China's Campaign to Predict Quakes

A vast, 30-year effort to monitor the earthquakes that regularly shake China has led to unprecedented—and controversial—success in predicting them. What's behind this empirical approach?

BEIJING—It began, so the story goes, as a simple request from an old peasant whose life had just been turned upside down by two earthquakes that struck Xingtai in northern China's Hebei Province in March 1966, killing 8064 people. They were the first major catastrophic quakes in the 17-year history of the People's Republic, and the country's leaders were very concerned. "We are grateful for what the government has done to help tide us over the disaster," the peasant is said to have told Premier Zhou Enlai, who had been dispatched to direct the relief work and express sympathy to the victims. "But next time, could the government give us a warning?" His plea also had political overtones: Many Chinese regard earthquakes as a portent of civil unrest and look to the government for reassurance that the political structure has remained intact.

Back in Beijing, Zhou gathered a group of China's leading earth scientists and asked them to help avert such disasters. In 1971 the State Seismological Bureau (SSB) was created to oversee an already burgeoning national program. And in less than 5 years the SSB had delivered on that peasant's request with the first successful short-term prediction in history: A warning issued 13 hours before a magnitude 7.3 quake struck Haicheng in Liaoning Province, in northeastern China, on 4 February 1975.

Thus was born China's earthquake prediction program, arguably the most effective in the world despite an elusive and very modest definition of success. It has grown into a national network of 863 earthquake and precursor observatories, six regional and 15 local telemetry stations, 10 digital earthquake-monitoring stations, and 257 separate strong-earthquake observatories. Some 10,000 researchers and engineers are involved with the network, which is fed by many times that number of observers throughout the country. This year China will spend $45 million on the program, a substantial investment for a country in which a few thousand dollars represents a sizable research grant.

After decades of secrecy, the Chinese have recently begun opening up this program to the West, giving foreign scientists a closer look at an effort about which many have been highly skeptical. And in December, China's efforts will attract more international attention when Beijing hosts a United Nations workshop on earthquake management to improve ties between scientists and public administrators in the developing world (see box).

From what they have seen so far, few Western researchers expect China's program to yield ready-to-use prediction methods. But it is becoming clear that the vast amount of data on past quakes might yield some provocative clues about quake precursors. "They've had more success than anybody else," says seismologist Paul Silver of the Carnegie Institution of Washington in Washington, D.C., who has recently argued for the value of such measurements (*Science*, 5 July, p. 77). "I think that we in the West certainly have a lot to learn from them."

Intense scrutiny. Regions with a higher than 10% probability of suffering severe damage in the next 50 years are targeted for extra monitoring.

At the same time, Silver and other Western scientists point to a serious flaw in China's activities. "Their methods are strictly empirical," says Silver. "They don't understand the underlying physics or geology." Other Western seismologists, who requested anonymity to avoid offending potential collaborators, talk disapprovingly of high false-alarm rates and the difficulty of verifying details of any particular prediction.

SSB officials acknowledge the limitations of their approach. But they defend it as the most effective way to save lives and property in a country that has suffered 10% of all the magnitude 7 or greater earthquakes recorded around the world in the past century. "We cannot afford to continue to sustain the losses and social instability from earthquakes," says Ge Zhizhou, the SSB's deputy director.

A mania for monitoring

The Chinese approach relies on the principle that, in Ge's words, "empirical prediction can work where physical interpretation fails." The successful 1975 prediction, for example, was based on foreshocks and a large cluster of geochemical, hydrological, and other anomalies. Its accuracy stunned the seismological world and generated a short-lived bandwagon for prediction, although some scientists believe the extensive foreshocks greatly outweighed the value of any other precursors. Since then the SSB has claimed success in predicting a dozen or more earthquakes and saving hundreds of thousands of lives.

Last year, for example, scientists used various precursors, including foreshocks and variations in water levels and temperature, to warn local authorities 1 day before a major earthquake struck southwestern Yunnan Province. In particular, says Chen Lide, director of the Forecast Center for the Yunnan Seismological Bureau, scientists relied on an analysis of 39 regional quakes of magnitude 6 or greater over 42 years, as well as extrapolating from a series of eight quakes of lesser magnitude that had occurred in the past 8 months. "If the interval between medium-force quakes is shorter than 47 days and more than five such quakes occur consecutively," says Chen, "another one with magnitude above 7 is likely to strike within 6 months." Civil authorities say the human toll from the magnitude 7.3 quake that hit Menglian on 12 July—11 deaths in a city of 600,000—would have been much higher without advance knowledge of the quake.

These local warnings are the final step in a process that begins each fall, when the SSB

The Lessons of Qinglong County

When the earthquake hit, Qinglong County was ready. Days before a magnitude 7.8 quake leveled the neighboring big city of Tangshan in northeastern China, county officials had decided to act on anomalous data collected by the State Seismological Bureau (SSB) that pointed to a major earthquake in the region during the latter half of July 1976. They set up a 24-hour command post, beefed up monitoring, strengthened safety measures at schools and other public places, and flooded the community with information about what to do before, during, and after an earthquake. Many villages ordered residents out of their homes and into makeshift sheds or fields.


QINGLONG COUNTY

Open education. Qinglong County schools held class outside in the days preceding the quake.

The initiative—no official prediction was issued—paid off handsomely when the earthquake struck at 3:42 a.m. on 28 July. Only one person from Qinglong County died from the quake, while more than 240,000 people were killed in Tangshan and the surrounding area. Its population of 470,000 survived unscathed despite the collapse of 7000 buildings and damage to 180,000 more structures. It was a "fortunate leak and misuse ... of inside information," says Ge Zhizhou, the SSB's deputy director.

The actions of these local officials, which have only recently become known to Western authorities, have galvanized a new United Nations program to mitigate the destruction caused by natural disasters in the developing world. The goal is to give local officials greater access to whatever scientific information exists about potential earthquakes in their countries, as well as to strengthen their ability to act on such warnings to save lives and property. In December, representatives from a dozen or so countries will meet in Beijing to discuss a range of joint activities. An anonymous donor has provided $150,000 in seed money for an effort that U.N. officials project could extend for 20 years and cost a total of $100 million.

"When they tell you a hurricane is coming, you prepare. But earthquakes are different—they are the disaster we have the most trouble managing," says Jeanne-Marie Col, who runs the U.N. Global Programme for the Integration of Public Administration and the Science of Disasters. "So when I found out what they were doing in China, I realized they could be predictable."

Although preparation is the key to successful hazard mitigation, it was a chance meeting at U.N. headquarters between Col and geophysicist Jean Chu that launched the U.N. program. Col and consultant Louise Comfort of the University of Pittsburgh were plotting a follow-up to a 1993 meeting in Jakarta, Indonesia, on disaster management, Col recalls, when "one day Jean Chu showed up and fulfilled my dreams." Chu, who now works in Beijing as both a researcher for the Institute of Geology of the Chinese Academy of Sciences and a U.N. consultant, had come to New York with the idea of raising public awareness of natural disasters as part of the International Decade for Natural Disaster Reduction. It was an ideal match: "I was looking for a forum," says Chu. "I had an idea that I wanted to connect to a specific project," says Col.

The U.N. program hopes to foster local and national monitoring efforts in such earthquake-prone regions as Turkey, Indonesia, and the Philippines, as well as sharing what China has learned about emergency preparation and management. The hope is that, armed with such information, public officials around the world will behave as prudently as did those in Qinglong County. –J.D.M.

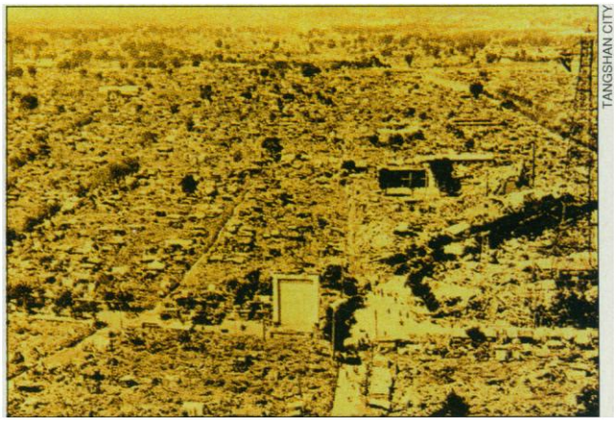
summons the nation's leading seismologists to Beijing and asks them to draw up a map of the areas of highest quake risk. Typically, about half of the areas each year are holdovers from previous lists. The meeting is the most important annual event in the country's seismological circles, and its conclusions, based on monitoring the most active faults in the country for seismic and other variables, are reported directly to the State Council, the highest body in the government. The areas on the list also warrant increased attention from scientists.

This year's map marked 12 areas believed most likely to suffer destructive earthquakes. Of the three serious quakes so far this year, two occurred within the designated regions—a magnitude 7 earthquake in Yunnan Province in February and a magnitude 6.9 quake in the northwest Xinjiang Uygur autonomous region—and within the time span—several days to several months—specified by the forecast.

The information is presented to regional and provincial officials, says Zhang Guomin, deputy director of the SSB's Center for Analysis and Prediction, but not made public, to "avoid unnecessary panic." A prediction of an impending quake is broadcast only to residents of the areas expected to be affected. The SSB claims an accuracy rate of 25% for these medium- to short-range forecasts, a figure that cannot be independently verified because the details are not disclosed.

Over the years, China's earthquake program has progressed from a giddy belief that prediction was imminent through a sobering reassessment of the importance of engineering. In its current phase, says Zhang Shaoquan, a research fellow with the SSB's Geophysics Institute, the goal is to combine the "two principles of preventing and resisting earthquakes, and [thus] to reduce the impact of the disaster."

Toward that end, in 1994 the State Council launched a 10-year program requiring all new construction in medium-sized and large cities to be able to resist earthquakes of at least magnitude 6. The building effort coincides with a decadal program to monitor


TANGSHAN CITY

No warning. The 1976 Tangshan quake killed 240,000 despite extensive monitoring of the region.

closely 21 areas and 13 major cities, and a raft of laws and regulations on emergency preparedness for China's 27 provinces.

Tough calls

Generating a torrent of information about high-risk areas doesn't guarantee success, however; data can also be disregarded. The program's biggest failure, Chinese officials acknowledge, was the lack of a short-term prediction for a magnitude 7.8 earthquake that struck Tangshan, 150 kilometers east of Beijing, in the predawn of 28 July 1976. Some 240,000 people in the industrial city of 1 million were killed, and the damage amounted to more than a half-billion dollars.

Indeed, some scientists worry that an overemphasis on prediction may give citizens the false impression that the government is capable of issuing real-time predictions for all earthquakes. "It is misleading and dangerous," says geophysicist Chen Yong, a member of the Chinese Academy of Sciences. "In fact, China's quake predictions still remain at the empirical stage," he says. Officials say the empirical approach is most effective when applied to quakes with foreshocks and many precursors, a small subset of all quakes. The Haicheng and Menglian quakes fit that description nicely.

Chen, who spent 15 years as the SSB's deputy director-general, is now chair of the prediction commission of the International Association of Seismology and Physics of Earth Interior. He has shifted his research from prediction to what he describes as a "more basic" study of risk assessment, but decries the low level—less than 10%—of the program's budget that goes for basic research.

Even Chinese officials say that success should not be overstated. "The three risk areas [on the current list where earthquakes have occurred this year] have been circled almost annually," says geophysicist Sun Shihong, who drafts the SSB's policies and regulations. "It is more due to chance and windfall than accuracy by scientific definition." Under a strict definition of prediction, notes geophysicist Zhang Shaoquan, "we have only been able to forecast a tiny number of quakes."

The SSB would like to improve that record. Ge Zhizhou says that Chinese earth scientists hope to "make some remarkable progress in improving the record of prediction accuracy" by the turn of the century, although he concedes that significant progress will be very difficult to achieve. Notes Sun, "We cannot expect to understand the earthquake mechanism in so short a time."

Western scientists who have recently seen some of the data amassed by the Chinese for the first time share these reservations. But they believe the information could point to some interesting lines of research. This summer, for example, a joint team of Chinese and U.S. researchers published an analysis of resistivity signals—a measure of current flow that correlates with the amount of cracks and fluid in the Earth's crust—from the Tangshan region in the 2 to 3 years preceding the 1976 quake that point to several possible precursors (*Journal of Geophysical Research*, 10 June, p. 13869). "These are interesting phenomena that suggest things we could measure," says co-author and seismologist Leonardo Seeber of Columbia University's Lamont-Doherty Earth Observatory, about a finding of lower resistivity and a descending water table in the period before the quake. "The next step is to understand the process and see if it can be generalized."

Apart from the value of the data sets, the authors see the collaboration as a step toward improved relations. "This is the first time we've been able to get our hands on the actual data," says co-author and geophysicist Chris Marone of the Massachusetts Institute of Technology. Adds Seeber, "The Chinese have proposed these results before, but the community had looked at them with skepticism."

To some Western scientists, the program also illustrates an interesting cultural difference in the way science is pursued. "The Chinese are more comfortable than Western scientists with conflicting and contradictory evidence," says Louise Comfort, a specialist in seismic policy at the University of Pittsburgh who drafted the proposal for the new U.N. program. "When they face this problem, they just broaden the scope of their inquiry and collect more data."

And collecting more data is exactly what the Chinese will continue to do. "We'll try to make accurate predictions while going on with our research, and we'll learn from both successes and failures," says Ge of the SSB. Even geophysicist Chen believes that the government's overenthusiasm for predictions is outweighed by the importance of the challenge and China's success to date. "If we had not been able to predict a certain type of quake," he says, "we would have given up the prediction effort altogether. But now we are right in the middle, and we are left with no alternative but to go ahead."

–Li Hui, with additional reporting by Jeffrey Mervis

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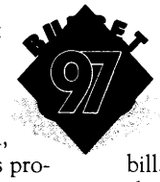
CONGRESS 1997

Senate Backs NASA Science Programs



NASA scored three victories last week when the Senate preserved a controversial life sciences program involving orbiting monkeys, rejected a move to cancel the space station, and protected a major earth sciences program. But controversies over social programs in the appropriations bill that funds NASA could make it hard for Congress and President Bill Clinton to reach agreement before the new fiscal year begins on 1 October.

Senators sparred bitterly over the Bion program, a joint U.S.–Russian effort that will place monkeys into orbit this fall and again in 1998 to study the effects of weightlessness (*Science*, 12 July, p. 175). The focus of the 3-hour debate was not whether the animals in the program are mistreated, as some animal-rights activists allege, but whether the science is valid and the money well spent.

In the end, the Senate defeated an amendment, identical to one already approved by the House, that would have halted funding for the project and transferred $16 million remaining in the $33 million program to other NASA efforts. The provision would not have stopped this fall's launch from Kazakhstan, but it would have jeopardized the 1998 mission. The House measure had caught the biomedical community off guard, but researchers waged a heavy lobbying campaign that contributed to a 54 to 42 Senate vote against the amendment.

Congressional staffers and NASA officials say they expect the Senate to prevail when the two chambers meet in conference to work out a final bill. Negotiations will also be necessary to resolve disagreements on the agency's Mission to Planet Earth program. The House wants to chop $200 million from the $1.3 billion program. The Senate approved the full amount, but voted to cut $100 million out of a larger account that includes the multisatellite research and monitoring system, the first launch of which is slated for 1998.

The fate of the once-controversial space station, however, will not be up for grabs in conference. The Senate defeated, by a vote of 60 to 37, an amendment to kill the program and then approved the same $2.1 billion already passed by the House. But House and Senate conferees are expected to allow a shift of more than $170 million in station science funding to construction to make up for severe shortfalls (*Science*, 9 August, p. 730).

These differences are minor compared to the fierce debate over other elements in the bill, notably the president's AmeriCorps service program, which the House has voted to kill. Lack of agreement on that issue could delay NASA's 1997 budget and that of the National Science Foundation.

–Andrew Lawler