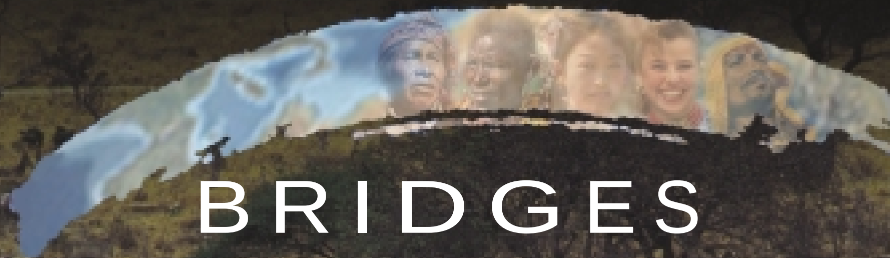

BRIDGES

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BRIGHAM YOUNG UNIVERSITY • DAVID M. KENNEDY CENTER FOR INTERNATIONAL STUDIES

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Geophysical Hazards in Indonesia

Who's Next?

Assessing Vulnerability to Geophysical Hazards in Densely-Populated Regions of Indonesia

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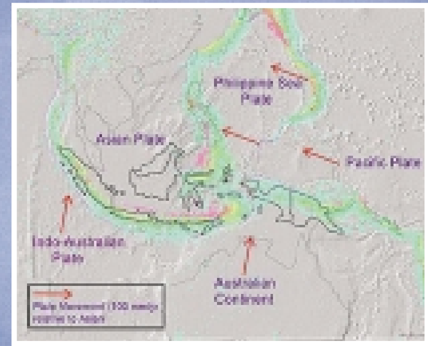

Figure 1
Earthquakes and motion of major tectonic plates of the Indonesian region. Each dot represents an earthquake epicenter during 1970–2000. The color of each event corresponds to earthquake depth: green (0–50 km), yellow (50–100 km), red (>100 km). The distribution of earthquakes defines the location of the major plate boundaries. Arrows correspond to the direction and velocity of plate movement.

Introduction

The densely-populated archipelago of Indonesia has more explosive volcanoes, major earthquakes, and destructive *tsunamis* than any other nation. The disaster potential of these geophysical hazards increases as population, urbanization, and rapid development expand into hazardous regions. Apart from reversing these trends, the disaster potential of recurring hazardous events can be reduced by focusing mitigation efforts on the most vulnerable parts of the country. The results of our collaborative research identify and characterize the regions in Indonesia that are most vulnerable to geophysical hazards, or, in other words, to predict—who's next?

Geophysical Hazards

Most geophysical hazards in Indonesia arise from its unique position in a three-way collision between some of the earth's largest tectonic plates (Figure 1). The movement of these plates is buffered by the nearly continuous release of tectonic strain energy in the form of large earthquakes, explosive volcanic eruptions, and associated tsunami and landslides that claim lives and cause societal and economic disaster. During the nineteenth century alone these hazards caused more than 200,000 fatalities throughout Indonesia (NOAA).

Present Risk

These violent and deadly geophysical disasters resulted because of the sudden release of strain energy that had accumulated for decades and centuries in various parts of the plate collision zone. A similar situation exists today. It has been hundreds of years since many parts of the collision zone have broken free. It is not a question of if, but when. Comparing measurements of how much strain was released during past events with measurements of the present rate of strain accumulation can help predict the most vulnerable regions of the collision zone.

The inevitable and catastrophic release of accumulated plate boundary forces will affect a very different Indonesia than before, one with much more to lose. Population has increased fivefold over the past century to more than 200 million people. The majority of the people are crowded into the island of Java, which has a land area the size of New York and is home to the majority of the nation's wealth. An increasing percentage of the population is concentrated in the sprawling urban centers of Jakarta, Bandung, Surabaya, Semarang, Yoyakarta, and other major cities dangerously exposed to multiple geophysical hazards (Figure 2 on next page).

The economy of Indonesia has expanded rapidly, with an overall growth rate of 7 percent over the past twenty years. During this time, per capita income has increased tenfold and Indonesia has attracted much foreign investment. Yet, little has been done to protect its people, property, and new development from imminent disaster(s). One of the most disturbing trends is that the few small earthquakes and volcanic eruptions of the past few decades have resulted in increasing numbers of fatalities and economic disruption. Development in Indonesia has proceeded with frightening disregard for geophysical hazards.

Seismic Hazards

Earthquakes are the most poorly understood and unpredictable of all natural hazards. During the twentieth century alone Indonesia had around two hundred major earthquakes (magnitude 7.5 or greater), more than all of North America or South America during the same time interval. At least 110 of these quakes were destructive; the majority jolted densely-populated western Indonesia and accounted for as many as

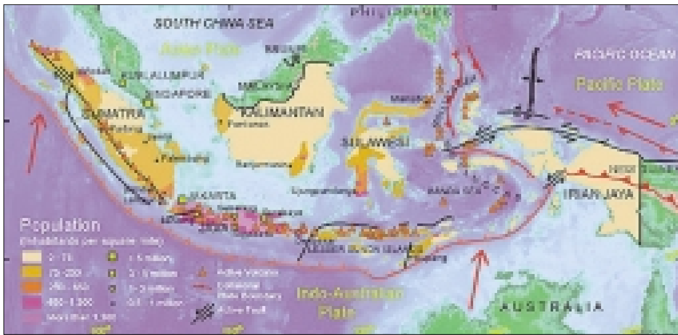

Figure 2
Population distribution, plate boundaries, and active volcanoes (red triangles) of Indonesia.

fifty thousand deaths.[1] The temporal distribution of these events indicates a twenty-year alternating cycle of frequent seismic activity followed by seismic quiescence.[2] The current period of quiescence began during the mid-1980s.

Seismic gap theory forecasts large earthquakes in regions along fault zones that have gone for decades or centuries without slip. According to this theory, the longer the plate boundary is stuck and plate motion energy accumulates in these 'gaps,' the larger the eventual quake will be. The most dangerous seismic gaps in Indonesia exist in populated regions of western Sumatra, south-central Java, and Timor—all part of the Sunda collision zone. The entire sixteen hundred-kilometer length of the Sumatra fault system has not slipped significantly for 130–150 years.[3] Since this time, seven to eight meters of potential slip have accumulated and will most likely be released suddenly to produce a magnitude 8.0 + event. Within fifty kilometers of the Sumatra fault zone, there are now seven major urban centers with a population greater than one million, and eleven other cities with populations between fifty thousand and 100,000 (Figure 1). A large seismic event along the Sumatra Fault Zone, like those of the past, will flatten many of these cities. The inevitability of catastrophe also threatens distant urban centers such as Jakarta, Singapore, and Kuala Lumpur.

The collisional plate boundary near densely-populated Java has some of the highest strain rates in the world (seven to eight centimeters per year).[4] They yield a seismic flux at least five times that of Sumatra, which is manifest by more frequent moderate earthquake events (M 5.5–7.5). However, because the convergence rate is higher, the combined seismic flux in Java is at least five times that of northern Sumatra. These dangerous events threaten eight times more people, most of the nation's wealth, and considerable foreign investment.[5] Although these moderate events are of lesser magnitude than larger events, they pose a greater threat due to the more frequent devastation and disruption they inflict. Central Java has the most consistent record of seismicity, but no historic events greater than M 7.2.[6] A distinct gap in total seismicity is found south of this region (Figure 2). Arnold interprets the central Java seismic gap as an area of accumulating strain between highly coupled plates, which could eventually generate a large earthquake. Harris *et al* speculate from archeological evidence that it was a large earthquake similar to the one predicted from strain measurements that triggered the large-scale eruption of Merapi volcano in the tenth century C.E., which led to the demise of the complex Majapahit civilization in central Java and the eventual transition from Hindu to Islamic culture.

East of Java, in the Timor region, the collision between the Asian and Australian plates takes on a different look as the northern edge of the Australian continent shoulders into the plate boundary. The positive buoyancy of the continental crust strongly resists subduction beneath the Asian plate, causing multiple strong earthquakes and explosive eruptions (Tambora) that threaten one of the most rapidly developing parts of Indonesia. The pattern of earthquakes sourced from this region is diffuse and difficult to predict.[7] Evidence abounds as to very large seismic events throughout the region, such as the flights of coral terraces found along the shorelines of most islands. Surveys of these terraces reveal that they were lifted out of the sea by strong earthquake events with recurrence intervals of around one hundred years.[8] Since the last major event over one hundred years ago, population and construction in these regions has dramatically increased. The rapidly expanding urban center of Kupang (Figure 2) is built on the new coral-covered land lifted out of the sea by large earthquakes. Since the last moderate earthquake in 1975, the urban population of Kupang has increased tenfold and now exposes around 700,000 people and an increasing investment of wealth to seismic hazards and tsunami from several active seismic source regions within one hundred kilometers (Figure 2).

Poorly-regulated development in these zones of high seismic flux poses a significant threat not only to the many cities with unfavorable site characteristics, but also densely-populated rural regions that have rapidly expanded into seismically unstable hillsides and cities along shorelines vulnerable to tsunami destruction.[9] Most buildings in these regions are incapable of withstanding even mild horizontal ground motions.[10] The most common construction practice is to build unreinforced walls using poorly-fired and deformed bricks

MAJOR GEOPHYSICAL DISASTERS OF THE NINETEENTH CENTURY

1815—eruption of dormant Tambora killed more than 92,000 people. The eruption is the only one to have an explosion index of seven, the equivalent of sixteen thousand megatons of explosives (800,000 times greater than the Hiroshima bomb). World climates were altered by this event for several years, causing the three years of crop failure that encouraged Joseph Smith, Sr. to move from Vermont to Palmyra, New York, near the Hill Cumorah.

1822—eruption of Galunggung in Java claimed 4,011 victims.

1833—slip along the southern segment of the Sumatra Fault generated a magnitude 8.8 earthquake, one of the ten largest ever documented.[S1] Houses were "rent" more than three hundred kilometers away. Most buildings within one hundred kilometers of the epicenter completely collapsed. A powerful tsunami generated by the event swept the western coast of Sumatra. Casualties were poorly documented.

1856—eruption of Awu claimed at least three thousand victims.

1861—slip along the northern segment of the Sumatra Fault produced a magnitude 8.4 quake and a seven meter tsunami that affected five hundred kilometers of the western Sumatra coast.[S2] The number of casualties from this quake and the seven major aftershocks is unknown.

1883—eruption of Krakatoa in the Sunda Strait claimed an estimated 86,000 lives.[S3] Several tsunami were generated throughout the eruption, the largest was thirty meters high. This wave washed away 160 villages and flooded the streets of Jakarta within fifty minutes of the largest blast.[S4] cemented with soft mortars. Walls are then stuccoed and covered with a heavy pantile roof. As witnessed in recent moderate seismic events such as those in Kobe, Japan, and in Latur, India, a magnitude 6.4 quake near densely-populated regions with weak dwellings can cause thousands of deaths, billions of dollars of damage, sever gas and water lines, damage critical facilities (dams, nuclear power plants, gas facilities, transportation, schools), and cause sudden economic collapse. These types of damage initiate new disasters as people are displaced, water sources are contaminated, and food supplies become limited.[11]

Volcanic Hazards

There are around five hundred volcanoes throughout Indonesia, 129 of which have erupted in historic time (Figure 1). Most of these volcanoes produce truly explosive eruptions, including the world's largest eruption in history (Tambora) and perhaps the largest prehistoric event (Toba Crater in Northern Sumatra). Due to the population density in Indonesia, volcanic eruptions are commonly fatal and account for 70 percent of all volcanic-related fatalities worldwide.[12] Many of the fatal eruptions occur with little or no warning from "dormant" volcanoes or those with little or no baseline data to use for predicting behavior. The probability is high that one or more of these volcanoes will have a full-scale explosive eruption during this century.

Hazards associated with explosive volcanoes vary in extent depending upon the type, style, intensity, and conditions of the eruption. In close proximity of the eruptive center (less than twenty kilometers), ash and lava flows, volcanic bombs, and gas emanations pose an immediate threat. Other effects of explosive eruptions extend far beyond the immediate vicinity of the eruption, such as airborne ash that can damage crops for hundreds of kilometers and pose a significant threat to aircraft. Volcanic mud flows or *lahars* (Indonesian for volcanic mud flows) also pose a threat to dwellings, bridges, and dams up to one hundred kilometers from an eruption. Hazard zoning procedures attempt to predict the limits of danger of each of these volcanic hazards at individual eruptive centers, but as demonstrated by recent volcano-related disasters in Indonesia and elsewhere, hazard zoning alone is not sufficient.

Collaboration with Indonesia

Collaborative research between BYU and several Indonesian universities and government agencies was initiated in 1998 to predict which regions of the country are most vulnerable to geophysical hazards and how best to use the limited resources available to prepare those regions for the inevitable. We designed a GIS-based model that provides a way to reclassify, score, weight, and combine multiple layers of hazards and population data into a total hazard map for Java and the Timor region of the plate collision zone. The model first assigns each pixel a linear distance from nearest geophysical events. Then a number of user-defined parameters are applied to reclassify the linear distance values into categories with different scores. The third reclassification weights each score according to relative contributions to overall hazard (i.e., frequency of eruption vs explosiveness). The final layer is a sum of all weighted layers to produce a total hazard map.

Java and the Timor region were selected because of the dangerous combination of dense population and development and frequent moderate to large geophysical events. The overall objective in constructing the maps is to assist in identifying the most vulnerable regions where disaster reduction activities can potentially do the most good. These activities include: site-specific risk assessments, detailed monitoring, emergency planning, and implementation of protective zoning and building practices.

Detailed studies involving students from BYU have been conducted throughout central Java, including Merapi volcano, and throughout the Timor region. A GPS network was constructed during summer 2001 that measures the accumulation of tectonic strain between several different islands in the collision zone. These measurements reveal how collisional strain is distributed and help us predict which fault zones and volcanoes are most dangerous.

We conducted a similar experiment using the GPS to measure strain accumulation along the Wasatch Fault of northern Utah. In collaboration with the University of Utah, we resolved a strain rate of two to three millimeters per year of westward stretching of the Salt Lake and Utah Valley regions relative to the rest of North America—forty times less than the strain accumulation rate in Indonesia.[13] This motion is currently being stored by the elasticity of rocks along the Wasatch Fault zone. However, when these rocks reach their elastic limit, they will slip, causing a major earthquake. Studies of the fault zone reveal that a major earthquake rocks the Wasatch Fault about every 350 years. The last time a large section of the fault slipped was around five hundred years ago in the Provo area. Other segments of the fault, such as the one that stretches from the Point of the Mountain through downtown Salt Lake City to Bountiful, have not slipped in over twelve hundred years. Very few people and no permanent structures existed the last time these faults slipped. Now, almost two million people live above this westward inclined fault zone. Perhaps we will be next.

Cooperative Implementation

To reduce the disaster potential of geophysical hazards, it is essential to design detailed plans for a prompt and efficient response to crises before they happen. This task can be initiated now and is not primarily an issue of money; rather, it is a commitment to face the risk and to apply already available knowledge toward reversing the cycle of mounting losses at the hands of nature. Building practices that protect the community are not a matter of cost as much as education and planning. Some of these include: 1) earthquake-resistant structures with foundations on consolidated ground, 2) barriers of trees to significantly reduce the effects of tsunami, floods, and lahar, 3) enforcing geologically sound zoning practices around active volcanic centers, and 4) practicing sound grading codes to significantly reduce slope failure. In the words of Boyden and David:

> Disaster mitigation has implications which are quite different—and much further-reaching—than those of disaster relief. . . . Mitigation aims to increase the self-reliance of people in hazard-prone environments, to demonstrate

that they have the resources and organization to withstand the worst effects of the hazards to which they are vulnerable. In other words, disaster mitigation—in contrast to dependency creating relief—is empowering.[14]

Natural disaster reduction efforts offer an unprecedented opportunity to integrate systems of knowledge, technology, and public policy to minimize losses in regions of high risk. It challenges scientists to work together with the engineering sector, media, policy makers, and vulnerable communities to achieve implementation. Each of these protagonists have traditionally played parallel, but separate roles in disaster reduction.

Many crises that became disasters demonstrate how the traditional approach is insufficient. One example is the 1985 eruption of Nevado del Ruiz in Colombia, which claimed twenty-three thousand lives.[15] This disaster could have been avoided if the scientific community, government officials, and media had cooperated. Although the risk of a lahar was clearly recognized from earlier geologic assessments, and sufficient time was available to implement existing recommendations made by both Colombian and visiting scientists, skepticism, lack of cooperation, and slow bureaucratic response defeated the best scientific intentions.[16] After several days of eruptive activity and political inaction, a lahar entombed twenty-three thousand people in the city of Armero, fifty kilometers from the eruption. This, and many other recent disasters demonstrate that science-based assessments are essentially useless if not clearly communicated to, and effectively used by, government officials in mitigation activities and emergency management.

Conclusion

Geophysical hazards have claimed around a quarter of a million lives in the past 150 years in Indonesia. Today the disaster potential of these hazards is much greater than the past due to exponential population growth, rapid development, and urbanization in hazardous regions that have recently experienced a period of tectonic quiescence. At highest risk are the regions around Bandung and Yogyakarta in Java, and Kupang and Dili in Timor. How Indonesia responds during its present phase of economic growth and development in these vulnerable regions, and how we respond as an international community to our own vulnerability and needs, will determine the extent to which these inevitable hazards will impact the standard of life and economic vitality not only of this resilient nation, but of the world community.

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RECENT DISASTERS

1991—magnitude 6.4 earthquake near Alor (north of Timor) claimed 181 victims, left 5,400 homeless, and caused 7.7 million dollars of damage

1992—earthquake in the eastern region of Flores island generated a tsunami that struck the coastal city of Maumere and offshore islands. Thousands of people were killed and ninety thousand were left homeless. Several coastal villages were completely washed away and left as bare ground scattered with coral debris.[S5] Most deaths occurred on low-lying and overcrowded islands and peninsulas completely engulfed by waves carrying large blocks of coral ripped from the reef offshore.[S6]

November 1994—Merapi, Indonesia's most active and potentially dangerous volcano, shed a flow of hot debris as part of its natural pattern of steamy, unstable slope failure. The only difference between this eruption and comparable ones, as recent as 1991, is that the ash cloud was channeled to the south toward a region that had not been affected by eruptions for at least two hundred years. Some new communities on the southern slopes of Merapi were in the path of the hot debris flow. They were destroyed by the relatively minor eruption. Only thirty-seven bodies were found. Hundreds were severely burned and hundreds more suffered from lack of medical facilities. This was the thirteenth time since 1600 C.E. that Merapi claimed victims from the burgeoning population at its base. The last full-scale eruption of this explosive volcano was in 1930. Since then, the population and development on Merapi's fertile slopes has increased exponentially.

June 1995—small earthquake offshore eastern Java generated a tsunami killing two hundred people and destroying over one thousand coastal dwellings (NOAA).

Sidebar Notes

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