Interpreting Seismic Activities Using Analog Modeling Techniques

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ABSTRACT

In this paper, we present an analog method to interpret earthquakes. It includes the identification of various phases appearing on seismograms, by measuring the changes in frequency and amplitude. Interpretation also includes the recognition of the waves with respect to possible travel paths through the Earth.

KEYWORDS: Earthquake, interpretation, phase, microseism, primary, secondary.

I. INTRODUCTION

A seismogram records the displacement, velocity or acceleration as a function of time, representing earth's motion during an earthquake. It is a reflection of the combined effects of the source, the propagation path and noise at the recording station, caused by the passing of seismic waves. Three-component seismograms are used to represent 3-D motion in space and time. These seismograms reveal the change in amplitude and direction of motion, which indicate the arrival times of seismic phase, the type and the polarization of wave motion and the direction of the wave arrival.

To identify the phase and location of earthquake, velocity models for radially stratified Earth have been developed which provide travel time for major seismic waves. For the past many years, J B tables [8] were used to determine the travel-time of seismic phases. In 1987, IASPEI generated new global travel-time tables for seismic phases, in an effort to update the J B tables. This effort resulted in two velocity models-iasp91 [9] and sp6 [10]. The two models reveal only small differences in predicted travel-times. The iasp91 model was later again modified in 1995 and akl35 model was proposed [11]. Sengbush etal. [1] formatted a linear filter model of the seismic process by assuming that the earth is described by the continuous velocity lo, the shot pulse is time-invariant and propagated as a plane wave with normal incidence and all multiples, and noise are negligible. Kulhanek and Persson described seismogram interpretation by identification of various seismic arrivals or wave types visible on seismograms. They pointed out that phase identification is a doorway and without correct seismogram interpretation hardly any analysis would be possible. Lomax and Michelini [3] described the use of spherical coordinates and lower hemisphere, equal-area projection to display and interpret seismograms. They emphasized that the use of spherical coordinates is a simple method for increased comprehension of the particle motion, wave polarizations and phase onsets in seismic record. Dispersion curves of surface waves show a complicated pattern with several local minima and maxima. Long period Rayleigh surface waves follow the law of inverse dispersion, an example of which is exhibited by Engdahl [6]. He used records from the deep earthquakes and identified seismic waves reflected as many as four times within the Earth's outer core. Bolt [4] reported some of such cases. He introduced some symbols to indicate seismic waves reflected at the underside of a secondary discontinuity, in the upper mantle. In this paper, we describe the analog method of earthquake interpretation.

II. INTERPRETATION OF SEISMOGRAMS

(1) Recognition of Earthquake Waves

Earthquakes are sometimes called activity. The first step in the interpretation of a record is to recognize the earthquake on seismogram. The time of beginning of activity is also important. If the activity is small, it will be difficult to recognize first arrival. Then, the preceding pattern of seismogram may be examined to see if any similar types of activity are present. After the selection of first activity, other activities may be chosen which are different from first activity either in amplitude or in time period. Recording due to the noise and earthquake activity must be differentiated. In case of earthquake, there is a decreasing pattern of waves which is not present in noise.

(2) Naming a Phase

As the time factor plays an important role in interpretation of seismograms, so it is very necessary to keep the clock attached with seismograph, corrected by comparing it with radio signals. While reading the arrival time of an event it may be measured to the nearest 10^{th} part of a second. Two types of arrival of phases are recorded on seismograms.

(i) Impulsive Phases: These phases are denoted by small English alphabet 'i'. These are sharp arrival of a phase, from which the direction of first arrival can be noted. The impulsive phases are read up to 10^{th} part of a second in each component (ZNE) separately. If the time of impulsive phase differs up to 1 or 2 seconds in different components then the earliest arrival time of wave is taken (Fig. 1).

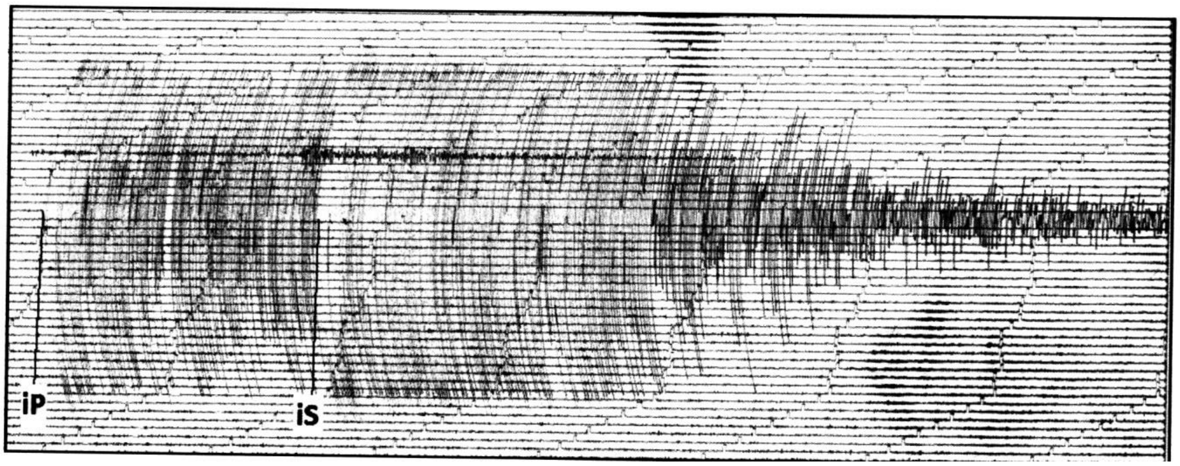

Fig. 1: Earthquake showing impulsive phases

(ii) Emergent Phases: These are denoted by the small English alphabet 'e' (e_p, e_s etc.). When the first arrival of a phase is not strong and the direction of first motion is not clear, then the phase is called emergent phase. The emergent phase can be read upto ½ part of a second.

Time correction may be used while writing the arrival time of a phase. It is positive when the clock of seismograph is slow and negative when the clock is fast.

(3) Direction of Ground Motion

By knowing the direction of ground motion the direction of epicentre is determined from recording station. For this purpose first direction of all three components (Up-down, North-South and East-West) installed at one recording station must be clear. For example, for a sudden northward movement of ground the relative motion of the pendulum is to the south. An impulsive ground motion is always opposite to the relative pendulum motion. The same reasoning applies to the other two components.

The direction of the ground motion on the arrival of the impulsive longitudinal wave (compressional, rarefactional waves) will be away from the epicentre if it is compressional and towards the epicentre it is rarefactional. In a vertical component installed at the station, upward ground motion is compressional and downward motion is rarefaction. When in vertical component, if motion is upward then it is denoted as 'C' and the direction of other two components is reversed. For example, if three directions are CNE (will be reversed and changed to CSW) the epicentre will be in the direction SW of the recording station. If the direction noted are DNE, then the direction of the epicentre will be towards NE of the recording station.

Sometimes following disturbances affect the smooth recording of earthquakes and it become difficult to recognize all phases in interpretation of seismograms.

(i) Microseisms: These are minute vibrations of the ground generated by different types of meteorological disturbances. As the phenomenon changes, the amplitude of these vibrations also changes. The recoding of microseisms (Fig. 2) is irregular on seismograms and sometimes due to this detection of earthquake phases become more difficult.

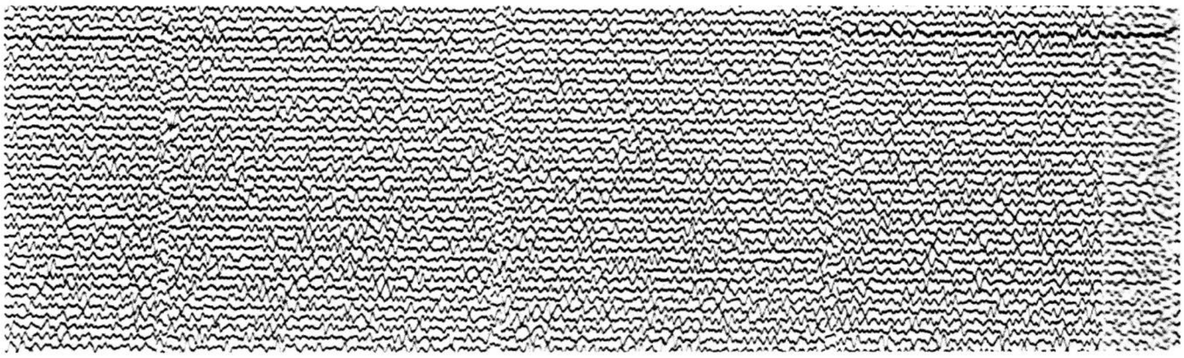

Fig. 2: Microseism recording on seismogram

(ii) Artificial vibrations: These are disturbances in day time due to cultural noise and are temporary. Sometimes it is difficult to distinguish weak local shocks from these types of disturbances.

(iii) Effect of meteorological conditions: Strong wind and convection currents also affect the pendulum motion and it affects the recording of shocks.

(4) Various types of shocks for interpretation

(i) Earthquakes at epicentral distances up to 10°: These earthquakes are called short epicentral distance earthquakes and in the time duration of these earthquakes is very small. Primary (P) and secondary (S) waves can be easily recognized in these shocks. It is difficult to distinguish between surface waves and secondary waves as their velocity difference is less. In short epicentral distances secondary and surface waves reach the station almost at the same time so the amplitude of secondary phase is more. There is no more vibration in the period of waves, so other phases can be recognized with the help of travel time table and charts.

Sometimes P-waves as well as PKP and PP waves are recorded and takes appearance of local shocks. On the records these are accompanied by the appearance of surface waves that have longer time period. So these waves can be differentiated by noting the amplitude and time period difference. In short epicentral distances, P-waves are recorded in the form of P_g, P^*,P_n and S-waves following the same path in the form of S_g, S^* and S_n (Fig. 3).

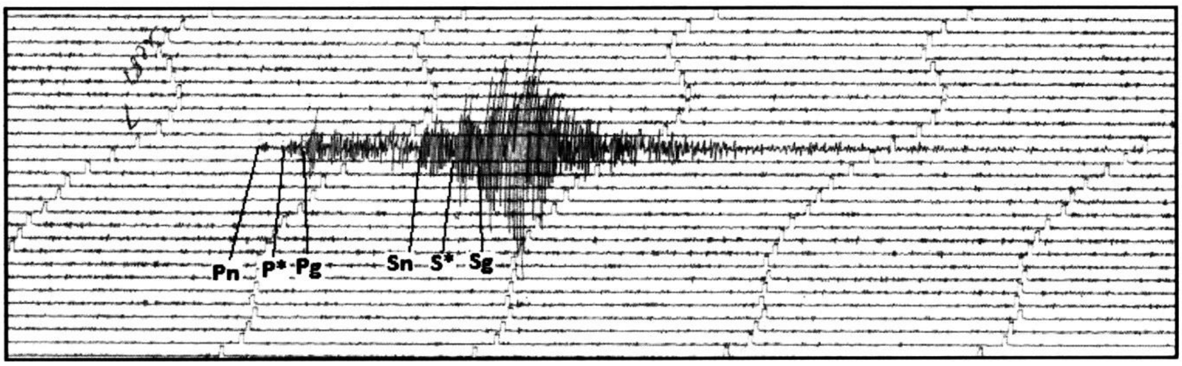

Fig. 3: Different earthquake phases for short epicentral distance

(ii) Earthquakes at epicentral distances from 9° to 103°: The records from earthquake at epicentral distance 9° to 103° are relatively simple and easy to interpret, as the wave propagation is dominated by the mantle (Fig. 4). Here the predominant period are 1 second for P-waves, 5 seconds for S-waves and 10-30 seconds for surface waves. S-waves show rather long period especially beyond 33°, and it is usually larger in horizontal component than in vertical. In the range 26° to 37° the PCP, SCP and SCS are often large, first two especially in vertical component and the third one is horizontal component. The SCS-wave is recorded as sharp impulse of relatively short period. The travel time of S and PCS-waves intersect at 40° and mis-interpretation of PCS as S-wave is a common error around this distance. PKP-wave is large at 75° on some occasions and it is recorded with amplitude as large as P-wave. Beyond 84° degree PP is often larger than P-wave and SKS proceeds S-wave.

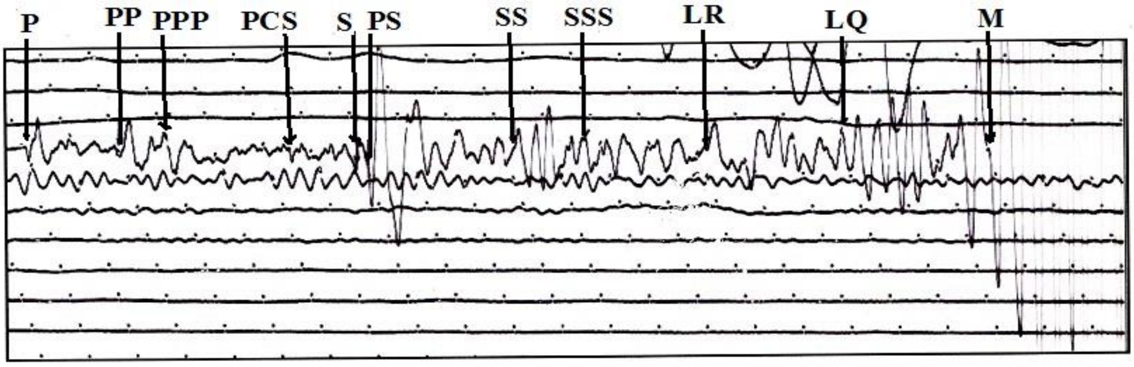

Fig. 4: Different earthquake phases with long epicentral distance

(iii) Earthquakes at epicentral distances from 103° to 180° : The records from earthquake at epicentral distance 103° to 180° is complicated due to existence of core. Here the record of a long period seismograph extends more than one hour after the arrival of P-phase. The periods of different phases also increase between 104° to 130°, first large phase is usually PP. PKP begins at 110° and this phase may precede PP as short period phase in vertical component. In this range P is absent but the diffracted P is sometimes recorded 4 minutes earlier than PP and is normally a long period motion, sometimes consisting of only one or two waves.

Diffracted P is recorded from large earthquakes only. In this range SKS is large near 120°. PKKP is larger and is usually found in short period components while SKS is strong at 132°. Between 115° and 125° PP and PS are large phases. A common elementary error is to identify these waves as P and S, with a false distance of about 80°. The result generally from ignoring the evidence of surface waves for 80°, these begin about 10 minutes after S and reach maximum in a few minutes, while at 120°, first surface waves are almost 20 minutes after PS and the maximum may not reach for another half of an hour. At epicentral distance 143°, PKP suddenly appears with spectacular large amplitude compared with rest of the seismogram. Beyond 143° interpretation is relatively simple and here PKP1, PKP2 and PP are important phases.

(5) Azimuth of source from recording station

Approximate azimuth of source from the recording station can be calculated by measuring the amplitude of P-wave in horizontal component and using the P-wave direction in vertical component. Let A_X and A_Y be the amplitude recorded in two perpendicular horizontal directions. Then $Q = \tan^{-1}\left(A_x / A_y\right)$ measured towards Y-direction gives the azimuth of P-wave in vertical component is dilatation (D). If P-wave motion in vertical component is up, the azimuth will be just opposite of Q. Azimuth is normally measured from north in clockwise direction.

A single seismograph station gives the epicentral distance and origin time. If the station is with 3 component seismograph then it gives the azimuth of the epicentre also. Thus moving from the station along the observed azimuth up to specified distance, locates the epicentre. We should use the map for this purpose which shows the station from which distance and azimuth have been observed. However measuring azimuth by means of amplitude in horizontal component is only an approximation. Thus location of epicentre by above method is approximate. Exact method is based on seismic data from three or more stations. In any case, reporting the initial motion of P-wave is of great utility. Using such initial motions from many seismographs stations, the zone of compression and dilatation is divided, this gives the plane of slip and direction of slip. This determination is important to know the forces generating the earthquakes in the area of their occurrences.

III. ACKNOWLEDGEMENTS

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