Programa de Estudios de la Alianza del Pacífico | UNIVERSIDAD ICESI

UNDERSTANDING SEISMIC RISKS: IMPLICATIONS FOR MEMBERS OF THE PACIFIC ALLIANCE

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The series of DOCUMENTOS DE TRABAJO DEL PEAP are reports or progress documenting the activity carried out by academics, students and other actors who share a common interest in studying the social, economic, political and natural aspects that take place in the geographical area formed by the Pacific Alliance in order to consolidate multidisciplinary researches to understand and exploit the opportunities offered by the region in an accessible language.

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Understanding Seismic Risks: Implications for Members of the Pacific Alliance

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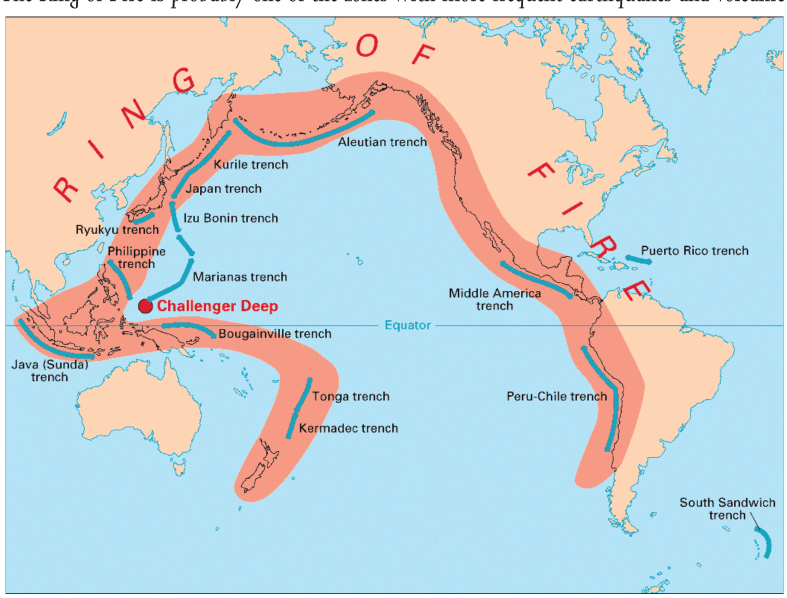
Introduction

The country members of the Pacific Alliance (PA) not only share their common interests but also territories on the Latin American Pacific. This strategic position on the Pacific Rim is capitalized on in order to reach the objective of interaction with other countries, for example in Asia, and to engage in exchanges of many kinds. However, along with shared wealth, resources and opportunities, the countries in this area also share in common threats. The territory is rather complex since it is located in an environment with historical tectonic earthquake activity due to the friction of tectonic plates. Seismic events of considerable magnitude have caused numerous human casualties and material damage (Stein & Wysession, 2009). The occurrence of large earthquakes and the resulting risks have always been a threat to the population of the region. Hence, the inhabitants of the more vulnerable zones need to be aware of the potential risks and take appropriate plans to address such impending occurrences.

Figure 1. The Ring of Fire is probably one of the zones with more frequent earthquakes and volcanic eruptions



Courtesy of the U.S. Geological Survey (http://www.usgs.gov)

It is well known that earthquakes are one of the most common natural disasters affecting society. Moreover, large earthquakes have proven to be the most rapid and destructive of natural disasters. This working paper focuses on analyzing the seismic risk of the PA members shared territory as part of the so called Ring of Fire (Figure 1). In this sense we provide a look at the Pacific Alliance to assess the common seismic risks faced by the region. This common fact, like many others, also creates identity within the member countries and is a reality that affects all members almost equally and for that reason they need to address it together.

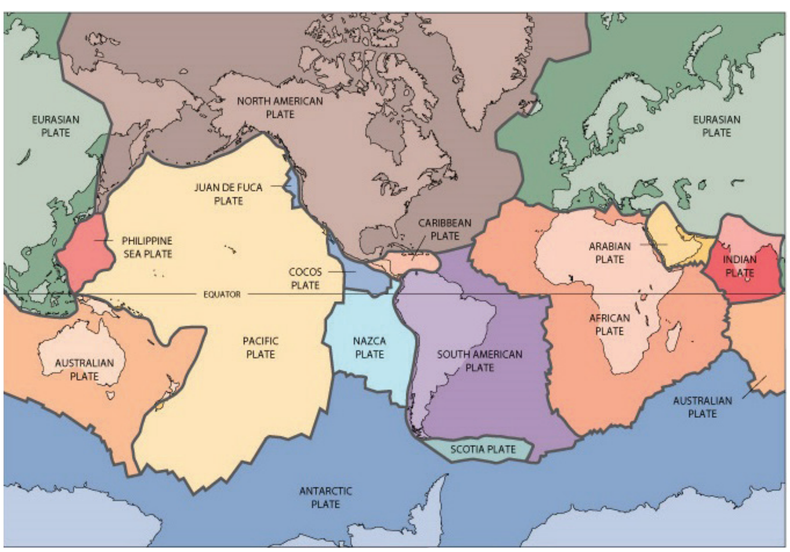
To meet this objective, the paper will develop the following points. First, a brief theoretical analysis of plate tectonics is presented, focusing on hazards caused mainly by subduction. This process deeply affects the members of the PA –the Latin American Pacific is one of the regions most affected by subduction. Second, a differentiation of the concepts of hazard, vulnerability and risk are discussed. Finally, in connection with these concepts, the model of mitigation is examined. From this last point, we focus on the generation of knowledge that leads to modify the threat of earthquakes through mitigation. In conclusion, general suppositions are outlined.

In the PA, a complex territory is shared, since it is located in an environment with historical tectonic earthquake activity due to interaction of tectonic plates.

Subduction: A Phenomenon that Affects the Pacific

In the early 1960s, the emergence of the *theory of plate tectonics* started a revolution in the earth sciences. Since then, scientists have verified and refined this theory, and now have a much better understanding of how our planet has been shaped by plate-tectonic processes. We now know that, directly or indirectly, plate tectonics influence nearly all geologic processes. Indeed, the notion that the entire Earth's surface is constantly shifting has profoundly changed the way we view our world.

Figure 2: The theoretical model of plate tectonics is based on the earlier theory of continental drift, and together with the growth of global seismology is one of the most major advances in earth science



Courtesy of the U.S. Geological Survey (http://www.usgs.gov)

People benefit from, and are at the mercy of, the forces and consequences of plate tectonics. With little or no warning, an earthquake or volcanic eruption can unleash bursts of energy far more powerful than anything we can create. While we have no control over plate-tectonic processes, we can learn from the phenomena. The more we know about plate tectonics, the better we can appreciate the grandeur and beauty of the land upon which we live, as well as the occasional violent displays of the Earth's awesome power. The outer part of the Earth is divided into about a dozen large plates (Figure 2). These large plates are constantly moving, thus generating movement of everything that is on the Earth. While they are considered rigid in the sense that almost no deformation occurs within them, their boundaries do deform. Therefore when the plates interact they give rise to mountains, volcanoes, and other phenomena –often very violent– that materializes in earthquakes. For example, the Pacific plate moves toward the northwest and the Nazca plate moves eastward opposite to that one. This interaction between the plates generates new oceanic crust.

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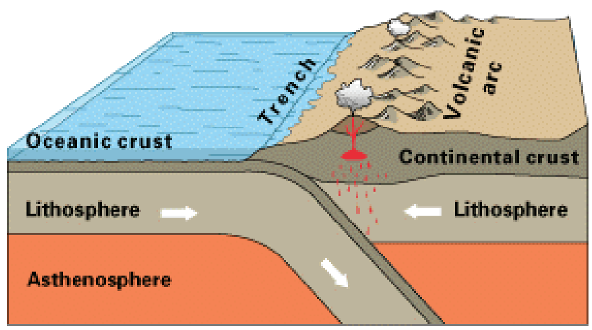
Something similar happens with the South American Plate, along the Peru-Chile trench moving to the southwest, pushing into and being subducted under the Nazca plate which moves in the opposite direction. The only way they can interact is by colliding, with one of the plates losing territory under the other (Figure 3).

Figure 3: The Nazca Plate is sinking smoothly and continuously into the Peru-Chile trench, below the South American Plate



Courtesy of the U.S. Geological Survey (http://www.usgs.gov)

The motion between the plates is neither easy nor smooth, this interaction generates earthquakes continously. Such interaction occurs on all plates that exist on Earth, a clear indicator that there is a direct correlation between the location of the plates' division and the location of most earthquakes. The easiest areas to identify that phenomenon are located around the globe in what is known as the Ring of Fire (Figure 1). This area is where about 90% of all earthquakes occur and 80% of the largest ones. The particularity of these is that they spread from the colliding zone where the plates are interacting with the continents. As earthquakes move towards the continents they get deeper, though some remain superficial and these can be the most dangerous. Earthquakes basically define the boundaries of the plates. Those areas where the plates collide very slowly and yield territories facing each other have a much more diffused deformation, and are called convergent boundaries.

Temperature is the engine that accelerates the movements of tectonic plates. Earth, about 4.500 million years ago, consisted of dust particles that were floating because of the Big Bang. Such particles were attracted by the Law of Universal Gravitation toward a new center. The attraction of this newly created matter made the particles collide with great speed and force. When the particles collided they transferred all their energy of motion into temperature. When this process was over, and the Earth was formed, it was a hot mass with a very high temperature.

When the Earth ceases to attract particles in abundance, the particles begin to lose heat and return to their thermal equilibrium, taking out the heat that was inside. That heat is moved from the inside out by two heat transfer processes: conduction, a form that is not efficient; and convection, where the hot material rises and gets cold producing low convection currents. These allow the material closer to the core to rise and cold material, which is near the surface, to go down. The points where the hot material rises is where the partition on the plate is created and where soils are generated. New plates move in divergent ways, as occurs between the Pacific Plate and the Nazca Plate. Concurrently, the points where the cold material tends to go down is where the plates converge; they collide and one of them goes into the earth, losing ground against the other, a process called subduction. The solid mantle of the Earth is unable to sustain these ongoing processes that occur at very low speeds. This is the nexus of everything that happens on the surface: the forces of subduction, through which the plates collide and generate new soil (Bebout et al., 1996; Kanamori, 1986; Stein & Wysession, 2009).

There are phenomena associated with subduction that are observable at plain sight and can be seen along the Pacific coast of Latin America, for example, the formation of mountains.

In the oceanic crust subduction zones, which are the densest, the plate will enter beneath the continent and sink to the core of earth and be recycled. With the interaction of the plates or continent, the movements are very abrupt, inducing big shocks. Between each shock, the top plate works as a big spring that stores energy as formation energy. When the later released in the form of earthquakes the plate occupies its original position. Addionally, there are other phenomena associated with subduction that can be seen along the Pacific coast of Latin America, for example, the formation of mountains.In contrast, no volcanoes exist in the central region of Peru; nor in Colombia in the north of *Nevado del Ruiz*; nor in some places in northern Chile. The assumption, regarding the nature of these places, is that no subduction is present or that the Nazca plate is flat and does not plunge beneath the continent.

Threats Associated with Subduction: Massive earthquakes and colliding plates

The first threat is the most obvious. Since the plates collide violently, these movements produce traumatic events that are earthquakes. The movement of the Nazca and South America plates can cause, as explained, massive earthquakes that may reach more than 9.5 degrees on the Richter scale, as occurred in 1964 in Chile, which was the biggest earthquake ever recorded. Colombia had one of the ten largest earthquakes in history, in 1906, which started in Esmeraldas, Ecuador, and ended in Buenaventura, Colombia, more than 400kms away. This is what we call a transnational earthquake. When such large earthquakes occur is very difficult to define where it started and the concepts of epicenter, source or focus, become meaningless, moreover national boundaries become irrelevant. For example, the rupture of Indonesia was about 1600km and its effects were distributed along all of its extension. These mega-earthquakes occur at the interface along the collision zone called ocean trench, where the oceanic plate enters beneath the continent. Throughout the trench, earthquakes can occur up to 1,500 km from the rupture and up to depths of 120 km on an interface that can be inclined 45°, which causes a rupture of the crust and upper mantle. These violent ruptures occur over large areas that generate mega-disasters, especially if they happen close to population centers.

Big earthquakes and colliding plates, tsunamis, volcanism and continental seismicity are threats associated with subduction.

Tsunamis

When earthquakes occur on the ocean trenches is when so called tsunamis may be generated. The Tsunami is basically the movement of an enormous mass of water in response to a quake. When the oceanic plate sinks in front of the continent, a part of its material will be shifted to the opposite direction. This causes the "piston effect" that makes the sea water rise and causes a disturbance on the surface that travels to the coast. To the extent that the sea loses depth the wave gains speed and height, so when the wave reaches the shore, it is very fast and destructive. This type of earthquake, along with those on land are what really affects people and cause deaths. Nevertheless, it is a kind of advantage to live in a seismically active zone since having the threat and constant phenomenon challenges people to build a lifestyle to live with them. We must learn to live with earthquakes, but controlling their effects.

The Volcanism

The process of plates' collision, as noted earlier, is a fairly traumatic one and causes various additional processes on the surface. Among them is the existence of volcanoes, a characteristic phenomenon where subduction occurs. Volcanoes arise from the wet material of the oceanic plate, which moves beneath the continental plate. As the material rises the mantle is heated and melted and ascends to the surface through a weak area. When this happens, the material becomes molten rock located in bubbles which are called magma chambers. Over these chambers appear the volcanoes, whose presence is usually due to the confluence of tectonic faults where the magma can rise more easily to the surface. Under normal conditions, where the plate collision occurs hot magma chambers are generated. Some of these are cooled inside the Earth and generate boulders; others come to the surface and create volcanoes. This is the reason why there are active volcanoes in the Pacific region and this is what forms the Ring of Fire (Figure 1), named as such because of its volcanic activity.

Continental Seismicity

Not all the energy generated by the movement of the plates is released into the subduction zone, there is also some of the energy that accumulates in the crust and causes it to break during very shallow earthquakes. The great threat of this occurrence is that earthquakes can even take place at 0km, generating surface ruptures that can be observed within plain sight. Normally earthquakes occurring at depth reach the surface with little energy, since it is lost while the seismic wave travels to the crust. But if the quake occurs near the surface, for example at 5km, this short distance is traveled by the energy, thus when it reaches the surface it does so with great force and will probably cause major damage.

The phenomena described are threats when related to the population. They can seriously affect people and buildings, causing social problems.

This becomes very relevant for populations living along the continental crust since it is where most of the cities are located. For example, the earthquake that occurred in 1983 in the city of Popayan, Colombia, happened because of this phenomenon. These shallow earthquakes are very dangerous because they usually occur near towns. This is an occurrence that can be observed in North America, especially in the United States. Although there is no subduction in certain areas, there does exist, in some locations, what are called transformation zones which generally pass through the middle of cities. For example, in Los Angeles, California, the geological fault goes almost through the middle of the city. Continental seismicity can seriously affect people and buildings, causing social problems as well.

The Concepts of Hazard, Vulnerability and Risk Associated to Seismicity

The concepts of hazard, vulnerability and risk have a broad applicability in the analysis of earthquakes and their impact on individuals and infrastructure of all kinds.

Hazard and vulnerability

Hazard relates to how an event will negatively act against property and people. For example, the possibility of occurrence of earthquakes is the hazard. There are some conditions that may modify the hazard in cities, for example, living in front of a mountain, where rock slopes are very hard and the ground does not amplify the intensity of the quake. But in the valley, away from the mountain, the ground will deploy all its amplifying effect and the hazard will be greater.

The other concept is vulnerability. This is the degree of exposure that people and property have against the hazard. For example, in reality, the degree of vulnerability is low the closer a person is to a seismic event; it is rare for a person to die simply from the occurrence of earthquake. However, vulnerability dramatically increases as the effects of an earthquake begin to take place, mainly because of its impact on the overall infrastructure. In other words, in the absence of civil structures, an earthquake is hardly a threat to the lives of a population. The vulnerability depends largely on the strength of the objects and precautions that people have against the hazard and susceptibility to damage. The problem of vulnerability lies in the fragility or fortification of buildings, which is a direct cause of vulnerability. For example, we can have two identical buildings constructed on the same site, in the same soil conditions, but vulnerability could be different due to the risk conditions that exist.

Hazard, vulnerability and risk are three concepts which are widely applicated in the analysis of earthquakes and their impact on individuals and infrastructure.

For example, in Cali, a city in south western Colombia, an earthquake occurs in average every 4 years, causing damage in many buildings. This creates a social problem because the damaged goods are devalued. What is needed is to diminish the effects that cause earthquakes, but this will not occur and although is difficult to get used to live with the damage, it is a necessity to adapt to have quality life among earthquakes. Especially since there is no place on earth free from earthquakes, although there are large areas where they scarcely occur, for example, in the territory east of the *Cordillera Oriental* in Colombia, and Brazil, which are geologically stable areas.

The concept of risk

Between hazard and vulnerability we find a very important concept: risk. This is the effect of the source that produces the hazard to the object which has the vulnerability. The risk lies with the potential of suffering any kind of loss due to proximity to hazard or because the conditions are not suitable for any type of hazard. This is sort of a combined criterion. As in the hypothetical case of having two similar buildings, as introduced earlier, the risk increases if you have a 10-story building fully occupied and the other is uninhabited. Likewise, variations in soil type can increase vulnerability and, therefore, the risk significantly. This increase or decrease depends on many variables that must be analyzed and taken into account.

The country members of the Pacific Alliance particularly have to work at reducing risk in relation to the threat of earthquakes and volcanic activity. We have an inescapable reality: closeness to hazard, as the country members face in the Ring of Fire of the Pacific and this fact cannot be changed other than to move elsewhere. In this sense, the populations of these countries are forced to live with the hazard and learn to change vulnerability to lower the risk. In general, the alternatives that can be taken to mitigate risk in these countries depend mainly on obtainable knowledge of how safely live in the region. The more you can identify the factors causing hazard and vulnerability, the better understanding you will manage to consequently reduce the risk.

Summary and Proposed Studies of Earthquakes in the Pacific Alliance

The science that is responsible for studying these phenomena, and which gives us the ability to understand and prevent them, is seismology. This is the study of the waves propagating in the earth, for it is based on science and many other tools such as mathematics, physics and most recently in computational sciences. By using these tools we can provide a better understanding about how much danger surrounds the people who live in active seismic regions, as the ones on the PA countries. That is what can be identified as the core of understanding seismic risk, an area in which the concepts are still being constructed since it is a relatively recent theory that began around the 1960s (Cornell, 1968; McGuire, 1993). The study of how to generate risk maps began in this decade and continues to be a priority to accomplish, especially in the geographical area where the member countries of the PA are, in particular for Colombia.

Any alternative that is intended for the country members of the Pacific Alliance should be aimed at reducing risk.

The long-term goal is to use the information of seismic sources. That information exists and has been compiled by national and international agencies that collect and analyze part of it. With this information it is possible to produce models of the structure of the Earth that allow for a better understanding of how the plates interact. Additionally, it has broad functionality in mineral exploration. These kind of studies can cover the whole Latin American Pacific, including parts of Central America. The development of this type of research is being performed by agencies such as the IRIS (Incorporated Research Institutions for Seismology), or other regional, and local agencies that collect such data.

Analysis of this data from a geophysical perspective will contribute to creating a much more accurate picture of the possible scenarios associated with an earthquake of great magnitude, and improve the ability to locate earthquakes more accurately. Additionally, it is useful to build models of the Earth's structure that can allow us to better understand it. Especially to understand the great earthquakes that have occurred and that have drastically affected the population and structures, as the ones witnessed in: Tumaco in 1979, which caused a great Tsunami and the death of 600 people; the one that occurred on the border of Colombia and Ecuador in 1987 which caused 1,000 deaths; the one in Armenia that happened in 1999 and left 1185 deaths, the 2010 Chile earthquake struck off the coast of central Chile having a magnitude of 8.8 (sixth largest earthquake ever recorded by a seismograph) with intense shaking lasting for about three minutes, and causing 525 casualties. These are very destructive earthquakes that can erase entire cities and towns from the face of the Earth and cause many deaths. The idea of studying, from a scientific perspective, the potential impact of an earthquake on the people is a key element of study for any nation, particularly for Colombia, because there are no have been no exhaustive studies of the region and it is a necessity to study these phenomena more fully. For example, from a brief analysis of the information found in the USGS US government agency, we can identify that earthquakes of greater magnitude are not necessarily the most deadly. One explanation for this is that population density was lower where the earthquake occurred, or there were fewer people located near the epicenter.

In summary, it is a necessary to bridge the gap of individual geophysical and geological analysis of data sets, especially due to the complexity of the region under study and the results that may be obtained. We propose to integrate information from different sources that are currently available for all countries in the PA, and obtain models that correspond to physically meaningful constraints. In return, we will have a better opportunity for understanding regional geophysical processes, and to help projects related to Earth exploration and seismic hazard assessment, which will impact local and regional disaster mitigation efforts.

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In this research project, we propose to integrate information from different sources that are currently available for all countries in the PA.

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