Acoustics • Shock • Vibration • Signal Processing **November 2001 Newsletter**

Greetings

I am very saddened by the tragic loss of innocent life that occurred as a result of the terrorist attacks on September 11.

The sacrifice of the heroic firefighters who gave their lives to save others brings to mind the scripture:

"Greater love hath no man than this, that a man lay down his life for his friends." John 15:13

May we all pray for peace.

I publicly express my support for President George W. Bush as he leads our nation through this painful ordeal. I also express my gratitude to the men and women serving in the U.S. military forces.

I have struggled over the content of this month's newsletter. To write about the engineering characteristics of the World Trade Center disaster seems opportunistic and sacrilegious. Nevertheless, we must try to understand this tragedy from every aspect, as part of the healing process.

Please donate to the Red Cross.

Sincerely,

Tom Irvine

Tom Irvine
Email: tomirvine@aol.com

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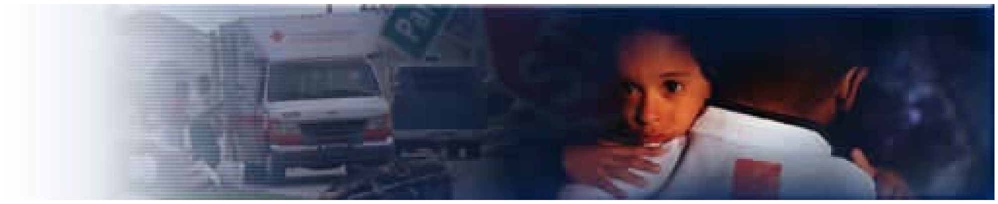
Articles

American Red Cross

Together, we can save a life



Please Donate

http://www.redcross.org/

Seismic Waveform Review   By Tom Irvine

There are four basic seismic waveforms as shown in the following table.

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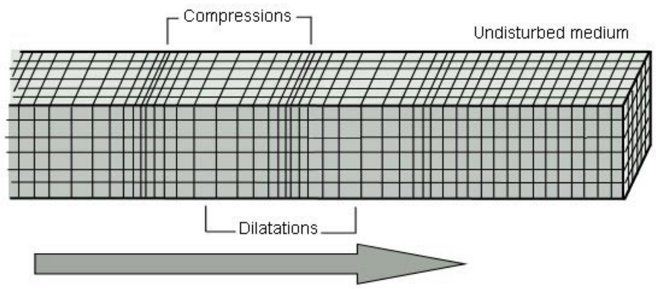
P Wave



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The primary wave, or P-wave, is a body wave that can propagate through the Earth’s core. This wave can also travel through water.

The P-wave is also a sound wave. It thus has longitudinal motion. Note that the P-wave is the fastest of the four waveforms.

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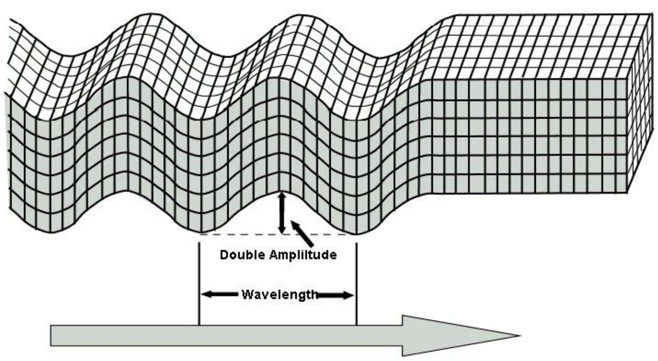
S Wave



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The secondary wave, or S-wave, is a shear wave. It is a type of body wave.

The S- wave produces an amplitude disturbance that is at right angles to the direction of propagation.

Note that water cannot withstand a shear force. S-waves thus do not propagate in water.

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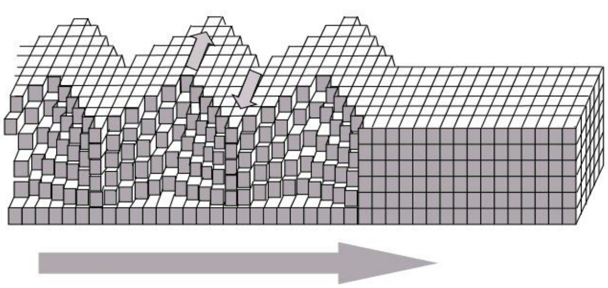
Love Wave



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Love waves are shearing horizontal waves. The motion of a Love wave is similar to the motion of a secondary wave except that Love wave only travel along the surface of the Earth.

Love waves do not propagate in water.

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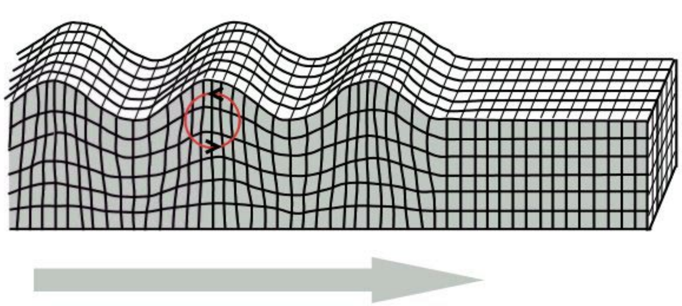
Rayleigh Wave



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Rayleigh waves travel along the surface of the Earth.

Rayleigh waves produce retrograde elliptical motion. The ground motion is thus both horizontal and vertical. The motion of Rayleigh waves is similar to the motion of ocean waves except that ocean waves are prograde.

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The World Trade Center Disaster: A Shock and Vibration Perspective

By Tom Irvine

I express gratitude to Dr. Terry C. Wallace, Professor of Geosciences, University of Arizona, for his contributions to this article.

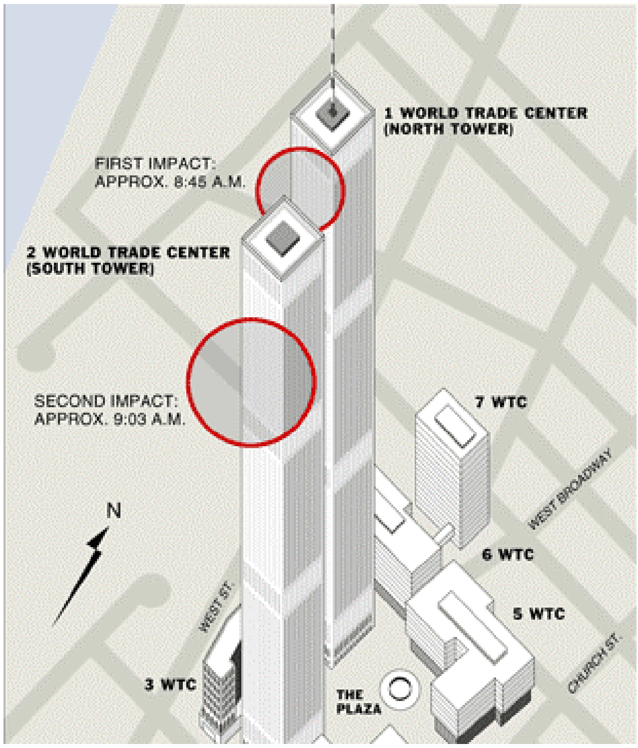


Image Courtesy of New York Times

Figure 1. World Trade Center Towers

Introduction

A hijacked passenger jet, American Airlines Flight 11 out of Boston, Massachusetts, crashed into the north tower of the World Trade Center at 8:46 a.m. EDT, tearing a gaping hole in the building and setting it afire. The north tower collapsed one hour and 40 minutes later.

A second hijacked airliner, United Airlines Flight 175 from Boston, crashed into the south tower of the World Trade Center and explode at 9:03 a.m. EDT.   The south tower collapsed 56 minutes later.

A diagram of the towers and the impact locations is shown in Figure 1.

Tower Construction

The towers were constructed of steel frames, glass, and concrete slabs on steel truss joists, as shown in Figure 2.

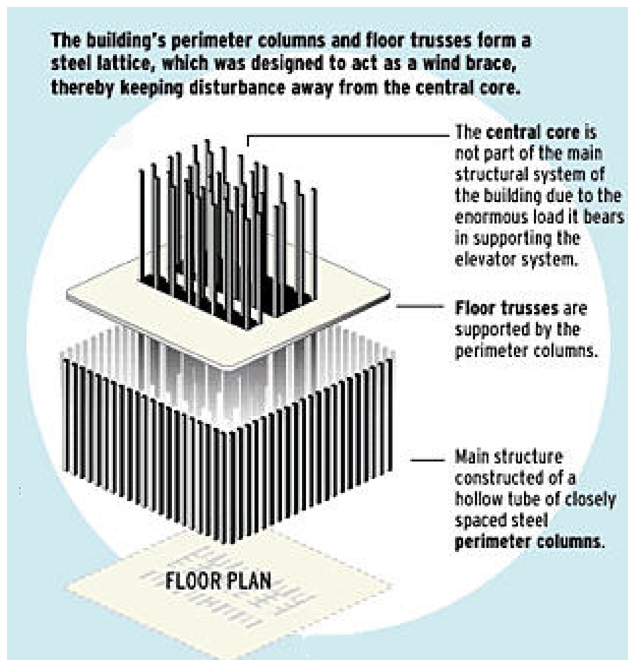


Image Courtesy of The University of Sydney – Department of civil Engineering

Figure 2. World Trade Center Construction

Each tower had 110 stories.

Furthermore, each tower was supported by a series of steel columns, which were built into the exteriors.   These columns were designed to withstand wind loads.

A central core of steel columns supported the elevator system weight.

Steel trusses supported the concrete slab of each floor and tied the perimeter columns to the core, preventing the columns from buckling outwards.

Collapse

The impact of each plane crash destroyed a significant number of perimeter columns on several floors of the building, severely weakening the entire system. Initially this was not enough to cause collapse, however.

The two jets had recently taken off. They thus contained a large volume of fuel. The impacts resulted in fires, which burned at enormously high temperatures.

The strength of steel drops markedly with prolonged exposure to fire. In addition, the elastic modulus, or stiffness, of the steel reduces, thereby increasing deflections.

Eventually, the steel columns and trusses in each tower weakened to the point where they could no longer support the floor slab weight. A floor thus collapsed in each tower, setting off a chain reaction of lower floors to fall. These events resulted in the total destruction of each building.

Seismic Events

The World Trade Center attack was recorded by seismometers deployed in the Northeast. The closest station was PAL, at Palisades New York.

The events are summarized in Table 1. The seismic time history data is plotted in Figure 3.

Table 1. WTC Seismic Events

Date	Origin Time (UTC)	Magnitude (Richter scale)	Time (EDT)	Dominant Period	Signal Duration	Remark
09/11/2001	12:46:26±1	0.9	08:46:26	0.8 sec	12 seconds	first impact
09/11/2001	13:02:54±2	0.7	09:02:54	0.6 sec	6 seconds	second impact
09/11/2001	13:59:04±1	2.1	09:59:04	0.8 sec	10 seconds	first collapse
09/11/2001	14:28:31±1	2.3	10:28:31	0.9 sec	8 seconds	second collapse
09/11/2001	21:20:33±2	0.6	17:20:33	0.7 sec	18 seconds	Building 7 collapse

Table Courtesy of Lamont-Doherty Earth Observatory of Columbia University.

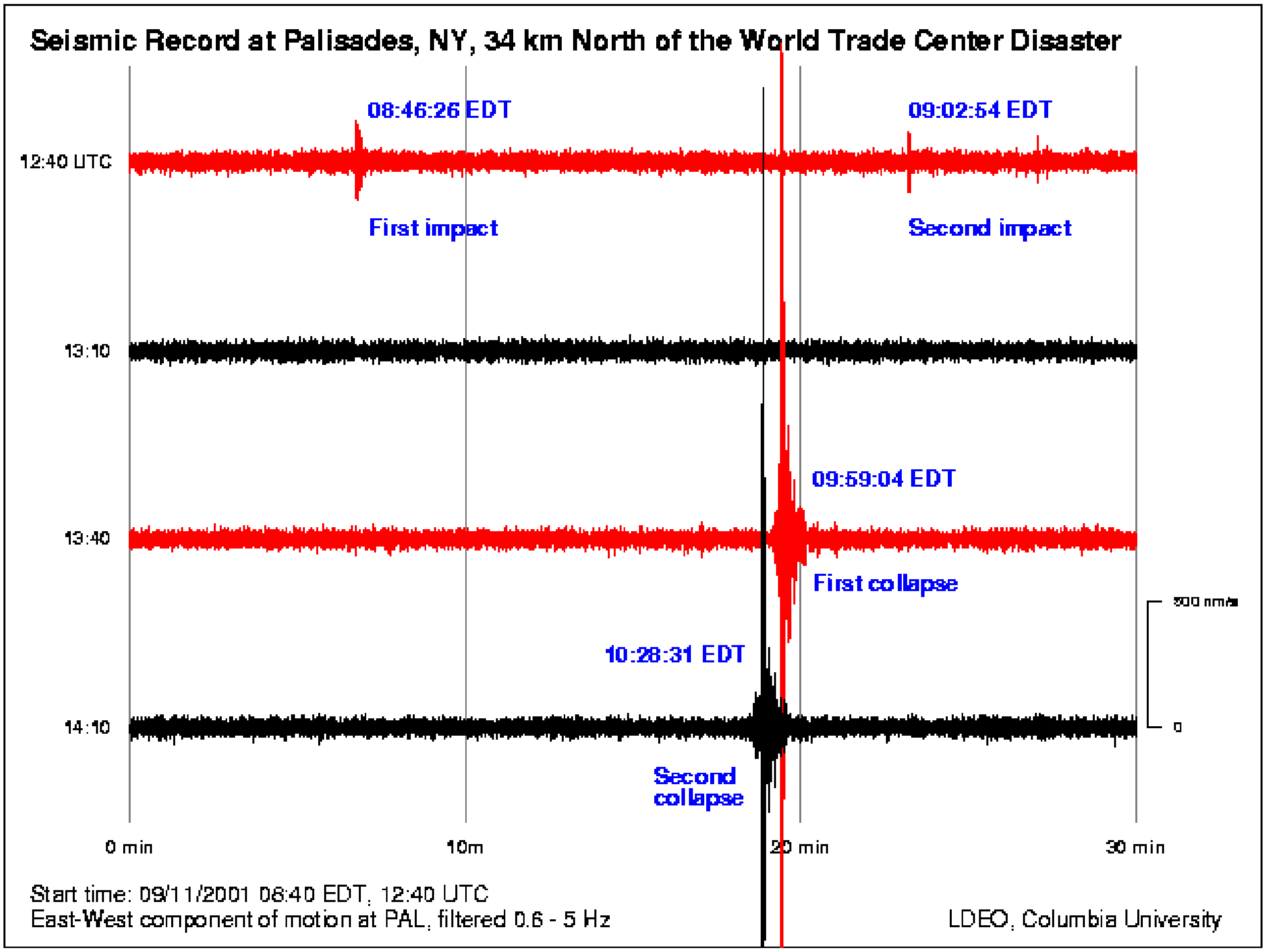


Figure 3. Seismic Time History Data

Four seismogram traces showing the two hours of seismogram recorded at Palisades, New York. Each trace is 30 minutes long. Note that the first impact resulted in the second collapse, and the second impact resulted in the first collapse.

Seismic Wave Generation Mechanisms

A diagram showing the impact of a jet into one of the towers is shown in Figure 4.

The building can be modeled as a tall cantilever beam, fixed at its base. The jet strikes near the top of the beam, delivering a sharp impulse. The beam vibrates in response at its fundamental frequency. A dynamic reaction force occurs in the ground at the base of the beam, generating horizontal shear waves, as shown in Figure 5.

These seismic waves are called "Love waves." They travel along the Earth's surface. A diagram of Love waves is shown on Page 3.

Note that the building itself was able to withstand this vibration. The collapse occurred well after the vibration cycles decayed.

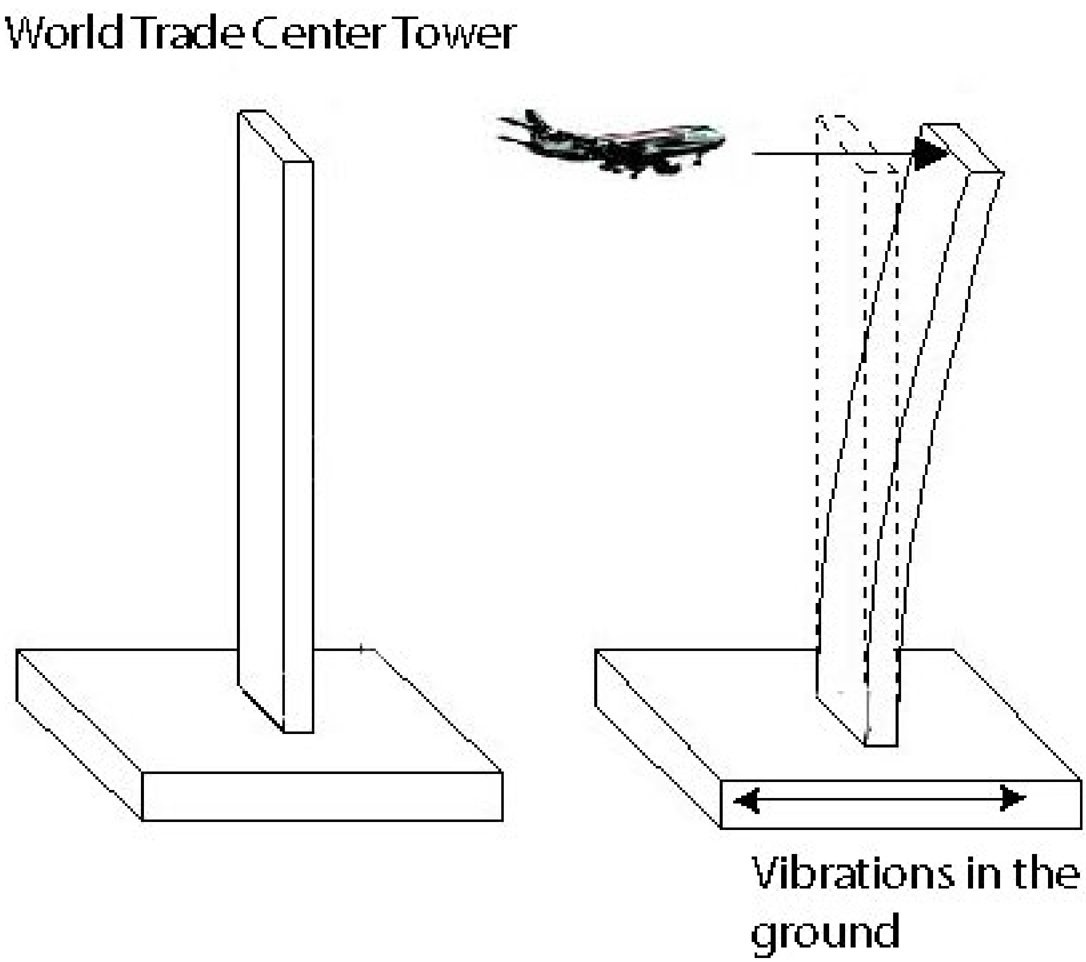


Diagram Courtesy of Dr. Terry C. Wallace, Professor of Geosciences, University of Arizona

Figure 4. Jet Striking World Trade Center Building

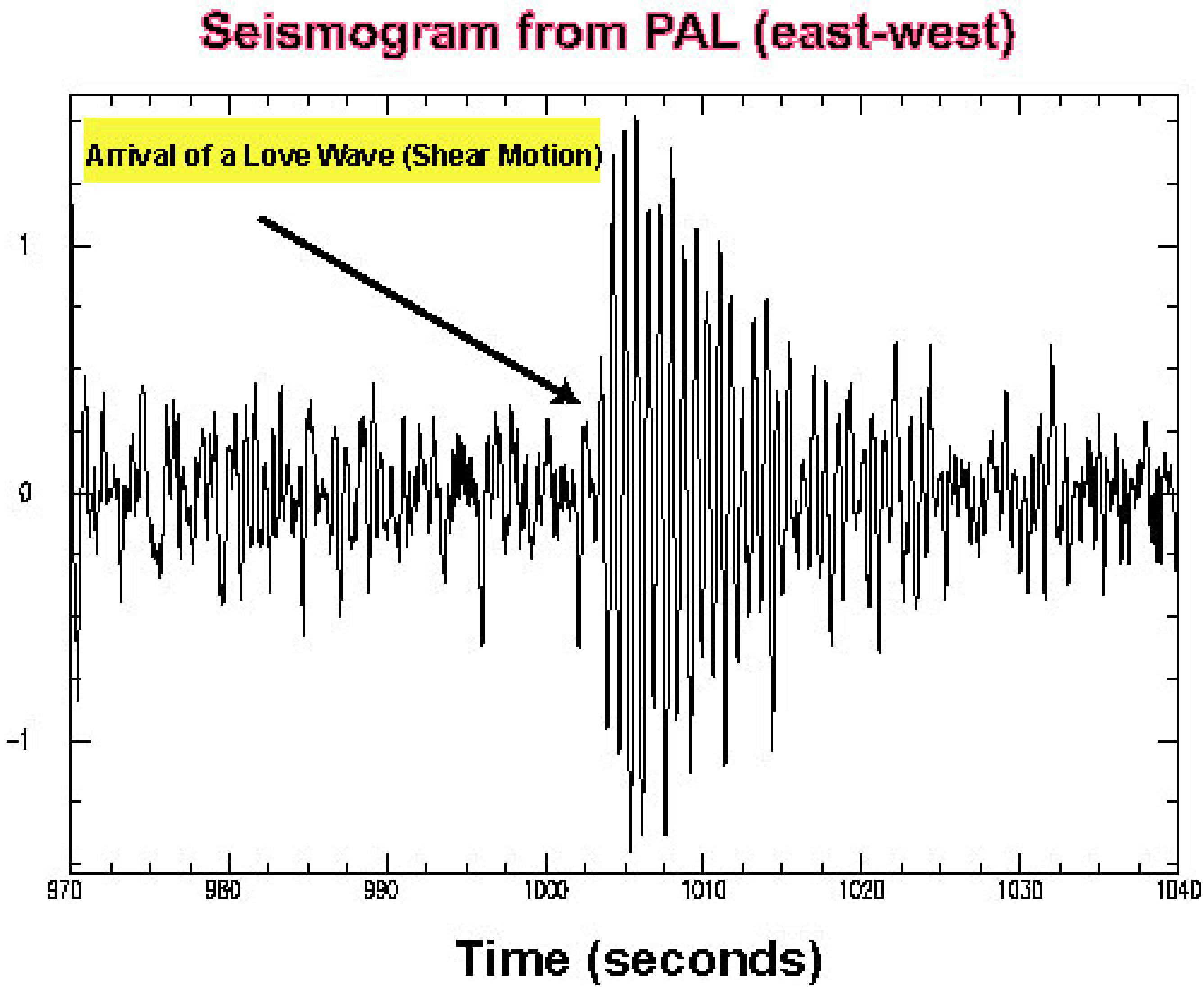


Figure 5. Love Wave

The waveform is the seismic energy from the first collision between the American Airlines Jet and the WTC recorded on the PAL seismic station east-west component.

The collapse of each building generated a downward force, as shown in Figure 6. This force created "Rayleigh waves" in the ground, as shown in Figure 7.

A Rayleigh wave is a type of seismic wave that travels along the Earth's surface. A diagram of Rayleigh waves is shown on Page 3.

The seismic magnitude of the collapse events was considerably greater than the magnitude of the impact events.

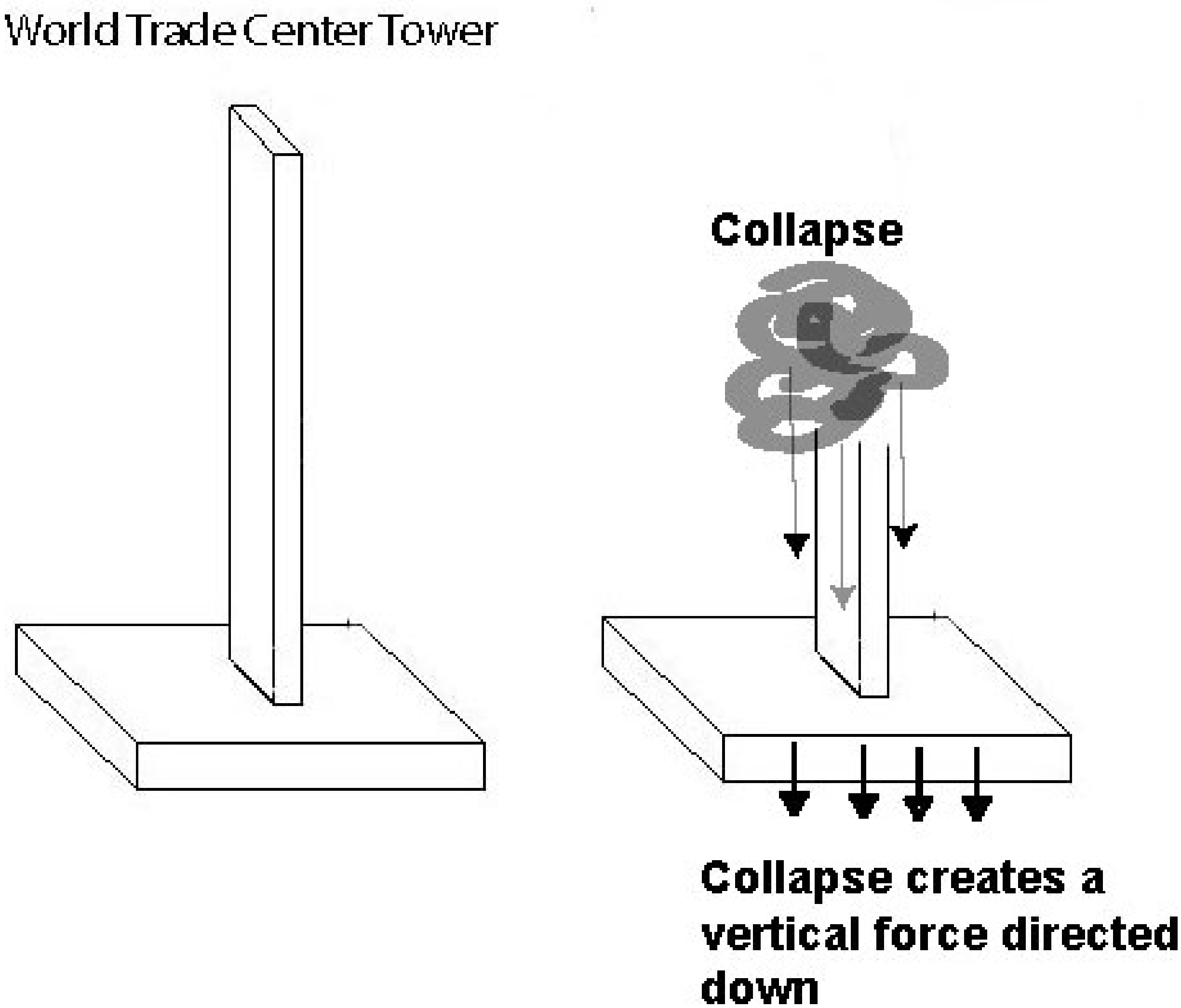


Diagram Courtesy of Dr. Terry C. Wallace, Professor of Geosciences, University of Arizona

Figure 6. WTC Collapse

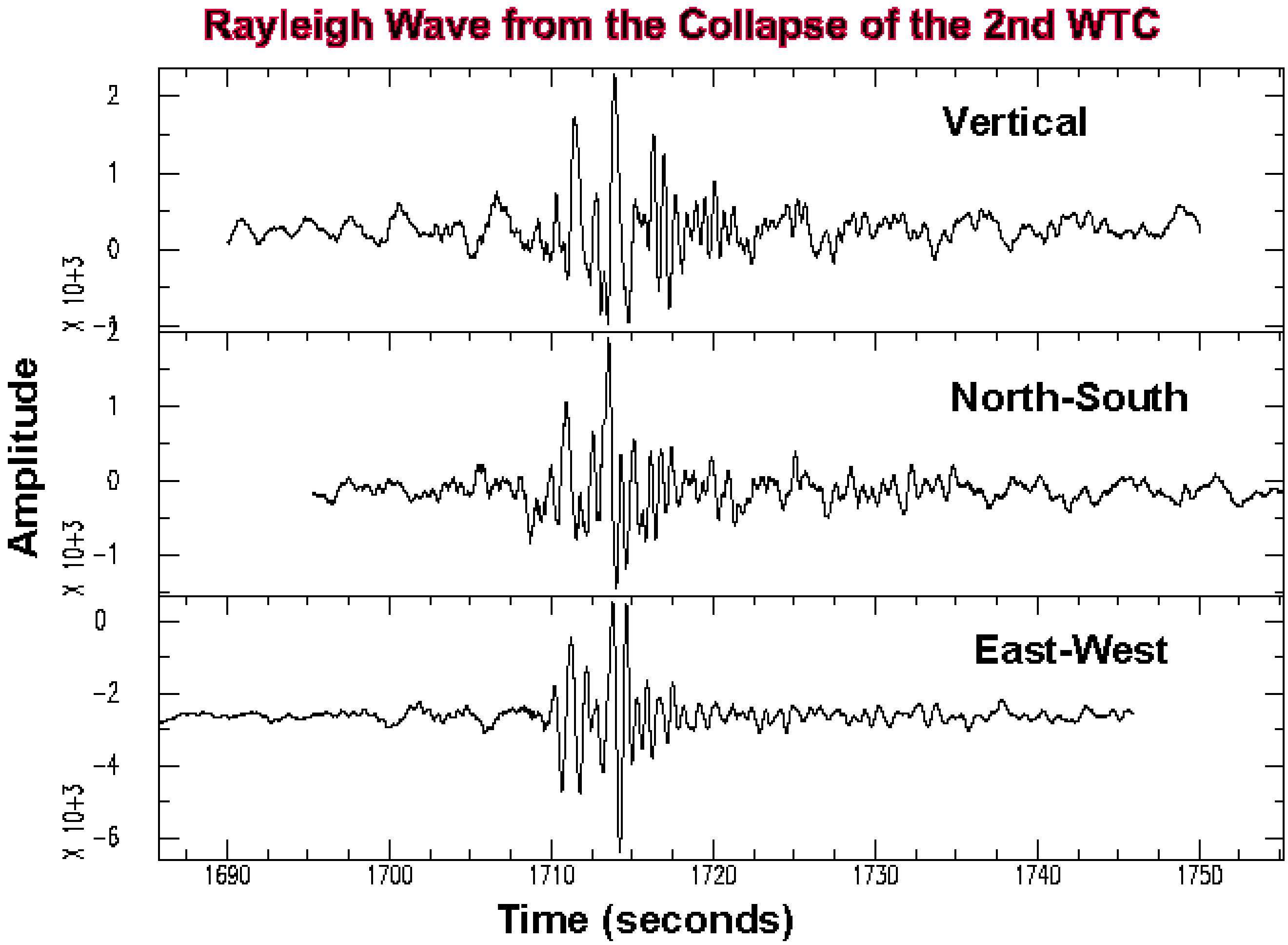


Figure 7. Rayleigh Waves

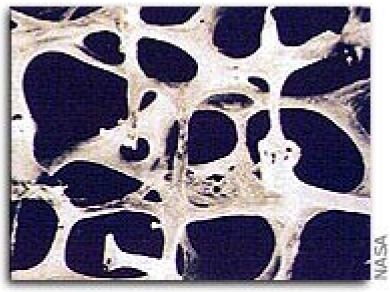
<u>Conclusion</u>

Civil engineers have always faced the task of designing tall buildings that could withstand ground shaking.

The collapse of the towers, however, was a reciprocal case where the buildings tragically shook the ground.

NASA PRESS RELEASE
Date Released: Monday, October 01, 2001

"Good Vibrations" May Prevent Bone Loss in Space



New NASA research suggests bones that are slightly shaken may help astronauts stay healthier during long spaceflights, and could be used to help people suffering from bone loss here on Earth.

Scientists funded by NASA and its National Space Biomedical Research Institute in Houston uncovered evidence that barely perceptible vibrations may stimulate bone growth, which would benefit astronauts on extended space missions, the elderly here on the ground, and other people immobilized by paralysis or bed rest.

A team of researchers, led by Dr. Clinton Rubin of the State University of New York at Stony Brook, discovered that normally active animals exposed to 10 minutes per day of low-magnitude (0.25 G), high frequency (90 Hz) vibrations experienced increased bone formation when compared to the control group.

In addition, when animals, prevented from regular, weight-bearing activity, were exposed to 10 minutes of vibrations per day, bone formation remained at near-normal levels. However, animals not exposed to the treatment, but participated in 10 minutes of weight-bearing activity each day, still exhibited signs of significant bone loss.

While preliminary results are encouraging, "a full clinical study must be completed to demonstrate the effectiveness of using vibrations to recover bone mass and architecture in people with osteoporosis or to prevent the bone loss known to occur in astronauts during long duration space flight," Rubin said.

The technique works by stimulating the bones' stress response. "Bone and muscle are plastic tissues that undergo structural changes to match the functional demands that are placed on them," said Dr. Bruce Hather, a muscle specialist at NASA Headquarters' Office of Biological and Physical Research in Washington. "The people you see working out with barbells at the local gym typically have larger muscles and stronger bones than someone who does little or no exercise."

While researchers do not fully understand the physiological mechanism at work, the vibrations appear to fool the bones into thinking they are working hard. This results in the retention, and even additional growth, of bone tissue.

This research may be particularly useful for long-duration space missions of the future. The absence of mechanical stimulation to bones and muscles in microgravity leads to substantial bone loss and muscle weakness in astronauts. In flights lasting four to six months, astronauts can lose bone mineral density approaching 1.6% per month.

Although there has not been enough long-term research to determine if such rates of bone loss would continue, scientists estimate that during a two and a half-year round-trip mission to Mars, astronauts could lose up to half of their bone density from specific parts of the skeleton. This could seriously jeopardize an astronaut's health on return to Earth.

At the same time, current astronaut exercise regimes for long-duration space missions are time consuming, eating away at valuable crew time. Low-level vibrations may offer a countermeasure for this condition without the need for a medicinal intervention.

Other members of the research team include Gang Xu and Stefan Judex, both of the State University of New York at Stony Brook.