ANALYSIS OF STRONG GROUND MOTIONS OBSERVED IN EARTHQUAKE INSTRUMENTS ARRAY

- Distinguish of Wave Groups and Generation of Simulated Waves Considering the Body and Surface Waves -

K.Muto(I), T.Ohta(II), H.Yoshida(III),
T.Sugano(IV), M.Miyamura(IV), S.Kan(IV), M.Kamata(IV)
Presenting Author: Tadashi Sugano

SUMMARY

At the Higashimatsuyama local station, seismometers have been placed on hard rock at four observation points centering towards one seismometer within respective distance of 500 M. By utilizing the ground motions actually observed, effort was expended to distinguish the wave groups by combination of various methods such as non-stationary spectra, phase spectra, particle orbits and dispersion curves. The significant feature of Rayleigh waves were found at around the main parts of ground motions in two typical earthquakes. Based on these results, the generation method for artificial waves, with consideration given to the body and surface wave, is proposed herein.

OUTLINE OF THE OBSERVATION SYSTEM AND THE EARTHQUAKE WAVES

Outline of the Observation System and Soil Condition

Accurate earthquake instruments array have been placed in operation since December 1978, at four separate rock sites surrounding Tokyo, which are located within radius of 150 km (Ref.1).

At one of the 4 sites, the Higashimatsuyama local station, the seismometers are placed at four observation points centering towards No.2 as shown in Fig-1. Also two more seismometers are installed at the ground surface and at GL-120m at the central point as shown in Fig-2(a). These four observation points from No.2 to No.5 are installed at relatively hard rock of which shear velocities are about 700-800m/sec, and surface layers to the ground are composed of sand and gravel. Deeper soil profile which were used for the calculation of dispersion curves was obtained by explosion test as shown in Fig-2(b).

(I) Member of Japan Academy, Professor Emeritus of Tokyo University
(II) Chief Research Engineer, Kajima Institute of Construction Technology
(III) Nuclear Power Construction Department, The Tokyo Electric Power Co., INC. Tokyo, JAPAN
(IV) Research Engineer, Muto Institute of Structural Mechanics, Kajima Corporation, Tokyo, JAPAN

Outline of The Earthquake and Observed Waves

The outline of the two earthquakes (EQ.1, EQ.2) of which focuses are located in the southern part of the station are listed in table-1. Fig-3 shows the time histories of accelerations of the three components at No.2. The horizontal two components, radial and transverse directions, were converted from NS and EW directions. Table-2 shows the maximum values of accelerations, integrated velocities and displacements.

Characteristics of Coherence

Coherence was computed in order to represent the quantitative similarity of the ground motions within the local station. Fig-4 shows the coherence between No.2 and No.3 ∿ No.5 of R-direction in lower frequency range (0.1 Hz - 1 Hz) of EQ.1. Coherence between No.2 and No.5 which is the closest distance shows high values from 0.1 Hz to 1 Hz, whereas No.3 and No.4 show peculiar valleys around 0.6 Hz and 0.7 Hz, which suggests local soil effects. On the other hand, in higher frequency range, coherence indicates low values and no specific features can be seen.

Phase spectra were computed to get information of phase lag in each frequency components. Fig-5 shows the circular phase spectra between No.2 and No.3 from 0 to 2 Hz of R-direction in two sections of EQ.1, where ground motions have high intensity level in power spectra. Each phase angle in section 1 (20-30 sec.) represents a mild change in each frequency component, while the phase angles in section 2 (30-40 sec.) vary depending on frequency components. This means that the dispersion tendency of wave groups is significant in section 2.

DISTINGUISH OF WAVE GROUPS AND DISPERSION PROPERTIES OF SURFACE WAVES

Effort was expended to distinguish wave group in accordance with the flow-chart shown in Fig-9, which was proposed in reference 2 and the method was applied for two earthquakes in table-1.

As the non-stationary spectra, response envelope spectra (R.E.S.) proposed by M.D. Trifunac (Ref.3) were computed. These spectra are defined as the output of multifiltering and their local maximum distribution corresponds to group velocity curve. As shown in Fig-6 both in two earthquakes, dispersion tendency can be seen at around 1.5 sec. in R and U directions. Fig-7 shows the circular phase spectra of R-U directions between 0 and 1 Hz at major two sections (20-30 sec., 30-40 sec.) of ground motions. No specific features can be seen in section 1, while, vertical components seem to have about $\pi/2$ phase lag to the radial components around 1.5 sec. in section 2 where dispersion tendency is remarkable.

Furthermore, after passing through narrow band pass filter which center is 0.7 Hz, particle motions were computed every five seconds as shown in Fig-8. The particle motions in the plane of R-U directions describe the counterclockwise elliptical orbits towards the travelling path between 30 and 40 seconds.

Juding from these orbits, dispersion curves, R.E.S. and phase spectra, the wave groups which arrived between 30 and 40 sec. seem to be prominent of Rayleigh wave.

By plotting of group velocity curves obtained by changing the distance X on the R.E.S., it was made clear that the dispersion tendency around 1.5 sec. corresponds to the local maximum values in R.E.S. of observed waves when the X is assumed to be about 10 km. This indicates the posibility that the Rayleigh waves are caused by the local soil discontinuity near the Higashimatsuyama station.

GENERATION OF ARTIFICIAL WAVES IN CONSIDERATION OF THE BODY AND SURFACE WAVE

The Generation Method for Artificial Waves

The generation of artificial waves is performed in accordance with the flow-chart shown in Fig-9 and its seismic conditions are shown in Fig-11.

(1) Frequency Contents: The response spectra of the observed earthquakes at 3 stations which are almost same soil conditions were idealized by the regression analysis using the parameter M and Δ. Fig-12 shows the spectrum of M=6.7, Δ=120 km, h=5% and this spectra were adopted as frequency contents of the artificial waves.

(2) Duration and Envelope Curves: The earthquake wave is considered to be composed of P-coda and S-coda which includes body and surface waves. The observed waves were divided by narrow band pass filter into 4 frequency band which central periods were 0.1, 0.3, 1 & 3 seconds and for each frequency band durations and envelope curves were analyzed. The duration of S-coda is defined as the 80% time integral of accumulative absolute acceleration.

The envelope curves were simplified and idealized by the shape of gamma distribution which is convenient to express the sharp initial motion of S wave and the exponential decay of the latter part of the motion.

The durations and envelope curves of the P-coda and S-coda were determined by the function of the magnitude, epicentral distance and frequency band by the analysis of 88 horizontal and 44 vertical waves. Fig-10 shows the durations and envelope curves which correspond to the seismic condition of this study.

(3) Phase angle: The distribution of phase angels for body wave is assumed to be uniform, and the vertical components of Rayleigh wave have $\pi/2$ phase lag to the horizontal components.

(4) Introduction of Surface Wave: It is assumed that the Rayleigh wave is prominent from 1.0 to 2.0 second periods and arrive at 9 seconds after the arrivals of S wave considering the distance between transition area to Rayleigh wave and the site. The Rayleigh wave lasts 10 seconds with peak value at mid-time. The envelope curve of Rayleigh wave is assumed to be the formula referring to M.D. Trifunac's and others (Ref.4) as follows:

$$g(t) = \frac{\sin\{\pi\cdot\Delta f(t-t_R)\}}{\pi\cdot\Delta f(t-t_R)}, \quad g(t)=1 \text{ (for } t=t_R) \quad \ldots\ldots \quad (1)$$

where t_R : peak time of Rayleigh wave (29 sec.)

Δf : difference of frequency (0.2)

t : $t_R - \frac{1}{\Delta f} < t < t_R + \frac{1}{\Delta f}$

Generated Artificial Waves

The summation of the body and surface wave was checked as to whether its response spectrum satisfies the compatibility with a target spectrum. After several iteration the final time history was obtained in Fig-11 and its spectrum compatibility is shown in Fig-12. After passing through narrow band pass filter, the particle motions of the generated earthquake in the R-U plane are shown in Fig-13 and the orbits describe the counterclockwise ellipse toward the travelling path which represents the same characteristics of the observed two waves.

CONCLUSION

The main results of this study can be summarized as follows:

(1) A function of coherence and circular phase spectra are made available for the quantitative representation of the similarity of adjacent ground motions.

(2) The combination method of the non-stationary spectra, phase spectra, particle orbit and dispersion curves make it possible to distinguish the wave groups.

(3) It was clarified that the proposed method is very effective tool for the simulation of artificial waves when considering the characteristics of the surface and body waves.

Acknowledgement

We are grateful to Mr. H. Koshida, Mr. M. Motosaka, S. Hiehata, Dr. M. Takemura in Kajima Corporation who provided us with valuable comments and advice, and also are thankful to Mr. K. Horikoshi, Mr. A. Amano who have developed computer codes used in this study. Valuable earthquake data were offered by "Committee of Strong-Motion Instruments Array" (Chairman is Prof. S. Omote).

REFERENCES

(1) S. Omote, et at. "Recent Developed Strong Motion Earthquake Instruments Array in Japan" 7WCEE INSTANBUL 1980

(2) K. Muto, et al. "Analysis of Earthquake Waves Observed in Strong Motion Earthquake Instruments Array" Third International Earthquake Mirozonation Conference June 28, 1982. pp. 507-518

(3) M.D. Trifunac, "Response Envelope Spectrum and Interpretation of Strong Earthquake Ground Motion " B.S.S.A. Vol. 61, No.2

(4) H.L. Wong and M.D. Trifunac "Synthesizing Realistic Ground Motion Accelerograms" Report No. CE78-07, U.S.C., Los Angeles, 1978

TABLE 1 *OUTLINE OF THE EARTHQUAKES*

	EARTHQUAKE NAME (DATE)	M	Δ (Km)	h (Km)
EQ.1	EAST OFF IZU PEN. (29 June,1980)	6.7	121	10
EQ.2	CENTRAL CHIBA PREF. (25 Sept,1980)	6.1	92	80

TABLE 2 MAXIMUM VALUES

	Direction	Acc. (Gal)	Vel. (Kine)	Disp. (cm)
EQ.1	Radial	5.9	0.91	0.27
	Trans.	5.6	0.93	0.24
	Up Down	5.2	0.79	0.13
EQ.2	Radial	11.3	0.92	0.21
	Trans.	9.4	1.69	0.38
	Up Down	12.4	0.78	0.14

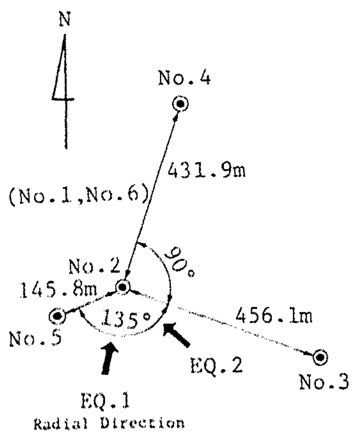
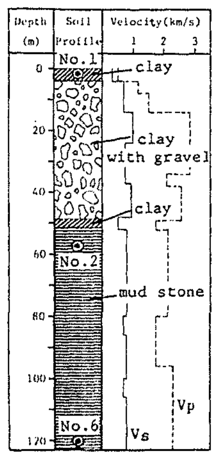
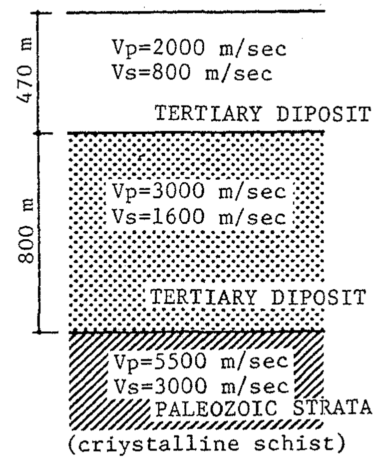


Fig. 1 PLAN OF OBSERVATION POINTS



(a) CORE BORING



(b) EXPLOSION TEST

Fig. 2 SOIL PROFILE

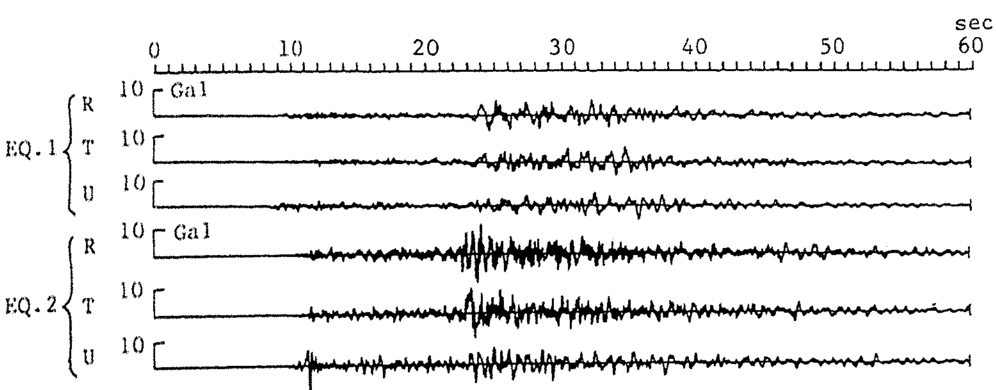


Fig. 3 OBSERVED WAVE (POINT NO.2)

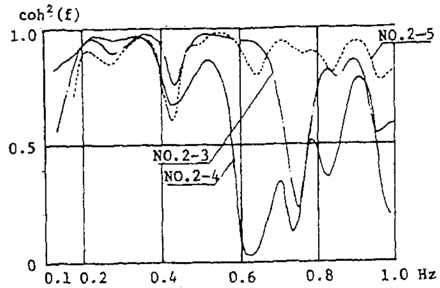


Fig. 4 COHERENCE BETWEEN NO.2 AND NO.3~5

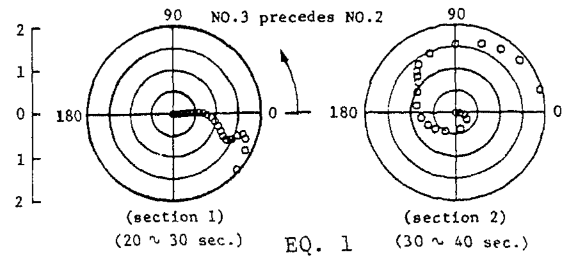


Fig. 5 PHASE SPECTRUM (NO.2 to NO.3)

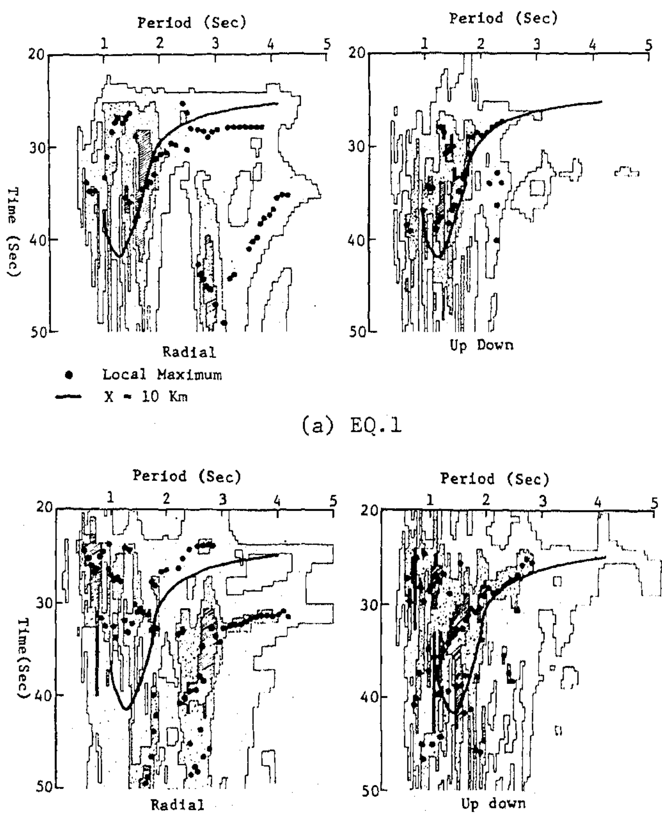


Fig. 6 RESPONSE ENVELOPE SPECTRUM

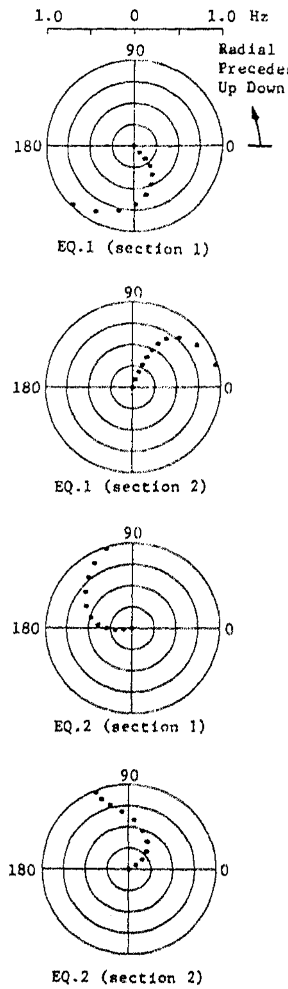


Fig. 7 PHASE SPECTRUM (RADIAL TO UP DOWN)

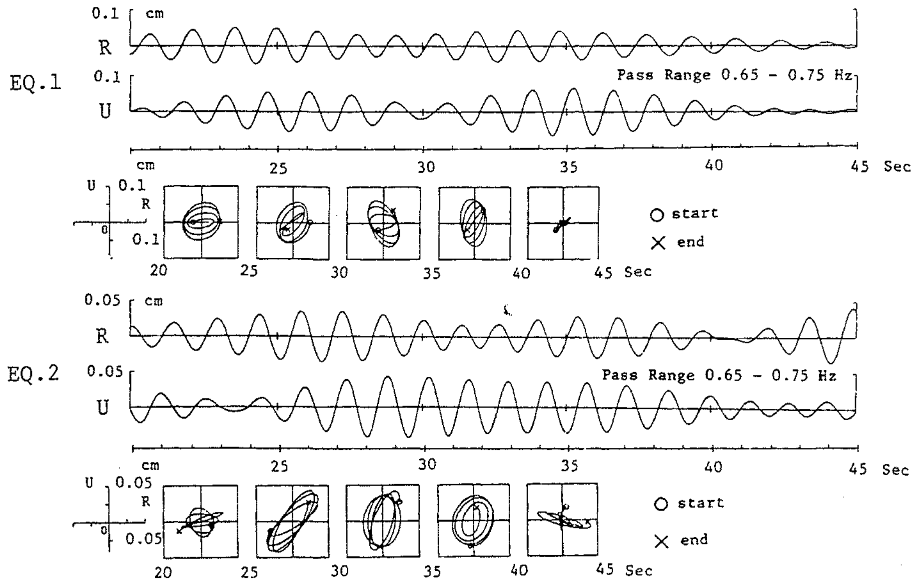


Fig. 8 BAND PASS FILTERED WAVE AND PARTICLE ORBIT

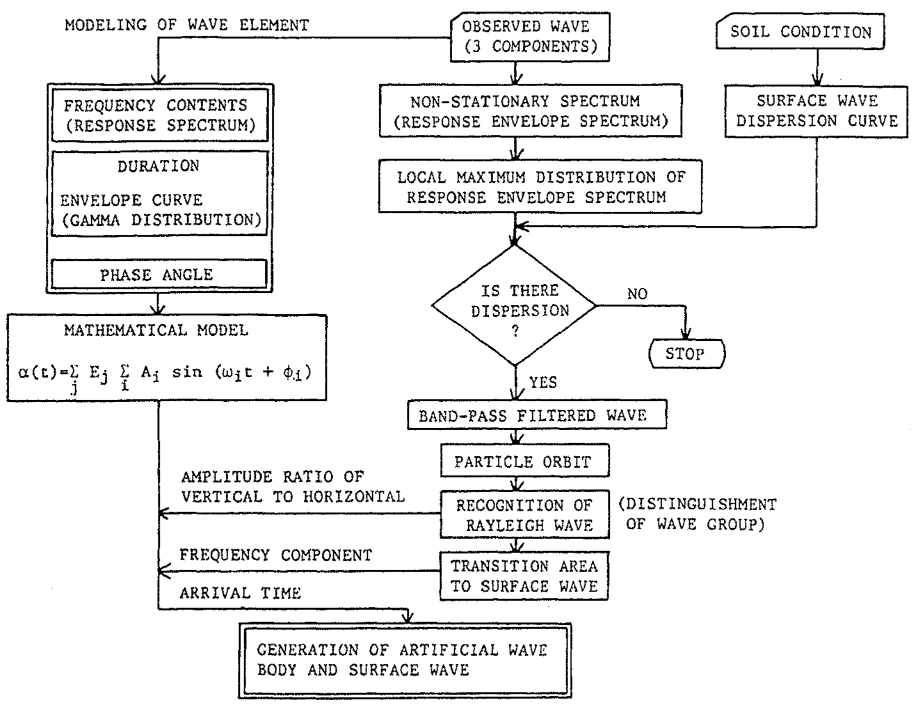


Fig. 9 FLOW CHART FOR GENERATION OF ARTIFICIAL WAVE

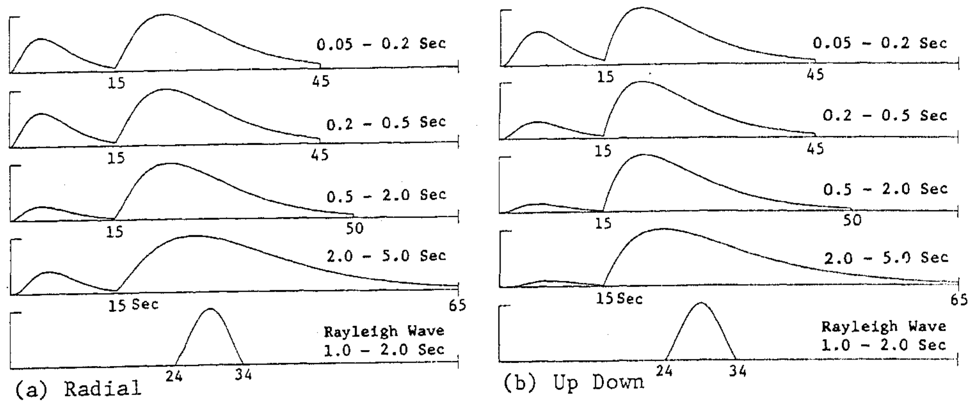


Fig. 10 ENVELOPE CURVE

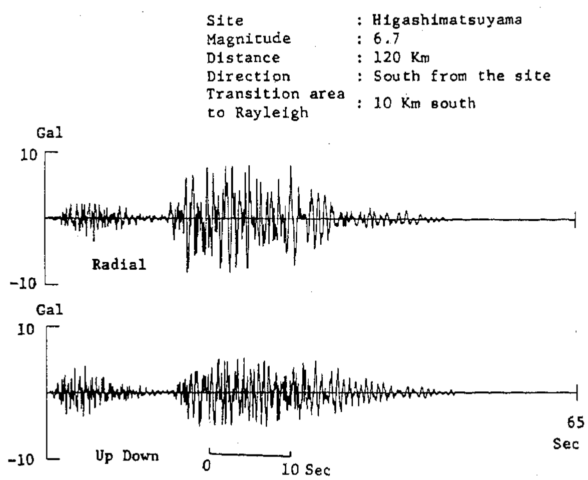


Fig. 11 GENERATED ARTIFICIAL WAVES

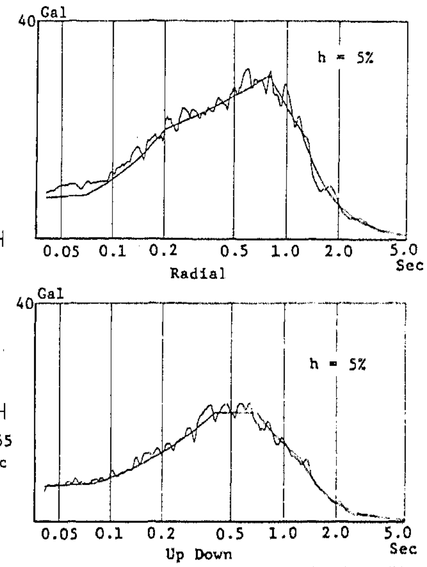


Fig. 12 SPECTRAL COMPATIBILITY

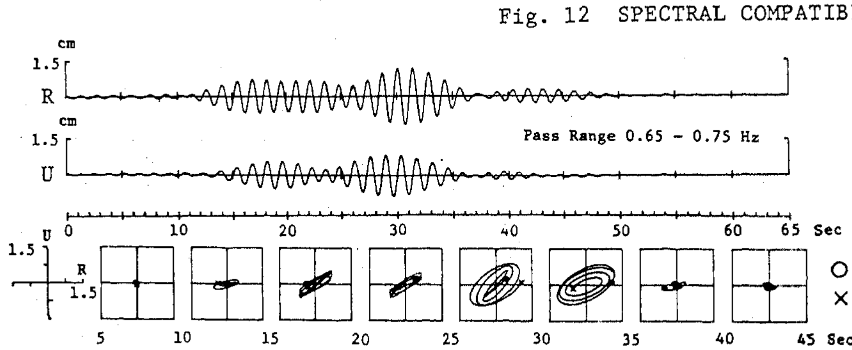


Fig. 13 BAND PASS FILTERED WAVE AND PARTICLE ORBIT