Paper No. 87. (quote when citing this article)
Eleventh World Conference on Earthquake Engineering
ISBN: 0 08 042822 3

PREDOMINANT PERIOD OF SEDIMENTARY SURFACE WAVE AND ANALYSIS OF EARTHQUAKE IN THE OSAKA PLAIN

H. YOKOYAMA

Resaerch Institute of Technology,Konoike Construction Co.,Ltd.
3-6-1-Chome, Kitakyuhoji-Machi, Chyo-Ku,Osaka,541,Japan

ABSTRACT

The earthquake observation conducted for the last 20 years in the Osaka plain and Kanto plain of Japan and the Mexico earthquake in September, 1985, proved that the later phase propagates, following the main wave, from the surrounding mountains using the ground surface and bedrock of the sedimentary layer. It is sedimentary surface wave which has long-period simple waveform, high accelaration and long duration. Persistent research to reveal analytically this phenomenon is continued. This phenomenon have been ascertained at several earthquakes and the Hyogo-Ken Nanbu Earthquake (M7.2,1995.1.17) in the Osaka plain . The sedimentary surface wave, called Atoyure , incident from side, is generated or grown, propagating over the sedimentary plain. It is greatly affected by the shape of sedimentary layer, underground velocity structure and characteristics of attenuation.

Using the numerical differential method of wave propagation equation in the displacement potential domain, the predominant period of sedimentary layer on bedrock in the SH and P-SV fields were analyzed . And based on the obtained result of this underground velocity structure investigation determined from explosions,which conducted by the Earthquake Observation Group of the Osaka plain in 1989 , a model of the Osaka plain was made, the analytical predominant period of sedimentary surface wave and the predominant period of the observed earthquake in the plain were compared to examine.

KEYWORDS

Wave Propagation, Numerical Differential Method, Sedimentary Layer, Sedimentary Surface Wave(Atoyure), The Hyougo-Ken Nanbu Earthquake, The Osaka Plain, Predominant Period, Underground Velocity Structure

PREDOMINANT PERIOD OF SEDIMENTARY SURFACE WAVE

SH Field

Using the numerical differential analysis of wave equation applying the potential expression, the author conducted the wave analysis of sedimentary layer on bedrock in the SH field. The elastic sedimentary layer (one layer) on bedrock which is shown in Figure 1 is taken as an analysis model. The layer thickness(H) is 10s and 15s. The distance interval is $s = 2\sqrt{3}\beta\tau$, where β is S wave velocity, and τ is time interval. When β = 600 m/sec and τ = 0.05sec, s is equal to 104 m and layer thickness is equal to approx. 1 km. It was assumed that that wave is input into the sedimentary layer through the point located on the surface at the left end in Figure 1 and that the input waves are three waves, namely pulse wave (P), sine wave (S) and earthquake observation wave (E). The input sine wave (S) has period NT = 40, 60, 120 τ , number of wave n = 1,5. For random wave (E), the author adopted the integral displacement of acceleration waveform observed on rock in case of earthquake (M5.9) which arose in November, 1973,

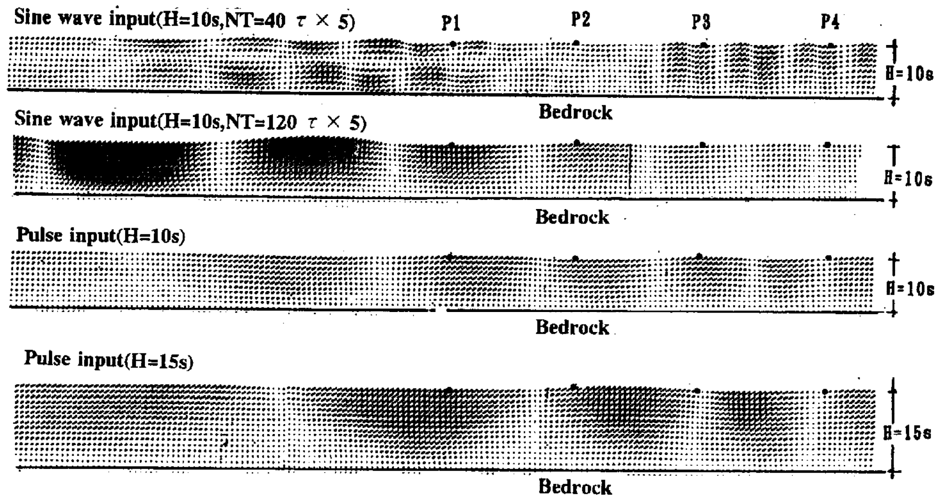


Fig.-1 Wave propagation displacement-diagrams of sedimentary layer after 800 τ step (SH Field)

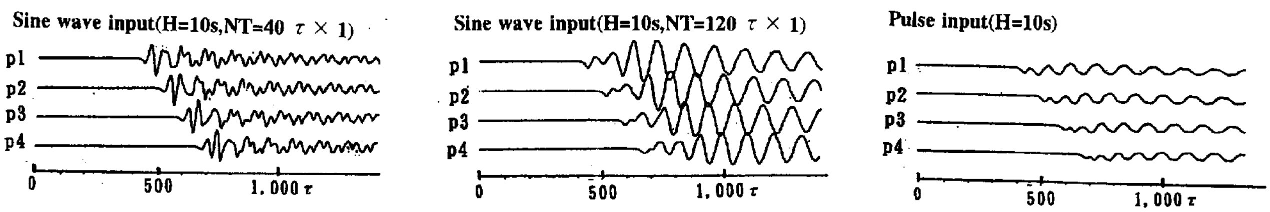


Fig.-2 Displacement time-histories on the point(p1 to p4) (SH Field)

accompanied by later phase wave(called Atoyure)in the Osaka plain.
Figure 1 shows wave propagation distribution after the lapse of time 800 τ when sine wave and pulse are input. The amplitude in the pulse input state is magnified by 4 times as compared to others. When pulse is input sideways, it propagates through the whole sedimentary layer, which resembles the foundamental mode. When 120 τ sine wave is input, as in case of pulse input, it propagates through the whole sedimentary layer which resembles the foundamental mode. The amplitude is magnified more. In case of 40 τ input the whole layer is shaken although initially the amplitude is small, and soon wave propagates through the sedimentary layer which resembles the 2nd mode unlike 120 τ input. The point resembling the nonmoving point appears at a depth 4s (0.4 x H) from the ground surface, and amplitude is reduced.
Figure 2 shows the history of displacement of ground surface(p1 to p4) at a distance of 120 s, 144 s, 168 s, and 192 s from the input point. In case of 120 τ input, unlike 40 τ input period, gives response waveform which is simple and has greater amplitude (resembling resonance). In case of pulse input the simple waveform resembling 120 τ input, although amplitude is small.

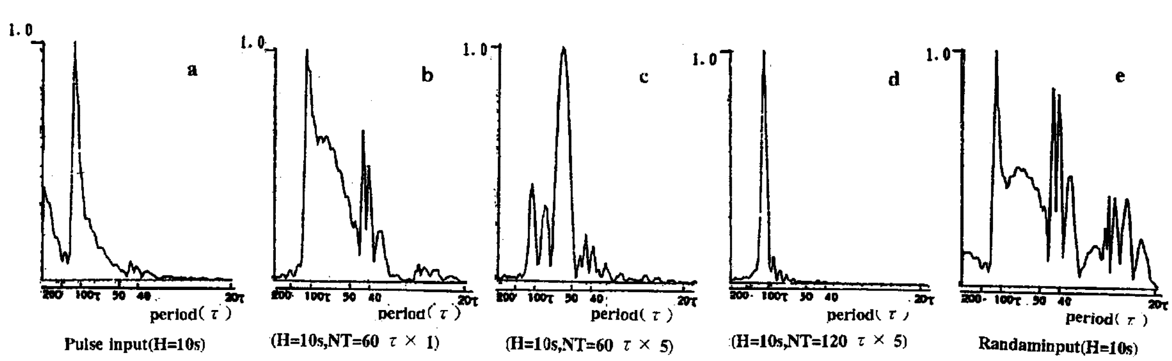


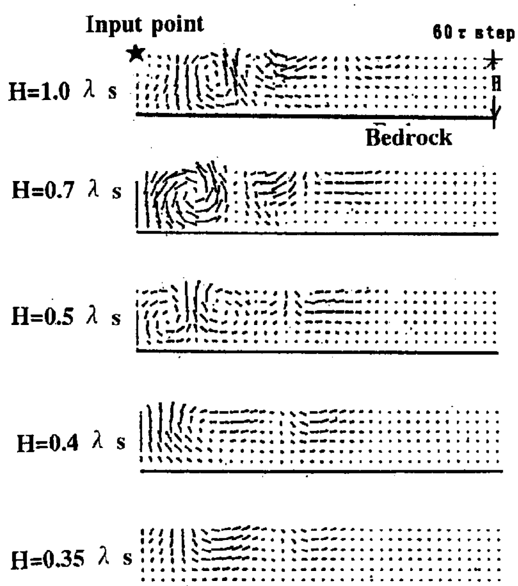
Fig.-3 Results of FFT analysis at p1 point(120s point form input point) (SH Field)

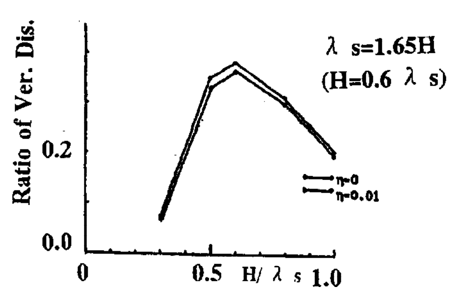
Figure 3 shows the result of FFT analysis of response waveform on p1 which relates to the displacement history shown in Figure 2 (and the result of analysis of pulse input to the ground surface from the lower bedrock). It is concluded that when the pulse is input from the side it is intensive for the ground period which is predominant in case of input into the lower bedrock and it appears earlier on the 6s point near the input point (0.6 × H). When the sine wave is input, the foundamental period of sedimentary layer($T=3.5H/\beta$) is predominant if the number of waves is 1. If the number of waves is 3 to 5, the input period becomes stable and its appearance becomes remarkable as shown in Figure 3 c,d. In case of random wave the foundamental period of sedimentary layer tends to become predominant as in case of pulse.

P-SV Field

The author applied the numerical differential analysis of wave equation which has been used also for analysis of SH field. Figure 4L shows the sedimentary layer displacement propagation after the lapse of time 60 τ and 120 τ as well as the vertical amplitude ratio of sedimentary surface wave when the sin wave (1 wave) is input into the side of surface in the condition that the period is changed in vertical direction of sedimentary layer(H=6s) having a regular topograpy.The predominant period of sedimentary surface wave in the P-SV field exists in condition of $H=0.6\lambda s$ ($T=1.65H/\beta$), and intensive vortex is formed. Namely, there is a specific relation between thickness(H)of sedimentary layer and S wave length(λs) as shown in Figure 4R. Hence, the conditions where wave becomes predominant exist. When the pulse wave is input, only this peak period grows.

Accordingly, the relation between the predominant period (T)of sedimentary ground and its layer thickness (H) in case of input into the side of surface is as shown in Table 1. That is, in the SH field $T=3.5H/\beta$, and in the P-SV field $T=1.65H/\beta$.





Where H:Thickness of sedimetary layer
λs : Wavelength of S wave
β : Velocity of S wave
T: Predominant period

Fig.-4 Left:Wave propagation displacement-diagrams of sedimentary layer after 60 τ step
Right:Relation curve between vertical amplitude of surface wave and $H/\lambda s$ of sedimentary layer

Table-1 Predominant period of sedimentary plain

Field	Input from side of ground surface	Input from lower bedrock
P-SV Field	$T=\lambda s/\beta=1.45\sim1.65H/\beta$	$T=\lambda s/\beta=3.65H/\beta$
SH Field	$T=\lambda s/\beta=3.5H/\beta$	$T=\lambda s/\beta=3.9H/\beta$

Where H:Thickness of sedimetary layer λs : Wavelength of S wave
β : Velocity of S wave T: Predominant period
But When sine wave is input,the input period is stable if the number of wave is 3 to 5

SEDIMENTARY SURFACE WAVE IN THE OSAKA PLAIN IN CASE OF THE HYOGO-KEN NANBU EARTHQUAKE

Outline of the Hyogo-Ken Nanbu Earthquake

The Hyogo-Ken Nanbu Earthquake occurred at 05:46 a.m.(51.9 seconds) on January 17, 1995. Its data is as shown in Table 2(AIJ,1995). The intensity of the Kanto Earthquake (far field earthquake) which occurred in 1923 was M = 7.9, $M_o = 0.55 \times 10^{26}$ dyn.cm, S=130x70 k m^2, U=2.1m, and the intensity of the Fukui Earthquake (near field earthquake) which occurred in 1948 was M = 7.1, $M_o = 3.3 \times 10^{26}$ dyn.cm, S =30x13k m^2, U=2m . The Hyogo-Ken Nanbu Earthquake is the near field fault earthquake of Fukui Earthquake level.

Table-2 Preface of the Hyogo-Ken Nanbu Earthquake(by Professor Kikuchi)

Depth of hypocenter:h=20km,	Magnitude:7.2
Strike of fault:N233° E, Dip of fault:85° , Slip angle:165°	
Earthquake with right-lateral fault(strike direction:N233° E, E/N53° E)	
Seismic moment:$M0=2.5 \times 10^{26}$ dyn・cm, Fault area:$S=40 \times 10km^2$, Stess drop:D=100 ~ 200 bar	
Duration time of main rupture: T=11sec	Relative displacement:U=2.1m

Underground velocity structure of the Osaka plain

It has been already revealed that the characteristics of earthquake wave in the Osaka plain, especially the long period sedimentary surface wave(called Atoyure) propagated following the main wave,are greatly affected by the shape of sedimentary plain and underground velocity structure. The bedrock depth in the Osaka plain and the velocity structure are briefly discussed. In 1989 the Earthquake Observation Group of the Osaka Plain (EOP Group) obtained the following results on the explosion experiment executed in the Hokko (Figure 5, X mark)(Toriumi,1990). The

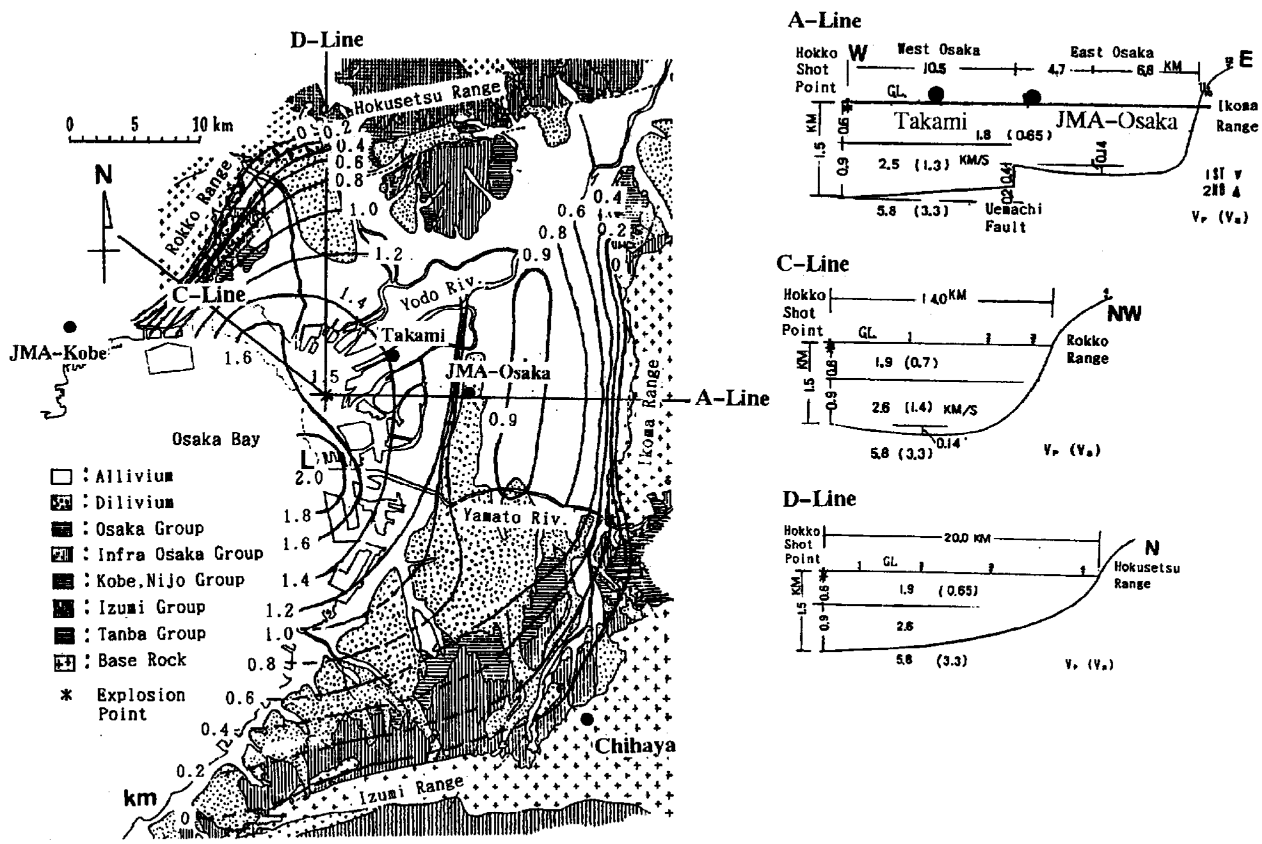


Fig.-5 Proposed contour map of depth to bedrock in the Osaka plain and observed sites of the Hyogo-Ken Nanbu Earthquake by the EOP Group experiment has revealed that in the line A which is a typical cross-section (East-West cross-section) of the Osaka plain as shown in Figure 5 the 1st layer (P wave velocity P_1 =1.8km/sec, S wave velocity S_1 =0.65km/sec) extends to the Ikoma mountainous district (H=642m) in the east region. The 2nd layer (P_2 =2.5km/sec, S_2 =1.3km/sec) exists in the West Osaka extending to the Uemachi fault, but it is not clear in the East Osaka. The bedrock in the West Osaka (depth 1.5 km in Hokko) is almost flat and has gentle upgrade toward the East. The Uemachi fault exists at the west side of the west end of Uemachi plateau. The difference in height is 400 m(depth 0.9km).In East Osaka the bedrock has pan-bottom-like shape (depth 1.04km) and extends to the Ikoma mountainous district. The South-North cross-section of line D, shown in Figure 5, has the maximum depth (2.0 km) near the mouth of Yamato river and has basically upgrade toward Hokusetsu mountainous district(North) and Idzumi mountainous district(South). The line C which is Northwest/Southeast cross-section of the center of Osaka and Rokko mountainous district (H=931m) seriously affected by the Hyogo-Ken Nanbu Earthquake has the pan-bottom-like shape (depth 1.64km at a distance of 1.5km from Hokko) and has upgrade toward the Rokko mountainous district. The Kobe Meteorological Observatory(K) which was an observation point of the Hyogo-Ken Nanbu Earthquake, is located on the steep upgrade of Rokko Mountains. Takami(F) in the Osaka plain is located on the point of sedimentary layer which has a depth 1.4 km, and the Osaka Meteorological Observatory(O) is located on the Uemachi plateau (layer thickness is 1.1km), and Chihaya(C) is located on the granite bedrock.

Characteristics of sedimentary surface wave of the Osaka plain

Figure 6 shows the acceleration waveform of the Hyogo-Ken Nanbu Earthquake observed by the Kobe Meteorological Observatory(K), Takami(F,40km distance from epicenter) of the Osaka plain, Osaka Meteorological Observatory(O) and Chihaya (C, on opposite bedrock beyond Kobe of the Osaka plain). The wave observed by the Kobe Meteorological Observatory is impulse wave having short-period (duration of approx. 10sec). Unlike the wave observed by the Kobe Meteorological Observatory, the wave observed on Takami of the Osaka plain and Osaka Meteorological Observatory is characterized by long-lasting long-period wave following the short-period main wave. The amplitude observed by the Osaka Meteorological Observatory located on the Uemachi plateau is extremely small. As is evident from Figure 9L showing the displacement waves the wave observed in the Osaka plain is significant long-period wave lasting for a long time. The wave observed on Chihaya located on the granite bedrock in the Southeast part of the Osaka plain is characterized by predominance of short-period wave (duration of about 10sec) as with wave observed by the Kobe Meteorological Observatory.

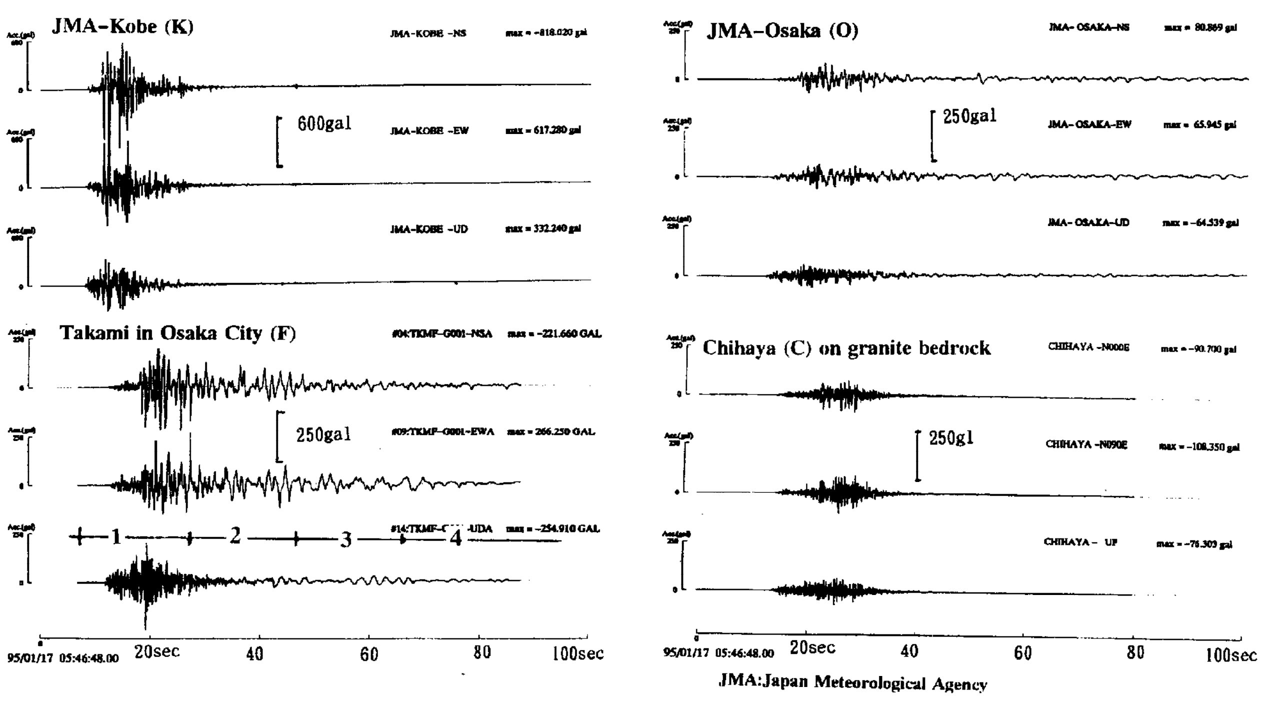


Fig.-6 Accelaration waveforms of observed sites at the Hyogo-Ken Nanbu Earthquake (Upper:NS, middle:EW, Lower:UD. Started time of waves are same.)

H.Yokoyama Pt

The spectral characteristics are as follows. As is evident from Figure 7 which shows the pseudo response spectrum of horizontal wave velocity (PSV, h=5%) which was observed by the Kobe Meteorological Observatory(K), Takami(F), Osaka Meteorological Observatory(O), and Chihaya(C), the trend of wave observed in the Osaka plain differs remarkably from the trend of wave observed in Kobe. The wave spectrum observed by the Kobe Meteorological Observatory has sharp peak on 0.8 sec point (especially EW Dir.). With the wave observed in the Osaka plain, the peak shifts to long-period side, and a new predominance of long-period (1sec or more) wave was observed by Takami and the Osaka Meteorological Observatory after the main wave as shown by spectrum of divided period shown in Figure 8. The predominance was found near 2sec and 5sec(Takami), and 2sec and 3.5sec (Osaka Meteorological Observatory). These observation places are arranged as follows in decreasing order of attenuation of short-period wave, namely Kobe Meteorological observatory> Takami> Osaka Meteorological Observatory. The vertical wave observed by the Kobe Meteorological Observatory has a peak on 0.8 to 1.5sec point. In the Osaka plain the predominance was observed for 2sec long- period after depression for 0.6 to 1.5sec. Especially on Takami this 2sec predominance appears also on the horizontal wave. The long-period wave following the main wave, which appeared as horizontal and vertical waves in the Osaka plain, is sedimentary surface wave, and the predominant period varies depending on the thickness of sedimentary layer.

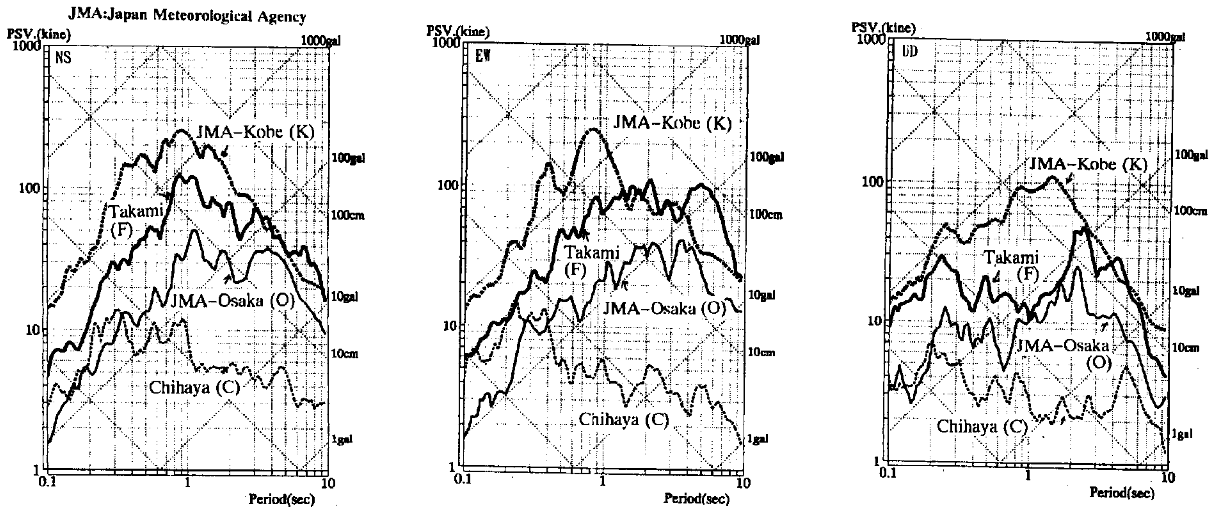


Fig.-7 Pseudo responce spectrum of velocity at site K,F,O and C (h=0.05%)

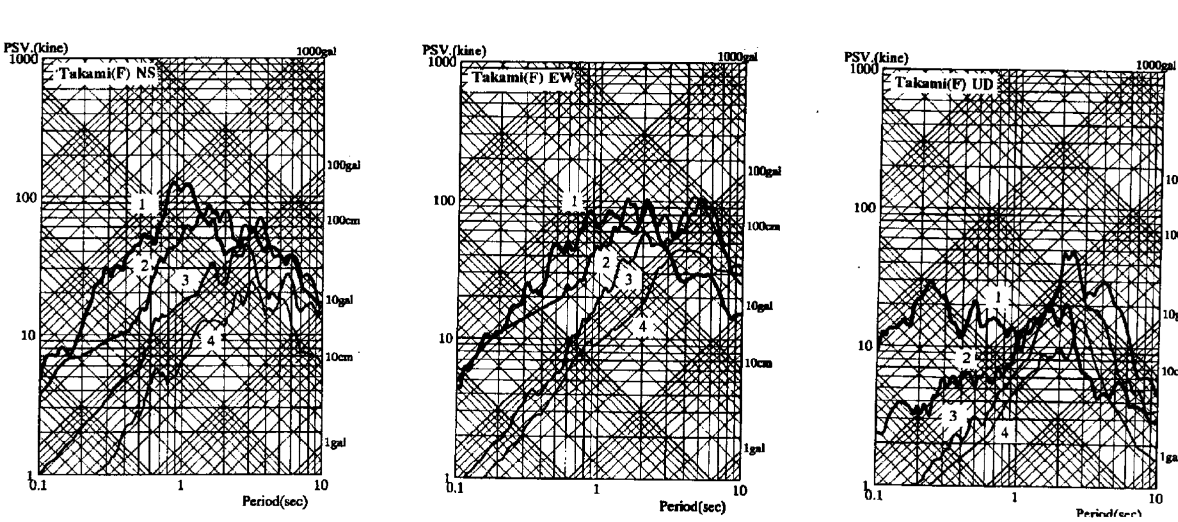


Fig.-8 Pseudo responce spectrum of velocity of divide periods at site F (h=0.05%)

Accordingly, as is evident from the waveform shown in Figure 6, Figure 9, and from the spectrum shown in Figure 7 and Figure 8, the long-period predominant wave (2 sec to 5 sec) in the Osaka plain is the sedimentary surface wave (called Atoyure) which propagates with a velocity 600m/s across the sedimentary layer, following the main wave which is incident from the lower bedrock and causes shake, repeating multiple reflection, whereon the predominance which relates to the layer structure and thickness of sedimentary layer reflects. This coincides well with the relation between the thickness of sedimentary layer of the Osaka plain which was determined by the numerical differential analysis method mentioned in the preceding chapter and the predominant period of sedimentary surface wave as shown table 3. The author considers that the wave propagated mainly through the 1st sedimentary layer.

Table-3 Predominant period of sedimentary plain
(the Osaka Plain at the Hyougo-ken Nanbu Earthquake)

Field	Input from side of ground surface	Takami(F),H=800m	JAM-Osaka(O),H=600m
P-SV Field	$T=\lambda s/\beta=1.45\sim1.65H/\beta$	T=2.2sec	T=1.65sec
SH Field	$T=\lambda s/\beta=3.5H/\beta$	T=4.7sec	T=3.5sec

Where H:Thickness of sedimetary layer λs : Wavelength of S wave
β : Velocity of S wave(600m/sec) T: Predominant period

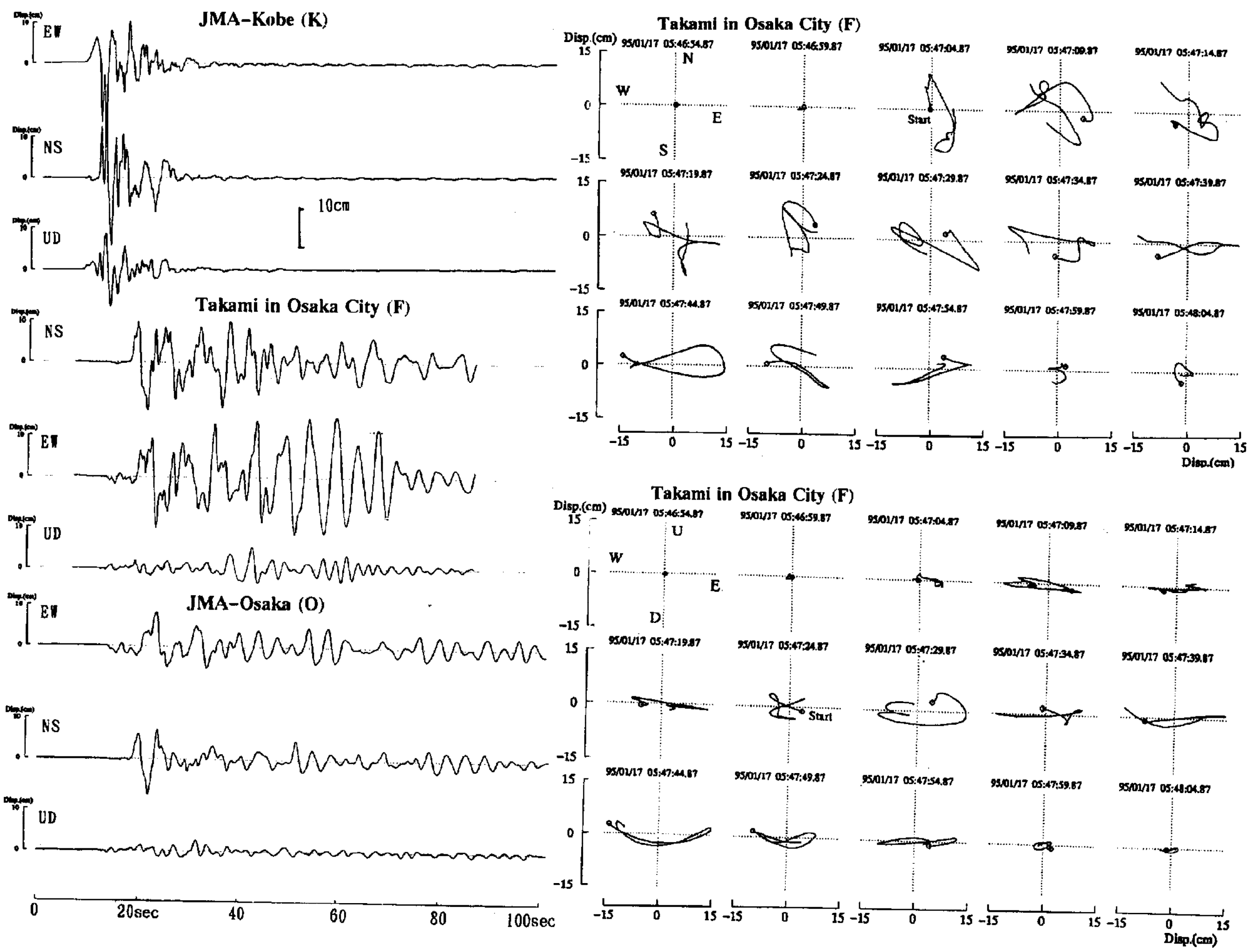


Fig.-9 Left:Displacement waveforms of observed sites at the Hyogo-Ken Nanbu Earthquake
(Upper:NS, middle:EW, Lower:UD, Started time of waves are same.)
Right: Particle motions of observed displacement waveforms at site F

As shown in the displacement waveform and particle motion graph(Figure 9) of Kobe Meteorological Observatory and Takami, the particle motion of horizontal displacement which was observed by the Kobe Meteorological Observatory indicates the displacement mainly in the Northwest-Southeast direction at a right angle to the earthquake fault direction. However, on Takami in the Osaka plain the displacement occurred slowly at first in the North-northwest-South-southeast direction, resulting in gradual counterclockwise shift of axis, and in the sedimentary surface wave section the axis shifts in the East-West direction. The vertical displacement is insignificant. The long-period Love wave and Rayleigh wave (with compressed vertical displacement) exist, causing significant slow waves.

CONCLUSIONS

1)In the case when pulse or randam wave is input from side into plain,the fundamental period of sedimentary is dominant as follows.

SH field : $T=3.5H/\beta$, P-SV field : $T=1.65H/\beta$

Where T:predominant period of sedimentary layer, H:thickness of sedimentary layer, β :S wave velocity

But when sine wave is input, the input period is stabilized if the number of wave is 3 to 5, and the input apperance becomes notable. Even if sedimentary layer has step on lower bedrock, characteristics of predominant period does not change fundamentally.

2) This displacement potential numerical differential method is effective to analyze characteristics of sedimentary surface wave of earthquake.

3) As results of several observation records in comparision with analysis in the Osaka plain, coexistence of Love wave and compressed vertical-displacement Rayleigh wave is found. It is a feature of sedimentary surface wave in the Osaka plain.

4) Sedimentary surface wave in the Osaka plain is observed cleary at the Hyogo-Ken Nanbu Earthquake,1995,1,17 and then relation between predominant period of the surface wave and thickness of the plain as above 1) is certified.

5) Many cities have suffered serious damage caused by the under-inland type earthquake accompanied by intensive impactive main wave lasting for about 10 seconds. It is predicted that the under-ocean type earthquake will be caused by the plate tectonics of Nankai trough in the near future. There is a high probability of occurrence of under-ocean type earthquake differing from the experienced earthquake which may affect the Keihanshin(Osaka-Kobe) area. In this case the long-period wave, namely sedimentary surface wave,which propagates with a velocity 600 m/sec across the Osaka plain, following the short-period main wave, shakes structures intensively and repeatedly. Therefore, when building structures in the sedimentary plain, it is necessary to take into account the characteristics of sedimentary surface wave as a long-period impact earthquake wave.

REFERENCES

Toriumi I. et al.(1984). Characteristics of earthquake motion in the Osaka plain. Research Institute of Disaster Sience (in Japanese)

Toriumi I.and Segawa T.(1988). Mechanism of Rayleigh type surface wave in the sedimentary plain,The 9th World Conference of Earthquake Engineering,pp.557-560

Toriumi I.and Segawa T.(1990). Growth of surface wave in sedimentary layer from surrounding rock site.The 8th Japan Earthquake Engineering Symposum,pp475-480.

Yokoyama H.(1993).Analysis for later phase of seismic motions in Osaka plain ,Summaries of Technical Papaers of Annual Meeting ,Architectural Institute of Japan(Kanto),pp195-196(in Japanese)

Yokoyama H.(1995).Study of seismic characteristics of sedimentary plain,Thesis of Osaka University

Prompt reprt of building damages in case of the Hyogo-Ken Nanbu Earthquake, Architectural Institute of Japan,(1995)