.

The next step is to quantify, by actual field measurement and observation, the packaged-product's distribution hazards in terms of their intensities and other conditions. For example, drops and impacts are measured, and the data analyzed according to height or velocity, package orientation at impact, and frequency of occurrence. Vehicle vibrations are measured, with the data typically analyzed as power spectral density (PSD) plots according to vehicle types and lading conditions, and time durations (or with a given relationship of time to trip length). Compression is measured in vehicles and warehouses, and data analyzed with respect to time and superimposed conditions. Atmospheric profiles are measured, and data analyzed in terms of extremes, rates of change, and combinations. These measurements are made possible by the current availability of small, self-contained electronic field data recorders (see Figure 3 on the next page). These instruments, often smaller than a brick, are able to record both static and dynamic information in such a way as to facilitate the required analyses.

Figure 3 Examples of self-contained electronic field data recorders

Finally, this information is translated into a lab testing protocol specific to the packaged-products and their distributions being considered. Data must be analyzed statistically and the tests based on sound use of the results. If there are variables and variations in the package, product, or system, it must be decided how to incorporate them into the protocol or whether to create separate protocols.

To the casual observer, it might be difficult to distinguish a focused simulation test from a comprehensive general simulation test being run in the laboratory. But the difference would be in the details: the drop and impact test heights and velocities, orientations, and total numbers of impacts would be different; the vibration profiles and times, the compression loadings and times, the superimposed conditions, and other parameters would be different. A good general simulation test covers all the hazards, but focused simulation links the characteristics of those hazards to a particular type or class of packaged-product, and particular means and modes of distribution.

Effectiveness of Focused Simulation

Focused simulation, properly researched and implemented, has the possibility of producing laboratory testing protocols with near-perfect correlation to the actual transportation/distribution environment. In its complete form, it is most appropriate for situations of high product value, where product liability or other issues require unmistakable demonstration of due diligence, or in scenarios where economics, environmental, regulatory, or other factors indicate and justify the using best possible approach. If packages pass the tests with minimum margin, focused simulation offers the best possibility for optimized designs, and could certainly be used to show compliance with requirements such as those of the European Packaging Directive.

It is important, when constructing the “distribution description”, that all routes, modes, package configurations, and conditions are properly identified. But it often happens that, even for seemingly simple distribution systems, there are a significant number of variations. One must be careful not to over-simplify by assuming that one variable is similar to or enveloped by another. Sometimes measurements must be taken only to ensure that a particular set of hazards can be safely ignored.

Sufficient field data must be taken to permit valid analyses and high statistical confidence in the results. The exact number of required trips or measurements or recordings depends upon many factors. It is recommended that appropriate statistical expertise be applied both in the design of the experiments (taking of field data) and in analysis of the results. The Taguchi Method has been shown to be effective in packaging and logistics applications [6].

In the actual configuration of focused simulation lab tests, it is sometimes necessary to compromise for practical reasons. For example, it may be well known that vehicle vibration occurs in combination with temperature extremes, but impractical to vibration test large specimens in a conditioned atmosphere. In such cases, less-than-ideal test approaches may have to be adopted (condition the specimens, then remove them from the conditioned atmosphere and test as quickly as possible), or a prudent adjustment of test intensities or other parameters may be necessary to compensate for hazards or combinations not tested.

An example of a focused simulation program, instituted by Stryker Instruments, was presented at ISTA-Con 2000 in Orlando, Florida [7]. A more limited focused simulation project, concentrating on the drop heights in LTL (less-than-truckload) shipment, is described by Pierce and Young [8].

"BLENDING" OF TEST PROTOCOLS

Increasingly, we see existing testing programs being upgraded to include more advanced approaches. It often happens that preshipment testing protocols are mixtures of two, or all three, of the test types. Sometimes this is by design (the ISTA 2-Series is a combination of integrity and general simulation tests, the 4-series is a combination of general and focused simulation tests [1]), and sometimes it occurs in response to specific situations. The following sections illustrate typical "blending" scenarios.

Integrity Tests with General Simulation

An organization is using a basic integrity test (vibration and drop), but finds that damage is occurring in actual distribution. The damage is felt to be caused by warehouse stacking in high-humidity conditions, so a compression test in a conditioned atmosphere is added to the protocol. No actual field measurements are made, the compression test is patterned after one element of a general simulation test.

Combination of General with Focused Simulation

An organization is using a general simulation protocol with good success, except that shipments to one particular country or geographical area have higher-than-normal damage levels when compared with all others. They undertake a measuring program to pinpoint and quantify the differences. Based on the results, they implement an increased-intensity test (typically vibration or drop) for shipments going to the problem area, and/or an alternate package design.

FOCUSED SIMULATION AS THE ONLY VIABLE APPROACH

There are situations in which focused simulation is the only viable approach to constructing preshipment testing protocols. If distribution structures and systems are known to be significantly different than what has been previously studied but there is no quantifying data, the only recourse is a focused simulation program. This most frequently happens as a consequence of globalization. Important and growing markets may exist in developing countries, but the distribution infrastructure common in the U.S., Western Europe, and other developed regions is lacking. The result is significantly different static, dynamic, and atmospheric conditions than are simulated by any existing test protocol. This has been observed to a lesser extent in Mexico, where it is now recognized that vibrations in road and rail vehicles are more severe than in the U.S.; the European Commission published a study (Source Reduction by European Testing Schedules [9]) which indicated, among many other findings, that transport conditions in Eastern Europe are significantly more severe than in Western Europe. But perhaps the best illustration of the need for focused simulation, and the program that resulted, is what has become known as "The China Project" [10].

The China Project

In 1999, a consortium of five multinational companies was formed to address a common problem: shipments to and in China were experiencing an unacceptably high rate of damage. It was agreed that all lacked a fundamental understanding of the distribution environments, not only the mechanical attributes but the also the human interactions and cultural influences. There was a shared concern that standard design and test methods are inadequate in these new environments.

Extensive personal observations were made in China, documented by abundant photos and videotapes. Static and dynamic measurements were recorded for a variety of packages, routes, vehicles, and channels. The data at this point is proprietary, but the following general observations were made public:

- Infrastructure is generally lacking.
- Lack of material handling equipment, lift trucks, and loading docks.
- Little unitized or palletized load shipment, mostly individual piece.
- Labor intensive operations, many manual handlings.
- Wide range of vehicles, including open trucks, motorcycles, bicycles, tricycles, and pedicabs.
- Wide range of road types, mostly unpaved.
- Extreme atmospheric hazards (rain, dust, temperature) from open transport and storage.

It was concluded that conditions are sufficiently different so as to require not only new testing protocols, but new approaches to the design of packages and perhaps in some cases even the products themselves. It is expected that each company will make changes appropriate to their own situations. But the China Project exemplifies a large-scale focused simulation program which was undertaken because there was simply no other choice.

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