Taking it all in Slide —
How the Trans-Alaska Pipeline Survived a Big One

Compiled by Heather Friesen

Designed to withstand a magnitude-8 earthquake with up to 20 feet of movement, the Trans-Alaska Pipeline is supported by rails on which it can slide freely during an earthquake.

The Nov. 3, 2002, magnitude-7.9 central Alaska earthquake was one of the largest recorded earthquakes in our nation's history. The epicenter of the temblor was located near Denali National Park, approximately 75 miles south of Fairbanks and 176 miles north of Anchorage. It caused countless landslides and road closures, but minimal structural damage, and amazingly, few injuries and no deaths.

In contrast, the 1906 magnitude-7.9 earthquake and subsequent fires took 3,000 lives and caused $524 million in property losses. The remote location of the magnitude-7.9 Denali Fault earthquake played a role in ensuring that the earthquake was not more devastating. However, advanced seismic monitoring, long-term research and a commitment to hazard preparedness and mitigation also played a key role. The science done before the Denali Fault earthquake aided in the successful performance of the Alaska pipeline, and the science done after the Denali Fault earthquake revealed more about large quakes that will help save lives and property during future temblors, especially in populated areas.

USGS seismologists and geologists serving on a federal task force were instrumental to ensuring that the Trans-Alaska Pipeline was designed and built to withstand the effects of a magnitude-8.0 earthquake with up to 20 feet of movement at the pipeline. The USGS design guidance proved to be on target. In 2002, the Denali Fault ruptured beneath the pipeline, resulting in an 18-foot horizontal offset. The resilience of the pipeline is a testament to the importance of science in hazard mitigation and decision making.

More than 30 years ago, Trans-Alaska Pipeline System (TAPS), formed by seven oil companies, confirmed the existence of a great deal of oil on the North Slope. In February 1969, TAPS announced plans to build a 4-foot diameter, 800-mile pipeline to carry crude oil from Prudhoe Bay to Valdez. Issues pertaining to the safety of the design emerged. Would the heat in the oil melt the pervasive, thick, permafrost layer and cause damaging spills? Would the pipeline be able to withstand a large earthquake in the nation's most seismically active state?

Walter Hickel, then U.S. Secretary of the Interior (1969-70), was alerted about the proposed pipeline and immediately appointed Bill Pecora, then USGS director (1965-71), to chair a technical advisory board. Pecora appointed the Menlo Park working group, made up mostly of USGS scientists, to advise the board.

USGS created several scientific documents to be used in planning the pipeline location and construction. Documents included an estimate of potential earthquake shaking levels and a report on thermal effects of a heated pipeline in permafrost that described how the pipe would float, twist and break.

In 1971, Pecora brought the Menlo Park group to Washington and thanked them for telling the oil companies "what they can't do," but now he wanted them to tell the companies "what they can do." Pecora locked the door of the conference room and told the group that he would not let them out until they had finished the analysis of the question "To bury or not to bury?" So the group put together the necessary stipulations on the pipeline construction. Among other things, the stipulations required that the pipeline system be designed to prevent oil leakage from the effects of a magnitude-8.0 earthquake on the Denali Fault.

In April 1974, construction of a 400-mile, all-weather road from the Yukon River to Prudhoe Bay was started. Pipeline and storage tank construction at Valdez began in 1975. Large segments of the Trans-Alaska Pipeline were elevated above ground to keep the permafrost from melting, and about half of the 800-mile pipeline was buried. A special fault design was adopted for crossing the Denali Fault Zone. Here the pipeline is supported by rails on which it can slide freely in the event of fault offset. In mid-1977, the first tanker shipped Alaska north slope oil from Valdez.

More than 14 billion barrels (nearly 550 billion gallons) have moved through the pipeline since startup in 1977. After the 2002 quake, the pipeline continued to carry 1 million barrels of oil each day, though it was temporarily shut down for inspection. With the pipeline intact, an important source of revenue for the state of Alaska was preserved. Moreover, as Alaskans know all too well, the consequences to the environment, should the pipeline have failed, would have been catastrophic.

"Good science made the difference between an emergency and a tragedy," said P. Patrick Leahy, USGS. "It's an example of how partnerships between the USGS, the Federal Emergency Management Agency, universities, state and local officials, and business leaders and the community enable us to apply our scientific knowledge. We know we can't stop the Earth from changing, but we can work together making public safety our primary goal."

The 2002 Denali earthquake is the largest seismic event ever recorded on the Denali Fault system — one of the longest continental faults in the world. The earthquake was similar to the magnitude-7.9 1906 earthquake, which ruptured the San Andreas Fault in Northern California. Both fault systems exhibit strike-slip movement, where blocks of continental crust slip horizontally past each other.

"Studying the 2002 Denali Fault earthquake is an opportunity to understand the consequences of a very large earthquake to better prepare for the time when one will occur in a much more densely populated area," said USGS scientist Peter Haeussler.

The Denali Fault earthquake was very directional. It ruptured rapidly over a long distance, focusing the earthquake energy in the direction of the earthquake

USGS Earthquake Scientists — A Nationwide Notion of Pride

David Oppenheimer

Title: Seismologist; Project Chief of the Northern California Seismic Network

Location: Menlo Park, Calif.

Length of service with the USGS: 28 years

The first memorable moment is scientific: In the mid-1980s, my colleague Paul Reasenberg and I developed software to compute the focal mechanism of an earthquake from first-motion polarities from seismograms. A focal mechanism indicates to seismologists the orientation and sense of relative motion of the fault on which the earthquake occurred. The ability to compute what was formerly done laboriously by hand opened up a new vista into the earthquake process.

When Paul, Bob Simpson and I began to look at the suite of focal mechanisms of aftershocks from the magnitude-6.2 Morgan Hill, Calif., earthquake in 1984, we were initially confounded. We discovered that the mechanisms for earthquakes adjacent to the Calaveras Fault were reflecting a state of stress in which the orientation of the maximum compressive stress was nearly perpendicular to the fault instead of being oriented approximately 30 degrees to the fault as predicted by classical mechanics.

This finding, together with borehole stress measurements, heat-flow measurements and geological observations, provided compelling evidence that the frictional strength of the Calaveras Fault was much lower than had been commonly thought. It was both exciting and gratifying to be making a new and fundamental observation that altered our understanding of fault mechanics and the process of how earthquakes are generated.

The second is operational: As the project chief of the USGS Northern California Seismic Network (NCSN), it has been my privilege to manage a complex project staffed by very creative and hard-working individuals who deploy and maintain seismic instrumentation and telecommunications, and who develop sophisticated, real-time data processing systems.

Perhaps the proudest moment was the occurrence of the September 28, 2004, magnitude-6 Parkfield earthquake. The Parkfield earthquake culminated in an effort that began more than 30 years earlier to instrument a section of the San Andreas Fault that repeatedly ruptures in similarly sized earthquakes every few decades. In an instant, the earthquake tested all phases of the NCSN and University of California-Berkeley monitoring system.

Not only did we successfully capture a rare data set for study by the seismological research community, but the results were automatically available on the Web. Within minutes after the earthquake, we were reliably and rapidly delivering earthquake information on the Web at a rate of 10,000 hits/sec. It was both exciting and gratifying to see that all of our instrumentation, telemetry and processing systems worked as designed.

rupture. As a result, said Haeussler, distant earthquake effects were most pronounced in one direction — southeast of the fault trace toward western Canada and the lower 48 states. Consequently, the Denali Fault earthquake was felt as far away as Louisiana. In the New Orleans area — more than 3,000 miles away — residents saw water in Lake Pontchartrain slosh about as a result of the earthquake's power. The earthquake also disturbed levels of water in Pennsylvania wells by up to two feet, damaged houseboats in Seattle from seismic sea waves, and triggered small earthquakes at many volcanic or geothermal areas in the direction of rupture. The most pronounced triggering was observed at Yellowstone, Wyo., with 130 small earthquakes recorded in the four hours following the 1,940-mile-away Alaskan rupture. By contrast, in the other direction, only one of the many active Alaskan volcanoes had triggered earthquakes.

"Research like this conducted by the USGS and collaborating institutions helps to anticipate the effects of future large earthquakes, such as the kind that will occur on the San Andreas Fault in the Los Angeles area," explained Lucy Jones, USGS scientist-in-charge for Southern California. "The effect of directivity may be important in hazard planning for future large Southern California earthquakes." The last time the San Andreas Fault ruptured in Southern California, in a magnitude-7.9 earthquake in 1857, the earthquake began in central California and ruptured southeastward toward the now highly urbanized Los Angeles region.

Thanks to George Gryc, Robert Page and Peter Haeussler.

Measuring Magnitude — What Do the Numbers Mean?

Compiled by Diane Noserale

Often two or more different magnitudes are reported for the same earthquake. Sometimes, years after an earthquake occurs, the magnitude is adjusted. Although this can cause some confusion in news reports, for the public and among scientists, there are good reasons for these adjustments.

Preliminary Magnitude

Following an earthquake, the first magnitudes that seismologists report are usually based on a subset of seismic-monitoring stations, especially in the case of a larger earthquake. This is done so that some information can be obtained immediately without waiting for all the data to be processed. As a result, the first magnitude reported is usually based on a small number of recordings. As additional data are processed and become available, the magnitude and location are refined and updated. Sometimes the assigned magnitude is "upgraded" or slightly increased, and sometimes it is "downgraded" or slightly decreased. It can take months before a magnitude is no longer "preliminary."

Sometimes the earthquake magnitude is reported by different networks of seismometers based on only their recordings. In that case, the different assigned magnitudes are a result of the slight differences in the instruments and their locations with respect to the earthquake epicenter. Depending on the specifics of the event, scientists might determine that the network closest to the event reports it most accurately. This is especially true where the instrumentation is denser. Other times, national networks, in which the instruments are often more state-of-the-art, produce the most reliable results.

Different Methods of Calculating Magnitude

The concept of using magnitude to describe earthquake size was first applied by Charles Richter in 1935. The magnitude scale is logarithmic so that a recording of 7.1, for example, indicates a disturbance with ground motion 10 times larger than a recording of 6.1. However, the difference in energy released is even bigger. In fact, an earthquake of magnitude 7.1 releases about 33 times the energy of a magnitude 6.1 or about 1,000 times the energy of a magnitude-5.1. Another way of thinking of this is that it takes about 1,000 magnitude-5.4 earthquakes to equal the energy released by just one magnitude-7.4 event. A earthquake of magnitude 2 is normally the smallest felt by people. Earthquakes with a magnitude of 7.0 or greater are commonly considered major; great earthquakes have a magnitude of 8.0 or greater.

Through the years, scientists have used a number of different magnitude scales, which are a mathematical formula, not a physical scale. Although news reports often call all magnitudes "Richter," scientists today rarely use Richter's original method. Unless further detail is warranted, USGS simply uses the terms magnitude or preliminary magnitude, noted with the symbol "M," in its news releases.

The Most Common Magnitude Scales in the United States

When earthquakes occur, energy is radiated from the origin in the form of different types of waves. Moment magnitude (M_W) is usually the most accurate measure of an earthquake's strength, particularly for larger earthquakes. Moment magnitude accounts for the full spectrum of energy radiated by the rupture and is generally computed for earthquakes of at least magnitude 5.5 when the additional data needed for this computation are available and the effort is warranted. Using some sophisticated regional networks in which noise is limited, seismologists can compute moment magnitudes for earthquakes down to less than magnitude 3.5.

Surface-wave magnitude (M_S) is computed only for shallow earthquakes, those with a depth of less than 30 miles. Body-wave magnitude (m_b) is computed for both shallow and deeper earthquakes, but with restrictions on the period of the wave. And local "Richter" magnitudes (ML) are computed for earthquakes recorded on a short-period seismometer local to (within 370 miles of) the focus of the earthquake.

Seismologists may measure an earthquake's magnitude with one scale. Then, once more data are available, reassign the magnitude using another scale deemed more accurate based on the additional data. For example, for the 1999 earthquake near Ismit, Turkey, the 7.8 magnitude first cited was a (M_S) surface-wave magnitude. The later figure of 7.4 is a (M_W) moment magnitude. Magnitudes assigned to a specific event for years can sometimes change.

Compiled with assistance from Steve Vandas.

USGS Earthquake Scientists — A Nationwide Notion of Pride

Brian Sherrod

Title: Research Geologist

Location: Seattle

Length of service with the USGS: 11 years

One of my most memorable times as a USGS scientist is when I found evidence of surface rupture along the Seattle Fault near Bellevue, Wash. I was looking for evidence of the Seattle Fault east of Seattle — using old aerial photographs taken from biplanes in the 1930s, more recent laser mapping data, geologic maps and lots of field work. I had a good idea where I thought a strand of the fault zone traversed the area I was working in, so I obtained permission to do some detailed work on an undeveloped parcel of land near the shoreline of Lake Sammamish.

After many hand-excavated test pits and soil auger holes, I thought I had found a trace of the fault that put weathered Miocene bedrock against young glacial deposits. The time had finally come to really test my ideas with a large excavation across what I thought was a fault. I remember being nervous when the backhoe arrived and we finally began excavating. Within a short time, though, we uncovered a thrust fault that placed weathered bedrock and old glacial deposits over a recent forest soil. The fault and buried soil were within a few meters of where I originally thought the fault was.

Want to know what was most satisfying about this discovery? I had many modern tools at my disposal, including LiDAR (laser) maps, geospatial information systems and a host of detailed geophysical studies, but it was getting down on my hands and knees in the dirt (oops, soil...) and doing the field geology that really made this study succeed.

Joan Gomberg

Title: Research Seismologist

Location: Memphis, Tenn.

Length of service with the USGS: 18 years

The most exciting thing for me was discovering the strong correlation between distant aftershocks and focusing of seismic waves (implying triggering by the waves) — a Eureka moment! Visiting Bhuj, India, was also memorable.