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EXPRESSIONS OF THE ANISOTROPY OF THE CRUST BY MEANS OF THE OBSERVATIONS OF THE EARTH TIDAL STRAINS

By

Izuo Ozawa

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Abstract

A weighted function between an azimuthal pattern of an observed tidal strain and that of a theoretically calculated tidal strain is obtained in order to express an anisotropy of the crust.

The weighted functions are calculated for the azimuthal pattern of the tidal strains at Osakayama, Kishu and Suhara. The phase angles of the weighted functions show that the axes of the anisotropy at Osakayama concord with the normal direction of the Japan Proper, and the axes of the anisotropy at Kishu concord with the axis of Kii Peninsular. The load tide is calculated as the difference between the observed tidal strain at Suhara and the theoretical direct effect of the earth tide for the earth's model of Gutenberg. The weighted function between this load tide obtained by the observation and the theoretical load tide calculated by use of the oceanic tide is calculated. This weighted function shows that the axis of the load tide is deflected by about $45°$ by the metamorphical geologic constructions around Suhara district.

1. Introduction

Everyone believes the earth crust has an inhomogeneous constitution. For example, information on the distributions of the seismic velocity in the crust shows that the earth crust is an amalgam of materials which have various elastic constants. It is very hard to estimate by means of how to amalgamate the different materials in the crust by using only the seismic wave velocity. It is the reason why the estimation of the behavior of the whole earth is difficult that even an anomalous materials which occupy very thin layers of the earth are importance. So, it is important to study the behavior of the whole earth as a phenomenon of the earth's tidal strain.

The earth tidal strain consists of the direct effect due to the tide generating force of the moon or the sun, and the in-direct effect due to the oceanic tide. The in-direct effect at near ocean is much important as same as the direct effect. H. Takeuchi et.al. [Takeuchi (1965)] and I. M. Longman [Longman (1963)] have calculated the direct and in-direct effect of the tidal strains of the model earth of B. Gutenberg. It, however, is difficult to calculate the in-direct effect (load tide) at any place. As $5/7$ of the earth's surface is covered with ocean, it is unnatural that the in-direct effect is isolated from the effect on the whole earth.

The author tries to obtain the in-direct effect at any point as a deflection from the mean value of the whole earth or the theoretically estimated values of the effect for the model earth. He also treats the deflection as the isotropy of the crust. Now, this is meant the crust which loads the ocean.

2. Principle

a) Weighted function. C. Tsuboi [Tsuboi (1940)] has explained concisely the weighted function or the means, and applications for the relations between the gravity anomaly and the mechanism of the isostasy. The calculations and the interpretations of the weighted function are complex in a general case, because the function is applied for nonperiodic functions. Naturally, the weighted function should be applied for the calculation of the relation between periodic functions.

An expression of the azimuthal pattern of the linear strain is given a function

$$F(p) = A + B\cos 2p + C\sin 2p$$
$$= A + \sqrt{B^2+C^2}\,\cos\left(2p - \tan^{-1}\frac{C}{B}\right). \qquad \ldots. \ (1)$$

This function $F(p)$ has only *3* constants A, B and C or A, $\sqrt{B^2+C^2}$ and $\tan^{-1}\frac{C}{B}$.

The applied force of $F(p)$ which is the observed earth-tidal strain is the tide-generating force. Let $f(p)$ be the azimuthal function of the theoretical function of the direct of the earth tide for the model earth as follow,

$$f(p) = a + b\cos 2p + c\sin 2p. \qquad \ldots. \ (2)$$

$F(p)$ and $f(p)$ are combined with a weight function shown as follows,

$$F(p) = \int_0^{2\pi} f(p+\tau)\,\varphi(\tau)\,d\tau$$

where

$$\varphi(\tau) = \alpha_0 + \sqrt{\alpha_2{}^2+\beta_2{}^2}\,\cos\left(2\tau - \tan^{-1}\frac{\beta_2}{\alpha_2}\right),$$
$$\alpha_0 = \frac{1}{2\pi}\frac{A}{a}, \quad \alpha_2 = \frac{1}{\pi}\frac{aA+bB}{a^2+b^2}, \quad \beta_2 = \frac{1}{\pi}\frac{bA-aB}{a^2+b^2} \qquad \ldots. \ (3)$$

b) Direct effects of the earth tide. The deformation of the spheroidal type only is usually considered in the earth tide. The horizontal strain elements, $e_{\theta\theta}$, $e_{\phi\phi}$ and $e_{\theta\phi}$, of the spheroidal type deformation of the semi-diurnal and diurnal components are given as follows

$$\left.\begin{aligned}
e_{\theta\theta} &= \sum_i (h_2-4l_2)\frac{W_2(1)_i}{ag} + \sum_i \frac{h_2 \sin^2\theta + 2l_2 \cos 2\theta}{\sin^2\theta}\frac{W_2(\frac{1}{2})_i}{ag} \\
e_{\phi\phi} &= \sum_i (h_2-2l_2)\frac{W_2(1)_i}{ag} + \sum_i \frac{h_2 \sin^2\theta - 2l_2(1+\sin^2\theta)}{\sin^2\theta}\frac{W_2(\frac{1}{2})_i}{ag} \\
e_{\theta\phi} &= \sum_i 4l_2 \sin\theta \cdot \tan(t+\phi)\frac{W_2(1)_i}{ag} \\
&\quad - \sum_i 4l_2 \cos\theta \cdot \tan 2(t+\phi)\frac{W_2(\frac{1}{2})_i}{ag}
\end{aligned}\right\} \quad \cdots\cdots (4)$$

where $W_2(1)_i = J_{1i} \sin 2\theta \cos(t+\phi)$, and is the diurnal component of the potential of the tide generating force. $W_2\left(\frac{1}{2}\right)_i = J_{2i} \sin^2\theta \cos 2(t+\phi)$, and is the semi-diurnal component of the potential of the tide generating force. J_{1i} and J_{2i} are the special constants of the component tides of the diurnal and semi-diurnal components, respectively. h_2, l_2, a, g, θ, ϕ and t are Love's number, Shida's number, the mean value of the acceleration of the gravity at the observatory, the colatitude, the east longitude and the hour angle of the heavenly body, respectively. According to formulas (4), these strain elements are decided by the values of h_2 and l_2. For example, the phase angles of $e_{\theta\theta}$ and $e_{\phi\phi}$ are $0°$ in the case of that $h_2=0.612$, and $l_2=0.083$ which are calculated by H. Takeuchi for the model earth of B. Gutenberg. I. M. Longman has obtained also as nearly equal values. However, the phase angles of $e_{\theta\theta}$ in diurnal and of $e_{\phi\phi}$ in semi-diurnal are $180°$ in the case $h_2=0.600$ and $l_2=0.200$ which shows the incompressible earth model. Now, we should examine the values of h_2 and l_2 again. According to the theoretical calculation, the horizontal areal strain $e_{\theta\theta}+e_{\phi\phi}$ is free from the effect of the load tide, and the phase angle of the observed areal strain is also almost equal to $0°$. And the amplitude of the horizontal areal strain obtained by observation distant from the occean is always greater than both of $e_{\theta\theta}$ and $e_{\phi\phi}$. Therefor, we can estimate l_2 is much smaller than h_2, and l_2 is smaller than $h_2/3$ at least. l_2 can be said to be much smaller than $0.204h_2$, because the observed phase of $e_{\theta\theta}$ of O_1-*tide* is nearly equal to $0°$, and the observed amplitude is large considerably. Because the observed phase of the radial component e_{rr} of the strain is nearly equal to $180°$, we can also estimate that the value of $a\frac{dh_2}{dr}$ near the earth's surface are considerably larger than $2h_2$. That shows h_2 decreased remarkably near the earth's surface.

3. Observations

We have three observatroies [I. Ozawa, (*1957*, *1966*)], Osakayama (*34° 59.6′* of the north latitude, *135° 51.5′* of the east longitude), Kishu (*33° 51.7′* of the north latitude, *135° 53.4′* of the east longitude) and Suhara (*34° 02.6′* of the north latitude, *135° 11.7′* of the east longitude) in Kinki District of Japan. The positions of these observatories are shown in Fig. *1*. Their distance from sea is *65 km* from Osakayama, is *16.5 km* from Kishu, and is about *100 m* from observing room at Suhara. All observations are conducted under the ground surface at depths more than *50 m* or *100 m*. The observed tidal constants at these observatories are listed in Table *1*.

The observed tidal strain elements and their horizontal main strains are calculated from the Table *1*, and are shown in Table *2, 3, 4* and *5*. The strain elements are calculated also in Tables *2, 3* and *4* in both the cases that $h_2=0.612$ and $l_2=0.083$, and that $h_2=0.600$ and $l_2=0.200$. And the elements and the main strains of some load tide of M_2-components of the oceanic tides at these three observatory and 0_1-component of the oceanic tide at Kishu are calculated and are listed in Table *2, 3, 4* and *5*, respectively. The vectors of these observed and theoretical values of the main strains are shown in Fig. *2, 3, 4, 5* and *6*. The elements and the main strains of the load tide are calculated for the sea region within *300 km* at Osakayama and those within *100 km* at Kishu and Suhara.

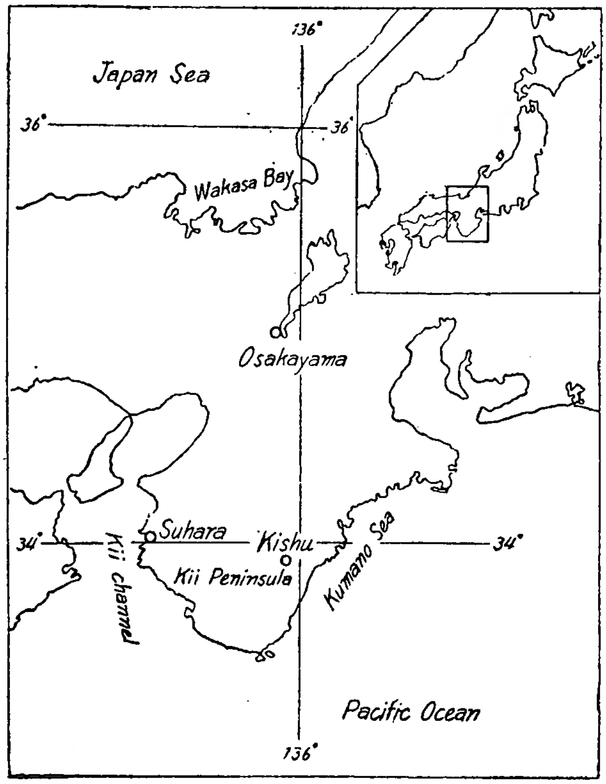

Fig. 1. Locations of observatories.

Table 1. Characters of the observations and of analysed constants

OSAKAYAMA 135° 51.5′ E, 34° 59.6′ N

Direction	Type	Sensitivity $\times 10^{-8}$/mm	Epoch	Mos.	M_2 Amplitude $\times 10^{-8}$	M_2 Phase	S_2 Amplitude $\times 10^{-8}$	S_2 Phase	O_1 Amplitude $\times 10^{-8}$	O_1 Phase	K_1 Amplitude $\times 10^{-8}$	K_1 Phase	M_3 Amplitude $\times 10^{-8}$	M_3 Phase
S38°W	H-59-B	0.070~0.198	1960. 8.25.	9	0.457	13.4°	0.132	339.0°	0.131	335.5°	0.245	328.0°	0.0033	346.7°
S38°W	H-59-B	0.207	1965. 8. 3.	1.5	0.382	11.0			0.244	334.4				
S38°W	H-59-B	0.201	1965. 9.24.	2	0.420	10.5			0.235	325.4				
S52°E	H-59-B	0.064	1960. 2.19.	1	1.630	0.9			1.001	34.3			0.032	12.3
S52°E	H-59-B	0.220	1960. 9.30.	9	1.537	353.5	0.755	310.4	0.775	8.5	1.181	27.2		
S52°E	H-59-B	0.181	1961.11. 5.	4.5	1.433	359.1			1.104	13.5				
E	H-59-B	0.53	1959. 3.28.	1	0.735	359.7			0.735	16.3			0.0041	314.0
E	H-59-B	0.37	1959. 5.24.	3	0.880	357.8			0.760	3.5				
N	H-59-B	0.57	1959. 4.23.	3	1.362	10.9			0.640	20.8			0.153	2.3
Z	V-59-D	0.562	1964. 8.12.	1	0.510	198.3			0.757	202.6				
Z	V-59-D	0.525	1964. 9.16.	1	0.525	198.4			0.582	219.2				

KISHU 135° 53.4′ E, 33° 51.7′ N

Direction	Type	Sensitivity $\times 10^{-8}$/mm	Epoch	Mos.	M_2 Amplitude $\times 10^{-8}$	M_2 Phase	S_2 Amplitude $\times 10^{-8}$	S_2 Phase	O_1 Amplitude $\times 10^{-8}$	O_1 Phase	K_1 Amplitude $\times 10^{-8}$	K_1 Phase	M_3 Amplitude $\times 10^{-8}$	M_3 Phase
N79.5°E	Wire	1.62	1955. 4. 9.	1	0.063	32.9°			0.015	11.2°				
N30°W	Wire	1.22	1956. 2. 2.	1	1.271	331.1			0.714	19.1				
N60°E	Wire	1.27	1956. 2. 2.	1	0.710	44.2			0.687	347.7				
E	H-59-C	0.298~0.367	1966.11.24.	6	0.089	133.5	0.109	229.2°	0.277	22.5	0.401	357.2°		
N	H-59-C	0.848	1967. 4.15.	3.5	0.780	349.3			0.240	0.7				
N	H-59-C	0.498	1961. 3.11.	3	0.437	346.7			0.109	5.1			0.0095	346.7°
N	H-59-C	1.256	1965. 5. 5.	2.5	0.600	353.6			0.241	6.9				

SUHARA 135° 11.7′ E, 34° 02.6′ N

Direction	Type	Sensitivity $\times 10^{-8}$/mm	Epoch	Mos.	M_2 Amplitude $\times 10^{-8}$	M_2 Phase
N	Wire	3.2	1956. 3. 9.	1	1.94	49.9
E	Wire	2.1	1956. 3. 9.	1	1.88	36.4
S70°E	Wire	10.1	1956. 3.19.	1	2.31	52.3

Table 2. Strain elements and main strains for M_2-component at Osakayama.

	Observed Value		Theoretical Value			
			$h_2=0.612$, $l_2=0.083$		$h_2=0.600$, $l_2=0.200$	
	Amplitude $\times 10^{-8}$	Phase	Amplitude $\times 10^{-8}$	Phase	Amplitude $\times 10^{-8}$	Phase
e_{rr}	0.588	196.4°	0.673	180°	0.753	180°
$e_{\theta\theta}$	0.612	25.7	1.356	0	1.770	0
$e_{\phi\phi}$	1.109	359.0	0.511	0	1.017	180
$e_{\theta\phi}$	1.080	172.7	0.490	270	0.458	270
$e_{\theta\theta}+e_{\phi\phi}$	1.678	1.2	1.867	0	0.752	0
Δ	1.109	1.6	1.194	0	0.000	——
	Amplitude $\times 10^{-8}$	Azimuth	Amplitude $\times 10^{-8}$	Azimuth	Amplitude $\times 10^{-8}$	Azimuth
main strain, cos term, e_1	1.124	121.3°	1.356	0°	1.770	0°
main strain, cos term, e_2	0.042	31.3	0.511	90	−1.017	90
main strain, sin term, e_1	0.281	102.9	−0.490	45	−0.229	45
main strain, sin term, e_2	−0.035	12.9	0.490	135	0.229	135

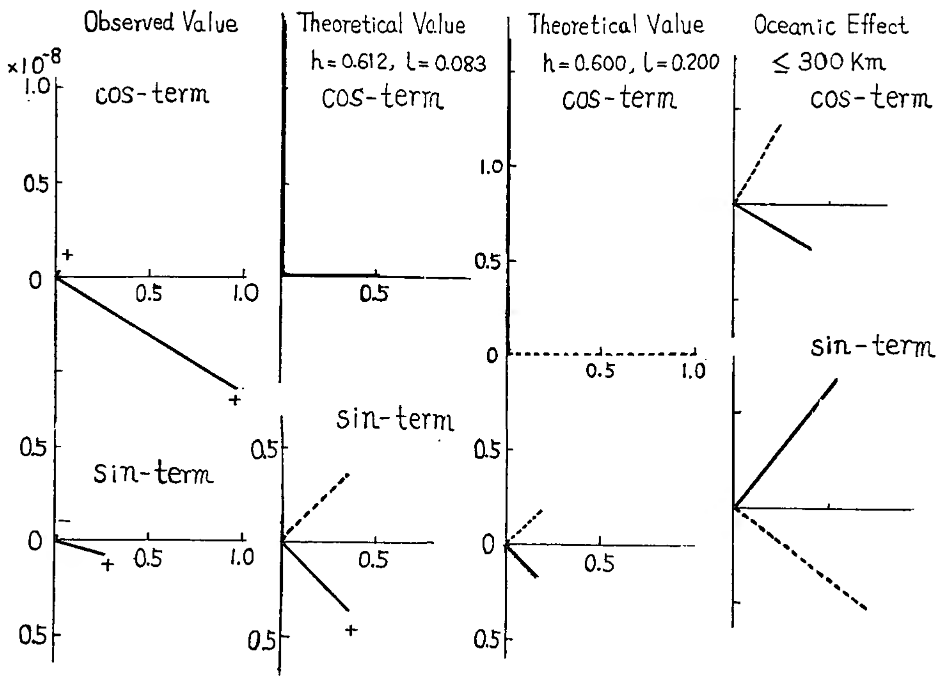

Fig. 2. Main strains of the observed, theoretical and load-tidal strains for M_2-component at Osakayama.

Table 3. Strain elements and main strains for O_1-component at Osakayama.

			Observed Value		Theoretical Value			
					$h_2=0.612$, $l_2=0.083$		$h_2=0.600$, $l_2=0.200$	
			Amplitude $\times 10^{-8}$	Phase	Amplitude $\times 10^{-8}$	Phase	Amplitude $\times 10^{-8}$	Phase
e_{rr}			0.647	214.3°	0.279	180°	0	——
$e_{\theta\theta}$			0.553	23.6	0.538	0	0.299	180°
$e_{\phi\phi}$			0.698	5.0	0.666	0	0.299	0
$e_{\theta\phi}$			0.972	262.0	0.322	90	0.979	90
$e_{\theta\theta}+e_{\theta\theta}$			1.242	13.2	1.204	0	0	——
Δ			0.672	353.3	0.925	0	0	——
			Amplitude $\times 10^{-8}$	Azimuth	Amplitude $\times 10^{-8}$	Azimuth	Amplitude $\times 10^{-8}$	Azimuth
main strain	cos term	e_1	1.062	129.1°	0.666	90°	−0.299	0°
		e_2	0.141	39.1	0.538	0	0.299	90
	sin term	e_1	0.204	141.9	0.161	45	0.490	45
		e_2	0.078	51.9	−0.161	135	−0.490	135

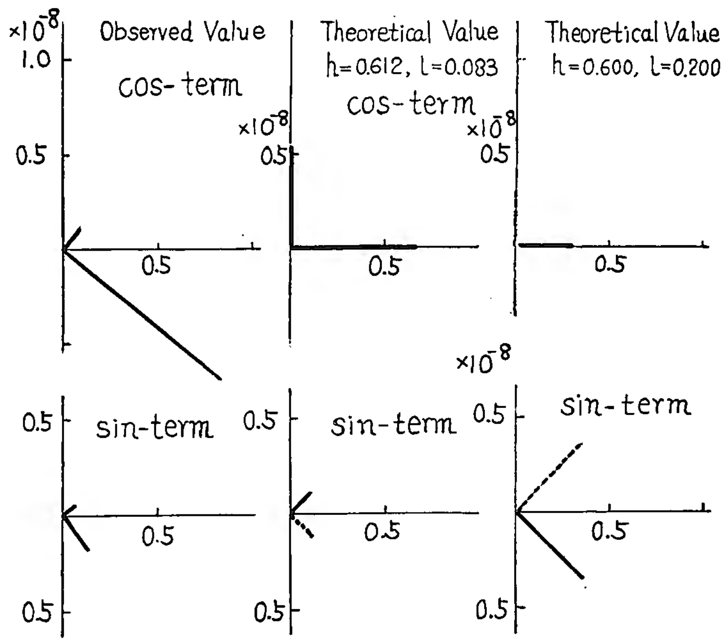

Fig. 3. Main strains of the observed, theoretical and load-tidal strains for O_1-component at Osakayama.

Table 4. Strain elements and main strains for M_2 and O_1 components at Kishu.

	Observed Value				Loading ($r < 100$ km)				Atmospheric Effect	
	M_2		O_1		M_2		O_1		S_2	
	Amplitude $\times 10^{-8}$	Phase	Amplitude $\times 10^{-8}$	Phase	cos-term	sin-term	cos-term	sin-term	Amplitude $\times 10^{-8}$	Phase
$e_{\theta\theta}$	0.657	350.1°	0.214	3.0°	32.15	−11.09	27.55	0.16	0.062	112.0°
$e_{\phi\phi}$	0.085	124.3	0.280	20.9	−32.15	11.09	−27.55	−0.16	0.133	112.0
$e_{\theta\phi}$	1.070	105.9	0.388	286.3	−97.02	18.98	65.82	−3.20	0.024	202.0
e_{rr}	——	——	——	——	——	——	——	——	0.065∼0.097	292.0
$e_{\theta\theta}+e_{\phi\phi}$	0.600	355.8	0.488	13.2	0.00	0.00	0.00	0.00	0.195	112.0
	Amplitude $\times 10^{-8}$	Azimuth	Amplitude $\times 10^{-8}$	Azimuth	Amplitude	Azimuth	Amplitude	Azimuth	Amplitude $\times 10^{-8}$	Azimuth
main strain, cos-term e_1	0.650	11.5°	0.297	56.7°	58.20	151.8°	43.42	31.3°	−0.109	172.7°
main strain, cos-term e_2	−0.051	101.5	0.178	146.7	−58.20	61.8	−43.42	121.3	−0.022	82.7
main strain, sin-term e_1	0.501	50.1	0.247	128.3	14.60	69.7	1.68	144.6	0.123	93.9
main strain, sin-term e_2	−0.544	140.1	−0.136	38.3	−14.60	159.7	−1.68	54.6	0.057	183.9

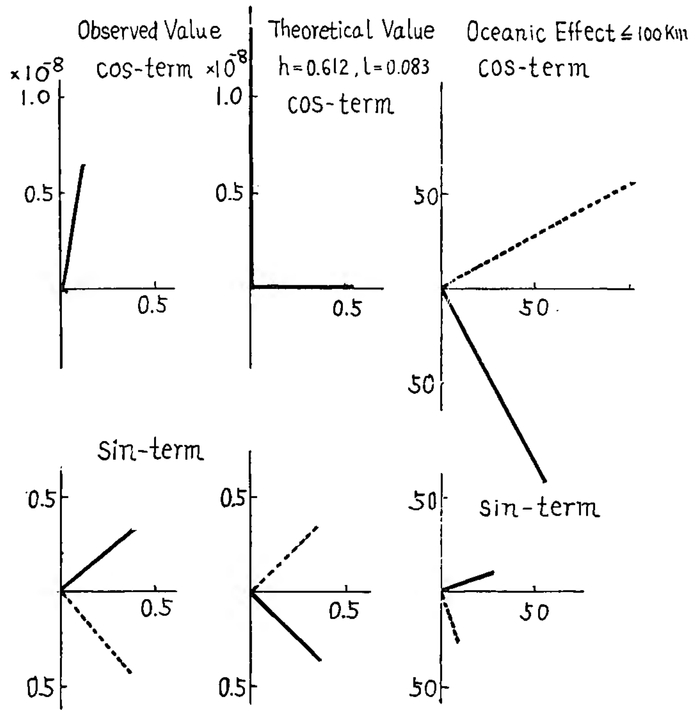

Fig. 4. Main strains of the observed, theoretical and load-tidal strains for M_2-component at Kishu.

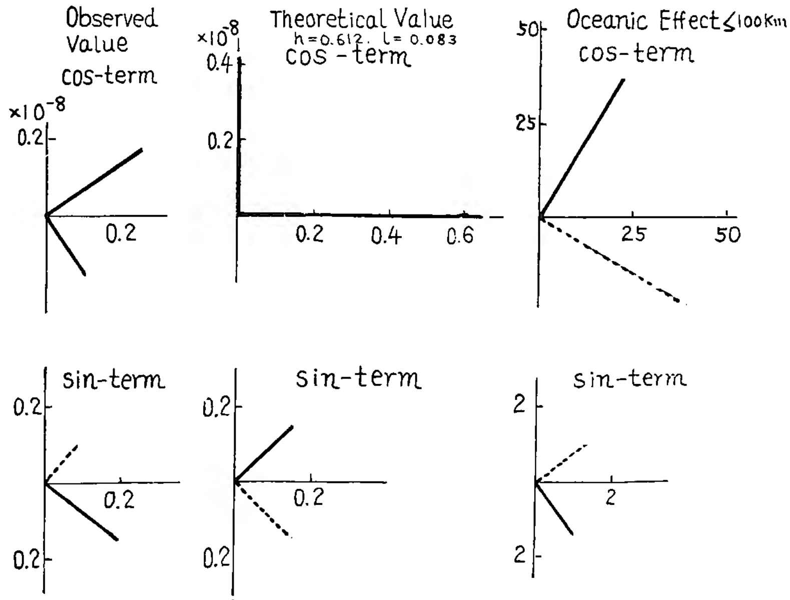

Fig. 5. Main strain of the observed, theoretical and load-tidal strains for O_1-component at Kishu.

Table 5. Strain elements and main strains for M_2-component at Suhara.

		Observed Value		Loading (<100km)		Observed Indirect Effect (h_2=0.612, l_2=0.083)	
		Amplitude $\times 10^{-8}$	Phase	cos-term	sin-term	Amplitude $\times 10^{-8}$	Phase
$e_{\theta\theta}$		1.940	49.1°	−2.46	−6.39	1.270	90.0°
$e_{\phi\phi}$		1.876	36.4	2.46	6.39	1.437	50.6
$e_{\theta\phi}$		2.092	96.2	374.90	−20.80	2.451	256.6
$e_{\theta\theta}+e_{\phi\phi}$		2.780	42.8	——	——		
		Amplitude $\times 10^{-8}$	Azimuth	Amplitude	Azimuth	Amplitude $\times 10^{-8}$	Azimuth
main strain	cos-term e_1	1.777	47.2°	187.47	45.4°	0.996	212.0°
	cos-term e_2	1.199	137.2	−187.47	135.4	−0.084	122.2
	sin-term e_1	2.200	42.8	12.21	105.7	2.385	86.2
	sin-term e_2	0.183	132.8	−12.21	15.7	−0.002	176.2

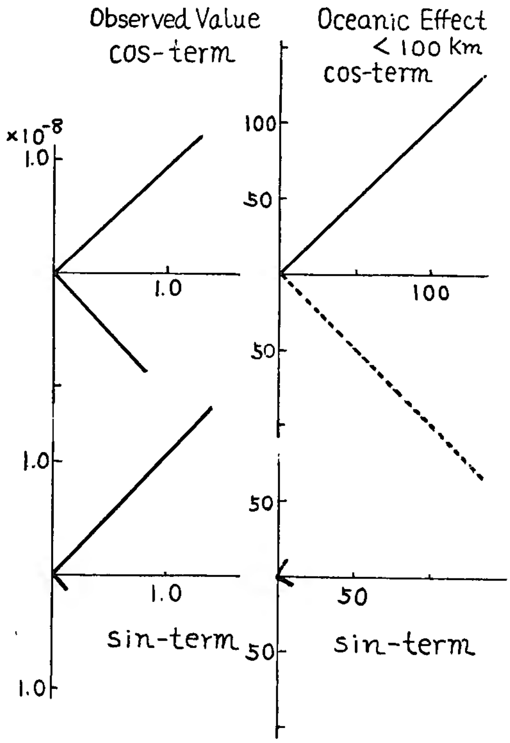

Fig. 6. Main strains of the observed, theoretical and load-tidal strains for M_2-component at Suhara.

4. Interpretations by means of weighted functions

It is hard to find directly the relations between the observed main strains and the theoretical ones by comparison at first glance of these vectors in Fig. *2*, *3*, *4* and *5* from the view-point of homogeneous earth crust. Now, we should attempt to find a relationship between the theoretical main strains of the homogeneous earth crust and the observed main strains by means of like a weighted functions. The relationship between these strains is analysed by means of the weighted means in the view-point that the earth crust is anisotropy as followings.

a) Osakayama. From formula (*1*), (*2*) and (*3*) and the Table *2* and *3*, we have the weighted functions between the observed tidal main-strains and those of the theoretical values in the case which $h_2=0.612$ and $l_2=0.083$ as followings,
for M_2—component

$$\varphi(\tau)=\frac{1}{2\pi}\frac{0.831\cos 2t+0.123\sin 2t}{0.934\cos 2t}+\frac{1}{\pi}\frac{1}{(0.423\cos 2t)^2+(0.245\sin 2t)^2}\times$$
$$[\{0.423\cos 2t\,(-0.279\cos 2t+0.142\sin 2t)+0.245\sin 2t\,(-0.536\cos 2t$$
$$+0.069\sin 2t)\}\cos 2\tau+\{-0.245\sin 2t\,(-0.279\cos 2t+0.142\sin 2t)$$
$$+0.423\cos 2t\,(-0.536\cos 2t-0.069\sin 2t)\}\sin 2\tau]$$

This result is generally given as the function of the time. In order to obtain the values at the specific times, we separate this weighted function into cosine and sine terms as follows,

$$\begin{aligned}\text{cos-term} \quad &: \quad \varphi_{cos}(\tau)=0.1416+0.1548\cos(2\tau-117.5°),\\ \text{sin-term} \quad &: \quad \varphi_{sin}(\tau)=\ \infty\ +0.1544\cos(2\tau-305.5°),\\ &\qquad\qquad\quad\ =\ \infty\ -0.1544\cos(2\tau-125.5°). \qquad \dots (I\text{–}2)\end{aligned}$$

The infinity of the first term in sin-term is caused by the error of the observations, and this term is negligible. The values of the cos-term is equal to the value of $\varphi(\tau)$ at *0* a.m. and p.m., and that of sin-term is equal to the value of $\varphi(\tau)$ at *3* a.m. and p.m.,

For O_1-component, we have the weighted function as follows,

$$\varphi(\tau)=\frac{1}{2\pi}\frac{0.601\cos t+0.141\sin t}{0.602\cos t}+\frac{1}{\pi}\frac{1}{(0.064\cos t)^2+(0.161\sin t)^2}\times$$
$$[\{0.064\cos t\,(-0.094\cos t+0.080\sin t)+0.161\sin t\,(-0.451\cos t$$
$$-0.182\sin t)\}\cos 2\tau+0.161\sin t\,(-0.094\cos t+0.080\sin t)$$
$$-0.064\cos t\,(-0.451\cos t-0.182\sin t)\}\sin 2\tau]\,. \qquad \dots (I\text{–}3)$$

This function is separate similarly as follows,

$$\begin{aligned}\textit{cos-term} \quad &: \quad \varphi_{cos}(\tau)=0.1589+2.2916\cos(2\tau-101.7°),\\ \textit{sin-term} \quad &: \quad \varphi_{sin}(\tau)=\ \infty\ -0.3907\cos(2\tau-156.4°). \qquad \dots (I\text{–}4)\end{aligned}$$

The values of cos-term is equal to the value of $\varphi(\tau)$ at midnight and noon, the value of sin-term is equal to the value of $\varphi(\tau)$ at six a.m..

We can find that these phase angles in these results of (*I-1*), (*I-2*), (*I-3*) and (*I-4*) are confined in the range from *101.7*° and *156.4*°. Therefore, we can estimate that the result shows the crust deformed remarkably in the direction of this range, and it shows that the crust is deformed easily in this direction. This direction coincides with the direction of the axis of Japan Proper.

b) Kishu. Similarly, we have weighted functions for the results at Kishu as follows, for M_2-component,

$$\varphi(\tau)=\frac{1}{2\pi}\frac{0.300\cos 2t-0.022\sin 2t}{0.959\cos 2t}+\frac{1}{\pi}\frac{1}{(0.417\cos 2t)^2-(0.244\sin 2t)^2}\times$$
$$[\{0.417\cos 2t\,(0.348\cos 2t-0.092\sin 2t)-0.244\sin 2t\,(0.147\cos 2t$$
$$-0.515\sin 2t)\}\cos 2\tau+\{-0.244\sin 2t\,(0.348\cos 2t-0.092\sin 2t)$$
$$-0.417\cos 2t\,(0.147\cos 2t-0.515\sin 2t)\}\sin 2\tau]$$

$$\text{cos-term}\ :\ \varphi_{cos}(\tau)=0.0498+0.291\cos(2\tau-337.3^\circ),$$
$$\text{sin-term}\ :\ \varphi_{sin}(\tau)=\infty+0.682\cos(2\tau-349.9^\circ).$$

for O_1—component

$$\varphi(\tau)=\frac{1}{2\pi}\frac{0.237\cos t+0.056\sin t}{0.534\cos t}+\frac{1}{\pi}\frac{1}{(0.122\cos t)^2+(0.203\sin t)^2}\times$$
$$[\{-0.122\cos t\,(-0.024\cos t-0.045\sin t)+0.203\sin t\,(0.055\cos t$$
$$-0.186\sin t)\}\cos 2\tau-\{0.203\sin t\,(-0.024\cos t+0.045\sin t)$$
$$+0.122\cos t\,(0.055\cos t-0.186\sin t)\}\sin 2\tau],$$

$$\text{cos-term}\ :\ \varphi_{cos}(\tau)=0.140+0.157\cos(2\tau-66.6^\circ),$$
$$\text{sin-term}\ :\ \varphi_{sin}(\tau)=\infty-0.300\cos(2\tau-344.4^\circ).$$

According to this result, these phase angles are confined within the range from *337.3*° to *349.9*° except *66.6*° at Kishu. We might estimate that the crust is deformable easy in the direction in this range from *337.3*° to *349.9*° in this district. Namely, it shows that the crust at Kishu which is in the eastern shoulder of the Kii Peninsular has been generated in the direction of the south-south-east.

c) Suhara. Similarly, we have the weighted function at Suhara as follows,

$$\varphi(\tau)=\frac{1}{2\pi}\frac{1.513\cos 2t+1.192\sin 2t}{0.322\cos 2t}+\frac{1}{\pi}\frac{1}{(0.4352\cos 2t)^2+(0.1855\sin 2t)^2}\times$$
$$[\{0.435\cos 2t\,(-0.0469\cos 2t+0.0787\sin 2t)-0.1855\sin 2t\,(-0.1275\cos 2t$$
$$+1.0380\sin 2t)\}\cos 2\tau+\{-0.1855\sin 2t\,(-0.0469\cos 2t+0.0787\sin 2t)$$
$$-0.4352\cos 2t\,(-0.1275\cos 2t+1.0380\sin 2t)\}\sin 2\tau],$$

$$\text{cos-term}\ :\ \varphi_{cos}(\tau)=0.233-0.099\cos(2\tau-290.2^\circ),$$
$$\text{sin-term}\ :\ \varphi_{sin}(\tau)=\infty+1.786\cos(2\tau-184.3^\circ). \qquad \text{.... (III)}$$

The author expected that the direct effect was negligible for the load tide because the Suhara Observatory was at coast. But, according to our observations, the load tide is not so much larger than the direct effect.

Now, the resultant effects $e_{\theta\theta}'$, $e_{\phi\phi}'$ and $e_{\theta\phi}'$ which are differences between the observed values and the theoretical direct effect in the case of $h_2=0.612$ and $l_2=0.083$ are calculated as follows,

$$\left.\begin{aligned} e_{\theta\theta}' &= (-0.0010 \cos 2t + 1.2701 \sin 2t)\times 10^{-8}, \\ e_{\phi\phi}' &= (0.9130 \cos 2t + 1.1132 \sin 2t)\times 10^{-8}, \\ e_{\theta\phi}' &= (-0.5766 \cos 2t + 2.3819 \sin 2t)\times 10^{-8}. \end{aligned}\right\} \quad \ldots\ldots \text{(III}'\text{)}$$

And the weighted function $\varphi(\tau)$ between the theoretical load-tide and the resultants are calculated as follows

$$\varphi(\tau) = \frac{1}{\pi}\,\frac{1}{(-2.46 \cos 2t - 6.39 \sin 2t)^2 + (187.45 \cos 2t - 10.40 \sin 2t)^2} \times$$
$$[\{(187.45 \cos 2t - 10.40 \sin 2t)(-0.4570 \cos 2t + 0.0785 \sin 2t)$$
$$- (-2.46 \cos 2t - 6.39 \sin 2t)(-0.2883 \cos 2t + 1.1910 \sin 2t)\} \cos 2\tau$$
$$+ (187.45 \cos 2t - 10.40 \sin 2t)(-0.4570 \cos 2t + 0.0785 \sin 2t)$$
$$- (-2.46 \cos 2t - 6.39 \sin 2t)(-0.2883 \cos 2t + 1.1910 \sin t)\} \sin 2\tau].$$

$$\text{cos-term} \;:\; \varphi_{cos}(\tau) = \infty + 0.001948 \cos(2t - 311.1^\circ),$$
$$\text{sin-term} \;:\; \varphi_{sin}(\tau) = \infty + 0.2179 \cos(2t - 302.6^\circ).$$

According to this result, the phase angles of $\varphi_{cos}(\tau)$ and $\varphi_{sin}(\tau)$ are 311.1° and 312.6°, respectively, and these almost equal each other. We can estimate that the crust around Suhara is deformed with the deflection of about 45° anti-clockwisely for the stress caused by the oceanic tide. The present author thinks that this deflection is caused by the geological constructions which consists of metamorphic rocks over the large area.

As these summaries, the tidal strains in Kinki District are much deflected by the constructions of the arc island, peninsular and the median line of the geological constructions.

And the present author suceeded in the expressions of the anomalous strain by means of the weighted functions.

At conclusion, the present author wishes to express his many thanks to Mr. K. Shinya at Suhara and the members of Kishu Mine belong to Ishihara-sangyo Joint-stock Company for their co-operations in these observations of the tidal strains.

References

Longman, I. M., 1963; A Green's function for determining the deformation of the earth under surface mass loads, Journal of Geophysical Research **68**. 485–496.

Ozawa, I., 1957; Study on elastic strain of the ground in earth tides, Bulletin, Disaster Prevention

Research Institute, Kyoto University, **15**, 1–36.

Ozawa, I., 1966; On the observations of the tidal strains at Osakayama Observatory, Special Contributions of Geophysical Institute, Kyoto University, **6**, 233–246.

Takeuchi, H. and L. E. Alsop, 1965; Comparison of theoretical and observational expression for elastic strains of the earth, Bulletin of the Seismological Society of America, **55**, 153–163.

Tsuboi, C., 1940; A problem of weighted mean, Bulletin of Earthquake Research Institute, Tokyo University, **19**, 458–475.