TRANSPORATION SHOCK DUE TO SPEED BUMPS AND ROAD OBSTACLES
Revision A

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Introduction

Trucks and passenger automobiles may be subjected to a variety of road environments including smooth highways, city streets, and washboard dirt roads.

These vehicles may contain sensitive electronic equipment, either as cargo or as permanently mounted equipment.

As an example, a GPS system might be mounted in a rental car to help the driver navigate city streets. A notebook PC might be mounted in a police vehicle to provide the officer with two-way data exchange with the dispatching center.

This equipment will be subjected to a variety of transportation shock environments as the respective vehicles encounter speed bumps, potholes, railroad tracks, and other obstacles. The equipment must be designed and tested to withstand these environments.

The purpose of this report is to consider some simple examples.

Natural Frequency

The fundamental natural frequency of sample vehicles is given in Table 1.

Table 1. Sample Vehicles

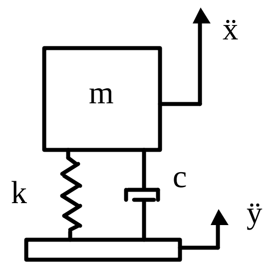
Vehicle	Fundamental Frequency (Hz)
Passenger Car	1 to 1.5
Sports Car	2 to 2.5
Hummer	4.5

The natural frequency is a function of the vehicle mass and the suspension stiffness. Note that the suspension system serves two purposes:

1. Provide a smooth ride by attenuating the shock from bumps and obstacles
2. Keep the tires in contact with the road.

Model

The vehicle is modeled as single-degree-of-freedom system for simplicity, as shown in Figure 1.



m = mass
c = viscous damping coefficient
k = spring stiffness
x = absolute displacement of the mass
y = base input displacement

Figure 1.

The free-body diagram is shown in Figure 2.

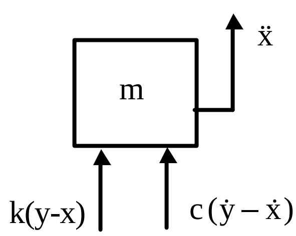


Figure 2.

Summation of forces in the vertical direction,

$$\sum F = m\ddot{x} \tag{1}$$

$$m\ddot{x} = c(\dot{y}-\dot{x}) + k(y-x) \tag{2}$$

Define a relative displacement

$$z = x - y$$

Substituting the relative displacement terms into equation (2) yields

$$m(\ddot{z} + \ddot{y}) = -c\dot{z} - kz \quad (3)$$

$$m\ddot{z} + c\dot{z} + kz = -m\ddot{y} \quad (4)$$

Dividing through by mass yields,

$$\ddot{z} + (c / m)\dot{z} + (k / m)z = -\ddot{y} \quad (5)$$

By convention,

$$(c / m) = 2\xi\omega_n$$

$$(k / m) = \omega_n{}^2$$

where ω_n is the natural frequency in (radians/sec), and ξ is the damping ratio.

Substituting the convention terms into equation (5) yields

$$\ddot{z} + 2\xi\omega_n\dot{z} + \omega_n{}^2 z = -\ddot{y} \quad (6)$$

Analysis

Consider a speed bump in the shape of a half-sine wave. Assume that the base width is 18 inches (46 cm) and that the height is 4 inches (10 cm).

Assume that the vehicle is a single-degree-of-freedom system with a natural frequency of 2.0 Hz and a damping value of 25%.

Calculate the response of a vehicle at various speeds to this base input.

Table 2. Base Input Parameters						
Speed (mph)	Speed (in/sec)	Base Width (inch)	Pulse Duration (sec)	Disp. (inch)	Accel. (in/sec^2)	Accel. (G)
10	176	18	0.102	4	3780	9.79
20	352	18	0.051	4	15,100	39.1
30	528	18	0.034	4	33,970	88.0

The base input displacement function $y(t)$ is

$$y(t) = \begin{cases} D\sin\left(\frac{\pi t}{T}\right) , & \text{for} \quad 0 \le t \le T \\ 0 , & \text{for} \quad t > T \end{cases} \tag{7}$$

where D is the displacement and T is the pulse duration.

The base input velocity function is

$$\dot{y}(t) = \frac{\pi}{T} D \cos\left(\frac{\pi t}{T}\right) , \quad \text{for} \quad 0 \le t \le T \tag{8}$$

The base input acceleration function is

$$\ddot{y}(t) = -\left(\frac{\pi}{T}\right)^2 D\sin\left(\frac{\pi t}{T}\right) , \quad \text{for} \quad 0 \le t \le T \tag{9}$$

Equation (9) can be substituted into equation (6). The resulting response can then be found via Laplace transforms as shown in Reference 1.

Results

The results are shown in Table 3 and in the accompanying figures.

Table 3. Acceleration Results

Input: 18 inch Wide, 4 Inch High, Half-Sine Speed Bump
Response: SDOF System, fn = 2.0 Hz, 25% Damping

Speed (mph)	Pulse Duration (sec)	Base Input Accel (G)	Peak Response Accel (G)	Figure
10	0.102	9.79	6.2	3
20	0.051	39.1	12.8	4
30	0.034	88.0	19.3	5

The suspension system provides attenuation at each speed.

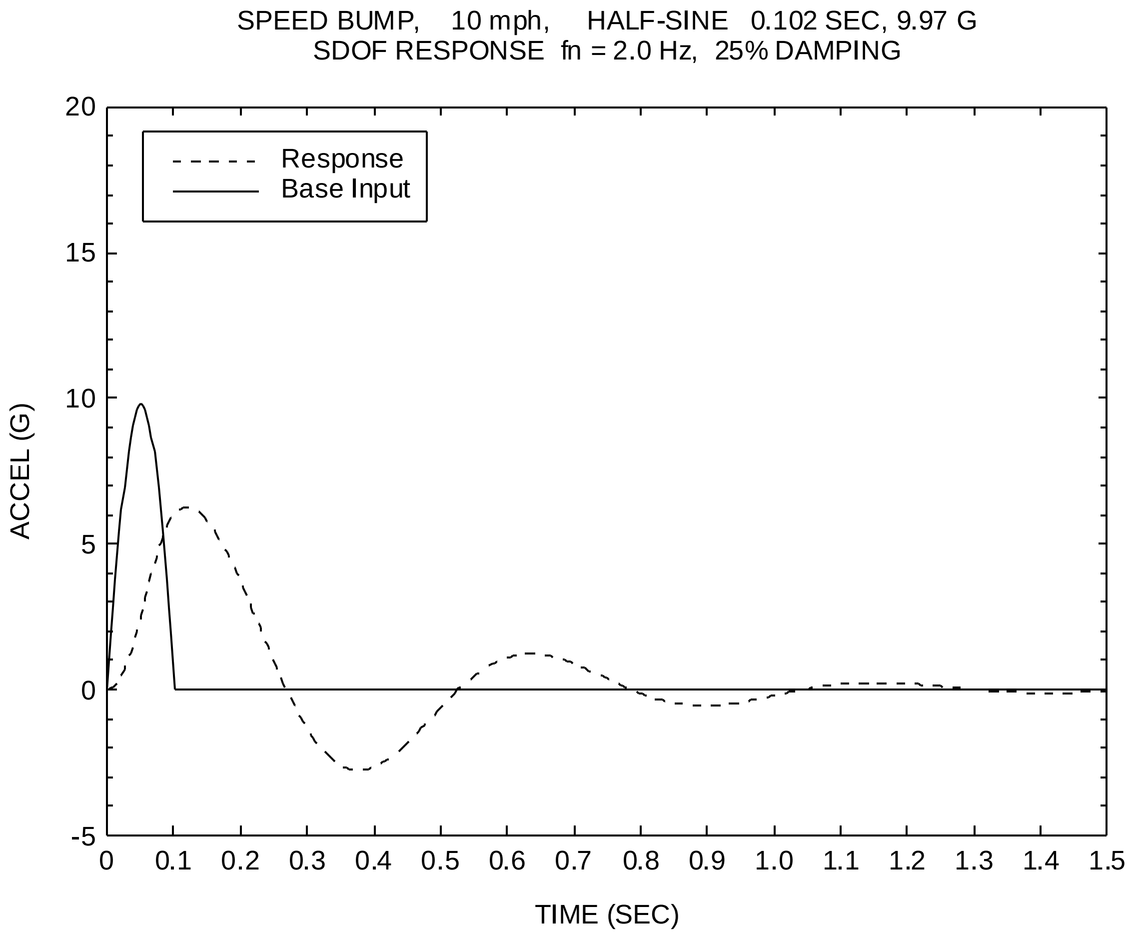
Obviously, slower speeds induce lower peak response accelerations.

Ray Magliozzi, co-host of the popular Cartalk radio program, recommends:

> So drive slowly over things like speed bumps, potholes, and railroad tracks. And slowly means, like five miles per hour.

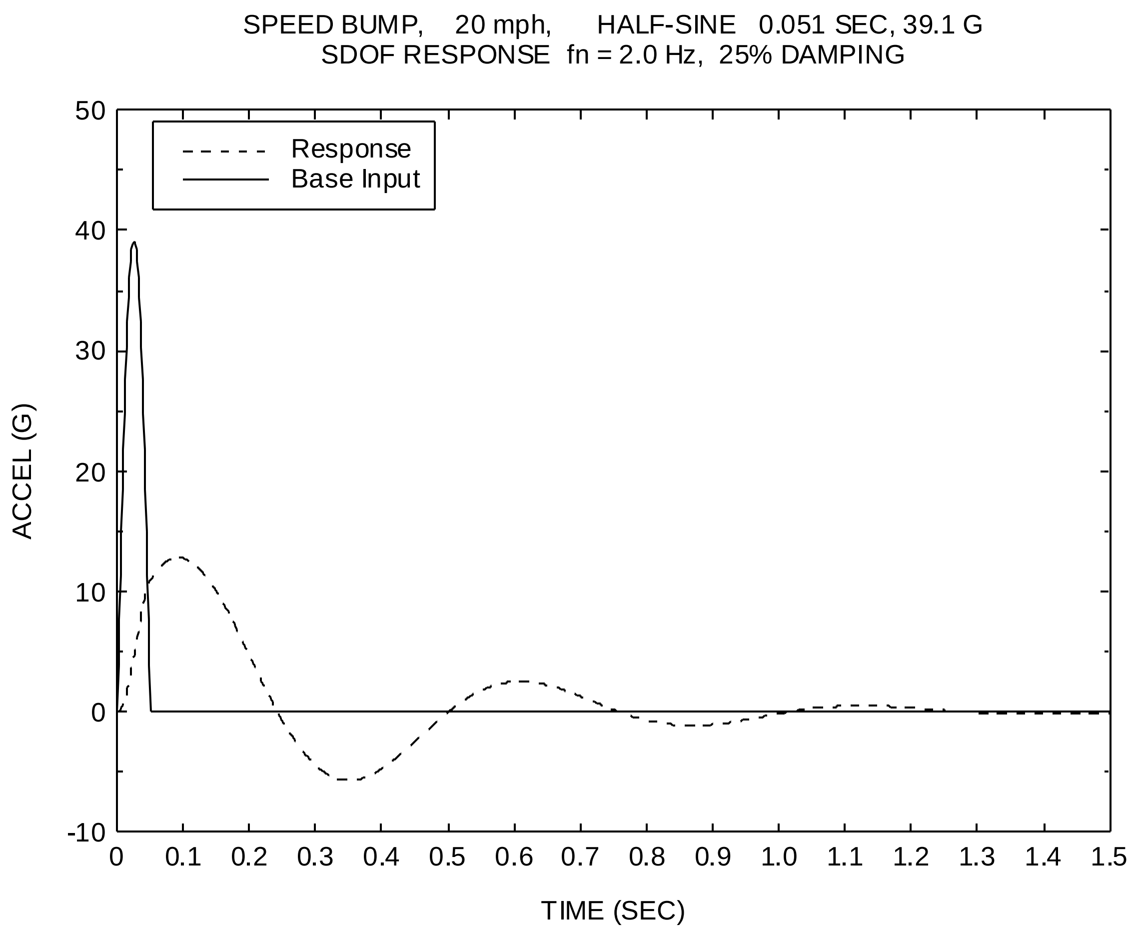
Equipment Testing

Equipment mounted in the hypothetical vehicle should be tested to shock levels that envelop each of the response curves in Table 3.



SPEED BUMP, 10 mph, HALF-SINE 0.102 SEC, 9.97 G
SDOF RESPONSE fn = 2.0 Hz, 25% DAMPING
Response
Base Input
ACCEL (G)
TIME (SEC)
20
15
10
5
0
-5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

Figure 3.



SPEED BUMP, 20 mph, HALF-SINE 0.051 SEC, 39.1 G
SDOF RESPONSE fn = 2.0 Hz, 25% DAMPING
Response
Base Input
ACCEL (G)
TIME (SEC)
50
40
30
20
10
0
-10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

Figure 4.

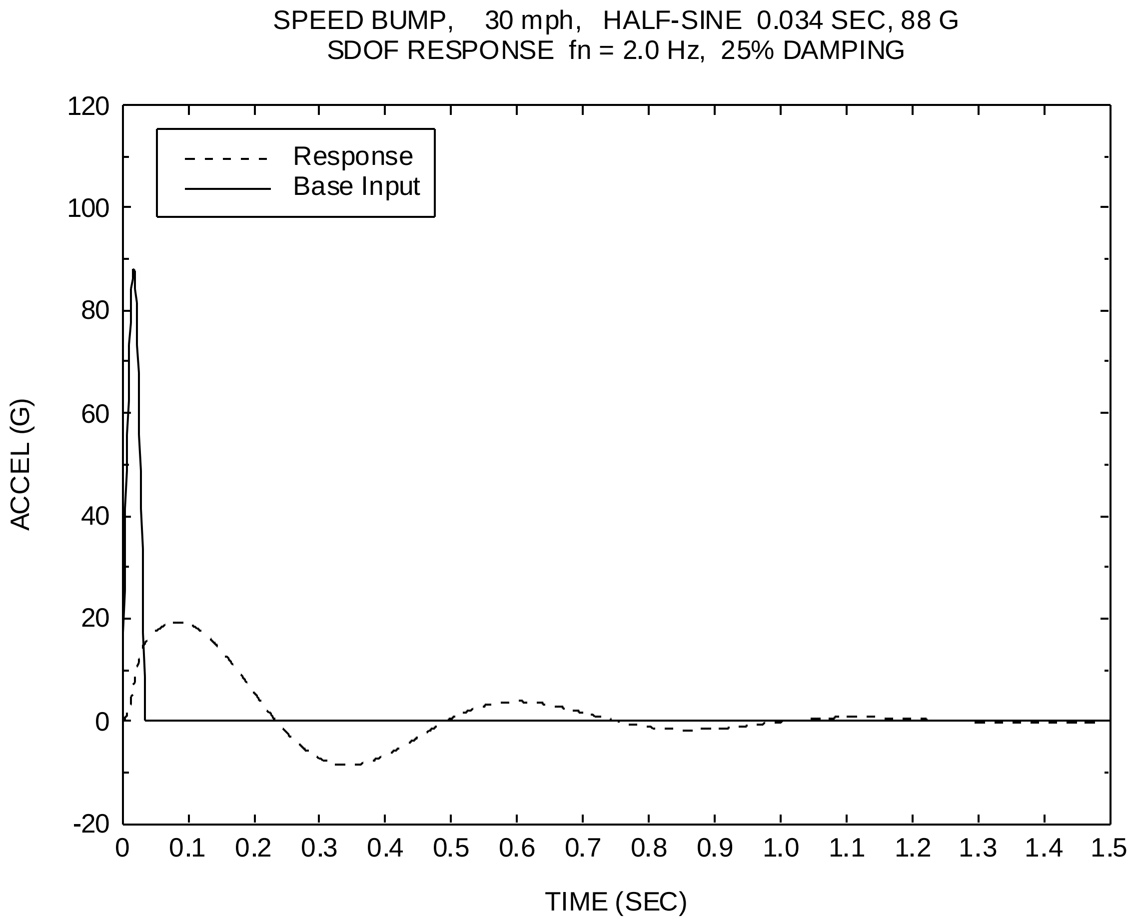

SPEED BUMP, 30 mph, HALF-SINE 0.034 SEC, 88 G
SDOF RESPONSE fn = 2.0 Hz, 25% DAMPING
Response
Base Input
ACCEL (G)
TIME (SEC)
120
100
80
60
40
20
0
-20
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5

Figure 5.

Military Standard TB 55-100

A sample test level from Reference 2 is given in Figure 6. The caption states that the level is appropriate for highway transportation. The results of this analysis, however, indicate that its amplitude is too low for speed bumps and other obstacles.

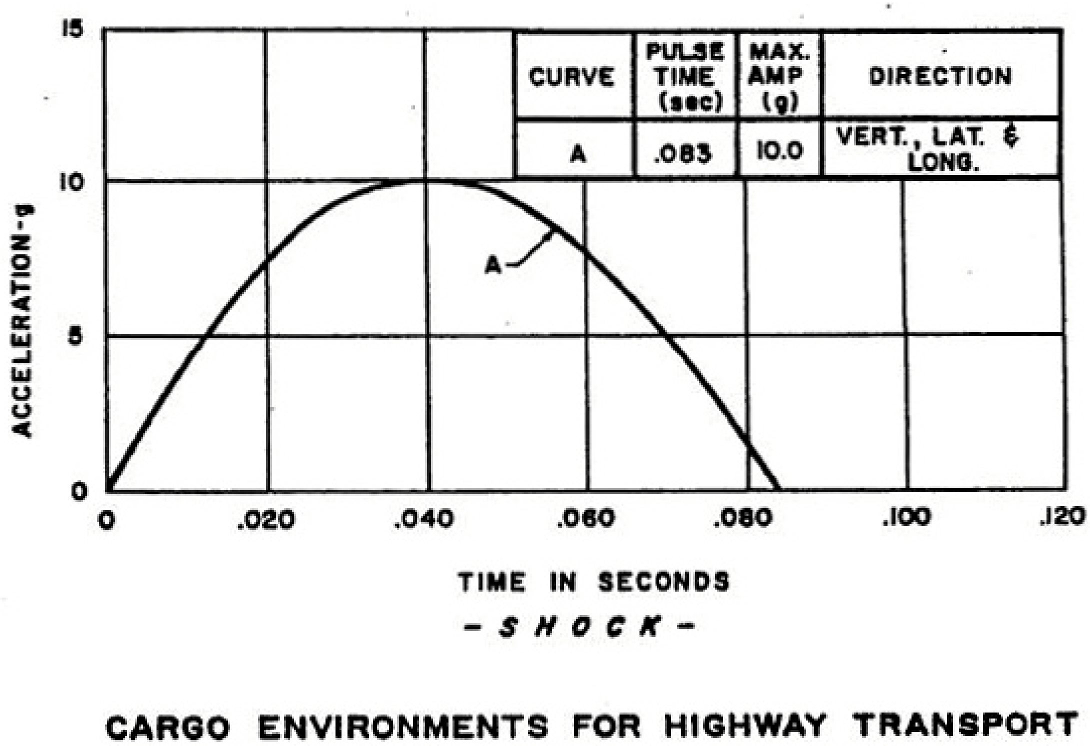
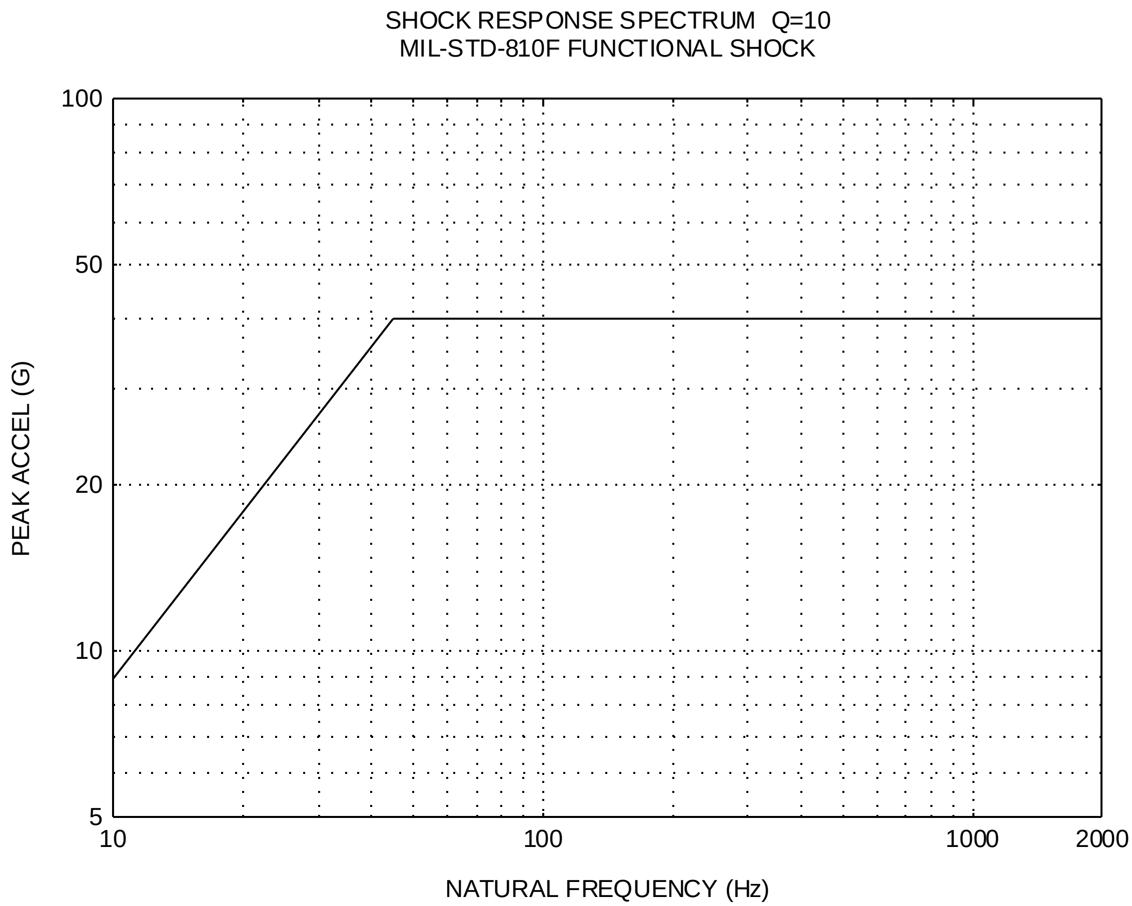


Figure 6.

Military Standard MIL-STD-810F

MIL-STD-180F, Method 516.5 has several test specifications for transportation shock. A typical specification is shown in Figure 7, in terms of a shock response spectrum.



SRS Q=10, MIL-STD-810F Functional Shock	
Natural Frequency (Hz)	Peak (G)
10	9
45	40
2000	40

Figure 7.

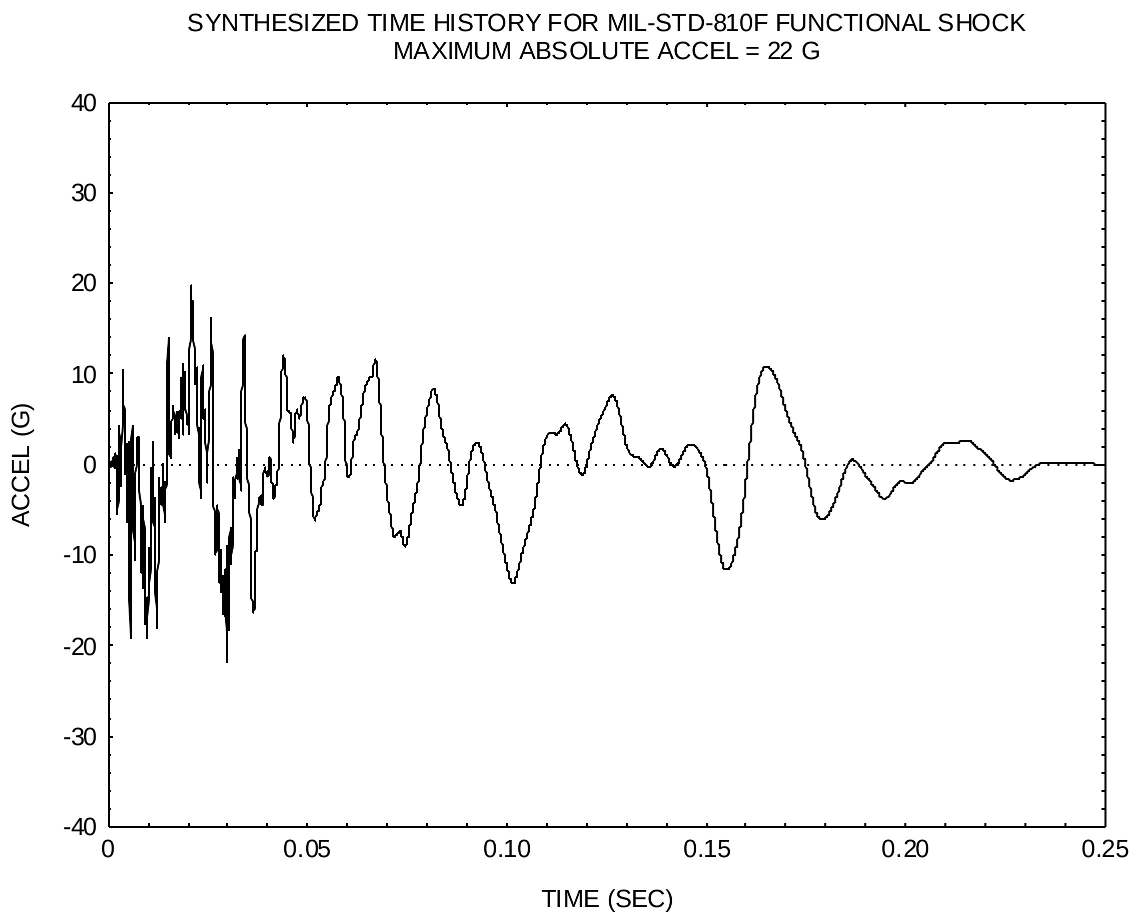


Figure 8.

The shock response spectrum in Figure 7 can be satisfied approximately by a 40 G, 10 millisecond, terminal sawtooth pulse. It can also be satisfied by the damped, sinusoidal pulse shown in Figure 8. The shock response spectrum of this pulse is shown in Figures 9 and 10, along with the specification.

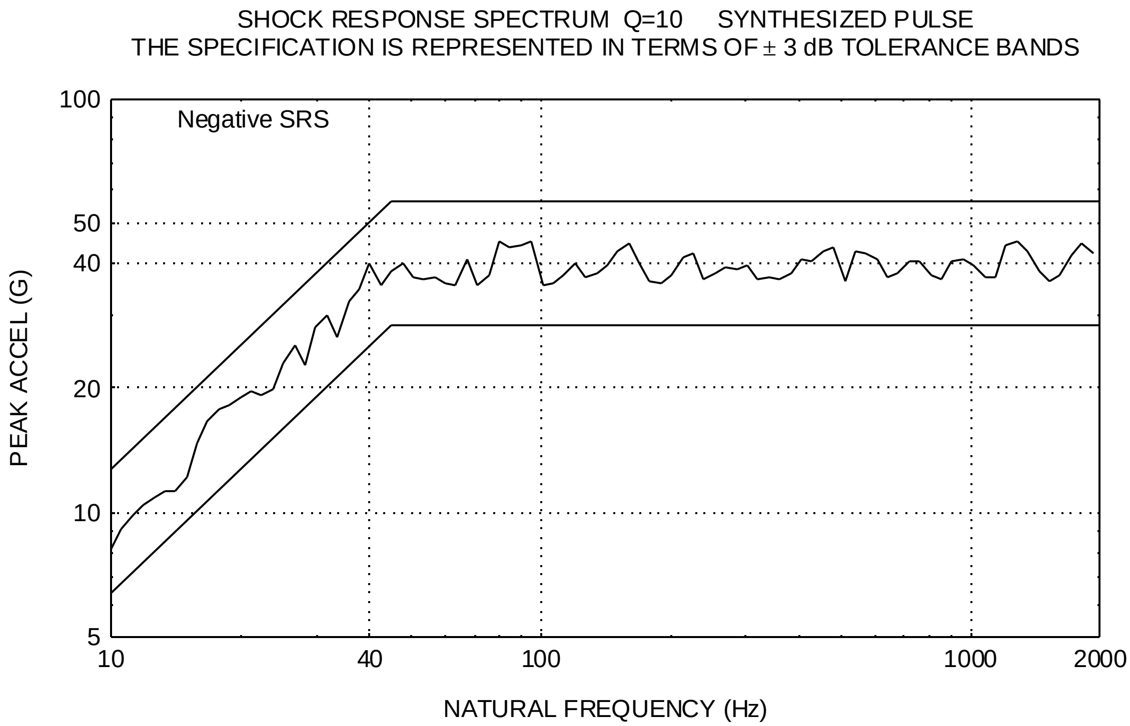


Figure 9.

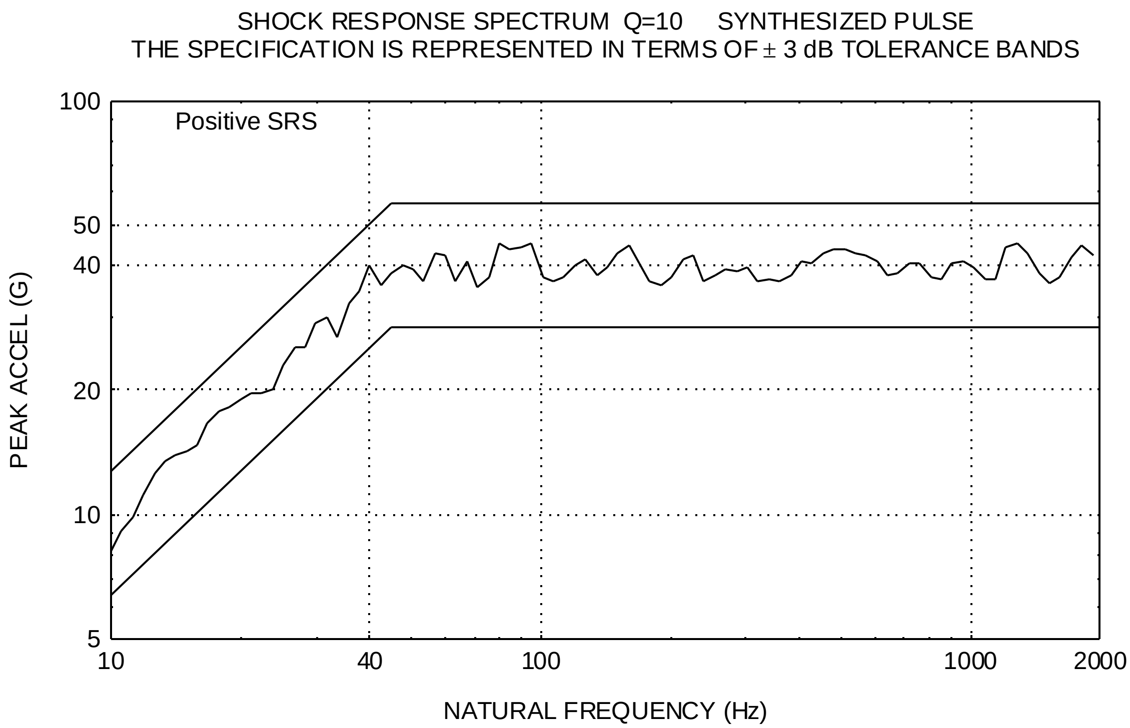


Figure 10.

References

1. Tom Irvine, Response of a Single-degree-of-freedom System Subjected to a Classical Pulse Base Excitation, Vibrationdata, 1999.

2. TB 55-100, Department of the Army Technical Bulletin, Transportability Criteria Shock and Vibration, Headquarters, Department of the Army, Washington, D.C., 17 April 1964.