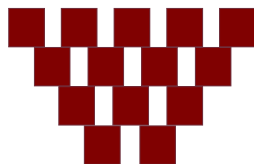


WHAT'S WRONG WITH THE DAMAGE BOUNDARY TEST?

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The concept of product shock fragility is well-established. Beginning in 1968 with the original fragility paper written by Dr. Robert Newton of the Naval Postgraduate School in Monterey (1), fragility testing has become a fairly commonplace laboratory test procedure. ASTM D3332 (2) is the generally accepted method for running this test.

BACKGROUND

The original concept of the Damage Boundary was a simplification of Shock Response Spectrum (SRS) analysis developed for architectural review of buildings and bridges in earthquake zones. The concept was to study how a structure responds to a shock input rather than trying to duplicate all the possible inputs that a structure might have to survive.

The SRS (Figure 1) tells us that mechanical components of a product (characterized as spring/mass systems) respond differently to different types of shock inputs. This response is primarily dependent on the frequency of the shock input as a function of the natural frequency of the system under study and the shape of the shock input pulse. In general, the concept was considered too complex for everyday use on consumer products or electronic goods.

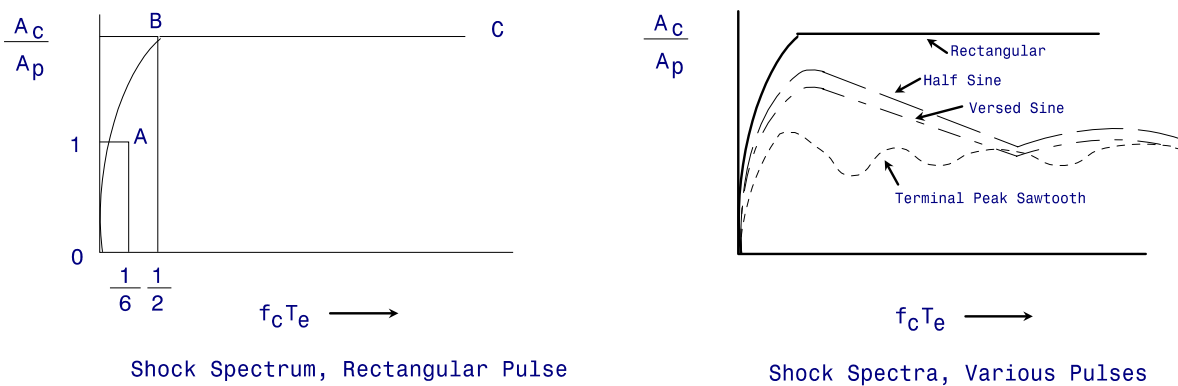


Figure 1

The genius of the Damage Boundary procedure lies primarily in the simplification of the test inputs. A short duration half sine pulse is used to excite the test item in the "velocity shock region" where spring/mass systems respond primarily to the energy content of the shock pulse ("brittle" failure) rather than to its peak acceleration and wave shape. (This type of event is often called a velocity shock.) The half sine pulse is used because it is easy to program on shock test machines, and the response of spring/mass systems in this region of the spectrum is independent of the shock input waveform.

The critical acceleration of a product (where "ductile" failure occurs) is tested by means of a "square wave" input. In actual practice, a trapezoidal shaped pulse is used because it is impossible to produce a mechanical "square" or rectangular pulse. (See Figure 2) The reason this waveform is used is that the response of a spring/mass system to a square input is a maximum. Thus, it results in a conservative estimate of the mechanical fragility of a product when subjected to a shock input. It also envelopes or encompasses the response of that same system to all types of shock pulse inputs.

ACCELERATION PULSE TERMINOLOGY

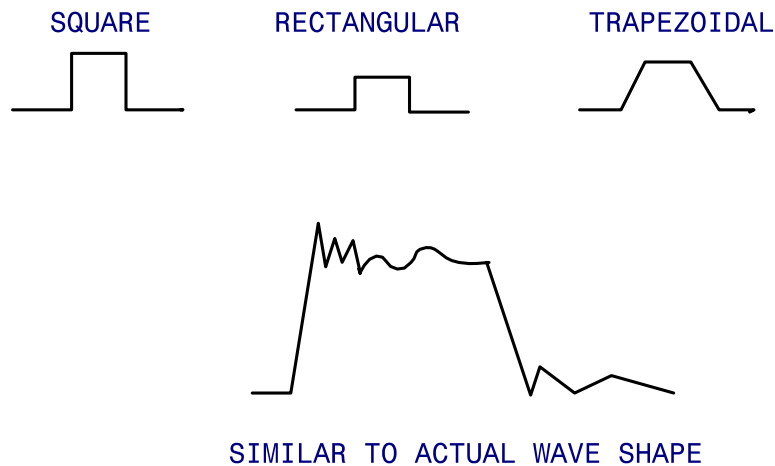
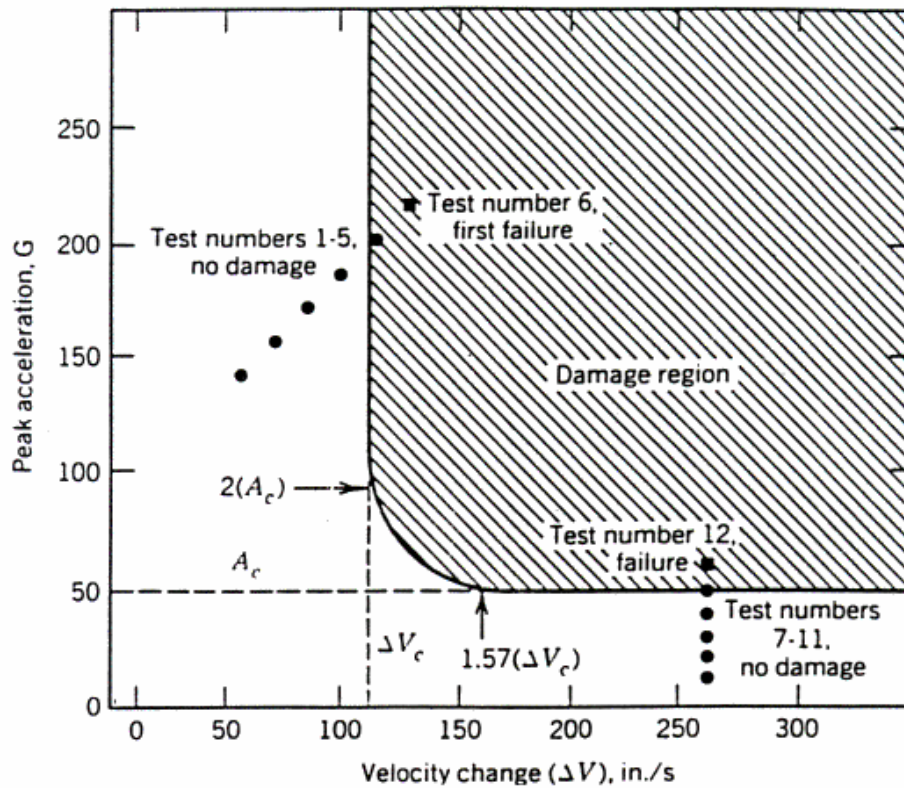


Figure 2
Source: Westpak "Perfect Package", October 1992

It can be seen from Figure 3 that the Damage Boundary plot closely resembles an inverted SRS plot. This was done on purpose in order to minimize the confusion between the two. (3)

THE NATURE OF THE VELOCITY CHANGE TEST



It was stated earlier that the shock pulse used to program critical velocity change must have a very short duration relative to the natural period of the spring/mass system (product) under test. For a single degree of freedom undamped spring/mass system, the requirement is that the input shock pulse have a period 1/6 or less the natural period of the spring/mass system (1). For pulses longer than this, the spring/mass system begins to respond to the acceleration and waveform of the input shock pulse, not just the velocity change. Once the period of the input shock pulse reaches one-half the natural period of the responding spring/mass system, the full effect of the waveform and its peak acceleration content is seen. Refer again to Figure 1.

It follows that one must have knowledge of the natural frequency of critical components within the product under test prior to running a Damage Boundary test. Specifically the engineer must know the lowest natural frequencies of critical components in order to determine the maximum duration of the shock pulse used to run the velocity change test. The original Damage Boundary theory and early versions of test standard ASTM D3332 suggested that a 2 or 3 msec pulse duration was adequate for most velocity shock test purposes (1, 2). However, it can be shown (figure 4) that spring/mass systems with natural frequencies above 28-42 Hz respectively are no longer in the velocity shock response mode but are starting to respond to the peak acceleration and waveform as well.

2 msec:	duration = .002 seconds = half period period = (2) duration = .004 seconds frequency = $1/P = 1/.004$ seconds = 250 Hz $1/6 \times 250$ Hz = 42 Hz
3 msec:	frequency = $1/P = 1/.006$ seconds = 167 Hz $1/6 \times 167$ Hz = 28 Hz

Figure 4: Pulse Frequency Calculation

The 2-3 msec duration normally specified for a velocity change test had its origins in the limitation of shock test equipment at the time the test standard was written. Shock machines, particularly those with higher payload capacities, tended to be unable to produce very short duration pulses. Their structures simply do not allow it. However, this does not mean that it is prudent to ignore the requirement of the shock response spectrum to program a short duration pulse for true velocity change testing.

This does mean that vibration testing should be conducted on a product prior to running a Damage Boundary velocity shock test in order that the natural frequency of the responding systems be known. This practice makes good sense from a practical standpoint as well. This testing is often conducted on prototype or expensive products where the availability of test specimens is very restricted.

Since vibration testing is rarely destructive by its nature, it is prudent to conduct vibration testing on scarce products prior to conducting the potentially destructive Damage Boundary test. Once the lowest natural frequency of the product is known, the natural period can be easily determined. (See Figure 4)

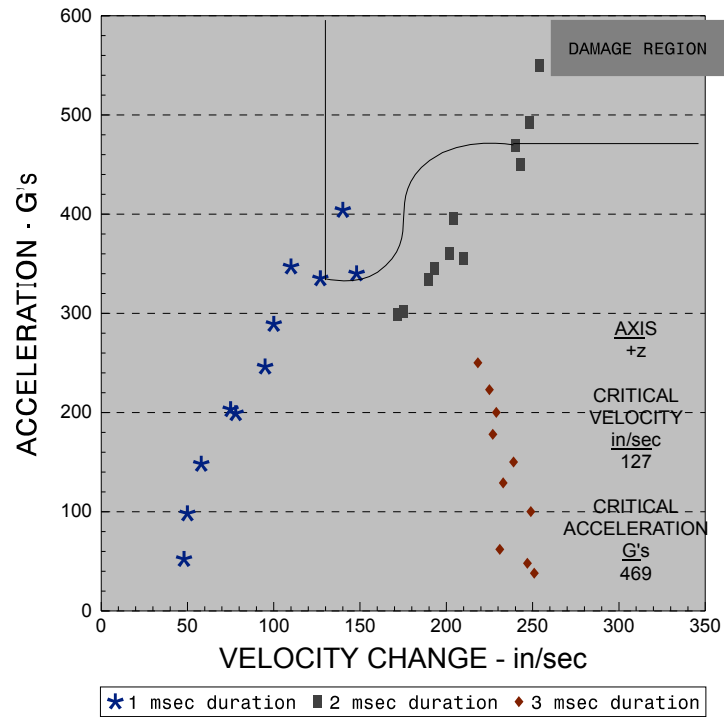
THE CASE OF THE WINCHESTER DISK DRIVE

Over the past decade much testing has been conducted on computer products, primarily Winchester disk drives (so-called hard drives). These products were initially very shock sensitive and were considered to be the weak link fragility wise in a personal computer. More recent products, especially those with smaller formats, have shown an amazing increase in their ability to withstand shock inputs. Acceleration sensitivities of 150 G's have been tested. In addition, the velocity sensitivity of these products is likewise increasing. Critical velocity changes in excess of 2.5 meters/sec (100 in/sec) are considered the norm.

As product size decreases and ruggedness increases, the natural frequency of critical components within the products tend to rise; some products show primary resonances well above 300 Hz. In a case like this, a 2 msec half sine is far too long to determine the critical velocity change of the product. This pulse merely subjects the product to a half sine waveform acceleration test. The reason is that the 2 msec pulse is very long in comparison to the natural period of the product. In order to determine true velocity sensitivity of this product, a pulse duration of approximately **200 microseconds** is necessary. The programming of such pulses requires specialized equipment that is very limited in its size and weight capacity or very expensive.

Vastly different results can be anticipated from velocity change tests using a 2 msec half sine vs. a shock pulse with a period of 1/6 the natural period of the lowest product resonant frequency. In the case of the hard disk, a velocity change test conducted with a 2 msec half sine produced a critical velocity change in the neighborhood of 2.8 meters/sec (110 in/sec). The same product subjected to a 200 microsecond pulse showed a true velocity sensitivity of approximately 1.8 meters/sec (70 in/sec).

It can be concluded that the first test was not a velocity change test at all, merely a peak acceleration test using a half sine waveform. Distorted Damage Boundary plots normally result from this type of procedure (See Figure 5)



ASTM D3332

Figure 5: Distorted Damage Boundary Plot

THE PRACTICAL USE OF VELOCITY CHANGE DATA

In general there are three practical uses for critical velocity change shock test data. The first is to determine whether or not a package is required for the product. The second use gives a good indication of the ruggedness of the product for the in-use or unpackaged environment. Finally, the velocity change data is used for programming a shock pulse for critical acceleration tests.

The primary use of critical velocity change data from the Damage Boundary test is to determine if a package system is required for the product. The conventional wisdom holds that if the critical velocity change is greater than the impact velocity, as determined from the designed drop height, then a protective package is not necessary. The reason for this is that the product would never experience a velocity change greater than the impact velocity from the designed drop height, and therefore, cushioning is not necessary. The only thing required is a package that would keep the product from getting scratched, scuffed, or suffering other aesthetic damage.

The second major use of velocity change data is in determining the ruggedness of the product for the in-use environment. If a product is unstable and likely to tip over during its manufacture or use, then the velocity change sensitivity would give a good indication of whether or not damage was likely during that type of event.

In the case of the Winchester disk drive in a laptop computer, the critical velocity change data would show how high this product could fall onto a rigid surface before damage was likely to the disk drive. For other products such as hand-held calculators, the in-use environment can be characterized in terms of the likely drop heights from the anticipated in-use environment.

Finally, the critical velocity change data gives a good indication of the duration or velocity change of the shock pulse used to program critical acceleration testing. The criteria generally applied is that the critical acceleration pulse should have a velocity change at least double that of the critical velocity. The reason for this is to avoid programming a critical acceleration pulse in the knee region of the Damage Boundary. Refer to Figure 3 for more details.

CONCLUSIONS

So what's wrong with the Damage Boundary test? Absolutely nothing if it's run correctly using the approach suggested in the Newton paper. There is something seriously wrong with strict adherence to the test procedures of ASTM D3332 including the inappropriate use of a 2-3 msec pulse to determine critical velocity change.

It's important to recognize that the Damage Boundary is not a cookbook for robotic technicians but rather a guideline to assist the engineer in setting up the test procedure to properly determine critical velocity change and critical acceleration for a product under test. It is necessary that the engineer understand both the product and the nature of the test in order to correctly conduct the test and properly interpret the results.

Without this understanding, the engineer is likely to conduct a test whose outcome may be misleading for package design or product ruggedization evaluation purposes. Accurate and reliable results can only be obtained from accurate and reliable testing. The engineer is encouraged to investigate these areas and modify test procedures and specifications when warranted.

REFERENCES

1. Newton, Robert E., "*Fragility Assessment Theory and Test Procedure*", Monterey Research Laboratory, Inc., Monterey, California, 1968.
2. American Society for Testing and Materials, vol. 15.09, D3332-88: Standard Test Methods for Mechanical Shock Fragility of Products Using Shock Machines; Philadelphia, Pennsylvania, 1992.
3. Conversation with Dr. R. E. Newton, Monterey, California, May, 1983.