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COMPOSITE SEISMIC ISOLATOR AND METHOD*

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A new seismic isolator composed of two conventional isolator units. It changes stiffness automatically, based on displacement demand, therefore provides equal protection in minor, moderate or major earthquakes.

Keywords: minor earthquake, moderate earthquake, major earthquake, seismic isolator, isolator stiffness, Force-Displacement Diagram.

History

Past earthquakes has taught us that buildings located in close proximity to an earthquake fault, or more specifically to the epicenter, experience very large ground accelerations and velocities resulting in very large horizontal displacement of the seismic isolators. In order to keep these lateral displacements within practical limits, the horizontal stiffness of the isolators has to be high. The consequence is that for "minor" and "moderate" earthquakes the lateral displacement of these stiff isolators is very small, the buildings behave during these earthquakes essentially as conventional fixed-base buildings and the benefits of seismic isolation are lost. Only for "major" earthquakes, which occur less frequently, will the buildings experience the benefits of seismic isolation. Conventional fixed based buildings can suffer very serious damage even in moderate earthquakes, as it was evidenced in the 1971 San Fernando earthquake in California. The earthquake registered only 6.4 on the Richter scale, accordingly it was called "moderate." Among other buildings several hospitals were severely damaged or destroyed by it.

There is therefore a need for a new and improved seismic isolator, which equally protects the buildings, their contents and occupants in "minor", "moderate" and "major" earthquakes. The Composite Seismic Isolator accomplishes this having two distinctly different stiffnesses, which are activated by the displacement demand. The Composite Seismic Isolator is made up of tested and proven conventional seismic isolators, and it is composed of two isolator units. Their sizes and physical properties, including horizontal stiffnesses, are individually designed for each project.

Seismic isolator "A" is soft horizontally and has a cylindrical form. Seismic isolator "B" is usually stiffer horizontally and can have cylindrical or any other form.

In the most practical combination of the two isolator units seismic isolator A is placed on the top of seismic isolator B. Figure 1.

Seismic isolator "A" carries the vertical load "W" on the seismic isolator assembly, transfers it to seismic isolator "B", which in turn transfer it to the foundation of the building. Seismic isolator "A" rests on steel plate "1", the two are connected with screws, bolts, shear dowels, or other means in such a manner that relative horizontal movement between the bottom of seismic isolator "A" and plate "1" is prevented.

*United States Patent: 5, 461, 835, Date: Oct 31, 1995.

At a distance "d" from the edge of isolator "A" a circular steel ring barrier surrounds the isolator and prevents the lateral displacement of the top of this isolator relative to the bottom to be more than "d". The steel ring is attached to plate "1" by welding or other means and is reinforced with stiffeners as required. Inside and on the top of the steel ring an elastomer ring cushions the contact with isolator "A" as the relative displacement of the top of the isolator approaches "d" during earthquake. The top of this seismic isolator is slightly higher than the top of the steel ring to allow vertical deflection of isolator "A" under vertical load and lateral displacement.

Seismic isolator "B" is connected on the top to plate "1" by screws, bolts or other means in such a manner that relative horizontal movement between plate "1" and the top of seismic isolator "B" is prevented. The bottom of isolator "B" is attached to the foundation base in a similar manner.

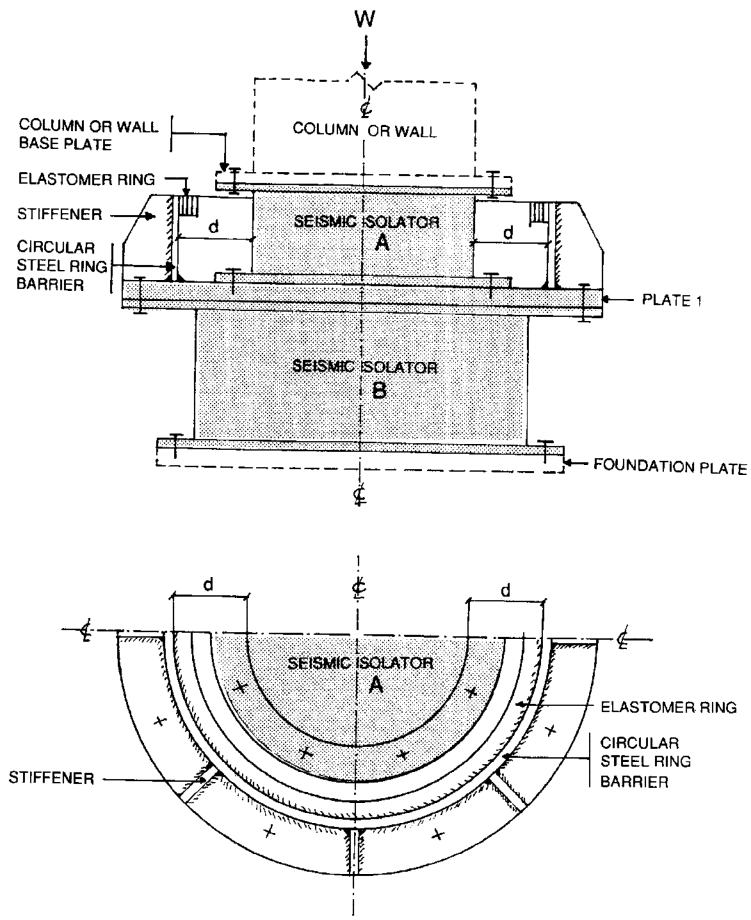


Figure 1

Figure 2 is a diagram of the typical lateral displacement position of the Composite Seismic Isolator during "minor" and "moderate" earthquakes when the total lateral displacement demand is less than "d".

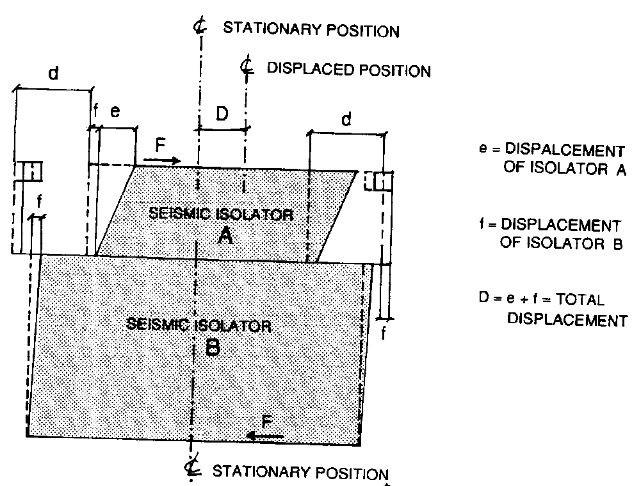


Figure 2

Figure 3 is a diagram of the typical lateral displacement position of the Composite Seismic Isolator during "major" earthquakes when the total lateral displacement demand is greater than "d".

The connections of the base isolator assembly must be capable to transfer the maximum horizontal earthquake force "F" to the foundation base plate.

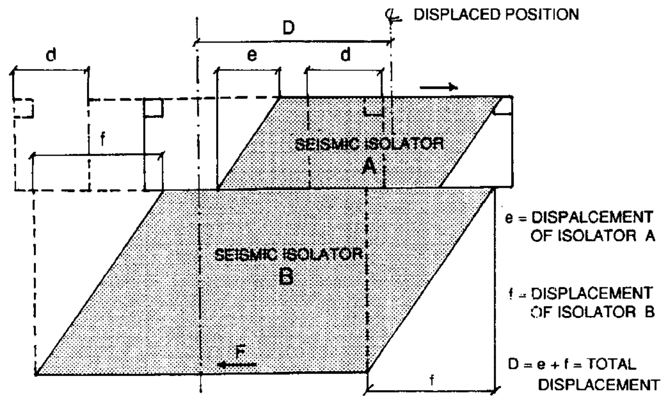


Figure 3

COMPOSITE SEISMIC ISOLATOR

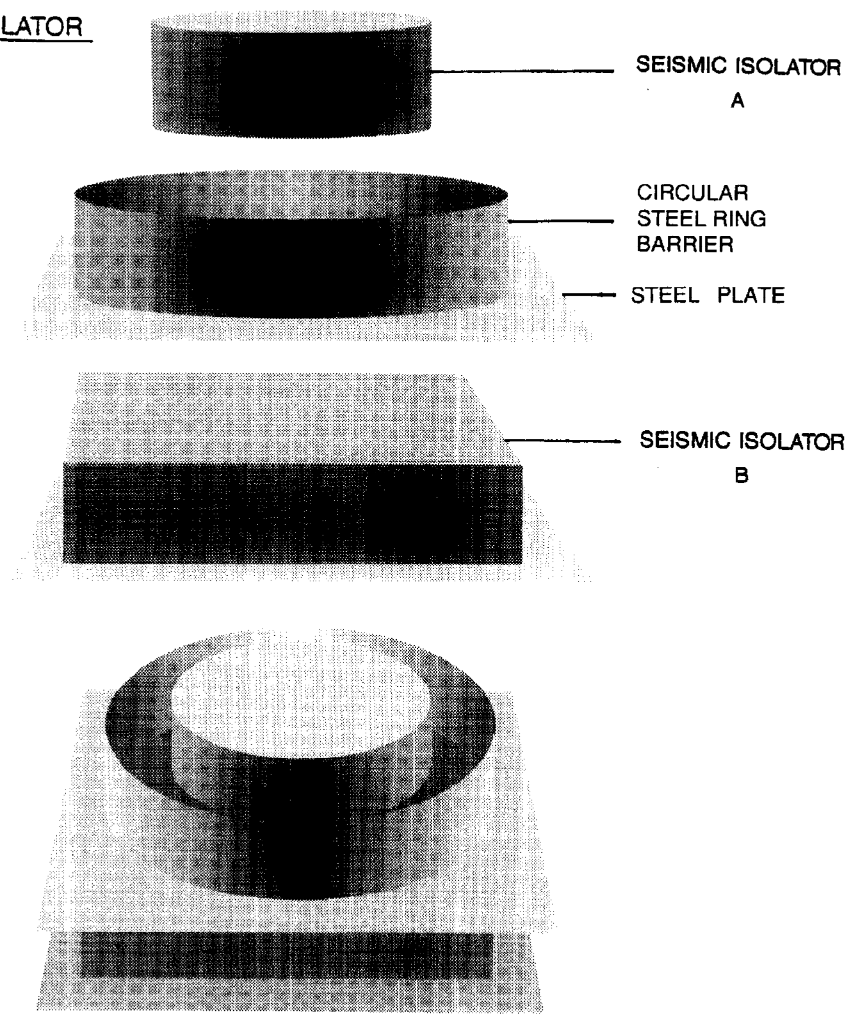


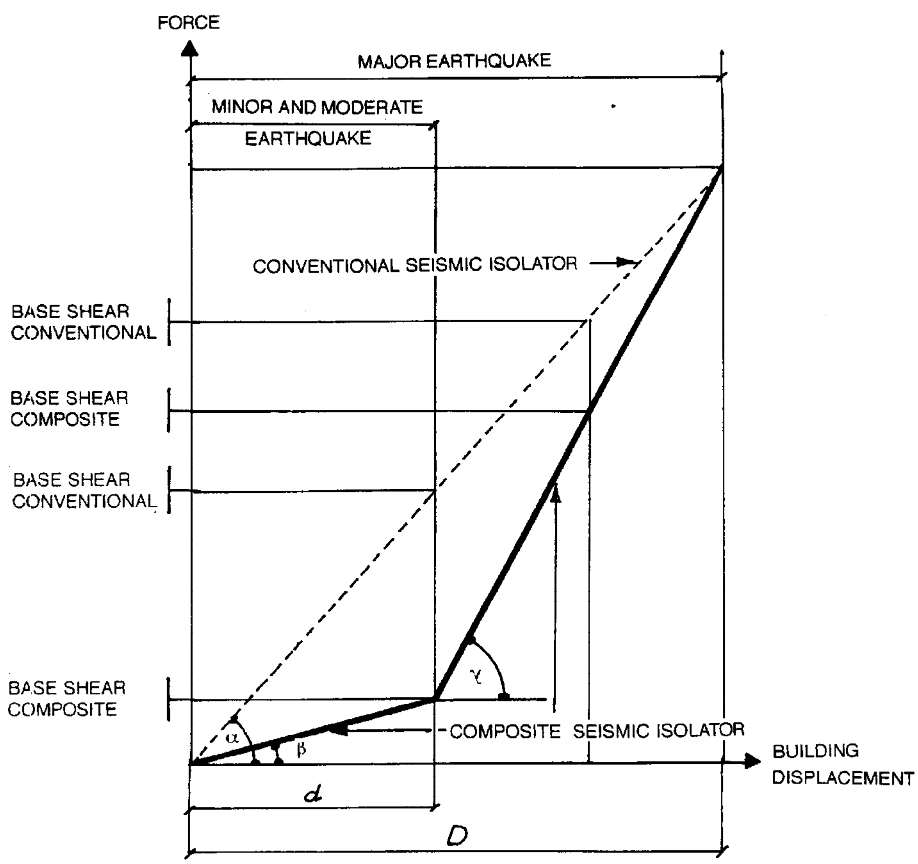
Figure 4

The effectiveness of a seismic isolator is measured by the force transmitted through the seismic isolator to the protected structure during an earthquake. This force is commonly referred to as "base shear." Smaller the base shear, more effectively the seismic isolator protects the structure.

A conventional elastomeric seismic isolator is characterized by essentially constant horizontal stiffness, which is computed by the formula K = GA/t, where

G = Shear modulus of elasticity of the elastomeric compound
A = Cross sectional area of the seismic isolator
t = Total sum of the thickness of the elastomeric layers.

Stiffness is defined as the force required to displace the top of the seismic isolator by one inch, which in turn equals the tangent of the slope of the "Force-Displacement" diagram Figure 5. Accordingly, the horizontal stiffness of a conventional seismic isolator is $K = \tan \alpha$. The Composite Seismic Isolator, being made of two different conventional seismic isolators, has two distinctly different horizontal stiffnesses by design. During "minor" and "moderate" earthquakes, when the displacement demand on the seismic isolator is less than the distance "d", the Composite Seismic Isolator is "soft," its stiffness: $K = \tan \beta$. During "major" earthquakes, when the displacement demand is greater than "d", the Composite Seismic Isolator is "stiff," its stiffness: $K = \tan \gamma$. The diagram also demonstrates another unique characteristic of the Composite Seismic Isolator, that during any seismic event, "minor," "moderate" or "major," the Composite Seismic Isolator always transmits smaller base shear to the protected structure than a conventional seismic isolator, designed for the same maximum design displacement "D".



FORCE - DISPLACEMENT DIAGRAM

Figure 5

EXAMPLE

This example demonstrates the preliminary design of a Composite Seismic Isolator, where a soft isolator is placed on the top of a stiff isolator. Using the Force-Displacement diagram it will also demonstrate the performance of the Composite Seismic Isolator during earthquakes as compared with a Simple Seismic Isolator.

For the purpose of this comparison a simple high-damping rubber seismic isolator was selected identical to one, which was fabricated and tested for a project in Southern California.

A. Simple Seismic Isolator.

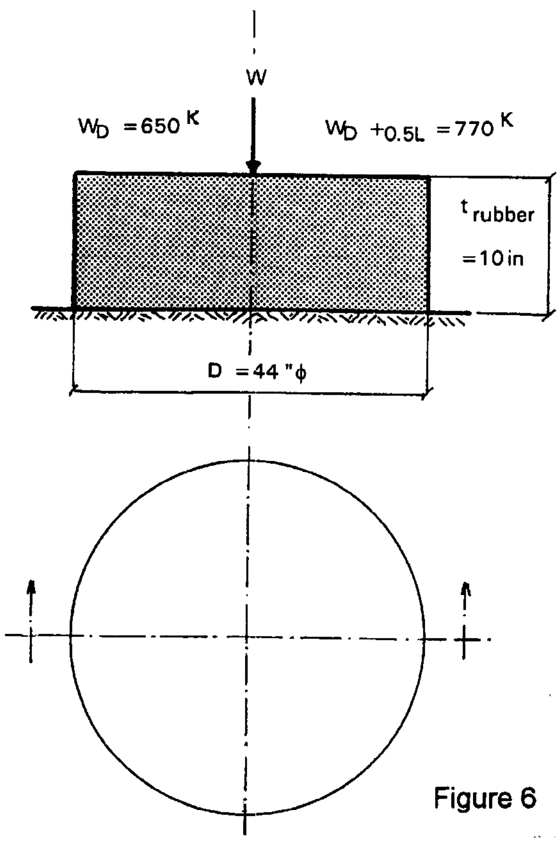


Figure 6

D = 44 in, Total thickness of rubber : t = 10 in

Average shear modulus of elasticity : $G = 90\ \#/in^2$

$$A = \frac{44^2 x 3.14}{4} = 1520\ in^2$$

Average horizontal stiffness

$$K = \frac{AG}{t} = \frac{1520\ x 90}{10 x 1000} = 13.7\, kips\ /in$$

$$T = 2\Pi\sqrt{\frac{M}{K}} = 6.28\sqrt{\frac{770}{32.2 x 12 x 13.7}} = 2.39\ sec$$

During testing a horizontal force of 30 kips moved the top of the seismic isolator from zero displacement to 0.28 in.

The seismic isolator exhibited an average initial stiffness of

$$K = \frac{30\, kips}{0.28\, in} = 107\ kips\ /in$$

in the zero to 0.28 in displacement range.

A horizontal force of 230 kips moved the top of the seismic isolator to 15 in displacement.

The seismic isolator exhibited an average stiffness of

$$K = \frac{(230 - 30)kips}{(15 - 0.28)in} = 13.6\, kips\ /in$$

This high damping rubber seismic isolator had a stiffness at the zero to 0.28 in displacement range

$$X = \frac{107}{13.6} = 7.9 \text{ times the average 13.6 kips/in stiffness.}$$

This factor of 7.9 will be used, when computing appropriate initial stiffnesses for the Composite Seismic Isolator.

See the Force-Displacement Diagram, Figure 8.

B. Composite Seismic Isolator.

The total lateral design displacement of the Composite Seismic Isolator is chosen to be 15 in. This displacement is divided into two components. The upper isolators will be displaced 7.5 in and the lower isolator also 7.5, a total displacement of 15 in. Other divisions, such as 9 in and 6 in are also possible.

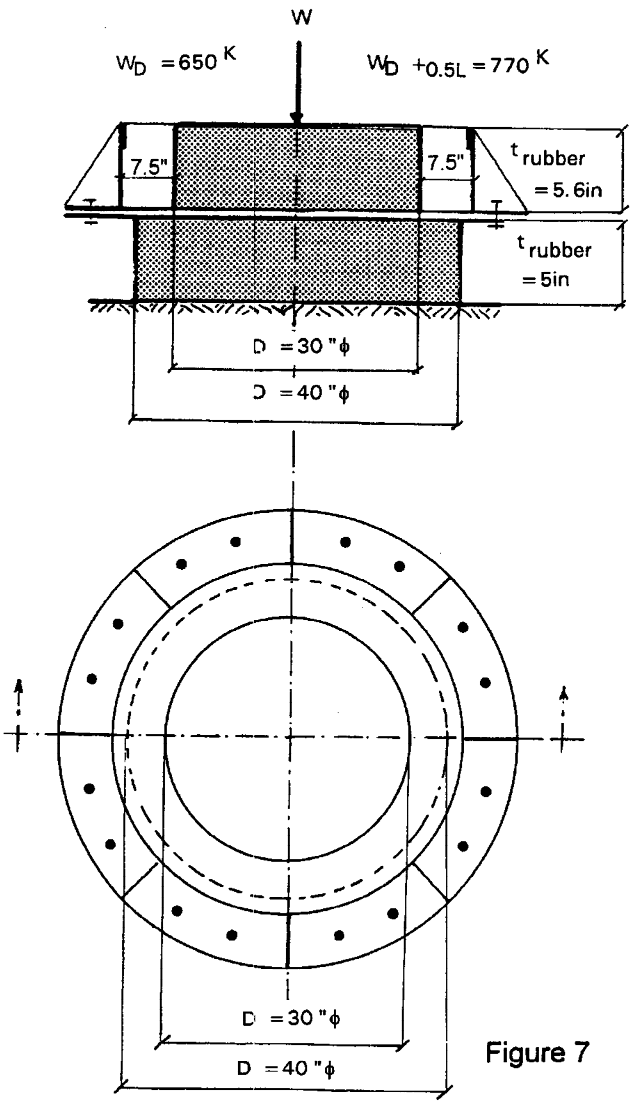


Figure 7

Upper Seismic Isolator

D = 30 in, Total thickness of rubber : t = 5.6 in,

$$\text{strain} = \frac{7.5}{5.6} = 134\ \%$$

Average shear modulus of elasticity ;

$$G = 60\ \#/\text{in}^2$$

$$A = \frac{30^2 \text{x} 3.14}{4} = 706.5 \text{in}^2$$

Average horizontal stiffness ;

$$K = \frac{AG}{t} = \frac{706.5 \text{x} 60}{5.6 \text{x} 1000} = 7.56 \text{ kips /in}$$

$$T = 2\Pi\sqrt{\frac{M}{K}} = 6.28\sqrt{\frac{770}{32.2 \text{x} 12 \text{x} 7.56}} = 3.2 \text{ sec}$$

Initial stiffness : K = 7.9 x 7.56 = 59.7 kips/in

Force required to move the top of the seismic isolator 0.28 in :

F = 0.28 x 59.7 = 16.7 kips

Force required to move the top of the seismic isolator 7.5 in :

F = 16.7 + (7.5-0.28) x 7.56 = 71.3 kips

Lower Seismic Isolator

D = 40 in, Total thickness of rubber : t = 5.0 in,

$$\text{strain} = \frac{7.5}{5} = 150\ \%$$

Average shear modulus of elasticity ; $G = 100\ \#/\text{in}^2$

$A = \frac{40^2 \text{x} 3.14}{4} = 1256 \text{ in}^2$ Average horizontal stiffness ; $K = \frac{AG}{t} = \frac{1256 \text{ x} 100}{5 \text{x} 1000} = 25.1 \text{kips /in}$

$T = 2\Pi\sqrt{\frac{M}{K}} = 6.28\sqrt{\frac{770}{32.2 \text{x} 12 \text{x} 25.1}} = 1.76$ sec Initial stiffness : K = 7.9 x 25.1 = 198.3 kips/in

Force required to move the top of the seismic isolator 0.28 in : F = 0.28 x 198.3 = 55.5 kips

See the Force-Displacement Diagram, Figure 8.

During an earthquake when a force of 71.3 kips moves the top of the upper isolator 7.5 in, the same force overcomes the original stiffness of the lower seismic isolator and moves the lower isolator

$$\Delta = 0.28 + \frac{71.3 - 55.5}{25.1} = 0.91\text{in}$$

The total horizontal displacement of the Composite Seismic Isolator now: $\Delta = 7.5 + 0.91 = 8.41$ in

Force required to displace the Composite Seismic Isolator 15 in : F = 71.3 + (15 - 8.41) x 25.1 = 236.7 kips

This is in close agreement with the F = 230 kips force required to displace the Simple Seismic Isolator 15 in, therefore a correct comparison can be made of the performance of the Simple Seismic Isolator and of the Composite Seismic Isolator.

In recognition of the 0.91 in horizontal movement of the upper seismic isolator, its effective stiffness in the Composite Seismic Isolator assembly becomes

$$K_{upper} = \frac{71.3 - 16.7}{8.41 - 0.28} = 6.7 \text{ kips /in, and}$$

$$T_{upper} = 2\Pi\sqrt{\frac{M}{K}} = 6.28\sqrt{\frac{770}{32.2 \times 12 \times 6.7}} = 3.4 \text{ sec.}$$

A Force-Deflection Diagram demonstrates significant reduction of the base shear force transmitted to the building by the Composite Seismic Isolator as compared with the Simple Seismic Isolator during any earthquake.

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The fabrication of the Composite Seismic Isolator requires less rubber compound than the Simple Seismic Isolator.

Composite Seismic Isolator:	760.5 x 5.6 =	3,956in^3	
	1256 x 5.0 =	6,280	
		10,326	
Simple Seismic Isolator:	1520 x 10.0 =	15,200	
	Difference:	4,964in^3	~ 30%

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Conclusions.

1. The Composite Seismic Isolator can reduce the maximum displacement to any required level, simply by making seismic isolator B adequately stiff.

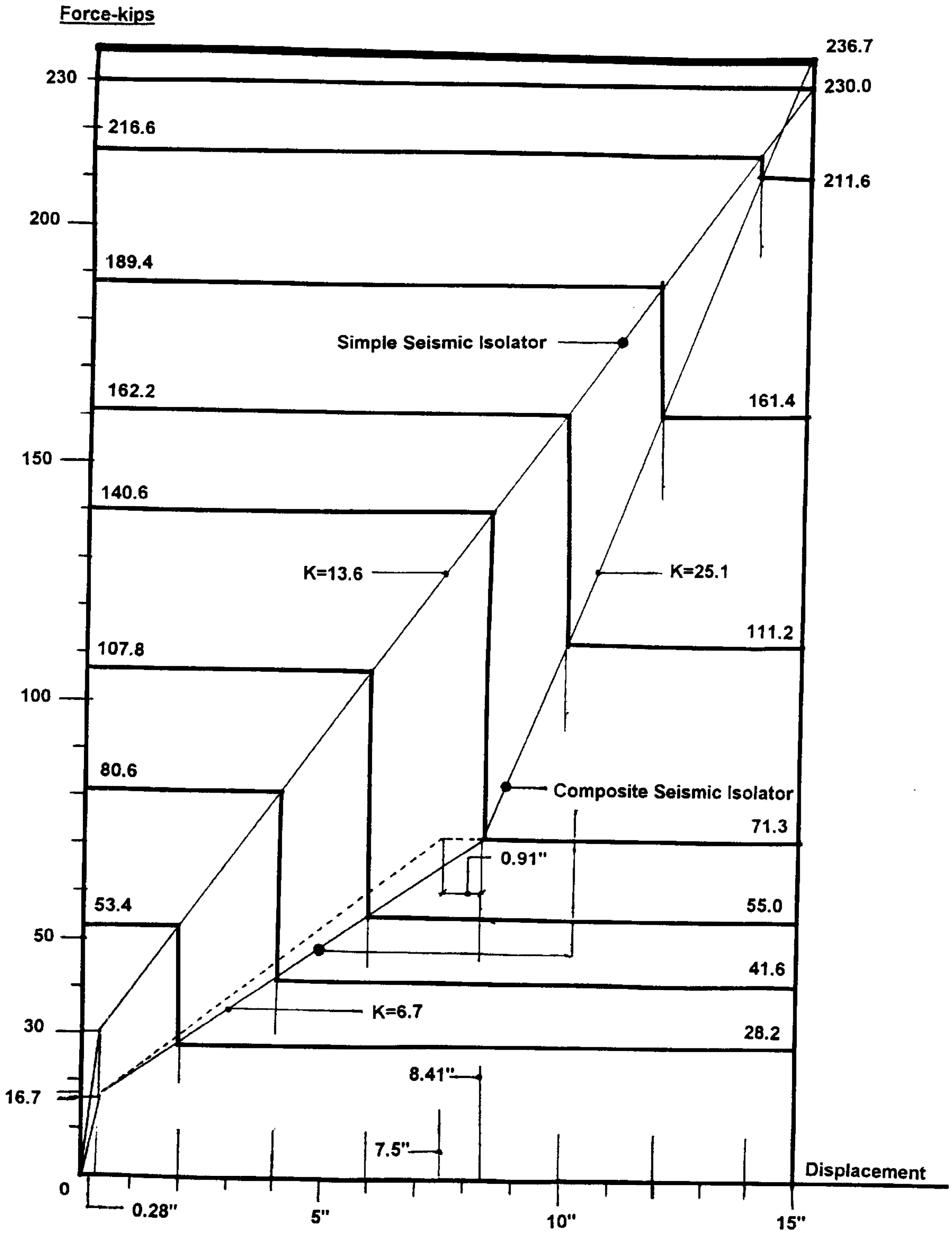
2. Increasing the stiffness of seismic isolator B does not effect the performance of the Composite Seismic Isolator in "minor" and "moderate" earthquakes and therefore the Composite Seismic Isolator is less sensitive than a conventional seismic isolator to the uncertainties associated with the prediction of the maximum design earthquake.

3. The Composite Seismic Isolator significantly reduces the base shear force transmitted to the building as compared with the Simple Seismic Isolator.

4. Can eliminate the use of and experimentation with different compounds, one soft compound can be used.

5. The displacements of the two isolator units are additive consequently the displacement demand on the individual isolator units are reduced. It simplifies base isolator fabrication.

6. Requires less rubber compound than a Simple Seismic Isolator. In the Example described, about 30% saving is demonstrated.



FORCE-DISPLACEMENT DIAGRAM

Figure 8