A Study on Long Period Waves in Coastal Waters of Toyama and Niigata

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Key words: long period waves, ocean tide, generating mechanism of wave, tectonic plates, polar motion

ABSTRACT

The research on waves has been carried out in National Institute of Technology, Toyama College (NIT, Toyama College) since 1967, but generating mechanism of long period waves is not clear yet. And so, long period waves were investigated by analyzing tide levels which were observed at coasts of Toyama and Niigata in this study. The results are as follows.

(1) There is a wave with period of about 321 days in residuals between observed and calculated tide levels, amplitude and phase of the wave in Toyama and Niigata are the same. The amplitude of the wave is 1.5cm and the phase of the wave is 284 degrees.

(2) There is a wave with period of about 420 days in residuals between observed and calculated tide levels, amplitudes and phases of the wave in Toyama and Niigata are slightly different from each other. The amplitude of the wave is 1.3 cm in Toyama and 1.2 cm in Niigata and the phase of the wave is 263 degrees in Toyama, 260 degrees in Niigata.

The wave with period of about 321 days, amplitude of 1.5 cm and phase of 284 degrees, which exists in coastal waters of Toyama and Niigata, is generated by fluctuation of the earth gravity. Further there is a possibility that the wave with the period of about 420 days, which corresponds to chandler period (about 435 days), is driven by the polar motion. Moreover, the waves suggest that tectonic plates are swaying relatively to inner earth under asthenosphere, and as a result, gravity on earth surface fluctuations with periods of 321 days and 420 days.

It is a future problem to make clear generating mechanisms of the long period waves.

1. Introduction

It is considered that people around Toyama Bay had known characteristics of swells in a coastal water at first in the world more than about 160 years ago, because the name of the swells which was written in 1864, represents the characteristics. Further the research on waves has been carried out in National Institute of Technology, Toyama College (NIT, Toyama College) since 1967, but generating mechanism of long period waves is not clear yet. And furthermore, wave disasters occur repeatedly since long ago on the coast of Toyama and Niigata. For example, a cargo ship of 1798 tons was drifted and grounded in Fushiki-Toyama Port in October 2017, as shown in Fig.1. A cause of the wave disasters is that wave height of swell increases twofold periodically due to long period wave with period of several minutes or several ten minutes (2017, 2019). Moreover, wave height of the long period wave fluctuates periodically, but the generating mechanism of the long period waves and mechanism of the periodic fluctuation of wave height of the long period wave are not made clear enough. Therefore, the long period waves in coastal waters of Toyama and Niigata were investigated to make clear the generating mechanism and so on. Consequently, it was found that waves with periods of about 321 days and 420 days exist in residuals between observed tide levels and calculated tide levels using tidal constants in coastal waters of Toyama and Niigata, and generating mechanisms of these long period waves were discussed. These results are reported in this paper.

Fig.1 Cargo ship grounded on wave dissipating blocks in Fushiki-Toyama Port on 23 October, 2017

2. Tide Level Observation

Tide level observation points are shown in Fig.2. In Fig.2, point A (36° 45.65' N,137° 7.88'E) shows tide station of National Institute of Technology, Toyama College in Toyama New Port, which is shown in Fig.3. And point B (36° 46.52'N,137° 7.08'E), point C (37° 59.43'N, 139° 13.03'E), point D (37° 59.43'N, 139° 3.67'E) and point E (36° 47.58' N, 137° 3.73'E) show tide stations of Hokuriku Regional Development Bureau, MLIT. Tide levels have been observed every hour since 1997 at tide stations of Hokuriku Regional Development Bureau, and tide level data observed at point B and point C for 16 years from 2004 to 2019 was used to investigate long period waves. Shortages of every hour tide levels at point B by tide gauge maintenance were supplied by every hour tide levels at point E, and similarly, shortages of every hour tide levels at point C were supplied by every hour tide levels at point D.

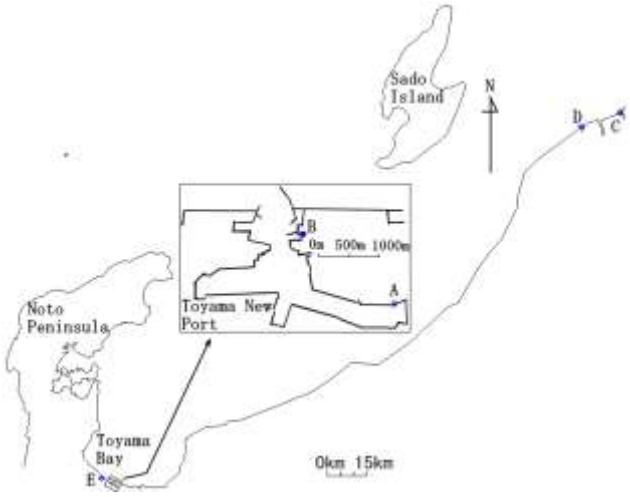


Fig.2 Location of tide stations in Toyama and Niigata

Fig.3 Tide station in Toyama New Port (A in Fig.2)

3. Tide Level Analysis

3.1 Analysis of Tide Levels for Several Years

Every hour tide levels which observed at point B in Fig.2 for 4 years after April 1, 2015 are shown in Fig.4, tide levels which were calculated every hour for 4 years after April 1, 2015 by tidal constants of Toyama provided by Japan Meteorological Agency (2022) are shown in Fig.5 (Report of Hydrographic and

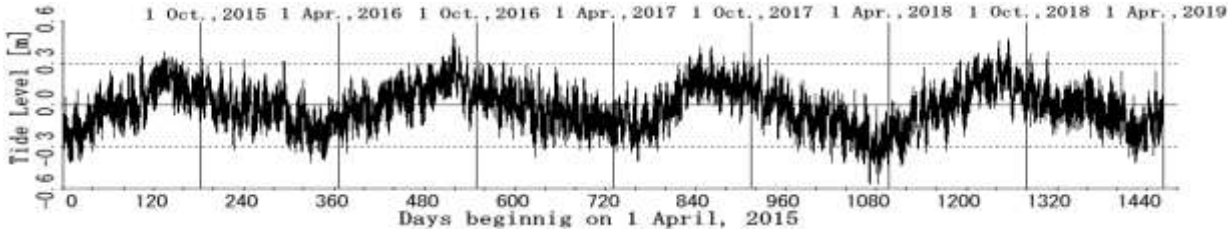


Fig.4 Tide levels every one hour at B of Fig.2 for 4 years after April 1, 2015

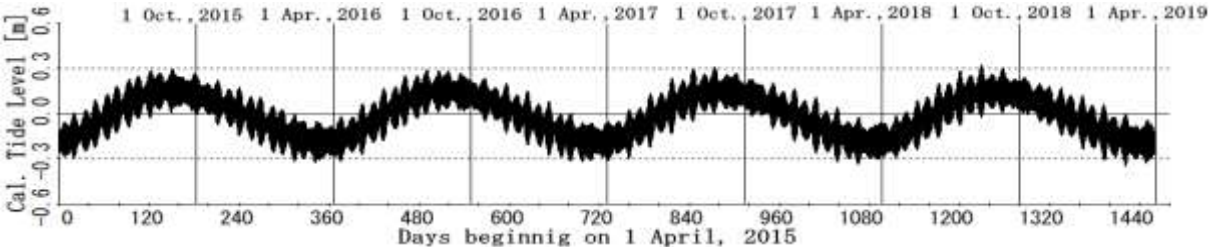


Fig.5 Tide levels which were calculated every hour for 4 years after April 1, 2015 by tidal constants of Toyama

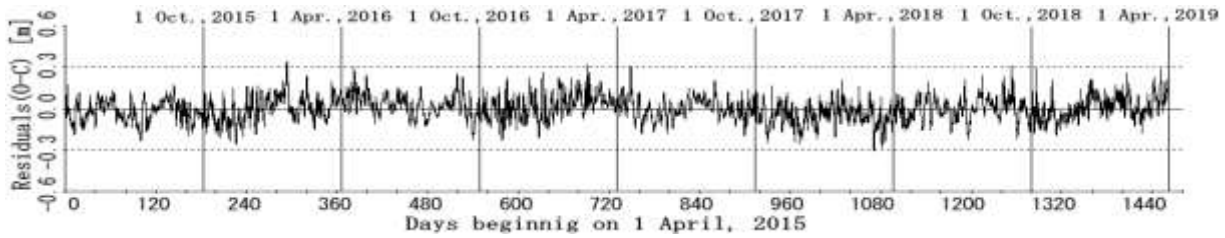


Fig.6 Residuals between observed tide levels and tide levels calculated by tidal constants of Toyama

Oceanographic Researchs, 2022) and residuals between observed tide levels shown in Fig.4 and calculated tide levels shown in Fig.5 are shown in Fig.6. The residuals between observed tide levels and calculated tide levels are written O-C simply. These figures show that tide levels fluctuate with period of one year and residuals (O-C) fluctuate periodically within range of plus or minus 30 cm. The residuals shown in Fig.6 are considered as prediction errors of tide levels.

Spectral density of tide levels in Fig.4 is shown in Fig.7, and spectral density of residuals (O-C) in Fig.6 is shown in Fig.8. These figures show spectrum densities of long period waves in Toyama, and spectrum densities of long period waves in Niigata are shown in Fig.9 and Fig.10. Fig.9 shows spectrum density of tide levels observed every hour at C in Fig.2 for about 3.7 years after April 1, 2015, and Fig.10 shows spectrum density of residuals (O-C) at C in Fig.2 for the same period as another. In these figures, period, phase and amplitude are

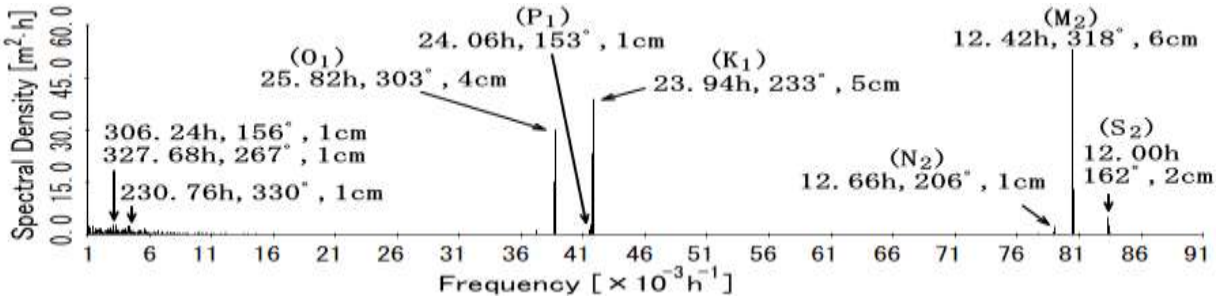


Fig.7 Spectrum density of tide levels shown in Fig.4 for about 3.7 years after April 1, 2015

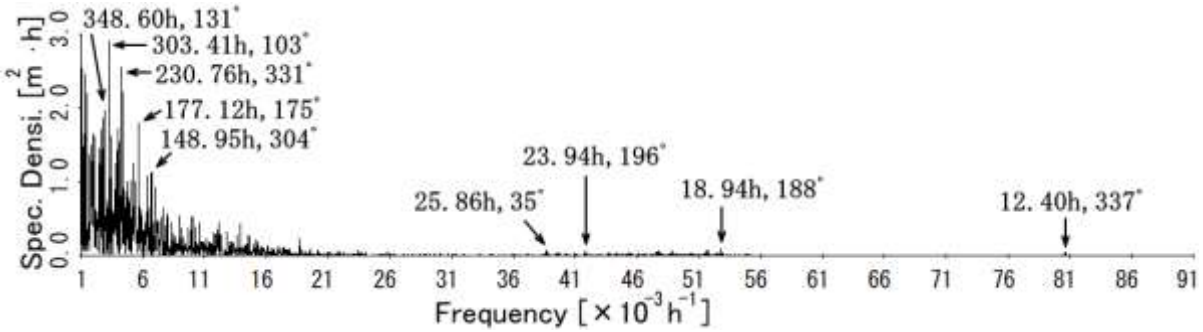


Fig.8 Spectrum density of residuals (O-C) shown in Fig.6 for about 3.7 years after April 1, 2015

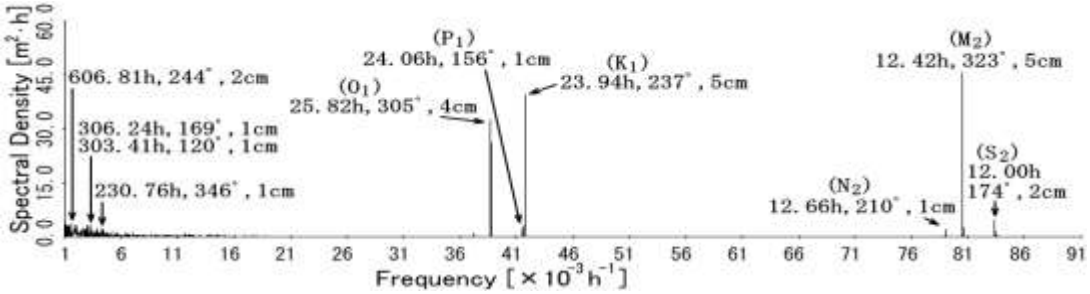


Fig.9 Spectrum density of tide levels observed every hour at C in Fig.2 for about 3.7 years after April 1, 2015

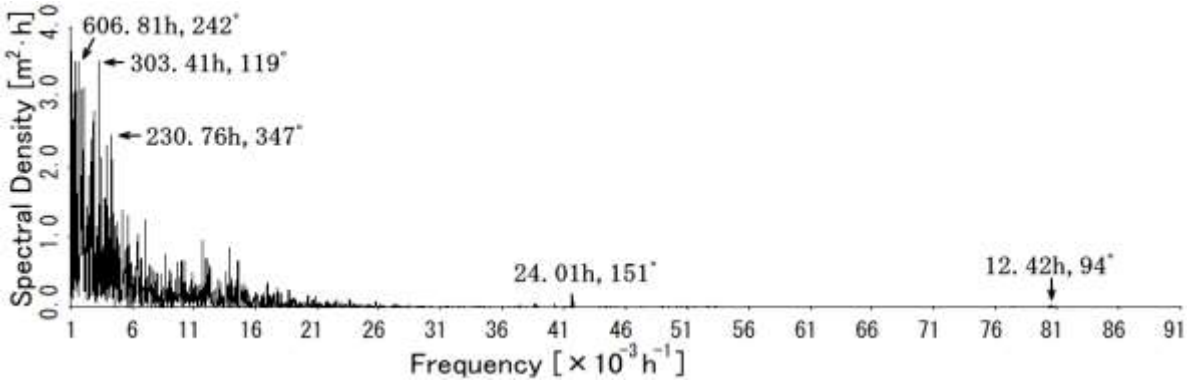
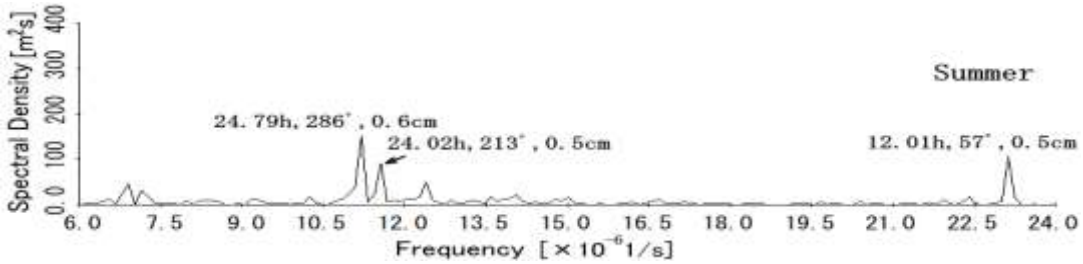


Fig.10 Spectrum density of residuals (O-C) at C in Fig.2 for about 3.7 years after April 1, 2015

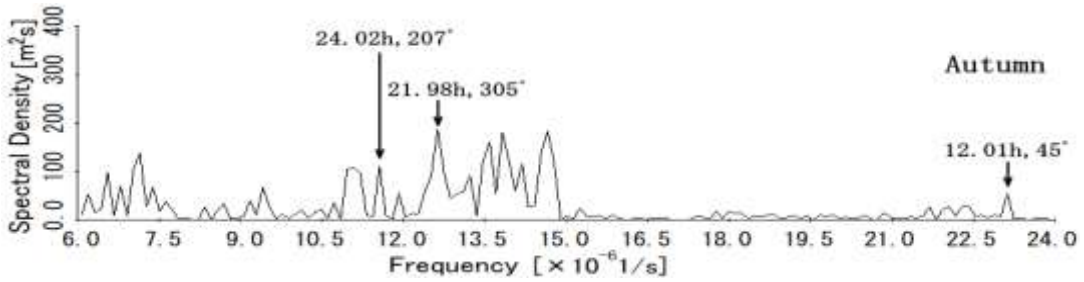
marked in this order on remarkable peaks of spectral densities, and the description is the same in another figures. As shown in Fig.7 and Fig.9, phase differences of S_2 tide, M_2 tide, K_1 tide and O_1 tide between Toyama and Niigata are 12 degrees, 5 degrees, 4degrees, and 2 degrees, respectively. Like this, phase differences of the waves which are directly driven by tide generating force between Toyama and Niigata are smaller as the wave periods become longer. Although phase differences of waves with periods of 230.76 hours and 306.24 hours between Toyama and Niigata are larger than the phase differences of these tides. Therefore, it is considered that the waves with periods of 230.76 hours and 306.24 hours in Toyama and Niigata are different from waves which are directly driven by tide generating force, such as S_2 tide, M_2 tide and so on, and so those waves are proper oscillations.

3.2 Analysis of Tide Levels in Each Season

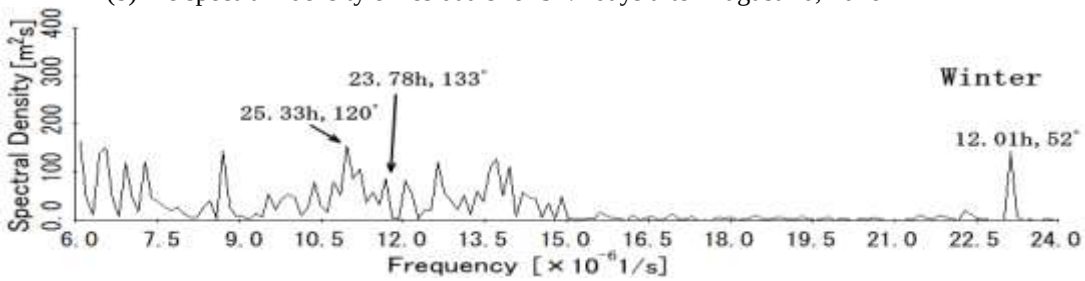
Residuals (O-C) was investigated in each season, using tide levels observed every second at A in Fig.2. In this section, summer, autumn, winter and spring are periods for three months centered on summer solstice, autumnal equinox, winter solstice and vernal equinox, respectively. Spectrum densities of the residuals in each season are shown in Fig.11. The figure shows that periodic water level fluctuation with one day period exists in residuals



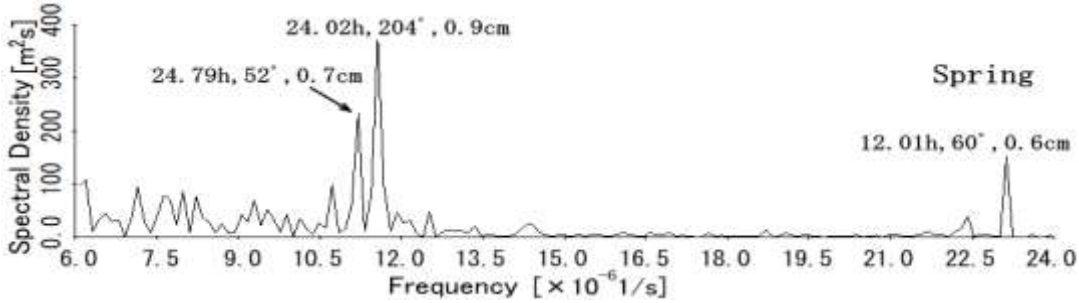
(a)The spectrum density of residuals for 97.1 days after May 10, 2016



(b)The spectrum density of residuals for 97.1 days after August 10, 2016



(c)The spectrum density of residuals for 97.1 days after November 10, 2016



(d)The spectrum density of residuals for 97.1 days after February 10, 2017

Fig.11 Spectrum densities of residuals between observed and calculated tide levels in each season at A of Fig.2

(O-C) in summer, spring and autumn, and the spectral density in spring is the largest. As a result of investigating the fluctuations with one day period in other years, it has become known that there is a tendency that the periodic fluctuations are large in spring and autumn.

Spectral densities of tide levels and residuals (O-C) with one day period in Toyama in each season after May 10, 2016 are shown in Table 1. The table shows that the spectral densities of tide levels with one day period have peaks in winter and summer, although the spectral densities of residuals (O-C) with one day period have peaks in spring and autumn. It shows that the phase of fluctuation of residuals (O-C) with one day period is delayed by three months to the phase of the tide with one day period. However, generating mechanism of the fluctuation of the residuals (O-C) with one day period is unknown.

Table 1 Spectral densities of tide levels and residuals (O-C) with one day period in Toyama in each season

	Spec.Den.(Tide) [m^2・s]	Spec.Den.(Residual) [m^2・s]
Summer	12175	91.96
Autumn	1841	109.97
Winter	13852	31.67
Spring	2780	373.16

3.3 Analysis of Tide Levels for 15 years

Long period waves with periods of one hundred or more days were investigated using tide levels every hour in Toyama and Niigata. Tide levels observed every hour at C of Fig.2 in Niigata for 15 years after January, 2004 and residuals between tide levels shown in Fig.12 and calculated tide levels by tidal constants of Sado are shown in Fig.12 and Fig.13 respectively. Fig.14 shows spectrum densities of the tide levels every hour for about 15 years after January 1, 2004 in Toyama and Niigata, and Fig.15 shows spectrum densities of residuals (O-C) for the same period as Fig.14 in Toyama and Niigata. Fig.14 and Fig.15 show that there is long period wave with period of 321 days in Toyama and Niigata, and although Toyama and Niigata are 200 km or more away from each other, amplitudes and phases of the long period waves which exists in residuals (O-C) in Toyama and Niigata are quite the same each other. Moreover, these figures show that long period waves with period of 420 days exist in residuals (O-C) in Toyama and Niigata, and amplitudes and phases of the long period waves are

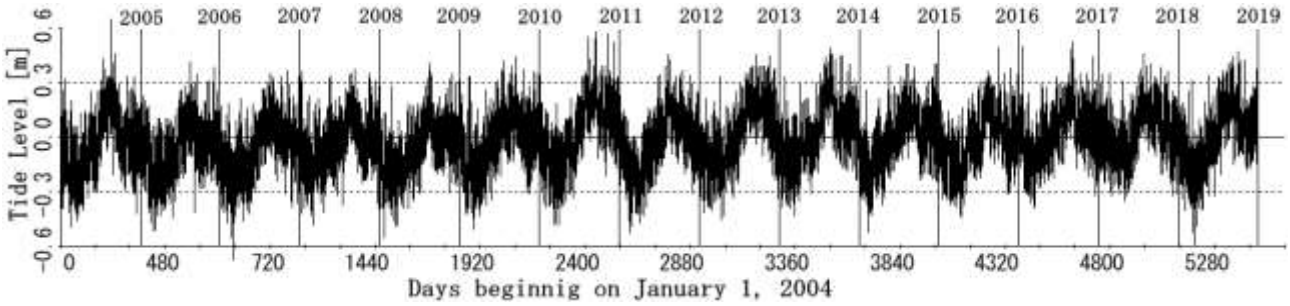


Fig.12 Tide levels observed every hour at C of Fig.2 in Niigata for 15 years after January 1, 2004

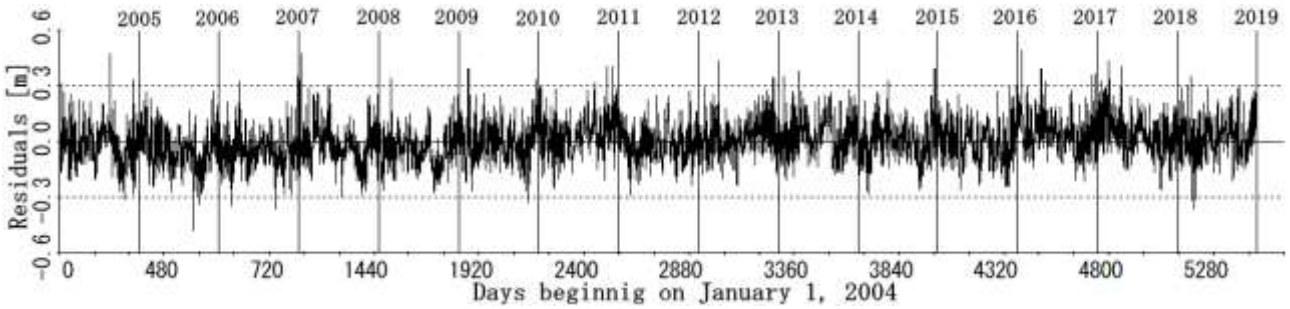
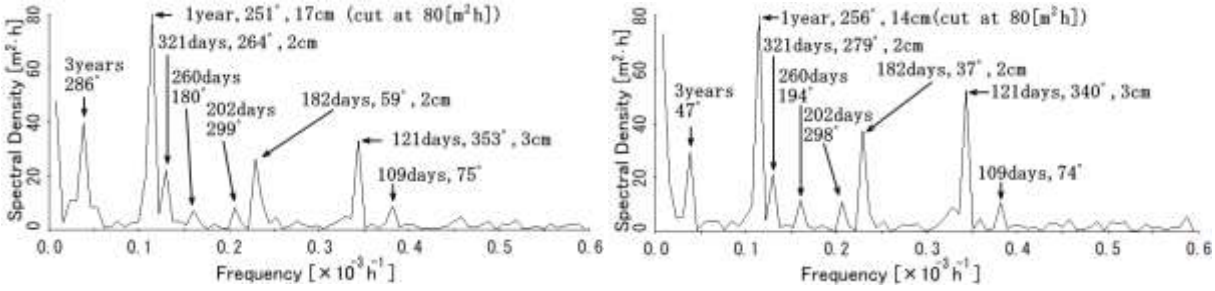
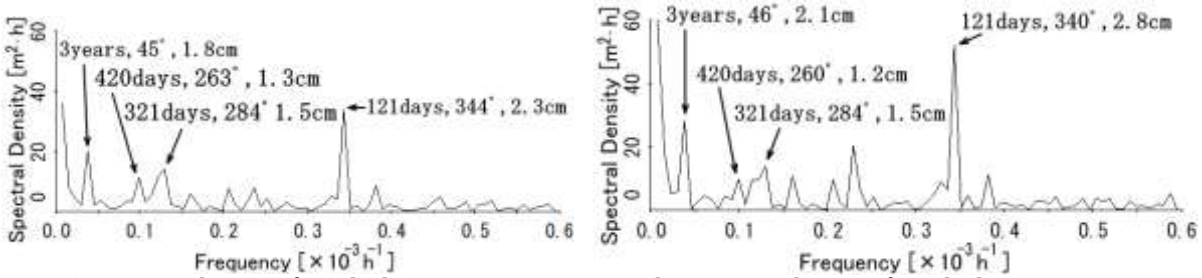


Fig.13 Residuals between tide levels shown in Fig.12 and tide levels calculated by tidal constants of Sado



(a)Spectrum density of tide levels at B in Fig.2 (b)Spectrum density of tide levels at C in Fig.2

Fig.14 Spectrum densities of tide levels observed every hour for about 15 years after Jan. 1, 2004



(a)Spectrum density of residuals at B in Fig.2 (b)Spectrum density of residuals at C in Fig.2

Fig.15 Spectrum densities of residuals (O-C) every hour for about 15 years after Jan. 1, 2004

almost the same each other. Therefore, the waves with periods of 321 days and 420 days are not proper oscillations, and they are not driven by tide generating force.

4. Discussion

The long period waves with period of 321 days and 420 days in Toyama and Niigata are not proper oscillations as shown above, and also there is no tide generating force with period of 321 days or 420 days. Therefore, these waves suggest that earth gravity is fluctuating with periods of 321 days and 420 days. And here, one idea to explain a cause of the Earth's gravity fluctuations is proposed as follows. Tectonic plates are floating on asthenosphere as shown in Fig.16. The earth rotation is braked by tide generating force, and the braking force is larger corresponding to the distance from the earth center. Therefore, there is a possibility that the rotations of tectonic plates and inner earth under asthenosphere are different from each other, in other words, tectonic plates are swaying relatively to the inner earth (1999). As a result, gravity on earth surface fluctuates with periods of 321 days and 420 days.

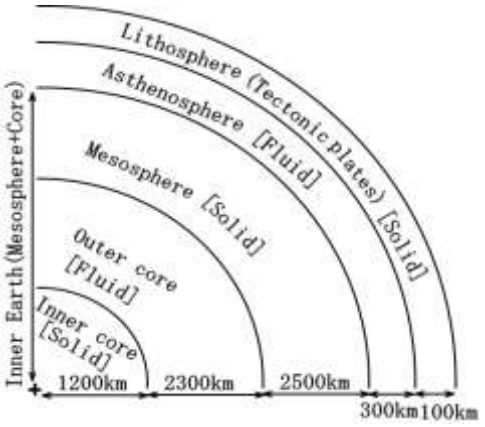


Fig.16 The inner structure of the earth

5. Conclusions

The long period waves which exist in residuals between observed and calculated tide levels (O-C) were investigated using tide levels observed in Toyama and Niigata. The results are as follows.

(1) There are long period waves with periods of 3 years, 121 days and so on, in residuals (O-C), and amplitudes and phases of these waves are different from each other in Toyama and Niigata. The fluctuation range of water level by these waves is equal to or less than plus or minus 0.3 meters.

(2) Water level fluctuation with one day period exists in Toyama, phase of the fluctuation is delayed by three months to the phase of tide with one day period.

(3) There is a wave with period of about 321 days in residuals (O-C), amplitude and phase of the wave in Toyama and Niigata are the same. The amplitude of the wave is 1.5cm and the phase of the wave is 284 degrees.

(4) There is a wave with period of about 420 days in residuals (O-C), amplitudes and phases of the wave in Toyama and Niigata are slightly different from each other. The amplitude of the wave is 1.3 cm in Toyama and

1.2 cm in Niigata and the phase of the wave is 263 degrees in Toyama, 260 degrees in Niigata.

It is considered that the long period waves with periods of 3 years, 121 days, and so on are proper oscillations, because the phases of these waves in Toyama and Niigata are significantly different from each other. Generating mechanism of the water level fluctuation with one day period which exists residuals (O-C) in Toyama is not clear. The waves with period of about 321 days and 420 days which exists in coastal waters of Toyama and Niigata, are generated by fluctuation of the earth gravity. Therefore, the waves suggest that rotations of inner Earth (mesosphere and core) under asthenosphere and tectonic plates are different from each other, and the fluctuation of the Earth's gravity occurs as a result. Further there is a possibility that the wave with the period of about 420 days, which corresponds to chandler period (about 435 days), is driven by the polar motion. It is a future problem to make clear generating mechanisms of the long period waves by investigating in detail on the long period waves such as waves with periods of about 321 days, about 420 days, and so on.

Acknowledgements

The authors wish to thank Hokuriku Regional Development Bureau, MLIT for providing tide level data which were observed at tide station in Toyama and Niigata. Furthermore, we would like to thank Japan Meteorological Agency which opens tidal constants to the public.

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