TIDAL ANALYSIS OF STRAIN MEASUREMENTS IN SOUTHWEST PART OF BAIKAL RIFT.

Timofeev Vladimir*, Ducarme Bernard, Semibalamut Vladimir***, Ribushkin Aleksandr***, Fomin Yurii***, Vandercoilden Leslie****.**

**Institute of Geophysics UIGGM SB RAS*
Koptiug pr.,3, 630090, Novosibirsk, Russia

***Chercheur Qualifié au Fonds National de la Recherche Scientifique*
Observatoire Royal de Belgique
Avenue Circulaire 3, 1180 Bruxelles, Belgium

****Laser Experimental Laboratory SB RAS*
Lavrentieva st.10, 630090, Novosibirsk, Russia

*****Observatoire Royal de Belgique*
Avenue Circulaire 3, 1180 Bruxelles, Belgium

Introduction

The strain response of the Earth to the tidal forces has been observed in Talaya station on the Baikal rift territory. As usual the equipment is installed in an underground gallery. Different types of extensometers were used: quartz tube, invar rod and laser. Preliminary results of short series of tidal strain observations have been presented in [1,2]. Long series of tidal strains are now available at this station. The station being located in the hearth of the Eurasian continent has a very low level of ocean influence but some instrumental and cavity effects were observed in this gallery. We present here the data processing and tidal analysis of long series summarising the 1989-1996 period of measurements.

Installation of the extensometers and observation.

The measurements were made in the geodynamic observatory Talaya (coordinates 51.68° N, 103.65° E) located 7 km to the west of the Southwest extremity of the Baikal lake and 3 km to the South of the Main Sayan fault. Our measurements are carried out in the 90m long underground gallery of the Talaya seismic station. The main gallery and the six perpendicular drifts have a cross section of 2x2 m^2 (figure 1). The equipment consists primarily of two short quartz tube extensometers and an invar rod strainmeter with induction sensors. Later on a laser extensometer with two 25m orthogonal legs was also installed. This set of extensometers was installed in different drifts and directions (-24° N, -22.5° N, 0° N, 90° N, 66° N), as we need at least three different directions to calculate the main strain axes variations for long term study of the tectonic activity [3].

Continuous observations of strain were made in the underground gallery of Talaya observatory since 1989 in a distant drift by quartz tube extensometers in N-S (base 1.3 m) and E-W (base 2.0 m) components. An invar bar extensometer (base 8.3 m) is placed 70 m apart from the gallery entry, along the gallery axis since 1990. An inductive displacement gauge was used in these extensometers. The signal was recorded close to the zero position of sensor to insure the linearity. The strainmeters in north-south and –22.5°N directions were placed on basements installed on the bed rock. The height of these basements, situated on the floor of gallery, is near 20 cm. For the east-west direction one side of the tube was sealed in the wall of the gallery and the sensor was placed on a large basement. The height of the system was near 1/2 meter under the floor of gallery. The angle between the tube direction and the wall direction was near 25-30°. A narrow crack system, 1-3 cm wide, is located along the axis of this drift and runs under the basements.

The signals are registered at a distance of 50 m from the gallery entrance in the building of the seismic station by an analog recording system at a speed of 20 mm/h and with a sensitivity of $1\text{-}6\times10^{-9}$ per mm. For calibration we used small displacements of the sensor plate as well in the laboratory as in the underground gallery. With this method we obtain a precision of 3 to 5 percents. In 1999 we started to use the mDAS digital system developed by the Royal Observatory of Belgium[4].

Since 1995 continuous laser extensometers observations (base 25 m, azimuths -24° N and 66° N) were performed in the underground gallery. The instrument has two light beams, perpendicular to each other. The instrument was developed at the Institute of Laser Physics SB-RAS (Novosibirsk, Russia) [2]. The mirror for first direction (-24°) is placed in a small cavity at the end of the main gallery. The mirror for second direction (66°) is placed near the axis of a big drift. Open laser light system is used in the gallery, as there are stable temperature conditions with mean temperature +1°C. The daily temperature stability is close to 0.001°C in the drifts which are far away from the entrance of the gallery. The annual stability is different: near the three entrance doors the variation reaches some degrees and in the longest drifts it is only one tenth of degree. Open laser system are sensitive to the air pressure variation. We tried to exclude this effect by additional laser measurements on one meter invar plate and extrapolating this result to the 25 meters bases. The main part of the air pressure effect has been excluded, but there is still some effect on the data.

The results of the laser strainmeter are registered in digital form on PC with one sample every 1 or 2 seconds.

Using the laser extensometer with two light beams is useful for the analysis of the temporal variations of the tidal amplitudes, as this instrument has a very stable scale coefficient connected with laser light wavelength. As already pointed out, the results are still slightly affected by air pressure. To solve this problem we make the difference between the two laser beams. In this case we have a minimum of air pressure influence and the results for the main semi-diurnal wave M2 showed high temporal stability and a low error level.

As it is well known strain results generally differ from global tidal deformation models [5] due to cavity effects, topography effects and the boundary conditions on a fault zone [6]. When possible we should thus try to evaluate and separate the global model and the local effects.

Earth Tide Analysis

The earth tide analysis of the strain data set 1989-1998 has been carried out with programs VEN66 and ETERNA 3.1 using respectively the Cartwright-Tayler-Edden and the Tamura tidal potential catalogue. As the results of tidal analysis by the two methods are very similar we give only the results obtained with VEN66. This method allows to compute the L/H ratio which is independent of the instrumental calibration. The results are not corrected for the air pressure or ocean loading.

The adjusted tidal parameters are given in Table 1 for the north-south component, in Table 2 for the east-west component and Table 3 for the –22.5°N component. The standard deviations for the different components are high. This can be due to temporal variations of the calibration factor and temporal variations of signal cable resistance. This last effect may explain the great S1 amplitude. This opinion is supported by the fact that the S1 amplification is much lower for the laser strainmeter.

For laser extensometer data the same methods of analysis were used and the results are shown in Tables 4 & 5. As expected we got lower standard deviations but not as small as expected with such an increase of length. We could suspect a residual influence of the air pressure variation.

Comparison of Observed and Predicted Tidal Parameters

The "residue" given in the last column of tables 1 to 5 is computed as the vectorial difference between the observed tidal vector and a model using values h= 0.6206 and l= 0.0904.

For all components S2 is systematically higher than the other waves. Here also we can suspect the air pressure influence.

The discrepancy in amplitudes for the NS and –22.5^{o}N instruments is at the 5-15 percents level for the main waves except for K1 NS. It should be noted the exceptional perturbation on S1 for this component. The discrepancy in phases reaches a maximum of six degrees.

Strong anomalies are registered in east-west component especially for the semi-diurnal waves where we should observe normally very low tidal amplitudes. It reflects probably the installation condition of the instrument as we get strong cavity effect when the instrument is fixed to the wall of a gallery. As we see the installation on the floor along the axis of the gallery was better.

The L/H ratios have been computed for the instrument with azimuth –22.5^{o}. They are very close to the theory for all the semidiurnal waves except S2. In the diurnal band the values are systematically too low and the liquid core resonance can be hardly seen.

For the 66°N direction the observed main semi-diurnal wave M2 is close to the model in amplitude but with a large phase difference. The tidal factors are very low in the diurnal band. For the other component (-24°N) a negative anomaly is observed for all the waves of the tidal spectrum. It reaches from 10 to 30 percents for the semi-diurnal waves. It may be connected with the installation condition of this instrument as the end mirrors are installed in a small cavity in the gallery wall.

As we shall see in the next paragraph, the best results for laser instrument was obtained for differential strain. In this case we obtain for M2 a discrepancy of 8% in amplitude and 20^{0} in phase.

The computed L/H ratios are not reliable for the component -24^{o}N. An internal test in the program cancelled their computation for most of the waves. Only some strange results emerged such as L/H=0.23(diurnals). The results are slightly better for the other component.

Strain difference

The best results for the laser system have been observed for differential strain as in this case we obtain the best elimination of the air pressure influence. We used for tidal analyses of strain difference between two orthogonal directions the version "0" (gravity) of the ETERNA analysis programs with with a convenient renormalisation to convert it to strain evaluation i.e. potential divided by g (absolute gravity) and by R (radius in the point of the observation).

As known [7] for strain in two directions of azimuth *a1* and *a2* we have:

$$e_{d1} = \cos^2 a1 \times e_{qq} + \sin^2 a1 \times e_{ll} + \cos a1 \times \sin a1 \times e_{ql},$$

$$e_{d2} = \cos^2 a2 \times e_{qq} + \sin^2 a2 \times e_{ll} + \cos a2 \times \sin a2 \times e_{ql},$$

We have for strain difference:

$$De = e_{d1} - e_{d2}$$

$$= e_{qq} \times (\cos^2 a1 - \cos^2 a2) + e_{ll} \times (\sin^2 a1 - \sin^2 a2) - e_{ql,} \times (\cos a1 \times \sin a1 - \cos a2 \times \sin a2)$$

When the first direction is perpendicular to the second one:

$$a2 = a1 + 90°$$

and we can use only one angle *a1* = a to express the strain difference:

$$De = (e_{qq} - e_{ll}) \times (\cos^2 a - \sin^2 a) - 2\, e_{ql,} \times \sin a \times \cos a$$

$=(e_{qq} - e_{ll}).\ cos2a - e_{ql,} \times sin2a$

For the different tidal waves we have:

Sectorial waves –

$e_{qq} = [h + 2((1-2sin^2q)/sin^2q) \times l] \times J_2/a \times g$

$e_{ll} = [h - 2((1+sin^2q)/sin^2q) \times l] \times J_2/a \times g$

$e_{ql} = 4l[(cosq / sin^2q) \times tan2H] \times J_2/a \times g$

Tesseral waves -

$e_{qq} = (h - 4l) \times T_2/a \times g$

$e_{ll} = (h - 2l) \times T_2/a \times g$

$e_{ql} = -2l \times (tgH/cosq) \times T_2/a \times g$

where h and l are tidal number, J_2 and T_2 - tidal potential, a - radius of Earth, g – gravity, q - colatitude, H - hour's angle.

Using these formulas for computing the strain difference, we get

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Sectorial waves

$De_2 = cos2a \times (e_{qq} - e_{ll}) - sin2a \times e_{ql,} =$

$\{[2l \times cos2a \times (2 - sin^2q) / sin^2q)] - [4l \times sin2a \times (cosq / sin^2q) \times tan2H]\} \times J_2/a \times g$

Tesseral waves

$De_1 = cos2a \times (e_{qq} - e_{ll}) + sin2a \times e_{ql,} = \{(-2l \times cos2a) + [2l \times sin2a \times (tgH/cosq)]\} \times T_2/a \times g$

After the calculation we obtain the theoretical values for amplitude factor and phase :

Sectorial waves

Amplitude factor F2 = $(2l/sin^2q) \times Ö[(2cosq \times sin2a)^2 + cos^2 2a \times (2 - sin^2q)^2]$

Phase Dj2 = -arctg[$2tan2a.cosq/(2 - sin^2q)$]

Tesseral waves

Amplitude factor F1 $= [2l/(cosq)] \times Ö(cos^2 2a \times cos^2q) + sin^2 2a)$

Phase Dj1 = arctg $[tan2a/cosq)]$

After the calculation with Talaya parameters: a = -24°N and the latitude f = 51.68°N we got:

F1 = 1.8197.**l**; Dj1 = -54.76°,

F2 = 8.2711.**l**; Dj2 = 42.83°

Taking tidal number l = 0.0904 we should obtain:

F1 = 0.1645 with a phase -54.76°;

F2 = 0.7477 with a phase 42.83°.

When we use the tidal program for gravity calculation we can adopt these values as reference values or compute apparent values of number **l**. We computed differential strain as well for the whole period(Table 6) as for consecutive three months periods. The results for M2 in consecutive three months series(Table 7) are very stable in amplitude as variations are within the error bars (0.5%). We got temporal variations in tidal phase up to 5° with error bars 0.2-0.4°.

Table 6
Comparison of predicted and observed tidal strain parameters: Difference of the component (-24°N) and the component (+66°N)

Wave	Ampl. Observ (nstr)	Ampl. Factor Predict	Ampl. Factor Obser.	Apparent Value of **L**	Ampl. Factor Error	Phase Predict	Phase Observ	Phase discrep	Phase error
O1	3.256	0.1675	0.2154	0.118	0.0045	-54°.76	-62°.12	-7°.36	0°.26
P1	1.499	0.1675	0.2132	0.117	0.0065	-54°.76	-63°.77	-9°.01	0°.38
K1	3.705	0.1675	0.1719	0.094	0.0025	-54.76	-73°.62	-18°.86	0°.14
N2	1.625	0.7477	0.7471	0.090	0.0229	42°.83	59°.30	17°.47	1°.31
M2	9.991	0.7477	0.6915	0.084	0.0037	42°.83	64°.55	21°.72	0°.21
S2	5.173	0.7477	0.7696	0.093	0.0091	42°.83	65°.79	22°.96	0°.52

Table 7 .
Analyses on 3 months consecutive periods for laser strain difference between (-24°) and 66° beams for M2 wave.

Period	Ampl.factor	Ampl.Factor Error	Phase in degree	Phase error
01-03.1995	0.7046	0.0054	61.08	0.31
04-06.1995	0.6917	0.0099	63.31	0.57
07-09.1995	0.7039	0.0051	65.72	0.29
10-12.1995	0.7034	0.0044	63.03	0.25
01-03.1996	0.7078	0.0040	63.73	0.23
04-06.1996	0.7077	0.0081	63.99	0.46
07-09.1996	0.6940	0.0053	64.86	0.30
10-12.1996	0.7039	0.0039	65.91	0.22
01-03.1997	0.6826	0.0063	66.65	0.36
04-06.1997	0.6590	0.0087	64.21	0.40
07-09.1997	0.6915	0.0037	64.55	0.21
10-12.1997	0.6959	0.0060	63.31	0.34
01-03.1998	0.6771	0.0046	63.11	0.26
04-06.1998	0.6966	0.0073	61.66	0.42
07-09.1998	0.6628	0.0230	61.89	1.32
10-12.1998	0.6576	0.0102	58.84	0.58

Conclusions

For the wave with the strongest amplitude, the discrepancies in amplitude for every component are shown in Table 8. We can see a maximum discrepancy of 5% for the quartz tube instruments corresponding to the associated internal error level. For the invar rod instrument a systematic amplification of 14% is apparent. For the laser instrument we have the residual influence of air pressure along the light path. The amplitude factor of the component in the azimuth of the gallery is reduced of 30% but the attenuation is only 10% in the 66°N azimuth for the strain difference between these two components. The temporal variation of difference strain amplitude during period 1995-1998 was near the error level (0.5 %). For the phase we observed 3 to 5 degrees of variation with an associated error level of 0.2-0.4 degree. It may be connected with the seismic activity of the region.

The discrepancies are connected with instrumental and cavity effects. Maybe boundary condition and geological structure effect can play an effective role as we have the main Sayan fault 3 km to the north , extending in a EW direction.

Table 8
Observed parameters for the strongest wave for different instruments and directions

Type of Instrument	Baselength (m)	Azimuth N to E	Wave	Obs. Ampl. (nstrain)	Reference	Observed Ampl. Fact.	RMS Error
Quartz	1.3	North-South	M2	10.81	1.0000	1.0077	0.0944
Quartz	2.0	East-West	O1	6.42	1.0000	0.9471	0.0456
Invar	8.3	-22.5°	M2	12.36	1.0000	1.1364	0.0348
Laser	25.0	-24.0°	M2	6.90	1.0000	0.7083	0.0259
Laser	25.0	+66°	M2	3.86	1.0000	0.9066	0.0578
Laser difference	25.0	(-24°) – 66°	M2	9.99	0.7477	0.6915	0.0037

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References

1. Timofeyev.V.Yu., Saritcheva You.K., Panin S.F., Anisimova L.V. et al. Effet dynamique du noyau liquide dans les observations de marees terrestres dans les stations de Siberie (Novosibirsk, Talaia, Irkoutsk). // J.Marees Terrestres, Bull.D'Informations, Belgium, 1994, n 120. pp.9344-9354.
2. Semibalamut V.M., Fomin Yu.N., Timofeev V.Yu. et al. Tidal parameters from the results of laser deformografic measurements in the South-West part of the Baikal rift, Talaya station. // J.Marees Terrestres, Bull.D'Informations, Belgium, 1995, n 123. p.9355-9364.
3. Timofeev V.Y. et al. Experimental models for the Earth's crust deformations in the south-west of the Baikal Rift Zone, Geologii i Geoficika, V. 40, 3, 1999, 387-394.
4. Timofeev V., Ducarme B., Van Ruymbeke M. Preliminary results of μDAS system for tilt strain monitoring at Baikal rift. Comptes-Rendus, 86th JLG meeting, M.Bonatz editor, Institut für Theoretische Geodäsie, Universität Bonn.
5. Dehant, V. Tidal parameters for an inelastis Earth. Physics of the Earth and Planetary Interior, vol. 49, 97-116, 1987.
6. Harrison, J.C. Cavity and topographic effects in tilt and strain measurements. Journal of Geophysical Research, vol.81, 319-328, 1976.

7. Melchior P. Physics and dynamics of planets. Pergamon Press.Oxford- London-Edinburgh-New York-Paris-Frankfurt, 1976, pp.483

Table 1
Tidal Strain Analysis
NS Component

Table 2
Tidal Strain Analysis
EW Component

Table 3
Tidal Strain Analysis
Azimuth –22°.5N

Table 4
Tidal Strain Analysis
Azimuth –24°N

Table 5
Tidal Strain Analysis
Azimuth 66°N

Figure 1
Sketch of the Talaya Underground Laboratory
D1 NS 1.3m, **D2** EW 2.0m, **D3** 22.5^{o} N 8.3m

Table 6.
Comparison of predicted and observed tidal strain parameters, component north-south

Wave	ampl. observed	ampl.fact. observed	Ampl.fact. Discrep.	ampl.fact. error	phase observed	Phase Error
O1	4.56	1.1410	+0.1410	0.1920	-0.96	9.64
K1	3.37	0.6010	-0.3990	0.1474	+1.39	14.05
M2	10.81	1.0077	+0.0077	0.0944	+4.78	5.65
S2	5.39	1.0806	+0.0806	0.2148	+15.40	11.50

Table 7.
Comparison of predicted and observed tidal strain parameters, component east-west

Wave	ampl. observed	ampl.fact. observed	Ampl.fact. Discrep.	Ampl.fact. error	phase observed	Phase Error
O1	6.42	0.9471	-0.0529	0.0456	-24.44	2.76
K1	5.84	0.6123	-0.3877	0.0353	-37.78	3.30
M2	6.43	16.3481	+15.3481	0.6261	-73.98	2.19
S2	2.51	13.7323	+12.7323	1.3691	-96.50	5.61

Table 8.
Comparison of predicted and observed tidal train parameters, component –22.5°N

Wave	ampl. observed	ampl.fact. observed	Ampl.fact. Discrep.	Ampl.fact. error	phase observed	Phase Error
O1	5.78	1.2618	+0.2618	0.0713	+6.25	3.24
K1	6.05	0.9402	-0.0598	0.0511	-2.48	3.10
M2	11.21	1.1364	+0.1364	0.0348	-0.54	1.75
S2	5.87	1.2794	+0.2794	0.0738	-9.56	3.34

Table 9.
Comparison of predicted and observed tidal strain parameters, component -24°N

Wave	ampl. observed	ampl.fact. observed	Ampl.fact. Discrep.	Ampl.fact. error	phase observed	Phase Error
O1	2.88	0.5944	-0.3056	0.0587	-10.16	3.36
K1	1.99	0.2925	-0.7075	0.0415	+0.54	2.37
M2	6.06	0.6349	-0.3651	0.0222	+9.06	1.27
S2	3.98	0.8975	-0.1025	0.0503	+10.22	2.88

Table 10.

Comparison of predicted and observed tidal strain parameters, component 66°N

Wave	ampl. observed	ampl.fact. observed	Ampl.fact. Discrep.	Ampl.fact. error	phase observed	Phase error
O1	2.28	0.3500	-0.6500	0.0425	+14.99	2.43
K1	3.41	0.3728	-0.6272	0.0283	+32.82	1.62
M2	4.60	1.0997	+0.0997	0.0358	-0.08	2.05
S2	3.07	1.5780	+0.5780	0.0804	+31.11	4.60

For any request please contact: Bernard DUCARME

Observatoire Royal de Belgique

Avenue Circulaire 3
BRUSSELS B-1180
BELGIUM

Tel: +32 2 373 0248
Fax: +32 2 374 9822
