MANUAL of EARTHQUAKE MONITORING

دليل المراقبة الزلزالية

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EARTHQUAKE MONITORING

INTRODUCTION

Earthquakes are considered to belong among the agents of natural disaster. When destructive seismic events occur, long lasting impact to society and the environment are left behind due to the generated earthquake hazards. A seismic event generates different kinds of hazards, and usually the most destructive types are the severity of seismic vibrations, the resonance effects of the vibrations period, and the potential dangers from the secondary effects such as tsunami and fire. The natural phenomenom called earthquake is generally described and classified in terms of parameters. The seismic parameters are defined terms that are expressed in quantities for utilization in the classification, description and comparison of different earthquake events. The parameters in quantified forms served as convenient data for used in seismological studies and researches.

To mitigate earthquake losses, comprehensive observation and study of their nature, characteristics, occurrences, and effects in space-time are essential and necessary. To attain the objectives of earthquake disaster mitigation, instrumented seismic monitoring of earthquake events in space-time is vital in the collation of high quality seismic data. Utilization of precise data in any seismological studies and researches leads to accurate results. Of particular importance in seismic monitoring are the studies about the scaling relations among the seismic parameters that have useful application to disaster mitigation.

To gain and have better understanding about earthquakes needs to be familiar with the terms and concepts used in describing these phenomena.

DEFINITION OF TERMS

Acceleration – a force with the units of gravity that denotes the rate of change in time of the movement of the ground during an earthquake.

Accelerogram – refers to a seismic record from an accelerometer, a device in recording the time history of ground acceleration at a site. Peak acceleration is the largest value of acceleration on the record and typically used in design criteria. Ground velocity and displacement time histories can be derived analytically from an accelerogram.

Acceptable risk – probability of occurrence of physical, social, or economic consequences of an earthquake that is considered by authorities to be sufficiently low compared to significant effects.

Artificial – type of an earthquake that is produced when explosive devices are detonated.

Attenuation – a decrease in the strength of seismic waves and seismic energy with distance from the source.

Azimuth – angle made by the longitude of the epicenter and the line joining the epicenter and recording station measured in a clockwise manner.

Built Environment – defines the temporal and spatial distribution of buildings and lifeline system exposed to hazards.

Body-wave Magnitude – when the magnitude value is determined from the body-waves.

Depth of focus – vertical distance between focus and epicenter.

Disaster – occurrence of a hazardous event which adversely affects a community to such a degree that essential social service and functions of physical structures are disrupted.

Duration – length of time between the onset and departure of a natural hazard.

Duration Magnitude – when the magnitude value is evaluated from seismic trace duration of a recorded earthquake event.

Earthquake - transient vibrations of the earth's crust due to the release of the stored strain energy in a focal volume. The energy is transmitted in all directions by means of the generated seismic waves. There are three classifications of earthquakes. These are classified as tectonic, volcanic, and artificial.

Earthquake Hazards – the primary and secondary physical effects generated by an earthquake such as ground shaking, differential ground movements, landslides, tsunami, and etc).

Elements at Risk – the people, ecosystem, environment, natural structures and man-made buildings that are exposed to natural and technological hazard.

Epicenter – is the location of an earthquake on the surface of the earth. It is directly above the focus. It is represented as a point that is defined by its geographical coordinates.

Epicentral Distance – distance between epicenter and a seismic recording station.

Exceedance probability – probability that an earthquake will generate a level of ground motion that exceeds a specified reference level during a given exposure time.

Exposure Time – the period of time that a structure or community is exposed to potential earthquake and other natural hazards.

Fault – a fracture or a zone of fractures in the earth which displacement of the two sides relative to one another has occurred as a consequence of compression, tension, or shearing stress. A blind fault is the term used to describe a fault system that is not visible at the surface of the ground. An active fault is one that exhibits physical characteristics such as historic earthquake activity, surface fault rupture, geologically recent displacement of stratigraphy or topography, or physical association with another fault system judged to be active.

Ground Failure – term referring to the permanent, inelastic deformation of the ground triggered by ground shaking.

Ground Shaking – refers to the dynamic , elastic, vibratory movement of the ground in response to the arrival of the different seismic waves.

Hazard – potential threat to humans and their welfare. The threat could be due to natural and technological origin.

Hazard Assessment – an estimate of the range of the threat such as the magnitude, frequency of occurrence, and duration of the natural and technological hazard to humans and their welfare.

Hazard Environment – defines the physical characteristics of the source, path, and site effects.

Hypocenter/Focus – a point in the earth where the earthquake originates. The hypocenter is a simple representation of the focal volume of an earthquake where strain energy is stored. The focal point can be assumed to be where the first break of rupture happens when an earthquake occurs.

Hypocentral Distance – distance between focus and a seismic recording station.

i or e – prefix to the international symbols used in the identification of the different seismic phases. i and e means an impulsive/sharp and emergent/gradual beginning of the initial onset of a recorded seismic phase on a seismogram respectively.

Intensity – a measure of the local ground motion effects on man and its environment, to all types of building structures, and on free nature. There are different intensity scales used in the seismological community. The scales are named after their respective founders or country of origin. Intensity scales are composed of grades/degrees expressed in the Roman numerals. Each grade described the limitation/extent of the observable effects to man and its environment, to building structures, and to free nature.

Landslide – refers to the falls, topples, flows of rocks from unstable slopes.

Local Magnitude – when based from Richter magnitude scale.

Love (LQ) – a wave that moves on a horizontal plane perpendicular to the direction of motion. It is prominently recorded in the horizontal components of a LP seismograph.

Liquefaction – refers to loss of soil bearing strength that occurs mainly in young, shallow, loosely compacted, water saturated sand and gravel deposits when subjected to ground shaking.

Magnitude – an instrumental measure of the relative size of an earthquake. It is a dimensionless number, and it is related to energy release during an earthquake occurrence. There are different magnitude scales used in determining the magnitude value of an earthquake. The scales are named after the particular recorded seismic waves or parameter from which the measurement is taken. These are body-wave magnitude, surface-wave magnitude, moment magnitude, local magnitude, and duration magnitude.

Mitigation – range of policies, legislative acts, professional practices, and social adjustments that are designed to minimize the effects of earthquakes and other natural hazards on a community.

Moment Magnitude – measure of the size of an earthquake referred from the moment of the equivalent body force and the over-all source spectrum of an earthquake.

Natural Hazard – potential threat to humans and their welfare caused by slow and rapid onset events having natural origin (atmospheric, geologic, and hydrologic) on a global, regional, and local scales (typhoons and storms, earthquakes and volcanic eruptions, floods, and tsunami run up).

Origin Time – time of occurrence of an earthquake. It is expressed in hours, minutes, and seconds in the universal coordinated time (UTC) or Greenwich meridian time (GMT).

Preparedness – refers to using mitigation processes on a community to plan for emergency response, recovery, and rehabilitation after a disastrous earthquake.

Primary Wave – is the first wave to arrive at a recording seismic station. It is a longitudinal type of wave that moves in a push and pull manner along the direction of motion. There are different types of p-wave in accordance to the mode of travel. These are the Pg, P*/Pb, Pn, and P.

Pg – a direct longitudinal wave in near epicentral distance.

P*/Pb – a guided longitudinal head wave that travels along the Conrad discontinuity.

Pn – a guided longitudinal head wave that travels along the Mohorovicic discontinuity.

Policy Environment – defines the community's hazards risk management policies and practices.

Rayleigh (LR) – a wave that moves in an elliptical manner along the direction of motion. It is prominently recorded in the vertical component (Z) of a long period (LP) seismograph.

Response Spectrum – a graph of the output of a mathematical model which shows how an idealized ensemble of lightly damped, simple harmonic vibrating building responds to a particular ground motion. The source of ground motion is an accelerogram that is used to excite the model in the period range 0.05-10 seconds, a period range of interest to engineers. The concept of response spectrum is used in building codes and design of essential and critical structures.

Risk – probability of loss to the elements at risk from the occurrence of natural and technological hazard.

Risk Assessment – an objective scientific assessment of the chance of loss or adverse consequences when physical and social elements are exposed to potentially harmful natural and technological hazards. Risk assessment integrates hazard assessment with the vulnerability of the exposed elements at risk.

Risk Management – public process of implementing decisions that involves choices and actions designed to minimize potential losses when risk assessment indicates the risk.

S*/Sb – a guided transversal head wave that travels along the Conrad discontinuity.

Secondary Wave – the second wave to arrive at a recording seismic station. It is a transversal type of wave that moves in an up and down manner perpendicular to the direction of motion. It is also known as a shear wave. There are different types of secondary wave in accordance to their mode of travel. These are the Sg, S*/Sb, Sn, and S.

Seismic Station – a place or site where a seismograph is installed and operated, and maintained.

Seismic Waves – are motions of disturbance when an earthquake occurs. There are two kinds of seismic waves. These are the body and surface waves. The body wave moves through the body of the earth. The surface wave moves through the surface of discontinuities in layered media. The body wave is composed of two types. These are the primary (p) and secondary (s) waves. The surface wave/long wave (L) is also composed of two types that were named after their discoverer. These are the Rayleigh (LR) and the Love (LQ) waves.

Seismic Zonation – the division of a geographic region into smaller areas or zones based on an integrated assessment of the hazard, built and policy environments of a region. Zonation maps are the results of a process that integrates data, results of research, built and policy environments. The maps contribute to risk reduction and sustainability of the growth and the new developments.

Seismogenic Structure – a geologic structure such as an igneous pluton dike, or sill that has earthquake activity associated with it.

Seismogram – a seismic record from a seismograph.

Seismograph – an instrument that records the relative motion of the ground.

Sg – a direct transversal wave in near epicentral distanceSSS.

Sn – a guided transversal head wave that travels along the Mohorovicic discontinuity.

Soil Amplification – a period-dependent property of the soil to ground motion. It is a function of the relative density of the soil to the base rock.

Soil/Structure Resonance – a physical phenomenon that increases the potential for destructiveness when the input seismic waves caused the soil and structure to vibrate at the same period.

Source Directivity – a physical phenomenon that increases ground shaking at a site due to the directional aspect of the fault rupture that cause most of the energy to be released in a particular direction instead of in all direction.

Surface-wave Magnitude – when the magnitude value is computed from the surface waves.

Surface Fault Rupture – a physical phenomenon of the rupturing fault breaking the surface of the ground and releases more energy on the side of the fault that is moving, thereby increasing ground shaking at the moving part than at the stationary block.

Tectonic – type of an earthquake that is generated when relative motion occurs among large deformed body of rocks.

Technological Hazard – potential threat to humans and their welfare caused by technological factors (chemical release, nuclear accidents, dam failure).

Volcanic – type of an earthquake that is generated due to magmatic movements in a volcano.

Vulnerability – potential loss in value of each element at risk from the occurrence and consequences of natural and technological hazards. The factors that influence vulnerability include demography, built and policy environments, social differentiation and diversity, and political and economical strategies. Vulnerability is a result of flaws in planning, siting, design, and construction.

INSTRUMENTATION

The seismograph is the instrumental device that is used in the monitoring of seismic events in space-time. To be able to monitor earthquake events affecting Saudi Arabia, networks of seismographs were established in the country. One is the Seismic Studies Center (SSC) of King Saud University (KSU) which can be considered as a seismological research observatory (SRO), and the other is the national network of King Abdulasiz City for Science and Technology (KACST). The SRO network of SSC is composed of sub-nets of seismographs whose seismometers are installed in the northwest, southwest, and central parts of the Arabian Peninsula. To each sub-net belongs a number of seismic stations/sites in its list. A seismograph has different components as follows:

(A) Components of a Seismograph

The major components of a seismograph are:

(a) seismometer/transducer/sensor- is an electrical-mechanical device that transform mechanical energy to electrical energy. It detects the ground vibrations and transforms it to electrical voltage. A seismometer is a highly sensitive instrument. It is ideally installed in remote areas to be free from the influence of noise. Seismometers are installed in vault rooms that are constructed 1 to 3 meters under the ground. A seismograph can have 1 to 3 seismometer components. These are the vertical and two horizontal components. The vertical (Z) component is oriented in the vertical direction, while the horizontal components are oriented in the north-south (NS) and east-west (EW) directions. Usually, a single component (vertical) seismograph is used in seismic monitoring, except in some cases when 3 components are used for other purposes.

(b) Voltage and Current Amplifier- the voltage amplifier provides damping to the seismometer, amplify the signals level, and shapes the frequency response of the seismograph, while the current amplifier interface analog data channels to the recorder (recording drum) and provides power gain and control of signals amplitude.

(c) Timing System- provides precise and distinguishing time marks for the hours and minutes to know the time of recordings of the detected seismic events. A precise time source for the SSC seismic network operation is provided by a digital timing system (global timing system-GTS-1). The clock (GTS-1) is synchronized to a global positioning system (GPS) time through a GPS receiver. The GPS time is taken from atomic mounted clocks from at least 4 satellites that relay the precise time. Correct time is essentially an important parameter in seismic monitoring. Accuracy in the origin time and location of a seismic event are time dependent parameters.

(d) Galvanometer and recorder- the galvanometer transforms back the amplified electrical voltages to seismic signals. The signals are recorded by means of a heated stylus pen on a revolving drum for each channel/component. The rotation speed of the drum is adjustable. The range of rotation could be one complete revolution in 10 minutes, 15, minutes, 45 minutes, or one hour.

(e) Voltage Controlled Oscillator (VCO)- provides amplitude limiting and low pass filtering of the input signals before going to the demodulator.

(f) Demodulator- demodulates frequency modulated (FM) signals and its output is equivalent to the input of the VCO.

(g) Very High Frequency (VHF) Transmitter- acts as signal carrier for the seismic signals.

(h) VHF Receiver- acts as signal receiver for the seismic signals.

A block diagram of the seismograph components is shown in fig. 1.

(B) <u>Types of Seismographs</u>

Seismographs have different types depending upon the specification of the seismometer that is used. These are:

(a) Short Period (SP)- suitable in real-time detection of local and near seismic events.

(b) Medium Period (MP)- suitable in real-time detection of local and regional seismic events.

(c) Long Period (LP)- suitable in the real-time detection of regional and teleseismic/distant seismic events.

(d) Intermediate Period (IP)- suitable in real-time detection of local, regional and teleseismic earthquakes.

(e) Broad Band (BB)- used in real-time detection of all kinds of seismic events.

(f) Strong Motion Accelerometer (SMA)- instrument used in the detection and measurement of ground acceleration caused by earthquakes. The seismic record from a SMA is known as accelerogram.

(C) SSC Seismic Network Configuration

The general configuration of the seismic network of the SSC is composed of a central recording station and sub-nets of seismic stations. The central recording station is at KSU, Riyadh City where the SSC is located. The sub-nets are located in the different sectors (northwest, central, and southwest) of the Kingdom. The SSC has 30 established seismic stations. Since the purpose of the SSC network is to monitor particularly local events, the seismometer at each station site in each sub-net is the SP vertical component, except for some selected seismic stations. Aside from the SP, there are also LP, IP, and MP seismic instruments at the central recording station. The central recording station serves as a digital world-wide standardized seismograph network (DWWSSN) station, and a first order observatory. For these reasons, there are different types of seismic instruments at the Center that can record all types of seismic events. The set of instrumentation at the Center makes it possible for the SSC to conduct its research and educational activities, and to respond to its local, regional, and international commitments.

The seismic stations configuration in the sub-nets are distributed in such a way that each sub-net can act independently, and be able to determine accurately the seismic parameters of earthquakes occurring within each respective areas of concern (fig. 2). A station list of the SSC and the corresponding seismic instrument in each station is also shown in fig.3

(D) Frequency Response of Seismographs

A seismometer is composed of a mechanical receiver (pendulum), a transducer which converts the mechanical movements relative to the frame into an electrical voltage, and some filters and amplifiers. The response of a seismometer system may be calculated and described by the transfer functions, where the transfer functions can be derived from its linear differential equation. The transfer functions are dependents on the instrumental parameters and described the amplitude and phase response of the system in the frequency range of interest. Seismological interpretation of seismograms is based on the knowledge of instrumental parameters. These parameters are the bases in seismogram restoration to determine the true earth movements. The system parameters should be re-checked from time to time to guarantee the reliability of data. System parameter determination and calibration of seismometers are of vital importance to SRO practices. Shown in fig. 4 to 7 are the frequency responses of the seismographic network of the SSC.

These graphs are useful in the determination of true ground motions from recorded amplitude traces of earthquakes on respective seismographs. A standardized frequency response of seismographs in a network is necessary and essential in understanding the characteristics and nature of earthquakes in space-time. Procedures in the preparation and determination of the frequency response curves are shown in the appendix.

(E) Real-Time Detection of Seismic Events

The seismic signals from the SSC sub-nets are telemetered continuously in the analog form to the central station in Riyadh via dedicated telephone lines and radio waves. Two systems of recording real-time event detection are used at the central station. These are the analog and digital systems. The telemetered signals are routed to banks of discriminators at the central station where these are converted to analog and digital (A/D) recordings by the A/D boards. The analog recordings are displayed on recording drums, while the digital recordings are stored on magnetic tapes for waveform analysis using microprocessor units (figs.8-10). The computerized system of recording real-time event detection is a powerful tool in earthquake monitoring. The system greatly enhanced reliability and accuracy in the analysis and interpretation of seismic recordings. Using digital system increased the resolution of recordings. A higher dynamic range of the system is attained to facilitate detection of micro-events.

A trigger criteria in recording real-time detection of seismic events in the digital system is selected to avoid large volume of storage data due to false alarm. This is the amplitude criteria. This criteria is based on the ratio of short term average (STA) and long term average (LTA) noises within a range of threshold level. The common threshold level is from 3 up to 5. A lower threshold level increases the rate of false alarm. A checking criteria reduces the false alarm rate. This is the voting criteria which needs 3 to 5 seismic stations to record an event before the system is triggered.

SEISMOLOGICAL ROUTINE

(A) Operation and Maintenance

The basic tasks of a seismological center are:

Maintains the equipment in continuous operation. Calibrate and adjust the equipment to conform to agreed standards.

(b) Produces seismic records that conform to standards in research work, internal use and international exchange.

(c) Undertakes preliminary records reading to meet the immediate requirement of data reporting to local, national, regional, and international agencies for scientific, commercial and other uses.

(d) Performs daily changing and annotation of analog recordings. The seismograms have stamped headers indicating the station code, type and magnification of the instruments, date and time when the records were put on and taken off respectively.

(e) Conducts time synchronization of the network clock and the GPS time. Synchronization is performed before removal of seismograms and or before replacement of the daily analog recordings to know the time correction to be applied to presently removed records, and to start the new day's recording with zero time correction.

(B) Data Analysis and Interpretation

The basic requirements in data analysis and interpretation are:

(a) Recognition of an earthquake in the analog and digital records (figs. 8-10).

(b) Identification of the nature of the clearly recorded group of seismic waves /phases (figs 11-12).

(c) Description of the seismic phases in the internationally agreed symbols of abbreviation (figs. 11-12).

(d) Reading the time of recordings of the different seismic phases.

(e) Reading maximum trace amplitudes and corresponding periods of the different seismic phases (fig 9).

(f) Determine the seismic parameters of the recorded earthquake events.

The seismic records in the analog and digital systems are complex since the recorded traces are influenced by distance, depth of focus, source mechanism, and size of the recorded event. Shown in figs. 11-14 are samples of recordings from different types of seismographs. The steps and procedures as outlined or its variation can be followed in the analysis and interpretation of seismograms.

(C) Computation Processes for the Seismic Parameters

The seismic parameters to be determined are: origin time/occurrence time of the event in hour, minute, and fraction of seconds; location (epicenter) of the event in terms of geographical coordinates; depth of focus; magnitude; and intensity if it is a felt/significant event. One requirement in the calculation processes for the parameters is an appropriate travel time curve/table or velocity model for the different seismic phases. Some of the velocity models (table 2) applied in the Center are shown below for near earthquake events. Table 3 is a travel time- table for local and distant earthquakes.

(1) Calculating Origin Time and Hypocentral Coordinates

The origin time and hypocenter of an earthquake event is determined from the assumption on the relation between travel time of the seismic waves and distance of the event to the recording seismic stations. The procedures of the calculations are as follows:

(a) S-P and P-O Method

The S-P and P-O method is used graphically or analytically in locating the epicentral or hypocentral coordinates and origin time of a recorded earthquake event in space-time. The derivation of the method starts from the equations:

$$D = V(P-O) \qquad (1)$$

$$D = U(S-O) \qquad (2)$$

where; D is the distance between station and the event, V and U are the velocities of the p and s waves respectively, P and S are the arrival times of the p and s waves respectively at a recording seismic station, and O is the origin/occurrence time of the event. (P-O) and (S-O) are the time differences of the P and S to O respectively. (S-P) is the arrival time difference of S and P. Elimination of O in equation (1) and (2) and solving for D gives

$$D = (S-P)\ (UV/(V-U)) \qquad (3)$$

Substitution of (3) in (1) yields

$$P-O = (S-P)\ (U/(V-U)) \qquad (4)$$

From (4) leads to

$$O = P-((S-P)\ (U)/(V-U)) \qquad (5)$$

If the velocities of the p and s waves are known, then equation (3), (4), and (5) can be used to determine the preliminary epicenter and origin time of the event from 3 or more seismic stations. P and S can be read from the seismogram. For accurate results, there should be at least one clear S-P recording from the seismic stations and an appropriate velocity model or travel time- table to be used. A travel time- table is preferable to facilitate the calculations. A travel time- table can be prepared from (1) and (3) to give the equivalent distances for different values of (P-O) and (S-P). When the respective distances are known, arcs of circles with the known distances as radii can be drawn from respective seismic stations to get the most common intersection point. This common intersection point is the preliminary epicenter of the earthquake event. If more clear (S-P) are available, the average O is a better starting point in the determination process by using the (P-O) in (1) and the (S-P) in (3). Equation (2) is infrequently used in practice because of the difficulty in identifying the s-phase.

Using a coordinate system (X, Y), equation (1) or (3) can be expressed as

$$X^2 + Y^2 = Di^2 \qquad (6)$$

which is the standard equation of a circle. The Di's are the respective distances of the seismic stations used in the calculations that can be taken from the (S-P) or (P-O) equivalents. In the form of (6), a software program like Surfer will facilitate the graphical representation of the determination. The most common intersection of the circles is the location of the event.

Equation (6) can also be re-written as

$$(Xe-Xi)^2 + (Ye-Yi)^2 = Di^2 \qquad (7)$$

which can be simplified to becomes

$$AiXe + BiYe = Ki \qquad (8)$$

where

$$Ai = 2(X1-Xn)$$

$$Bi = 2(Y1 - Yn)$$

$$Ki = D1^2 - Dn^2$$

Xe and Xi are the latitudes of the epicenter and the seismic stations respectively. Ye and Yi are the longitudes of the epicenter and the seismic station respectively. Di is the respective epicentral distances of the seismic stations. X1, Y1, and D1 could be made as fixed variables, while Xi, Yi, and Di vary from 2 up to n , where n is the number of seismic stations used in the process of determination. From (7) to (8) requires a minimum of 3 stations to solve for Xe and Ye algebraically. If more than 3 stations are used, a software program in regression analysis will provide rapid and accurate solution. In regression analysis, the system of linear equations in (8) which are composed of different constants Ai, Bi, and Di will be solved for their common intersection point which are the constants Xe and Ye.

Some examples will demonstrate the application of the method graphically. This is shown in figures 16-17.

Equation (1) and (3) can also be represented in 3 dimensions by a coordinate system (X, Y, Z). This can be expressed as:

$$\mathbf{(V(Pi\text{-}O))^2 = (Vt)^2 = (Xe\text{-}Xi)^2 + (Ye\text{-}Yi)^2 + (Ze\text{-}Zi)^2 \qquad (9)}$$

where; X, Y, Z, t are latitude, longitude, depth, and travel time respectively. The subscript (e) and (i) stand for the epicenter and the seismic stations respectively. Given an accurate (S-P) from one seismic station, the equivalent epicentral distance (D) and the O time can be obtained from a travel time- table. This O time can be used to get the equivalent distance for each respective (P-O) of the other recording seismic stations from the travel time- table. The respective distance values can be substituted in (9) to form a system of linear equations when simplified. The simplified equations are represented as:

$$\mathbf{AiXe + BiYe + CiZe = Ki \qquad (10)}$$

where;

$$\mathbf{Ai = 2\ (X1\text{-}Xn)}$$

$$\mathbf{Bi = 2\ (Y1\text{-}Yn)}$$

$$\mathbf{Ci = 2\ (Z1\text{-}Zn)}$$

$$\mathbf{Ki = D1^2\text{-}Dn^2 - (X1^2\text{-}Xn^2) - (Y1^2\text{-}Yn^2) - (Z1\text{-}Zn)^2}$$

$$D1^2 = (V(P1\text{-}O))^2 \qquad Dn^2 = (V(Pn\text{-}O))^2$$

Since there are 3 unknowns (Xe, Ye, Ze) in (10), a minimum number (n) of 4 seismic stations are required in the process of elimination to obtain the preliminary coordinates of the hypocenter of the recorded seismic event. Like in (8), the X1, Y1, Z1, and D1 can be made as fixed variables, while the Xi, Yi, Zi, and Di vary from 2 up to n, where n is the number of seismic stations used in the process of determination. Using 5 or more seismic stations in the process of determination, a software program in regression analysis could be applied to get the required unknown values. Same as in (8), the system of linear equations in (10) when using regression analysis will be solved for their common intersection point which are the constants Xe, Ye, and Ze.

It is also possible in (9) to obtain the origin time of the event and velocity of the p-wave, provided the velocity is assumed constant in the process of determination. Using one seismic station as reference station, the P arrival times at different seismic stations are subtracted respectively from the P arrival time (Pr) of the reference station. A set of reduced system of linear equations can be formed in (9) to give,

$$AiXe + BiYe + CiZe + FiV^2 - Ei(OV^2) = Ki \qquad (11)$$

where;

$$Fi = Pr^2 - Pn^2$$

$$Ei = 2(Pr - Pn)$$

$$Ki = Xr^2 - Xn^2 + Yr^2 - Yn^2 + Zr^2 - Zn^2$$

Ai, Bi, and Ci are as given previously in (10).

The set of equations in (11) could be solved algebraically to determine the preliminary hypocentral coordinates, origin time of the event, and the velocity of the propagated wave. To solve (11), a minimum number (n) of 6 seismic stations are required. With more numbers of stations, a software program in regression analysis makes the solution easier and accurate.

The solution will give the give the common intersection point which are the constants Xe, Ye, Ze, V^2, and OV^2. The constants values for the terms V^2 and OV^2 respectively need to be simplified to get the respective value of O and V. The preliminary values of O and V can be used for recalculations until a better resolution is attained. Computerized solution will facilitate the determination of the parameters accurately in short period of time.

(b) Trigonometric Method

The cosine of the epicentral distance (Di) between the epicenter and a recording seismic station is given as

CosDi = SinXe SinXi + CosXe CosXi Cos(Ye-Yi) (12)

from spherical trigonometry. Xe and Xi are the latitudes of the epicenter and seismic station respectively. Ye and Yi are the longitudes of epicenter and station respectively. Equation (9) can be expanded to become

CosDi = SinXe SinXi + CosXe CosYe CosXi CosYi

+CosXe SinYe CosXi SinYi

which can be re-written as

CosDi = ASinXi + BcosXi CosYi + CsinYi CosXi (13)

wherein;

A = SinXe

B = CosXe CosYe

C = CosXe SinYe

From at least 3 seismic stations with known epicentral distance, taken from their equivalent (S-P) and (P-O) from an appropriate travel time-table, the 3 linear equations can be solved algebraically for the preliminary epicenter using elimination techniques. For better and accurate results, 5 or more seismic stations should be used, and employ regression analysis software program in the process of solution. In (13),

Xe = (180/pi)*arcSinA

Ye = (180/pi)*arcCos(B/Cos(180/pi*Xe))

= (180/pi)*arcCos(Bi/Cos(arcSinA))

or

Ye = (180/pi)*arcSin(C/Cos(180/pi*Xe))

= (180/pi)*arcSin(C/Cos (arcSinA))

when Xi, Yi, Di, A, B, and C are in the units of radians. Xe and Ye in their respective expressions will be in the units of degrees. The initial solution can be used for re-calculation using iterative method for a better resolution.

(2) Calculation of Earthquake Magnitude

In the statistical study of earthquakes, it is essential to have a scale for rating the earthquake size in terms of their original energy independent from effects generated at any particular point of observation. This rating scale is known as magnitude. The size of an earthquake event is related to the hazards it generates, so that it becomes imperative that hypocentral location and magnitude of a recorded event should be known as early as possible to reduce earthquake losses. This information becomes the bases of actions and reactions of concerned disaster and relief agencies in implementing the appropriate measures. There are different magnitude scales. The scales and the calculation of their respective magnitude values are as follows:

(a) Duration Magnitude

A linear relation has been consistently observed between oscillation duration and magnitude of seismic events. This is given as

Md = 2.55LogT + 0.018D – 2.21 (14)

which is empirically determined for application in the SSC sub-net in the Aqaba region, northwestern Saudi Arabia (1999). T is the total duration in seconds of the recorded seismic wave traces from the initial onset of the first p-wave arrival up to the point where the amplitude signal is twice the noise level. D is the epicentral distance in degrees. The dependence in D is small for distances less than 500 km, so that when D is not considered in the regression analysis, the relation reduces to

Md = 2.55LogT – 2.15 (15)

which could be approximately expressed as

Md = 2.6LogT – 2.2 (16)

Application of (15) or (16) is shown in the attached demonstration in calculating the different types of magnitude.

(b) Body-wave Magnitude

The formula in calculating the magnitude values for this scale was internationally agreed at the International Association of Seismology and Physics of the Earth's Interior (IASPEI) meeting in 1967. This is given as

mb = Log(A/T)max + Q(D, h) (17)

wherein; mb is the body-wave magnitude, (A/T)max is the maximum true ground motion, and Q is the calibrating function based on epicentral distance and depth of focus. For simplicity in application, (Amax/T) is used instead of (A/T)max. Amax is the maximum seismic trace amplitude from the recorded p or s-wave, T is the corresponding period in seconds of the amplitude Amax, and Q is the Gutenberg and Richter calibrating function (1955). Amax is measured from the maximum double amplitude (MDA-peak to peak) divided by 2, or from zero (baseline) to peak. To get the true ground motion (Amax/T), the amplitude Amax is converted to micrometer divided by the magnification (frequency response-figs. 4-7) of the instrument at the corresponding period. The Q values (Charts 1 & 2) starts from the distance of 5 degrees for the p-wave and 20 degrees for the s- wave. These conditions limit the applicability of the formula to distances less than the given restrictions.

The steps and procedures in the calculation of body-wave magnitude can be described as follows:

(i) Locate the earthquake event to know its epicentral distances from the recording seismic stations. If not possible, the equivalent epicentral distance from the recorded (S-P) and (P-O) can be used in the calculation.

(ii) Measure the recorded maximum trace amplitude (MDA/2) of the p-wave (Z-component) or s-wave (H-component) and the corresponding period (T).

(iii) Convert the amplitude measurement to micrometer, and divide this value by the magnification of the instrument at the corresponding period/frequency to get the true ground motion.

(iv) Compute the decadic logarithm of the true amplitude of motion and add the Q value (Charts 1 & 2) as indicated in formula (17). The result is the body-wave magnitude of the recorded event. Incorporate station correction when available for accuracy of result.

(v) If more than one seismic station is used in the process of determination, the average value within a specified range is preferable

The adapted local magnitude scale for the SSC sub-net in the Aqaba region (1999) in terms of mb is given as

Ml = Log(A/T) + 3.4LogD + 3.55 (18)

wherein Ml is the adapted local magnitude scale, (Amax/T) is the true ground motion, Amax is half the sustained maximum double amplitude (SMDA/2 or 0 to peak), T is the corresponding period of Amax, D is the epicentral distance in degrees equal and greater than 5 degrees. To get the true ground motion, Amax should be converted to micrometer and divided by the magnification of the instrument at the corresponding period. Perform the indicated mathematical operation in formula (18) to get the local magnitude value of the event.

An example in calculating the body-wave magnitude and adapted local magnitude are shown in the attachment of calculating the different types of magnitude.

(c) Surface-wave Magnitude

The surface-wave magnitude formula is usually used in determining magnitude values of teleseismic large-scale earthquake events. Depths of foci are equal and less than 50 km. Epicentral distance is from 20 to 160 degrees. Period of the surface waves from which measurements of the maximum amplitude are taken is from 18 to 22 seconds. The recommended formula by IASPEI (1967) is

$$Ms = Log(A/T)max + 1.66LogD + 3.3 \qquad (19)$$

wherein Ms is the surface-wave magnitude, (A/T)max is the maximum true ground motion or simply (Amax/T), D is epicentral distance in degrees, and T is the corresponding period in seconds of Amax. The Amax is measured from the maximum double amplitude (MDA/2 or zero to peak) of the recorded surface wave in the range of period from 18 to 22 seconds. The maximum true ground motion is obtained by converting the measured amplitude to micrometers divided by the magnification of the instrument (figs. 4-7). The period of the magnification should correspond to the period of the measured amplitude. The requirements for Ms calculation can be obtained from LP, IP and BB seismographs.

The steps and procedures in calculating surface-wave magnitude are:

Locate the teleseismic event to know the epicentral distances of the recording seismic stations. If not possible, the equivalent epicentral distance from the recorded (S-P) and (P-O) can be used in the calculation.

1. Measure the maximum trace amplitude (MDA/2 or zero to peak) in the vertical component (Z) of the LP in the period range from 18 to 22 seconds. In using the horizontal components (EW and NS), the resultant of the measurement is to be used in the calculation. The amplitude measurements should be taken at the same time of recording in the period range from 18-22 seconds to be able to get the resultant displacement.
2. To get the true ground motion, amplitude measurements are to be converted to micrometer divided by the corresponding magnification of the instruments.
3. Substitute the required values in formula (19) and compute as indicated. Incorporate station correction when available for better accuracy of result.
4. An example in calculating the surface wave magnitude is shown in the attachment of calculating the different types of magnitude.

(d) Moment Magnitude

The simplicity of the seismic energy-magnitude relation is thought to give underestimation of the energy released in an earthquake. It is believed that to obtain the total energy, the amplitude and period must be integrated over the whole duration of the signal in time. Since crustal earthquakes are due to fracturing connected to dislocations, the best way to quantify their sizes is to relate these to moment of the body force and the overall source spectrum. Analysis of seismic records gives information about the seismic source and rupture processes.

The corner frequency is related to the length or width of a propagating fault. It is the intersection of the high and low frequency asymptotes from far field recordings. The length (L) and width (W) of the fault is related to the moment (Mo) in the dislocation model by

Mo = uLWd (20)

wherein u is the shear modulus. In the dynamic model, Mo is related to the stress drop (S), which is the difference between final and initial stresses, and the radius (R) of the circular shear crack. This is given as

Mo = (16/7)SR^3 (21)

which is related to the radiated seismic energy (Es) given by Keilis-Borok (1959)

Es = (1/2u)SMo (22)

Taking the decadic logarithm on both side of (29) gives

Log(Es) = Log(Mo) + Log(S/2u) (23)

Since Es is related to the magnitude of an earthquake, an empirical determination of the relation found by Kanamori (1977) is

Mw = (2/3)Log(Mo) –10.73 (24)

where Mw is the moment magnitude. The relation of Mw to Ms is also found to be

Mw = Ms + 0.1 (25)

(e) Isoseismal / Iso-intensity Map

One essential part of a standard operating procedure (SOP) in a seismological center is the immediate preparation of a preliminary isoseismal map after the occurrence of a felt significant earthquake event. An isoseismal map shows the adversely affected areas. This kind of information is vital to concerned and relief agencies in the implementation of countermeasures to mitigate further disaster from potential secondary effects. The primary effects to natural and man-made structures of a felt significant earthquake event are evaluated by means of field investigation and questionnaires. These methods of evaluating the effects can delay the assessment of damage, due to the processes and conditions that are involved. A first hand information about the effects of a felt significant earthquake event is vital in the assessment of damage, since the effects are affected by the occurrences of aftershocks, renovations of the damage portions, and other changes made in time. To avoid the time delay in the preparation of a preliminary iso-intensity map, a theoretical approach is conceived to be the solution. The applied method relies in using equations that were derived from the scaling relation among the parameters and the intensity attenuation equations (figs. 18-19) with regards to epicentral distance. The equations are as follows:

(i) Depth of focus (=< 10 km)

Iu = 2.17mb –1.1LogD – 0.012D –5.5 **(26)**

Il = 2.17mb – 1.54LogD – 0.019D –5.5 **(27)**

mb = 0.46Io + 2.53 **(28)**

Ms = 0.53Io + 2 **(29)**

(ii) Depth of focus (> 10 km)

Iu = 1.67mb – 1.1LogD – 0.0052D – 2.28 **(30)**

Il = 1.67mb – 1.54LogD – 0.0048D – 2.28 **(31)**

mb = 0.6 Io + 1.37 **(32)**

Ms = 0.7 Io + 0.67 **(33)**

(iii) Scaling Relation

The scaling relations obtained for mb, Ms, Md (1998 & 1999), and Ah (1977) are:

Md = 0.89 mb + 0.48 (34)

mb = 0.89 Ms + 0.79 (35)

Log(Ah) = 0.3Io + 0.014 (36)

The scaling relations can be substituted in (26) to (33) when needed in calculations to facilitate the required solutions. Iu and Il are defined as the upper and lower bound intensities at corresponding maximum and minimum epicentral distances (D) respectively. Ms, mb, and Md are the surface-wave, body-wave, and duration magnitude respectively, Io is the intensity at the epicenter, and Ah is the horizontal ground acceleration. Application of equation (26) to (33) is restricted to the indications as described in their area of limitations.

The application of the equations in the preparation of an isoseismal map is shown in fig. 20.

(f) Seismic Wave Velocities and Travel Time Curve

Knowledge in the respective velocity of the different seismic phases (Pn, P*, Pg, Sn, S*, Sg) is an essential and necessary requirement in locating earthquake events. Usually, the precise and practical measurement of the seismic wave velocities is conducted in explosion seismology. In the absence of artificial earthquakes, the natural events could be used to obtain the approximate velocity values for the different seismic phases. With sufficient number of earthquake events, the average value of each seismic phase could be estimated. The respective averages can be assumed to be representative values that can be utilized in determining the preliminary location of an earthquake event. Knowing the distance and velocity, the travel time can be calculated.

The steps and procedures in determining seismic wave velocities from earthquake events are as follows:

(i) Read the arrival times of the recorded different seismic phases in an earthquake event.

(ii) Locate the event to get the preliminary origin time and hypocentral location.

(iii) Plot the arrival times and or travel times of the different seismic phases versus distance.

(iv) If the arrival times are plotted against distance (D) and the fitted equation is

P = Pe + D/V

for the p-arrival time (P) and

S = Se + D/U

for the s-arrival time (S), then V and U are the apparent velocity of the p and s waves respectively for the direct wave. Pe and Se are the p and s waves arrival times at the epicenter respectively.

(v) If the travel time (P-O) and (S-O) are plotted against hypocentral distance, and the fitted equation is

$(V(P\text{-}O))^2 = (V(Pe\text{-}O))^2 + D^2$ **and**

$(U(S\text{-}O))^2 = (U(Se\text{-}O))^2 + D^2$, then V and U are the average velocities for the seismic waves.

(vi) Relocate the event using the velocities obtained in (v).

(vii) Repeat the procedures from (iii) to (v) until a high resolution is attained.

The steps and procedures in calculating seismic wave velocities is shown in fig. 21-22 as described in the attached demonstration.

STANDARD OPERATING PROCEDURE

Any seismological Center should and must have a standard operating procedures (SOP) that serves as guidelines in its internal and external activities and commitments to the seismological community and other agencies. Particularly in the monitoring of seismic events, a SOP is an essential and integral part of the operation. Usually, for simplicity and clarity, a SOP is prepared in terms of a flowchart The SOP flowchart clearly shows and indicates the appropriate steps and procedures to be taken as required by the mandated function of the Center. For the SSC, its SOP flowchart is as shown below.

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Preliminary Determination of Epicenter and Calculation of Magnitude

(a) Duration Magnitude

From fig. 15, the following data are taken:

MKNA (T) = 120 mm

BADA (T) = 130 mm

BMSH (T) = 130 mm

SALT (T) = 145 mm

Substitute these values in the formula: Md = 2.55*Log(T)-2.15

MKNA: Md = 2.55*Log(120/1.5) – 2.15 = 2.7

BADA: Md = 2.55*Log(130/1.5) – 2.15 = 2.8

BMSH: Md = 2.55*Log(130/1.5) – 2.15 = 2.8

SALT: Md = 2.55*Log(145/1.5) – 2.15 = 2.9

It is appropriate that the magnitude value should be the average of the obtained magnitude values from the seismic stations when the variations are not significant from the point of view of the analyst.

(b) Body-wave and Adapted Local Magnitudes

The Greece earthquake of 19 September 1999 is taken as an example in calculating the mb and Ml. The preliminary location is determined by using the S-P and P-O method. The respective epicentral distances of the seismic stations from the KSU Seismic Network used in the determination are taken from Table B, and are shown in the accompanying figure. Some data are taken from fig. 12. From the seismograms, the following seismic phases were read:

Station.					**Seismic Phases**			
		H	**M**	**S**		**H**	**M**	**S**
HQL	eP	11	59	55	eS	12	02	05.3
MKNA	eP	12	00	0.67	eS		02	21.5
AYN	eP	12	00	06.67	eS		02	33.33
RYD	eP	12	02	04	eS		06	12

The S-P of RYD is 4 minutes and 8 seconds. Using this S-P from RYD, the corresponding values of P-O from Table B are 4 minutes and 8 seconds. This value was obtained by using interpolation method. The first column in Table B is the epicentral distance, the second column is the P-O, and the third column is the S-P. When the P-O value is subtracted from the p-arrival time of RYD, the origin time O is obtained, that is O= 11H: 56M: 56.23S. Subtracting this O time from the p-arrival time of seismic stations HQL, MKNA, and AYN yields: 3min,01.77sec: 3min,04.44sec; and 3min,10.44sec respectively. From Table B, and using interpolation technique when necessary, the following epicentral distances are obtained for HQL= 12.53 degrees, MKNA= 12.96 degrees, and AYN = 13.42 degrees. The epicentral distances can be used to draw respective circles as shown in the accompanying figure, and get the most common point of intersection. This point is the epicenter of the event. Using computer program like Surfer can facilitate the procedure of determination.

The body-wave and local adapted magnitudes are determined as follows. From the seismograms, preliminary location, and frequency response curves:

STA	Ampl.	Dist.	Period	Magnification
SHRF (SPZ)	17 mm	12.76 deg	0.8 sec	800000
MKNA (SPZ)	22 mm	12.96 deg	0.8 sec	880000
AYN (SPZ)	20 mm	13.42 deg	0.8 sec	880000

Q values from Chart 1 is approximately 7.0. The magnitude given by the Greece Seismological Observatory is 5.9. From

mb = Log(A/T) + Q follows

SHRF mb = log(17000/800000) + 7 = 5.33

MKNA mb = log(22000/880000) + 7 = 5.4

AYN mb = log(20000/880000) + 7 = 5.36

Adapted Local Magnitude from SSC of KSU is

Ml = Log(A/T) + 3.4*LogD + 3.55 follows

SHRF Ml = log(17000/800000) + 3.4 *log(12.76) + 3.55 = 5.64

MKNA Ml = log(22000/880000) + 3.4*log(12.96) + 3.55 = 5.73

AYN Ml = log(20000/880000) + 3.4*log(13.42) + 3.55 = 5.74

(c) Surface-wave magnitude

The Turkey earthquake of 16 August 1999 is taken as an example in the determination of the surface-wave magnitude. The preliminary location was determined by using the S-P and P-O method. The respective epicentral distances of the seismic stations from the KSU Seismic Network used in the determination are taken from Table B, and are shown in the accompanying figure. Some data are taken from fig. 14. From the seismograms, the following seismic phases were read:

STATION.		Seismic Phases					
		H	M	S		M	S
BADA	eP	00	04	40.67			
RYD	ePZ(LP)	00	06	32	eS	10	24
DHR	ePZ (LP)	00	06	39.44	eS	10	39.44
KMSA	eP	00	06	52.5			

The S-P of RYD and DHR are 3 min, 52 sec ; and 4 min respectively. From Table B, the P-O for RYD is 4min, 48.53sec by interpolation. From their S-P, the epicentral distances for RYD and DHR are 21.56 degrees and 22.5 degrees respectively in Table B by interpolation. Using the P-O value obtained for RYD, this value was subtracted from the p-arrival time of RYD to get the O which is 00H : 01M: 41.47S. Subtracting this O to the p-arrival times from seismic stations BADA and KMSA, the following P-O values were obtained: BADA= 3min, 01.5sec, and KMSA = 5min, 23.33sec. These values have equivalent epicentral distances from Table B obtained by interpolation technique, which are 12.57 degrees for BADA and 23.85 degrees for KMSA. Using Surfer program, the respective epicentral distances can be drawn as radii of circles to get the most common point of intersection. The point of intersection is the epicenter of the event as shown in the accompanying figure.
The surface-wave magnitude is determined as follows. From the seismogram, preliminary location, and frequency response curves.

STA	Ampl.	Dist.	Period	Magnification
RYD (LPZ)	17 mm	21.79 deg.	22 secs	140
RYD LPN)	25 mm	21.79 deg	20 secs	135

The magnitude given by USGS is Ms =7.4. From

Ms = Log(A/T) + 1.66*LogD + 3.3 follows

RYD (LPZ) Ms = log(17000/140) + 1.66*log(21.79) + 3.3 = 7.61

RYD (LPN) Ms = log(25000/135) + 1.66*log(21.79) + 3.3 = 7.79

The value obtained from RYD (LPN) is larger than RYD (LPZ). This is to be expected since the resultant displacement is used when evaluating the magnitude from the horizontal components

The Intensity Attenuation and its Application

Usually, one of the most destructive hazards poised by earthquakes on land areas is the severity of seismic vibrations. The effects of the seismic vibrations can generate destruction to building structures, liquefaction, landslides, and others potential source of danger. Since intensity is the local effects of the ground shaking, this parameter can be considered as a measure of earthquake danger. Intensity is found to be dependent on the strength and distance of the source, that is, it attenuates with distance as shown in figs. 18-19. In the absence of the physical bases in determining intensity, the source strength known as intensity at the epicenter (Io) is difficult to determine, and may require certain duration of time. As a measure of seismic danger, the intensity distribution during a felt significant earthquake event in a locality should be known as early as possible, to minimize earthquake losses from the secondary potential source of hazards. Hence, an instrumental measure for the Io is necessary and essential. Since the magnitude (M) of an earthquake event is an instrumental measure of its size, the Io is correlated to M.

As shown in figs. 18-19, each curve has a range of magnitude values for each Io, that is, the intensity at 0 km To use the figures in the estimation of intensity, the preliminary location and magnitude of the event must have to be known quantities. Measure/ calculate the distance of a place whose intensity value is in need to be known. Measure this distance at the distance axis. Project this distance vertically upward until it intersects the curve whose range of magnitude values covers the determined magnitude of the event. From the point of intersection, projects the point horizontally until it intersects the intensity axis. The intensity value at the point of intersection, when rounded off is the intensity at the required place.

An application of the upper and lower bound intensities in the preparation of an isoseismal map is shown in fig. 20.

Determination of the Apparent Seismic Wave Velocities

The earthquake of 12 November 2000 as shown in fig. 15 is taken as an example in calculating apparent seismic wave velocities. The respective epicentral distances were obtained from Table A using the S-P and origin time from seismic station AYN. The arrival times of the distinct phases for the p and s-waves were plotted against respective epicentral distances as shown by the accompanying figures. Regression analysis was applied to the plotted data and the corresponding required values were obtained as shown. The following apparent velocities were obtained: Pn = 7.78km/sec; P* = 6.98km/sec; Pg = 5.37km/sec; Sn = 4.1km/sec; and Sg= 3.06km/sec. The data that were used and the calculations that were performed are as follows:

Frequency Response Curve

The seismograph system may deviate from its design characteristic for various reasons. In order to correct the deviations, it is essential to calibrate the seismograph periodically. By simulating known seismic wave frequencies to the seismograph system, a magnification curve with flat acceleration response is generated. The equation which govern the magnification of a seismograph system is

M = A/Y

and Y is given as

Y = 1000000*G*I / 4m*(pi)^2*f^2

where

M – magnification

A – trace amplitude in microns (peak to peak)

Y – equivalent earth motion in microns (peak to peak)

m – weight of mass in kilogram

I – current through the calibration coil

f – frequency of calibration signal

G – calibration coil motor constant

The simulation procedure is performed by using a function generator whose outputs at different frequencies are fed as inputs to the calibration coil that generate corresponding amplitude signals that are recorded on a recording drum.

DETERMINATION OF APPARENT SEISMIC WAVE VELOCITIES

The earthquake of 12 November 2000 as shown in fig. is taken as example in calculating apparent seismic wave velocities. The respective epicentral distances were obtained from the travel time table for near earthquake events (table A). The arrival times of the distinct phases for p and s-waves were plotted against epicentral distances as shown in fig. . Regression analysis wass applied to the plotted data to obtain the corresponding wave velocities.

		P-Time		S-Time		Distance (Table)
	Hour	Min	Sec	Min	Sec	Degrees
AYN	12	7	43	7	58	1.125
		7	48.5			
		7	53.67			
SALT	12	7	49.33	8	10.67	1.57
		8	0.67	8	18.67	
		8	5.2			
BMSH	12	7	51.33	8	9.33	1.71
		8	3.2			
		8	8.67			
BADA	12	7	52	8	17.67	1.76
		8	4.67	8	26.67	
		8	9.67			
MKNA	12	7	56.67	8	23.33	2.08
		8	7.67	8	36.67	
		8	18			

P-Wave Velocity

STA	Time	D(degrees)			
AYN	43	1.125	Regression Output:		
SALT	49.33	1.57	Constant		26.894307
BMSH	51.33	1.71	Std Err of Y Est		0.0421561
BADA	52	1.76	R Squared		0.9999459
MKNA	56.67	2.08	No. of Observations		5
			Degrees of Freedom		3
			X Coefficient(s)	14.294538	7.78
			Std Err of Coef.	0.0606817	
SALT	54	1.57	Regression Output:		
BMSH	57.8	1.71	Constant		30.167367
BADA	59.67	1.76	Std Err of Y Est		1.4296056
MKNA	62.67	2.08	R Squared		0.8964993
			No. of Observations		4
			Degrees of Freedom		2
			X Coefficient(s)	15.936872	6.98
			Std Err of Coef.	3.8289955	
AYN	48.5	1.125	Regression Output:		
SALT	60.67	1.57	Constant		26.800265
BMSH	63.2	1.71	Std Err of Y Est		2.020885

					9
BADA	64.67	1.76	R Squared		0.9440908
MKNA	67.67	2.08	No. of Observations		5
			Degrees of Freedom		3
			X Coefficient(s)	20.704509	5.37
			Std Err of Coef.	2.9089694	
AYN	53.67	1.125		Regression Output:	
SALT	65.2	1.57	Constant		25.130708
BMSH	68.67	1.71	Std Err of Y Est		0.1568277
BADA	69.67	1.76	R Squared		0.9997634
MKNA	78	2.08	No. of Observations		5
			Degrees of Freedom		3
			X Coefficient(s)	25.416187	4.38
			Std Err of Coef.	0.225746	

S-Wave Velocity

STA	Time	D(degrees)			
AYN	58	1.125		Regression Output:	
SALT	70.67	1.57	Constant		28.221585
BMSH	75.8	1.71	Std Err of Y Est		1.1825337
BADA	76.67	1.76	R Squared		0.9882945
MKNA	83.33	2.08	No. of Observations		5

			Degrees of Freedom		3
			X Coefficient(s)	27.09061	4.10
			Std Err of Coef.	1.702201 1	
AYN	62.67	1.125	Regression Output:		
SALT	81	1.57	Constant		23.21243
BMSH	86.67	1.71	Std Err of Y Est		1.839876 1
BADA	88.33	1.76	R Squared		0.984280 3
MKNA	96.67	2.08	No. of Observations		5
			Degrees of Freedom		3
			X Coefficient(s)	36.29810 2	3.06
			Std Err of Coef.	2.648414 3	

CALCULATION OF MAGNITUDE

Duration Magnitude

Body-wave Magnitude and the Adapted Local Magnitude

The Greece earthquake of 19 September 1999 is taken as an example in
calculating the body-wave (mb) and the adapted local

magnitudes (Ml).
The preliminary location and respective epicentral distances from the
KSU Seismic Network used in the determination
is shown in fig. .

From the seismograms:

STA	Ampl.	D (deg.)	Period	Magnification (V) (fig.)
AYN (SPZ)	20mm	13.42	0.8	880000
MKNA (SPZ)	22mm	12.96	0.8	880000
SHRF (SPZ)	17mm	12.76	0.8	800000

Q values from fig. ( )　　M (Greece) = 5.9

AYN	7
MKNA	7
SHRF	7

mb = Log(A/T) + Q
= Log(A/V) + Q

AYN　mb = Log(20000/880000) + 7.0 =　5.36

MKNA　mb = Log(22000/880000) + 7.0 =　5.40

SHRF　mb = Log(17000/800000) + 7.0 =　5.33

Adapted Local Magnitude (KSU)　Ml = Log(A/T) + 3.4*LogD + 3.55

AYN　Ml = Log(20000/880000) + 3.4*Log(13.42) + 3.55 =　5.74

MKNA	Ml = Log(22000/880000) + 3.4*Log(12.96) + 3.55 =	5.73
SHRF	Ml = Log(17000/800000) + 3.4*Log(12.76) + 3.55 =	5.64

Surface-wave Magnitude

The Turkey earthquake of 16 August 1999 is taken as an example in the determination of the surface-wave magnitude. The preliminary location and respective epicentral distances determined from the KSU Seismic Network is shown in fig. ( ).

From the Seismograms:

STA	Ampl.	Period	D (deg)	Magnification (fig.)
RYD (LPZ)	17	22	21.79	140
RYD (LPN)	25	20	21.79	135
RYD (SPZ)	12	1	21.79	25000

Ms = Log(A/T) + 1.66*LogD + 3.3   Ms (USGS) = 7.4
= Log(A/V) + 1.66*LogD + 3.3

RYD (LPZ)	Ms = Log(17000/140)+1.66*Log(21.79)+3.3 =	7.61
RYD (LPN)	Ms = Log(17000/140)+1.66*Log(21.79)+3.3	7.79

=

RYD	mb =	5.93
(SPZ)	Log(12000/25000)+6.25 =	