CHARACTERISTICS OF LONG-PERIOD STRONG GROUND MOTIONS DUE TO EARTHQUAKES IN THE EASTERN MARGIN OF THE JAPAN SEA

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SUMMARY

Characteristics of long-period (2 to 20 sec) strong ground motions due to the earthquakes in the eastern margin of the Japan Sea were investigated using displacement type strong motion seismograms at JMA observatories. For the events in the northern part of this region, amplification factors at most stations have a sharp peak at a period of about 10 sec, and seismic wave at this period is growing as propagating. Spectrum at Niigata during the 1964 Niigata earthquake estimated using the ratio of the spectra at Niigata and Tokyo, was more than 200gal□sec at periods of 8 to 9 sec. It coincides with the fact that the large sloshing of liquid in oil storage tanks occurred during this earthquake. Using amplification factors, we predicted the acceleration spectra for the hypothetical event pointed out by Ohtake (1993). It was found that the spectral levels at a period of about 10 sec at Sakata, Niigata, and Akita exceed the regulation regarding sloshing wave height of an oil storage tank.

INTRODUCTION

Large earthquakes in the eastern margin of the Japan Sea such as the 1964 Niigata earthquake, the 1983 Nihonkai Chubu earthquake, and the 1993 Hokkaido Nansei-Oki earthquake, caused the damage of oil storage tanks by liquid sloshing. In particular, in the 1964 Niigata earthquake, great fires of oil storage tanks due to the liquid sloshing broke out and burnt factories and residents. On the other hand, Ohtake (1993) pointed out that a large earthquake can occur in the very near future with magnitude of 7.5, because there is a seismic gap of the first kind in this area.

In this paper, first, amplification factors of long-period ground motions from 2 to 20 sec for this area are evaluated at several observatories of Japan Meteorological Agency (JMA) by comparing observed acceleration spectra with semi-empirical ones using strong motion records. Second, the acceleration spectrum at Niigata during the 1964 Niigata earthquake is estimated, and finally acceleration spectra for the above mentioned hypothetical earthquake are predicted on the basis of the amplification factors and the risk of damage of oil storage tanks due to liquid sloshing is examined.

DATA

JMA was operating the displacement type strong motion seismographs at many sites from 1950 to about 1990. Since the natural period of the seismometer is about 6 sec, it is competent to record long-period ground motions. However, these should be digitized, because these seismograms are analogue records. Then, we developed a system to digitize seismograms semi-automatically using a personal computer and a scanner. Analogue records at seven observatories for fifteen events as shown in Figure 1 were digitized, and acceleration spectra were calculated after removal of the instrumental response. Acceleration spectra are adopted as the data, because the sloshing wave height is approximately proportional to the acceleration spectrum at the natural period of liquid sloshing of an oil storage tank.

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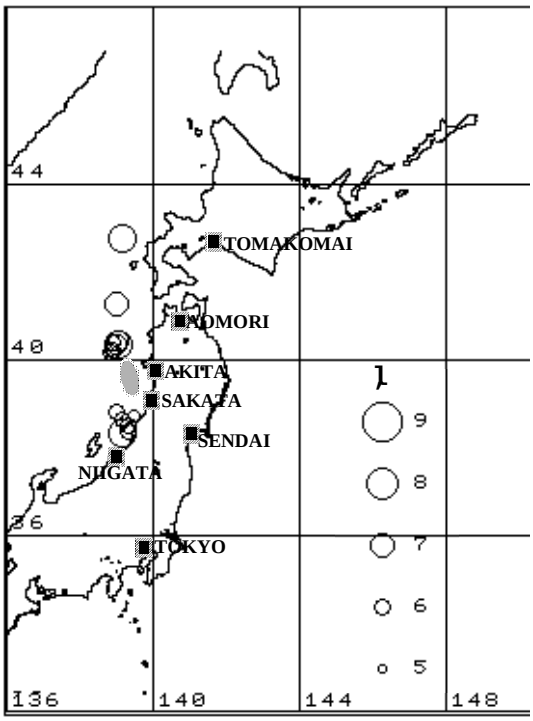


Figure 1: Distribution of epicenters and JMA observatories Shaded area off Akita is the source region of the hypothetical earthquake pointed out by Ohtake(1993).

FEATURES OF SPECTRA

Figure 2 shows acceleration spectra for two large events. The one is located at the southern part and the other is located at the northern part of this region. Focussing on the form of the spectrum at a period of about 10 sec, we found that the pattern for each event is different except for Tomakomai. For the northern event (right), we can see the distinct peak at a period of 10 sec, in common to all the observatories. On the other hand, such a peak cannot be seen for the southern event. This suggests that this region should be classified into two blocks, namely the southern and northern parts from view of seismotectonics and of amplification characteristics of long-period ground motions.

In order to investigate the wave propagation process, we calculated inter-station spectral ratios as shown in Figure 3. For the northern events, spectral ratios are stable and the spectral amplitude at a period of 10 sec becomes larger as wave propagating. On the other hand, spectral ratios for the events in the southern part are not so stable as for the northern part, and are almost below one. It is well known that the long-period strong ground motion mainly consists of surface wave. The surface wave at a period of about 10 sec is growing as propagating to the south through the off coast of this region, where the thick sediment more than 3,000m exists from Niigata to Akita [Matsuda, 1980]. However, the amplification characteristics of the wave propagating to the north differ from the ones of the wave propagating to the south. This suggests that the distribution of the depth down to the basement of the sedimentary basin is complex. The amplification between Akita and Tomakomai suggests the existence of thick sediment around Tomakomai.

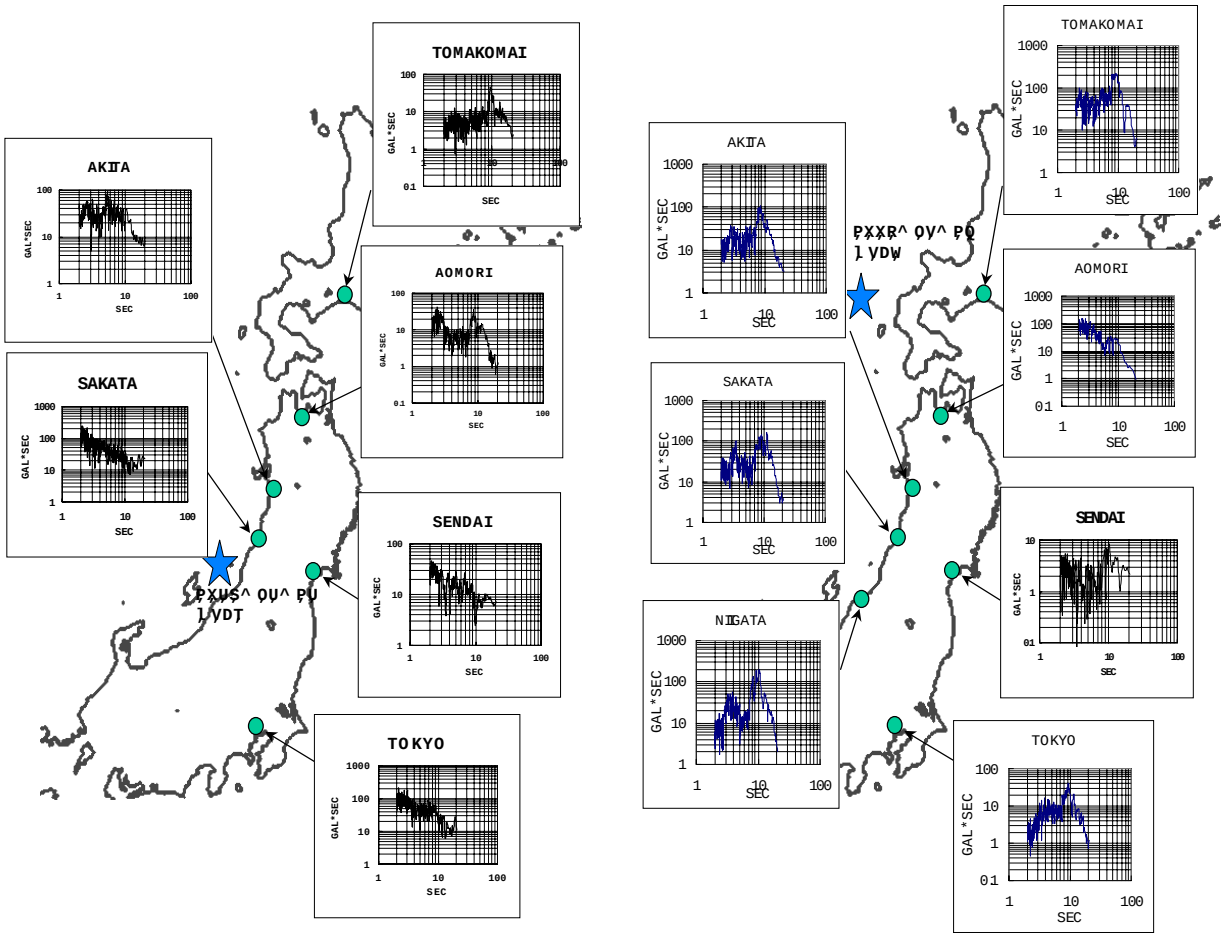


Figure.2: Acceleration spectra for the 1964 Niigata earthquake (left) and for the 1993 Hokkaido Nansei-Oki earthquake (right)

ACCELERATION SPECTRA AT NIIGATA DURING THE 1964 NIIGATA

In the 1964 Niigata earthquake, as mentioned above, great fires of oil storage tanks caused by liquid sloshing, broke out and burnt factories and residents. Although there are two records at Niigata for this earthquake, that is, SMAC record and JMA strong motion record, SMAC record was obtained at the building inclined by the soil liquefaction, and the horizontal components of the JMA record was saturated by the strong ground motion. Then, we estimated the acceleration spectrum at Niigata, by utilizing that inter-station spectral ratios for the events in the northern part are stable. Here, we adopted the averaged spectral ratio between Niigata and Tokyo as a transfer function, and calculated the acceleration spectrum at Niigata by the product of the observed spectrum at Tokyo for the 1964 Niigata earthquake and the spectral ratio as shown in Figure 4.

The estimated spectrum predominates at periods from about 2 to 4, and from 8 to 9 seconds. Spectral amplitudes at these periods are about 300 and 200 gal/sec, respectively. The natural period of sloshing of oil storage tanks caused the great fires is 8.8 sec. The spectral amplitude of 200 gal/sec at this period is two times as large as the regulation (100 gal/sec) concerning liquid sloshing of oil storage tank. Therefore, it is natural that the large sloshing occurred during the 1964 Niigata earthquake. A distinct peak at a period of 6 sec can be seen in the acceleration spectra of the horizontal component of SMAC record [Kudo, 1992]. In other hand, there is not a peak at this period in Figure 4a. Then, we estimated the spectrum of the vertical component by the same method and compared with the observed spectrum of JMA record, as shown in Figure 4b, because the vertical component of JMA record is not saturated. The close agreement between the observed and calculated spectrum suggests that soil liquefaction lead to the peak at a period about 6 sec in SMAC. The fact that such a peak cannot be seen for the 1964 Niigata earthquake in the left of in Figure 2 and another sites, supports this assumption.

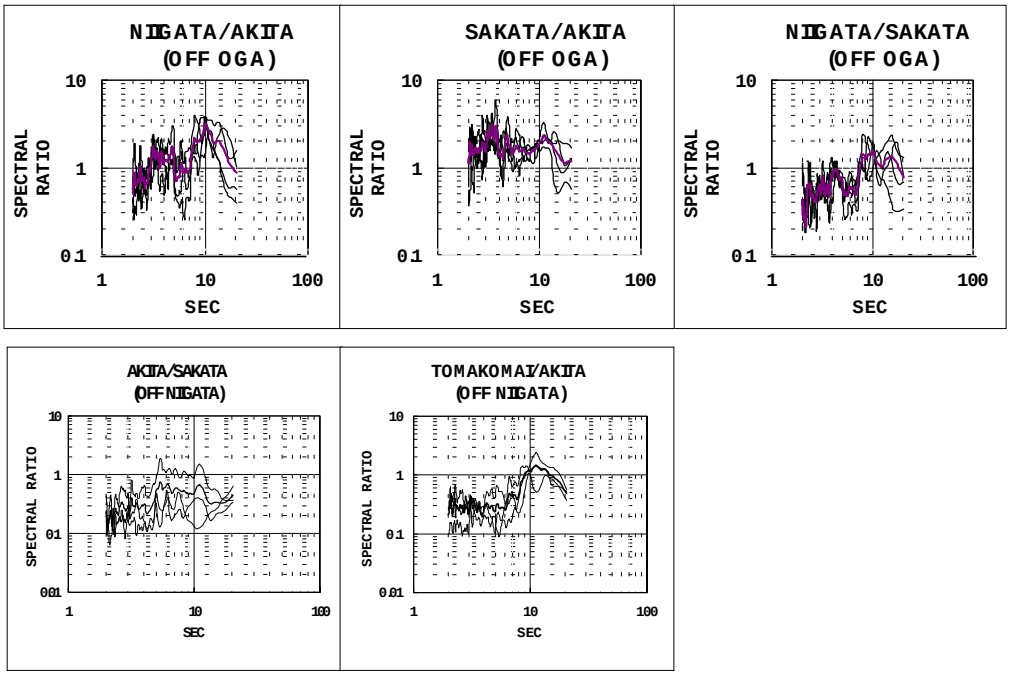


Figure 3: Inter-station spectral ratio
Upper: for events in the northern part Lower: for events in the southern part

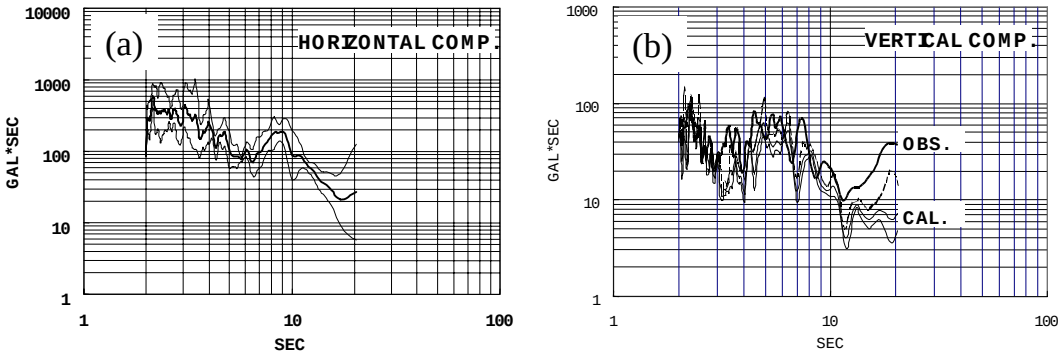


Figure 4: Predicted acceleration spectra for the 1964 Niigata earthquake at Niigata
(a) Horizontal component: lines show average and standard deviation.
(b) Vertical component: lines show the observed, calculated spectrum and its standard deviation.

AMPLIFICATION FACTORS

It is often observed that seismic waveforms from earthquakes in a seismic source zone are very similar with one another. This suggests that the effects of source and path on the ground motions are almost same. Here, we try to withdraw these effects at each observatory for events in the east margin of the Japan Sea. Using the normal mode theory and Haskell-Savage source model, Kudo (1989) derived the semi-empirical equation to express the acceleration spectrum (Fo(T)) in terms of only earthquake magnitude (M) and epicentral distance (r) as follows.

$$Fo(T) = 4.8 \times 10^{\square\square\square\square\square\square} \exp(-\alpha(T)r) / r^{\square\square\square} \quad (T \square Tc), \tag{1}$$

$$Fo(T) = 4.8 \times 10^{\square\square\square\square\square\square} \exp(-\alpha(T)r) \times (Tc/T)^{\square} / r^{\square\square\square} \quad (T \square Tc), \tag{2}$$

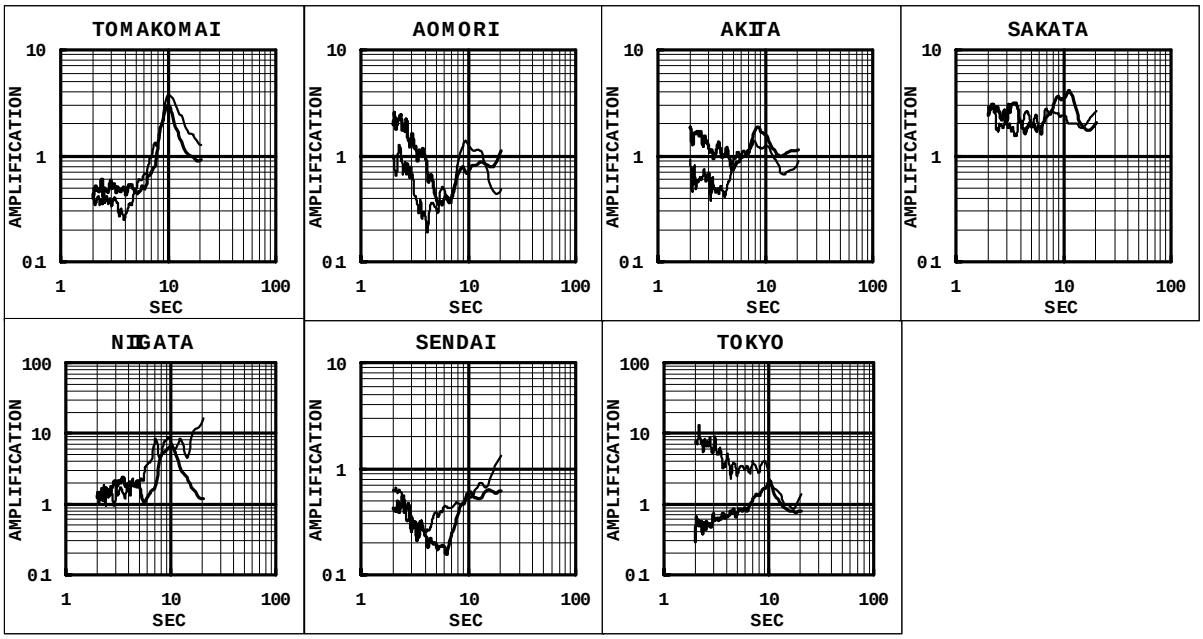
$$\log\alpha(T) = 9.11 / T - 4.26, \tag{3}$$

$$Tc = 10^{\square\square\square\square\square\square\square\square} \tag{4}$$

Since the ratios of the observed to the standard spectrum given by (1) or (2) are not always same, we defined an amplification factor as the averaged ratio for each seismic source zone. As mentioned above, the target seismic source zone should be divided into two areas, that is, northern part and southern part of the eastern margin of the Japan Sea. Therefore, amplification factors were calculated for two areas as shown in Figure 5.

For events in the northern part, we can see a peak of amplification factor at a period of about 10 sec except for Aomori and Sendai. The largest value is about seven at Niigata. Tomakomi has also a sharp peak around 10 sec. For events in the southern part, the distinct peak around 10 sec appears in Tomakomai and Amori. In Sakata, the amplification factor is almost independent of period. The difference of amplification factors between for the southern and for the northern part strongly depends on the period and the site.

Figure 5: Amplification factors as a function of period



Thick and thin lines show the values for the events off Akita and for off Niigata, respectively.

PREDICTION OF ACCELERATION SPECTRA AND RISK OF LARGE SLOSHING OF OIL STORAGE TANK FOR THE HYPOTHETICAL EARTHQUAKE OF OFF AKITA

Acceleration spectrum can be calculated by the product of the amplification factors and the standard spectrum obtained by substituting both the magnitude of 7.5 of the hypothetical earthquake indicated by Ohtake and the epicentral distance measured from the center of the source region into the equation (1) and (2). Since the source region is located near the northern part of the eastern margin of the Japan Sea, amplification factors for the northern part were used.

From the predicted spectra shown in Figure 6, we judged that the expected sloshing wave height of oil storage tanks at Sakata and Niigata exceed the regulation against the sloshing at periods of 2 to 4 and 10 seconds.

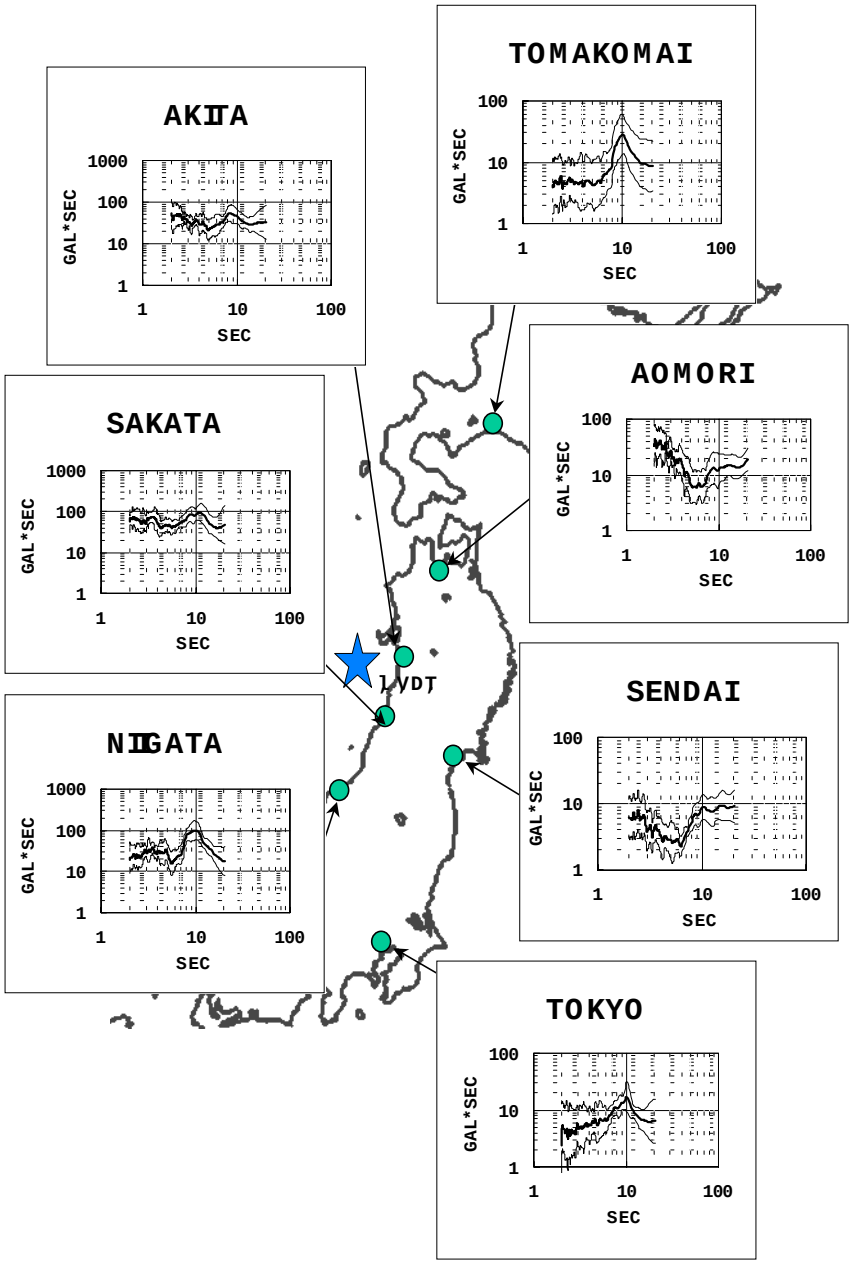


Figure 6: Predicted acceleration spectra for the hypothetical off Akita earthquake (M7.5) indicated by a star

Thick and thin lines show the average spectrum and standard deviation.

CONCLUSIONS

Using JMA displacement type strong motion records, characteristics of long-period ground motion were investigated for the earthquakes in the eastern margin of the Japan Sea. The results are as follows:

(1) Spectral shape indicates that the seismic source region should be divided into two small blocks, namely northern and southern part.

(2) Amplification factors for the events in the northern part have a peak at a period of about 10 sec at almost all the observatories.

(3) Inter-station spectral ratios for the events in the northern part are stable. As propagating, the spectral ratio at a period of about 10 sec becomes larger. On the other hand, spectral ratios for the southern part are unstable. Accordingly, the subsurface structure in this seismic source region seems to be complex.

(4) Acceleration spectrum at Niigata during the 1964 Niigata earthquake was estimated using the spectral ratio between Niigata and Tokyo, and are about 200 gal□sec at periods from 8 to 9 seconds. Comparing the

estimated spectrum with the observed spectrum of the SMAC record, a peak at a period of 6 sec is considered as the effect of soil liquefaction at the site.

(5) Predicted acceleration spectra for the hypothetical earthquake off the coast of Akita exceed the regulation (□100 gal□sec) concerning the liquid sloshing of oil storage tank at periods from 2 to 4, and about 10 seconds at Sakata and Niigata.

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