# THE APPLICATION OF ENERGY DISSIPATING DAMPING DEVICES TO AN ENGINEERED STRUCTURE OR MECHANISM

by

Douglas P. Taylor, President
Taylor Devices, Inc.
90 Taylor Drive
P.O. Box 748
North Tonawanda, NY  14120-0748

www.shockandvibration.com

# Taylor Devices Incorporated

**Founded in 1955 by Paul H. Taylor**

**Traditional business is 60% military with commercial products based on proven military designs**

**Product Lines ~**

**Dampers**
**Shock Absorbers**
**Vibration Isolators**
**Gun Mounts**
**Shock Transmission Devices**
**Fluid Springs**
**Air Springs**
**Shock Isolation Systems**
**Satellite Deployment Systems**

# World-Wide Markets

**Aerospace and Defense**
**Land, Sea, Air and Space**

**Heavy Industry**
**Steel Mills, Aluminum Mills**
**Shipbuilders**
**Offshore Oil Drilling**

**General Industry**
**Machine Tools**
**Robotics**
**Electro-Optical**
**Electronics**

**Civil Engineering**
**Buildings**
**Bridges**
**Stadiums**
**Towers**

**Theme:**

**The design of a structure or mechanism subjected to shock and vibration can be greatly improved by the addition of isolation or damping devices.**

## Improvement Areas Include:

Reduced Deflection and Stresses
Reduced Weight
Improved Biodynamics
Longer Fatigue Life
Architectural Enhancement
Reduced Cost

At Taylor Devices, Inc. our applications come from two separate kinds of customers, irrespective of market.

1. The structure can have its overall life cycle cost reduced by the addition of isolation or damping devices.

2. The structure has been built, was tested, and failed to perform as specified. Energy dissipation devices can improve the structure's performance without a complete redesign.

## Three Keys To Shock Isolation

1. Know the input
2. Bound the output
3. Mitigate the difference between 1 and 2

*Dana Johansen*
*U.S. Naval Sea Systems Command*
*1989*

**The Key To Damping**

**When in doubt, damp it out.**

***Gregg Haskell***
***Haskell & Haskell***
***1995***

**Failure inducing phenomena of a transient pulse:**

**Ground Motion, Vibration**
**Ground Motion, Shock**
**Ejecta**
**Over-pressure**
**Thermal Radiation**
**Other Radiation**
**Cratering**

**Isolation and damping can affect the performance of a structure under the first four items.**

**Isolation and damping cannot improve performance degradations caused by the last three.**

# Dampers/Isolators - Everything Old Is New Again

**Major aerospace programs using high capacity fluid dampers and shock isolators:**

| | |
|---|---|
| ***Navy -*** | **Triple T Missiles, 1955** |
| | **F-8 Aircraft, 1955** |
| | **Tomahawk Missile, 1979** |
| | **MK41 Vertical Launch System, 1982** |
| | **Seawolf Submarine, 1985** |
| | **MK49 Navigator, 1986** |
| | **Q/70 Shipboard Electronics, 1987** |
| | **Virginia Class Submarine, 1998** |
| ***Air Force -*** | **Atlas ICBM, 1959** |
| | **KC10 Aircraft, 1975** |
| | **MX ICBM, 1977** |
| | **B-2 Stealth Bomber, 1986** |
| | **Joint Strike Fighter, 1998** |
| ***Army -*** | **CH54 Skycrane Helicopter, 1965** |
| | **M109A6 Paladin, 1986** |
| | **THAAD Missile, 1990** |
| ***NASA -*** | **Apollo Program, 1962** |
| | **Space Shuttle, 1977** |
| | **EELV Heavylift Missile, 1998** |

## What's The Deal With Dampers And Isolators?

***Dampers*: Dissipate energy within a system by converting it to heat. If designed properly, damping forces can be completely out of phase with structural stress. Thus, the right damper can reduce stress and deflection - simultaneously.**

***Isolators*: Used to provide a low frequency bypass or connection between masses. Isolators usually include damping and spring elements, the damping being used to limit deflection and attenuate resonance.**

## Can We Use Dampers Without Springs?

***Answer*: Yes, as long as the structure itself provides the spring response. This approach is typically used in tall buildings to provide earthquake protection. Fluid dampers as large as 1,000 tons of force are routinely used today in the earthquake engineering field.**

**A potential use for this technology is to suppress keel whipping in warships, essentially a resonance in a heavy, un-damped member. The concept is not new, and in fact the original framing of the Frigate Constitution used long diagonal wood members with slotted friction connections as spring-damper elements to prevent "hogging" or bending of the hull under high wind-full sail conditions.**

# Transient Shock Response
# Potential Improvements From Added Damping And Isolation

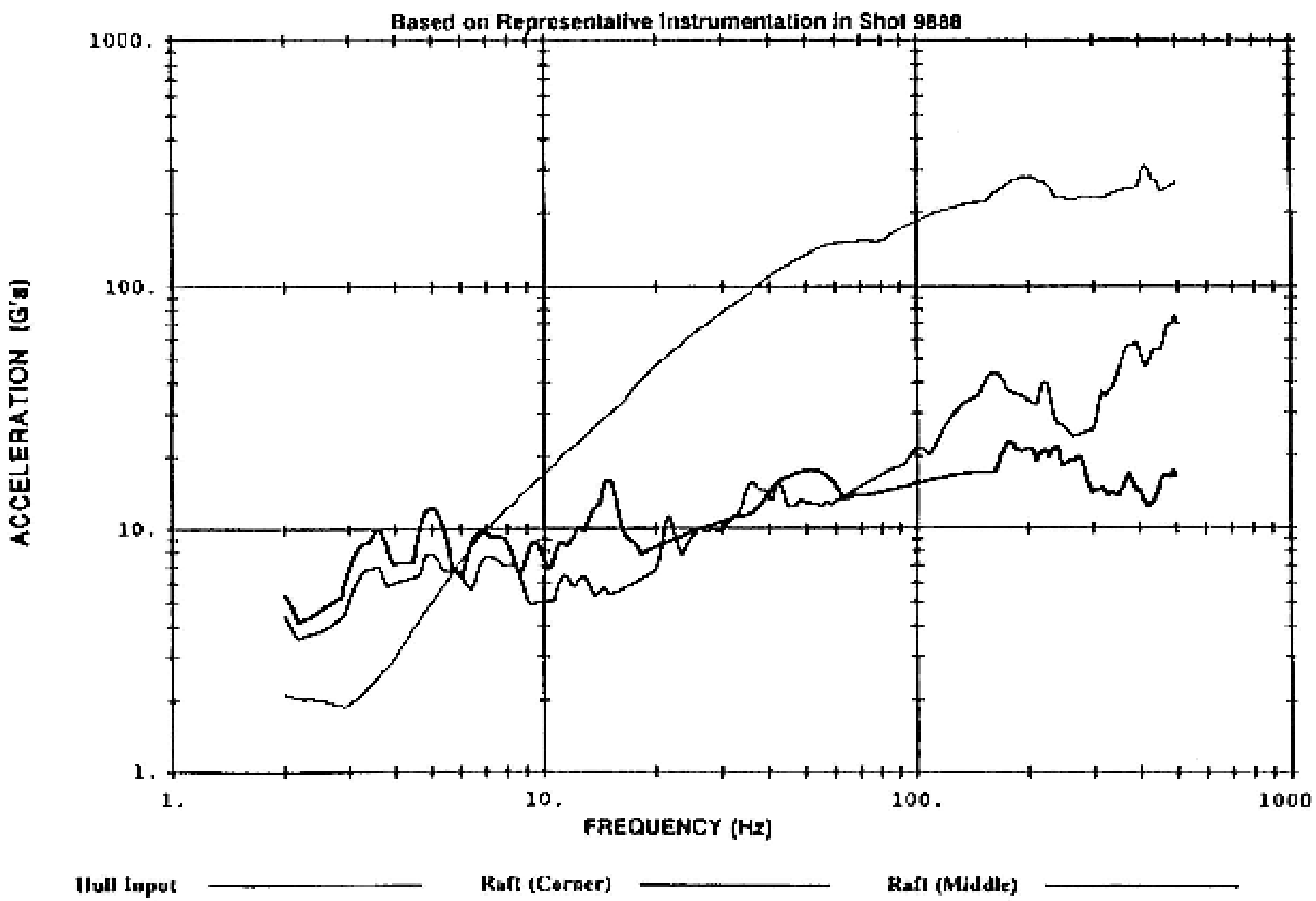
**Added Damping Alone:**

**The addition of 25% to 35% damping to a structure will reduce both stress and deflection by 50% to 75%, compared to the 5% damped case.**

**Added Isolation:**

**Combining springs and dampers into a practical shock isolator can reduce stress and deflection by up to 95%, provided that sufficient rattle space is provided.**

**The following illustrates the reduction of loading typical for the deck of a naval vessel isolated on hard centering liquid spring isolators, with integral damping.**




**Isolation Payoff for an LSI**

## Shock Isolators

**A shock isolator combines a spring and damper element. Spring types are:**

***Mechanical-Coil, Leaf, Wire Rope –***

**Advantages:** Low cost, long life
**Disadvantages:** Bulky, large sizes unavailable

***Elastomer-Tube, Block, Shear, Strap –***

**Advantages:** Low cost, moderate life
**Disadvantages:** Temperature sensitive, not manufactured in large sizes

***Pneumatic –***

**Advantages:** Compact, moderate life
**Disadvantages:** Temperature sensitive, difficult to seal in large sizes

***Liquid –***

**Advantages:** Very compact, moderate life, easy to incorporate damping
**Disadvantages:** Temperature sensitive, requires high-strength steel

## Mechanical Arrangement Of Spring Elements

***Un-centered –*** **Displacement changes with load like an auto suspension.**

***Soft Centering –*** **One preloaded spring is used to pre-compress the main isolator spring to mid-stroke.**

***Hard Centering –*** **Spring is loaded by a mechanism to provide re-centering force in either direction from center. The hard centering force is usually 2-4 Gs.**

# Types Of Damping Devices

1. Structural
2. Coulomb Friction
3. Elastomer
4. Active Drivers
5. Passive Hydraulic
6. Semi-Active Hydraulic
7. Adaptive Hydraulic

## Types Of Damping Devices Selection Criteria

**When utilizing a damping device, one must have the following:**

1. **The exact output function of the damper over the entire anticipated translational velocity range.**
2. **All environmental aspects of the application, and how these will affect damper performance.**
3. **A software code that can accurately model the anticipated non-linearities and environment performance shifts of the damping device.**

# How Much Damping Can Be Used?

1. **Most objects have less than 5% inherent structural damping.**

2. **Considering automobiles, which are subjected to extremely broad band inputs:**

   **20-25% damping is used in "standard" automobile suspensions.**

   **30% damping is typical for a "heavy-duty" suspension.**

   **40% damping is typical for a "high-performance" suspension.**

   **Damping levels above 40% prove very uncomfortable to humans, and tend to loosen structural joints.**

3. **For attenuation of life threatening or catastrophic pulses, damping as high as 2000% critical has been used successfully, but damping of this level is often highly non-linear and structured for a very specific pulse signature. In applications of this type, it is sometimes less expensive to add massive amounts of damping rather than adding structure.**

# Types Of Dampers


***Structural Damping –***

1. **Inherent in a structure, not inherent in a mechanism.**
2. **Magnitude varies widely with the design of the structure and construction tolerances thereof.**
3. **Can be as low as 1-2% of critical for a "rigid" structure.**
4. **Can be as high as 10% of critical for massive structures having light-weight construction and complex joints.**

**Example:**
**Structural damping in the Space Shuttle averages 8-10% of critical.**

5. **Structural damping is impossible to quantify in the design of any new object.**
6. **Structural damping varies with temperature as joints expand and contract and materials alter their output characteristics.**

*The Bottom Line –*

**Assuming structural damping values above 2% puts your professional ability on the firing line.**

*Structural Damping, Modeling –*

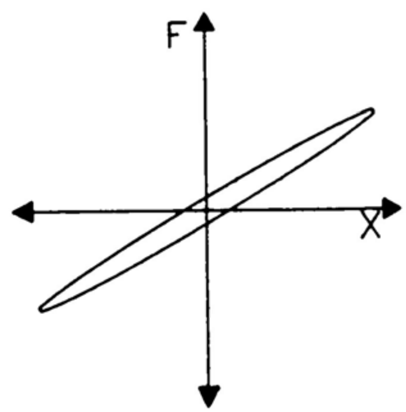
1. **If damping values are below 5% of critical, then equivalent viscous damping models can be used, such that:**

$$F_d = C\dot{X}$$

**C = A Constant**

$\dot{X}$ **= Translational Velocity**

2. **A more realistic approach to structural damping uses a simple visco-elastic model of the following output curve:**



# Types Of Dampers
# 2 of 7

*Coulomb Friction Damping –*

**Often obtained by slippage of a joint, at a stress level below that of yield.**

1. **Can also be obtained by plastic deformation of a plate or similar element.**

3. **Damping can be of any value, although values of about 10% of critical will usually begin to increase stresses in a structure.**

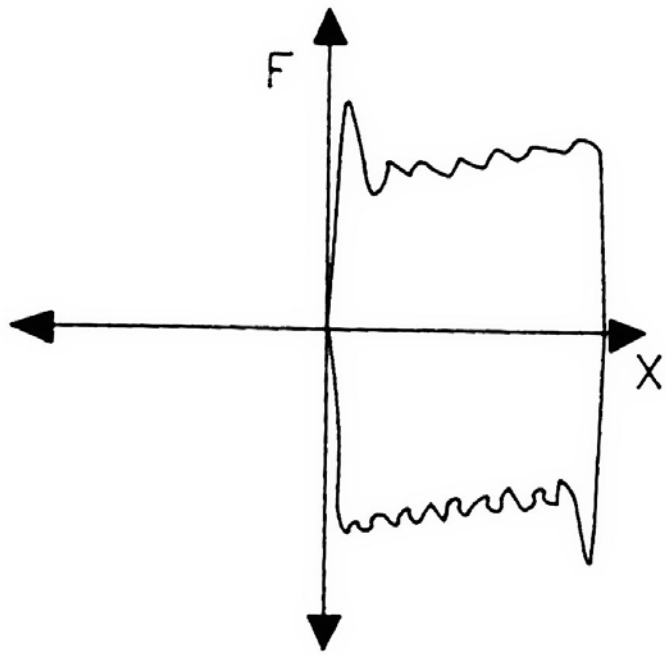
4. **Usually leaves a permanent drift or offset in a structure after the transient has passed. The higher the damping ratio, the greater the drift.**

5. **Damping output will vary somewhat with temperature for plastic deformation types. Damping can vary greatly with temperatures in a poorly designed slipping joint.**

6. **Damping will vary with the total number of cycles, corrosion of the damping elements, and aging of the damping elements. Slipping joints can deteriorate in output if exposed to water, oil, or paint.**

*Coulomb Friction Damping, Modeling –*

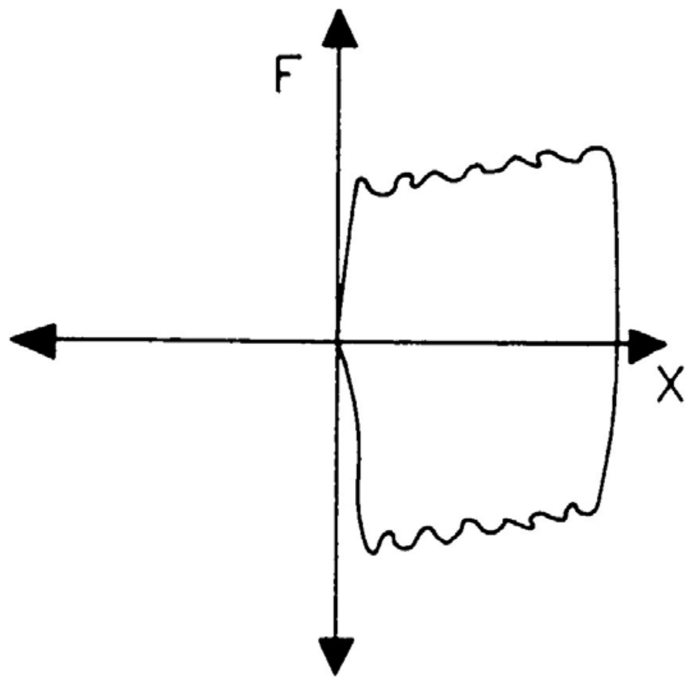
1. **Sliding joint type output:**




**Stick-slip sliding of joint should include 30-50% stick factor.**

**Slight ramping of output is typical for long deflections, and can only be characterized by test.**

2. **Plastic deformation type output:**




**Slight ramping is similar to sliding joint, and can only be characterized by test.**

# Types Of Dampers


## *Elastomer Damping –*

1. **All conventional elastomers have some degree of damping inherent in their structure. So-called "high damping" materials provide damping levels of approximately 10% of critical.**

2. **So-called "viscoelastic" materials can be designed with virtually any damping level, although values in excess of 10% of critical are rarely used due to size, cost, and system constraints.**

3. **Great care must be exercised in the design of elastomer dampers. Current U.S. Military requirements prohibit any bonding agents or glue in the construction of these devices.**

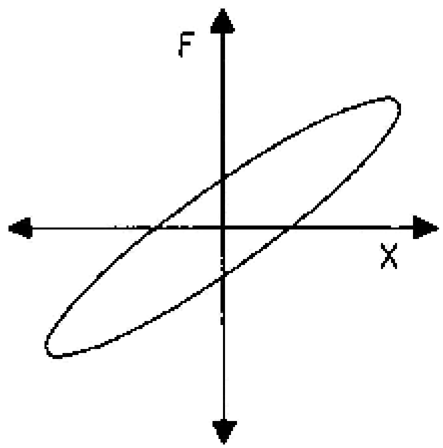
4. **All elastomers produce a damping output with a high degree of non-linearity. The output is essentially in-phase with the system stress. Thus, elastomer damping *decreases* deflection of a system while *increasing* stress.**

5. **Elastomer damping devices vary damping *radically* with temperature. For example, a temperature shift from +20 degrees to +120 degrees F will typically alter elastomer damping by a factor of fifty to one. Thus, all dynamic models must incorporate thermal correction factors.**

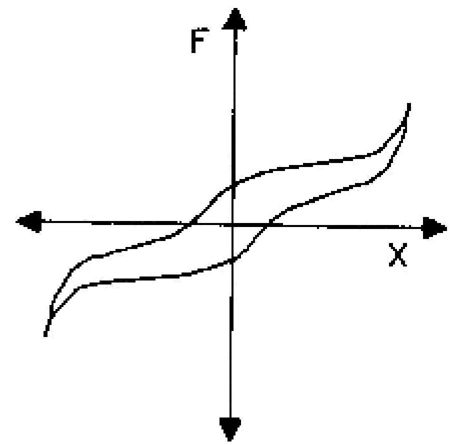
6. **Elastomers are also subject to environmental degradation, due to age and chemical reagents.**

*Elastomer Damping, Modeling –*

1. **A simple elastomer damping element:**




**Model**




**Real World**

2. **Other studies have indicated that much more elaborate modeling techniques may be necessary to properly characterize visco-elastic behavior. These include temperature shifts, frequency shifts, and hardening of the damping exponent.**

# Types Of Dampers


***Active Drivers as Dampers –***

1. **Provided that the control system can be designed and adequate power made available, it is possible to use an active driver to accomplish the same response as any type of damper.**
2. **Any electrical, mechanical, or hydraulic device that can be used as a driver can be used as an active damper.**
3. **The major concern with any driver is the availability of power to operate the device. An analysis must be performed at a suitably small time step to accurately determine the average and peak power requirements during all expected transients. This analysis must be both accurate and conservative. Inadequate power can cause the damper to increase system stresses to higher levels than even the undamped case, possibly leading to catastrophic failure.**
4. **Current design practice suggests that any active damper should have a "fail-safe" or "limp-in" mode in the event of power or control failure**

***Active Driver, Modeling –***

1. **Numerous control approaches have been suggested and used for active drivers used as damping devices. Some have been tested, some have not.**

2. **Any suggested control equations and hardware should be tested on a sub-scale basis prior to final validation on a complete, full size structure.**

# Types Of Dampers


*Hydraulic Damping –*

## Definition:

**A hydraulic damper is a device that removes mechanical energy from a system by converting it to heat. The damper absorbs energy by forcing fluid through orifices, thereby causing the damper to apply a force over a displacement, this force being dissipative.**

**Classical hydraulic theory indicates that the functional output of a damper is as follows :**

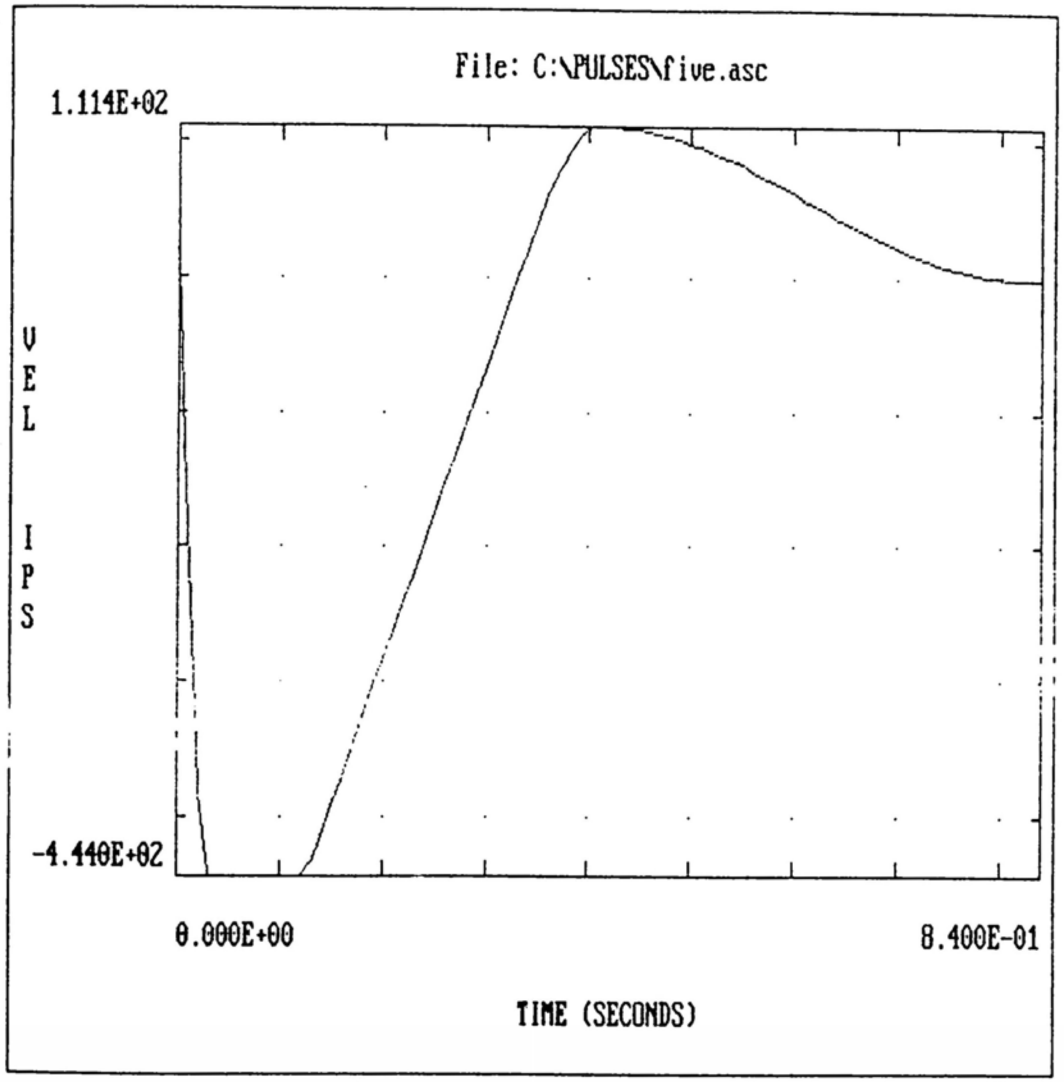
| | | |
|---|---|---|
| F Output | = | C Ve^2*f(x) |
| Where C | = | Damping Constant |
| Ve | = | Fluid velocity through the damping orifices |
| f(x) | = | Variance in orifice area with damper stroke position |

**Dampers built from the 1800's to the 1970's utilized this type of output.**

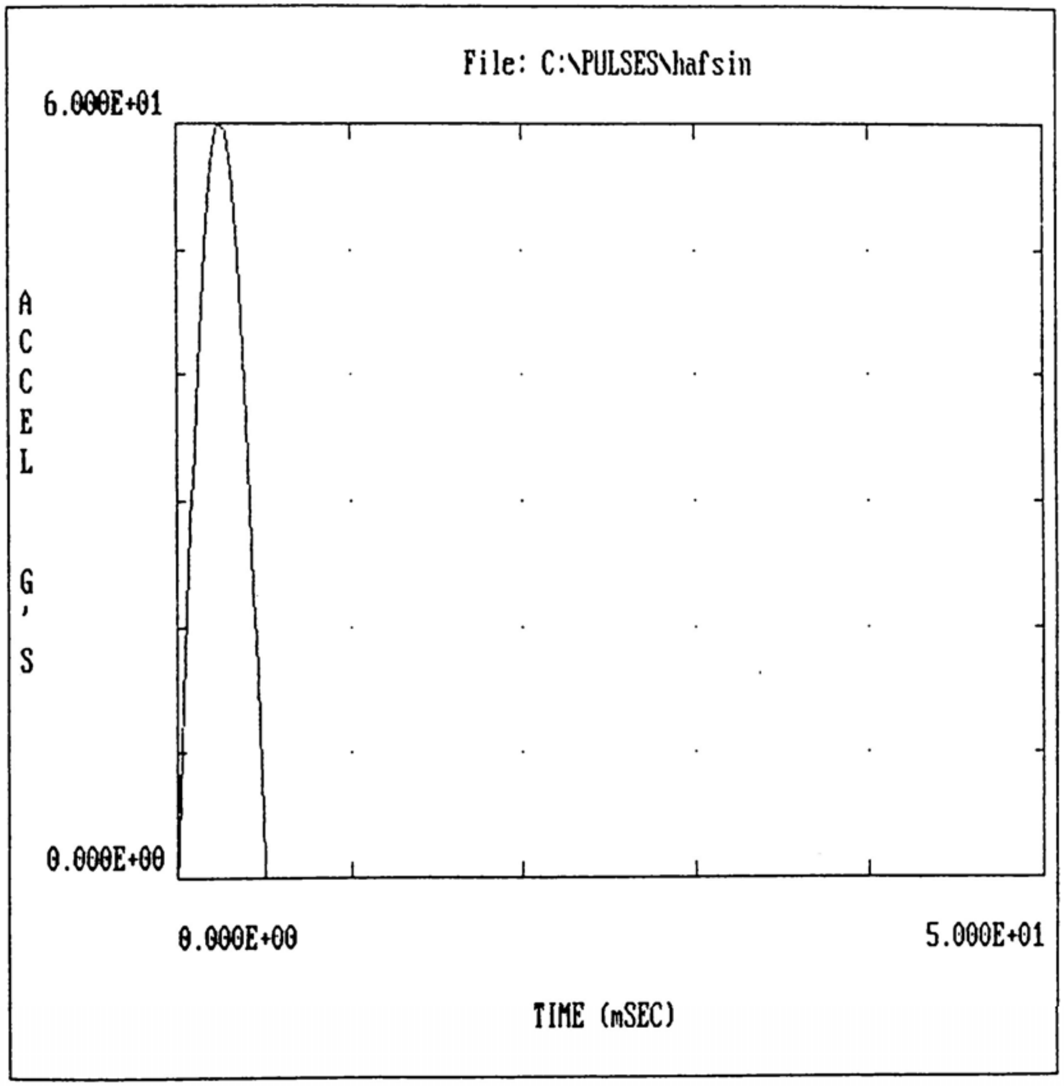
**Modern dampers use the high velocity flow properties of fluidic controls to achieve much different outputs from the classical case. These outputs are optimized for performance in systems subjected to a highly variable pulse field, those that are "real world" in nature. Real world transients include:**

1. **Seismic Events**
2. **Transportation and Handling Shock**
3. **Weapons Effect Pulses**

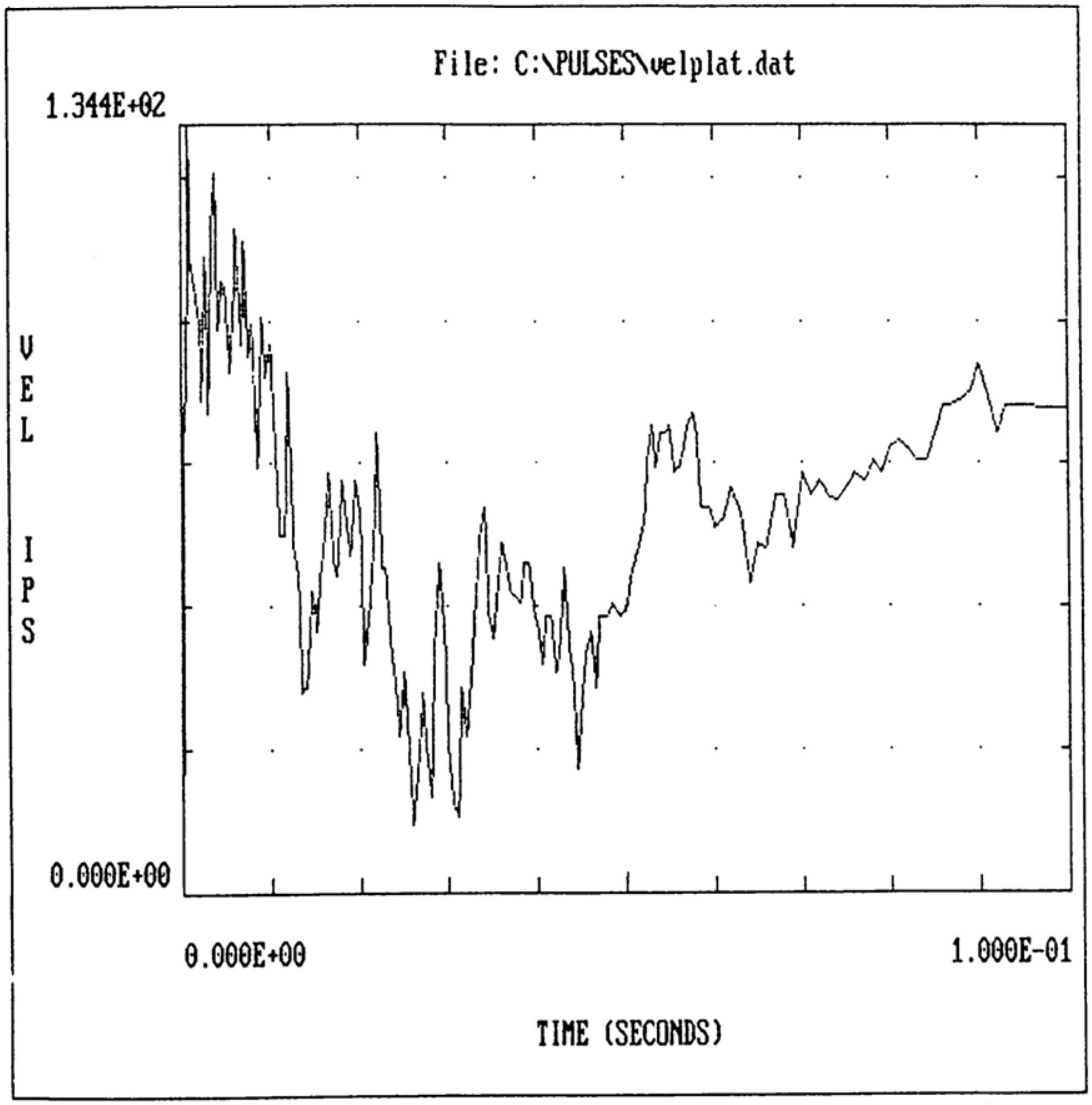
## Nuclear Weapon's Ground Motion



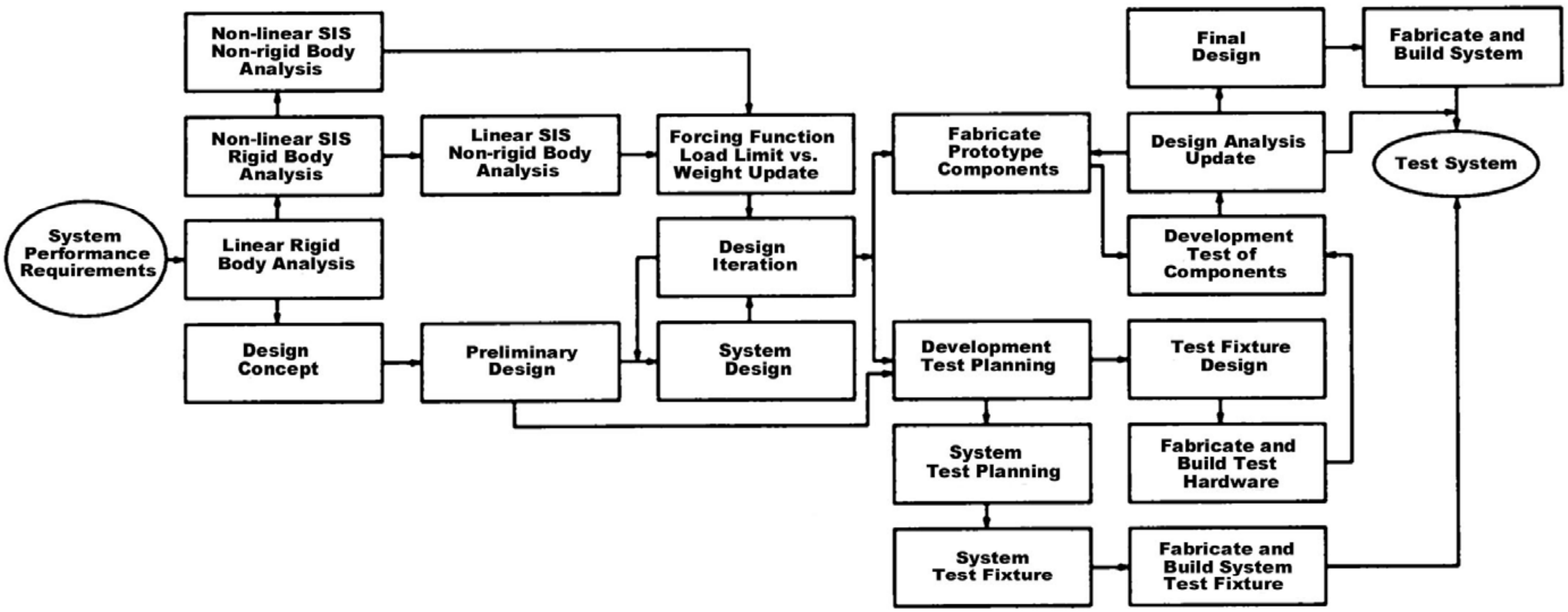
# Transport and Handling Shock, Generic



# Naval Shipboard Shock



# Taylor Devices, Inc.
# Flow Chart: Shock Isolation Systems



# History Of Hydraulic Dampers

**The first production usage of high performance hydraulic dampers was in the 75 mm French artillery rifle of 1897. The damper was used to reduce recoil forces and had a stroke of over 48 inches.**

**The exact design of this damper was considered a national secret of the French Government, and was shared with the U.S. and Great Britain during World War I only after extensive negotiation.**

**Features of the 1897, 75 mm French artillery damper:**

1. **Double acting output, different in tension and compression by use of a biasing valve.**
2. **Continuously variable output, using a continuously varying tapered pin orifice of eccentric cross section.**
3. **Adaptive damping, i.e., damping was continuously varied depending on the angle of elevation of the weapon, using a sector gear drive which rotated the continuously tapered pin of eccentric cross section to open bypass ports.**

**Thus, the damper was set to smoothly absorb recoil when the gun fired, and smoothly apply counter-recoil force to control the recoil springs as the gun repositioned itself after firing, all while varying force with respect to gun elevation.**

**Today, this complex design is still used in many large artillery prices, and elements of this design are used in most aircraft landing gears.**

# Other Milestones In Hydraulic Damping

**1925** First rotary (knee-action) shock absorbers built for automotive use. Invented in Buffalo by Ralph Peo of Houdaille Hydraulics.

**Note:** Rotary seals lasted longer than sliding seals, given that leather rings were state-of-the-art.

**1935** First successful compressible fluid-spring-damper built by Sir George Dowty of Great Britain. Never produced in volume due to high cost.

**1949** Delco introduces the first successful linear automobile shock, using twin tubes with relief valves. Rod was mounted "up" so that gravity could help the crude rubber seals.

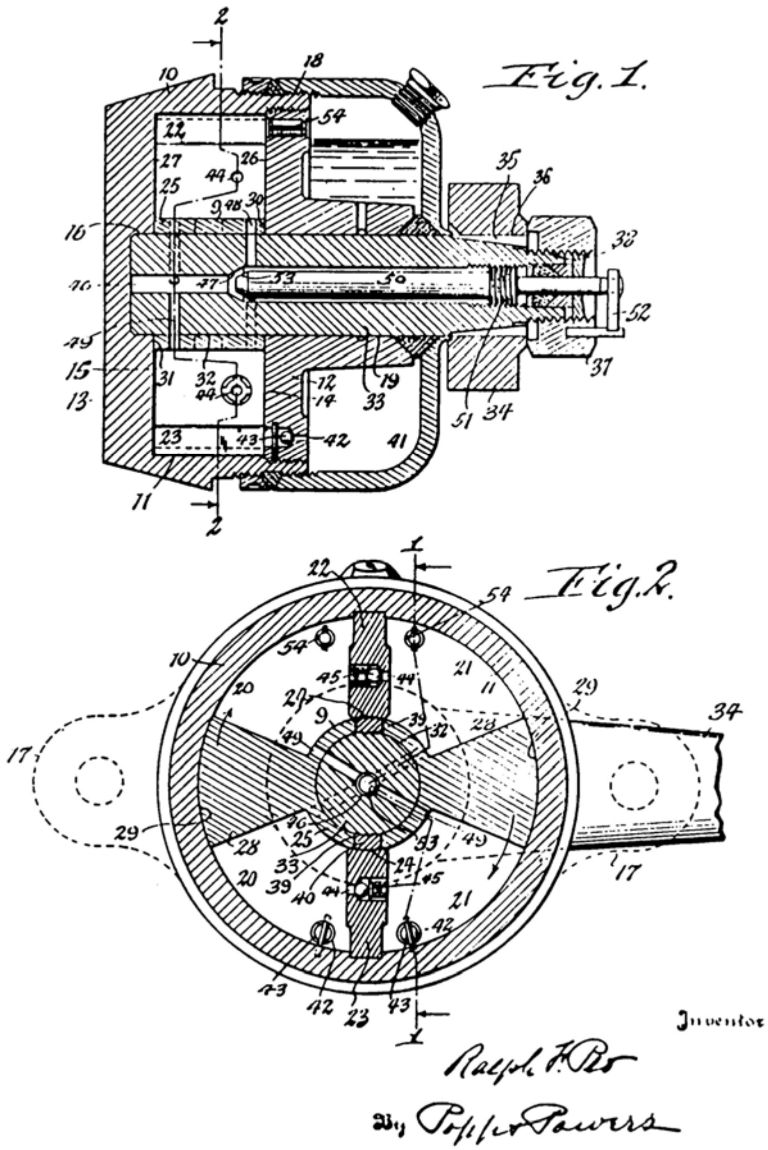
**1952** First production of compressible fluid-spring-damper, built by P. Taylor of Wales-Strippit Corporation, founder of Taylor Devices in 1955. Used in mechanical press to strip parts.

**1956** First use of hydraulic damping in a structure, Chance-Vought F8 Aircraft with Taylor Devices' Fluid Spring Damper in tail hook.

**1970** Taylor Devices patents a fluidic damping system which can provide linear damping with high pressure hydraulics.

**1985** Taylor Devices patents a high pressure frictionless damper with hermetic flexure seals, for spacecraft use.

# R. Peo’s Rotary Shock Absorber - 1925



# R. Peo’s Rotary Shock Absorber - 1925

Fig. 3.

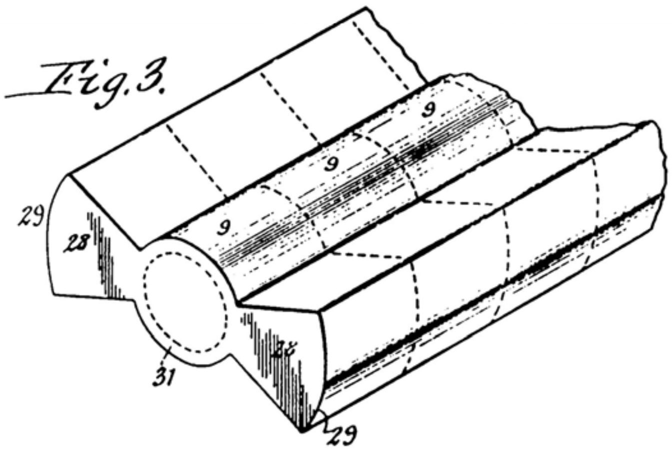
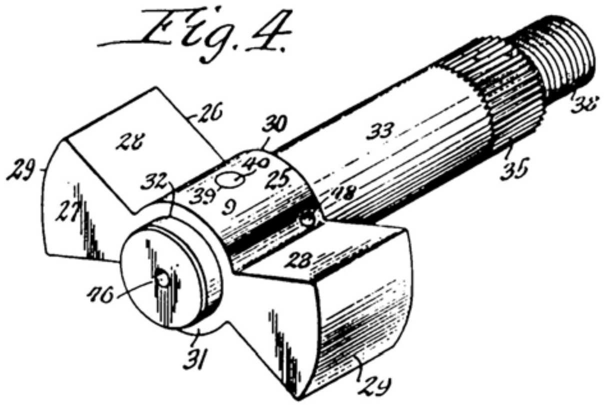



Fig. 4.

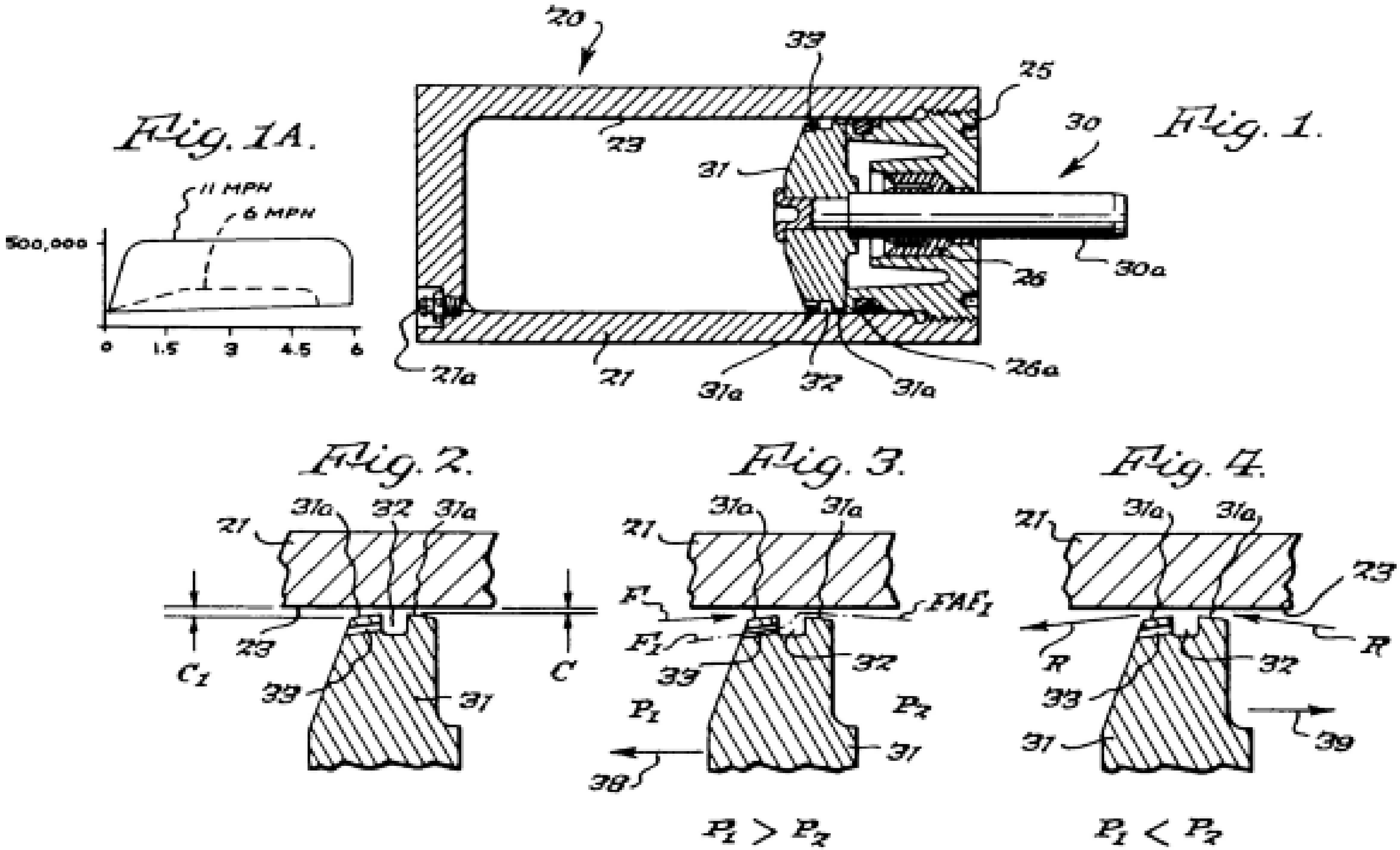



Inventor

Ralph F. Peo

By Popp & Powers

# Taylor Devices' Fluidic Damper - 1970



# Taylor Devices' Fluidic Damper - 1970

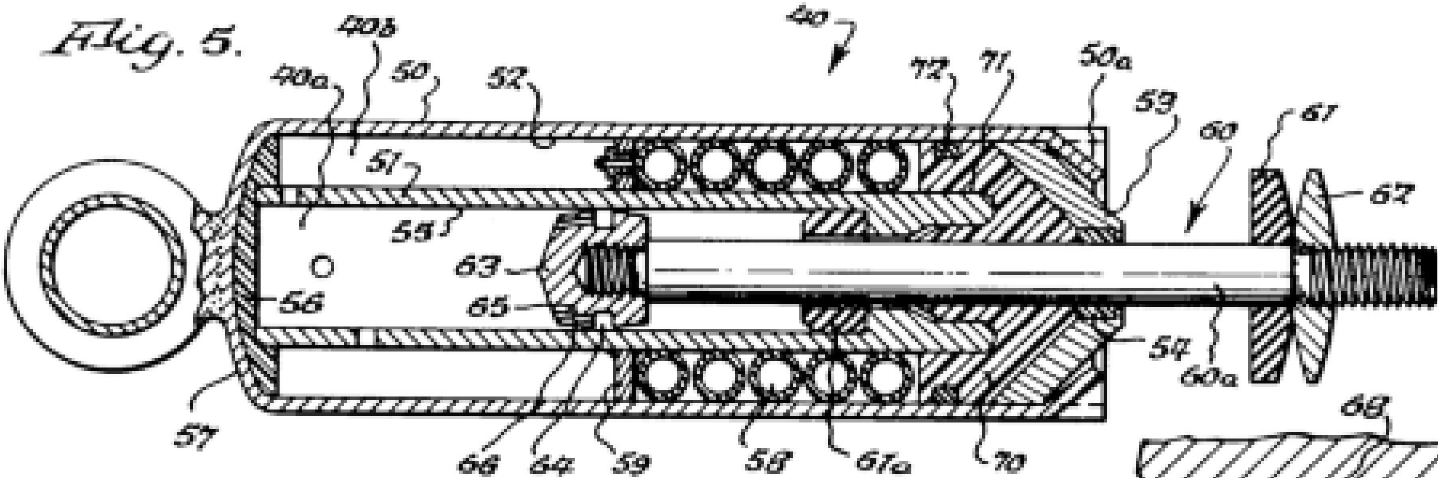


Fig. 5.

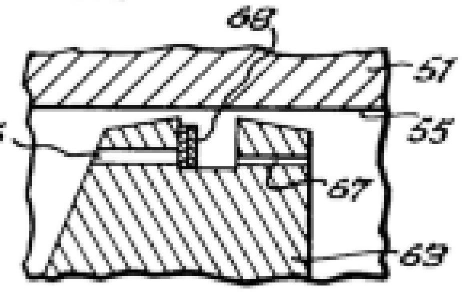


Fig. 5A.

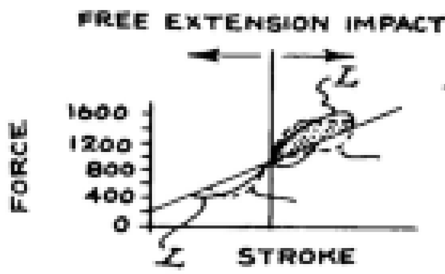



Fig. 6.

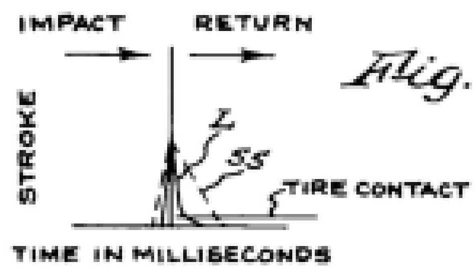



Fig. 7.

# Taylor Devices' Frictionless Damper - 1985

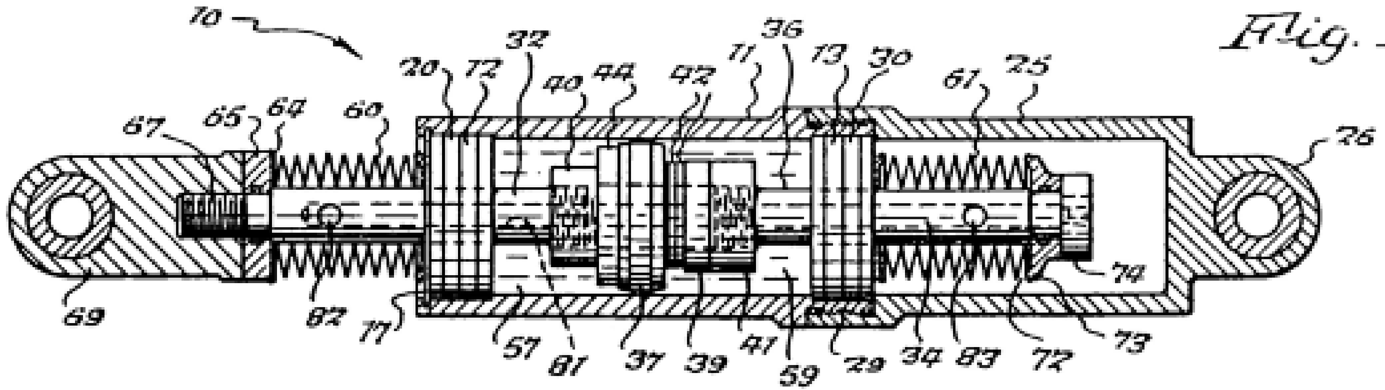


Fig. 1.

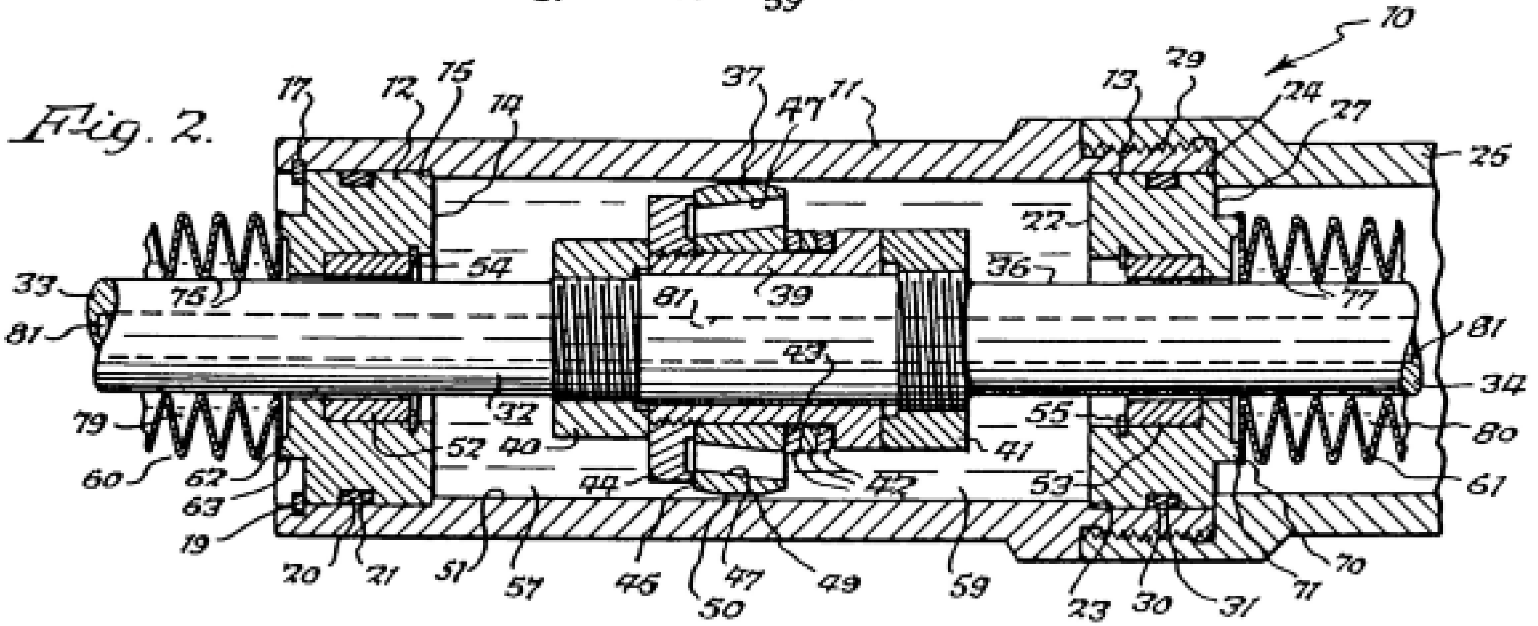


Fig. 2.

# Passive Hydraulic Dampers

## *Current Types:*

1. **Fluidic - Uses specially shaped orifice to achieve output characteristics ranging from:**

   **$F = CV^{0.4}$ to $F = CV^{1.8}$**

2. **Metering Tube - Uses a piston which progressively covers a series of ports.**

   **Output is:**

   **$F = CV^2 * f(x)$**

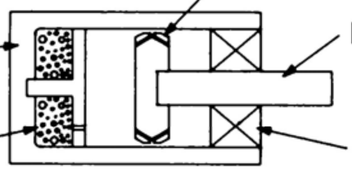
   **This design is effective only when tuned for a specific pulse signature.**

3. **Metering Pin - Similar to metering tube, but orifice is continuously varied.**

4. **Pressure Responsive Valve - Uses multiple spring loaded poppet valves.**

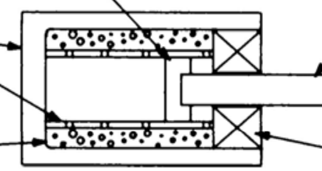
**Only types 1 and 4 are capable of attenuating random fields of pulses effectively. This is because they are relatively insensitive to velocity, and not sensitive to position.**

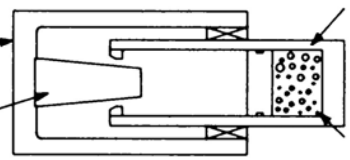
# Design Characteristics




*1. Fluidic*

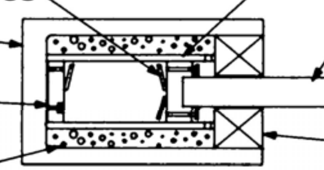
*2. Metering Tube*



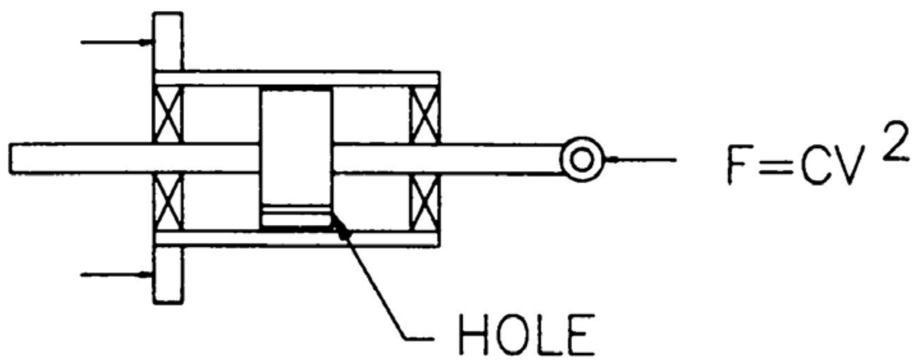

*3. Metering Pin*

*4. Pressure Responsive Valve*



*Question:*

**Why do we go to such trouble designing such relatively complex designs? Why can't we just use a simple damper?**




*Answer :*

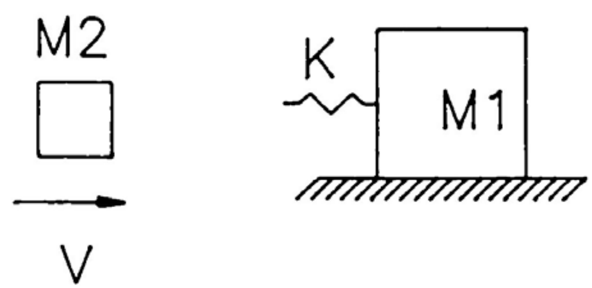
**As the French discovered in 1897, a "simple" damper will rarely "square the pulse." This means that it will not offer much improvement.**

***Statement:***

**I don't understand, show me!**

**Consider a simple structure with a primary spring rate of K and mass M1, being impacted by an object of weight M2 moving at initial velocity V**

1. **A very simple math model:**
   **Assume M1 > > M2**



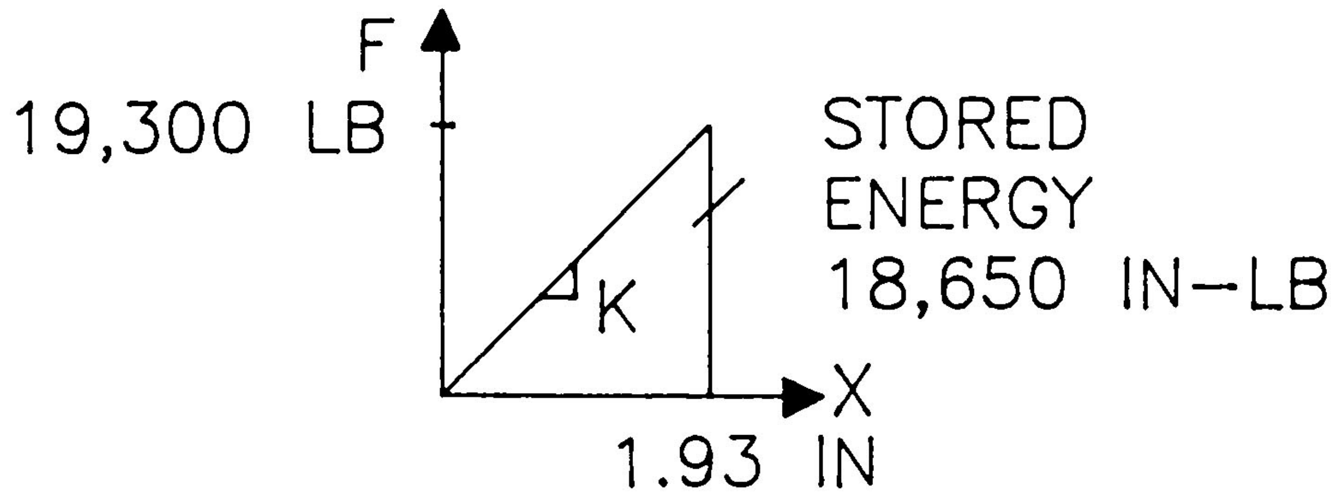
**Let's assign values:**

| | | |
|---|---|---|
| **M2** | **=** | **2 Tons** |
| **V** | **=** | **5 Ft/Sec.** |
| **K** | **=** | **10,000 Lb/In.** |
| **M1** | **=** | **Very Large** |

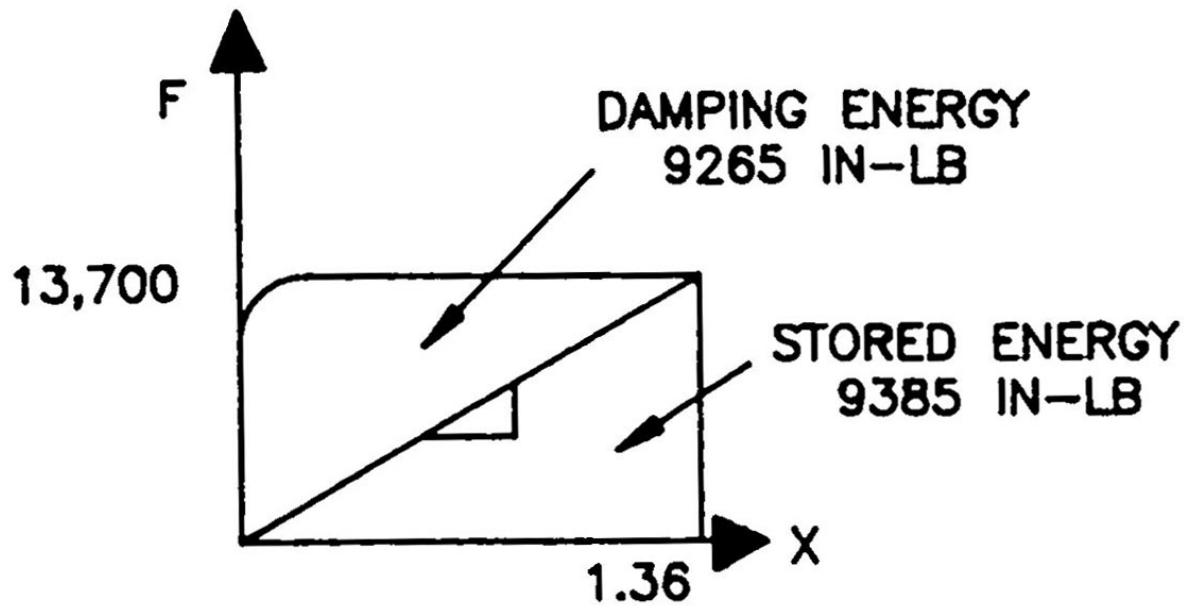
2. **Solve for kinetic energy of M2:**

**K.E. = 1/2 M $V^2$ = 1554 Ft-Lb. = 18,650 In-Lb.**

3. **Generate a force-deflection curve for spring K until it has stored all the energy.**

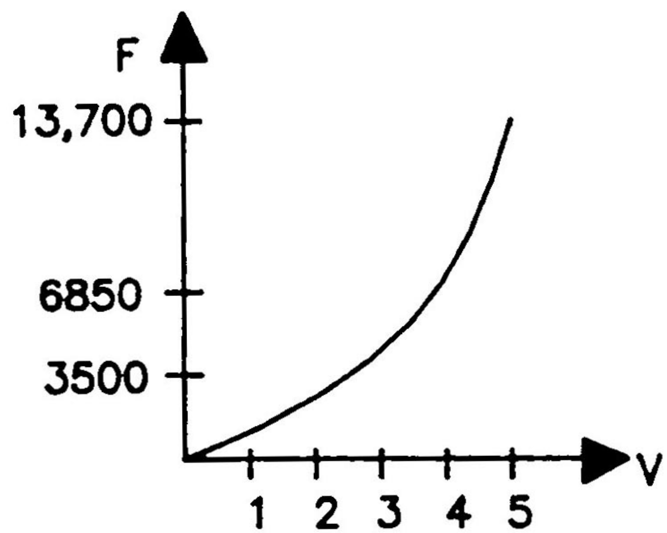


4. **Now, let's add damping to square the curve; reducing stress and deflection.**




**Thus, by adding damping to "square the curve," we have reduced both stress and deflection by approximately 30%**

5. **If we manipulate this curve, we can "back into" a plot of force vs. velocity for the damper.**



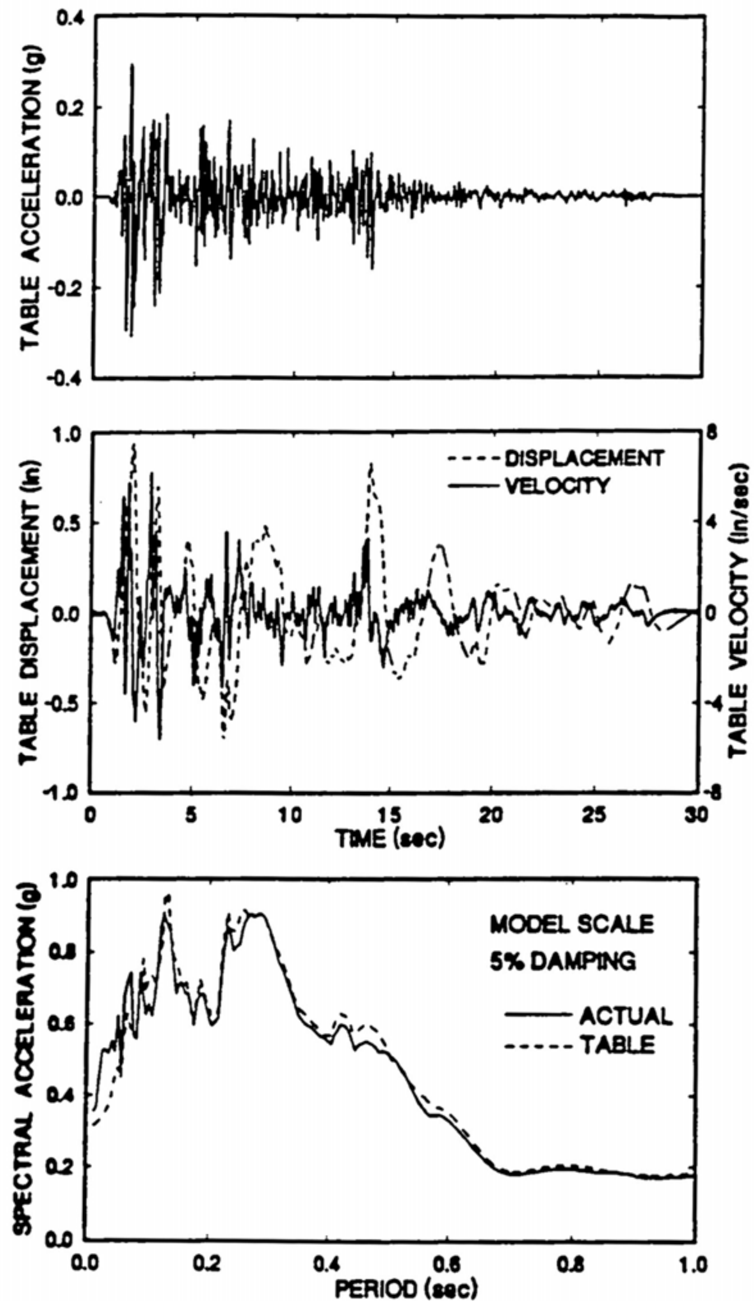

**A reasonable equation for this particular damping function is $F = 548V^2$. Thus, a $V^2$ damper functions well for this case, and if all transients were simple initial condition ones like this, all the world would ever require is $V^2$ dampers!**

**Let's consider some tests by NCEER with a complex seismic input into a structure, with added dampers. In this case, the seismic pulse field indicated that a linear damper, F = CV, was a "best fit."**

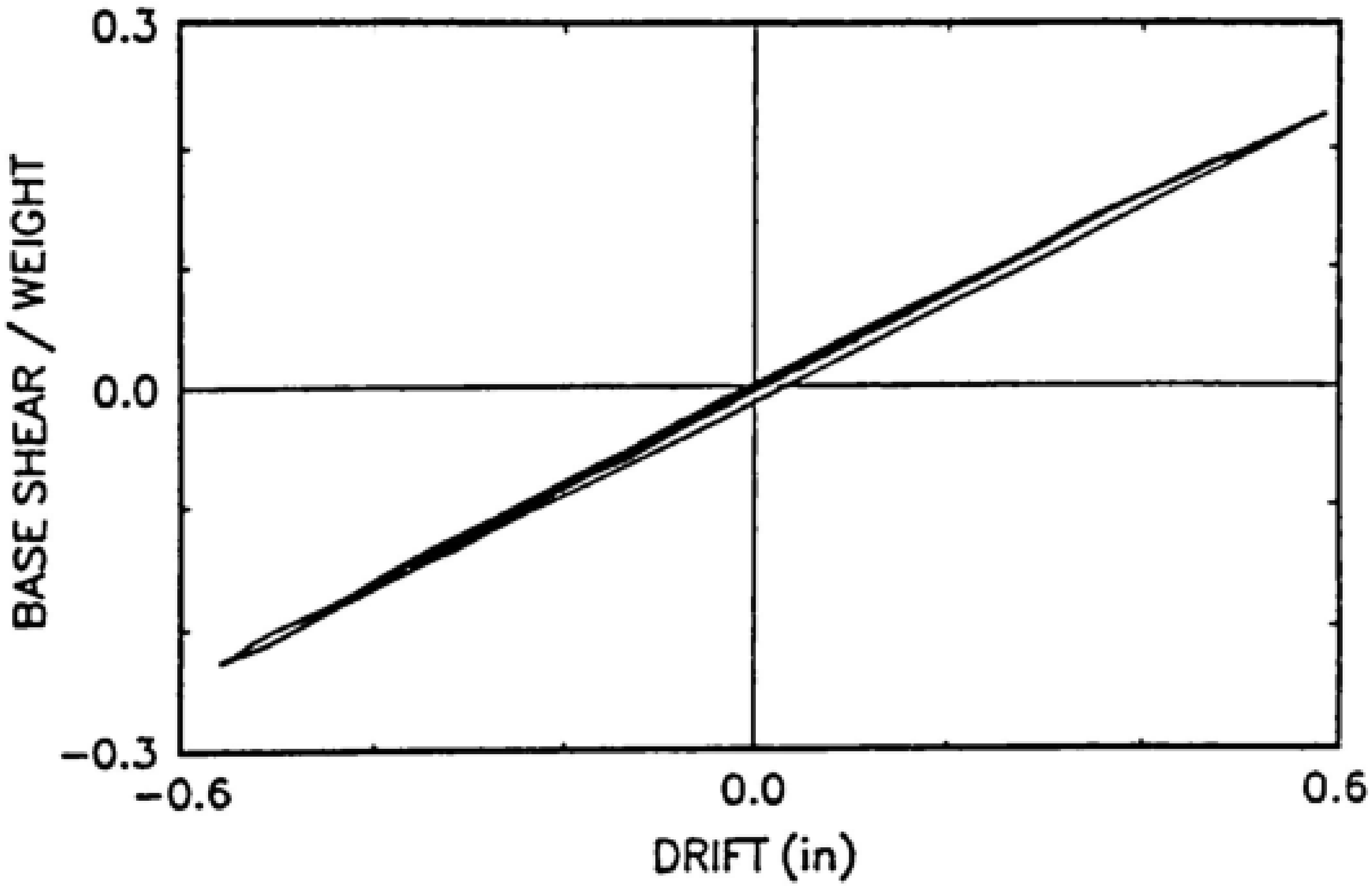
**The pages that follow show:**

- **Time history of the scaled 100% El Centro earthquake input to the test building.**
- **Response of the test building without dampers, input scaled at 33% El Centro.**
- **Response of the test building with two dampers added as diagonal braces, input scaled 33% El Centro.**
- **Response of the test building with two dampers added, input scaled 100% El Centro.**

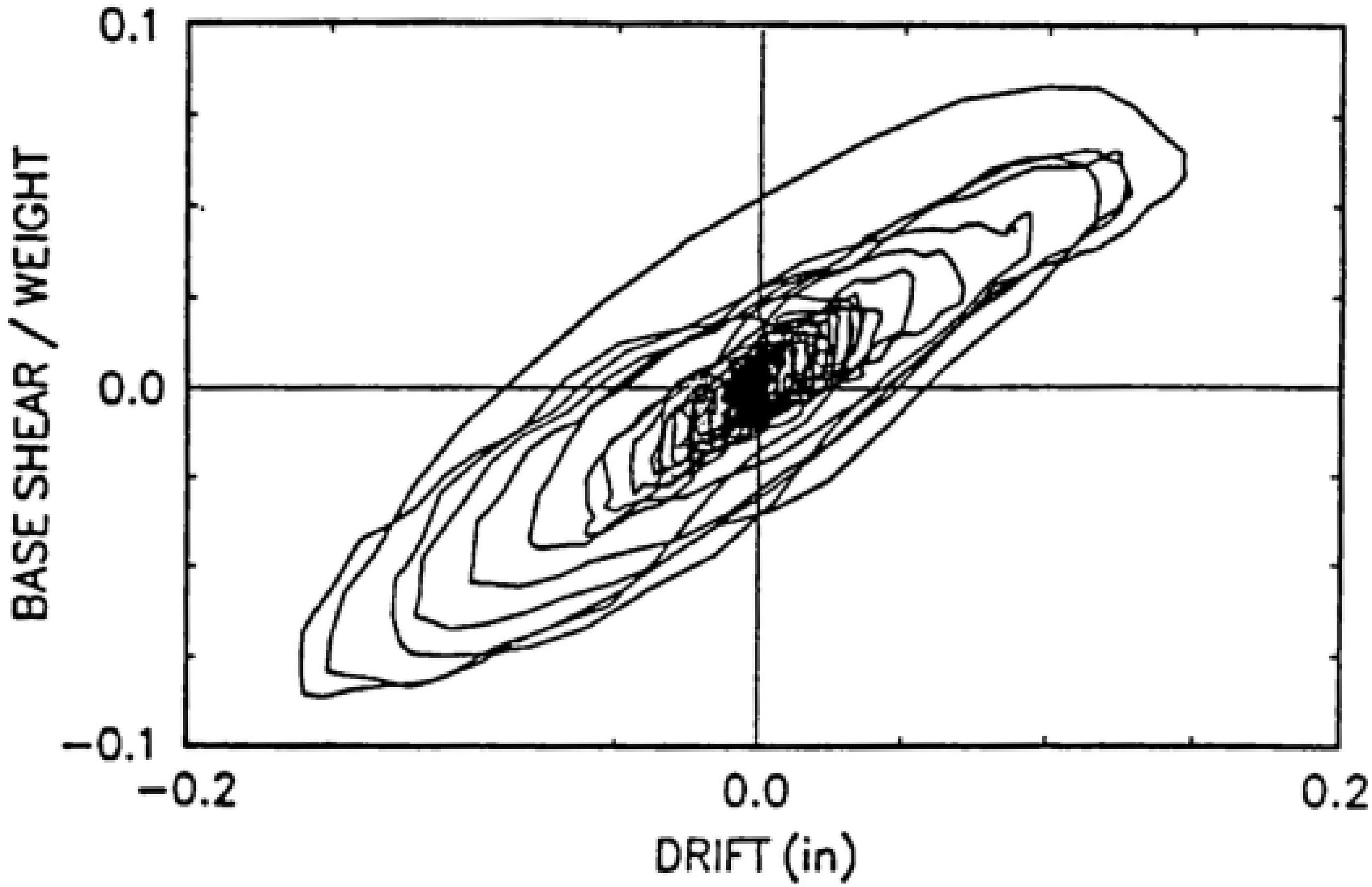
**Time Histories of Displacement, Velocity and Acceleration and Spectral Acceleration and Displacement of Shaking Table Excited with El Centro 100% Motion (1 in. = 25.4 mm)**



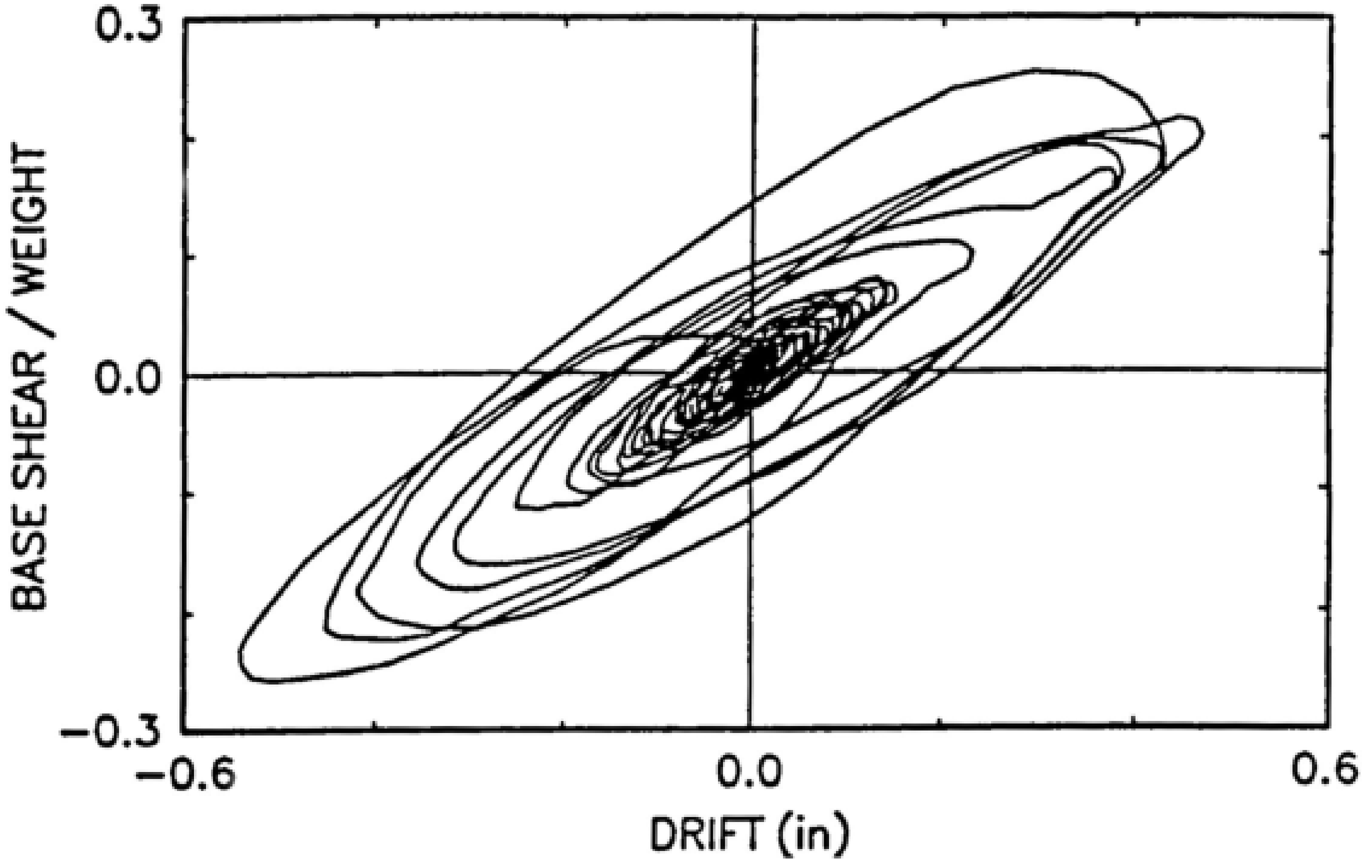
## 1-Story, No Dampers, El Centro 33.3%



## 1-Story, 2 Dampers, El Centro 33.3%



**1-Story, 2 Dampers, El Centro 100%**



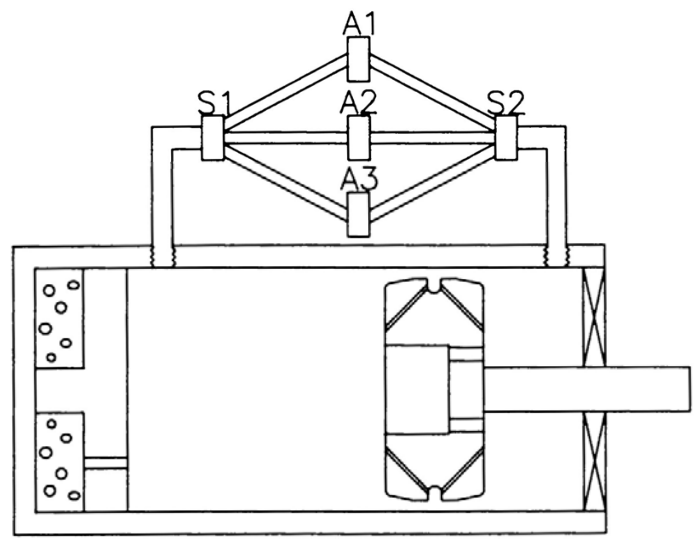

**The deflection improvement is a factor of three, with only two dampers.**

**The seismic capability is also increased by a factor of three, on a G-load and/or energy basis.**

# Types Of Dampers


*Semi-active Hydraulic Damping –*

**A semi-active hydraulic damper actively varies the size of its passive hydraulic orifices.**




A. **S1 and S2 are selector valves, to select different orifice functions A1, A2, A3**

B. **A discrete set of orifice paths are shown, but proportional control can also be used**

*Advantages of the Semi-active Damper –*

1. **Similar performance to active drivers, but with very little power consumption.**

2. **Reversion to passive fixed orifice in event of failure  a fail-safe design.**

**Alternate designs of semi-active dampers exist where valves are replaced with electrorheological (ER) or magnetorheological (MR) fluids.**

**Presently, dampers using this technology are large and bulky, with operating pressures limited to less than 2,000 psi by the characteristics of the fluid itself.**

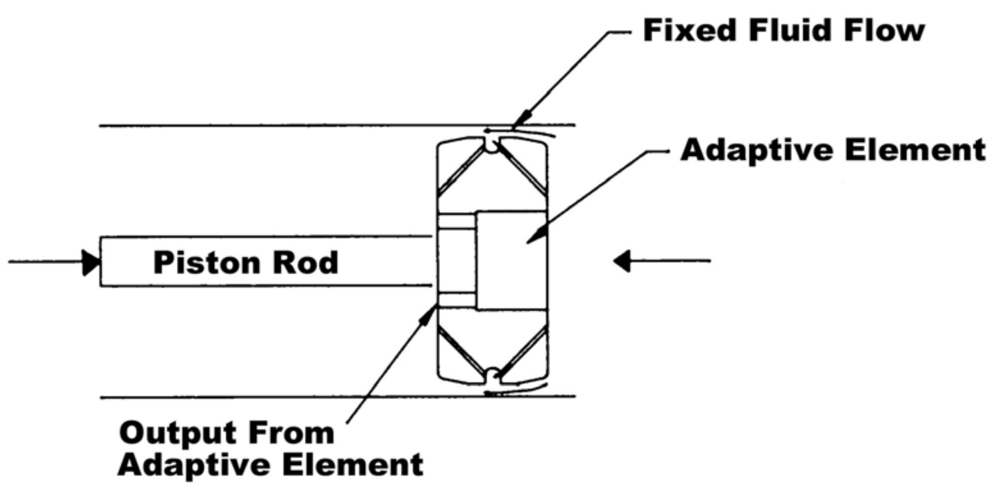
# Types Of Dampers


*Adaptive Hydraulic Damping –*

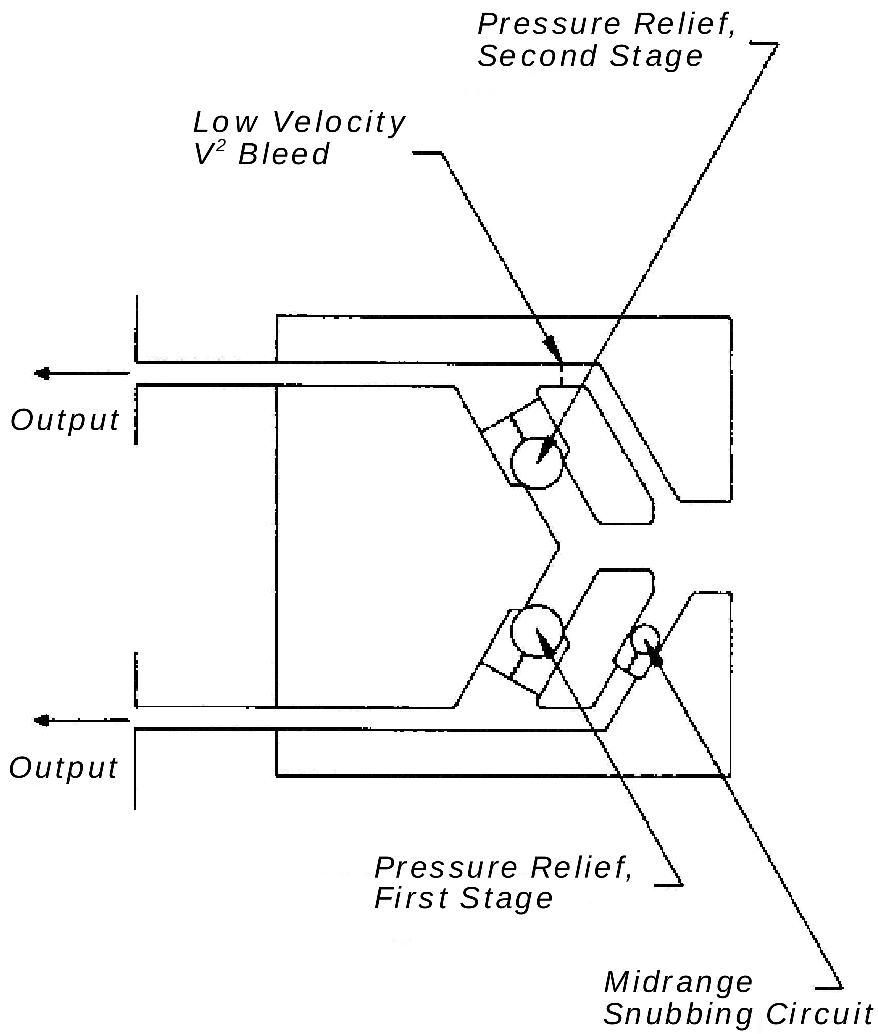
**An adaptive hydraulic damper combines various available orifices with an internal logic system, with a fixed path response.**

*Example –*

**A fluidic orifice with an adaptive logic element added. A single adaptive element is depicted for simplicity.**



***The following is a typical adaptive element –***



# In Conclusion

**If you remember only one thing from this discussion, remember the following:**

***The Three Keys To Shock Isolation ~***

1. **Know the Input**
2. **Bound the Output**
3. **Mitigate the Difference**

**T*he Key To Damping ~***

**When in doubt, damp it out.**