Shook Up

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What will happen when an earthquake strikes?
What measures can be taken to limit its damage?
How far in advance can we predict such events?

These are the questions shaping the research agenda of the ICTP Structure and Non-Linear Dynamics of Earth (SAND) Group.

This summer's earthquake in western Turkey, which left 15,000 dead, hundreds of thousands injured and tens of billions of dollars in property damage in its wake, was a shocking event that generated untold misery and captured media attention around the world. In rapid succession, earthquakes in Taiwan and Mexico killed thousands more. Indeed three major tremors in less than three months have placed earthquakes high on the agenda of global concerns.

However startling the pictures and statistics have been, the fact remains that earthquakes are not uncommon. About 10,000 earthquakes with tremors strong enough to be felt occur each year, and about 100 of these tremors cause considerable damage. Moreover, every year or so, some place in the world experiences a super-catastrophic event on the scale of what took place in Turkey.

Fortunately, these events often take place in unpopulated areas. These numbers show that earthquakes can be expected, and experts agree that we had better be ready for them, especially in vulnerable, heavily populated areas. Shoddy construction, poor building codes, limited public awareness and inadequate disaster-response training make developing countries and their megacities particularly vulnerable. In 1950, about 50 percent of the world's urban earthquake-threatened population lived in developing countries. Today, it's 85 percent. Earthquakes, moreover, can devastate economies, especially those of developing countries. The 1972 earthquake in Guatemala caused an estimated 40-percent loss in gross domestic product (GDP). In contrast, devastating earthquakes in Kobe, Japan, in 1995 and Los Angeles, USA, in 1994 led to a loss in GDP of less than 1 percent in each of those countries.

In response to these alarming disparities, and in the context of this International Decade of Natural Disaster Reduction, the United Nations Educational, Scientific and Cultural Organization (UNESCO), the European Commission, the North Atlantic Treaty Organization (NATO), and other international organisations have launched several projects aimed at improving earthquake prediction, raising public awareness, enhancing readiness and sharing information. One UNESCO project involves a massive international collaboration on modelling seismic events in megacities: ICTP Structure and Non-Linear Dynamics of Earth (SAND) Group is a key collaborator in this initiative.

Geological disasters—for instance, earthquakes, volcanic eruptions and landslides—occur in the outer shell of the solid Earth—the lithosphere or rock domain—which consists of blocks that move relative to each other, through fluid interactions, friction, buckling and fracturing. Such mechanisms create strong instabilities, turning the lithosphere into a 'hierarchical' chaotic system. Geological disasters, like earthquakes, are critical phenomena in this system.

Short-term earthquake prediction—the where and when—remains a dream. Yet, with sufficient information about a site's geology, we can compute the local ground motion that would result from sizeable earthquakes. Scientists from countries as far apart as Chile, China and Romania, to name just a few, have adopted a common approach for modelling ground motions caused by destructive earthquakes. Earthquake research at ICTP is the responsibility of SAND, led by Giuliano Francesco Panza, who is also a professor of seismology at the University of Trieste. Associates and visiting scientists focus on two distinct questions: What happens to the ground during a quake, and where and when will such events take place? The first makes use of knowledge of ground and experimental data collected from actual events to create hazard maps used, for example, in devising building codes.

SAND projects have examined the physical instability of megacities through seismic hazard mapping. Such research parallels the agenda of UNESCO's project "Realistic Modelling of Seismic Input for Megacities and Large Urban Areas." Begun in 1997, this five-year project focuses on being prepared for seismic events. About 20 cities, including Beijing, Cairo, Delhi, Mexico City, and Rome, are included in the project. These cities face a wide range of seismic risks, which require different strategies for attaining sufficient levels of preparedness. The project, moreover, requires extensive collaboration. Collecting data is a multidisciplinary task, involving on the one hand knowledge of soil engineering, geophysics and lithology, and on the other, information on tectonics, paleoseismology and seismotectonic models.

Detailed models are used to predict seismic ground motion and prepare hazard maps. These efforts are made possible through data input from a network of global observation points, together with the application of modern theories and powerful computers.

ICTP has also contributed to a European Union (EU)-COPERNICUS-funded project addressing the security of nuclear power reactors in Bulgaria, Hungary, Romania and Slovenia. The goal is to determine how to retrofit existing plants to make them more secure. Centre researchers also participate in a related project, "Impact of Vrancea Earthquakes on the Security of Bucharest and Other Adjacent Urban Areas," involving "ground motion modelling and intermediate-term prediction". The latter has been organised within the framework of the NATO Science for Peace programme. The other line of research at ICTP, which tackles actual earthquake prediction, combines non-linear dynamics modelling, based on concepts of chaos and self-organisation, with vast databases assembled through observations. The findings of such research are relevant to a wide class of so-called hierarchical chaotic systems, a subject currently generating multi-faceted research at ICTP in areas ranging from condensed matter to statistical physics to the physics of weather and climate.

Applied to earthquake prediction and seismic-risk analyses, the approach focuses on intermediate-term prediction. This effort is spearheaded by a group of Russian researchers who are regular visiting scientists at ICTP. Vladimir Isaakovich Keilis-Borok is the group leader.

The team's two main projects are non-linear dynamics of lithosphere blocks and the testing of algorithms for earthquake prediction. Their efforts are conducted within the framework of several international initiatives funded by the European Union, U.S. National Science Foundation, NATO, INTAS (an association promoting co-operation among the republics of the former Soviet Union), and bilateral initiatives involving France, Italy, South America, Sweden, and the United States.

The ultimate goal of intermediate-term prediction is to narrow the forecast and area in which an event will likely occur and to develop predictive measures of its magnitude. ICTP collaborators have developed a model that predicts strong quakes based on empirical studies of anomalies in everyday weak seismic activities. Significant variations—warning signs that something serious may happen—are fed into a system of empirical formulas that use pattern recognition techniques to signal the time of increased probability for the occurrence of an earthquake with a magnitude above a given threshold.

The global predictive capability of this approach has exceeded 80 percent. The technique predicted the 1994 quake in Northridge, California, which caused at least US$20 billion in economic damage. The prediction, made well in advance, covered an area of 400 square kilometres and time span of 18 months. On the other hand, the technique failed to predict the recent earthquake in Turkey.

As Keilis-Borok notes, "four unstable systems—earth, life, engineering and society—are tied together in megacities." As a result, a powerful quake could claim tens of thousands lives, cause billions of dollars in damage, and lead to long-term social disruptions and even economic depression. Basic research exploring chaotic systems could help improve our efforts to curb the impact of earthquakes and other types of disasters. Events like the recent tragedies in Turkey, Taiwan and Mexico remind us that such mitigation efforts are well worth pursuing.