Surface tilt as a measure of the imminence of future earthquakes

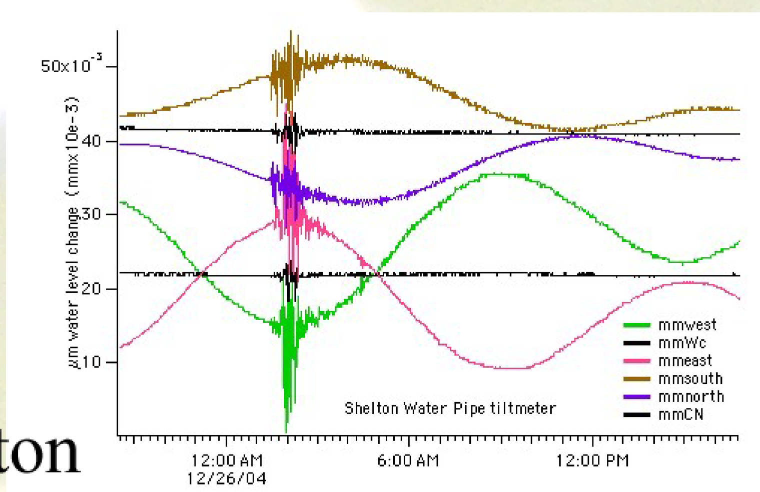
A M=9 earthquake occurred beneath Seattle in January 1700. Earthquakes release strain energy that develops over many hundreds of years. Since 1700 the Cascadia region has developed 13 m of potential slip, sufficient to drive another 8<Mw<9 earthquake.

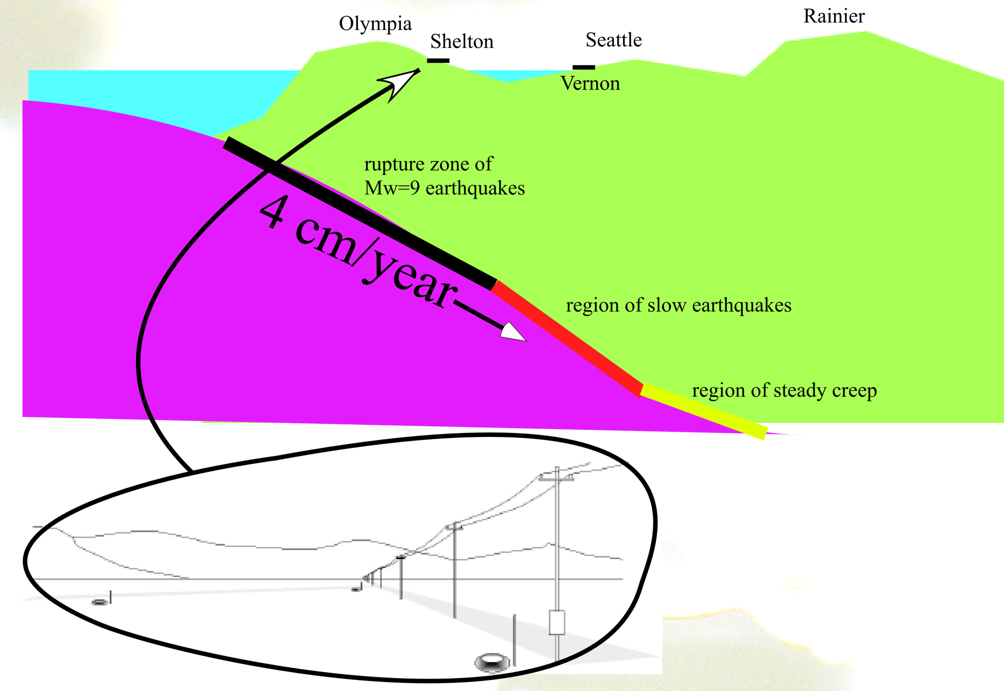
A curious phenomenon observed every 14 months to occur near the base of this future rupture zone is that the deeper part of the plate boundary (30-40 km) slips sluggishly ≈5 cm, releasing the preceding year's accumulated plate convergence (at that depth). These take about two weeks to occur and are accompanied by a subsonic vibration at 1-10Hz. The vibration may be caused by fluid motion or by frictional chattering.

One hypothesis is that a future damaging earthquake will follow one of these slow slip events - "the straw that breaks the camel's back". There is thus considerable interest in detecting this slip with high fidelity. Although GPS registers the slow slip as a horizontal displacement the signal is barely above the noise. We have installed two tiltmeters to detect the slow 40 km wavelength ripple that travels across the Earth's surface when the slip occurs. The tiltmeters are 10-100 times more sensitive than GPS.

Two pipes at right angles define the tilt vector. A novel feature of the new tilt meters is that they use a central transducer to provide two independent measures of tilt - providing a valuable measure of signal coherence

The figure right shows the six records obtained from the biaxial tiltmeter at Shelton during the Sumatra Mw=9.3 earthquake

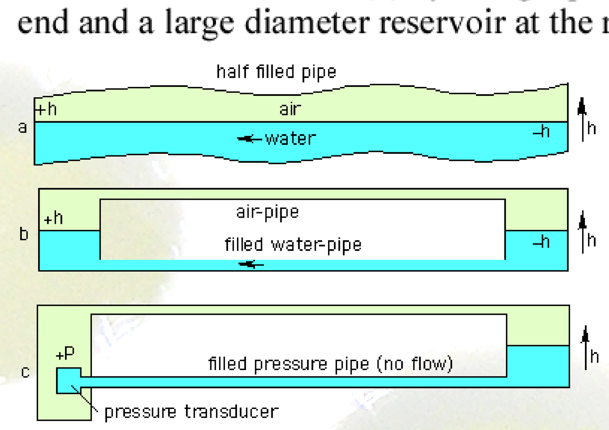




500-m-long water pipe tilt-meters

A sealed 6" PVC pipe is buried at a depth of 1-2 m and half-filled with water to emulate a 500 m long underground lake. Tilts of the ground are measured relative to this horizontal water surface. To reduce sensitivity to ground motions caused by rainfall and snow loads the sensors are attached to buried piles driven 10 m into the sub-surface. Data are transmitted from each vault via radio modems.

Three configurations have been used to measure tilt with long tubes. We use a sealed half-filled pipe (a) as devised by A.A. Michelson in 1920 tom measure the rigidity of the Earth. A closed tube (b) tends to have large thermal noise but this noise can be reduced in (c) by using a pressure sensor at one end and a large diameter reservoir at the remote end.

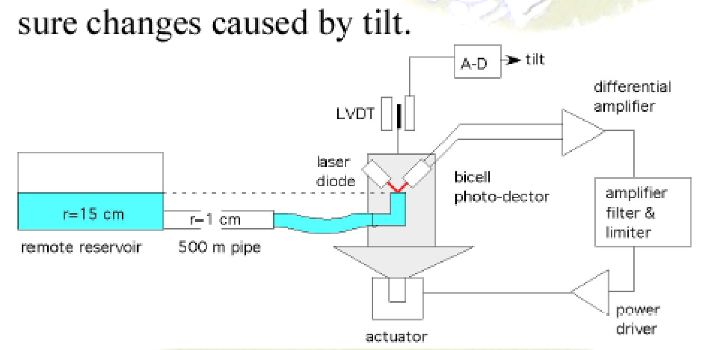


20 m to DC

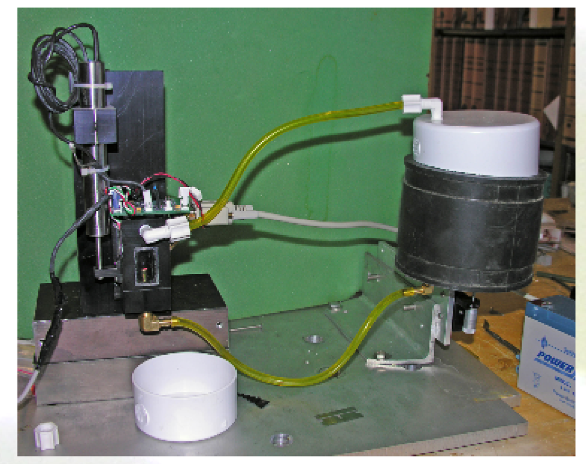
20s to DC

2s toDC

No flow occurs in (c) but the pressure sensor tends to drift and to require frequent calibration to detect reliablysmall pressures (<5 mm of water height). We have tested a new meniscus pressure sensor that overcomes this propensity to drift by using a servo-controlled orifice whose elevation is shifted to null pressure changes caused by tilt.



A filled pipe connects a vertical tube to the remote reservoir. A water meniscus forms whose curvature is proportional to the height below or above the remote free surface. The curvature of the meniscus deflects a laser beam to cross a split photocell. A microprocessor senses the laser position and drives the meniscus to a neutral position by raising or lowering it. A transducer measures the position of the tube which is recorded by a computer several times each second. CIRES machine shop devised the servo system.



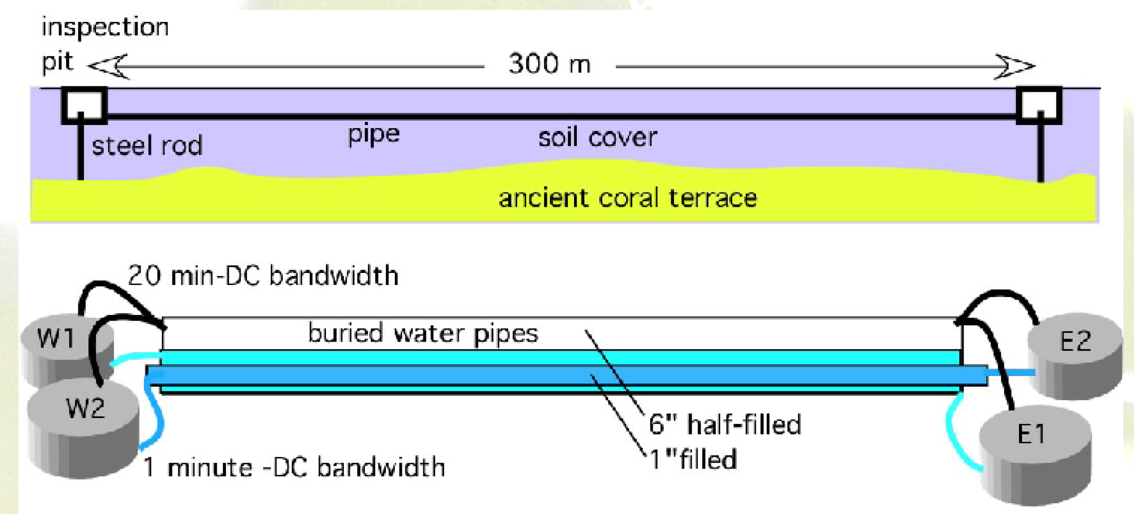
In the pilot design we found that the motor actuator had too much inertia to respond to meniscus fluctuations sufficiently rapidly, and overshot the equilibrium point resulting in "hunting". The system is now being re-designed around a woofer speaker coil that will respond to 1000 times faster.

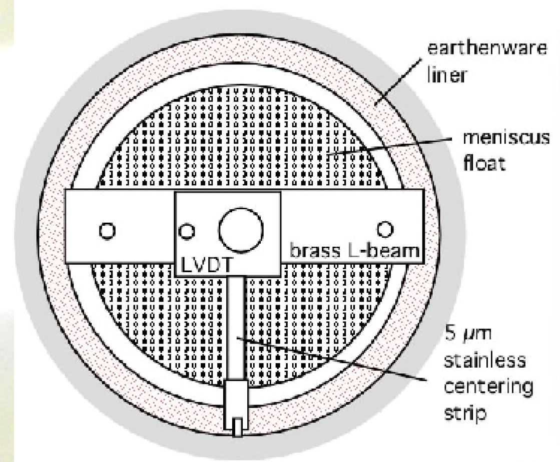
CIRES Innovation - a 31 gm meniscus-float!

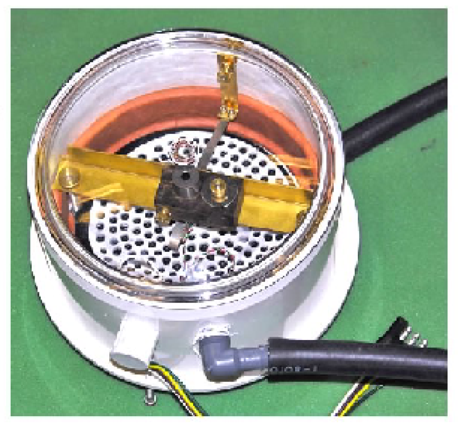
Our sensors have hitherto used a glass float to monitor the surface of the water to 1 µm. Its vertical position is a balance between mass (770 gm) and buoyancy supplemented by surface tension, whose effects are minimized by arranging the water to meet the top surface of the glass float horizontally. The buoyancy decreases with increasing temperature. During the experiments on the meniscus pressure sensor we noted that meniscus curvature can exert large forces on the capillary tube that contains it. We therefore experimented with a disk-shaped float designed to *exploit* surface tension rather than minimize its effects.

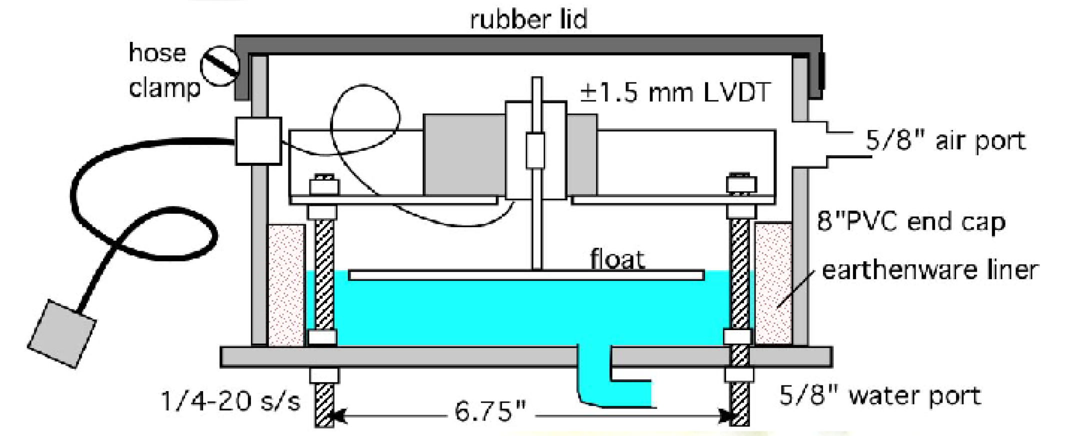
The new float is made from 3.2 mm thick polypropylene (0.95 gm/cc) perforated by 203 holes. The mass is equivalent to a 6 cm diameter disk, but its inner and outer perimeter length is equivalent to one 1.4 m in diameter. The new float is roughly 3 times more resistive to departing from the water surface than our existing floats and weighs 25 times less.

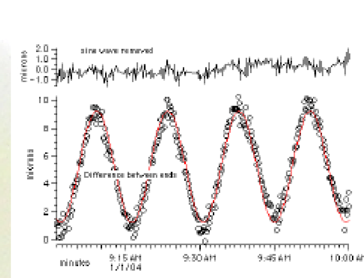
The October 2005 Andaman Island Tilt-meter











Data from two meniscus float systems track each other to ≈1 µm.

The new meniscus float is robust and a pair have been shown to track each other within 1 µm. We have designed a new sensor system that we will install in the Andaman islands in October 2005 to search for slow earthquakes following the Mw=9.5 earthquake of 26 Dec 2005. The float is lined with porous earthenware to prevent the water from sticking to the reservoir (adhesion tension). To extend the high frequency response from 20 minutes to 20 seconds we shall install two tilt meters in the same trench. One will uses a 1 inch pipe inside the 6 inch diameter pipe of the other See (a) and (b) in center panel.