Modeling Well Level Fluctuations as Seismograph

Prerna Agrawal, Shweta Khemani, N.P. Dewangan and Amit Mishra

Abstract The development of Richter scale for earthquake magnitude in 1935 was a major breakthrough in seismology. The Richter magnitude is calculated from the maximum amplitude recorded by the seismograph. It is quite interesting and surprising to know that a well founded in confined aquifer exhibit the characteristics of a seismograph. Eaton and Takasaki (Seismol Soc Am Bull 49(3):227–245, 1958) extended this concept to measure seismically induced water level fluctuation of a well in confined aquifer. This measurement comprises of the hydroseismic magnitude, which is identical to the surface wave magnitude from the Richter scale and a factor which represent the influence of local geology, hydrology, well construction, and magnification on the water level fluctuation for a series of quakes recorded in the same wells as well as for a single quake recorded in the nearby and distant well. Each recorder-equipped well is a potential standby seismometer for the largest quakes because most seismographs to go off scale so maximum amplitude fails to record. The present paper is based on the project work for the B.E. degree of the authors in this paper, Vorhis method of calculating the hydroseismic magnitude has been presented so that it can be applied to the seismic water level fluctuation and help permanent installation of instruments in well so that it can act as standby seismograph and record micro water level fluctuations.

Keywords Richter magnitude · Hydroseismic magnitude · Nomogram · Stereographic chart

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1 Introduction

An earthquake is the result of a sudden release of energy in the earth's crust that creates seismic waves. The seismicity, seismic or seismic activity of an area refers to the frequency, type, and size of earthquakes experienced over a period of time. Earthquakes are measured using observations from seismometer. The moment magnitude is the most common scale on which earthquakes larger than approximately 5 are reported for the entire globe. The more numerous earthquakes smaller than magnitude 5 reported by national seismological observatories are measured mostly on the local magnitude scale, also referred to as the Richter scale. These two scales are numerically similar over their range of validity. Magnitude 3 or lower earthquakes are mostly almost imperceptible and magnitude 7 and over potentially causes serious damage over large areas, depending on their depth. The largest earthquakes in historic times have been of magnitude slightly over 9, although there is no limit to the possible magnitude. The most recent large earthquake, of magnitude 9.0 or larger, was the 9.0 magnitude earthquake in Japan in 2011 (as of March 2011), and it was the largest Japanese earthquake since records began.

Earthquake engineering deals with the effects of earthquakes on people and their environment with method of reducing those effects. It is very young discipline, many of its most important developments having occurred in the past 30–40 years. Earthquake engineering is a very broad field, drawing on aspect of geology, seismology, geotechnical engineering, structural engineering, risk analysis, and technical fields. Its practice also required consideration of social, economical, and political factors.

2 Earthquake and Richter Scale

2.1 Earthquake

2.1.1 Types

There are main three types of earthquake, *Tectonic earthquake, Volcanic earthquake, Explosion earthquake*.

2.1.2 Causes

There are two main causes of earthquakes. First, they can be linked to explosive volcanic eruptions; they are in fact very common in areas of volcanic activity where they either proceed or accompany eruptions. Second, they can be triggered by

Tectonic activity associated with plate margins and faults. The majority of earthquakes worldwide are of this type.

2.1.3 Faults

There are mainly three type of faults *Plate tectonics, Normal fault, Strike, and dip*.

2.1.4 Seismic Waves

Earthquakes are three-dimensional events, the waves move outwards from the focus, but can travel in both the horizontal and vertical plains. This produces three different of waves which have their own distinct characteristics and can only move through certain layers within the Earth.

$$M_{\circ} = \mu AD$$

μ Strength of material
A area
D avg. amount of slip

Wave is two types-Body waves and surface waves.

1. *Body wave*: Body wave is travel interior of the earth. Types of body wave are p wave and s wave
2. *Surface waves*: Wave is result from the interaction between body wave and S wave. Types of surface wave are Rayleigh and L wave.

2.1.5 Seismograph

Earthquakes generate seismic waves which can be detected with a sensitive instrument called a **seismograph**.

Advances in seismograph technology have increased our understanding of both earthquakes and the Earth itself.

A seismograph, or seismometer, is an instrument used to detect and record earthquakes. Generally, it consists of a mass attached to a fixed base. During an earthquake, the base moves and the mass do not. The motion of the base with respect to the mass is commonly transformed into an electrical voltage. The electrical voltage is recorded on paper, magnetic tape, or another recording medium. This record is proportional to the motion of the seismometer mass relative to the earth, but it can be mathematically converted to a record of the absolute motion of the ground. **Seismograph** generally refers to the seismometer and its recording device as a single unit.

2.1.6 Measurement

Earthquakes can be measured in several ways.

1. *Intensity*: Intensity is the measure, in terms of degrees, of damage to the surface and the effects on humans. Intensity records only observations of effects on the crust, not actual ground motion or wave amplitudes which can be recorded by instruments.
2. *Magnitude*: Magnitude is a measure of the amount of energy released during an earthquake.

2.2 Richter Scale

The Richter magnitude scale was developed in Richter (1935a, b) by Charles F. Richter of the California Institute of Technology as a mathematical device to compare the size of earthquakes. The magnitude of an earthquake is determined from the logarithm of the amplitude of waves recorded by seismographs. Adjustments are included for the variation in the distance between the various seismographs and the epicenter of the earthquakes. On the Richter scale, magnitude is expressed in whole numbers and decimal fractions. For example, a magnitude 5.3 might be computed for a moderate earthquake, and a strong earthquake might be rated as magnitude 6.3. Because of the logarithmic basis of the scale, each whole number increase in magnitude represents a tenfold increase in measured amplitude; as an estimate of energy, each whole number step in the magnitude scale corresponds to the release of about 31 times more energy than the amount associated with the preceding whole number value.

3 Vorhis Model and Its Verification

3.1 Introduction

The Robert C. Vorhis gives the second extension of the Richter scale in 1964 for a well in the crystalline rocks of north Georgia and he used the hydroseismic data for calculation of Earthquake magnitudes.

3.2 Purpose

Although data on earthquake-induced water level fluctuation in wells have been printed in many seismologic & hydrologic publications, they have been treated for the most part only as curiosities.

But the purpose of Vorhis was to stimulate evaluation of the accumulated published data, interpretation of newsworthy fluctuations, and permanent installation of instruments to record precise time and amplitudes of microscopic water level fluctuations.

3.3 Method and Formula

The seismologic method for calculating earthquake magnitude is adapted. Here the fluctuation is converted to M_s + log C or the hydroseismic magnitude plus a variable.

In this form rough comparisons can be made from quake to quake and from well to well.

A stereographic chart is included to calculate graphically distance from epicenter to well and a nomogram to estimate $\boldsymbol{M_s} + \mathbf{log}\ \boldsymbol{C}$.

3.4 Calculation of M_s + log C

Hydroseismic magnitudes plus log C can be computed in three steps:

1. Determination of arc distance from the epicenter to the well in degrees.
2. Measure the maximum single amplitude of seismic fluctuation recorded in the well.
3. Draw a line in NOMOGRAM connecting the arc distance to single amplitude and read at the intersection with the center line.

Fluctuation and double amplitude are considered as synonyms. For those fluctuations where rise is equal to fall, single amplitude is any of three values: (1) the amount of rise, (2) the amount of fall, (3) one-half the fluctuation.

3.4.1 Calculation of Arc Distance

1. *By Stereographic chart*: The chart is a stereographic projection of a hemisphere on which the meridians and parallels are drawn at intervals of 2°. The significantly different features of the projection are four different steps by which degrees are numbered on it. The latitude north and south are given around the outside and are strictly conventional, north being at top and south at the bottom. Two sets of degrees are numbered along the equator; one to measure longitude west of the right-hand bounding meridian, so this set thus uses minus signs; the other to measure longitudes east of the left-hand bounding meridian. Along the vertical axis the latitude lines are numbered from 0° to 180° upward from the South Pole, and it is from this set that the arc distance is read.
2. *By trigonometric formulas*: Three formulas given below.

If a is the arc distance between two points that lie on latitudes λ_1 and λ_2 and meridian separated by $\Delta\Gamma$, then

$$\mathrm{hav\,a} = \mathrm{hav}(\lambda_1 - \lambda_2) + \cos\,\lambda_1 \cos\,\lambda_2\,\mathrm{hav}\,\Delta\Gamma \tag{1}$$

$$\sin^2 a/2 = \sin^2(\lambda_1 - \lambda_2) + \cos\,\lambda_1 \cos\,\lambda_2 \sin^2 \Delta\Gamma/2 \tag{2}$$

$$\cos\,a = \cos(\lambda_1 - \lambda_2) - \cos\,\lambda_1 \cos\,\lambda_2 + \cos\,\lambda_1 \cos\,\lambda_2 \cos \Delta\Gamma \tag{3}$$

Using any of above equation arc distance can be calculated.

4 Result and Discussion

The Richter magnitude is calculated from the maximum amplitude recorded by the seismograph. After extension of Eaton and Takasaki (1958), this measurement comprises by Vorhis, as the hydroseismic magnitude, which is identical to the surface wave magnitude from the Richter scale (M_s) and a factor (log C) which depends upon parameters of well aquifer system as local geology, hydrology, well construction, and magnification on the water level fluctuation. The value of M_s + log C can be calculated rather easily but its use is limited. The variable log C is constant for a same well and vary for different wells. As the same well is considered in this study for all the regions of Table 1, the properties of representative well situated at 37.137N/80.4386W is considered that will remain constant for all regions in the analysis (Figs. 1, 2 and 3).

Table 1 Calculation of hydroseismic magnitude by Vorhis model

S. no.	Region	Latitude/longitude	Arc distance	Fluctuation	Single amplitude (in feet)	M_s + log C	log C	M_s
1	M9.0, Honshu Japan, 03/11/11	38.297N/142.372E	65.1°	4.00	2.00	10.70	2.1	8.60
2	M7.5, Nicobar Island, India region 21/06/10	7.848N/91.917E	31.1°	1.08	0.54	9.50	2.1	7.40
3	M7.6, Southern 30/09/09	0.724S/99.856E	40.6°	1.08	0.54	9.80	2.1	7.70
4	M7.6, Andaman Island India, 10/08/09	14N/92.9E	25.7°	1.33	0.67	9.50	2.1	7.40
5	M7.7, Sea of Okhotsk, 05/07/08	53.888N/142.869E	78.1°	0.42	0.21	9.80	2.1	7.70
6	M7.9, Eastern Sichuan, China, 12/05/08	30.67N/104.07E	112.1°	5.00	2.50	11.20	2.1	8.10
7	M8.0, Coast of Central Peru, 15/8/07	13.3545S/76.5092W	81.43°	2.92	1.46	10.70	2.1	8.60
8	M7.2, Vanuatu, 01/08/07	17.561S/168.028E	95.6°	0.08	0.04	9.30	2.1	7.20
9	M8.2, East of the Kuril Islands, 13/01/07	46.272N/154.455E	83.2°	2.58	1.29	10.70	2.1	8.60
10	M7.9, Tonga, 03/05/06	20.088S/174.219W	80.91°	1.67	0.84	10.50	2.1	8.4

Worldwide Earthquakes Recorded in well 27F 2 SOW 019 located in Christiansburg, Virginia (USA) at Latitude and Longitude of Well: 37.137N/80.4386W

5 Conclusion

Vorhis method of calculating the hydroseismic magnitude can be applied to the seismic water level fluctuation and help permanent installation of instruments in well so that it can act as standby seismograph and record micro water level fluctuations. Results obtain from Vorhis method, i.e., hydroseismic magnitude is almost same as result from Richter scale.

6 Brief on Kyoshin Net

The strong motion data for the present work has been acquired from the kyoshin net. The K-net is a Japanese earthquake record system, which sends strong motion data on the internet, which are obtained from 1000 observatories, deployed all Japan. The avg. station to station distance is about 25 km. Each station has a digital strong motion seismograph with white dynamic characteristics and frequency band, having a maximum measurable acceleration of 2000 Ga. The records obtained from

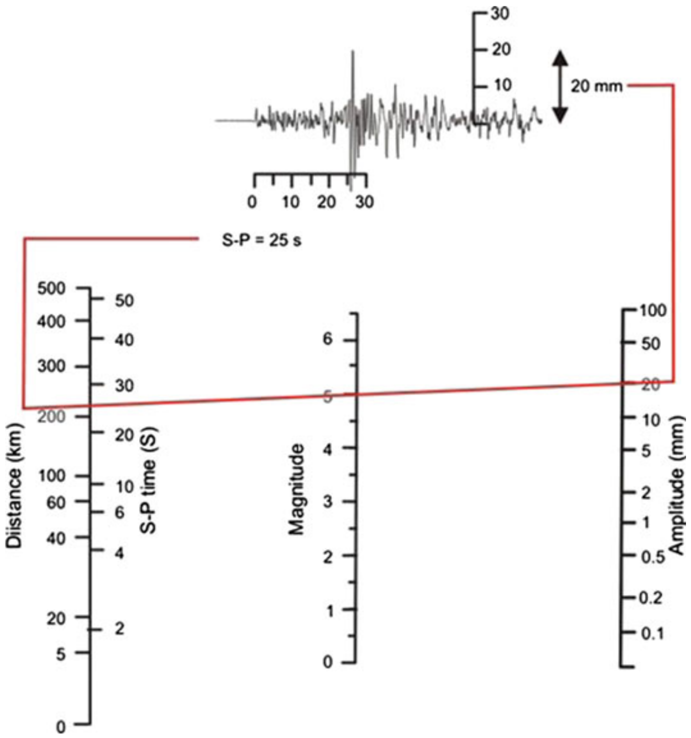

Fig. 1 Richter scale

these seismographs are acquired at a controlled center in Tsukuba by telemetry. At each site, the soil condition, and the P&S-waves velocity profiles, has been obtained by the down-hole measurement. The controlled center compiles these strong motion records, including the distribution map of maximum acceleration and makes it available on the internet.

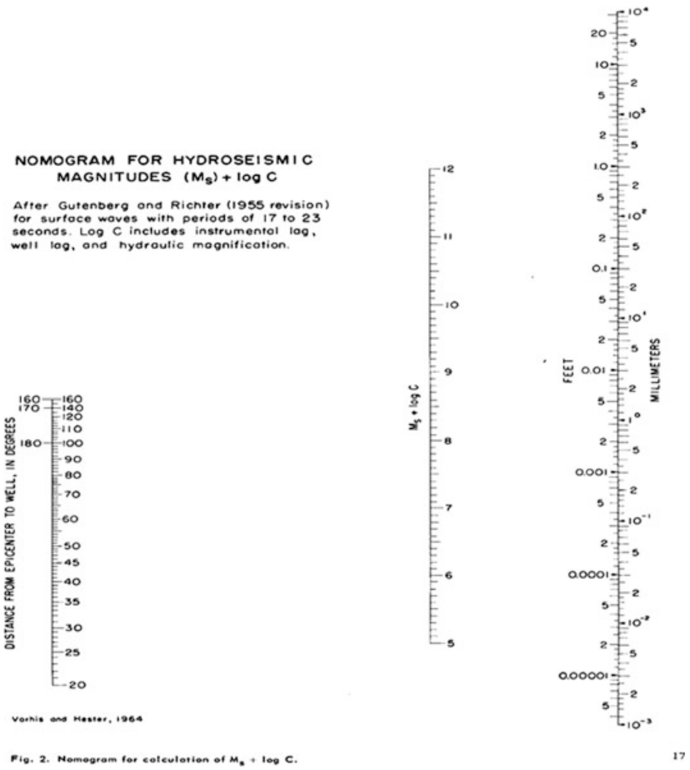

Fig. 2 Nomogram for calculation of M_s + log C (Vorhis 1964)

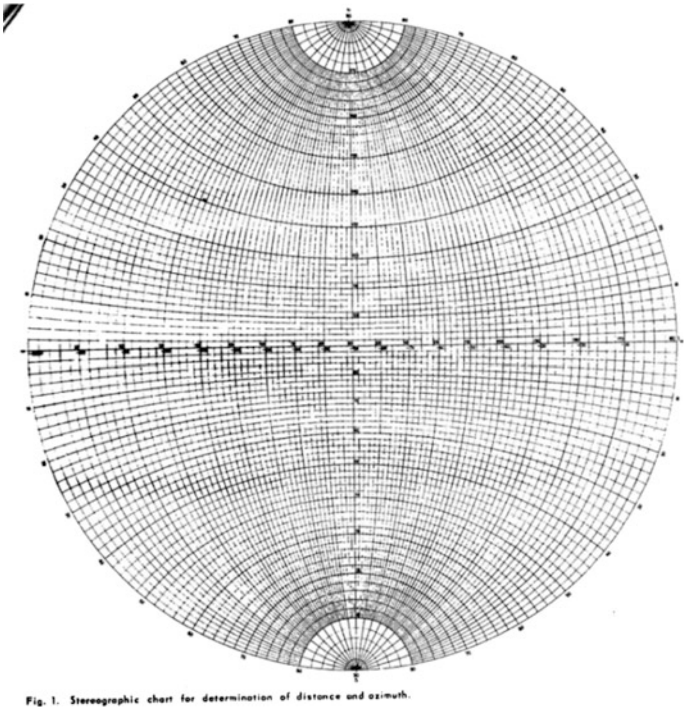

Fig. 3 Stereographic chart for determination of distance and azimuth (Vorhis 1964)

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