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"WORKING *PAPER 5*"

The collaboration between Mexico and Japan in earthquake engineering and seismology

Francisco Sánchez-Sesma, Hiroshi Kawase and Joseline Mena

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Francisco Sánchez-Sesma, Hiroshi Kawase and Joseline Mena

Resumen

A pesar de su lejanía uno del otro, Japón y México comparten una característica crítica: El peligro sísmico. En el pasado, ambas naciones han sido golpeadas por grandes sismos que han provocado graves pérdidas humanas y materiales. Si bien la predicción de estos aún no es posible, el desarrollo de sistemas de alerta temprana y su constante innovación es una prioridad, en particular el estudio de la relación espectral horizontal a vertical de microsismos, que puede ayudar al estudio y comprensión de la naturaleza de los sismos, así como su impacto en la infraestructura. Es en el mutuo beneficio de Japón y México, que aumente la cooperación entre las instituciones universitarias especializadas en estudios sismológicos para crear de manera conjunta mecanismos de estudio e innovación.

Abstract

Despite their remoteness from each other, Japan and Mexico share a critical characteristic: the seismic hazard. In the past, both nations have been hit by great earthquakes that have caused serious human and material losses. Although the prediction of earthquakes is not yet possible, the development of early warning systems and their constant innovation is a priority, especially the studies of the horizontal-to-vertical spectral relationship of microseisms, which can help the study and understanding of earthquakes' nature, as well as their impact on infrastructure. It is for mutual benefit to Japan and Mexico that cooperation between university institutions specialized in seismological studies increases to jointly create study and innovation mechanisms.

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Introduction

Although Japan and Mexico have diverse cultures and historical backgrounds, both people are aware that they inhabit seismic countries. This chapter delves into the pioneeJapanese developments in seismology, which consolidated after the great Kanto earthquake in 1923 that produced devastation and a great fire in Tokyo. We also point out that a worldwide acclaimed probabilistic seismic hazard analysis originated in Mexico. In 1985, Mexico was shaken by the great Michoacán Earthquake. It was a coastal earthquake, far away from Mexico City, yet it caused an unprecedented life loss toll and damage. Many studies revealed the damage was caused by the combination of source, path and site effects.

This paper shows a brief description of the formulation of a theory to model the Horizontal-to-Vertical Spectral Ratios of Microtremors (MHVRs), proposed by Nakamura which provides the dominant period of a site. The new formulation emerges from the diffuse field concept and allows the inversion of Horizontal-to-Vertical Spectral Ratio (HVSR).

The prediction of earthquakes is not possible yet, their occurrence prompted the development of research based on the measured response and damages that they produce. Moreover, diverse institutions and organizations that promote research and the implementation of prevention plans were created. These, in order to have a better quality of life in highly seismic countries like Mexico and Japan.

Iconography in Pre-Hispanic Mexico and Traditional Japanese Legends

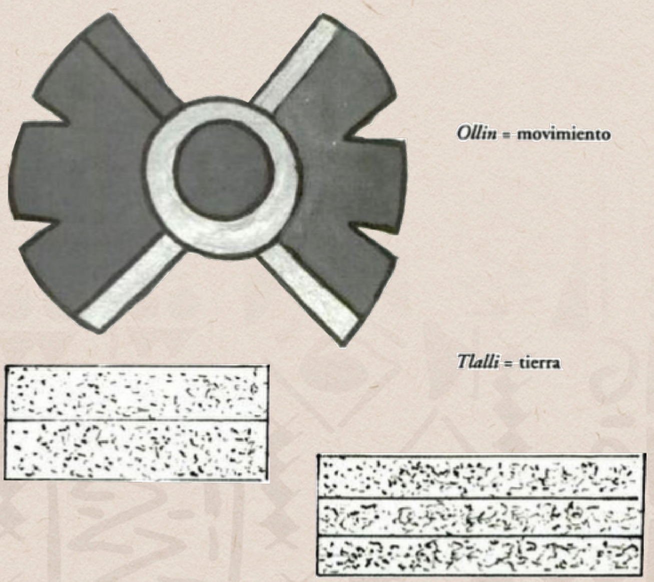
Iconography is the study of symbols and images, of their origins and meaning. Mexico and Japan have been fertile grounds for symbols and images. Regarding pre-Hispanic art we have diverse examples characteristic of different cultures that flourished in Mesoamerica. The Olmeca, Maya, Tolteca, Mixtec, Mexica and Aztec cultures had several types of deities, for example, Tlaloc (the God of rain) or Huitzilopochtli (the God of war). However, considering ground motions, within the Mixtec mythology we find Tepeyollotl (the God of the land of mountains) which evidently refers to earthquakes and seismic disturbances (Spence, 2010).

On the other hand, for Aztecs, Tepeyollotl is a God in the shape of a jaguar and according to León-Portilla (1963) and Saunders (1998), is a manifestation of the deity Tezcatlipoca (the God of sky and land, source of life and happiness). In the codices and annals, the tremors were recorded through the glyphs ollin and tlalli, which mean movement and earth, respectively. The first is represented by a circumference, around which four blades appear, that give an idea of movement (Florescano, 1987; García, 2001) and the second represents one or several strips of land on which a series of points appear simulating seeds (as shown in Figure 1a). Thus, tlalollin means movement of ground or earthquake (Ayala, 1987; Garcia, 2001).

In Japanese culture, several legends emerged as well. Perhaps, the most famous one produced by their mythology is the one in which Japan is on the top of a giant catfish, a Namazu (Hammer, 2006). The supreme God of Kashima temple used to stop the giant moving fish by holding his head with a rock called Kanameishi, but when the God relaxed his guard, leaving the rock in the hands of a caretaker, the animal turned into anger and, consequently, an earthquake happened (Figure 1b).

Figure 1.

a) Pictographic Representations of the glyphs.



b) Japanese Mythology, a giant cat-fish is under Japan

Source: a) García (2001).

b) Hammer (2006).

Nowadays, thanks to scientific knowledge, we know that earthquakes are the result of the continuous movement of tectonic plates that compose the lithosphere. These plates are parts of a broken shell that floats over the mantle, slowly pushed by enormous convective currents. Most earthquakes originate in the plate boundaries, and Mexico and Japan have the most active regions of the world and have their share in the belt of fire.

Development of Seismology

Research in Japan

An earthquake occurs when there is a release of energy in the boundaries of tectonic plates manifesting itself in the form of propagating seismic waves (longitudinal, transverse and surficial) that travel in the interior of the Earth and along the surface penetrating the crust as a function of their period. Those waves generate a shaking of the ground with different intensities that depend upon many factors like size of the fault and the velocity of rupture, distance to the observation site, characteristics of the propagating medium and the effects of surface geology. Earthquakes have a great impact on society.

Seismology is a science based on data called seismograms which are records of the earth vibrations caused by natural and artificial man-made sources. The aim is to describe the Earth's interiors and contribute to understanding the dynamics of the planet which includes volcanoes, mountains, plate tectonics. Moreover, seismology is of interest to engineers and society in general because earthquakes are also a source of concern because seismic ground motion is a hazard to human constructions. Earthquake engineering community is aware of seismic hazards and the exposure and vulnerability of are elements that contribute to establishing the seismic risk to society.

The rate at which earthquakes occur is more or less the same as it has been during the last hundreds of millions of years, but the organized historical record is more recent. Our account will necessarily cover little more than the last century. We are living what is perhaps the golden century of humankind (Amador, 2010).

During the 19th century, several earthquakes shook Japan, marking its history. One of them was the Ansei-Edo earthquake in 1855 with a magnitude of M6.7. Between seven and eight thousand people died, less than one percent of the population of the Edo Empire. This complex event took place in a society much different from the modern one, where the legends proliferated. Scientific knowledge also began to emerge alongside intense political issues and transformations (Smits, 2014).

Another significant event was the Nôbi earthquake in 1891; the losses were big; they included more than seven thousand casualties, and it served as a catalyst for the development of a modern nation as new ideas emerged about the future of the country's architecture and organization. In 1892, the Imperial Earthquake Investigation Committee (IEIC) was created to investigate if there was a method to predict earthquakes and to create plans of damage reduction (Clancey, 2006).

However, the great Kanto earthquake, on September 1 1923, was the greatest disaster (Samuels, 2013) in many years. The human tragedy was enormous, according to Schenking (2013), more than a hundred thousand people perished, buildings collapsed and fire turned Tokyo into an inferno. After the catastrophe, Japan implemented a much more complex national reconstruction program.

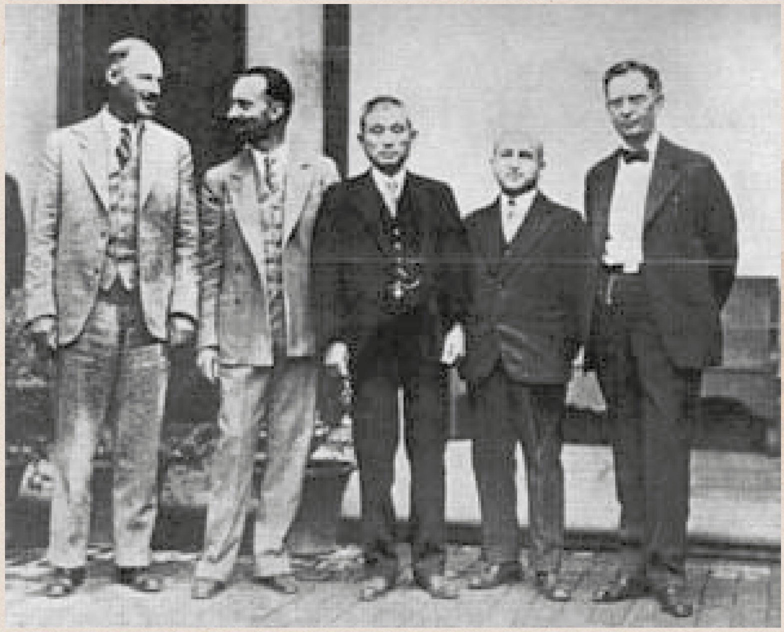
Evoking this disaster there is an important story around the Seismology of the Kanto earthquake in Japan (Aki, 1980). This account began at the University of Tokyo, where Omori and Immamura, two seismologists who had opposing opinions regarding the occu-rrence of an earthquake. The first, who was one of the founders of seismology in Japan, thought that earthquakes never occur repeatedly in the same area unless during historical time, while Immamura held the theory that an earthquake has to occur on the area belon-ging to the seismic belt of greater earthquakes, but that lacked historical records of such occurrence. Instead, Omori wanted to minimize social concerns while Immamura wanted to promote disaster prevention measures. The irony is that the disaster of the great Kanto earthquake consolidated Immamura as a transcendental seismologist. For Tokyo inhabitants, it was a disgrace.

Meanwhile, Omori was in Australia to preside over the second Pan-Pacific Sciences Congress. Imamura, Omori's junior (because Omori was his advisor) colleague, was sitting in the office of the seismology department at the University of Tokyo, at first he thought that the earthquake was not going to be that long, the preliminary lasted 12 seconds, with Omori's formula, he calculated the epicentral distance of 100 km. Previously, Immamura had anticipated the site of Sagami Bay as a possible quake zone. He had previously written an article to prevent and predict the death of thousands of people by fire in the largest earthquake in Japan, that article was criticized by scientists, especially by Prof. Omori. Seventeen years before the earthquake, his life was dark. If the 1923 earthquake had not happened, his life would have been miserable. On the other hand, when Omori returned to Japan, he fell ill and died days after his return. This is an amazing history inside seismology in Japan.

Throughout the seismological history of Japan, several researchers have proposed new theories and contributed new knowledge to the development of seismology in order to understand the mechanism of earthquakes and develop a culture of prevention not only in Japan, but also around the world. Below are the main researchers, their approaches and their contributions to seismology.

One of the most important seismologists was Prof. Suehiro who advocated engineering seismology to mitigate earthquake damage. He was the founder and first director of Earthquake Research Institute (ERI), which was established after the Kanto earthquake. The terminology of engineering seismology was introduced for the first time when Prof. Suehiro was invited by the American Society of Civil Engineering to visit the US in 1931 (Photo 1).

Photo 1. Prof. Suehiro in the center when visited US in 1931.



Source: Taken by https://rnavi.ndl.go.jp/kaleido/entry/jousetsu141.php (May, 2019).

Prof. Suehiro appointed K. Sezawa, a young doctor to work in ERI. He just graduated from the Department of Naval Architecture of the Imperial University of Tokyo in 1921, and his main research topic was focused on the study of longitudinal, transverse and surface waves, and their propagation in the soil. His most noted contribution was a general solution for the wave equation in the horizontally layered medium, which was soon called Sezawa's solution. He was awarded the Imperial Prize in 1931, later he published the book "Theory of Vibration" in 1932.

Drs. Sezawa and Kanai worked together investigating Rayleigh waves (surface waves that produce a retrograde elliptical movement of the ground). It is said that Sezawa was a prodigious calculator as he produced dispersion curves using a sliding rule, an outstanding feat even for today's standards. There are two pioneering papers dealing with the dissipation of vibration energy of superstructure into the soil (1935 and 1936). Sezawa became ERI director in 1942, and he died in 1944 from pulmonary consumption (Iguchi, 1982 personal communication).

Photo 2.

a) Prof. Katsutada Sezawa (1895-1944).

b) Dr. Kiyoshi Kanai (1907-2008).

Sources: a) Taken by https://rnavi.ndl.go.jp/kaleido/entry/jousetsu141.php (May, 2019). b) Dr. M. Iguchi, personal communication.

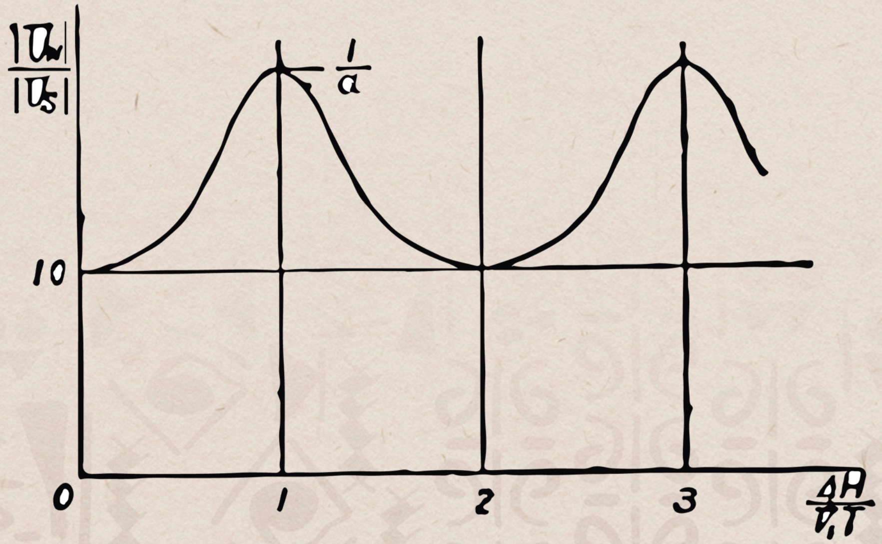
Although weak tremors are not destructive, they provide large amounts of useful information for understanding side effects and the response of structures. This subject has its beginnings in Suehiro's work. He developed a multi-pendulum recorder, which we consider a predecessor to the response spectrum concept; he used to refer to his pendulum as a seismic vibration analyzer. In parallel, Biot (1933, 1941) introduced the response spectrum theory and developed an analog device to obtain it. He was aware of Suehiro's work and following him pointed out that according to recent observations by Suehiro in Tokyo, there seemed to exist characteristics frequencies of the ground at given locations.

After an earthquake was recorded, for instance, in a smoked paper, people computed Fourier and response spectra in an approximately like counting the zero crossings. Sundry theoretical works by Sezawa and co-workers at the ERI used the theory of elasticity and some simple expressions were developed from the basic theory of Takahashi and Hirano (1941), who considered a vertically incoming harmonic shear wave, satisfying the 1D wave equation and assumed a single layer of thickness *H*, speed V_1 and mass density ρ_1 overlaying an infinite space with properties V_0 and ρ_0. For a circular frequency ω=2π/T, where T=period, they found that the motion amplitude Uw relative to the motion in absence of layer Us, can be written as:

$$\frac{|U_W|}{|U_S|} = \frac{1}{\sqrt{\frac{\omega H}{V_1} + \alpha^2 \frac{\omega H}{V_1}}}$$

Where $\alpha = \frac{V_1\rho_1}{V_0\rho_0}$ is the impedance ratio. This famous formula implies the concept of a transfer function for the first time in earthquake engineering and seismology. Fig. 1 depicts this transfer function against the argument $\frac{\omega H}{V_1} = \frac{2\pi H}{V_1 T} = \frac{\pi}{2\left(\frac{4H}{V_1 T}\right)}$ and displays amplifications $\frac{1}{\alpha\ (if\ \alpha<1)}$ or de-amplifications $(if\ \alpha < 1)$ for $\frac{\omega H}{V_1} =$ odd multiples of $\frac{\pi}{2}$.

Figure 2. The theoretical transfer function for the motion of a surface receiver on a layer over a half-space, relative to the motion without layer, under the incidence of a unit plane wave



Source: Takahashi and Hirano (1941).

This fundamental result did not reach worldwide dissemination quickly. Those years were difficult, as World War II had already started. After the war, different advances took place. We may mention the fundamental work by Haskell (1953) regarding multilayered mediums. The famousº Thomson-Haskell propagators easily allowed computation of transfer functions in realistic cases. The observed seismic response of Mexico City soils in 1962 was explained with a similar method (Herrera and Rosenblueth, 1965).

Extrapolating Aki's (1980) paper, there are two approaches for the future in seismology: the active and the passive ones. The first consists of constructing a large generator of seismic waves in a remote place of the Earth. The device will continuously send timed signals through the Earth's interior, which could be used to monitor, in a seismic area, changes in velocity and attenuation (the loss of energy of waves when they propagate in the medium) in order to predict earthquakes. The disadvantage is that such a machine will generate unbearable shaking. On the other side, it is the use of microseisms generated under the ocean, having a sufficient number of stations it will be possible to identify simultaneously locations and origin times of local earthquakes, the advantage is that microseisms exist 24 hours a day, all year around, a lot of information may be used for a deep structure study. It is important to highlight that both approaches are complicated to carry out because of the vast amount of resources that they would need Aki said. Certainly, the vision of Aki materialized in modern seismology as the seismic ambient noise is becoming a major field of study in seismology worldwide.

In seismology like in many human endeavors the achievements rarely come in a single event; they emerge after the work of many individuals. Iguchi (1982) explored the future in different areas of engineering seismology. He focused on earthquake engineering, mainly in the evaluation of effects for the soil foundation to determine the seismic response. Iguchi (1982) describes an approximate procedure for evaluation of the input motions for rigid embedded foundations; he shows a formulation of this in an elastic media obtained by evaluating free field displacement and stresses. Therefore, it is very important to know theoretical results for different vibration modes. It is necessary to confirm theoretical estimates by direct earthquake observation. This is essential research in engineering seismology for different types of buildings. We are sure Iguchi influenced on the work of the late Mexican researcher Javier Avilés (1958-2018) who did fundamental research on kinematic and dynamic soil-structure interaction and promoted it to include their effects in the building codes.

Perhaps the most popular method for site characterization is based on the measurement of seismic ambient noise to calculate from it the Horizontal-to-Vertical Spectral Ratio (HVSR). The so-called Nakamura's (1989) ratio has been used as a convenient way to extract the predominant frequency at a target site. The measurement may even beused to derive an S-wave velocity structure at the site. On the other hand, Arai and Tokimatsu (2004) considered the excitation of Love and Rayleigh waves by assigning their amount of participation. They proposed the use of average directional energy densities (DEDs) in order to compute MHVRs as the square root of ratios of DEDs. Sánchez-Sesma (2017) presented an account of the emergence of a theory to explain HVSR, the Nakamura's ratio, in terms of the imaginary parts of Green's function tensor components. In fact, the Horizontal-to-Vertical Spectral Ratio (HVSR) of Seismic Ambient Noise and Earthquakes leads to a suite of issues: Its measurement and the modeling and Inversion. Using the Diffuse Field Concept was a success that resulted primarily from a collective development by researchers in Japan, Mexico and around the world.

Research in Mexico

Earthquakes may generate Tsunamis if the rupture mechanism and depth produces significant vertical uplift at the bottom of the sea. A tsunami near the coast may have large waves with several meters of height, parsimoniously carrying great energy. They may carry on everything they encounter on their way.

In Mexico, a tsunami of great impact took place on 28 March 1787. According to Suárez and Albini (2009, cited by Chávez *et al.*, 2016), it was produced by an earthquake on Oaxaca's coast with a magnitude of about 8.6. Some years later, on 19 July 1858, a tremendous earthquake (Santa Juliana) was reported both in the state of Michoacán and in Mexico City, the magnitude is estimated to be about M7.7. Initially "trepidatory" (vertical) motion followed by N-S oscillation that changed to E-W. The movement was so strong that affected houses, buildings, and cracks appeared on the ground (Singh *et al.*, 1996).

Mexico is an active zone that shakes continuously; nevertheless, one of the earthquakes that marked Mexico in many ways, was the 19 September 1985, M8.1, Michoacán earthquake which occurred along the Mexican subduction zone of the Pacific in Michoacán near the Guerrero gap. Unprecedented destruction in Mexico City left perhaps several tens of thousands of causalities (Campillo *et al.*, 1989). Therefore, several investigations were performed with the goal to understand the damage in Mexico City. For example, Sánchez-Sesma et al. (1988) and Campillo et al. (1989) explain damage and the ground motion by considering, in a unified way, source, path and site effects. Curiously, they successfully related teleseismic records with epicentral vertical displacements. The work by Kawase and Aki (1988) shed light on issues like the long duration of strong motion in Mexico City.

Nowadays, it is known that Mexico City is divided in three zones: Lake Zone, which consists clays with high water content and sand deposits; Transition Zone, composed by materials of sandy and silty layers (alluvial origin) with clay intervals, and the Hill Zone, which combines alluvial with glacial deposit and lava flows (Sánchez-Sesma *et al.*, 1988). The damage during the 1985 earthquake was because the soft soil amplified the surface waves together with the duration, exceeding up to four excruciating minutes. Sánchez-Sesma *et al.* (1988) describe some features of damage for one and two-dimensional wave's propagation models. The one-dimensional model has been useful to reproduce the main ground motion characteristics.

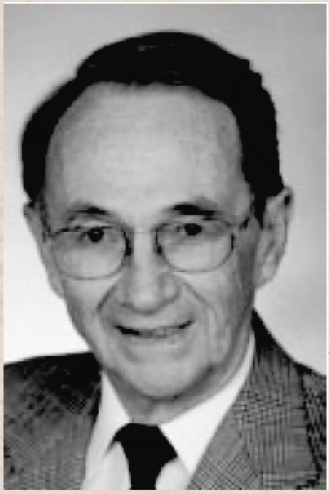
Meanwhile, Campillo *et al.* (1989) analyze the effects caused by the rupture process in the Michoacán earthquake with Teleseismic waveforms, and consider that the damage in Mexico City is by periods from 2 to 4 seconds, and the radiation from this earthquake is characterized by a period of 3 seconds, which have originated shortly after the beginning of the rupture process. Campillo *et al.* (1989) contemplated two models of rupture: (1) dislocation on a square fault plane and (2) smooth crack model with unilateral propagation. According to numerical results, they proposed a model similar to a smooth crack with varying rupture velocities. They concluded that the strong destructive ground motion in Mexico City during the earthquake of 1985 was the result of source effects at a period of 3 seconds, efficient propagation of crustal guided Lg waves and local amplification induced by site conditions.

The seismic hazard concept arose in earthquake engineering. It indicates the probability that an earthquake will happen in a time, in a geographic area, with an intensity of ground, movement, and with estimated risk. In fact, McGuire (2007), defines probabilistic seismic hazard analysis (PSHA) like an evaluation of annual frequencies of exceedance of ground motion levels at a site. This concept emerged in the early 1960s. During that time, in Universidad Nacional Autónoma de México (UNAM), several studies regarding the relationship between occurrence of earthquake and ground motion at a site were developed by, they then PhD student, Luis Esteva, Prof. Emilio Rosenblueth and coworkers

According to McGuire (2007), Allin Cornell was a civil engineering professor who temporarily taught a Probability class in UNAM, interacted with Luis Esteva who is a civil engineer as well, both exchanged ideas (see photos 3a, 3b). Also, there was a group in UNAM who studied the dependence of peak ground acceleration, velocity and displacement on earthquake magnitude and distance. These studies allowed Luis Esteva to publish the first map of seismic zones that includes modified Mercalli Intensity (MMI). Cornell did the derivation of equations for probability of exceedance of MMI intensity level, given an earthquake on a fault of length, in 1968 he published the formulation of seismic hazard analyses, showed how to model an arbitrary complex region as a set of faults or a set of annular sources that contribute to hazard further the total hazard was the sum of hazards from contributing sources.

Photo 3.

a) Allin Cornell (1938-2007).



b) Luis Esteva (1937-).

Source: Dr. R. K. McGuire (2007)

On the other hand, Esteva did first publish hazard curves for spectral ordinates where recognized uncertainty, associated with their occurrences, is included. In 1970, the formulation of PSHA was generalized using the Total Probability Theorem, which recognizes that earthquake magnitude distributions are not unlimited as was assumed in the first formulation. Cornell (focused on probabilistic analysis) with Esteva (focused on distributions of earthquakes magnitudes) developed the mathematical formulation for selecting seismic design levels around the world. PSHA is indeed the basis of modern building codes.

Joint Research in Japan and Mexico

Site effects during earthquakes are of great concern in both Japan and Mexico. In order forestablish the underground structure, the use of passive techniques is becoming popular to this task.

It's important to know about the theory of diffuse field which has its origin in statistics physics and postulate that due to heterogeneities of the ground the seismic waves suffer multiple diffraction (Sánchez-Sesma *et al*., 2011).

Diverse research has been developed about elastic responses that produce earthquakes on ground. One of them is proposed by Campillo and Paul (2003) where they show cross-correlations of coda waves (last part of the seismic signals, and they are believed to provide information of propagation media) then they found a low-frequency coherent part in the diffusive field. They considered that coda waves can be used to compute impulse response between perfectly located positions and produce images of the inner Earth structures.

In accordance with Sánchez-Sesma and Campillo (2006), the equipartition means that in the phase space the available energy is equally distributed, with fixed average amounts. They consider as a canonical problem a uniform random distribution of plane waves within a homogeneous elastic medium and computed the cross-correlation of the fields produced at two points by plane waves, then azimuthally averaged and display that the Fourier transform of the average of the cross-correlation of the motion between two points is proportional to the imaginary part of the tensor of the Green's function between these points, provided there is an energy ratio. Finally, their results show that for an elastic medium, equipartition is a necessary condition to retrieve the Green's function from correlations of the isotropic elastic field.

It is possible to retrieve the Green function averaging cross-correlations if a uniform illumination is guaranteed. The representation theorem permits the verification of the well-known result by averaging correlations of motions produced by a diffuse field. In homogeneous and heterogeneous cases, the equipartition of the background is a necessary and sufficient condition to retrieve exact Green function from correlations. And the average autocorrelation of the diffusive displacement field at a point is proportional to the imaginary part of Green function at the source precisely at this point (Sánchez-Sesma *et al.*, 2008).

Continuing with Perton and Sánchez-Sesma (2009) who focused on the concept of diffuseness in a radiating elastic field with the concept of energy equipartition which is usually described in terms of the distribution of wave intensity in direction and polarization. There are two equivalent approaches that describe at least two ways in which equipartition occurs, one of them in a full three-dimensional 3D elastic space, the transverse and longitudinal waves have energy densities in fixed proportions, on the other side, there is an alternative point of view that associates equal energy with the independent modes of vibration. The authors gather theoretical results for diffuse elastic fields in a full-space and extend them in a half-space.

The damage in an earthquake depends on site conditions which are characterized by spectral ratios of recorded motions and according to Sánchez-Sesma, Rodríguez *et al.* (2011) these ratios are called Empirical Transfer Functions (EFT) and for seismically active locations can be easily obtained. For a diffusive field, they can establish that the average autocorrelation of motion for a given direction at a given point is proportional to the "Directional Energy Density (DED)" and the energy density at given directions are proportional to the imaginary part of Green function tensor components at such point.

Retaking the "Nakamura" method proposed by Nakamura (1989) who assumed that microtremor (HVSR) directly provides us with the S-wave amplification factor or earthquake in the horizontal components. However, based on the diffuse field concept, MHVSR modeled by the square root of the ratio of the sum of the imaginary parts of two horizontal Green's function components and the corresponding imaginary part of vertical Green's function (see Sánchez-Sesma *et al.*, 2011 and Kawase *et al.*, 2015).

$$\left[\frac{H}{V}\right](\omega) = \sqrt{\frac{Im[G_{11}(x,x;\ \omega)] + Im[G_{22}(x,x;\ \omega)]}{Im[G_{33}(x,x;\ \omega)]}}$$

This formulation naturally allows for the inversion of HVSR including the contributions of Rayleigh, Love and body waves based on Sánchez-Sesma *et al.* (2011) where they applied this theory to noise records at Texcoco (site near Mexico City).

Indeed, for understanding the behavior of surface wave in a horizontally layered structure, there is a horizontal-to-vertical spectral ratios of microtremors (MHVRs) which have been interpreted as representing either the Rayleigh wave ellipticity or the amplitude ratio of the sum of Rayleigh and Love waves (surface waves) and this is useful for finding the dominant frequency of a site and also for site characterization and microzonation or invert S-wave velocity structure at the site (Kawase *et al.*, 2015).

Kawase *et al.* (2015) revised the microtremor data from previous studies and validated the diffusive field method (DFM), as proposed by the theoretical formula for MHVRs to establish MHVRs technique.

In one recent account, Sánchez-Sesma (2017) reviewed the physical basis for the measurement, modeling and inversion of the microtremors H/V spectral ratio (MHVSR). The measure became popular for evaluating the dominant frequency of sites. He reviewed the connection between average autocorrelation (measured directional energy) of motion belonging to a diffuse field with given directional energy densities (DED) which are proportional to the imaginary parts of the Green's function, this led to the understanding of the MHVSR's behaviour. He discussed the joint inversion of dispersion curves over an area of Almeira, Spain.

The effectiveness of the diffuse field concept has also been proved for the earthquake H/V spectral ratio (EHVSR) through the collaboration between researchers in UNAM and DPRI, Kyoto University. First, Kawase *et al.* (2011) showed that EHVSR averaged over many weak motions from a variety of earthquake sources corresponds to the 1-D S-wave transfer function divided by 1-D P-wave transfer function with the H/V amplitude correction factor at the bedrock. Then Nagashima *et al.* (2014) used Kawase et al.'s (2011) theory to invert both S- and P-wave velocity structures based on the observed EHVSRs in Japan. The formulation is quite robust to determine an S-wave velocity structure down to the seismological bedrock (a topmost layer of the upper crust).

Institutional Cooperation UNAM-DPRI

Over time, as earthquakes occur, different institutes, organizations and plans were developed with the purpose of researching sites, ground motion and occurrences of these in order to safeguard lives and have the best life quality. We know that earthquakes predictions are not possible and Mexico and Japan are the most active zones, so it shakes daily.

Geophysics Institute, UNAM – DPRI, University of Kyoto

According to Kyoji *et al.* (2014), Disaster Prevention Research Institute (DPRI) was founded at Kyoto University in 1951. The DPRI proposes joint research programs with other Japanese universities and research organizations through the Natural Disaster Research Council (NDRC) which was established in DPRI in 2001. The mission of NDCR includes planning scientific strategy to promote natural disaster science, arranging research projects and teams for emergent investigation on disaster events taking place in Japan and abroad. The mission of DPRI is to pursue the principles of natural hazard reduction, establish integrated methodologies for disaster loss reductions based on natural and social sciences, and educate students in related fields (for more details visit: https://www.dpri.kyoto-u.ac.jp/en/).

There was a meeting on April 1, 1904, between eighteen countries in France to create the International Seismological Association to improve seismic instrumentation around the world where Mexico committed to forming the National Seismological Service (SSN) which was decreed on September 5, 1910. SSN was placed under the charge of the National Geological Institute. Between 1910 and 1923, nine autonomous mechanical seismological stations were installed. SSN became part of UNAM (National Autonomous University of Mexico) in 1929 and since 1948 was attached to the Institute of Geophysics of the UNAM. Today the SSN has 22 seismic observatories throughout the country. The mission of SSN is to register, store and distribute ground movement data to inform the authorities and the general population about the country's seismicity, promote the exchange of data and cooperate with other national and international monitoring and research institutions (for more details visit: http://www.ssn.unam.mx/).

DPRI Award

After a series of visits to one of the authors to the Disaster Prevention Research Institute of Kyoto University that started in 1988 with a visit to Prof Kojiro Irikura, a continuous cooperation has been maintained since then. Fruitful cooperation was established between Profs. Hiroshi Kawase and Shinichi Matsushima.

On February 23, 2015, Dr. Naoto Oshiman, Director of DPRI, signed the granting of DPRI Award 2015 "for Outstanding Contributions in Research and Education" to Dr. Francisco J Sánchez-Sesma, Professor of UNAM. The certificate points out the promotion of international recognition to DPRI through research collaborations and the education of young researchers and students.

SATREPS Project MEXICO-JAPAN

SATREPS (Science and Technology Research Partnership for Sustainable Development) is a Japanese government program that promotes international joint research (for more details visit: https://www.jst.go.jp/global) in four research fields: Environment and Energy, Bioresources, Disaster preventions and Mitigation and Infectious Diseases Control. In Mexico, there is one active project, "Hazard Assessment of Large Earthquakes and Tsunami in the Mexican Pacific Coast for Disaster", which is focused on the mitigation of disasters along the Pacific Coast of Mexico through the scientific and sociological studies as a joint project primarily between UNAM and Kyoto University (see e.g. Cruz-Atienza *et al.*, 2018).

CENAPRED

After the disastrous 1985 Michoacán earthquake, different programs and plans of prevention were implemented in the schools, buildings in order to raise awareness that we are a seismic country. Apart from the investigations that were carried out, there was a great event that marked the course in Seismology of Mexico. It was the creation of the National Center o Disaster Prevention (CENAPRED), which was built as a part of the federal government office with the donation by the Japan International Cooperation Agency (Lee *et al.*, 2003). CENAPRED is mainly engaged in monitoring activities of earthquakes and volcanoes and technological development in disaster risk assessment. During the first ten years after the establishment of CENAPRED Japanese experts were continuously visiting CENAPRED to work together with Mexican researchers on various problems to mitigate disasters.

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