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Determination of Phase Velocity and Direction of Wave Approach from Station Arrays

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Abstract

The multipartite station array method is described in comparison with the conventional tripartite technique, to obtain the apparent wave velocity and direction of approach averaged over a limited area, in the studies of crustal structures, velocity distribution with depth, epicenter determination and so forth. These averaged values and their probable errors can be determined from arrival times of coherent waves at more than four stations by means of linear least squares. The two methods were applied to teleseisms recorded at the Berkeley network, California and to near earthquakes observed at the Wakayama network, western Japan. The results have shown that the multipartite least squares gave the averages which in most cases agree within the probable errors with their expected values, while selected sets of tripartite net yielded a mean variation of 20% in the velocity and 9 degrees in the direction. Some significant deviation in the former case might be associated with variations in crustal structure. To detect local anomalies within the area investigated, the tripartite method may be useful when compared with the multipartite results.

1. Introduction

There are several methods for determining the phase velocity and direction of wave approach of seismic waves. The station array methods make it easy to obtain informations about the nature of coherent earthquake waves from an intercomparison of seismograms. Of those methods, the tripartite net technique is the simplest and has been widely used for both body and surface waves to measure their local velocity and propagating direction in a limited area, both of which being indicative of underground structure beneath the net.

In recent observations of microearthquakes, such as aftershocks and local shocks, attempts have been made to locate their foci by a combination of directions of approach and apparent velocities, sometimes together with S-P times, determined from one or several sets of minor tripartite nets (Asada and Suzuki, 1950 ; Miyamura et al., 1959, 1962, 1963 ; Aki et al., 1959, 1962, 1963 ; Matumoto, 1959 ; Suyehiro, 1960 ; Kayano, 1965 ; Hashizume et al., 1965). It will be possible, by extending the methods to larger arrays, to detect variations in crustal structure, such as the dipping of the Mohorovicic discontinuity, velocity anomalies beneath a certain region and so forth. The same technique may also be applied to body waves from distant earthquakes to obtain the gradient of time-distance curves directly, which can be used for the determination of velocity distribution within the earth (Miki, 1963 ; Bolt, 1965 ; Niazi and Anderson, 1965). It has been shown (Evernden, 1954 ; Press, 1956) that the use of phase velocity of surface waves across tripartite nets can give local details on average crustal structure in comparison with theoretical predictions.

It is not to be expected, however, that the tripartite net will always be the best method of station arrays for the studies. Since two unknowns involved are determined from two independent observations of arrival time differences, their probable errors cannot be obtained in the usual statistical sense. To reach at a reliable conclusion, a close estimate of the errors has to be made in other ways (Miyamura and Tsujiura, 1959 ; Suyehiro, 1960). It cannot also be said that the determined values by the tripartite array always represent those over the area investigated ; there could be some distortions due to unusual structural irregularities.

To avoid these difficulties, the array technique may be generalized to the case of multipartite stations distributed over a limited area, provided that there were no pronounced difference in underground structure beneath the stations. In this case, the apparent wave velocity and direction of approach averaged over the area can be determined from data at more than four stations, by the method of least squares, and the probable errors can easily be evaluated. It should be noted that this statistical procedure averages travel time deviations over an order of dimension of the network on the assumption of homogeneous structure. In order to detect local anomalies within a span of the network, it would be necessary to compare results from each set of tripartite nets with the least squares result.

This paper is a preliminary report on a comparison of the multipartite station array with the conventional tripartite technique, both of which have been applied as a test to the Berkeley network in California and to the Wakayama network in western Japan.

2. Multipartite Station Array

The multipartite station technique is described below. Suppose there are n stations within the area investigated. A standard station is chosen as the origin of the coordinate, taking the x-axis eastward and the y-axis northward. Let the coordinates of the j-th station be (x_j, y_j), its azimuth measured from north at the origin in a clockwise sense be φ_j, and the distance between the station and the origin be d_j.

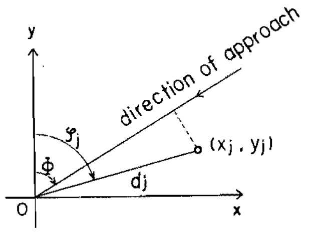

Fig. 1.

It is easily seen in Fig. 1 that the following relation holds for the plane waves propagated in an azimuth of Φ with a horizontal phase velocity of V ;

$$d_j \cos(\varphi_j - \Phi)/V = T_0 - T_j \tag{1}$$

where T_j and T_0 are the travel times from the source to the j-th station and to the origin respectively, although only their difference can be observed. Since

$$d_j \sin\varphi_j = x_j \quad \text{and} \quad d_j \cos\varphi_j = y_j,$$

if we put

$$T_j - T_0 \equiv T_{j0}, \quad 1/V \equiv p = dT/d\Delta$$

$$p\sin\Phi \equiv X \quad \text{and} \quad p\cos\Phi \equiv Y,$$

equation (1) can be linearlized in the form with a residual R_j ;

$$R_j = x_j X + y_j Y + T_{j0} \quad (j=1, 2, \cdots\cdots, n-1) \tag{2}$$

For $n=3$ the case reduces to that of tripartite stations, for which the solutions are obtained from two simultaneous equations with $R_j=0$.

In the general case the problem is that of linear least squares. Minimizing the square sum of the residuals, $E=\sum_j R_j^2 = \sum_j (x_j X + y_j Y + T_{j0})^2$, on the condition that $\partial E/\partial X = 0$ and $\partial E/\partial Y = 0$, we have the normal equations ;

$$\begin{aligned} X\sum x_j^2 + Y\sum x_j y_j + \sum T_{j0} x_j &= 0 \\ X\sum x_j y_j + Y\sum y_j^2 + \sum T_{j0} y_j &= 0 \end{aligned} \tag{3}$$

The solutions for (3) are expressed as follows, substituting the summation symbols by Gaussian brackets,

$$X = ([Ty][xy] - [Tx][yy])/D \quad \text{and} \quad Y = ([Tx][xy] - [Ty][xx])/D \tag{4}$$

and their probable errors are ;

$$\delta X = 0.6745\sqrt{\frac{[yy][ee]}{D\,(n-3)}} \quad \text{and} \quad Y = 0.6745\sqrt{\frac{[xx][ee]}{D\,(n-3)}} \tag{5}$$

where

$$D = [xx][yy] - [xy]^2 \quad \text{and} \quad [ee] = X[Tx] + Y[Ty] + [TT].$$

Equation (1) or (2) implies that the travel-time residual at the standard station is assumed to be zero, in other words, the time-distance curve is determined so as to go through a plotted point for the station. This would lead to different results, depending on the selection of a standard station, in spite that our aim was to get an average over the area by the least squares.

To improve the results in this point, a station residual $\varDelta T_0$ at the standard station is introduced here as an unknown parameter. In this case, eq. (2) should be,

$$R_j = x_j X + y_j Y - \varDelta T_0 + T_{j0} \; (j=1, 2, \cdots\cdots, n-1) \tag{2'}$$

Similar conditions as in the foregoing case, $\partial E/\partial X = 0$, $\partial E/\partial Y = 0$ and $\partial E/\partial \varDelta T_0 = 0$, give the normal equations ;

$$\begin{aligned} X[xx] + Y[xy] - \varDelta T_0[x] + [Tx] &= 0 \\ X[xy] + Y[yy] - \varDelta T_0[y] + [Ty] &= 0 \\ X[x] + Y[y] - \varDelta T_0(n-1) + [T] &= 0 \end{aligned} \tag{3'}$$

Eliminating $\varDelta T_0$ from eq. (3'), we have the same form as of eq. (3) ;

$$\begin{aligned} X[x'x'] + Y[x'y'] + [T'x'] &= 0 \\ X[x'y'] + Y[y'y'] + [T'y'] &= 0 \end{aligned} \tag{3''}$$

where $[x'x'] = [xx] - [x]^2/(n-1)$, $[y'y'] = [yy] - [y]^2/(n-1)$,
$[x'y'] = [xy] - [x][y]/(n-1)$, $[T'x'] = [Tx] - [T][x]/(n-1)$ and
$[T'y'] = [Ty] - [T][y]/(n-1)$.

The solutions for (3″) and their probable errors can be obtained in the forms of (4) and (5), by substituting x'_j, y'_j and T'_{j0} for x_j, y_j and T_{j0} respectively.

It is noticed that the above procedure is equivalent to the translation of the coordinate and of the time axis. That is, the residual R_j can be re-written as follows by using the third equation of (3′) ;

$$R_j = x'_j X + y'_j Y + T'_{j0} \tag{2''}$$

where $x'_j = x_j - \bar{x}$, $y'_j = y_j - \bar{y}$ and $T'_{j0} = T_{j0} - \bar{T}$, indicating translations by $\bar{x} = [x]/(n-1)$, $\bar{y} = [y]/(n-1)$ and $\bar{T} = [T]/(n-1)$. It is evident that eq. (3″) can be derived from (2″). The station residual in eq. (2′) vanishes when the center of gravity in the array $(\bar{x}, \bar{y})$ is taken as the origin of the coordinate, as has been pointed out by Otsuka (private communication, 1965).

The phase velocity V across the network, the inverse of the velocity, p, and the direction of wave approach Φ, and their probable errors can be derived from equations (4) and (5). That is,

$$V = 1/\sqrt{X^2+Y^2}, \quad p = \sqrt{X^2+Y^2} \quad \text{and} \quad \Phi = \tan^{-1}(X/Y) \tag{6}$$

$$\begin{aligned} \delta V &= (|X\delta X| + |Y\delta Y|)\cdot V^3 \\ \delta p &= (|X\delta X| + |Y\delta Y|)\cdot V \\ \delta\Phi &= (|Y\delta X| + |X\delta Y|)\cdot V^2 \end{aligned} \tag{7}$$

A Fortran program based on the technique has been written for an IBM 7090 computer. This computes the epicentral distances and azimuths, the inter-distances between array stations, the apparent velocity across the net and direction of approach of the relevant waves, from given location (latitude and longitude) of the stations and of assumed epicenter and the observed arrival times at the stations.

3. Application to Observed Data, Results and Discussion

Both the multipartite and tripartite array techniques are applied to the Berkeley and Wakayama networks, where there are well-distributed stations, for which the techniques are to be favorably compared with each other.

The earthquakes used in the present analysis are tabulated in Table 1, in

TABLE 1.
Earthquakes used in the present study.

No.	Date	Time h m s	Latitude	Longitude	Depth (km)	Distance (km)	Azimuth (deg)
240	April 21, 1956	19 26 46	35°01′N	135°32′E	11	98	20 (W)
254	April 23, 1956	19 26 00	33 45 N	134 14 E	10	98	240 (W)
348	Aug. 25, 1959	13 13 28	30 41 N	132 12 E	20—30	478	217 (W)
371	Aug. 31, 1959	15 00 31	35 25 N	136 13 E	10—15	167	25 (W)
400	Aug. 25, 1963	12 18 12	17 30 S	178 48 W	565	8505	235 (BRK)
500	March 28, 1964	03 36 13	61 06 N	147 43 W	30	3127	334 (BRK)

which their origin times, locations, epicentral distances and azimuths are given. The first four near earthquakes, which have been recorded at the Wakayama network during temporary observations of microearthquakes, may involve the data that are sensitive to the upper crustal structure. The last two distant earthquakes have been well observed at most ot the stations in the Berkeley network, and the data will provide information on the lower crustal structure under the Pacific margin. The present analyses are made for coherent first peaks or troughs of P waves, and in some cases for those of distinct S phases.

(1) *Berkeley network*

The University of California has a network consisting of 18 seismograph stations distributed in central and northern California, as shown in Fig. 2. Seismic signals from ten of the stations with Benioff short period seismographs are telemetered directly to Berkeley, and recorded on a 16-channel film recorder of a speed of 10 cm/min. This situation makes it possible to identify coherent seismic phases on the film with a high accuracy, which would be less than one tenth of a second. The stations here used, as indicated in Table 2, are clustered around the San Francisco Bay area. (At the two stations, SFB and PAC, photographic recordings are made independently.) The

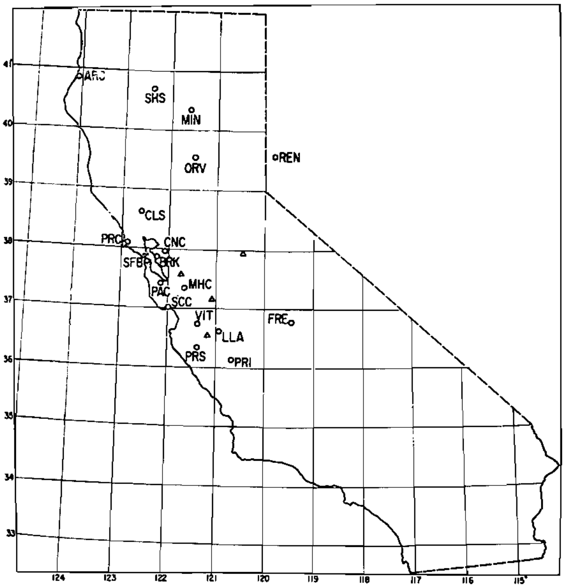

Fig. 2. Location of seismograph staitions in Berkeley network.

TABLE 2.
Oveservation stations in Berkeley network.

Station	Abbr.	Latitude	Longitude	Elevation (m)
Calistoga	CLS	38°38'.2N	122°35'.1W	457
Pt. Reyes	PRC	38 04 .8	122 52 .0	404
Concord	CNC	37 58 .1	122 04 .3	36
Berkeley	BRK	37 52 4	122 15 .6	81
San Francisco	SFB	37 46 .6	122 27 .1	100
Palo Alto	PAC	37 25 .0	122 10 .9	83
Mt. Hamilton	MHC	37 20 .5	121 38 .5	1282
Santa Cruz	SCC	37 00 .4	121 59 .8	128
Vineyard	VIT	36 45 .0	121 23 .3	380

TABLE 3.
Obtained results for the Berkeley network.

No.		Stations used	V (km/sec)	Φ (degree)	Standard Station
400	P	T—Δ	19.03±1.43	235.0	(BRK)
		J—B*	20.6		
		SCC, PRC, VIT, BRK, MHC, CNC, CLS	17.62±0.50	238.7±1.4	(CLS)
		CLS, PRC, BRK, MHC, SCC	16.36±2.75	233.1±9.4	(BRK)
		*CLS, PRC, BRK MHC, SCC	16.70±2.72	233.4±9.2	
		CLS, PRC, BRK	18.70	239.9	
		CLS, PRC, MHC	18.56	239.5	
		CLS, PRC, SCC	19.65	236.0	
		CLS, BRK, CNC	15.71	241.3	
		BRK, PRC, CNC	15.72	233.2	
		BRK, PRC, MHC,	18.17	238.9	
		BRK, CNC, MHC	16.18	239.3	
		BRK, PRC, SCC	16.91	236.1	
		BRK, MHC, SCC	15.63	236.2	
		BRK, SCC, VIT	15.88	237.3	
500	P	T—Δ	11.48±0.83	333.2	(CLS)
		J—B	12.4		
		CLS, PRC, BRK, SFB, PAC, MHC, SCC	10.71±0.35	355.9±4.3	(CLS)
		CLS, PRC, SFB, PAC, SCC	10.65±0.19	347.2±0.8	(CLS)
		CLS, PRC, BRK, MHC, SCC	10.03±0.89	0.2±8.1	(BRK)
		*CLS, PRC, BRK, MHC, SCC	10.46±0.66	356.4±5.5	
		CLS, PRC, BRK	11.83	359.4	
		CLS, PRC, SFB	15.76	344.4	
		CLS, BRK, SFB	9.25	21.5	
		PRC, BRK, SFB	7.72	0.4	
		BRK, SFB, PAC	7.79	9.1	
		BRK, MHC, PAC	7.88	8.6	
		BRK, MHC, SCC	9.10	0.6	
		BRK, SFB, SCC	8.36	12.9	
		CLS, BRK, SCC	10.43	346.3	
		CLS, PRC, SCC	10.66	348.1	
		CLS, BRK, MHC	10.09	295.7	

reason for the selection of these 7 stations was that the crustal structure under the area has been determined from seismic refraction measurements (Eaton, 1963 ; Healy, 1963 ; Hamilton *et al.*, 1964) and inferred from the phase velocity of Rayleigh waves using a tripartite net (Press, 1957) ; the other stations are too far to be incorporated in this study. The average distance between neighboring two of the selected stations is of order of 50 km, which is several times the wavelength of recorded waves.

The results of multipartite least squares and ${}_nC_3$ combinations of tripartite array for two earthquakes are shown in Table 3 and Figs. 3 and 4, together with two theoretical apparent velocities, one being expected from Jeffreys-Bullen's Table (*J-B*), and the other (*T-Δ*) determined from travel time curves on the assumption that the waves travel along a great circle path from epicenter to station.

It is found from the multipartite result that seismic waves from earthquake No. 400 approach the network from a southwestern direction with little deviation from the great circle path. This agrees with the results for Rayleigh waves from South Pacific earthquakes (Evernden, 1954). The apparent velocity, however, determined from the 7 stations shows a definitely lower value than expected. As might be expected, on the other hand, 10 selected sets of tripartite net yield scattered values, which may be attributable to local velocity anomalies, and the shape of tripartite net relating to the azimuth of wave approach. The maximum variation in the velocity is about 23% and that in the direction of wave approach is 5 degrees. It appears that the lower velocities come from tripartite nets including either of the combinations of BRK and CNC or of BRK and SCC. If the two stations CNC and SCC were excluded, a higher velocity would be obtained by the least squares.

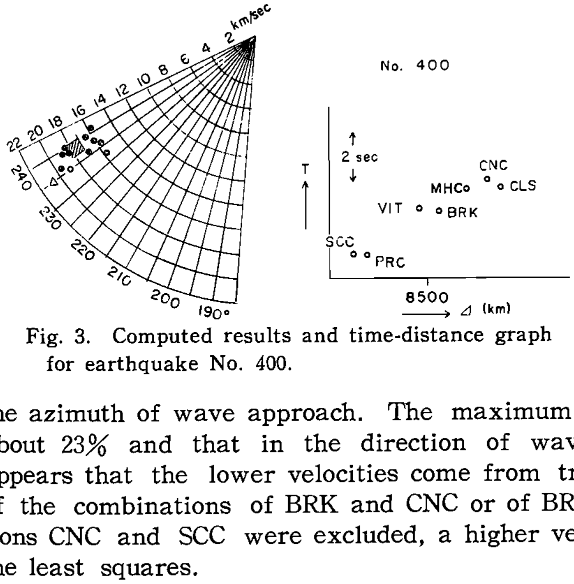

Fig. 3. Computed results and time-distance graph for earthquake No. 400.

Another example (No. 500) is the Good Friday Alaskan Earthquake of March 28, 1964. The multipartite least squares computation using 7 stations shows that the apparent velocity of first P waves is significantly lower than those expected from J-B table and *T-Δ* curve, and that the waves have deviated to the north by more than 20 degrees from the great circle path. An arbitrary exclusion of two data, for example, of BRK and MHC, gives a slightly lower velocity and a smaller deviation of azimuth. On the contrary, ten sets of tripartite net provide widely scattered results, as can be seen in Table 3 and Fig. 4. The maximum variation in the determined velocities exceeds 50% and that for the direction of approach reaches 25 degrees.

The tripartite nets including a pair of BRK and SFB or BRK and PAC seem

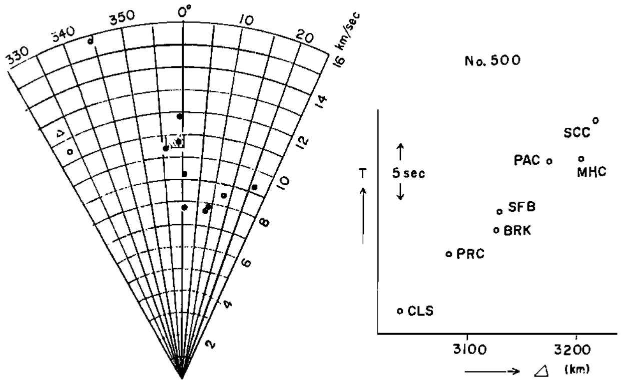

Fig. 4. Computed results and time-distance graph for earthquake No. 500.

to be responsible for the larger deviation from the average. A part of the reason might be in local recordings at SFB and PAC, which could introduce larger errors compared with a synthetic film recording. It should be noticed, however, that the velocity obtained from a combination of BRK, SFB and PAC, which has been used by Evernden (1954) and Press (1957) for the studies of Rayleigh wave propagation, does not necessarily represent the one around the Bay area, indicating a much lower velocity than the average. If the same situation occurred for surface waves, it follows that Press has underestimated the phase velocities of Rayleigh waves across the area. It might be due partly to these circumstances that the crustal thickness determined by him from the phase velocities is considerably larger than that from recent seismic refraction studies (Eaton, 1963 ; Healy, 1963 ; Hamilton et al., 1964). Even if the late arrivals of SFB and PAC, as would be seen in Fig. 4, were excluded from the least squares, however, there still exist significant discrepancies between the computed and expected values.

A combination of CLS, PRC, BRK, MHC and SCC, which covers the Bay area with four legs extending from their center BRK, may be considered to offer a suitable basis for comparing results from a number of earthquakes. The results computed from the 5 stations are also given in Table 3, in which an asterisk* shows the values obtained by the improved least squares mentioned in section 2. The improved results for the two earthquakes seem to suggest that the deviations both in the velocity and direction of approach from their theoretically predicted values depend on the epicentral distance and azimuth. A combined work of seismic and gravity data (Mikumo, 1965) indicates that the Moho-discontinuity beneath the Pacific margin dips toward inland. This should give a possibility for the said deviation to be a function of azimuth. To establish this hypothesis, much more data need to be analysed. Recently, Otsuka (1965) has actually obtained cyclic velocity-anomaly functions for the coastal region of central California from some 30 earthquakes. He associated this relation with a steeply dipping Moho-discontinuity and inhomogeneities in the upper mantle under the area.

(2) *Wakayama network*

Temporary observation networks have been established three times during the past ten years in the Wakayama region, where microearthquakes are frequently taking place (Mikumo, 1960). At most of the stations recordings were made photographically, and the time marks were recorded by the JJY standard radio signals on an oscillogram with a speed of 5 mm/sec. The errors in time readings are estimated to be less than 1/20 sec. Locations of the stations used are shown in Fig. 5 and Table 4. A span of this network is of order of 10 km, which is again several times the wavelength of recorded local earthquake waves.

The results obtained for four earthquakes by the multipartite and tripartite techniques are given in Table 5. *T-Δ* indicates an apparent velocity determined by the conventional least squares from the time-distance curves which were given in a previous paper (Mikumo, 1960).

It may be said for the four earthquakes that the apparent velocities and propagating directions averaged over multipartite stations by the least squares show a good agreement within the

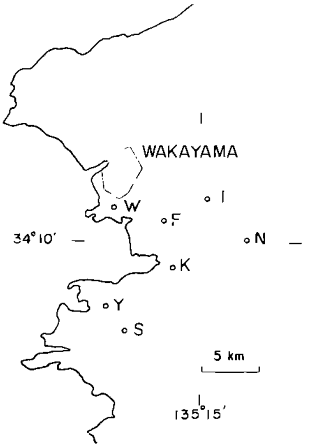

Fig. 5. Location of temporary stations in Wakayama network.

TABLE 4.
Observation stations in Wakayama network.

Station	Abbr.	Latitude	Longitude	Elevation (m)
Wakayama	W	34°11'.38N	135°10'.07E	35
Idakiso	I	34 11 .86	135 15 .24	35
Nokami	N	34 09 .78	135 17 .83	80
Yoro	Y	34 06 .90	135 09 .66	15
Shimotsu	S	34 06 .31	135 10 .10	40

TABLE 5.
Obtained results for the Wakayama network.

No.		Stations used	V (km/sec)	Φ (degree)	Standard Station
240	P	*T—Δ*	5.92±0.03	15.7	(I)
		I, N, W, K, Y	5.81±0.09	15.1±0.8	(I)
		I, N, W	5.52	15.1	
		I, W, K	6.80	19.3	
		I, N, K	5.85	13.0	
		I, Y, W	5.74	15.9	
		I, K, Y	5.96	20.6	
		I, N, Y	5.65	14.3	
		W, K, Y	5.74	16.3	
		N, W, K	6.22	15.1	
		N, W, Y	5.88	15.1	
		N, K, Y	4.65	9.7	
	S	*T—Δ*	3.50±0.07	15.7	(I)
		I, W, N, K, Y	3.50±0.14	16.1±2.3	(I)

254	P	*T—Δ*	6.53±0.43	244.6	(Y)
		Y, W, K, N, I	6.30±0.19	228.7±1.7	(Y)
		Y, W, K	6.27	230.4	
		Y, W, N	6.31	229.6	
		Y, W, I	6.03	232.6	
		Y, K, N	6.14	225.3	
		Y, K, I	6.10	224.3	
		Y, N, I	6.10	224.7	
		W, K, N	6.39	230.5	
		W, K, I	5.84	230.3	
		W, N, I	5.52	225.0	
		K, N, I	6.23	224.6	
	S	*T—Δ*	3.89±0.21	244.6	(Y)
		Y, W, K, N, I	3.67±0.06	227.0±0.9	(Y)
348	P	*T—Δ*	7.96±0.09	217.2	(S)
		S, W, N, I	7.95±0.03	216.8±0.3	(S)
		S, W, N	7.94	216.6	
		S, W, I	7.90	216.8	
		S, N, I	7.89	216.2	
		W, N, I	7.84	217.1	
	S	*T—Δ*	4.55±0.05	217.2	(S)
		S, W, N, I	4.53±0.03	216.3±0.4	(S)
371	P	*T—Δ*	5.96±0.09	32.8	(I)
		I, N, W, S	6.10±0.20	34.0±1.8	(I)
		I, N, W	6.43	35.4	
		I, N, S	6.04	37.1	
		I, W, S	5.89	31.7	
		N, W, S	6.27	28.5	
	S	*T—Δ*	3.65±0.04	32.8	(I)
		I, N, W, S	3.64±0.10	34.1±1.6	(I)

uncertainties with their expected values, except the direction for the earthquake No. 254. It is also to be noted that the direction of approach of S waves agrees well with that of first P waves. This fact supports the propriety of identification of the S phases, and at the same time suggests that heterogeneities in the crust under this region behave in the same manner for the propagation of transverse waves as for that of longitudinal waves.

In Fig. 6 the results for the earthquakes No. 240 and 371 are illustrated for comparison's sake, since waves from the two shocks have travelled with a nearly equal velocity along a similar path from the northeast. A slight difference between the velocities across the nets is not significant in view of their probable errors. Ten sets of tripartite net in the earthquake No. 240 give a maximum variation of 37% in the apparent velocities and that of 11° in the directions of approach. If the largest and smallest velocities were excluded, the variations are reduced to 12% and 6° respectively. The maximum variations in 4 sets of tripartite net in the case of the earthquake No. 371 are 9% and 9°. In the both earthquakes no fixed combinations of stations seem to be associated with the large deviations from the average.

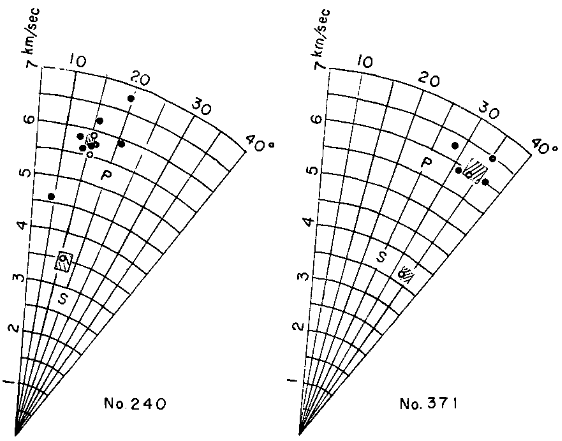

Fig. 6. Computed results for earthquakes No. 240 and 371.

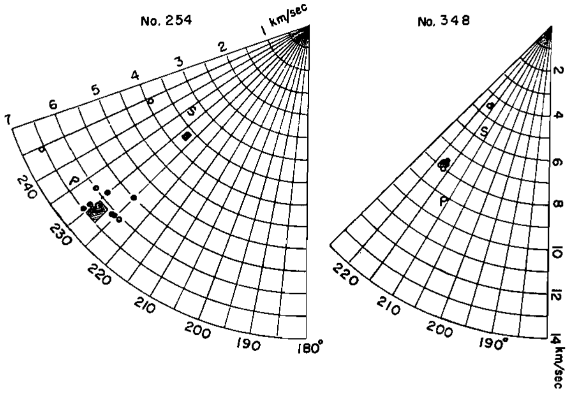

Fig. 7. Computed results for earthquakes No. 254 and 348.

The same diagrams are drawn in Fig. 7 for the two earthquakes No. 254 and 348 which occurred southwest of the network. Their epicentral distance and focal depths indicate that the apparent velocities of the former earthquake, which agree within the probable errors with those of the two foregoing earthquakes, are crustal velocities, while the latter velocities may be those in the upper mantle. Ten sets of tripartite net in the earthquake No. 254 yield a maximum variation of 13% in the velocities and 8° in the azimuth. It seems that the lower velocities result from a combination of W and I, but this is not always the case for other earthquakes. In the earthquake No. 348, on the other hand, the velocities and wave directions of P waves calculated for 4 sets of tripartite net show a surprisingly close agreement with each others. The situation may be the same for S waves, since the multipartite result gives little difference from the T-Δ value. It is to be noticed that the waves propagated in the upper mantle were not subject to the effects of local irregularities compared with the waves having travelled only in the crust along a similar path. A possible explanation for the difference may be attributed to a difference of the angles of incidence. The deviation of direction of approach from the expected azimuth in the earthquake No. 254 may be significant, but no reasonable conclusion can be drawn because of little deviations in three other earthquakes.

4. Concluding Remarks

In this paper, a comparison has been made for the multipartite station array here proposed with the conventional tripartite technique, to make an effective use of the array for further studies of crustal structures, velocity distribution with depth, epicenter determination and so forth. The results have shown that the multipartite least squares can give the apparent velocity and direction of wave approach averaged over a network, which in most cases agree within the probable errors with their expected values, while selected sets of tripartite net yield scattered values ; a mean variation of about 20% in the velocity and 9 degrees in the azimuth. Some of the large deviations from the average in the Berkeley network were interpreted partly as local anomalies beneath a certain region within the network, but no evidence of systematic localities was found in the Wakayama network. A conclusion is that the combined use of the multipartite and tripartite techniques should be made in order to obtain the average over the area investigated as well as to detect local anomalies within the area. Once the local anomalies were detected as a function of both epicentral distance and azimuth, by comparing results for a number of earthquakes from the two methods, the deviations could be applied as a station correction to the station in question.

In the microearthquake observation of 1965, the multipartite station array here proposed will be established in a limited area within a radius of 1 km for the epicenter determination as well as for the phase identification of coherent seismic waves.

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