Contributions, Geophysical Institute, Kyoto University, No. 12, 1972, 101～115

SECULAR CHANGE OF GRAVITY NEAR LAKE BIWA-KO

By

Mikio SATOMURA and Ichiro NAKAGAWA

(Received September 16, 1972)

Abstract

Gravity measurements have repeatedly been carried out several times in the area around Lake Biwa-ko since 1950 in order to detect, if possible, secular change of gravity. Results obtained by means of LaCoste & Romberg gravimeters in 1964, 1967, 1970 and 1971 show that gravity value has been increasing by about 0.1 mgal during recent several years on both shores of the southern part of the Lake Biwa-ko. Results obtained by levelling surveys in the region concerned show the similar tendency as those by the gravity measurements.

1. Introduction

The development of portable gravimeter of the spring type enables gravity measurements to be easily, rapidly and accurately carried out, and investigation on whether the secular change of gravity can be detectable or not has recently been made in many regions of the world (*e. g.* Honkasalo [1971]). In the Kinki District, gravity measurements have repeatedly been carried out several times since 1950, and gravity change amounting to 0.1～0.3 mgal had been observed by means of a North American gravimeter during the period of 1950～1953 (Ichinohe [1955]), and that amounting to 0.3～0.6 mgal had also been observed by means of both North American and Worden gravimeters during the period of 1952～1962 (Ichinohe, Nakagawa and Sumitomo [1963]). Both results show that the gravity value increased on both shores of the southern part of Lake Biwa-ko during the periods concerned. The amounts are far beyond what can be explained by the subsidence of ground or the change of underground water level. From the tectonic point of view, this area is situated in a region of extremely negative Bouguer anomaly, and it is, furthermore, considered to be in an isostatically unstable state. It is naturally speculated that, in such an unstable region, subterranean substances may change their distribution to recover a stable state (Ichinohe, Nakagawa and Sumitomo [1963]).

In 1956, the Geographical Survey Institute [1965] carried out a gravity survey by means of a North American gravimeter at the first order bench marks distributed in the Kinki District. Thereafter, gravity measurements in the region of Lake Biwa-ko were carried out four times by using LaCoste & Romberg gravimeters in 1964, 1967, 1970 (measurements at Yōno and Nakanogō were made in 1969) and 1971.

Using the results obtained through the recent four gravity measurements, secular change of gravity near the Lake Biwa-ko is discussed in the present article.

2. Location of Stations and Method of Measurements

Gravity measurements before 1953, in 1956 and after 1964 were carried out referring to the Primary Reference Station of Gravity (UL), the National Fundamental Station of Gravity (FS) and the Gravity Station of Geophysical Institute, Kyoto University (GI), respectively. As the gravity measurements among these three reference stations were carried out repeatedly, the gravity differences are precisely determined (Nakagawa *et al.* [1970]).

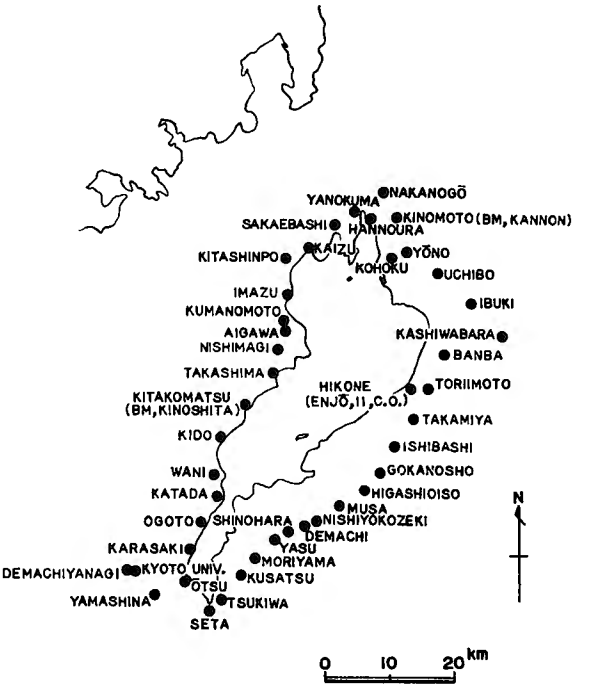

Fig. 1. Locations of the stations.

Location of the observation stations is shown in Fig. 1, and their details are shown in both Table 1 and Note.

One-way measurement was adopted before 1967, but back and forth measurement was adopted after 1970 in order to determine gravity values at the observation stations as accurately as possible.

3. Results of Measurements

Data obtained through the gravity measurements were corrected for closure errors at Ōtsu, and the results are shown in Table 2. But the data obtained in 1971 were not corrected for closure errors because all the observation stations were directly

Table 1. Description of the stations

	Latitude	Longitude	Height	Gravity value	Free air anomaly*	Bouguer anomaly*
	° ,N	° ,E	m	gal	mgal	mgal
Kyoto Univ. (UL)	35 01.6	135 47.1	54.98	979.7230	− 7.9	−14.0
Kyoto Univ. (FS)	35 01.7	135 47.2	60.82	7211	− 8.1	−14.9
Kyoto Univ. (GI)	35 01.7	135 47.2	59.86	7216	− 7.9	−14.6
Demachiyanagi	35 01.6	135 46.4	53.66	7258	− 5.4	−11.4
Yamashina	34 59.3	135 49.4	62.85	7180	− 7.2	−14.2
Ōtsu	35 00.1	135 52.4	90.58	7033	−14.4	−24.5
Seta	34 58.2	135 54.5	89.	7036	−11.9	−21.9
Tsukiwa	34 59.2	135 56.6	109.62	6999	−10.7	−23.0
Kusatsu	35 00.8	135 57.7	97.	7001	−16.7	−27.5
Moriyama	35 02.7	135 59.2	97.22	7017	−17.7	−28.5
Yasu	35 03.6	136 01.4	99.36	7013	−18.6	−29.7
Shinohara	35 04.6	136 03.6	103.	7037	−16.5	−28.0
Demachi	35 05.0	136 04.8	114.	7033	−14.2	−26.9
Nishiyokozeki	35 05.6	136 05.9	100.	7024	−20.2	−31.4
Musa	35 06.7	136 08.0	100.48	7042	−19.9	−31.1
Higashioiso	35 07.8	136 10.0	103.	7026	−22.2	−33.7
Gokanoshō	35 09.2	136 12.0	108.	6957	−29.5	−41.6
Ishibashi	35 11.0	136 13.3	99.88	6998	−30.5	−41.6
Takamiya	35 13.8	136 15.5	104.61	7087	−24.1	−35.8
Hikone (Enjō)	35 16.4	136 15.6	95.	7175	−22.0	−32.6
Hikone (Ii)	35 16.4	136 15.6	95.	7172	−22.3	−32.9
Hikone (CO)	35 16.2	136 15.3	95.	7144	−24.7	−35.3
Toriimoto	35 16.5	136 17.1	102.80	7184	−18.8	−30.3
Banba	35 18.8	136 19.2	114.79	7218	−15.0	−27.8
Kashiwabara	35 20.5	136 24.5	177.	7124	− 7.5	−27.3
Ibuki	35 22.9	136 22.8	180.	7177	− 4.7	−24.9
Uchibo	35 25.6	136 17.9	113.	7293	−17.6	−30.2
Kohoku	35 26.7	136 14.9	99.	7276	−25.2	−36.3
Yōno	35 27.2	136 15.8	101.21	7330	−19.8	−31.1
Kinomoto (Kannon)	35 30.1	136 13.7	120.	7281	−23.1	−36.5
Kinomoto (BM)	35 30.5	136 13.4	121.68	7285	−22.7	−36.3
Nakanogō	35 32.5	136 12.5	147.50	7314	−14.7	−31.2
Hannoura	35 30.0	136 11.4	140.	7271	−17.8	−33.4
Yanokuma	35 30.7	136 09.1	105.	7171	−39.5	−51.2
Sakaebashi	35 30.1	136 08.1	90.	7249	−35.5	−45.5
Kaizu	35 27.6	136 04.6	90.	7222	−34.6	−44.7
Kitashinpo	35 26.7	136 02.2	105.	7183	−32.7	−44.4
Imazu	35 23.8	136 02.4	87.31	7183	−34.0	−43.8
Kumanomoto	35 21.4	136 02.0	93.	7148	−32.3	−42.7
Aigawa	35 20.7	136 01.9	96.84	7129	−32.1	−42.9
Nishimagi	35 19.6	136 01.7	91.25	7103	−35.8	−46.0
Takashima	35 17.7	136 01.0	87.02	7036	−40.2	−49.9
Kitakomatsu (BM)	35 14.8	135 58.4	91.	7059	−32.5	−42.6
Kitakomatsu (Kinoshita)	35 14.8	135 58.4	91.	7061	−32.3	−42.5
Kido	35 11.8	135 55.4	104.55	6996	−30.4	−42.1
Wani	35 09.1	135 55.4	95.58	7002	−28.7	−39.4
Katada	35 07.3	135 55.2	87.88	7004	−28.4	−38.2
Ogoto	35 05.3	135 53.8	87.41	6977	−28.4	−38.1
Karasaki	35 02.7	135 52.6	87.	6958	−26.7	−36.5

* The International Gravity Formula (1930) was used in calculation.

Table 2. Results of gravity measurements

Period of measurements	Dec. 1950	Dec. 1951 ~ Jan. 1952	Nov.~Dec. 1952	Dec. 1953	July 1956	Nov. 1964	Apr. 1967	Sept. 1970	Sept.~Oct. 1971
Gravimeter used	North American AG–108	North American AG–108	North American AG–108	North American AG–108	North American AG–133	LaCoste G–83	LaCoste G–29	LaCoste G–83	LaCoste G–196
	gal	gal	gal	gal	gal	gal	gal	gal	gal
	979.	979.	979.	979.	979.	979.	979.	979.	979.
Kyoto Univ. (UL)	7230	7230	7230	7230					
Kyoto Univ. (FS)	7208		7210	7208	72112				
Kyoto Univ. (GI)						721583	721583	72158	721583
Demachiyanagi	7256	7255	7255	7255					725816
Yamashina	7177	7179	7178	7176	71812	717998	717974		
Ōtsu	7031		7032	7032	70341	703323	703301		703337
Seta	7036	7037	7037	7036	70385	703561	703563		703638
Tsukiwa					70005	699810	699828		699876
Kusatsu	6998	7002	7000	7000	69979	700003	700021		700082
Moriyama					70178	701564	701582	70169	701691
Yasu	7012	7014	7012	7014	70147	701248	701227	70136	701339
Shinohara	7037	7038	7036	7037		703674	703688		703745
Demachi					70344	703169	703186	70330	703260
Nishiyokozeki						702235	702322		702360
Musa	7040	7042	7040	7041	70431	704062	704081	70417	704153
Higashioiso						702549	702553		702587
Gokanoshō					69599	695663	695539		695735
Ishibashi	6998	6999	6998	6997	70000	699804	699809		
Takamiya	7086	7088	7085	7086	70891	708697	708711	70875	708720
Hikone (Enjō)	7172	7173	7172	7171		717404	717436		717454
Hikone (Ii)							717122		717156
Hikone (CO)	7142		7142	7142		714427	714449		
Toriimoto					71854	718313	718289	71847	718401
Banba						721795	721770	72186	721777
Kashiwabara						712393	712454		712448
Ibuki						717676	717674		
Uchibo						729328	729356		729345
Kohoku						727513	727538		727562
Yōno					73296		732961	73305*	733015

Kinomoto (Kannon)							728055		728074
Kinomoto (BM)					72847	728377	728430		728450
Nakanogō					73143		731385	73149*	731395
Hannoura						726986	727028		727057
Yanokuma						717064			717119
Sakaebashi					72501	724937	724915		724940
Kaizu					72210	722173	722197		722221
Kitashinpo						718408	718247		718280
Imazu	7180		7182		71820	718231	718222	71829	718295
Kumanomoto	7146		7147			714654	714687		714796
Aigawa					71285	712810	712845	71291	712899
Nishimagi					71032		710273	71034	710311
Takashima	7034		7036		70357	703454	703509	70362	703557
Kitakomatsu (BM)						705868	705878	70595	705942
Kitakomatsu (Kinoshita)	7059		7061			705988	705995		706064
Kido	6994		6996			699529	699541	69965	699604
Wani	7002		7003		70019	700125	700156	70026	700226
Katada	7004		7005		70027	700278	700289	70040	700389
Ogoto			6976			697651	697611	69770	697710
Karasaki			6960			695670	695712		695798

* Measurements at Yōno and Nakanogō were made in August 1969.

Table 3. Apparent change of gravity (unit: μgal)

	1967–1964	1970–1964	1970–1967	1971–1964	1971–1967	1971–1970
Kyoto Univ. (GI)	0	0	0	0	0	0
Yamashina	− 24					
Ōtsu	− 22			+ 14	+ 36	
Seta	+ 2			+ 77	+ 75	
Tsukiwa	+ 18			+ 66	+ 48	
Kusatsu	+ 18			+ 79	+ 61	
Moriyama	+ 18	+126	+108	+127	+109	+ 1
Yasu	− 21	+112	+133	+ 91	+112	−21
Shinohara	+ 14					
Demachi	+ 17	+131	+114	+ 91	+ 74	−40
Nishiyokozeki	+ 87			+125	+ 38	
Musa	+ 19	+108	+ 89	+ 91	+ 72	−17
Higashioiso	+ 4			+ 38	+ 34	
Gokanoshō	−124			+ 72	+196	
Ishibashi	+ 5					
Takamiya	+ 14	+ 53	+ 39	+ 23	+ 9	−30
Hikone (Enjō)	+ 32			+ 50	+ 18	
Hikone (Ii)					+ 34	
Hikone (CO)	+ 22					
Toriimoto	− 24	+157	+181	+ 88	+112	−69
Banba	− 25	+ 65	+ 90	− 18	+ 7	−83
Kashiwabara	+ 61			+ 55	− 6	
Ibuki	− 2					
Uchibo	+ 28			+ 17	− 11	
Kohoku	+ 25			+ 49	+ 24	
Yōno			+ 89		+ 54	−35
Kinomoto (Kannon)					+ 19	
Kinomoto (BM)					+ 20	
Nakanogō			+105		+ 10	−95
Hannoura	+ 42			+ 71	+ 29	
Yanokuma				+ 55		
Sakaebashi	− 22			+ 3	+ 25	
Kaizu	+ 24			+ 48	+ 24	
Kitashinpo	−161			−128	+ 33	
Imazu	− 9	+ 59	+ 68	+ 64	+ 73	+ 5
Kumanomoto	+ 33					
Aigawa	+ 35	+100	+ 65	+ 89	+ 54	−11
Nishimagi					+ 38	
Takashima	+ 55	+166	+111	+103	+ 48	−63
Kitakomatsu (BM)	+ 10	+ 82	+ 72	+ 74	+ 64	− 8
Kitakomatsu (Kinoshita)	+ 7			+ 76	+ 69	
Kido	+ 12	+121	+109	+ 75	+ 63	−46
Wani	+ 31	+135	+104	+101	+ 70	−34
Katada	+ 11	+122	+111	+111	+100	−11
Ogoto	− 40	+ 49	+ 89	+ 59	+ 99	+10
Karasaki	+ 42			+128	+ 86	

connected with the base station (GI). The values shown in Table 2 were obtained by taking the gravity values at UL, FS and GI as 979.7230 gal, 979.72112 gal and 979.721583 gal, respectively.

4. Consideration

Higher accuracy with more than 0.05 mgal is essential in gravity measurements in order to investigate the secular change of gravity. Generally speaking, it is thought that either the measuring accuracy of the North American gravimeter or that of the Worden gravimeter is less than that of the LaCoste & Romberg gravimeter. Only the results obtained by LaCoste & Romberg gravimeters are, therefore, used in the present purpose. Apparent changes of gravity obtained through recent four successive measurements by means of LaCoste & Romberg gravimeters are shown in Table 3 and also in Figs. 2 and 3. All values of gravity are referred to that at the Gravity Station of Geophysical Institute, Kyoto University (GI), and the gravity value at the GI was assumed to have suffered no change during the period concerned.

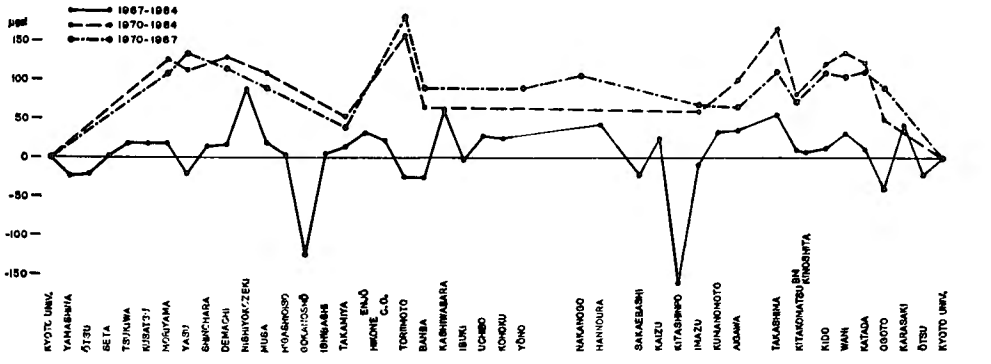

Fig. 2. Gravity change obtained by gravity measurements.

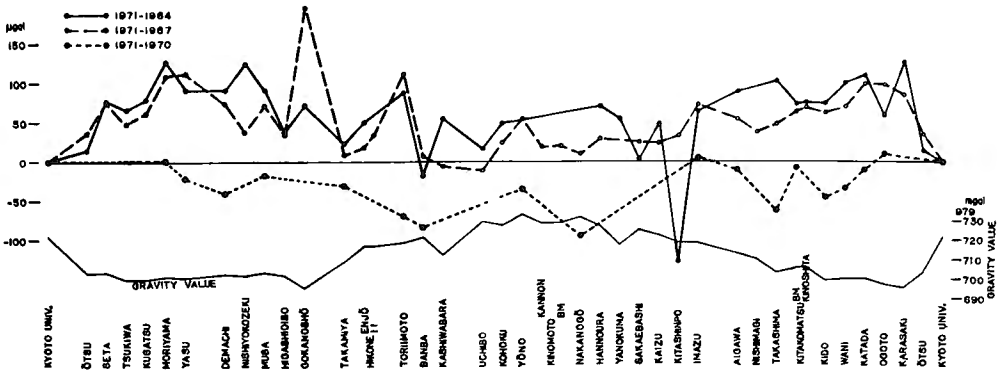

Fig. 3. Gravity change obtained by gravity measurements. Scale factor given by the maker was adopted in calculation.

Gravity changes at Gokanoshō and Kitashinpo are abnormal in the period between 1964 and 1967, as shown in Fig. 2. A similar tendency is also found, as shown in Fig. 3, for the apparent change of gravity at Gokanoshō between 1967 and 1971 and that at Kitashinpo between 1964 and 1971, but the cause is not clear. It is naturally presumed that the measuring value of 1967 at Gokanoshō is too small and that of 1964 at Kitashinpo is too large for a certain reason. The gravity increase amounting to 0.087 mgal at Nishiyokozeki is predominant except for both stations of Gokanoshō and Kitashinpo, and, in general, the gravity value has increased about 0.02 mgal during the period of 1964~1967. A measuring accuracy by a single LaCoste & Romberg gravimeter is confirmed to be 0.02~0.03 mgal in field gravity measurements (*e. g.* Nakagawa [1971]), and so there is no significant change during the period between 1964 and 1967.

During the periods of both 1964~1970 and 1967~1970, the gravity values increased more than 0.1 mgal at almost all of the comparable stations. If the results obtained are assumed to be true, the gravity value increased all over the area around the Lake Biwa-ko during the period between 1967 and 1970.

Gravity change in the period between 1964 and 1971 and that between 1967 and 1971 are similar with each other except for both stations of Gokanoshō and Kitashinpo, as shown in Fig. 3. The common characteristic for these two periods is that gravity values increase in small quantities in the northern part of Lake Biwa-ko, but they increase about 0.1 mgal on both shores of the southern part of the Lake. Gravity change at Toriimoto shown in Fig. 3 is thought to be caused by change of the measuring point. Comparing gravity values of 1970 with those of 1971, there is no significant change in the southern part of the Lake, but the gravity value decreases about 0.05~0.1 mgal in the northern part.

Apparent gravity change obtained at each typical station is shown in Fig. 4. As can be easily seen from the Fig. 4, measuring values of 1970 are similarly large

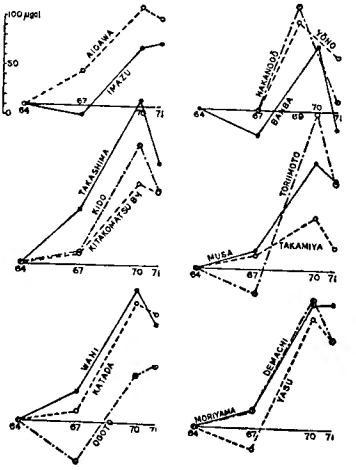

Fig. 4. Gravity change obtained at each station.

comparing with others, and both the values of 1964 and 1967 are similar, and those of 1970 and 1971 are also similar in the southern part of both shores of the Lake, and, therefore, the gravity value seems to be increased during the period between 1967 and 1970. However, only the values obtained in 1970 are significantly large at Banba and Nakanogō in the northeast part of the Lake. It is probable that the value at stations near the base station — *i. e.* Kyoto in the present case — is relatively reliable because of the direct connection with the base station, but that the more stations are relayed, the lower the accuracy obtained (Tajima [1970], Nakagawa and Satomura [1971]). Therefore, the measuring values obtained in the northern part of the Lake are to be thought less accurate than those in the southern part.

Judging from this consideration, no significant change of gravity is found in the northern part of Lake Biwa-ko, but it may be assumed that the gravity increased about 0.1 mgal during the period between 1967 and 1970 on both shores of the southern part of the Lake.

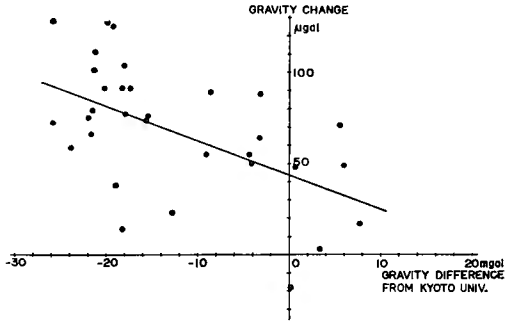

Fig. 5. Correlation between gravity value and gravity change (1964～1971).
r: correlation coefficient
$r=-0.57$
$a=(-1.86\pm0.52)\times10^{-3}$
$b=43.9\pm8.3\mu$gal

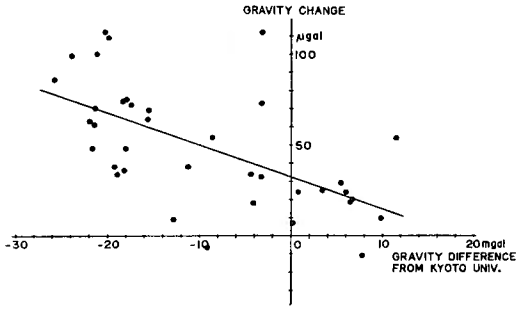

Fig. 6. Correlation between gravity value and gravity change (1967～1971).
$r=-0.58$
$a=(-1.75\pm0.39)\times10^{-3}$
$b=32.3\pm5.8\mu$gal

However, as can be seen in the Fig. 3, gravity difference from the base station (Kyoto) is large at stations located on the both shores of southern part of the Lake, and it may therefore be assumed that there exists a certain correlation between gravity changes (1964~1971 and 1967~1971) and gravity difference from the base station. This is shown in Figs. 5 and 6. Correlation coefficients obtained are -0.57 and -0.58 for Figs. 5 and 6, respectively. Therefore, the apparent gravity change obtained is partly caused by the scale factor of the gravimeters used. For this purpose, scale factor of the LaCoste & Romberg gravimeter G-196 (1971) should be changed to about $(1+1.8\times10^{-3})$ times greater than that of either the gravimeter G-29 (1967) or G-83 (1964). Scale factors of LaCoste & Romberg gravimeters used in the present investigation were often examined (Fujii *et al.* [1964], Tajima [1969, 1970], Tazima [1969]), and the results showed that the discrepancy for the scale factors and secular change of the scale factor itself were always lesser than the order of 10^{-4}. Under such circumstances, neither discrepancy nor the secular change of scale factor can be the cause of the apparent change of gravity. To make sure, recalculation using $(1+1.8\times10^{-3})$ times of the scale factor of the LaCoste & Romberg gravimeter G-196 was made instead of the original scale factor given by the maker, and the result is shown in Fig. 7, showing also the gravity increase of 0.05~0.1 mgal in the southern part of Lake Biwa-ko.

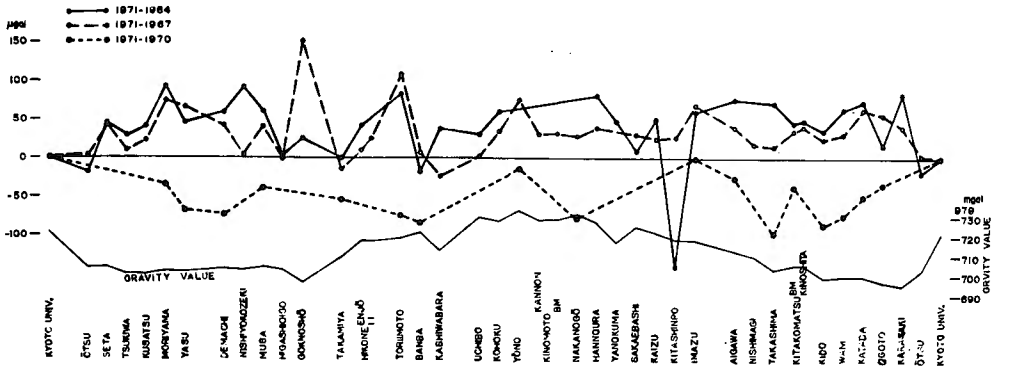

Fig. 7. Gravity change obtained by gravity measurements. 1.0018 × scale factor of the LaCoste & Romberg gravimeter G-196 in 1971 was adopted in calculation.

At the time of the gravity measurements in 1971, both back and forth measurements with the omission of some stations on the way and one-way measurements were carried out in addition to the main measurements, in order to examine the measuring accuracy of gravity and to find a suitable measuring method with a single gravimeter. The results obtained by back and forth measurements and one-way ones were within ±0.03 mgal compared with those by the main measurements, as shown in Fig. 8. Therefore, the gravity change amounting to about 0.1 mgal found in the southern part of Lake Biwa-ko cannot be explained by a measuring error or by some change in the calculation method for the data.

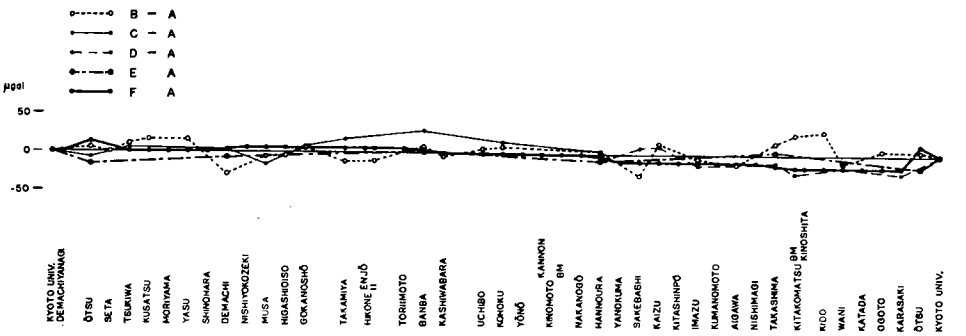

Fig. 8. Difference in the results obtained by different method of measurements and data arrangements.

A: main measurements (perfectly back and forth measurements)
B: one-way measurements
C: back and forth measurements on the east shore of Lake Biwa-ko
D: back and forth measurements on the west shore of Lake Biwa-ko
E: back and forth measurements made at selected stations along the route
F: results obtained through different data arrangements

From this consideration, it is considered that the gravity value increased about 0.1 mgal in the southern part of both shores of Lake Biwa-ko during the period between 1967 and 1970. A similar change of gravity is also obtained by a North American gravimeter and a Worden gravimeter (Ichinohe [1955], Ichinohe, Nakagawa and Sumitomo [1963]).

5. Comparison with Levelling Survey and Water Level of Lake Biwa-ko

According to unpublished data of the last levelling survey by the Geographical Survey Institute, on the east shore of the Lake (1965~1971), significant change in height did not occur to the north of Yasu, but subsidence of the ground became larger going south from Yasu, and the subsidence reached 3~5 cm at Ōtsu. On the other hand, on the west shore of the Lake (1948~1971), there was no significant change in height along the route between Imazu and Hōrai (between Kido and Wani), but there was subsidence in the south of Hōrai, and its subsidence amounted to 5~7 cm at Ōtsu. Comparing the results obtained by the gravity measurements with those by the levelling surveys, a similar tendency was found but the amount of the former was about 10 times greater.

As for data on water level of Lake Biwa-ko, 6 stations belonging to the Kinki Regional Construction Bureau are available, that is, Mihogasaki (near Ōtsu), Hikone, Katayama (near Kohoku), Shiotsu (between Hannoura and Yanokuma), Ōmizo (Takashima) and Katada. Level difference referring to the Mihogasaki is shown in Fig. 9, and there is no significant change in difference of water level.

Gravity change of 0.1 mgal would necessitate a density change of 0.005 gr/cm^3 in the subterranean layer of 500 m thickness, or 0.024 gr/cm^3 in the layer of 100 m.

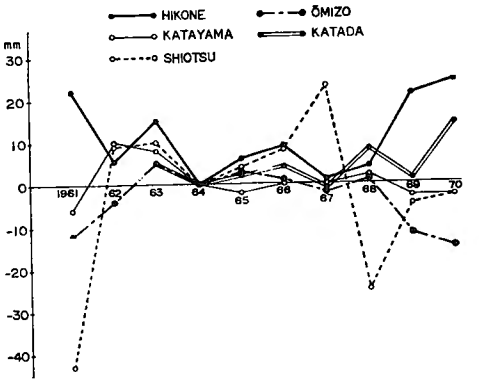

Fig. 9. Level difference of the Lake surface observed at several stations, referring to the Mihogasaki in 1964.

But there is no information for investigating the density change in the subterranean layer.

6. Summary

The results of the gravity measurements carried out four times during the period of 1964~1971 in the area around Lake Biwa-ko are summarized as follows:

(1) Gravity change amounting to about 0.1 mgal was found by using the LaCoste & Romberg gravimeters on both shores of the southern part of Lake Biwa-ko during the period of 1967~1970. There is no contradiction with results previously obtained by means of the North American and Worden gravimeters.

(2) Levelling surveys and water level measurements in the area concerned show a similar tendency to the gravity measurements, but both changes in height and water level are too small for explaining the gravity change. Therefore, if the gravity change obtained is assumed to be true, one possibility is that it is due to a density change in the subterranean layer, but there is no evidence to prove this.

Though the gravity measurements in 1971 were made on bench marks and instrumental height was precisely measured, they were not sufficient before 1970. It is needless to say that future gravity measurements should be carried out at the same position and with the same method as before. Gravity measurements at observation stations with small gravity difference for the base station are strongly recommended for detecting the secular change of gravity because of free from scale factor of the gravimeters used (Nakagawa and Satomura [1971, 1972]), although the area is limited. In case where many relay observation stations exist on the route, accuracy of the measurements usually becomes inferior, therefore direct connection with the base station is also recommended.

Acknowledgements

The authors wish to express their sincere thanks to Professor T. Ichinohe, Mr. N.

Sumitomo, Mr. Y. Fujii, Dr. T. Tanaka, Mr. H. Doi, Mr. Y. Tanaka and many other colleagues belonging to the Geophysical Institute of Kyoto University for their devoted assistance in the measurements. The authors wish also to thank to the Geographical Survey Institute for its generous permission to use valuable measuring values. The calculations were carried out at the Data Processing Center, Kyoto University.

Note : Description of the Measuring Stations

Kyoto Uṇiv. (UL)	:	the Primary Reference Station of Gravity in Japan, on floor (not on stone base)
Kyoto Univ. (FS)	:	the National Fundamental Station of Gravity in Japan, on floor (not on stone base) before 1953, on stone base in 1956
Kyoto Univ. (GI)	:	the Gravity Station of Geophysical Institute, Kyoto University
Demachiyanagi	:	B. M. 241
Yamashina	:	B. M. 214.1
Ōtsu	:	B. M. J 213
Seta	:	B. M. 211 before 1956, the lower landing stair in the square beside the Seta Bridge after 1964
Tsukiwa	:	B. M. 210.1
Kusatsu	:	traces of old B. M. 209.1, on road in front of Minami Dental Office
Moriyama	:	B. M. 208.1 before 1970, traces of B. M. 208.1 in 1971
Yasu	:	B. M. 207.1
Shinohara	:	B. M. 206.1 before 1951, on floor of Mobil gasoline station after 1952 (the height was changed in 1971)
Demachi	:	B. M. 206
Nishiyokozeki	:	B. M. 205.1
Musa	:	B. M. 204.1
Higashioiso	:	substitutional station of B. M. 203.1, on underground passage under the Route 8
Gokanoshō	:	substitutional station of B. M. 202.1, on floor of bell tower, in the Zenjū-ji Temple
Ishibashi	:	B. M. 201.1
Takamiya	:	B. M. 200
Hikone (Enjō)	:	on ground in front of 2 meters apart from the monument stone of "Kendō Enjō" before 1951,

		inside of palisade between 1952 and 1964, on stone remains of the monument after 1967, in the Hikone Castle
Hikone (Ii)	:	on the uppermost stair in front of statue of "Naosuke Ii" in the Hikone Castle
Hikone (CO)	:	on ground in front of 1.5 meters apart from the right hand pillar of porch, formerly the Hikone City Office
Toriimoto	:	B. M. 198.1
Banba	:	B. M. 197
Kashiwabara	:	on the lowermost stair in front of main shrine, Hachiman Shrine
Ibuki	:	on step stone in front of lodging No. 5, Ibuki Meteorological Observatory
Uchibo	:	on floor in front of monument stone for soul
Kohoku	:	on the lowermost stair in front of main shrine, north 300 meters apart from the Kohoku Town Office
Yōno	:	B. M. 10500
Kinomoto (Kannon)	:	on the lowermost stair in front of the great statue of Jizō, Jōshin-ji Temple
Kinomoto (BM)	:	B. M. 10504 in 1964, traces of B. M. 10504 after 1967
Nakanogō	:	B. M. 10506
Hannoura	:	on the lowermost stair in front of main shrine, Hachiman Shrine
Yanokuma	:	on the uppermost stone stair in front of the stage for Nō-play, Yaai Shrine
Sakaebashi	:	on floor in front of the monument stone beside the Sakae Bridge
Kaizu	:	on the lowermost stair in front of main temple, Fukuzen-ji Temple
Kitashinpo	:	on the lowermost stair in front of main shrine, Temma Shrine
Imazu	:	B. M. 1326
Kumanomoto	:	on road in south-western corner of intersecting point before 1967, on concrete wall of ditch 10 meters apart from the old station in 1971
Aigawa	:	B. M. 1323
Nishimagi	:	B. M. 1322
Takashima	:	B. M. 1320
Kitakomatsu (BM)	:	B. M. 1316, near B. M. 1316 only in 1967

Kitakomatsu (Kinoshita) : on road in front of 1 meter apart from the name post of "Kinoshita Shrine", Kinoshita Shrine

Kido : B. M. 1312

Wani : B. M. 1309

Katada : B. M. 1307,
on road near B. M. 1307 in 1952 and 1953

Ogoto : B. M. 1305

Karasaki : B. M. 1302 in 1952,
on stone floor of the well in the Karasaki Shrine, after 1964

References

Fujii, Y., S. Kogure, T. Saito, K. Inoue and I. Murata, 1964; On the reading accuracy and the scale factor reliability for the LaCoste and Romberg Geodetic Gravity Meter G–29, Jour. Geod. Soc. Japan, **10**, 36–45 (in Japanese).

Geographical Survey Institute, 1965; Gravity survey in Japan (4). IV. Gravity survey in the Chūbu, Kinki and Chūgoku Districts, Bull. Geograph. Surv. Inst., **10**, 55–183.

Honkasalo, T., 1971; Report of IAG Special Study Group No. 4.21 on Special Techniques of Gravity Measurements, XV General Assemb. IUGG, Moscow.

Ichinohe, T., 1955; Study on change of gravity with time. Part II. Repeated gravity surveys in the Kinki District, Mem. Col. Sci., Univ. of Kyoto, Ser. A, **27**, 317–334.

Ichinohe, T., I. Nakagawa and N. Sumitomo, 1963; On secular change of gravity, Ann. Disast. Prev. Res. Inst., Kyoto Univ., **6**, 13–16 (in Japanese).

Kinki Regional Construction Bureau, 1961–1970; Suiri-Nenpyo (Annual of Hydrography), **15–24** (in Japanese).

Nakagawa, I., 1971; Some remarks on gravity survey, Jour. Geod. Soc. Japan, **17**, 67–75 (in Japanese).

Nakagawa, I. and M. Satomura, 1971; On precise gravity survey at specially selected stations with an almost equal gravity value, and an experiment on characteristics of LaCoste & Romberg gravimeters due to vibrations, Jour. Geod. Soc. Japan, **17**, 49–60 (in Japanese).

Nakagawa, I. and M. Satomura, 1972; On precise gravity measurement at stations of small gravity difference (Part 1), Jour. Geod. Soc. Japan, **18**, 17–22 (in Japanese).

Nakagawa, I., M. Satomura, E. Abe, K. Katsura and S. Nishimura, 1970; On the new gravity value at the National Fundamental Station of Gravity in Japan, Jour. Geod. Soc. Japan, **16**, 9–15.

Tajima, H., 1969; On gravity survey, Jour. Geod. Soc. Japan, **15**, 9–13 (in Japanese).

Tajima, H., 1970; On precise gravity survey in Miura and Bōsō Peninsulas — On results of re-survey —, Jour. Geod. Soc. Japan, **16**, 54–59 (in Japanese).

Tazima, M., 1969; Accuracy of gravity survey, Jour. Geod. Soc. Japan, **15**, 14–19 (in Japanese).