浜名湖の内部静振

誌名	東海大学紀要. 海洋学部
ISSN	13487620
著者	稲葉, 栄生
巻/号	14号
掲載ページ	p. 1-9
発行年月	1981年1月

J. Fac. Mar. Sci. Technol., Tokai Univ., No. 14, pp. 1—9 (1981)

Internal Seiche in Lake Hamana*

Hideo INABA

Abstract

Lake Hamana shows a complicated topography having a few additional inner bays and /or inlet, and is connected with the open sea through a channel. There is a deep basin at the northern part of the lake. Self-recording current measurements were carried out at two points at the deep area of the northern part of the lake. Fourier series expansions and harmonic analyses were applied to the results of the measurements, in order to find the predominant tidal constituent. From these analyses, it became clear that the dominant tidal constituent is diurnal, although for tide itself the semidiurnal tidal constituent (M_2) is the most dominant. From the predominance of the diurnal tidal current and the existence of the sharp pycnocline, it can be inferred that the tidal current is baroclinic and is corresponding to the internal seiche. The calculated period of the internal seiche of the lake is about 26 hours and this value is very close to the period of the diurnal constituent. Therefore, the predominant amplitude of diurnal tidal current is regarded as the coupling of the internal seiche with the diurnal tide for water surface elevation.

1. Introduction

Lake Hamana is one of the most large brackish lake in Japan and the shape of the lake is very complicated. The lake consists of the main lake and a few additional inner lakes and/or bays, *i. e.*, Inasa-hosoe, Inohana-ko, Hamana Port, etc, and opens the mouth to Enshu-nada through the channel of Imakire-guchi, having about 200 m width and 10 m depth. The depth of the southern part of the lake is shallower than about 5 m except the channel of Imakire-guchi. During the low water, the bottom at some areas of the southern part of the lake appears and narrow water-ways, so-called "Miosuji", are formed. The depth of the northern part of the lake is rather deep and the greatest depth of the lake is about 12 m. There is a wide deep area, deeper than 5 m in the northern part of the main lake, and the mouth of inlet Inasa-hosoe has a rather wide mouth (about 1500 m), but another inlet at the northern half of Lake Hamana, Inohana-ko, has a very narrow mouth. Several rivers flow into the northern part of Lake Hamana bringing plenty of fresh water into the lake. Saline water, on the other hand, intrude into the northern part of the lake accompanied with the tidal flush. Because of the influences of a) fresh water, b) saline water and c)

* Contribution A No. 169 from the Faculty of Marine Science and Technology, Tokai University. Accepted September 24, 1980.

warming and cooling of the lake water, the condition of the lake shows apparent seasonal variation. In warm season the dominant pycnocline are found in the northern part of Lake Hamana.

The data on Lake Hamana have been gathered by Shizuoka Prefectural Fisheries Experiment Station, Hamana-ko Branch, and used in the studies of Lake Hamana. AI (1968) investigated the general feature of water chlorinity at Lake Hamana. UNOKI (1974) studied the exchange and vertical mixing in Lake Hamana. UEMURA and FUSHIMI (1979) studied the general feature of water temperature and its seasonal characteristcs. NONAKA *et al.* (1973) analysed the results of direct current measurements at the Hamana Port mainly. MAZDA (unpublished paper) carried out detailed investigation of the condition of Lake Hamana. No results on the current measurement in Lake Hamana has ever been reported.

It is well known that a internal seiche occurred in layered lakes and relatively closed bays, and have been discovered in many lakes all over the world (*e. g.*, DEFANT, 1961) as well as in Japan, *i. e.*, Lake Biwa (KANARI, 1974).

The author carried out self-recording current measurements at several points of Lake Hamana in warm season and cool season. The internal seiche with diurnal tidal frequency was discovered in warm season in deep area of the northern part of Lake Hamana. Internal seiche is discussed in this paper on the basis of the results of surface current measurements.

2. Method of measurements and data processings

The two stations of the current measurements (Stns. A and B) were set up at the deep area of northern part of Lake Hamana. Stn. A is at the deepest point of the basin of the main lake, and Stn. B is at the mouth of inlet Inasa-hosoe as illustrated in Fig. 1. The measurements with self-recording current meters were carried out at the surface layer (1 m below the surface) of the two stations. The period and the duration of measurements were different for two stations. The measurements at Stn. A and Stn. B were carried out from August 20 to September 7, 1979 and from September 7 to 15, 1979 respectively. The period of the measurements was so short for the harmonic analysis of tidal current associated with 4 major tidal constituents,

An NC type current meter manufactured by Kyowa-shoko Co. Ltd. was used for the present investigations. The longest continuous recording time for this instrument is restricted to approximatly one month. The currentmeter registers the average speed over 3 minute intervals and instantaneous direction every 20 minutes. The E-Wward and N-Sward components of current velocities were computed from the records of speed and direction every 20 minutes. Mean values of three consecutive measurements centering on every hour were considered to represent the hourly values of current velocities and were used in the following analysis.

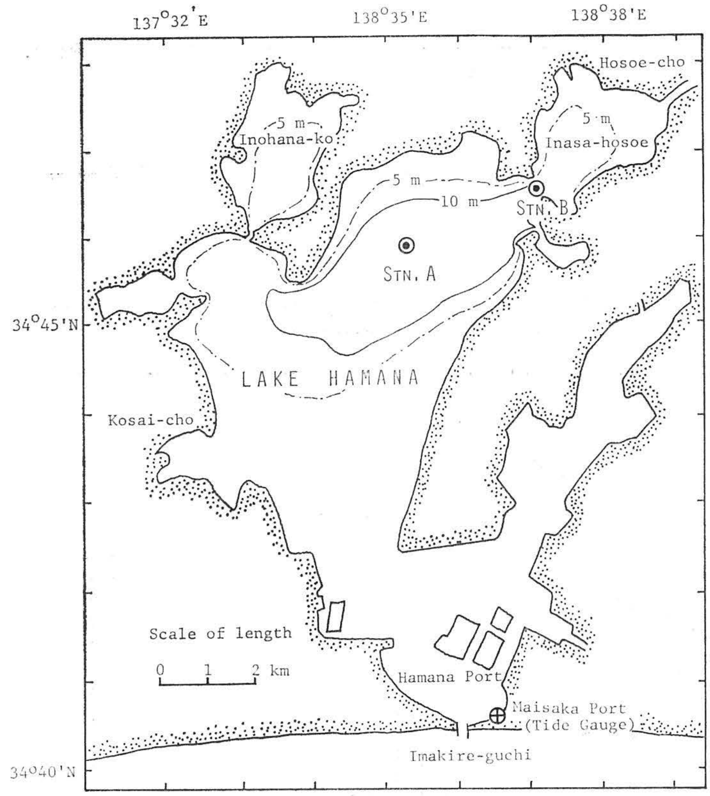

Fig. 1. Location of current measurement stations and topography of Lake Hamana.

3. Results of current measurements

a) Time series of hourly current at two stations

The time series of hourly eastward and northward components from August 20 to September 7, 1979 at Stn. A are shown in Fig. 2. It can be seen that the current values, generally, are rather small (smaller than about 10 cm/cec) but the spike like and sine curve like large values are found in the time series at about one day interval. The amplitudes of semidiurnal tidal current for both the eastward and northward components do not predominate throughout the whole period at Stn. A although the semidiurnal tidal constituent predominates at Maisaka Port.

The time series of hourly current from September 7 to 15, 1979 at Stn. B are shown in Fig. 3. It can be seen that the eastward components of the diurnal tidal current predominates remarkably throughout the whole period accompaning with a weak semidiurnal tidal current as well as low and high frequency variations.

b) Relative frequency distributions of current speeds and directions

The relative frequency distributions of the current speeds at Stn. A and Stn. B are shown in Fig. 4. With regard to Stn. A, the current with the speed from 0 cm/sec to 10 cm/sec are very predominant having the percentage of about 70%. It is noticeable that the

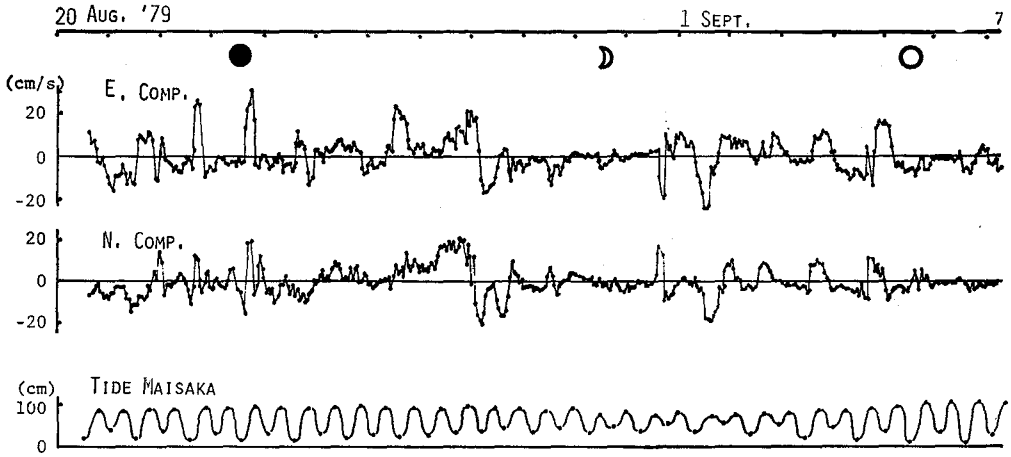

Fig. 2. Time series of eastward and northward components of current at Stn. A from Aug. 20 to Sept. 7, 1979.

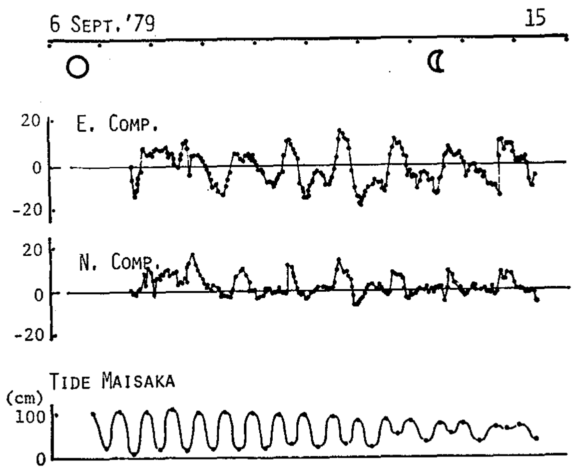

Fig. 3. Time series of eastward and northward components of current at Stn. B from Sept. 6 to 15, 1979.

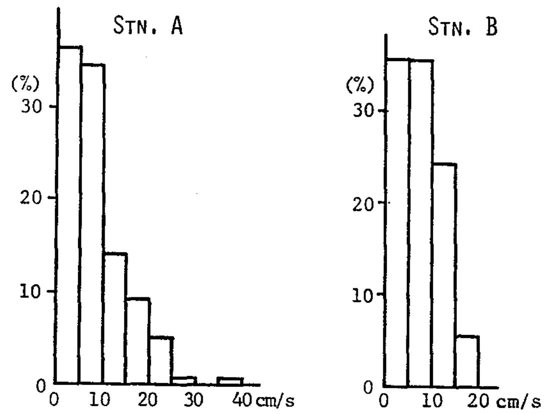

Fig. 4. Relative frequency distribution of current speeds at Stns. A and B.

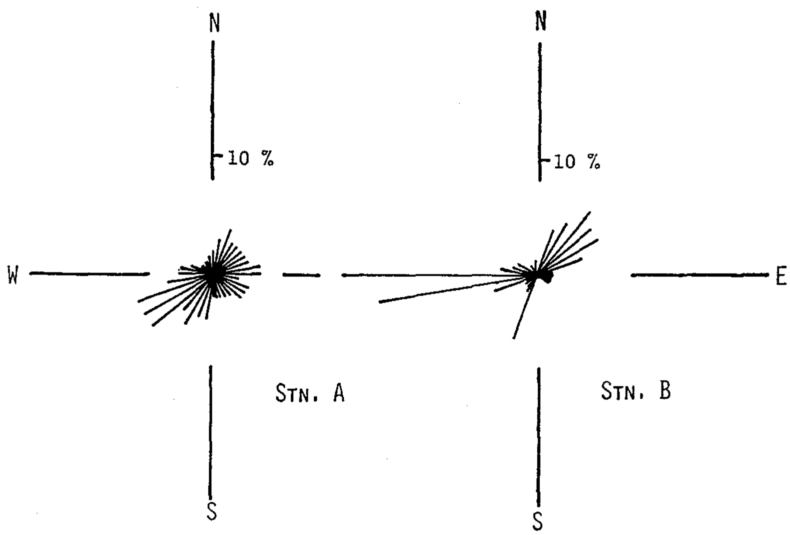

Fig. 5. Relative frequency distribution of current directions at Stn. A and Stn. B.

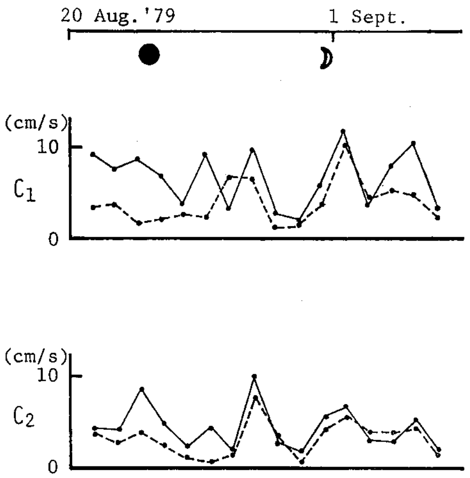

Fig. 6. Amplitudes of diurnal (C_1) and semidiurnal (C_2) tidal currents at Stn. A ; with full lines denoting eastward component and dash lines denoting the northward component.

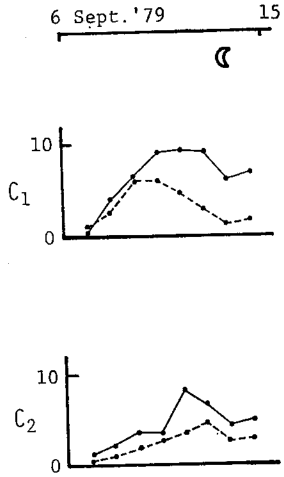

Fig. 7. Amplitudes of diurnal (C_1) and semidiurnal (C_2) tidal currents at Stn. B ; with full lines denoting eastward component and dash lines denoting the northward component.

values from 30 cm/sec to 35 cm/sec were not found, while the values from 35 cm/sec to 40 cm/sec were found in this histogram. With regard to Stn. B, the current speed from 0 cm/sec to 10 cm/sec are very predominant and its percentage reaches to 70% similar to Stn. A, but the jumping distribution of the histogram as seen at Stn. A is not found in this figure.

Relative frequency distributions of the current directions at Stn. A and Stn. B are shown in Fig. 5. It can be seen that the current directions at the both stations are under the strong influence of the topography of the lake. Therefore, they are parallel to the mid-line of the lake, *i. e.*, NE and SW are predominant.

4. Tidal current

a) Expansion of current variations in Fourier series

In order to know the short-term variations, the expansion in Fourier series is carried out for eastward and northward components of the current for successive 25-hour period, after taking off the trend by calculating the deviations from 25-hour running mean of the time series.

The Fourier series expansion can be expressed by the following formula

$$F=C_0+C_1\cos(\sigma t+\varphi_1)+C_2\cos(2\sigma t+\varphi_2)+\cdots\cdots\cdots \quad (1)$$

where σ stands for 2π/25-hour. The diurnal amplitude (C_1) and the semidiurnal amplitude (C_2) at Stn. A and Stn. B are shown in Fig. 6 and Fig. 7, respectively. The diurnal constituent of the current is predominant throughout the whole period associated with fluctuations of a few days, but is invariant with the age of the moon, *i. e.*, at the spring tide after newmoon (Aug. 20, 1979) the amplitude (C_1) does not become quite large. The amplitude

Table 1. Harmonic constants of 4 major tidal constituents of current at Stn. A and Stn. B. (unit : cm/s)

Stations	Stn. A		Stn. B	
Components	E	N	E	N
Constituents M_2	0.5	1.5	3.4	1.2
S_2	1.5	1.0	2.1	1.5
K_1	3.9	1.8	4.4	2.0
O_1	0.9	0.6	4.0	0.8

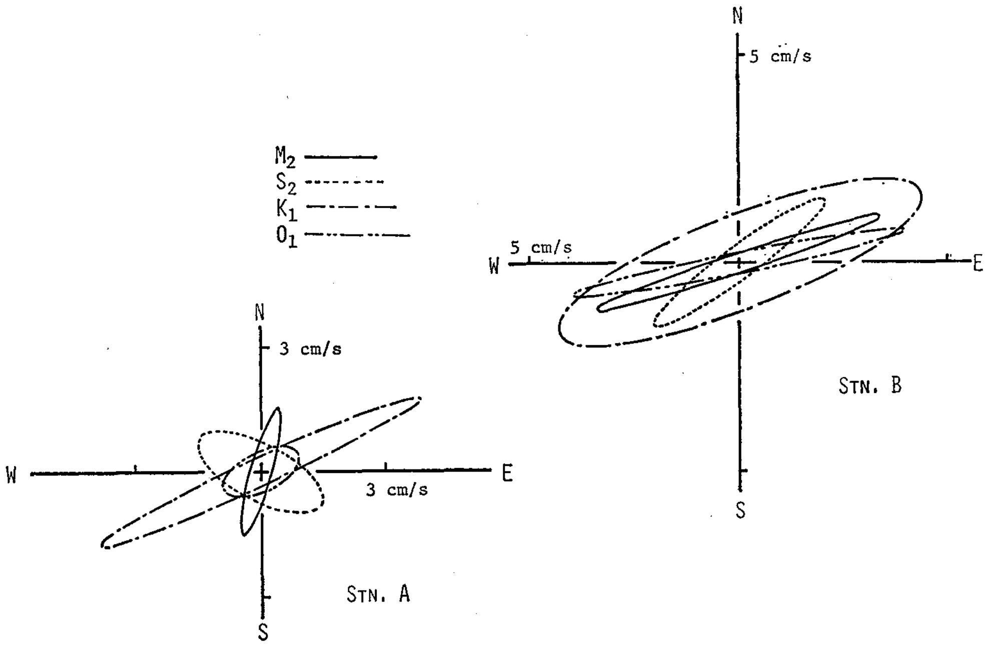

Fig. 8. Tidal ellipses of 4 major tidal constituents at Stn. A and Stn. B.

of semidiurnal constituent (C_2) of current is rather small compared with that of the diurnal (C_1) and does not change with the age of the moon.

b) Harmonic constants of tidal current associated with 4 major tidal constituents.

In order to eliminate the long-term trend, deviations from 25-hour running mean have been calculated from the hourly values of the current velocities for eastward and northward components separately. Then the harmonic constants of tidal current associated with the M_2, S_2, K_1 and O_1 tidal constituents are calculated by means of the least square method. The harmonic constants of the tidal current are shown in Table 1. With regard to the amplitudes of the tidal current, it should be noted that the K_1 constituents predominate at Stn. A and Stn. B, although the largest amplitude of tidal constituent at Maisaka Port is M_2.

c) Tidal ellipses at Stn. A and Stn. B

Tidal ellipses are very usefull to study the behavior of tidal current. The tidal ellipses corresponding to the 4 major tidal constituents at Stn. A and Stn. B are shown in Fig. 8.

It can easily be seen that the K_1 tidal ellipses are relatively flat under the influence of coast line of the lake and the major axes of the tidal ellipses are in almost the same directions.

5. Discussion

The dominant constituent of the tidal current is diurnal, although for the tide itself the M_2 constituent is the most dominant for water surface elevation. The dominant pycnocline is found in the northern part of the lake at the warm season (AI, 1968 ; UEMURA and FUSHIMI, 1980 ; MAZDA, unpublished paper). From the predominance of the diurnal current and the existence of the sharp pycnocline, it can be inferred that the tidal current is baroclinic and is corresponding to the internal seiche.

The period of the internal seiche at a lake or a closed bay is given by PROUDMAN (1960)

$$T=2L\sqrt{\frac{\rho}{g(\rho-\rho')}\frac{h+h'}{hh'}} \tag{2}$$

where L is the length of the bay or the lake, ρ' and ρ are the density of the upper and lower layers, h and h' are the width of upper and lower layers. The value of L, in this case, can be assumed to be the distance from the coast line at Kosai-cho (western portion in the inner part of the lake) to the coast line at Hosoe-cho (north-eastern portion in the inner part of the lake), and is 11. 25 km. The station A is near the node considering the internal seiche of fondamental mode and the coast at Kosai-cho and Hosoe-cho are near the loops (Fig. 9). The values of ρ' & ρ and h' & h are estimated from the temperature and salinity measurement near the stations during the warm season (MAZDA, personal communication). These values are shown in Table 2. The period of the internal seiche calculated from the formula (2) are about 26-hour, the calculated period are very close to the period of the diurnal constituent. Predominance of the diurnal tidal current may be account for the coupling of the internal seiche with the diurnal tide for water surface elevation.

6. Conclusion

Self-recording current measurements were carried out at the deep area of the northern part of Lake Hamana. A Fourier series expansion and harmonic analyses were applied to the results of the measurements, in order to see the predominant tidal constituent. From these analyses the dominant constituent of the tidal current is diurnal constituent, although for the tide itself the semidiurnal constituent, M_2, is the most dominant. The dominant pycnocline are found in northern part of Lake Hamana during warm season and it is well known that an internal seiche could frequently happen in a layered lake. The calculated period of the internal seiche at the lake are about 26 hours and the period are very closed to the period of the diurnal. The predominant amplitude of the diurnal tidal current are regarded as the coupling of the internal seiche with the diurnal tide for water surface elevation.

Table 2. The values associated with internal seiche.

L	11.25 km
ρ'	1.0172 g/cm^3
ρ	1.0198 g/cm^3
H'	3.5 m
H	5.2 m

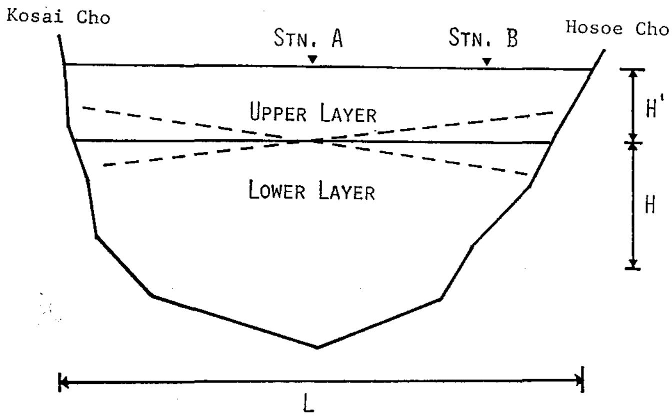

Fig. 9. Schematical explanation of an internal seiche.

Acknowledgements

The author wishes to express his hearty thanks to the staffs of the Preservational Section of Air and the Prevention Center of Pollution, Shizuoka Prefectural Office, for their financial halp. He is also obliged to Dr. A. Y. TAKENOUTI, Professor of Tokai University, for his valuable discussions, to Dr. S. OKABE, Professor of Tokai University, for his encouragement and, to Mr. Y. MAZDA, Assistant Professor of Tokai University, for his valuable discussions on the present investigation. He is very grateful to the staffs of the Fishermen's Cooperative Association of Hamanako and to his students, who were engaged in the field work of deploying and recovering the moored instrumentation buoys.

REFERENCES

AI, T. (1968) : On the water conditions of Lake-Hamana, with special reference to the chlorinity (in Japanese). Jap. Res. Group Fish. Eng., **5**(1), 37—41.

DEFANT, A. (1961) : Internal waves. *in* Physical Oceanography, **2**, Pergamon Press, Oxford, 517—570.

INABA, H. (1981) : Mean and tidal period variation of surface current in the inner part of Suruga Bay. J. Oceanogr. Soc. Japan, (in press).

KANARI, S. (1974) : Some result of observation of the long period internal seiche in Lake Biwa. Jap. J. Limnol., **35**(4), 136—147.

NONAKA, M., T. MURAMATSU and T. HIRAI (1973) : Effects of the dredging operation for development of fishing-ground in Lake HAMANA-KO (in Japanese). Jap. Res. Group Fish. Eng., **10**(1), 47—51.

PROUDMAN, J. (1953) : Internal seiches, tides and waves. *in* Dynamical Oceanography, Methuen & Co. Ltd., London, 333—368.

UEMURA, N. and H. FUSHIMI (1979) : Oceanographycal studies on Lake Hamanako—1. Description of general features of water temperature and its characteristics (in Japanese). Bull. Shizuoka Pref. Fish. Exp. Stn., (13), 21—41.

UNOKI, S. (1974) : A note on the exchange of sea water and vertical mixing in estuaries (in Japanese). Bull. Coastal Oceanogr., **11** (2), 85—95.

浜名湖の内部静振

稲 葉 栄 生

要　旨

浜名湖は内湖や入江が付随し複雑な形状をした塩水湖であり，南側の導水路によって遠州灘へと通じている．浜名湖の北部には海盆状の深い海域が存在するが，ここで自記測流を実施した．

測得流は概して微弱であるが，その中にスパイク状の強い流れがみられる．調和解析結果をみると，潮流の卓越成分は１日周潮である．一方潮位の卓越分潮は半日周潮であり，潮位と潮流の卓越成分が異なる事が判明した．

暖候期の浜名湖北部には，顕著な密度躍層が形成される．そこで水温塩分の測定結果を用いて，浜名湖北部における内部静振周期を計算すると，約26時間の値が得られる．この値は１日周潮周期に非常に近く，したがって測得流の１日周潮流の卓越は，１日周潮と共振した内部静振によるものと結論される．