# Using induced earthquakes to prevent large magnitude natural earthquakes


## Abstract

The tectonic plates movement cause faults in the earth crust, which are the center of earthquakes and volcanic activity. Rock blocks on two sides of a fault accumulate elastic energy during many years and release it instantly in the form of an earthquake. It is possible to eliminate the risk of earthquakes by preventing the accumulation of the rocks elastic energy. Generating large shocks in the ground above the faults can induce earthquakes with small magnitude that will release the accumulated elastic energy. To create those socks we suggest a device that lifts a heavy weight to a considerable height and then drops it to the ground to create a powerful shock.


## Introduction

Earthquakes are the outcome of the natural movements of earth crust, caused by the drifting of the tectonic plates.  Earthquakes always accompanied villages and cities and seen inevitable menace that disrupt the normal every day life. Earthquakes strike randomly and claim life and property. Over the years we learn much on earthquakes: we learned where they typically occur we learned how to build buildings and lifelines that will withstand earthquakes and we are researching how to predict upcoming earthquakes.  However, population growth increased population density in the cities and increased the height of city buildings. Even though the construction technology and standards progresses, the vulnerability of life and property loss stays high, similarly to ancient times. We shall suggest in this article a device that not only can give us control on the time of the earthquakes but can decrease the magnitude of the earthquake to such a low level that damage to life and property will be eliminated. Building and researching such a device will cost only small fraction of the property damage from earthquakes.  Using this device can assure that living in an earthquake prone city is safe, stable and will continue without random violent interruptions of earthquakes. The device will increase the property value in that city - this will quickly return the investment of researching and constructing this device.

## Earthquakes occur when the rock elastic energy is accumulated and released

The tectonic plates movement is the main cause of earthquakes. The tectonic plates move between 1 to 16 centimeters each year. The movement of the tectonic plates creates large fractures or faults in the rock. Block of earth crust on either side of the fault moves relative to one another crushing and colliding at the fault. There are several types of faults three of them are shown in figure 1. In a Srike-Slip fault the fracture is vertical; there is lateral movement of the rock blocks but no vertical movement. An example of Strike-Slip fault is the San Andreas Fault stretching along the United States west cost and known to cause large earthquakes in San Francisco and Los Angeles. The Dip-Slip Normal fault is an inclined fracture wherein the rock block above the fault is slipping downhill relative to the other. The Dip-Slip Thrust fault is also an inclined fracture wherein the block above the fault is slipping uphill.

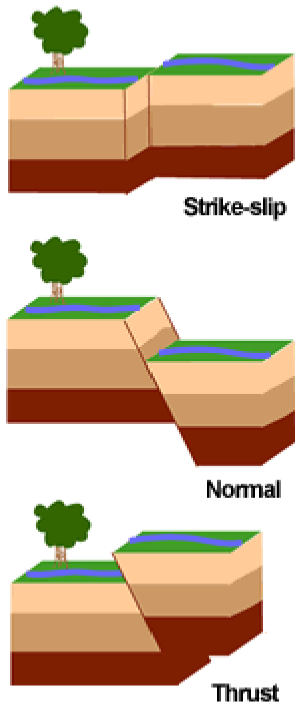


**Figure 1:** Two blocks of rock sliding relative to each other create faults. In the Strike-Slip Fault the two rock block slide laterally along a vertical fracture. In the Dip-Slip Normal Fault, one rock block is sliding downhill, on top of a second rock block, along an inclined fracture. In a Dip-Slip Thrust Fault one rock block is sliding uphill relative to the second rock block.

The tectonic plates move slowly between 1 to 16 centimeters each year. The slow motion and the high friction between the nearby rock blocks prevent the continuous movement along the fault. When the faults are stuck and the tectonic plates keep moving the rocks are compressed or stretched. The stress strain curve of figure 2 shows that at first the rocks behave elastically, so as the tectonic plates move, the potential elastic energy is accumulated. When the force exerted by the moving plates overcomes the friction in the fault, the rocks rupture and the fault slips. The stored elastic energy of the rock is suddenly and violently released in the form of an earthquake. After an earthquake it is possible to detect displacement of the crust near the fault - this demonstrates the release of the elastic energy accumulated before the earthquake. Usually the fault zone will skip the plastic mode and will continue directly from elastic accumulation to rupture. Figure 3 curves the stress near the fault with respect to time. The stress is continuously increasing until it is released suddenly in an earthquake that eliminates the stress; this process repeat itself in cycles to yield a saw teeth pattern.

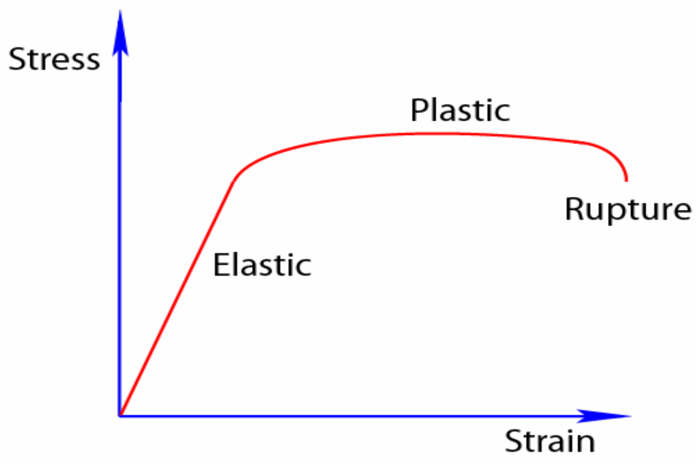


**Figure 2:** Stress-Strain curves of rocks shows the three forms of rock deformation - elastic, plastic and rupture. The stress applied by the movement of the tectonic plates will first be accumulated by elastic energy. After bypassing the yield point the rocks will plastically deform or will suddenly rupture and release their energy in the form of an earthquake.

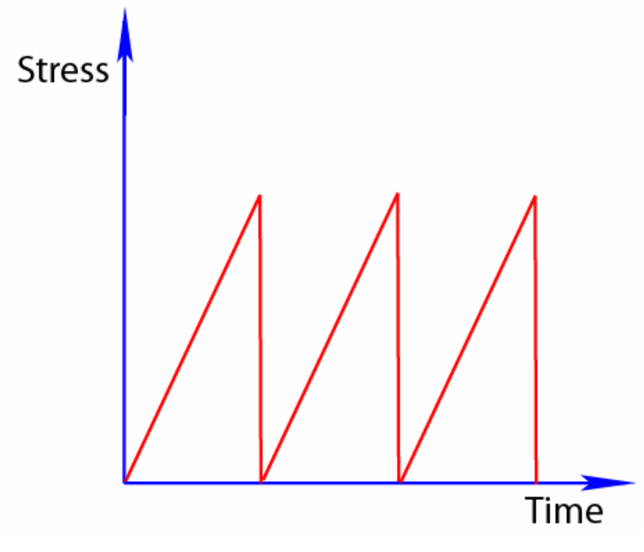


**Figure 3:** Stress versus time curve of rocks near a fault. The rock accumulates elastic energy and suddenly ruptures to create earthquake. The curve shows that there is a periodic cycle that repeats itself to build stress and release it to create earthquakes. In a certain region there will be a delay between large earthquakes. The longer the stress is given to accumulate the stronger will the earthquake be.

## Preventing accumulation of elastic energy by shocking the ground

Earthquakes take place in a sequence. First there are the foreshocks that precede the main shock; then the main shock that is the shock with the highest magnitude in the sequence and then the aftershocks that can continue for some time after the main shocks. We can mention the strong aftershocks of the 1994 Los Angeles earthquake that continued for at least a year. The aftershocks as stated in Omori's law are usually smaller then the main earthquake, however, there are sometimes strong foreshocks that precede the main shock. Therefore, we can not conclude that in a sequence of earthquakes, a big earthquake is always followed by a smaller earthquake, because there is also the case of a small earthquake followed by a larger earthquake. The device suggested in this article can therefore induce an earthquake with magnitude larger then the magnitude of the shock produced by the device itself.

The fact that earthquakes came in sequence suggest that one earthquake can induce another earthquake. The fault that are locked or stuck in one place could be released by nearby earthquake. The shocks from the nearby earthquake decrease the friction in the fault and releasing the elastic energy to create the new earthquake.
If shocks from an earthquake can create new earthquakes then, artificial or man made shocks can also induce earthquake. The suggested device operation is based on this concept. The device will shock the ground by a falling weight to induce new earthquake and release the stress buildup and the elastic energy.

Research yielded an empirical relation between the frequencies of earthquake to the magnitude of the earthquake. If the frequency of earthquakes in fault region increases, the earthquake magnitude decreases. There is less buildup of stress and elastic energy to produce large earthquake. The relation between frequency and magnitude was first described by Gutenberg and Richter (1965) who derived the empirical relation of the form:

$$\mathrm{Log}\ N = A - bM$$

Where M is the magnitude of the shocks.
N is the frequency of shocks with magnitude larger then M.
A and b are seismic constants specific to the region.

The frequency that the suggested device should be activated, in order to limit the future earthquakes magnitude to safe levels, can be obtained by extracting the frequency from the Gutenberg and Richter relation.

$$N = 10^{A-bM}$$

Gathering data from many large earthquakes around the word shows that Gutenberg and Richter equation tend to saturate at large magnitudes. Figure 4 curves the frequency magnitude relation (Chinnery and North, 1971) of large earthquakes around the world.

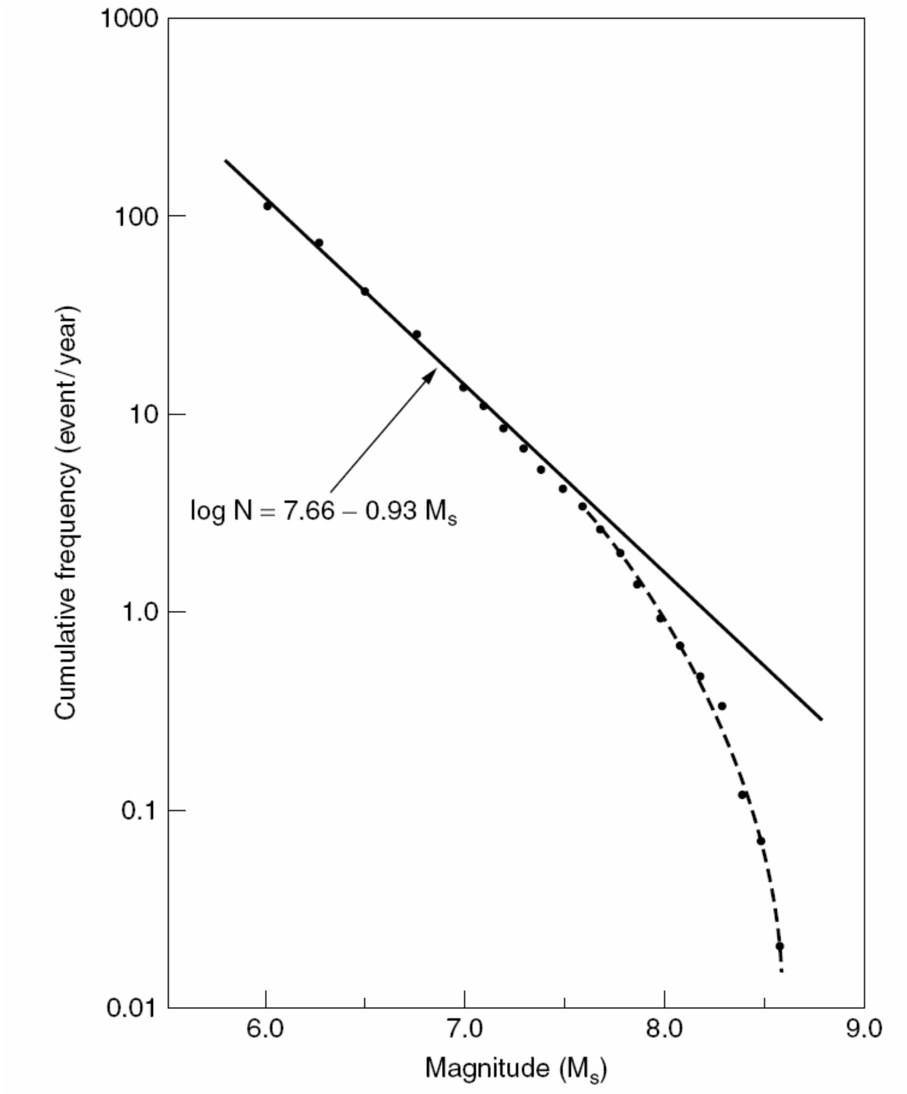


**Figure 4:** Cumulative curve of large earthquakes around the world according the Gutenberg and Richter equation. The curve tends to saturate at large magnitudes. From the curve it is clear that increasing the earthquakes frequency will decrease the earthquakes magnitude. The suggested device will do just that by inducing earthquakes to increase the frequency.

According to the Gutenberg and Richter equation, increasing artificially the frequency can decrease the magnitude of earthquakes, and thereby protects lives and property. For instance, in order to decrease an 8 in Richter scale earthquake to a 6 in Richter scale earthquake, the frequency must be increased by 100. If the said 8 in Richter scale earthquake is expected every 100 years then, operating this device to induce earthquake every year, will limit the earthquakes to only 6 in Richter scale. Operating this device twice or four times a year can further decrease the expected earthquake magnitude.

Inducing earthquakes by shocks can give as two benefits: first, we can control the time of the earthquake to evacuate or warn the nearby population; second, we can prevent large accumulation of elastic energy and limit the magnitude. The accumulation of elastic energy can take decades - so trying to induce earthquakes, for instance, every year can prevent this accumulation. This in fact will convert one high magnitude earthquake to many smaller earthquakes. In figure 5 there is a stress versus time curve showing the decrease in stress buildup (relative to figure 3) and increase in the number of small earthquakes, when using shocks to decrease the risk of damage from earthquakes.

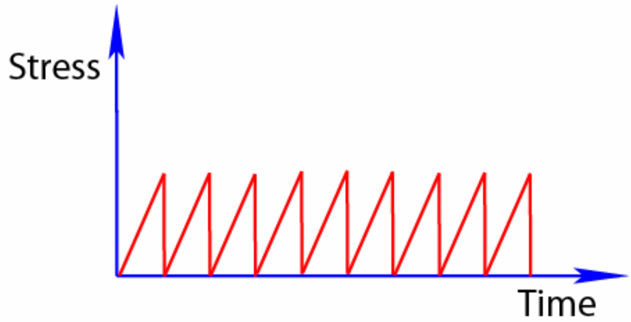


**Figure 5:** In relation to figure 3, increasing the frequency of the earthquakes will limit the stress buildup and the accumulation of elastic energy. This will decrease the magnitude of the earthquake and will eliminate the risk to lives and property.

There are two simple methods to produce those shocks, one is to use explosives and the second is to lift large mass and let it free fall on a flat hardened surface. Using explosives is a very ineffective because the duration of the explosion can take many seconds, so the energy of the explosion will be dispersed as many but small in magnitude shockwaves to the ground. Also the explosion cannot be directed toward the fault and its energy will be dispersed in all directions. The second method of lifting heavy mass is preferred. The heavy mass could be a steal box filled with heavy material like lead, to weight about 10000 tons. It could be lifted to a steal tower, to a height of for instance, 50 meter. The lifting mechanism could be a system of pulley similar to those used in large cranes. When the steel box will fell to a steel flat surface, the time of the impact will be so short that a strong P-wave will be created. The P-Wave will also be directed downward toward the fault.

The operation of the device is depicted graphically in Figure 6. In figure 6a there is a top view of a Strike-Slip Fault segment. This fault experienced earthquake lately therefore, there is no accumulation of elastic energy, and we denote it by straight lines perpendicular to the fault. In figure 6b the tectonic plates and the rock blocks, on the two sides of the fault, moved relative to each other. This accumulates elastic energy in the rock - the accumulation of the elastic energy is denoted by curved lines on the two sides of the fault. In figure 6c the artificial shock is applied at the position of the red circle. Aftershocks follow the artificial shock and there is a displacement of the rock blocks at the two sides of the fault. The displacement eliminates the elastic energy in the fault and revert the fault to its discharged state of figure 6a.

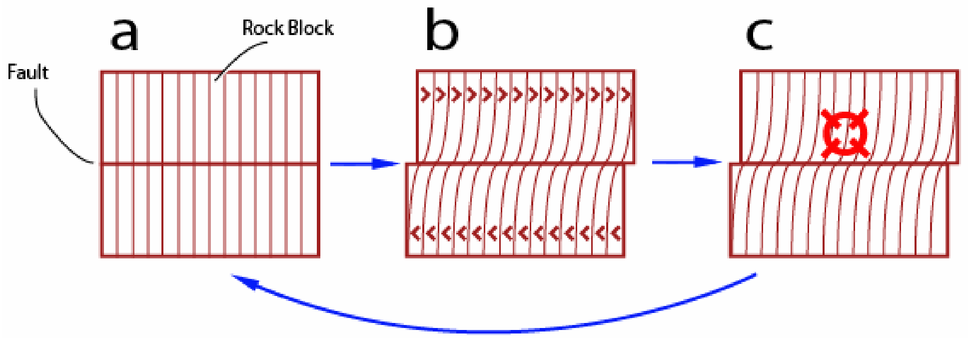


**Figure 6:** The effect of the device operation on the Fault. In 6a there is no stress buildup or elastic energy in the rocks. After movement of the rock blocks there is stress buildup in the rocks 6b. The operation of the device on 6c releases the stress buildup, reverting the rock blocks to their discharged condition at 6a.

This method of preventing earthquake resembles snow avalanche prevention methods. To decrease the risk of snow avalanche on mountains slopes near ski resort or downhill towns, explosives are used to trigger small avalanches. The small avalanches remove the snow from the mountain and prevent the massive buildup of snow on the mountain. This way one large and destructive avalanche is converted to many harmless small avalanches.

## Detailed description of the shock device setup

The device basic operation is to lift a heavy weight to a height of several tens of meters and to quickly release it. The heavy weight will free fall to the ground, where it will hit a flat hardened surface. The impact from the collision between the falling weight and the ground will produce a shockwave or p-wave that will propagate downward to the fault beneath. The device is comprised of several components required to its operation: The heavy weight, a lifting mechanism that contain system of pulleys driven by an electric motor, a releasing mechanism that enable to release quickly the weight from the pulley to start its free fall, and a steel tower strong enough to carry and lift the weight.

Figure 7 depicts the overall structure of the device including the steel tower, the weight, the pulley, the releasing mechanism and the flat surface.
The weight is constructed from a steel box. The walls of the box are assembled from sheet metals riveted or welded together. The inside of the box is filled with high density lead to create a box significantly heavy but with small in dimensions. To withstand the shocks from the free fall the box can be filled with small hollow blocks of steel which are filled with lead. Such blocks can have sizes of 30x30x30 centimeters, where the steel wall of the blocks will be 2 cm thick and the rest filled with lead. The required overall weight of the box is 10000 tons so by using the density of lead 11.34 g/cm$^3$ we can find the volume of the box. So if one cubic meter of lead weight 11340 kg a box 10x10x10 meters made of steel and lead will weight roughly 10000 tons.

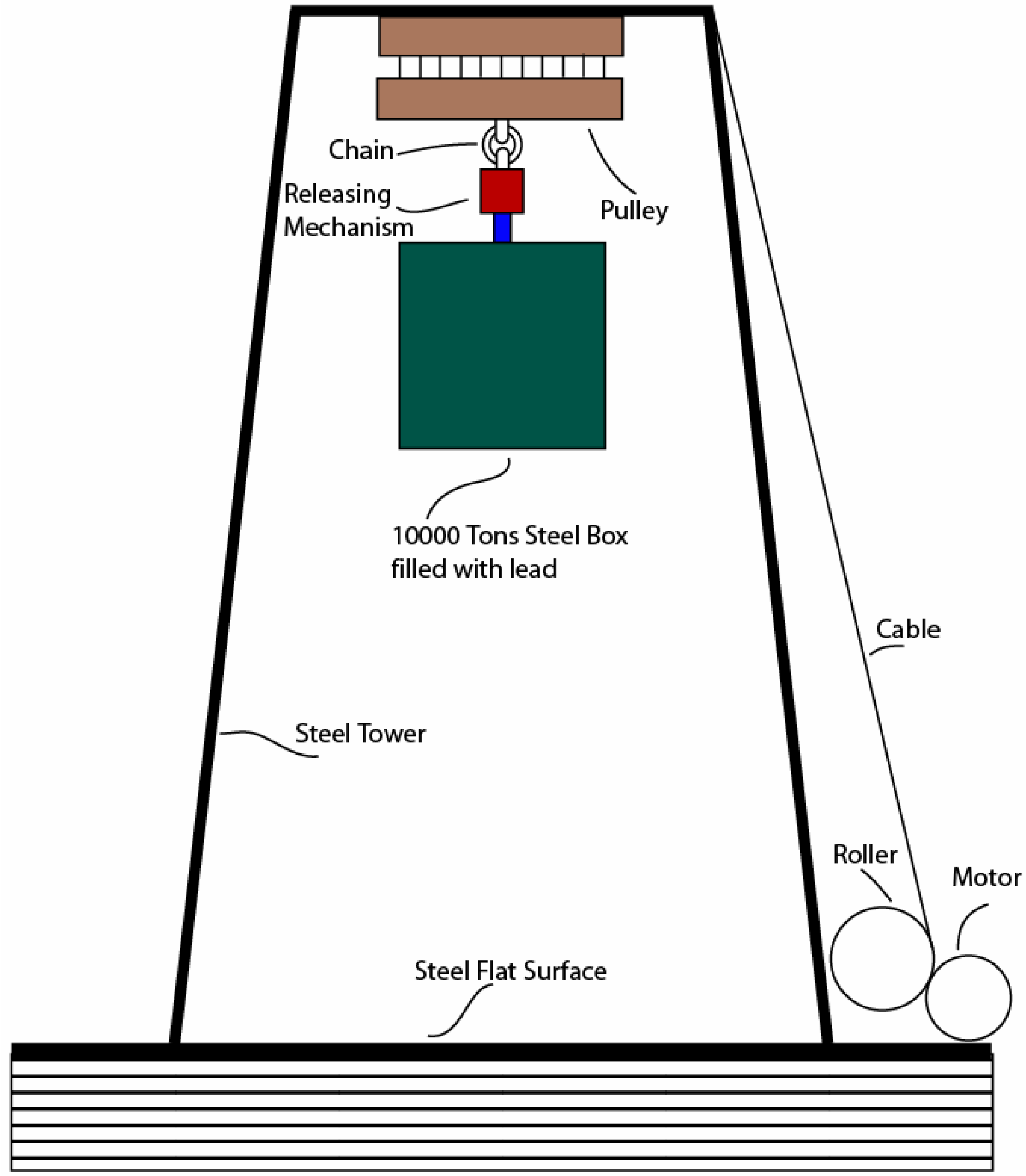


**Figure 7:** The device includes a steel tower to carry and lift a heavy steel box. The device includes a lifting mechanism based on pulleys. A motor will rotate a roller that will pull the pulley cable. A releasing mechanism will disconnect the steel box from the pulley after the steel box is fully lifted. The steel box will free fall to the steel flat surface to produce a strong shock.

The flat surface, that will sustain the falling steel box, is made of several layers of I-Shaped steel beams. The beam layers should be webbed so each layer of beams will be perpendicular to the above or below layers of beams. The contact area of the steel box to the flat surface needs to be very accurate so there is a perfect match between the bottom of the steel box and the flat surface. If there will be no good match between the steel box and the flat surface, the impact of the steel box and the flat surface will produce smaller shockwaves. The impact energy will be dispersed to many small shockwaves and part of the energy will be absorbed in deforming the steel components of the box and the flat surface. The lifting and releasing mechanisms that

carry the steel box need to be calibrated so that the bottom of the steel box will be perfectly parallel to the flat surface. This can be accomplished by placing weights on the upper corners of the steel box.
The flat surface needs to be perforated for air outlets. The bottom of the steel box will be about 10x10 meters so when the box will free fall, air will be trapped between the steel box and the flat surface. If there are no air outlets the air will absorb and suppress the impact.

The fact that the device will experience heavy shocks limits the use of concrete. Concrete will be cracked and fractured under these conditions and will not provide any structural support. However, if the device is constructed on soil, concrete could be used to solidify the soft soil below the device to better propagate the shockwave toward the bedrock below.

The lifting mechanism is comprised of pulleys and cables system driven by an electric motor. The electric motor will rotate a roller. The roller will pull a cable that will tighten the pulley to lift the steel box. Similar mechanism could be found in large cranes - some of them can lift up to 4000 tons.

The releasing mechanism is shown in figure 8 in which 8a is the side view and 8b is the top view.  The mechanism is comprised of inner and outer parts. The inner part has teeth projecting to the outside while the outer part has teeth projecting to the inside. The inner and outer teeth fit in diameter and can be meshed together. When the inner and outer teeth are aligned along the same line, the inner and outer parts are locked, and can carry the weight of the steel box. When the inner and outer teeth are misaligned the inner part slip in the outer part, the locking is disengaged, and the steel box is released. In figure 8b the teeth are shown misaligned so the inner part can freely slide out. To change the alignment of the teeth - and thereby to release the steel box, a pneumatic actuator is used as shown in figure 8b. The change between the locked and unlocked states of the release mechanism requires some angular movement. The freedom for the angular movement could be provided by a hinge or bearing between the steel box and the release mechanism, or by a heavy chain comprised of few loops as shown on figure 7.

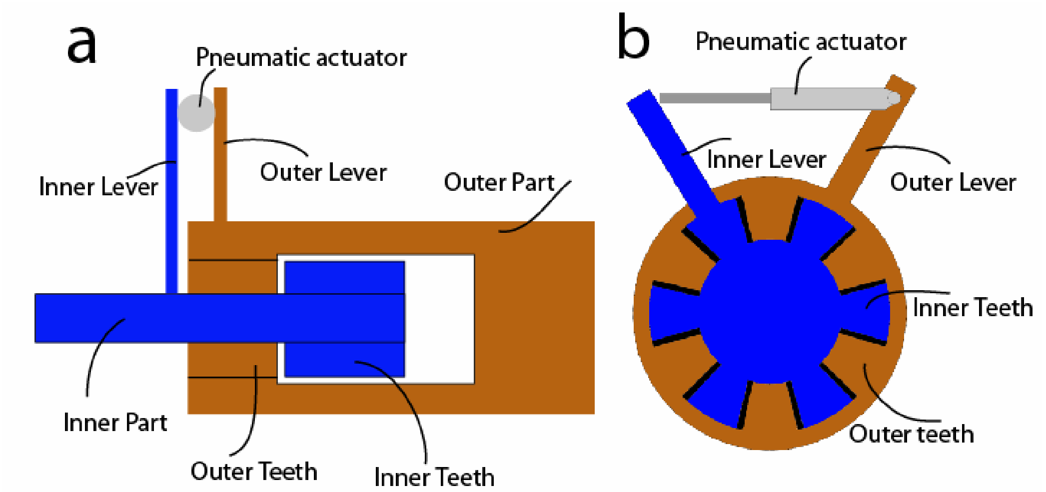

**Figure 8:** The releasing mechanism is comprised of inner and outer parts with meshing teeth. When the teeth are aligned the mechanism is locked. When the teeth are misaligned as in 8a the there is no locking and the steel box is released. A pneumatic actuator can disengage the teeth by rotating the inner part relative to the outer part.

A fence containing acoustic barrier could encircle the device to minimize the extreme noise created when the steel box hits the ground.

In figure 9 there is an alternative design of the device. This design lacks the steel tower and will not affect the landscape. This design is based on a large steel lever that is connected to the ground by hinge at one end, and carries the steel box at the other end. The lever is raised from its horizontal position to a perpendicular position, in which the steel box height is equal to the steel lever length. As with the tower design a pulley system is used to raise the lever. When the lever is released the steel box fall backs to the ground reverting the lever back to its horizontal position.

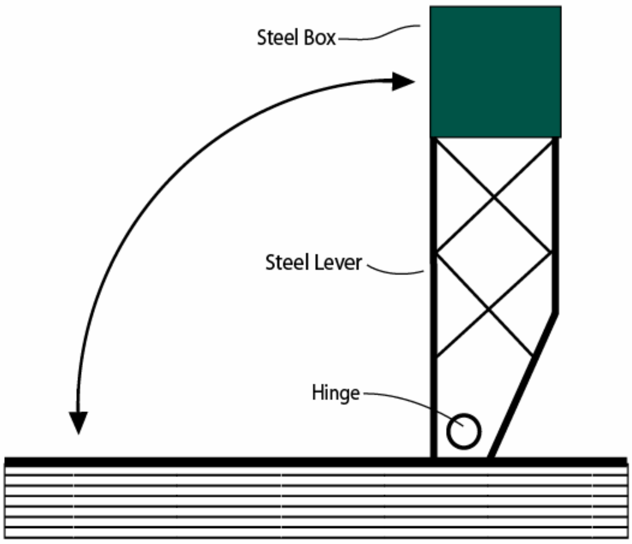


**Figure 9:** An alternative design of the device in which the steel box is lifted by a steel lever. At one end of the steel lever the steel box is connected, and at the opposite end a hinge is connecting the lever to the ground. The steel box is lifted by pulling the lever from a horizontal position to a vertical position. The steel box is then released, to return the lever to its horizontal position, and shock the ground.

## Finding the right location to install the device

To research this device it must be first activated in an unpopulated area. The device when operated needs to produce small displacement of rock blocks near the fault. This displacement can signify that the device induced an earthquake that released the elastic energy by causing slip along the fault. We also need to find the more accurate evaluation of the tower height and the steel block weight. This can be done by dropping the steel block from lower heights to see if a smaller shock can induce an earthquake. The gravitational potential energy of the steel box depends of the height of the steel tower and the mass of the steel box according to the relation u=mgh where u is the potential energy, m is the mass of the steel box, g is the gravitational constant 9.81 and h is the height of the steel box above the flat surface. To change the potential energy of the steel box we can change its weight or we can change the height of the steel tower.

The device should be installed near a city which is built close to a fault. The general rule in finding the location of the device is to draw an imaginary line between the city and the fault, where the line is perpendicular to the fault. The device should be located on that line near the fault. In figure 10a there is a strike-slip fault in which the device is located very near the fault and at the same rock block of the city. In a normal or thrust fault 10b the device should be placed above the expected focus of the earthquake. The expected focus should be estimated based on historical data of earthquakes that strike before near that fault.

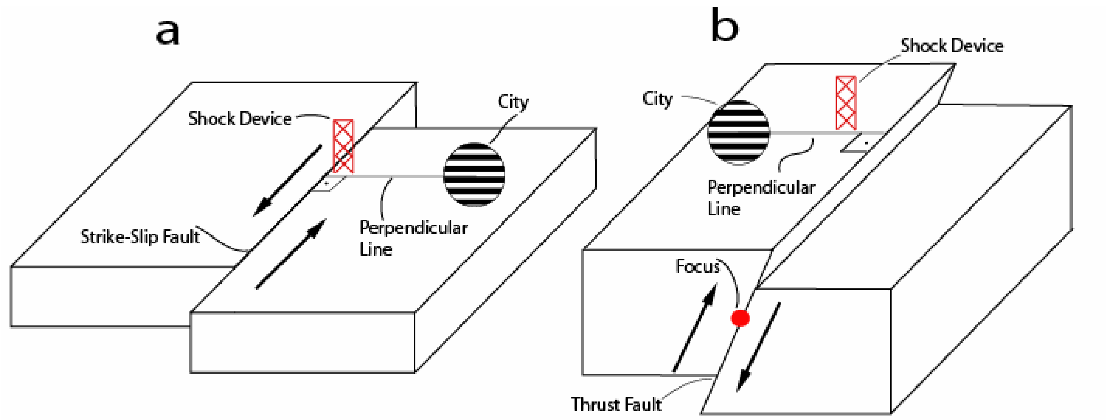


**Figure 10:** The device should be located near the fault on a line perpendicular to the fault. For a strike-Slip Fault 10a the device should be place as close as possible to the fault. For a Normal or Thrust Fault 10b the device should be placed slightly far from the fault above the expected focus of the earthquakes.

Another approach in finding the location of the device is to analyze historical earthquakes in the region and to place the device near the focus of large earthquakes that occurred lately in the area.

The device should be placed on solid ground preferably on rock layers and not on soft soil. Soft soil will absorb the wave and will not propagate it properly to the fault. The device will not function if placed on soft soil.

If for instance, we want to find the location of the device to protect San Francisco from earthquakes. The device should be placed on the San Andreas Fault near the 1838 earthquake focus. A second device could be placed north to San Francisco, on the San Andreas Fault near Stinson beach. This will be far below the 1906 San Francisco earthquake focus.
In San Francisco the device cannot be located on a line perpendicular to the fault because this will be in sea water.

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