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A TECHNIQUE FOR AUTOMATIC DETECTION OF ONSET TIME OF P- AND S-PHASES IN STRONG MOTION RECORDS

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SUMMARY

The author developed a technique, capable to pick up automatically onset times of P- and S-phases in strong motion records, using a comparatively simple approach. This technique picks up the onset times, employing full power of the AR-AIC algorithm and the STA/LTA ratio, which are frequently used for detecting the onset time of seismic-waves initial motion, and a new STA-LTA approach, devised by author. This technique, being applied to a large set of strong motion records obtained by the observation networks in Japan, demonstrates high detection ability.

INTRODUCTION

In Japan, several new large strong motion observation networks have been quickly deployed after the 1995 Hyogo-ken Nanbu earthquake. Because many of strong motion records, obtained by those networks, are opened, it is become possible to use vast amount of records. A lot of information about the earth structure, such as the propagation characteristics and the ground structure under the observation site is included into these records.

The first important step of analysis of such seismograms is to pick up the onset time of P- and S- phases, and to build a database. The picking up of the onset times by eye is a large work. Therefore, an automatic phase picker is useful for quick identifying of phase arrivals. In the 1970's and the 1980's, automatic detecting algorithms were investigated intensively, and many automatic hypocenter determination systems, that employed these algorithms, were developed. Those results are summarized in Matsumura [1]. To pick up phases, a Short-Term-Average to Long-Term-Average ratio (STA/LTA ratio; e.g., Blandford [2], Ruud and Husebye [3], Tarvainen [4]) and an Auto Regression- Akaike Information Criterion (AR-AIC) model (e.g., Takanami and Kitagawa [5], Leonard and Kennett [6]) have been used. The first technique is excellent to detect the amplitude changes. On the other hand, the latter can respond to the changes of frequency and phase, as well as amplitude. The accuracy, however, heavily depends on the reliability of the detection interval.

The goal of this work is to produce an automatic detection algorithm of onset time of both P- and

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S-phases in any strong motion record without any site-specific threshold settings. In this paper, an automatic detecting technique of this kind, applicable to the velocity and acceleration records, is suggested, and the accuracy of the detection is examined by applying to a large set of strong motion records obtained by the strong motion observation networks.

THE PICKING PROCEDURE

The technique proposed here detects onset time using the AR-AIC method. For the setting of detection intervals, STA/LTA ratio for P-phase and the difference of STA and LTA (STA-LTA) for S-phase are used. Although the STA/LTA ratio is very effective for detection of amplitude changes, it also has harmful property to pick up a pulse-like noise details (especially contained in microtremors), unrelated to the earthquake seismic wave. On the other hand, STA-LTA has characteristic to emphasize waves with a comparatively long period and large amplitudes, and does not affected by a pulse-like noise so much. Another idea of the developed technique is to reduce detection interval step by step, using approaches above, and in this way to reduce probability of erroneous detections.

Here, the proposed technique is explained using the velocity record obtained on August 18, 2002 at Toyonaka site of strong motion observation network of The Committee of Earthquake Observation and Research in the Kansai Area (CEORKA). The waveforms of the vertical record and predominant component of the horizontal record are shown in Figure 1a and Figure 2a, respectively. Time windows of STA and LTA used in the proposed technique, are specified as 0.5 seconds and 5 seconds, respectively.

Procedure for detecting the onset time of P- and S-phases contains next 9 steps. First 5 steps are applied to estimate P-wave onset time and last 4 steps are applied to estimate S-wave onset time.

(1) Generation of a "cumulative envelope" function of the vertical acceleration record (Figure 1b). First, in order to make smaller the microtremor noise, band-pass filter from 5Hz to 7Hz is applied to the vertical acceleration record (narrow-band record). Next, in order to normalize large amplitudes of S-wave, transformation shown by the following formula is applied to the filtered record $a_{v1}(t)$.

$$a_{v2}(t) = \frac{|a_{v1}(t)|}{|a_{v1}|_{\max}} - \frac{a_{v1}(t)^2}{a_{v1}{}^2{}_{\max}}. \tag{1}$$

Then the envelope function $a_{v3}(t)$ is generated from $a_{v2}(t)$ using the following formula:

$$\begin{aligned} a_{v3}(t) &= a_{v2}(t-1) \qquad (\text{if } a_{v2}(t) \le a_{v2}(t-1)) \\ a_{v3}(t) &= a_{v2}(t) \qquad (\text{if } a_{v2}(t) > a_{v2}(t-1)). \end{aligned} \tag{2}$$

At this step, the detection interval, including the onset of P-phase, is defined as an interval from the first count of the record to the count i_1, when the envelope reaches the maximum.

(2) Calculation of the STA/LTA ratio for the envelope function (Figure 1c). The detection interval after this step becomes narrower: from the first count of record to the peak-value count i_2 of the STA/LTA ratio.

(3) First application of the AR-AIC method. The AR-AIC method is applied to the third power of the narrow-band vertical record $a_{v1}(t)$, and new detection interval is estimated (Figure 1d). Taking the third power of record makes the onset more remarkable, and it becomes easier to detect it when the AIC is applied. Here, the detection interval is reduced to the interval between counts $(2i_3 - i_2)$ and

i_2, where i_3 is the count of minimum value of AIC.

(4) Second application of the AR-AIC method. The AR-AIC method is applied to the third power of original wide-band vertical record (Figure 1e). Using a wide frequency range increases accuracy of detection of P-wave onset time.

(5) Estimation of the onset time of P-phase. The count i_4 of the minimum value of the AIC at last step is considered as the onset time of P-phase.

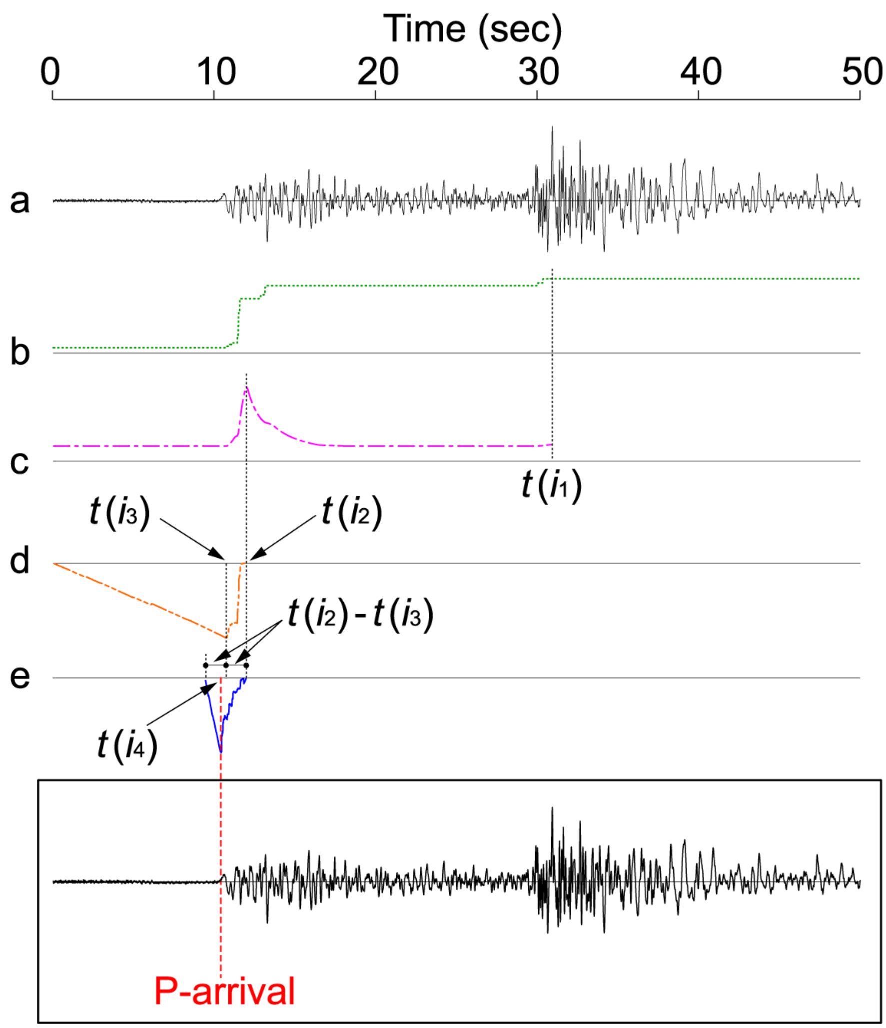


Figure 1. Procedure for detecting of the onset time of P-phase. (a) The vertical component of velocity record obtained on August 18, 2002 at Toyonaka site of the CEORKA strong motion observation network. (b) Calculation of a "cumulative envelope" function of the vertical acceleration record. (c) Calculation of the STA/LTA ratio for the envelope function. (d) First application of the AR-AIC method. The AR-AIC method is applied to the third power of the narrow-band vertical record. (e) Second application of the AR-AIC method. The AR-AIC method is applied to the third power of original wide-band vertical record. The count of the minimum value of the AIC at last step is considered as the onset time of P-phase.

(6) <u>Calculation of the STA-LTA of the predominant component of the horizontal acceleration record</u> (Figure 2b). In order to make smaller the amplitude of P-coda and the noise contained in it, 10 Hz high cut-off filter is applied to the record before applying the STA-LTA. Here, the detection interval, including the onset of S-phase, is from count i_4 calculated in step (5) to the last count of the record.

(7) <u>Calculation of the STA-LTA using the reverse time direction</u> (Figure 2c). To estimate left boundary of the detection interval, the STA-LTA function is calculated again, in the same time range as in step (6), in opposite direction: starting from the end of record. The detection interval in this case is from the count i_6 of minimum value of STA-LTA calculated in this step to the count i_5 of maximum value of STA-LTA calculated in step (6).

(8) <u>Application of the AR-AIC method.</u> The AR-AIC method is applied to the third power of the predominant component of the original wide-band horizontal record.

(9) <u>Estimation of the onset time of P-phase</u>. The count i_7 of the minimum value of the AIC at step (8) is considered as the onset time of S-phase (Figure 2d).

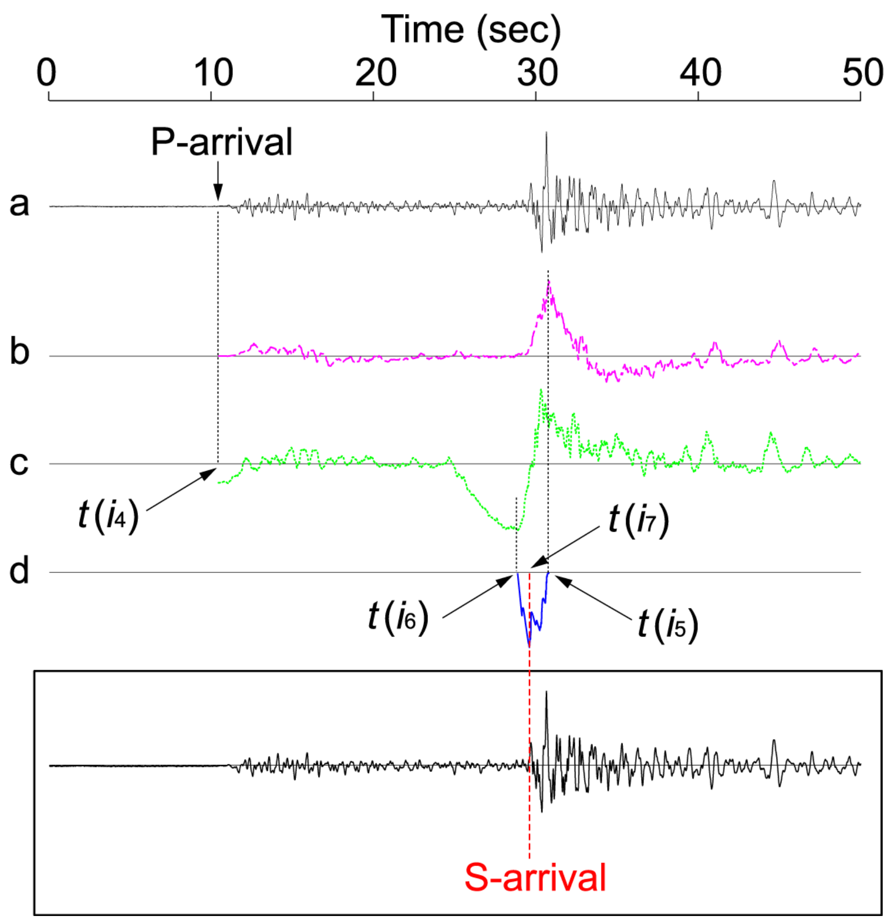


Figure 2. Procedure for detecting the onset time of S-phase. (a) The predominant component of the horizontal record obtained on August 18, 2002 at Toyonaka site of the CEORKA strong motion observation network. (b) Calculation of the STA-LTA of the predominant component of the horizontal acceleration record. (c) Calculation of the STA-LTA using the reverse time direction. (d) Application of the AR-AIC method. The count of the minimum value of the AIC is considered as the onset time of S-phase.

EFFICIENCY TEST OF THE PROPOSED TECHNIQUE

The efficiency of the proposed detection algorithm is verified by application to a large set of strong motion records obtained at observation sites with various ground conditions. Here, records obtained by three networks are used. One is the CEORKA, already mentioned above. In this observation network, velocity type strong motion seismographs are installed. In this study, the records obtained by all 26 sites in 2002 year are used. Two remaining are K-NET and KiK-net deployed by the National Research Institute for Earth Science and Disaster Prevention (NIED). In these networks, acceleration type strong motion seismographs are installed. All records obtained by these two networks in Osaka Prefecture after starting of observation were inspected. The location of the observation sites is shown in Figure 3. In addition, the statistics of the rock sites and the sedimentary sites for each network are shown in Table 1.

Table 1. **Statistics of the rock sites and the sedimentary sites for each network.**

	Rock Site	Sedimentary Site	Total
CEORKA	7	19	26
K-NET	2[*1]	8	10
KiK-net[*2]	4	4	8

*1) The rock is covered by a few meters of sediments.

*2) One accelerometer is installed on the surface (sedimentary site) and another in deep borehole (rock site).

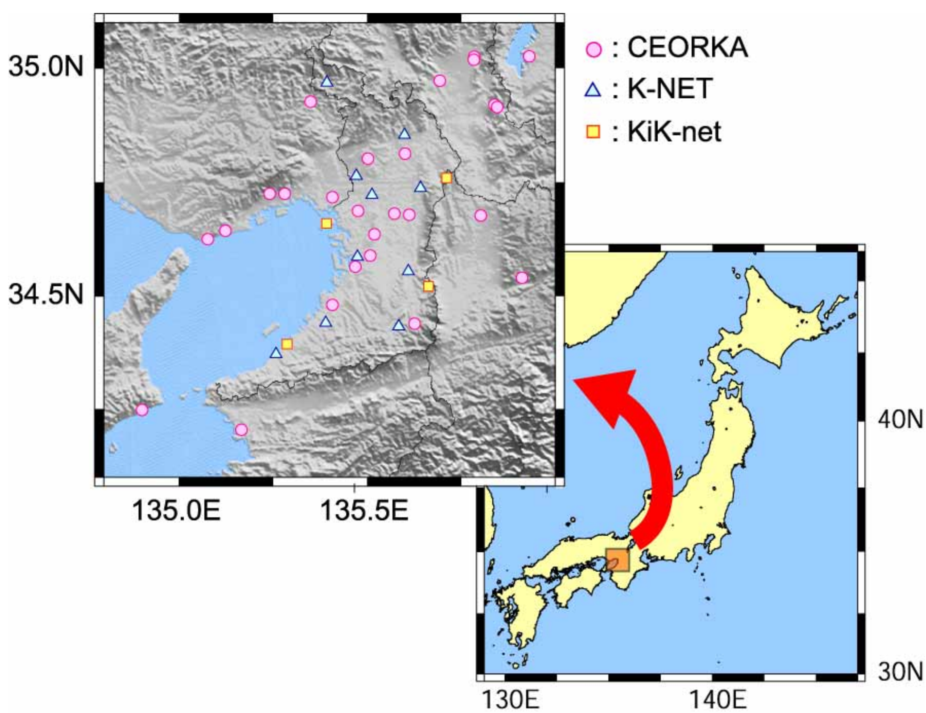
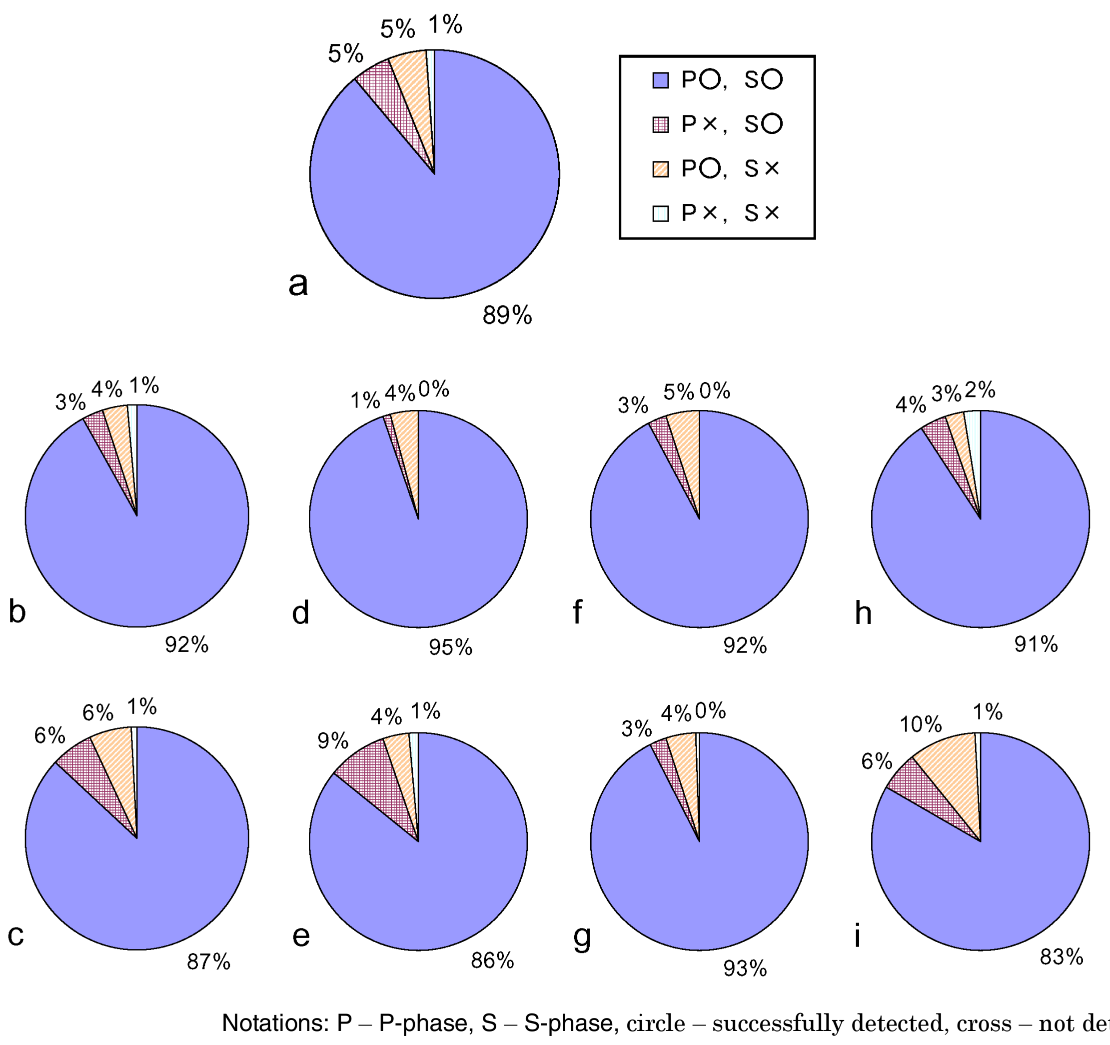


Figure 3. Location of the strong motion observation sites of the CEORKA, K-NET and KiK-net networks. Here, for the last two networks only sites in Osaka are show. In this paper, the proposed technique is verified by application to the records obtained at these sites.

However, because the proposed algorithm uses records in which both P- and S-phases are covered (triggered), the records in which these phases are not contained are not used. Total number of records tested is around 380 obtained by CEORKA, around 330 obtained by K-NET, and around 490 obtained by KiK-net.

The statistics of detection results of onset times of P- and S-phases is shown in Figure 4. Figure 4a shows result for all records. The number of records having both P- and S-phases successfully detected is 89%. Moreover, if only P- or S-phase is considered, detection rate become higher: 94% in both cases. Figure 4b and Figure 4c show results for records obtained at the rock sites and the sedimentary sites separately; farther, statistics of results separated by the network are shown in Figure 4d-i. The detection rate has the tendency to be higher for the rock sites than for the sedimentary sites. The detection rate of P-phase in the



Notations: P – P-phase, S – S-phase, circle – successfully detected, cross – not detected.

Figure 4. Statistics of detection results of onset times of P- and S-phases. Plot (a) shows result for all records. Plots (b) and (c) show results for records obtained at the rock sites and the sedimentary sites separately. Plots (d)-(i) show results separated by the network: (d) and (e) show results of CEORKA, (f) and (g) show results of K-NET, and (h) and (i) show results of KiK-net, for the rock and sedimentary sites respectively.

rock sites of CEORKA network has especially high value: 99%. Examples of records with the successfully detected P- and S-arrivals are shown in Figure 5. The technique has detected onset times with sufficient accuracy not only in records with common seismic waveform shown in Figure 5a, but also in records with very short P-S time (Figure 5b), and with small Signal to Noise ratio (Figure 5c).

To understand limitations of the proposed algorithm it is important to analyze the cases, when onset time of P- and S-phases was not detected. Roughly, we can classify them in the following way.

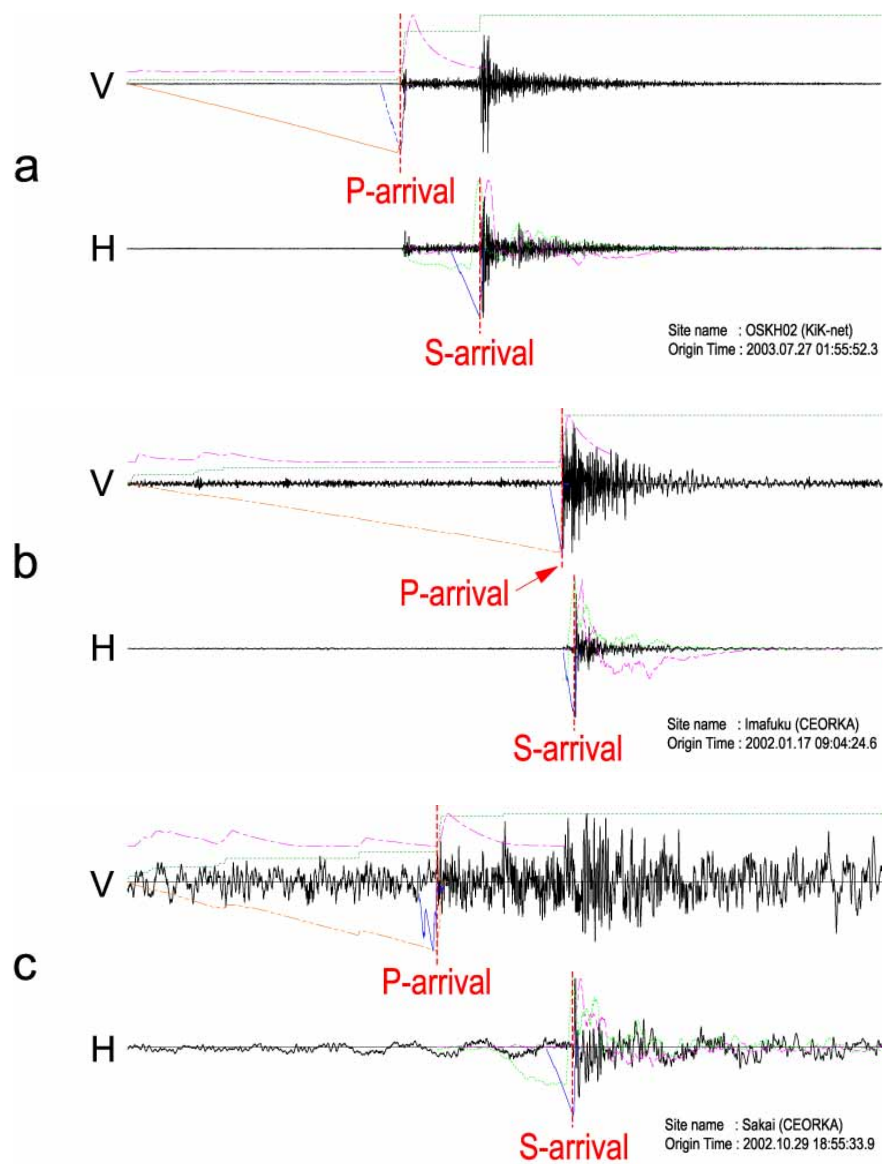


Figure 5. Example of records with the successfully detected P- and S-arrivals. The proposed technique has detected onset times with sufficient accuracy not only in records with common seismic waveform (a), but also in records with very short P-S time (b), and with small Signal to Noise ratio (c).

(1) <u>The cases when the onset of P-phase was not detected</u>. In this case, about 50% of the records contain some kind of noise before the P-arrival (human-made noise, pulse-like noise, coda-waves of previous event etc.), see example in Figure 6a. In case of CEORKA and KiK-net sedimentary sites, shown in Figure 4e and 4i, the detection rate is lower than for K-NET namely due to the noisy records (probably this is industrial noise of the urban areas that have tendency to coincide with the sedimentary valleys). Another ~20% is the cases when the onset of P-phase is not clear; many records at the epicentral distance 100km or more have this tendency. The rest of records have either very low Signal to Noise ratio or a head wave or, in case of subduction events, the wave propagating inside the high-velocity Phillipine slab and arriving to station earlier than the direct P-wave.

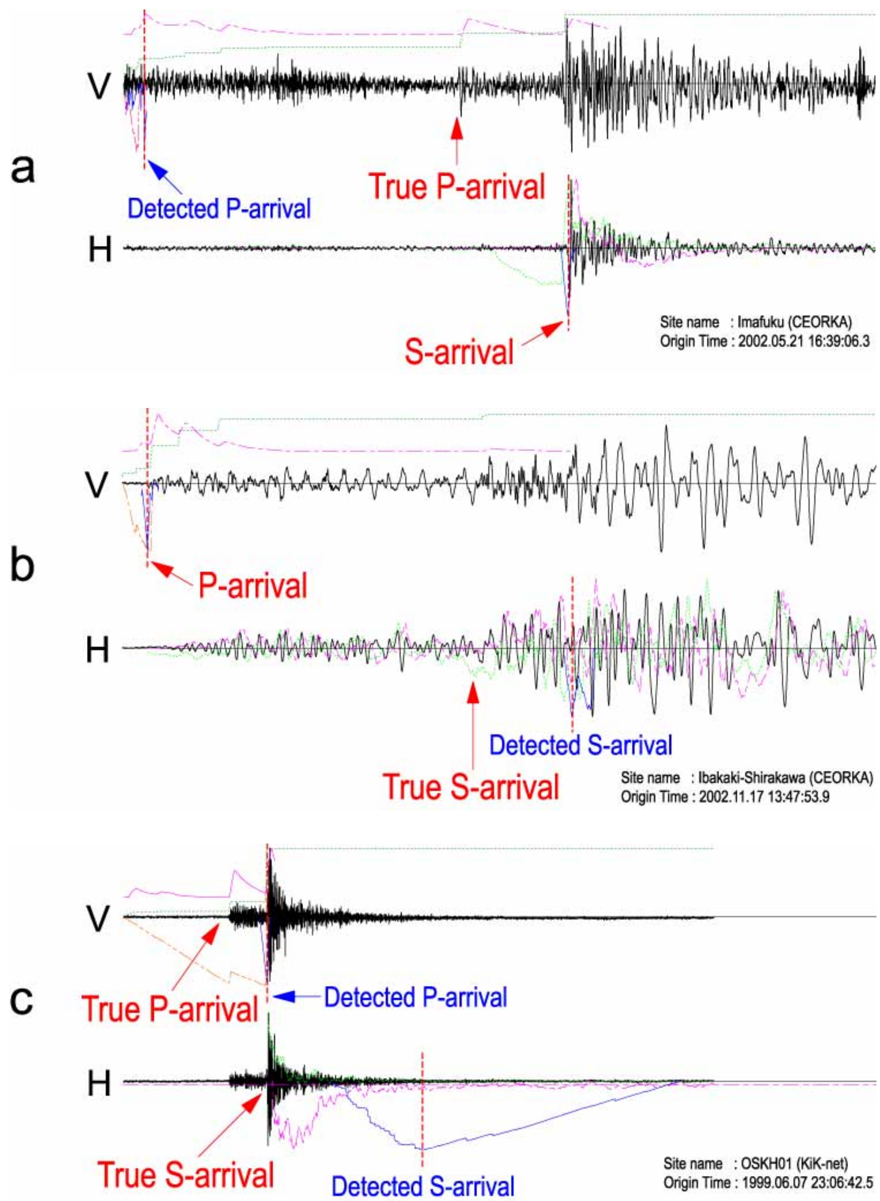


Figure 6. Examples of records with the false detected onsets: (a) record with the false detected P-arrival, (b) record with the false detected S-arrival, (c) record with the false detected both P- and S-arrivals.

(2) The cases when the onset of S-phase was not detected. Many records here have no clear onset of S-phase (see example in Figure 6b) or various phases (Sn, SmS etc.) are mixed with S-phase. Most of records in this case have epicentral distance 100km or more. Even the identification by eye is difficult for such records. In addition, at some sites strong SP converted wave tends to appear before S-phase. In this case, the proposed technique has a tendency to recognize it as the onset of S-phase. Result for KiK-net, shown in Figure 4i, has much lower detection rate of the onset of S-pahse than the CEORKA and K-NET networks, namely because of such site, OSKH02, having many records with converted SP phase.

(3) The cases when neither P- nor S-onsets were detected. For most of records in this case, the onset of S-phase was recognized as onset of P-phase, and search interval for S-phase lie far behind the S-arrival. Example of such case is shown in Figure 6c.

CONCLUSIONS

In this paper, a technique, which is able to pick up automatically onset times of P- and S-phases in the strong motion records covering both phases, was proposed. The proposed technique narrows down the detection intervals step by step, applying several techniques: the STA/LTA ratio, STA-LTA difference and the AR-AIC method. Onsets itself are then detected by applying the AIC technique to the final detection interval. The detection accuracy of the proposed technique depends both on the correctness of detection interval and on the detection accuracy of the AIC itself.

The important feature of this technique is the ability to delimit detection intervals using only maximum or minimum values without any site-specific threshold settings. This means that there is no need in any preparatory study of observation sites. This simplification is limiting the detection rate when applied to all/any observation records (especially when applied to records at regional distances 100km and more), however it is expected that the proposed technique will be useful for processing of the vast sets of records.

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REFERENCES

1. Matsumura S. “Computer-based systematization of seismic data processing and its progress.” ZISHIN 2 42, 1989: 371-390 (in Japanese).
2. Blandford RR. “Seismic event discrimination.” Bull. Seism. Soc. Am. 72, 1982: S69-S87.
3. Ruud BO, ES Husebye. “A new three-component detector and automatic single-station bulletin production.” Bull. Seism. Soc. Am. 82, 1992: 221-237.
4. Tarvainen M. “Automatic seismogram analysis: statistical phase picking and locating methods using one-station three-component data.” Bull. Seism. Soc. Am. 82, 1992: 860-869.
5. Takanami T, G Kitagawa. “A new efficient procedure for the estimation of onset times of seismic waves.” J. Phys. Earth. 36, 1988: 267-290.
6. Leonard M, Kennett BLN. “Multi-component autoregressive techniques for the analysis of seismograms.” Phys. Earth Planet. Inter. 113, 1999: 247-263.