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A Practical Classroom Exercise On The Application Of Wavelet Inversion For A Geophysics Class

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ABSTRACT.

In this work we present the pedagogical experience directed for students of cadastral engineering in the subject of geodesy, idea developed under the parameters of a pedagogical orientation seen from the conceptual change and the application of the theory for a case, in which data are collected and treated with the necessary rigor that allow to establish the pedagogical advantage of the student. Here the experience is obtained from the treatment of seismic data together with the analysis of the dispersion of super-surface waves, a topic developed in a class session whose theme of waves, will allow the student to generate wave velocity models in a study area for which data is available. Allowing to identify the different components that structure the subsurface. these components and their location in the crust allow to define the particular characteristics that can be identified by the velocity models obtained from the inversion of each of the dispersion curves acquired with the multiple filtering method.

Keywords: multiple filtering,seismic data,seismic data,surface waves,geological structures**.**

I. INTRODUCTION

The response of the students to the developed topic of waves and their application in earth sciences is a fundamental and attractive aspect for the engineering student, since it allows to formalize the aspect of intellectual formation in related topics and their application in items related to earth sciences, giving to understand that it is very important that the students are allowed to experiment in the whole formative process of consultation, investigation and application of the concepts seen in class.

The academic orientation allows to establish that the importance of this type of methods is that they are not invasive and what is sought is to promote the use of them, through a primary study of small geographical areas in size, to determine approximately the depth of mold and eventually apply it in the Colombian territory and thus not sully the environment, at the same time students establish that these are not so expensive methods and with which you can get comfortable results which can be applied in future research.

One of the techniques implemented for the interpretation of seismic data is based on the inversion of dispersion curves, a method that consists of conceiving a crustal model from the variation of wave velocities in the subsurface structure with respect to depth, performing the respective processing of these data, optimizing the signal, eliminating noise and improving data quality, allowing the analysis of a group of traces according to the arrival times recorded by the receivers, in order to identify the characteristics and physical properties of rocks and subsurface materials. This is a consequence of the fact that, in the classroom, a fundamental aspect of waves has been explained, such as their velocity, both for mechanical and electromagnetic waves.

Another important aspect is that students have been explained the importance that the study of the subsoil has acquired today and that geophysical prospecting methods are no longer limited only to oil exploration, but encompass a much broader field of study, allowing that over time different exploration techniques have been developed that continue in practice today and are aimed at identifying the different structures that make up the interior of the earth.

II. UNDERSTANDING THE PROBLEM FROM THE STUDENT'S PERSPECTIVE

The development of the class experience, allows to collect the ideas of the course, which can be reflected in this way, the student wonders assertively and solves their doubts in relation to the processing and analysis of these signals are often used mathematical transforms that are applied to the signals to obtain additional information that is not readily available in the signal in the time and frequency domain. In this case the Fourier transform is the most used transform for spectral analysis, but its application is limited only to stationary signals, whose frequency content does not change with time and this generates a loss of information when processing.

This allows you to see the importance of applying a different processing method that allows you to know in detail the geological structures found in the subsoil and at the same time verify how reliable it can be. Based on the above. Then collecting the fundamental ideas of the exercise we establish that the problem to develop in the project is: To determine the structure of the subsoil in the study area for which seismic data are available that will allow to work the inversion of surface wave dispersion curves.

The students with their dedicated work and their constant review of aspects of dynamism of the country, come to the conclusion that currently the country is advancing a large number of mining and oil exploration projects, the circumstances lend themselves to find optimal spaces for the use of new methods of analysis, since as cadastral engineers and geodesists are able to analyze seismic information, and generate from this data, the establishment of knowledge that is useful for the population and its future development.

III. THE NECESSARY THEORETICAL ELEMENTS EXPOSED IN CLASS, AS PERFORMANCE FOR THE DEVELOPMENT OF A GOOD WORK

One of the many items developed in class, seismic prospecting is a very useful research tool for the internal knowledge of the earth, since with it you can examine with a sensitive resolution from the first meters of the ground to reach hundreds of kilometers deep. Since it is based on the measurement of the propagation of mechanical waves of longitudinal or transverse type through the mechanical medium, which we call subsoil, generating waves by means of artificial sources, through percussions or small explosions. This method records the arrival times of the waves produced, once they have been reflected or refracted in the different geological formations present in the study area.

Another aspect developed in class, seismic exploration methods are based on the study of the behavior of seismic waves in the subsurface. Seismic waves are waves that propagate through the earth as mechanical waves in an elastic medium, which can be originated by natural or artificial sources. These seismic waves are classified into two groups according to the way they propagate in the earth: body waves and surface waves. Here the student has awakened his interest, since he is committed to the exploration of new topics of his interest and possible applications in his future as an engineer. As the pedagogical experience has allowed, this aspect is not very simple to explain in class, but its effects and data capture allow to see the differences of these types of waves, a situation that leads to a broader learning of the exposed topic.

Now, the student has been introduced to the subject of surface waves, and has been told that they are disturbances of the medium and that they propagate over the Earth's surface. It has been explained that their amplitudes at the surface can be very large, however, they present an exponential decay with depth. In the case of earthquakes, which occur more than 1000 km away from the observer, the surface waves arrive much later than the body waves, and we can see that they present dispersion; this is due to the fact that waves of different frequencies travel with different velocities.

Another conceptual aspect studied is oriented to the theory of propagation of surface waves in stratified media, where the velocities of these waves in their propagation experience dispersion, which means that waves of different frequencies propagate with different velocities. by analyzing the dispersion they experience when passing through a medium, it is possible to infer particularities of the structure through which they have traveled. therefore, it is important to differentiate between two kinds of velocity: phase velocity and group velocity.

Students have thus been introduced to the fact that the speed with which a single frequency of a wave group or a phase, such as the crest or valley of a wave group, propagates through a medium is determined by measuring the length of a wave of a given frequency.

And that the group velocity with which a wave group propagates or the velocity with which the amplitude envelope moves along the x-axis. It is also the speed with which energy propagates. It can be measured by determining the time required for a pulse to propagate along a given length of the waveguide.

With these topics of interest, it is important to explain that many changes occur in the interior of the Earth, and one of them is called seismic discontinuities, which are coarse changes in the velocity of propagation of seismic waves. In addition, they indicate changes in the composition or physical state of the materials that are traversed. From these changes, studies are made on the Earth's Seismic Model.

IV. CONCEPTUALIZATION IN THE CLASSROOM ON THE MULTIPLE FILTER METHOD

The topic has been developed for the students regarding the determination of the group velocity, which is based on the application of the multiple filter technique (mft) that is used to obtain the dispersion curve of the group velocities of a preprocessed trace, using a digital filter of Gaussian type. Given the function f(t) that describes the seismogram recorded at the passage of a surface wave, once filtered by means of the Gaussian window y , it can be expressed in the following form:

$$\mathbf{h_n(w_n,t)} = \int_{-\infty}^{\infty} |\mathbf{F(w)}|\, \mathbf{e}^{-\propto\left(\frac{w-w_n}{w_n}\right)^2} \mathbf{cos\,[\,k(w)r - wt]\,dw}$$

The student has asked about the multiple filtering technique, for which we have taken into account in the explanation the part of the consideration that the time for which the envelope of the seismic signal filtered with a Gaussian filter centered on "W_n" reaches its maximum, corresponds to the time of arrival of the maximum energy or the time of the wave group in the neighborhood of that frequency "W_n". Where, the envelope of the filtered seismic signal can be calculated as the amplitude of the analytical signal. This amplitude or envelope is defined by

$$\mathbf{g_n(t)} = \sqrt{\mathbf{h_n^2(w_n,t)} + \overline{\mathrm{h}}_{\mathbf{n}}^{\mathbf{2}}\mathbf{(w_n,t)}}$$

V. EXPLAINING TO THE STUDENT THE CONCEPT OF SEISMIC INVESTMENT

The process of seismic inversion is considered the inverse of direct modeling, sometimes referred to as modeling. direct modeling starts as a model of the subsurface properties, then mathematically simulates a physical experiment or process on the subsurface model, and finally provides a modeled response as output.

if the model and assumptions are accurate, the modeled response resembles the actual data. Inversion does the reverse, starts with actual measured data, applies an operation that backtracks through the physical experiment, and produces a model of the subsurface. If the inversion is performed correctly, the subsurface model resembles the actual subsurface.

Inversion is used in many disciplines and can be applied in a wide range of scales and levels of complexity. In inversion two types of inversion are handled specifically, amplitude inversion and the one in our case study, velocity inversion, the latter is used for depth-scale imaging. Using seismic traces, a velocity-depth model of the subsurface is devised that extends kilometers in the vicinity and depth. In many cases these images are used to determine the shape and depth of seismic reflectors.

VI. ACQUISITION OF SEISMIC DATA FOR ACADEMIC EXPERIENCE WITH FUTURE ENGINEERS

The data used in this study correspond to the earthquakes recorded by the stations of the National Seismological Network of Colombia of the Colombian Geological Service (RSNC-SGC), where the stations were selected depending on the type of sensor, the type of operation and the area of study; in this case the chosen stations have broadband seismic sensors and are of continuous operation. The selected RSNC-SGC stations and their location characteristics are presented below.

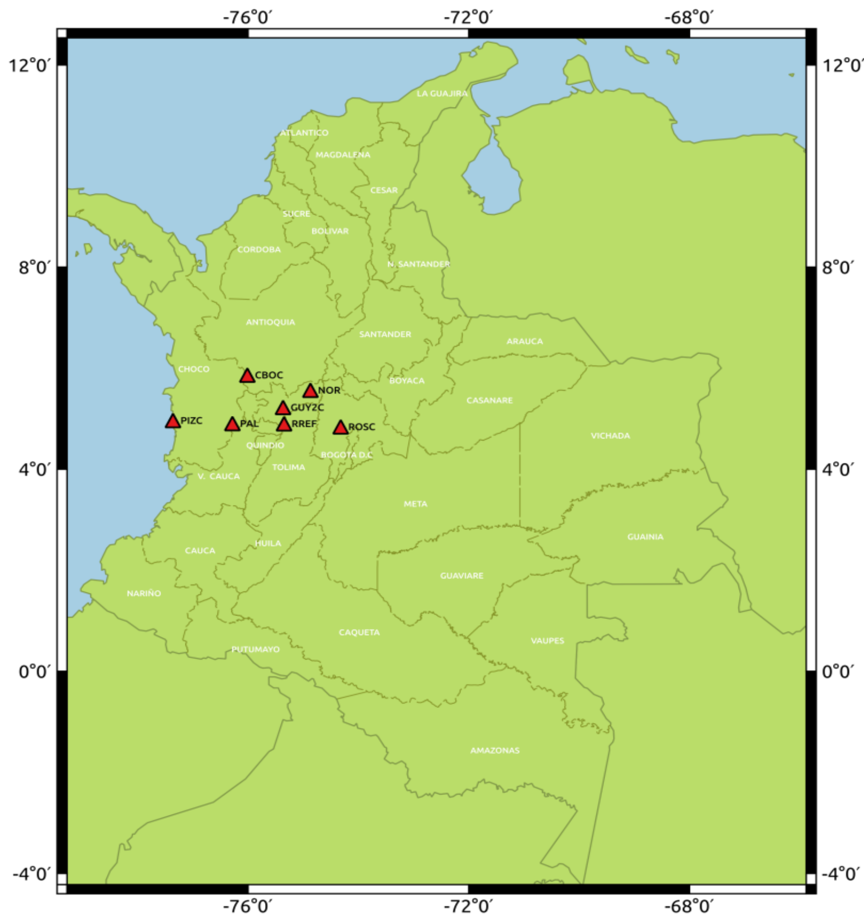


Figure 1. Map of the RSNC-SGC broadband seismological stations.

The orientation to the students for the realization of the selection process of the stations, was carried out through a compilation of all seismic records with epicenters in the area between latitudes 60°N and 60°S and longitudes 130°E and 0°W, with depths less than 45 km and magnitudes greater than 5.9, obtaining a total of 233 surface events from January 2006 to March 2015. This classification of earthquakes is carried out from the United States Geological Survey (USGS) earthquake database and digital files provided by the Colombian Geological Survey in SEISAN format.

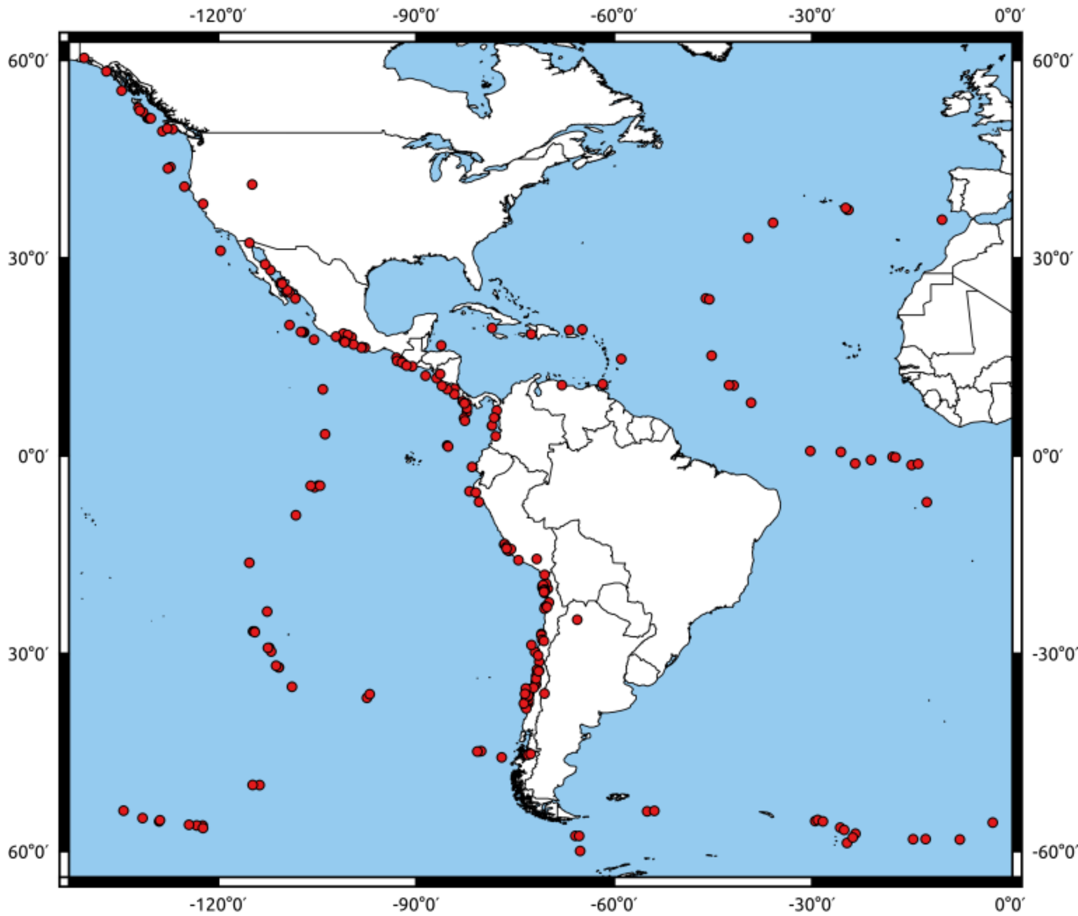


Figure 2. Distribution of the earthquakes selected for this study.

The western region of South America is located within the so-called Pacific Ring of Fire; a complex strip of tectonic trenches, where the major plates of the earth's crust interact through processes of expansion and collision, causing earthquakes and volcanic eruptions. Due to its location in the northwestern corner of South America, the Colombian territory has been subjected since the geological past to great efforts directed in different directions by the effect of the convergence of three tectonic plates: the Caribbean oceanic plate to the north, the Nazca oceanic plate to the west and the South American continental plate located to the east of the previous one.

It has been established that the Caribbean plate moves in a southeast direction, which creates a compression zone between this plate and the South American plate. Although there are records of the existence of events associated with this interaction, the frequency and magnitude of these events are relatively low. The speed of movement of this plate has been estimated to be around 1.9 cm/year. While the South American plate moves in an east-west direction at an average speed of 1.5 cm/year, the South American plate moves in an east-west direction at an average speed of 1.5 cm/year.

VI. METHODOLOGY PROPOSED FOR THE PEDAGOGICAL EXPERIENCE

The methodology proposed and applied by the class, for data processing, obtaining the dispersion curves and the surface wave velocity model, is briefly described below:

The first phase of processing consists of preparing the data, selecting the seismograms from the continuous time series called raw data, obtained from each of the stations. The time series used were chosen from the events reported by the U.S. Geological Survey; and using the SEISAN program, the seismograms are loaded and chosen according to the dates of the events, observing the stations that had recorded the event, the behavior of the seismogram and the stations that had not recorded information in the three components, where they are then classified and cut to have seismograms of a maximum duration of 40 minutes or less where the P, S and surface waves will be visualized..

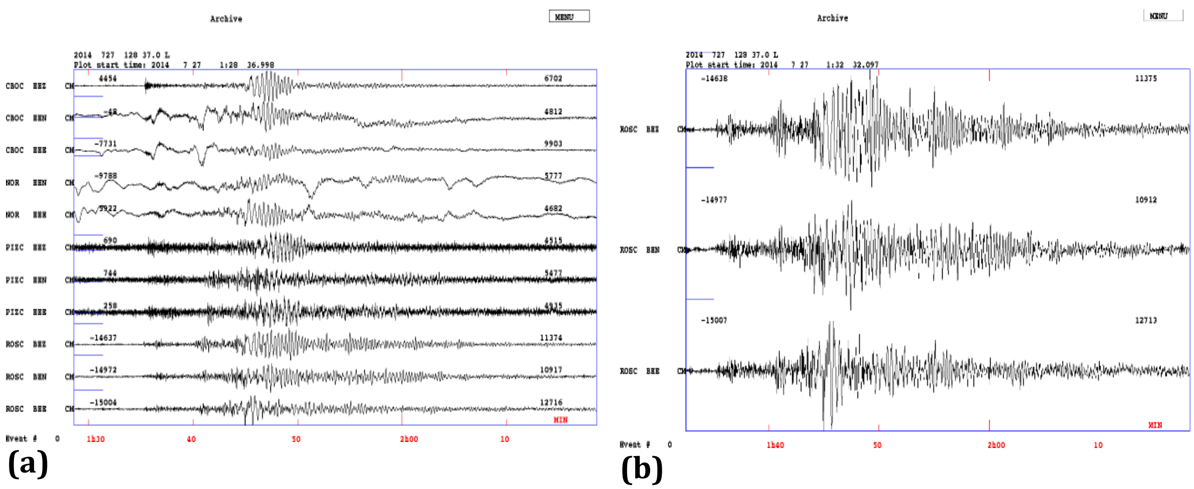
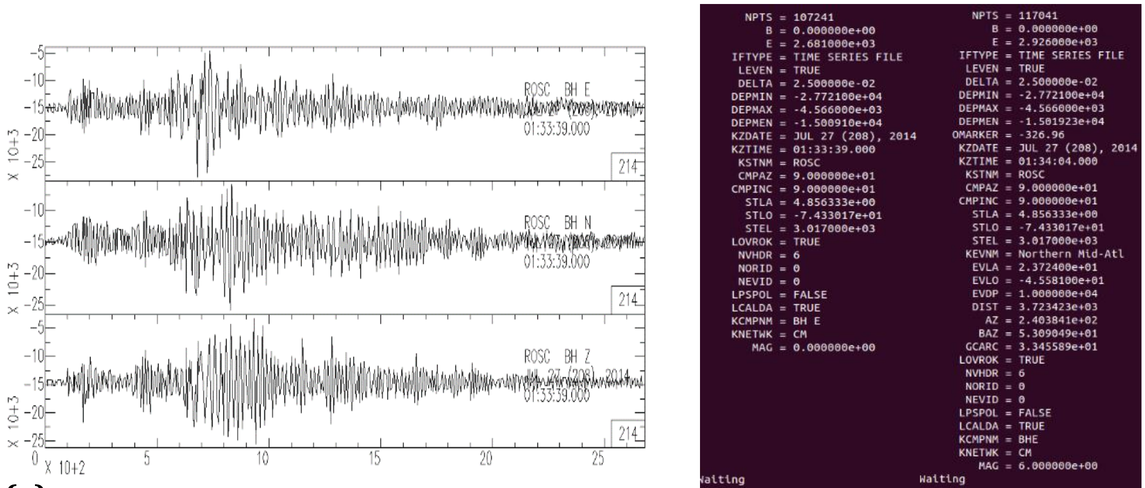


Figure 3. (a). Example of an RSNC record of a seismic event that occurred on July 27, 2014, present at several stations. (b). View of a seismogram when doing the extraction of the 3 components (Z, N and E) from El Rosal station (ROSC).

Since each recorded earthquake is recorded in a SEISAN type binary format file, the format of the files was changed to SAC to obtain the vertical (Z), north-south (N) and east-west (E) components of the seismograms in independent files; after changing the format, loading and reading the files corresponding to the three components and noticing that they did not have all the information, data on the location of the event such as latitude, longitude, depth, magnitude and time of origin were entered in the headers of each of the components; In this process, SAC calculated important parameters such as azimuth (azimuthal angle from the event to the station), back-azimuth (azimuthal angle from the station to the event) and circle great arc (arc of the maximum circle between the event and the station, the shortest path between the two points); which were used in the rotation of the horizontal components, as shown in Figure 4.



(a) **(b)**

Figure 4. (a). Seismogram converted from SEISAN binary format to SAC binary format. (b). Header of a file in SAC format.

In the second phase of the processing and once the data were selected, the seismograms were cut in such a way that only the surface waves were obtained. Since each of the seismograms is composed of the sum of the information from the source, the medium in which it propagates and the instrument that records it, an effect better known as convolution; and in order to analyze only the information from the seismic source, it is necessary to remove the mean, the linear trend, the instrumental response by means of deconvolution and the discontinuity at the ends of the signal.

Both mean reduction and linear trend are two processes commonly used in the treatment of seismic signals. Sometimes it happens that the mean of a seismic record is displaced from the zero line and has a slope (Figure 4); as a solution what is sought is to move the mean line of the record to the zero level and correct the linear trend by eliminating any diagonal from the record so that it presents a horizontal mean. This ensures that the final result has a mean equal to zero.

In the case of seismic signals, seismograms are distorted by the instrumental response of the equipment. In order to obtain real information of the place where the sensor is located, it is necessary to previously eliminate the effects introduced by the instrumental system. In this process, the seismic record is deconvoluted with the instrumental response using the SAC transfer from evalresp tool, which allows removing any instrumental response defined by poles and zeros, within a certain frequency band, thus eliminating the effect of the sensor in the record.

The third phase consisted of obtaining the dispersion curves through the multiple filtering technique, which was performed by analyzing the earthquake record in different periods. This analysis is performed by filtering the surface wave packet with a narrow bandwidth Gaussian filter to obtain information from a single period. Following this method, we start from the consideration that the time for which the filtered seismic signal envelope reaches its maximum value corresponds to the time of arrival of the maximum energy, or group time t_g for the frequency w_n, or period T_n that was selected as the center of the Gaussian filter. Where, the group velocity is obtained by dividing the epicentral distance by the difference between the group time and the origin time.

VII. CONCLUSIONS AND RECOMMENDATIONS

A total of 229 seismic events were processed to calculate 458 dispersions of surface wave curves, 229 Rayleigh wave and 229 Love wave events collected at the RSNC broadband stations.

In the processing of this work, the group velocities were calculated reflecting the shallow depth of the inversion, according to the calculations made, the discontinuity is identified at a depth of approximately 35 km, more precisely at 34.3 km.

The important thing to rescue from the work is that a fundamental result is the definition of the velocity model, this is used for the location of the earthquakes and in the calculation of the crust, this model in the Colombian case has great relevance since the lithographic and topographic variety vary the limit of the mold.

The calculation of dispersion curves depends on the pre-processing of the surface wave file, in order to obtain waves without seismic noise, time variations or error in the midline of the record and thus obtain dispersion curves that comply with the theoretical concept of their shape, thus generating a model of velocities at the time of the inversion that is more adjusted.

With the inversion performed it is necessary to identify the different periods that present the group velocities in order to classify them since the result of the dispersions of each event generates very robust information and to generate the inversion it is necessary to have more discrete data, this is how the period path maps are generated, each map represents the density of information per period and per type of Rayleigh or Love wave for the inversion.

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