TIDAL ANALYSIS OF QUARTZ-TILTMETER OBSERVATIONS 1988-1998 AT THE TALAYA OBSERVATORY (BAIKAL RIFT)

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Introduction

For many years on the former USSR territory ,the standard sensor to determine the tilt response of the Earth to the tidal forces was a short baseline metallic tiltmeter named Ostovsky, usually installed in underground stations as an high stability of environmental parameters was required. Another type of sensor was the quartz tiltmeter constructed by D.Gridnev. It was used some years in Garm and Poltava stations [1]. Long series were obtained with this instrument in Siberian stations for different purposes [2, 3]. Such quartz tiltmeters has been operated in the Talaya underground gallery since 1985. Preliminary result of short series of tidal tilts have been presented in [4]. Long series of tidal tilts have been observed at this station between 1988 and 1998. The station is installed in the centre of the Eurasian continent and the oceanic tidal loading is thus very low: 0.15mas for O1 and 0.06mas for M2 in North-South component and 0.22mas for O1 and 0.26mas for M2 in East-West component. The data processing and tidal analysis of these long series is described in this paper.

Installation of the tiltmetes.

Talaya station is an underground station primarily devoted to seismology. The station is situated in the South-West part of the Baikal rift. The Main Sayan fault is located a few kilometers to the North. It has an East-West orientation in the vicinity of Talaya observatory. Continuous observations of tilts were made in the 90 m underground gallery. This gallery is cut horizontally in the marble and granite-gneiss rock massif in the 332° N azimuth. It has six side galleries (drifts) 20-25 m long. Drifts are oriented perpendicular the main gallery. The gallery is cut in the steep slope of a valley. According to geological data, the rock massif is old, of Archean age. It is generally monolithic. a fractured zone is noticed in the more distant drift, along its axis. A set of tiltmeters was installed on a special basement built on the bedrock. Tilts are measured in North-South and East-West directions. The azimuth of the tiltmeters can be accidentally changed during servicing e.g. when changing the lamp illuminating the photocells. This procedure is required once every three or five years. The tiltmeter's basement are placed in a 10 m drift at 47m from the gallery entrance (Figure 1). The cross section of the drifts and the gallery is nearly 2x2 m^2. The average temperature in the gallery is +1 ^oC, with an annual variation in the range of one degree. The humidity is high during the summer season(July-September) with condensation and water infiltrating from the surface. From October to June there is a long frost period and the depth of frozen ground reaches up to 2 m in this region. Snow covers the surface at the end of October and disappears in the beginig of May.

Gridnev quartz tiltmeters have a Zollner suspension. Calibration is possible using either the torque of a spring or an electromagnetic coil system. The elements of tiltmeters construction - beam, base and spring, are prepared from melted quartz. Instrumental period is asjusted between 5 and 10 second. Small deviation angles are measured by a photoelectric sensor with a resolution of 0.1nanorad. The photoelectric sensor consists of two photocells, designed for space solar batteries assembly, and a 0.3 Watt light source. The beam displacement change the photocell illumination (Figure 2). The current is registered without amplification on the photorecorder with the speed 10 mm per hour. The galvanometer period being 16s, the short period noise between 2 and 6 seconds is attenuated. The recording system, including galvanometers, is located in a building at 30 m from the gallery entrance. The signal cable is suspended close to the ground surface (from 0 to 4 m). An analog recording system was used until the end of 1998. Hourly readings were taken on the curves.

Observation and calibration.

Two different calibration methods are possible either by an electromagnetic system or by a micrometric screw driving a quartz spring. Both systems act directly on the lower fixation point of the beam(Figure 2). We keep the beam position close to zero to reduce the non-linearity of the registration system. The long term drift of the beam is compensated by the quartz spring only for the N-S component and by the spring and the electromagnet(up to end of 1988 only) for the E-W one. Calibrations were performed by moving the micrometric screw of 6 divisions and by injecting a stable current in the coils. Results obtained with the two methods are presented in Table 1.

Table 1.

Comparison of Calibration Methods
EW component from 87/02/05 to 87/07/06

Calibration with Micrometer (mm/arc second)	Electromagnetic Calibration (mm/arc second)
1556.3	1551.5
1546.1	1556.9
1591.5	1519.4
1467.7	1530.1
1647.8	1470.2
1488.2	1470.2
1520.0	1587.9
1564.3	1605.0
1600.1	1545.1
1584.7	1620.0
1601.8	1596.4
	1632.8
	1583.6
	1585.7
	1583.6
	1557.9
Mean 1560.8 ± 16.0 (±1.0%)	Mean 1562.3 ± 11.8 (±0.7%)

The agreement on the mean value is excellent but with a large scattering.

The error of calibration was on 1-3 percents level. The main problem is that we have to approach the instrument for manual calibration so that there is a thermal effect during some hours. We tried to calibrate always in the same position of the elecro-optical transducer. The time between the calibration steps was 10-15 minutes for the electro-magnetic method and from half an hour to one day for the quartz spring. To determine the phase shift we used the decay curve following each step of micrometer or each change of the current. This value varied from 1 to 3 minutes during the observation period. This variation is connected to changes of the input resistance of the galvanometer.

After 1988 we used only the micrometer for calibration. The scale coefficients during ten years varied from 500 mm per arc second up to 3000 mm per arc second according to the different free periods of the pendulums. Usually this value was kept around 1000-1500 for North-South direction and 1500-2500 for East-West direction, depending on photocells characteristics.

The annual meteorological effect was estimated to be in the 10^{-7} - 10^{-8} radian limits. Rain effect is only effective during the short summer season and reaches a similar amplitude. Long term seasonal effect, connected with the annual Baikal Lake level variation reaching 1.5 m, was near 0.1" for tilt in the E-W direction. A long term drift of the order of 0.1" per year up to 3" per year was observed and is related to the strong seismic and tectonic activity of the Baikal rift.

Earth Tide Analysis

The earth tide analysis of the quartz tiltmeters data set 1988-1998 has been carried out not only with method VEN66 using the CTE550 tidal potential and filtering on 48 hours blocks but also with ETERNA 3.0 using the Tamura tidal potential and Pertsev numerical filters. The adjusted tidal parameters are given in Tables 2 & 3 for North-South component and in Tables 4 & 5 for East-West component. The standard deviation of weight unit for different components and for different periods reaches 2 to 2.5 mas. The results of tidal analysis by the two methods are similar in amplitude and in phase. The discrepancies are due to the different filtering techniques interfering with the gaps.

Slight changes are observed between successive partial analysis. They can be due to temporal variations of the calibration factor and temporal variations of the signal cable impedance. This last effect is probably responsible of the large S1. Tidal analysis of barometric pressure (table 6) shows a diffuse effect in the diurnal band with a maximum at S1 frequency and only one peak on S2 in the semi-diurnal band.

Comparison of Observed and Predicted Tidal Parameters

For comparison with the observed tidal parameters, the tilt tide parameters have been modelled from the Wahr-Dehant model[5] and ocean-tide loading computed using the Farrell procedure and the Schwiderski ocean tide model (Tables 7 & 8). Tidal oceanic loading is below 0.15mas in NS but reaches 0.25mas in EW. The consideration of this effect in the modelling does not improve the fit with the observations.

In NS component we compare the results of the two analysis methods with the predicted tidal factors in table 7. For amplitude factors we have a positive anomaly for all the main waves. We observe a phase advance in semi-diurnal waves and a phase lag in diurnal ones. It should be pointed out that for this component the diurnal part of the tidal spectrum is very weak at the latitude of Talaya station.

In East-West component (Table 8) with the two analysis methods we observe a phase lag for all waves and a negative anomaly for amplitude factors with the exception of M2. The liquid core resonance effect is fairly well observed between O1 and K1. The instrumental phase lag cannot explain the phase discrepancy as this one has a similar amplitude for diurnal and semidiurnal waves.

Concerning the causes of these anomalies we tried to consider cavity effects[6] but the discrepancies between NS and EW directions remain unexplained. The installation of the tiltmeters in the drift gallery is similar as the angle with drift axis is similar in both cases from 35° to 50°. On the other hand the angle between main gallery direction and North direction is 22° - 24° and in this case according to the theory we should observe very weak influence, but we have opposite result. For topographic effect we have the similar situation as the mountain range near the station is oriented in azimuth 35°-50°N and we would have the same effect on the North-South and East-West components. Considering the effect of geological structures we have many geological boundaries around the station. However for wave M2 in E-W component the tilt-strain coupling effect is minimal as for this latitude the amplitude of semi-diurnal strain is minimal.

As a conclusion for North-South component we can use practically only M2 wave. Internal error on M2 reaches 0.5 percent. For this wave we have discrepancy at the level of 3 percents on the amplitude factor but nearly 10 degrees in phase which represent a 10% out of phase signal. It may be explained by the geological structure effect as we have 3 km to the North of the station the main Sayan fault oriented in EW direction.

In East-West component amplitude factors fits with modelling at the 4% level for M2 and O1. The phase lag reaches 2 degrees which represent a 4% perturbing signal in out of phase component. It may be due to cavity and topographic effect.

For S2 and K1 wave we do always have a larger discrepancy in amplitude and in phase probably caused by strong temperature effects changing the resistance of the 30m cable laid between gallery and building with recorder.

Table 7.

Comparison of predicted and observed tidal tilt parameters
NS component

Wave	ampl. theor.	ampl. fact. predict.	Ampl. Fact. Observ.	Ampl. Fact. Discrep.	Error ampl. Fact.	Phase predict.	phase observ.	Phase discrep.	error phase
VEN66									
O1	1.49	0.6159	1.0714	0.4555	0.0452	+6.36	+1.81	-4.55	2.42
K1	2.09	0.6922	1.0590	0.3668	0.0317	+4.04	-3.49	-7.53	1.72
M2	7.69	0.6792	0.7039	0.0247	0.0059	-0.16	+9.36	+9.52	0.48
S2	3.58	0.6849	0.7966	0.1117	0.0125	-0.33	+4.98	+5.31	0.92
ETERNA									
O1	1.49	0.6159	1.0676	0.4517	0.0293	+6.36	+2.52	-3.84	1.68
K1	2.09	0.6922	1.0557	0.4635	0.0209	+4.04	-3.97	-8.01	1.19
M2	7.69	0.6792	0.7036	0.0244	0.0043	-0.16	+9.57	+9.73	0.25
S2	3.58	0.6849	0.8013	0.1164	0.0094	-0.33	+5.43	+5.76	0.54

Table 8.

Comparison of predicted and observed tidal tilt parameters
EW component

Wave	ampl. theor.	ampl. fact.	Ampl. Fact.	ampl. fact.	Error ampl.	Phase predict.	phase observ.	Phase discrep.	error phase

		predict.	Observ.	discrep.	Fact				
VEN66									
O1	5.11	0.6528	0.6215	-0.0313	0.0137	+2.29	0.78	-1.51	1.29
K1	7.19	0.7172	0.6440	-0.0732	0.0095	+2.87	2.76	-0.11	0.84
M2	9.80	0.6657	0.7111	0.0454	0.0051	+1.36	-0.14	-1.22	0.41
S2	4.56	0.6708	0.6564	-0.0144	0.0110	+2.03	-2.40	-4.43	0.94
ETERNA									
O1	5.11	0.6528	0.6288	-0.0240	0.0090	+2.29	0.82	-1.47	0.51
K1	7.19	0.7172	0.6457	-0.0715	0.0063	+2.87	2.17	-0.70	0.36
M2	9.80	0.6657	0.7091	0.0434	0.0041	+1.36	0.03	-1.33	0.23
S2	4.56	0.6708	0.6574	-0.0134	0.0089	+2.03	-1.82	-3.85	0.51

Acknowledgement

This work has been supported by the Belgo-Russian agreement for Scientific and Technical Cooperation and by the Russian Fund for Scientific Research (98-05-65227, 98-05-65278). The authors wish to thank P. Melchior for interest of this work.

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TABLE 2
Tidal Analysis Results for NS Component
VEN66 Method

TABLE 3
Tidal Analysis Results for NS Component
ETERNA Method

TABLE 4
Tidal Analysis Results for EW Component
VEN66 Method

TABLE 5
Tidal Analysis Results for EW Component
ETERNA Method

TABLE 6
Tidal Analysis of the Atmospheric Pressure
VEN66 Method

Figure 1. Sketch of the Talaya underground laboratory
The location of the tiltmeters is indicated by an arrow

Figure 2a. Gridnev quartz tiltmeter
1- lamp, 2- differencial photocells, 3- galvanometer,
4- control panel for coils, 5- lever-spring(quartz),
6- support(quartz), 7- mirror of beam(quartz), 8- magnets,
9- coils on quartz tubes, 10- quartz spring, 11- micrometer

Figure 2b. Tidal recording in NS direction
Vertical scale is given in 10^{-6}" (5.10^{-12}rad) units
Tidal amplitude reaches 0.03" (0.15µrad)

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