Abstract

The JMA-59-type electromagnetic seismograph was the standard seismograph for routine observations by the Japan Meteorological Agency (JMA) from the 1960's to the 1990's. Some features of those seismograms include 1) displacement wave records (electrically integrated from a velocity output by a moving-coil-type sensor), 2) ink records on paper (analog recording with time marks), 3) continuous drum recording for 12 h, and 4) lengthy operation time over several decades.

However, the digital revolution in recording systems during the 1990's made these analog features obsolete, and their abundant and bulky paper-based records were stacked and sometimes disregarded in the library of every observatory. Interestingly, from an educational aspect, the disadvantages of these old-fashioned systems become highly advantageous for educational or outreach purposes. The updated digital instrument is essentially a "black-box," not revealing its internal mechanisms and being too fast for observing its signal processes. While the old seismometers and recording systems have been disposed of long since, stacks of analog seismograms continue to languish in observatories' back rooms.

In our study, we develop some classroom exercises for studying earthquakes at the mid- to high-school level using these analog seismograms. These exercises include 1) reading the features of seismic records, 2) measuring the S-P time, 3) converting the hypocentral distance from Omori's distance formula, 4) locating the epicenter/hypocenter using the S-P times of surrounding stations, and 5) estimating earthquake magnitude using the Tsuboi's magnitude formula. For this calculation we developed a "nomogram"a graphical paper calculator created using a Python-based freeware tool named "PyNomo."

We tested many seismograms and established the following rules: 1) shallow earthquakes are appropriate for using the Tsuboi's magnitude formula; 2) there is no saturation at peak amplitude; 3) seismograms make it easy to read S-P time and maximum amplitude; 4) they also make it is easy to locate an earthquake's hypocenter. For advanced study, particularly of the source mechanisms of earthquakes, P-wave arrival phases are typically determined from wave records. In this exercise, we use displacement-based records for use by students for recognizing these arrival phases directly rather than by using velocity or acceleration records.

Following are some advantages of using these JMA-59-type seismograms: 1) displacement records are easy to compare with real ground motion; 2) ink records can help young students visualize the analog images of a legacy seismograph; 3) scale dimensions such as amplitude of 100 times and time scale of 1 mm/s are easy to explain while using these seismograms as an exercise resource. We confirmed the availability of our exercises by cooperation with our high-school students.

Classroom Exercise

This exercise consists of

1) A handling text with our original "nomogram" for the magnitude estimation.
2) Wave records (No saturation and P and S phases are recognized easily).
3) Map for the epicenter location.

The 59 type wave records are particularly useful with their dimensions;

Time: 60mm=60[sec]=1mm/1[sec] Amplitude: x100 1[mm] -> 10[μm]

Therefore students can easily read the PS time* and the Max. amplitude.

The area in this exercise locates at the Kinki district including Hikone, Osaka, Toyo-Oka cities. The earthquake used in this study was recorded on 28th June 1994, as the final operation year by this legacy seismograph.

The detail of our exercise is written in the following sheet.1 to 3.

* In the Japanese science text book, the "S-P time" is usually called the "PS time".

Sheet.1 Procedure

Exercise ★. Epicenter and Magnitude

Purpose.

Learn how to determine the epicenter and magnitude!

Read arrival times of P- and S-waves and maximum amplitudes from the seismograms recorded by the JMA-59 type seismographs, which were standard for routine observations conducted by the Japanese Meteorological Agency (JMA) from the 1960's to 1990's, and determine the epicenter and earthquake magnitude from those values.

What you need.

Ruler, Compass

Let's try.

Fig. 1, 2 and 3 are displacement seismograms of an earthquake which occurred on June 28, 1994. The seismograms were recorded by a pen recorder or a seismograph installed in Hikone, Osaka and Toyo-oka, respectively. Each seismograph recorded three components(NS, EW and UD) of a ground motion: NS indicates north-south, EW indicates east-west and UD indicates up-down.

[Reference]

Seismograms were recorded from left to right in chronological order. The mark of ( ) was stamped every minute. It is 60 mm between the marks and 1 mm of the record corresponds to 1 second.

Step 1.

Read arrival times of P- and S-waves by 0.1 second in Fig.1, 2 and 3 and write them down in Table 1. It will be easier to work using a ruler. The time with a mark (○) is for reference.

Pick P-wave in the vertical (UD) component and pick S-wave in the horizontal (NS and EW) components. The arrival time of the S-wave should be the earlier pick among the two components.

Step 2.

Read maximum amplitudes of horizontal (NS and EW) components by 0.1 mm and write them down in Table 1.

Step 3.

Calculate each duration of preliminary trends of the earthquake (S-P time): T sec and calculate each hypocentral distance: D km in Table 1. Round them off to a decimal place and write them down in Table 1. The Omori coefficient k is fixed to 8.23 here.

Step 4.

Obtain each amplitude of three seismograms: A mm from the maximum half-amplitudes of the two components (NS and EW) in order to determine magnitude: M. To be simple, obtain this value by drawing a figure halve the maximum amplitudes read in Step 2 and draw a right triangle whose sides adjacent to the right angle are of lengths of the maximum half-amplitudes (see Fig. 4). Read the value of A using a ruler, and write them down to a decimal place in Table 1.

[Reference]

The formula to calculate M in this exercise is $M = \log(A) + 1.73 * \log(D) - 0.83$; this is used by JMA for earthquakes shallower than 61 km. The term A in this formula is the horizontal amplitude in mkine. Given the maximum half-amplitudes of the two components (NS and EW).

Step 5.

Draw three circles with each observation station at its center and with a radius of the hypocentral distance D and determine the location of the epicenter, as shown in Fig.5.

[Reference]

Three or more seismograms should at least be the records of earthquakes with a radius of the hypocentral distances always intersect at a point. This is the epicenter.

Step 6.

Fig. 6 is a nomogram which shows the logarithmic scale of amplitude A on the left, the logarithmic scale of hypocentral distance D on the right and the scale of magnitude M between them. A value of M at an intersection of the scale of M and a line connecting points of A and D becomes a magnitude of an earthquake with the amplitude A at a location with the hypocentral distance D. Draw a line for the earthquake and read a magnitude for each observation station. Write the values in Table 1.

Let's consider.

1) Compare the location of the epicenter determined in this exercise and that of the epicenter determined by JMA.
2) Let the value of a magnitude of the earthquake in this exercise be the average of the three magnitudes in Table 1. Write the value in the right ( ) and compare with the value determined by JMA. about ( )
3) Use the nomogram and see how the magnitude changes with 10 times of D but leaving the value of A as it is. Also, see how it changes with 1/10 of A keeping the value of D fixed.

Class Name

Earthquake Observation with JMA-59

Table 1 : Values to obtain in this exercise

	Hikone	Osaka	Toyooka
A arrival time of P-wave	13:08:51.8	13:08:51.2	13:08:56.5
A arrival time of S-wave	13:08:58.8	13:08:58.0	13:09:07.3
S-P time : T	7.0	6.8	10.8
A hypocentral distance $D = k \times T$ (k =8.23)	57.6	56.0	88.9
Maximum amplitude (NS)	48.0	29.0	37.8
Maximum amplitude (EW)	26.6	31.0	27.0
Maximum half-amplitude (NS)	24.0	14.5	18.9
Maximum half-amplitude (EW)	13.3	15.5	13.5
Amplitude : A	27.4	21.2	23.2
Magnitude	4.6–4.7	4.5	4.9

Sheet.2 Map and Nomogram

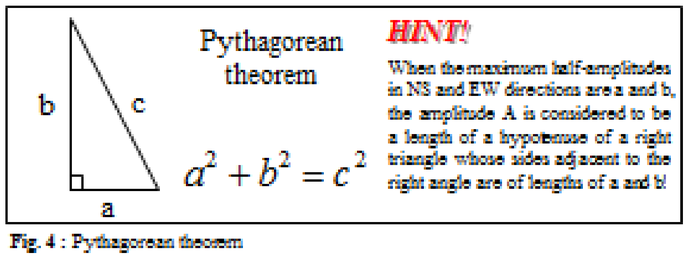


Fig. 4 : Pythagorean theorem

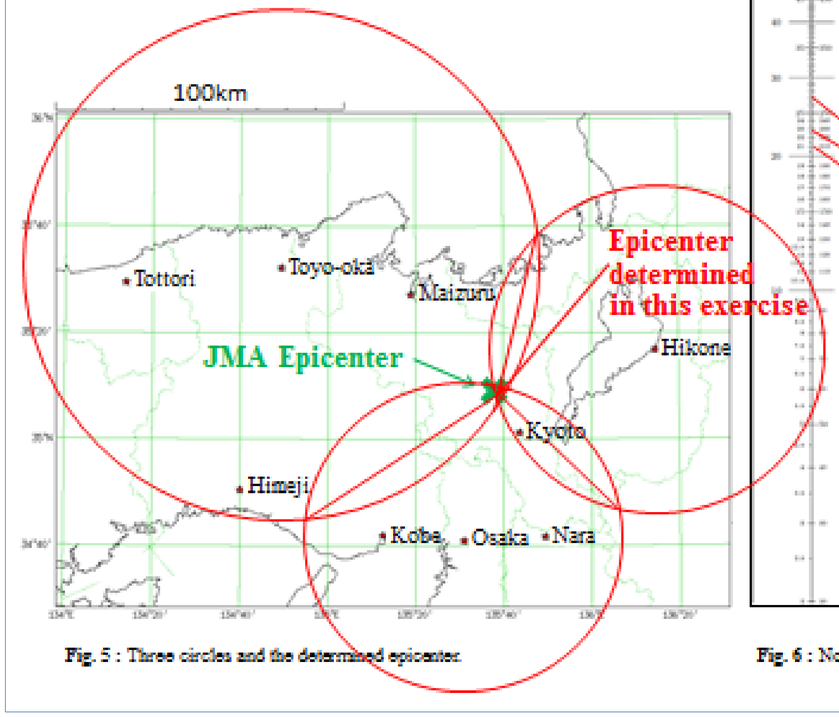


Fig. 5 : Three circles and the determined epicenter.

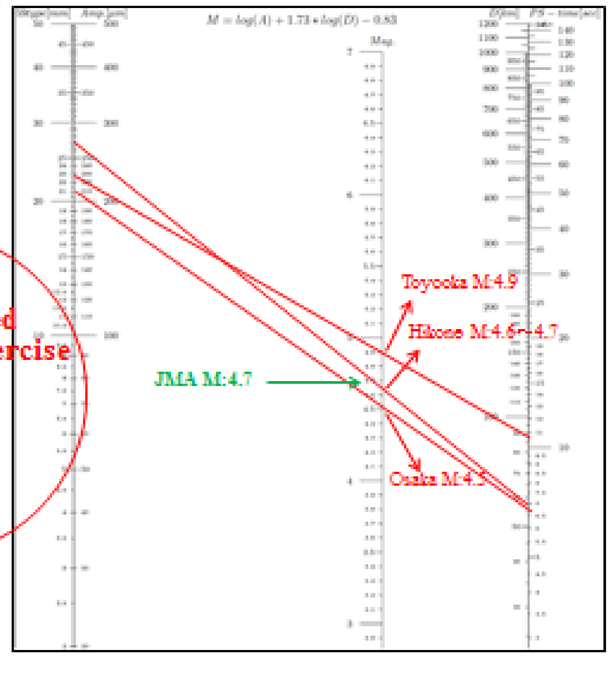
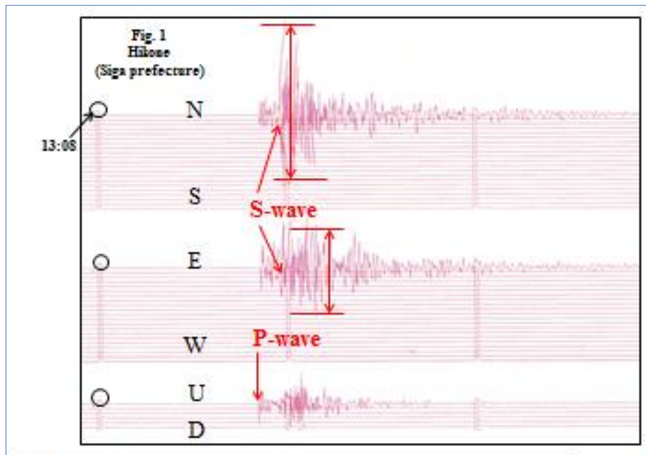
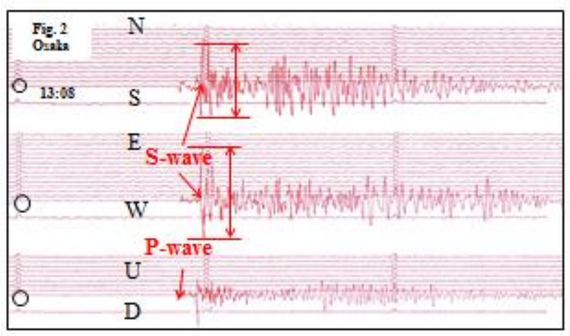


Fig. 6 : Nomogram

Sheet.3 Seismograms





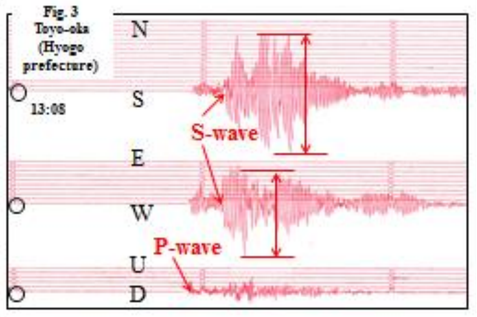


Fig.1, 2 and 3: Displacement seismograms provided by local district meteorological observatories in each region.

Results of our exercise

24 students of 12th grade, senior high, tried to test our exercise. Fig.7 and Fig.8 show their results.

1) PS times are scattered with a narrow range with a tiny standard deviation.
2) Epicenter location: their results closely locate at the JMA epicenter.
3) Magnitude estimation: their results also indicate good estimation with a small variation.

Evaluation of our exercise from student's comments are as follows;

1) They recognized and confirmed these exercises are good enough to study earthquakes and seismograms.
2) They enjoyed and rediscovered the importance of an analog procedure such as our method different from a modern digitalized style.

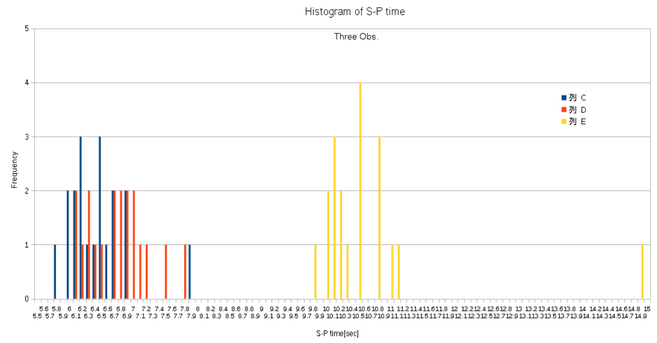


Fig.7 Histogram of S-P times by students.
Blue:Osaka Red:Toyo-Oka Yellow:Hikone

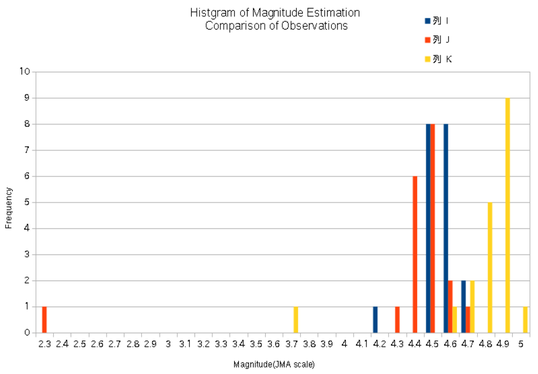


Fig.8 Histogram of M estimations.
B:Osaka R:Toyo-Oka Y:Hikone

Advanced study

Using Seismograms, We can study the characteristic of the P-wave arrival phases at the three observatories. The exercise has two purposes; 1) To indicate the direction of epi-center. 2) To navigate the earthquake focal mechanism. First, we measure the each length of the initial phase of P wave in three components in mm with magnified records (Fig.9) Second, the incident vector of P-wave is calculated from these lengths. Third, the horizontal direction of the incident vector is plotted the map (Fig.10). The result shows a good agreement with the true epicenter.

The seismogram also shows the Up and Down initial phases respectively (Down: Hikone and Toyo-Oka, Up: Osaka), indicating the hidden mechanism of this quake, governed under E-W major stress. Therefore, the students can easily recognize the importance of the P arrival phases, directly related with the focal mechanism.

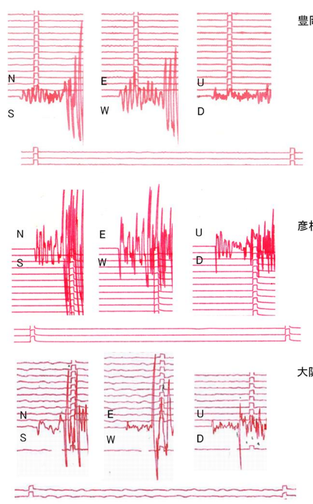


Fig.9 Magnified P-Arrival phases.

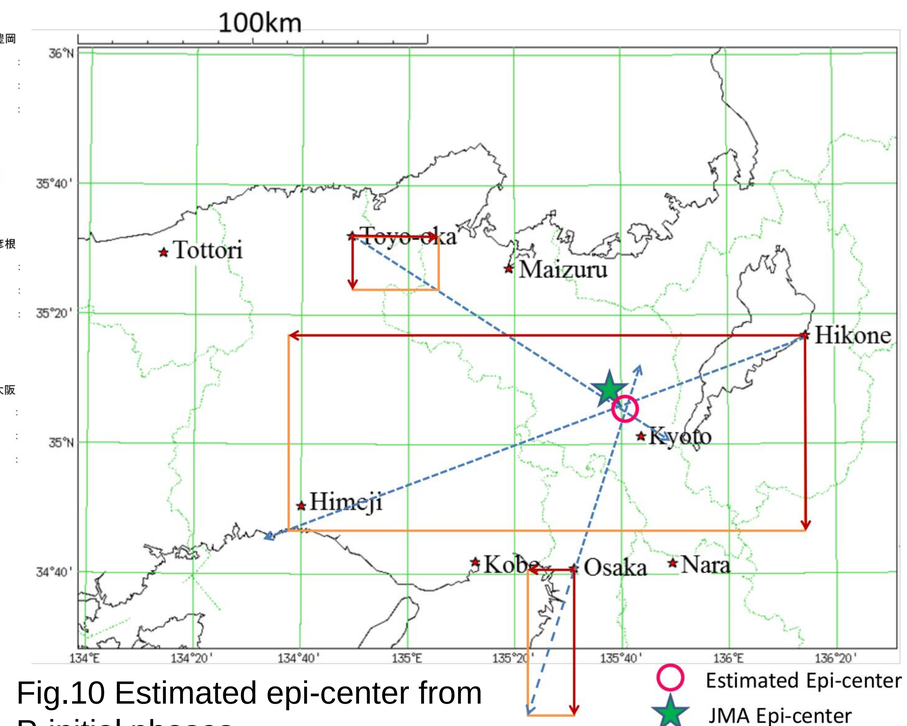


Fig.10 Estimated epi-center from P-initial phases

Discussion

1) Finding the useful data for educational purpose are too hard as thought before. Because the wave data are always limited for their status; no saturation, no blurred line, easy to identified P and S phases, etc.

There are more abundant wave records stacked in each observatory around Japan. The more staff are anticipated to join our project.

2) On the other hand, nowadays huge amount of digitized records by the dense networks are distributed via the Internet. However, the most of data are recorded by a velocity or acceleration sensor, which are less appropriate for educational purposes. Therefore, these modern data must be converted to the "legacy analog style"! We hope a new software carry out it and the data will be distributed freely to everyone!

3) In this exercise, we use Omori's constant K=8.23 for calculating the epi-central distances from our other seismogram analysis. However, this constant are slightly varied under regional or focal conditions. Therefore, the evaluation of this constant K is important and interesting!

Conclusions & Further study

Following are advantages of using these JMA-59-type seismograms:

1) Displacement records easily compare with real ground motions.
2) Scale dimensions such as the amplitude of 100 times and the time scale of 1 mm/s are fully appropriate for class room use.
3) The derived parameters are good agreement with the JMA catalog.
4) We confirmed the availability of our exercises by a cooperation with our high-school students.

The network data map, especially P-arrival times and UD phases, are used for the epicenter determination, the crustal Vp estimation and the focal mechanism study. The JMA seismicity catalog also can be used for these class room exercises after some data extraction or modification. Also, the new seismograms will be added to update our exercises more efficiently. At the same time, we try to gather more useful wave records from the JMA stations to publish a wave data sheets collection for educational use.

Acknowledges & References

We thank to the students of Tennoji high-school attached to Osaka Kyoiku University for their contribution with our exercises. The wave data are collected with the help of the following staffs of the JMA observatories; Ryoichi Tahara (Kobe Local Meteorological Observatory), Shigeru Nakaoka (Hikone LMO), Masaki Hato-Oka (Wakayama LMO) and Kazuhiko Nose (Kyoto LMO). Kazumitsu Yoshikawa (Sendai District Meteorological Observatory) provided us some useful suggestions for the analysis of the seismograms. Yoko Igarashi (Japan Meteorological Agency) helps us for English translation of our exercise sheets. We fully appreciate the supports from above persons. This study is supported by MEXT/JSPS KAKENHI Grant No. .25350200. Ref.Catalog: Seismicity annual report 1994 (Jishin Nenpo CDROM in Japanese), Japan Meteorological Agency

The resources of our study will be soon available on our web site: http://www.osaka-kyoiku.ac.jp/~yossi/ Email: yossi@cc.osaka-kyoiku.ac.jp