



Fiber Optics System for Rotational Events & Phenomena Monitoring

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Investigation of Building Rotational Motion Using Set of AFORSs (Autonomous Fibre Optic Rotational Seismographs)

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Outline

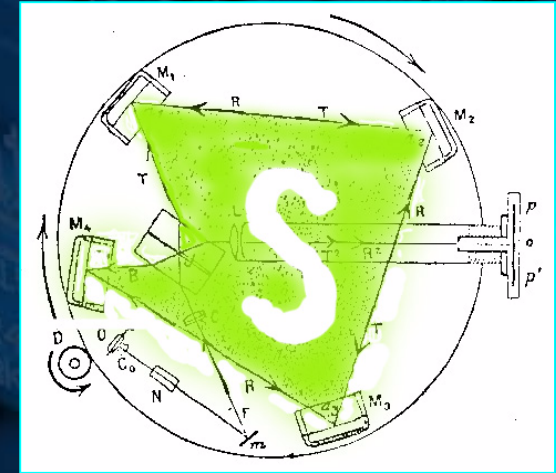
- Sagnac effect – how its use for rotation monitoring?
- Rotational Seismometer – why not FOG?
- Autonomous Fibre-Optic Rotational Seismographs:
 - optic and electronic part construction
 - calibration and accuracy estimation,
 - remote control
- AFORSs application for monitoring building rotation
- Outcome
- Conclusions



Sagnac effect

1913 Georges Sagnac – interferometer for rotation detection where the two directions within the rotating loop see slightly different optical paths. Sagnac's original experiment used a loop about 1m square and detected fringes shift when the loop rotated at a few times a second.

$$\Delta Z = 4 \frac{\Omega \cdot S}{\lambda_0 c}$$



[Post, *Rev. Mod. Phys.*, 39, 1967]

The Sagnac interferometer measures rotation with respect to the fixed star in the galaxy, rather than with respect to the rotating Earth's surface.

The observed fringe shift does not depend on:

- the presence of a comoving refracting medium in the path of the beam,
- the shape of surface area S,
- the location of the center of rotation.

FOSREM

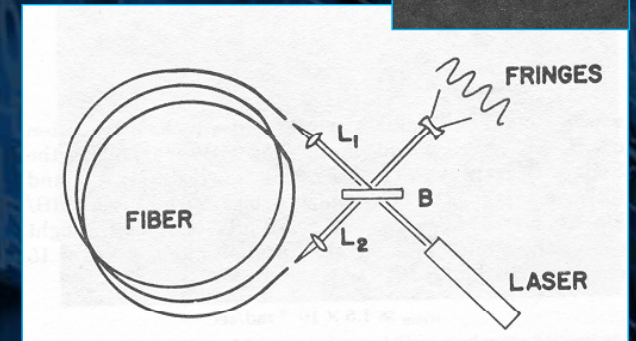
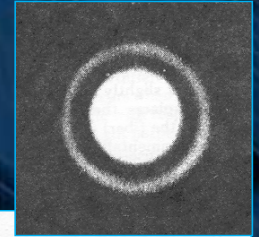


How is use for rotation monitoring?

$$\phi_s = \frac{2\pi LD}{\lambda c} \Omega$$

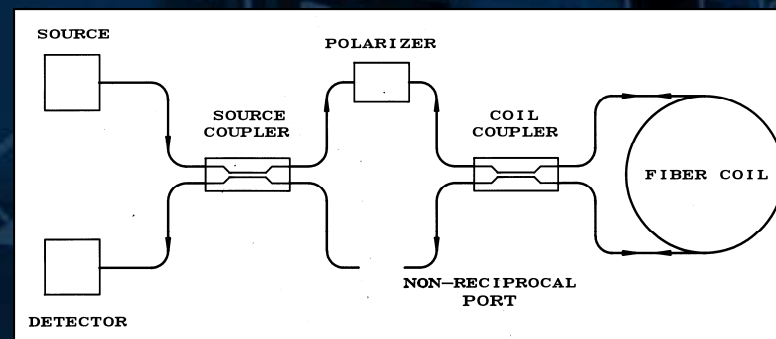
The phase shift increase with L – practical way for FOG development.

L=10 m, D=15 cm,
 $\lambda=630$ nm



[Vali et al, *Appl. Opt.*, 15(5), 1976]

The reciprocal condition for ϕ detection – the reciprocal configuration [Urlich, 1980] also called the minimum configuration [Arditty and LeFevre, 1981]



Combined single-spatial-mode and single-polarization filtering at the common input-output port

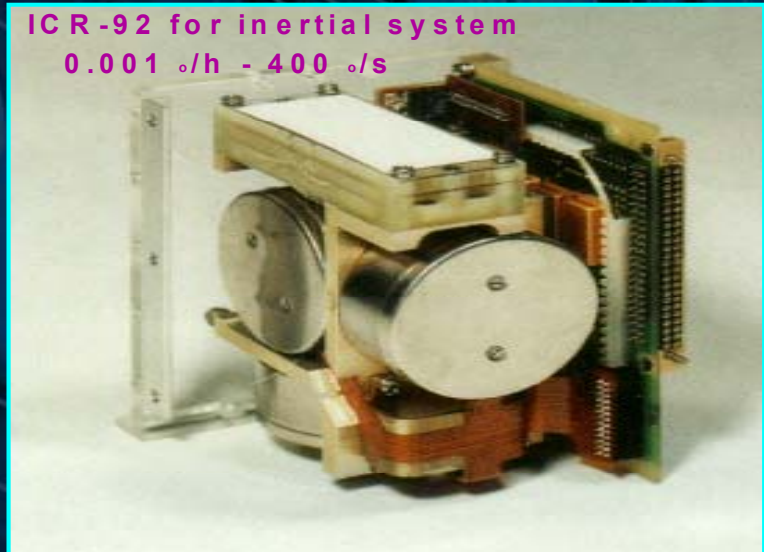
FOSREM



Rotational Seismometer – why not FOG?



ICR-92 for inertial system
0.001 °/h - 400 °/s



$$\Delta\phi = \frac{4\pi RL}{\lambda c} \Omega = \frac{1}{S_o} \Omega$$

Fibre-Optic Rotational Seismometer

FORS optimization:

1. Optical Unit – increase sensitivity & minimalization external influences
2. Electronic Unit - proper signal processing for long time operation & remote control

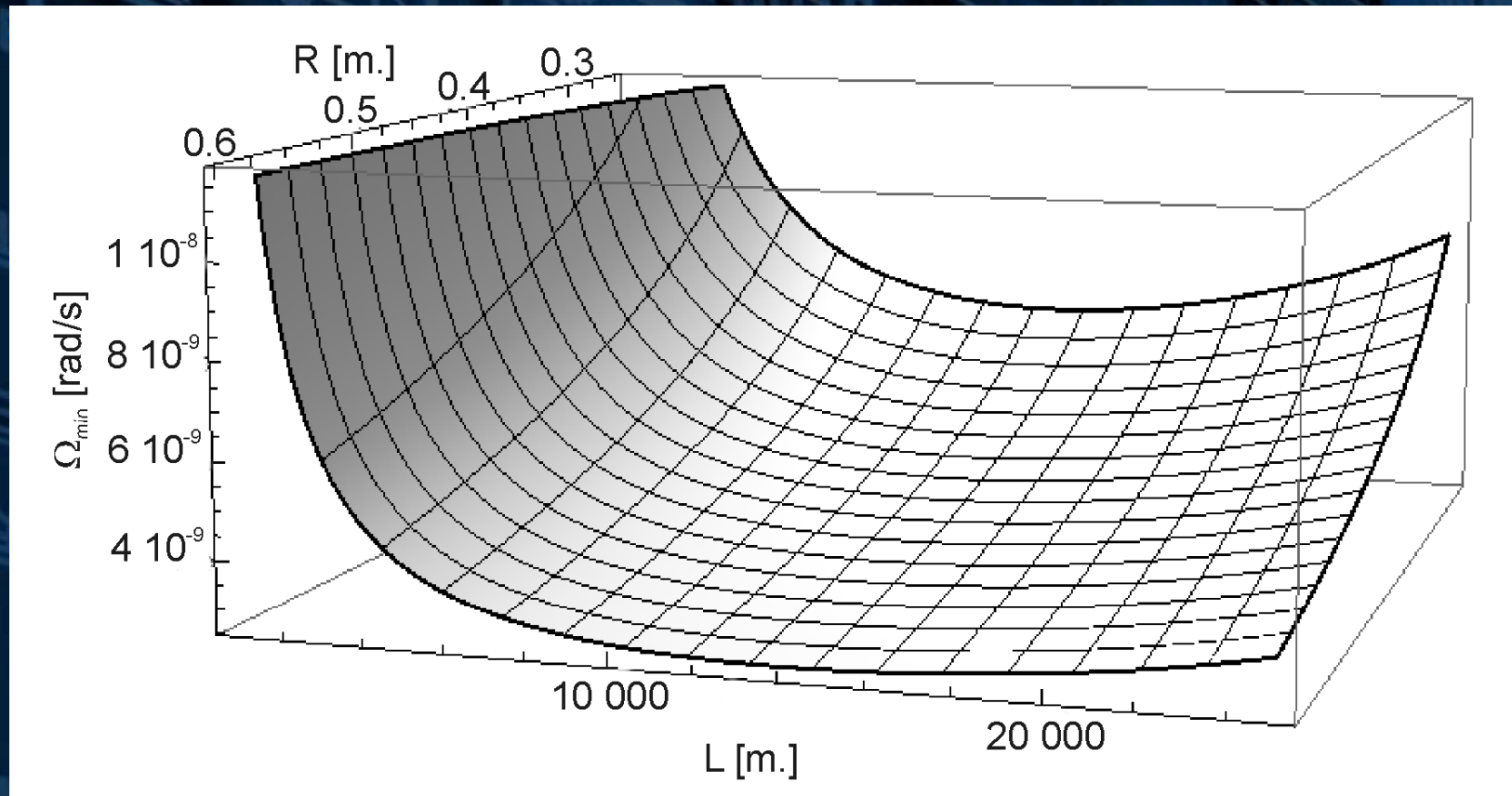
$$FOG \Rightarrow \vartheta = \int \Omega dt$$

Problems with:

1. Drift phenomenon,
2. Dynamic range,
3. Applied dedicate electronics for angle not rotation speed detection,
4.

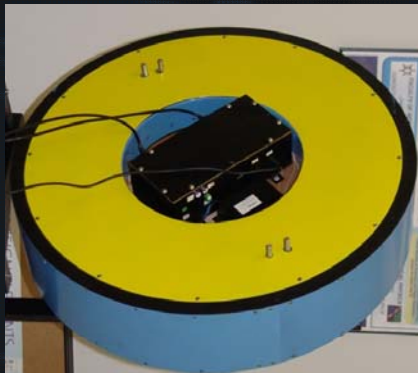
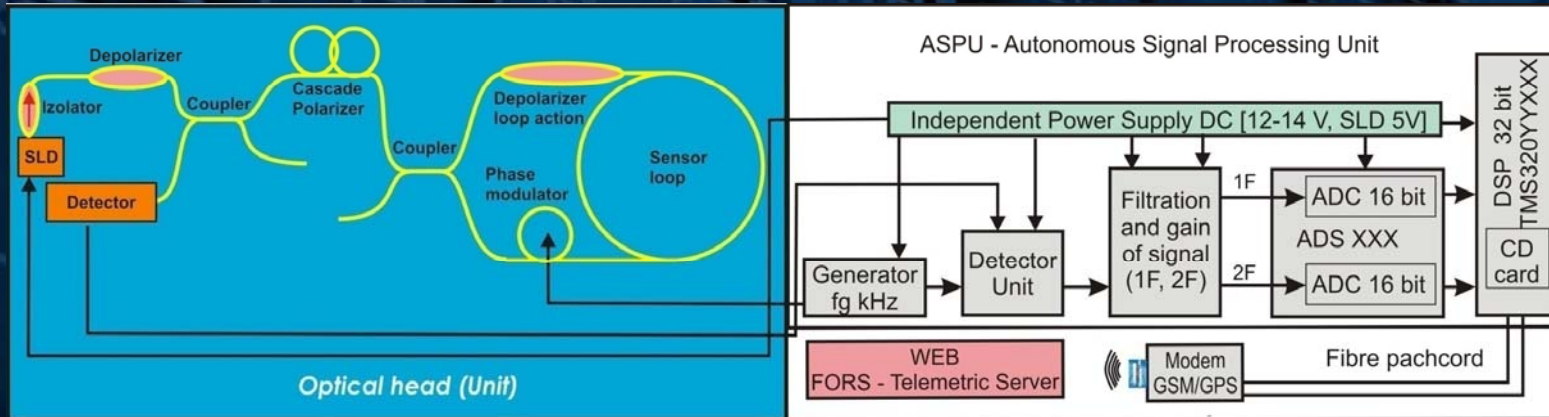


Influence of SMF-28 fibre length on system sensitivity for constructed AFORS



AFORS resolution versus total optical length L and loop radius in 1 Hz detection band. Parameters for simulation: wavelength $\lambda=1285$ nm, fibre attenuation $\alpha=0.45$ dB/km, optical path loss $\sigma=15$ dB, optical power $P=20$ mW [L. R. Jaroszewicz, et al., in R. Teisseyre, H. Nagahama, E. Majewski (eds.), *Physics of Asymmetric Continuum: Extreme and Fracture Processes*, Springer-Verlag, Chap. 2, 2008.]

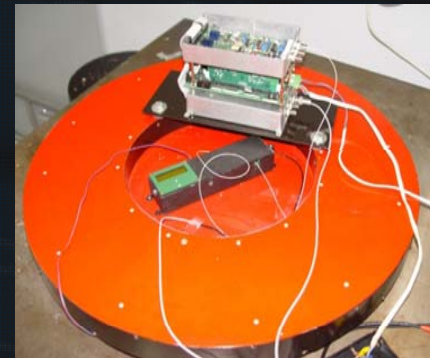
Autonomous Fibre-Optic Rotational Seismographs



AFORS-2

$\Omega_t = 2.46 \cdot 10^{-9} \text{ rad/s/Hz}^{1/2}$

$L = 15\,000$ [m], 15 layers, double quadropole winded, $\alpha = 0.446$ [dB/km], loop $R = 0.340$ [m] contains permaloy particles, $\sigma = 13.16$ [dB], cascade polarizers (46 and 55 [dB]), depolarizer with 0.02 [dB] extinction ratio, $\Delta\lambda = 31,2$ [nm], $\lambda = 1326.9$ [nm], $P_L = 20$ [mW], $fg = 6.8$ kHz.



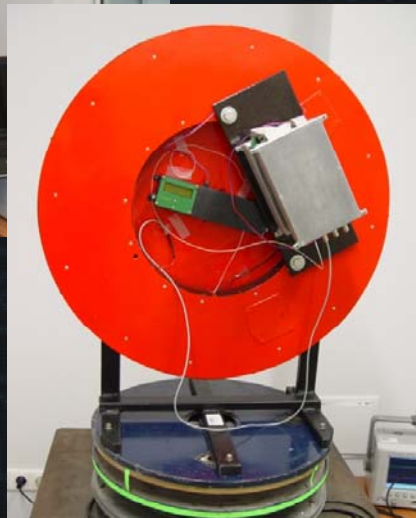
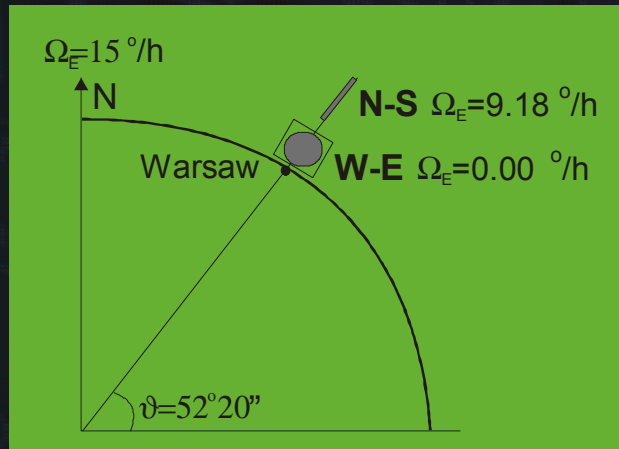
AFORS-3

$\Omega_t = 1.83 \cdot 10^{-9} \text{ rad/s/Hz}^{1/2}$

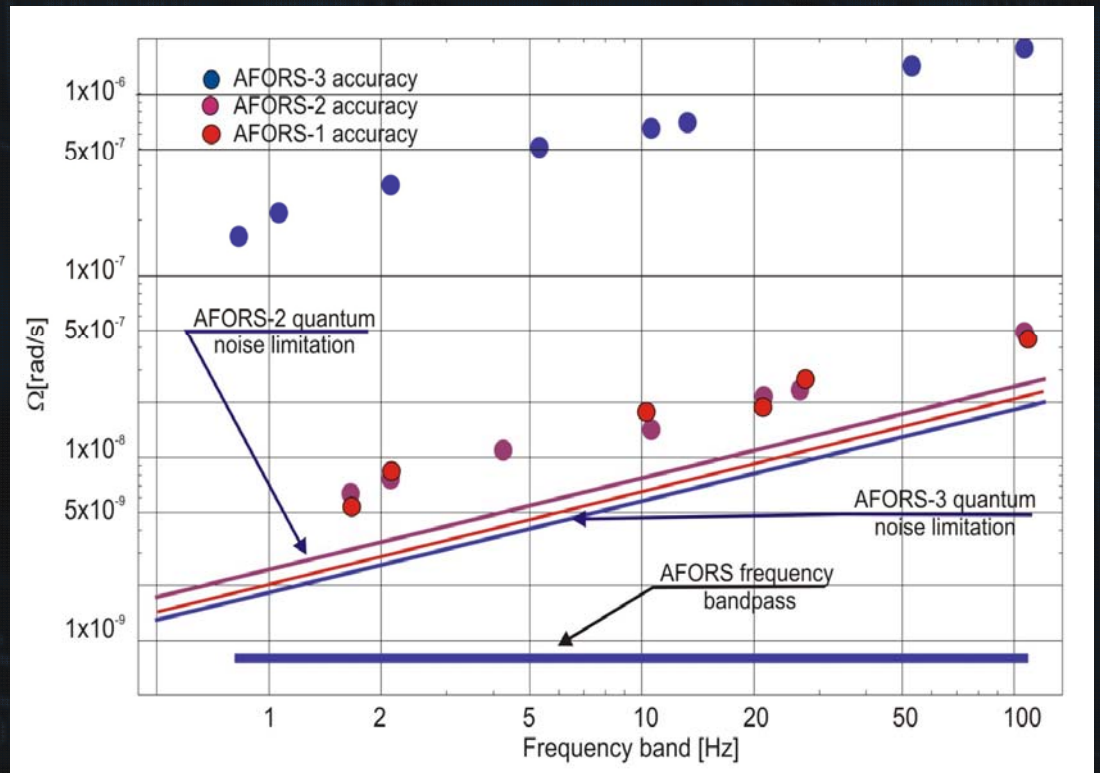
$L = 14\,360$ [m], 47 layers, double quadropole winded, $\alpha = 0.379$ [dB/km], loop $R = 0.315$ [m] contains permaloy particles, $\sigma = 11.74$ [dB], cascade polarizers (46 and 55 [dB]), depolarizer with 0.02 [dB] extinction ratio, $\Delta\lambda = 51,2$ [nm], $\lambda = 1311.2$ [nm], $P_L = 17.3$ [mW], $fg = 7.1$ kHz.



AFORSs calibration



$$\Omega = S_o \arctan [S_e \cdot u(t)]$$



	Accuracy		
$\Delta B =$	0.83 [Hz]	13.3 [Hz]	106.15 [Hz]
AFORS-2	$4.8 \cdot 10^{-9}$ [rad/s]	$1.5 \cdot 10^{-8}$ [rad/s]	$6.1 \cdot 10^{-8}$ [rad/s]
AFORS-3	$1.6 \cdot 10^{-7}$ [rad/s]	$6.9 \cdot 10^{-7}$ [rad/s]	$1.8 \cdot 10^{-6}$ [rad/s]



Remote Control

See POSTER <http://fors.m2s.pl>
Login&password: AFORSbook



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FORS – Telemetric Server 2010-08-18

Start
Measurements
Devices
Album
Users
Organizations
Logout

FORS-TS
Fiber-Optic Rotational Seismographs Telemetric System v.10.7 developed for remote control and data collection from installed FORSs in seismological laboratories.

Credits
Lesław R. Jaroszewicz PhD (Eng) (Osic)
Henryk A. Kowalski (J)
Jerzy K. Kowalski PhD (Eng)
Zdzisław Kojewski PhD (Eng)
Grzegorz Mazur (J)
Paweł Zimbo (J)

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Institute of Applied Physics

FORS – Telemetric Server 2010-10-08

Measurements

Search: Device name: Date from: to: Status: OK C: Yes Subtract the average:

Find 176

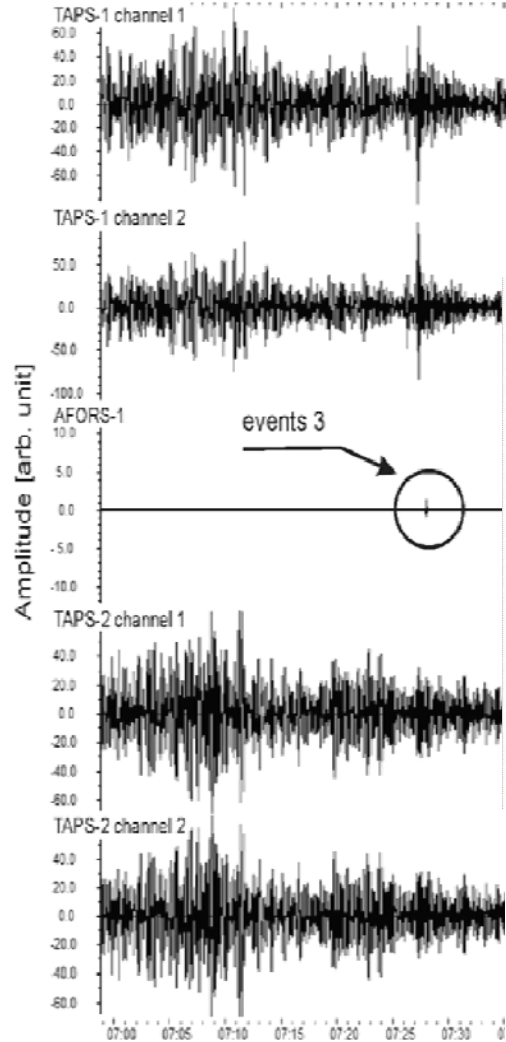
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1	1	2010-10-05 23:58:58	2010-10-06 01:58:58	3556833010028533	AFORS-1	000001287E678458	24	CSV	RT	D	
2	1	2010-10-05 23:37:19	2010-10-06 01:37:19	3556833010028533	AFORS-1	000001287E539C8C	21	CSV	RT	D	
3	1	2010-10-05 03:54:00	2010-10-05 05:54:00	3556833010028533	AFORS-1	000001287A184D68	21	CSV	RT	D	
4	1	2010-10-04 01:06:14	2010-10-04 03:06:14	3556833010028533	AFORS-1	0000012874583A2C	26	CSV	RT	D	
5	1	2010-10-03 22:14:12	2010-10-04 00:14:12	3556833010028533	AFORS-1	0000012873BA47FE	304	CSV	RT	D	
6	1	2010-10-03 22:11:01	2010-10-04 00:11:01	3556833010028533	AFORS-1	000001287307CE64	21	CSV	RT	D	
7	1	2010-10-03 22:04:07	2010-10-04 00:04:07	3556833010028533	AFORS-1	0000012873B1790F	28	CSV	RT	D	
8	1	2010-10-02 19:29:26	2010-10-02 21:29:26	3556833010028533	AFORS-1	000001286DF95551	2435	CSV	RT	D	
9	1	2010-10-01 21:33:24	2010-10-01 23:33:24	3556833010028533	AFORS-1	00000128694897FB	42	CSV	RT	D	
10	1	2010-10-01 21:27:28	2010-10-01 23:27:28	3556833010028533	AFORS-1	0000012869433808	23	CSV	RT	D	
11	1	2010-09-27 18:01:23	2010-09-27 20:01:23	3556833010028533	AFORS-1	000001285DE2AA63	741	CSV	RT	D	
12	1	2010-09-26 21:43:21	2010-09-26 23:43:21	3556833010028533	AFORS-1	000001284F91EF37	40	CSV	RT	D	
13	1	2010-09-26 21:17:35	2010-09-26 23:17:35	3556833010028533	AFORS-1	000001284F7A5838	27	CSV	RT	D	
14	1	2010-09-26 20:29:21	2010-09-26 22:29:21	3556833010028533	AFORS-1	000001284F4E24E5	131	CSV	RT	D	
15	1	2010-09-26 18:14:04	2010-09-26 20:14:04	3556833010028533	AFORS-1	000001284ED2145A	22	CSV	RT	D	
16	1	2010-09-26 17:46:44	2010-09-26 19:46:44	3556833010028533	AFORS-1	000001284E892E30	20	CSV	RT	D	
17	1	2010-09-26 16:23:21	2010-09-26 18:23:21	3556833010028533	AFORS-1	000001284E6CEB00	20	CSV	RT	D	
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19	1	2010-09-25 19:27:23	2010-09-25 21:27:23	3556833010028533	AFORS-1	0000012849EF1756	22	CSV	RT	D	
20	1	2010-09-25 18:23:58	2010-09-25 20:23:58	3556833010028533	AFORS-1	0000012849E0F840	22	CSV	RT	D	
21	1	2010-09-25 18:21:09	2010-09-25 20:21:09	3556833010028533	AFORS-1	0000012849E9503D	23	CSV	RT	D	
22	1	2010-09-25 17:48:52	2010-09-25 19:48:52	3556833010028533	AFORS-1	000001284994E265	21	CSV	RT	D	
23	1	2010-09-25 13:49:06	2010-09-25 15:49:06	3556833010028533	AFORS-1	0000012848B9957B	22	CSV	RT	D	



Example of events recording in Książ

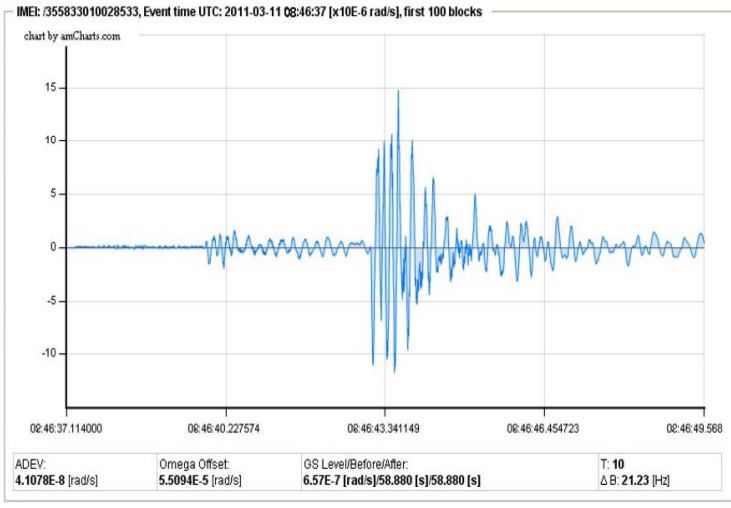
1. Jaroszewicz, L. R., Krajewski, Z. & Solarz, L. (2006). Absolute Rotation Measurement Based on the Sagnac Effect. in: *Earthquake Source Asymmetry, Structural Media and Rotation Effects*, R. Teisseyre, M. Takeo & E. Majewski E. (Eds), pp.413-438, ISBN 3-540-31336-2, Springer, Berlin
2. Jaroszewicz, L. R. & Krajewski Z. (2008). Application of the Fibre-Optic Rotational Seismometer in Investigation of the Seismic Rotational Waves, *Opto-Electron. Rev.*, Vol.16, No.3, (September 2008), pp. 314-320, ISSN 1230-3402
3. Jaroszewicz, L. R. & Wiszniowski J. (2008). Measurement of Short-Period Weak Rotation Signals, in: *Physics of Asymmetric Continuum: Extreme and Fracture Processes*, R. Teisseyre, H. Nagahama & E. Majewski, (Eds.), pp.17-47, ISBN 978-3-540-68354-4, Springer, Berlin
4. Jaroszewicz, L. R., Krajewski, Z., Kowalski, H., Mazur, G., Zinówko, P. & Kowalski, J. K. (2011a). AFORS Autonomous Fibre-Optic Rotational Seismograph: Design and Application. *Acta Geophys.*, Vol. 59, No.3, (March 2011), pp. 578-596, ISSN 0001-5725
5. Jaroszewicz, L. R., Krajewski, Z. & Teisseyre, K. P. (2011b). Usefulness of AFORS – Autonomous Fibre-Optic Rotational Seismograph for Investigation of Rotational Phenomena, *Journal of Seismology*, Special issue: Rotational Ground Motions, 16(4) (2012), 573-586, DOI: 10.1007/s10950-011-9258-3,
6. L.R. Jaroszewicz, Z. Krajewski, K. P. Teisseyre „Fibre-Optic Sagnac Interferometer as Seismograph for Direct Monitoring of Rotation Events” in D'Amico Sebastiano (Ed): *Earthquake Research and Analysis/Book 5*, InTech Open Access Publisher, Rijeka 2012, Ch.16, 335-354, ISBN 9790953-307-681-1



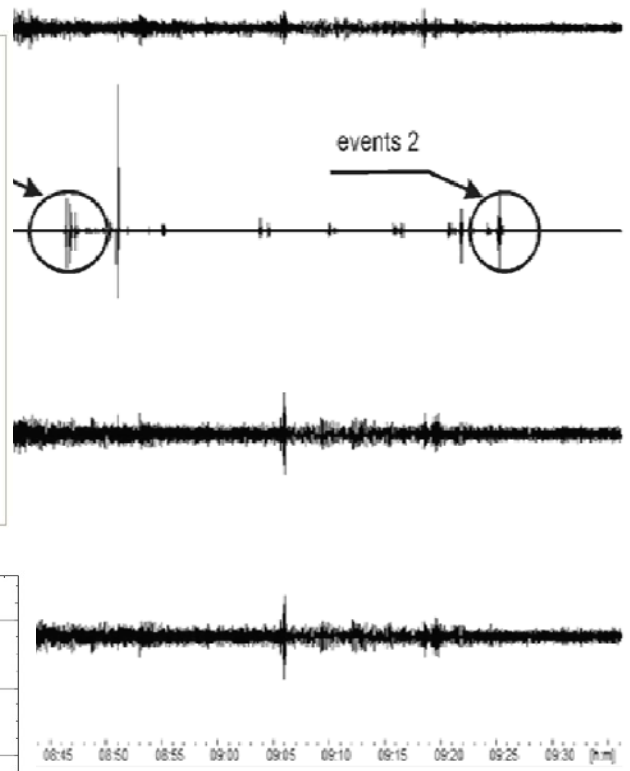


events 3

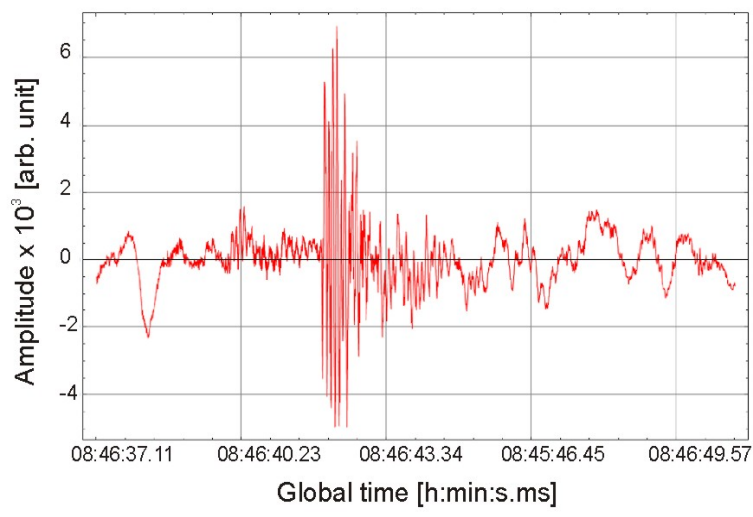
Measurements



events 2



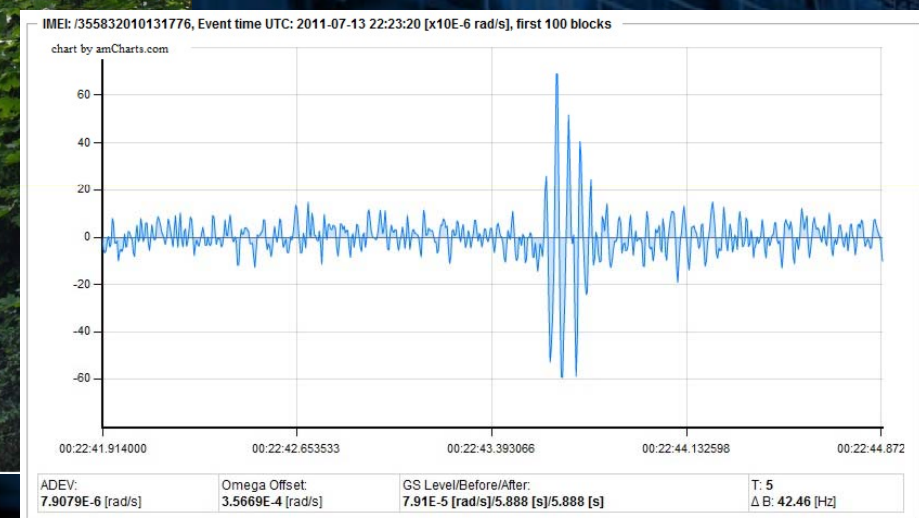
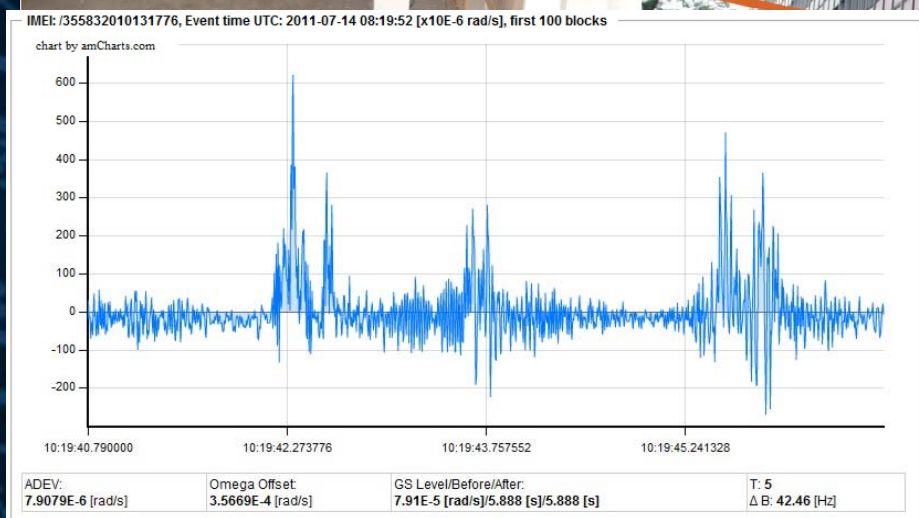
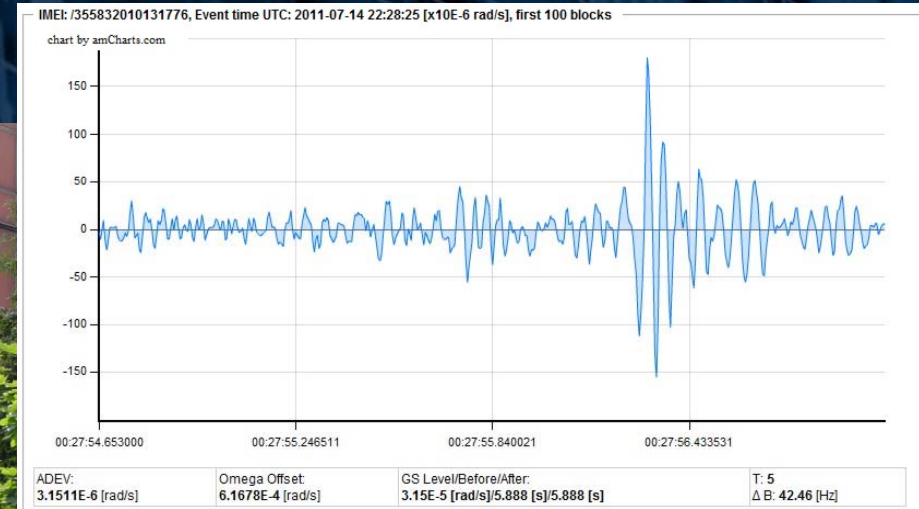
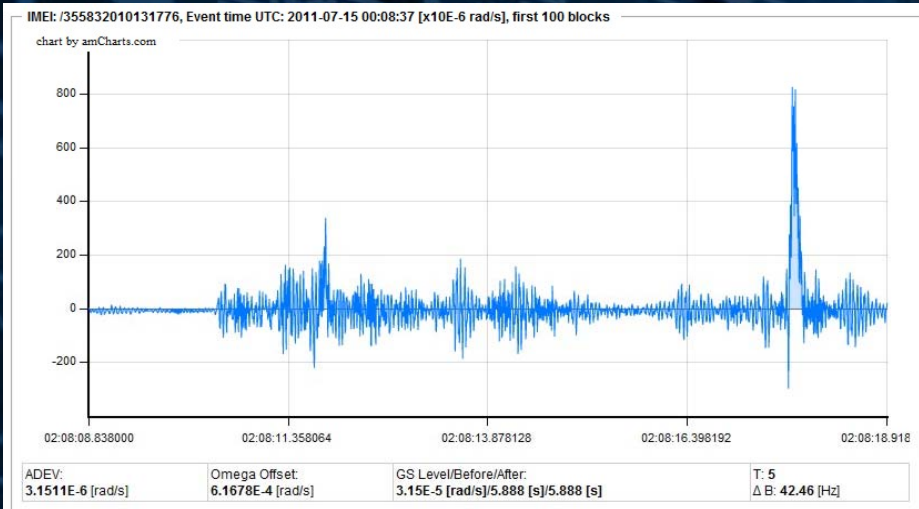
The plots of the seismic data from 6 h 58 min, after



March 11th, 2011, starting times UTC



Example of events recording in Warsaw



The data recorded as response for ground moves generated by morning intensity on the street in a distance about 50 m from and parallel to the long building wall.

The data recorded as response for ground moves after tram pass through street in distance about 50 m from and parallel to long building wall.

[L.R. Jaroszewicz, et al., in Oren Lavan, Mario De Stefano (Eds): Seismic Behaviour and Design of Irregular and Complex Civil Structures, Springer 2013, Ch.23, 339-351]



AFORSs application for monitoring building rotation



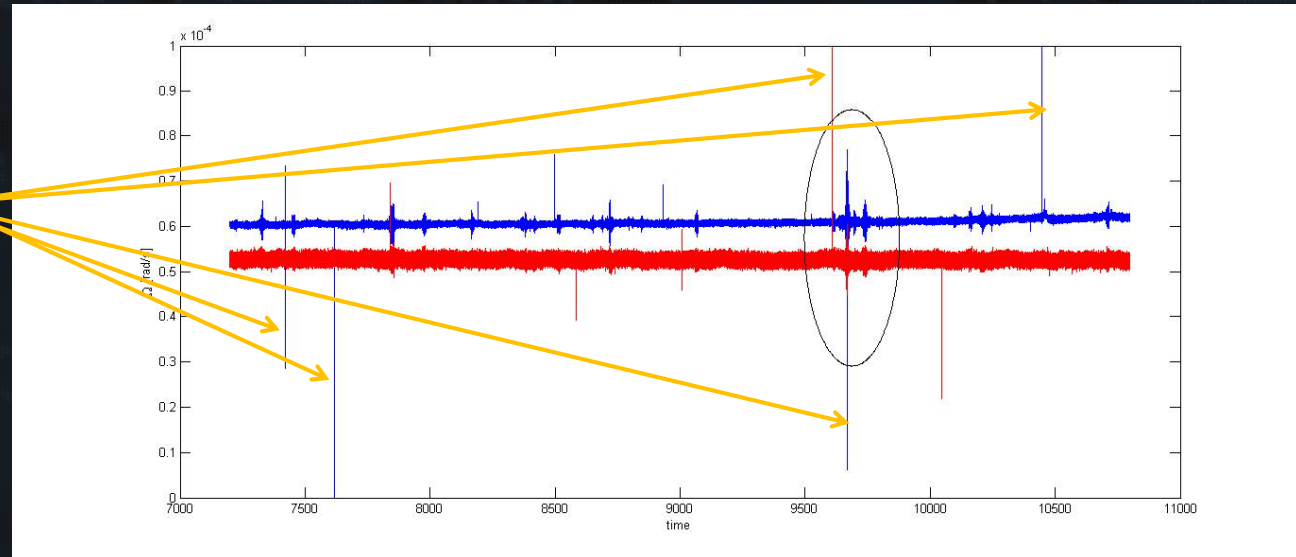
← AFORS - 2

AFORS - 3 →



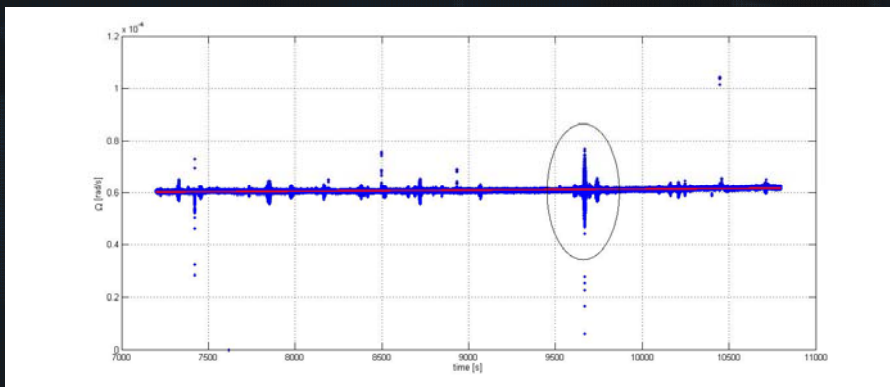
Outcome

Analogue to digital conversion errors



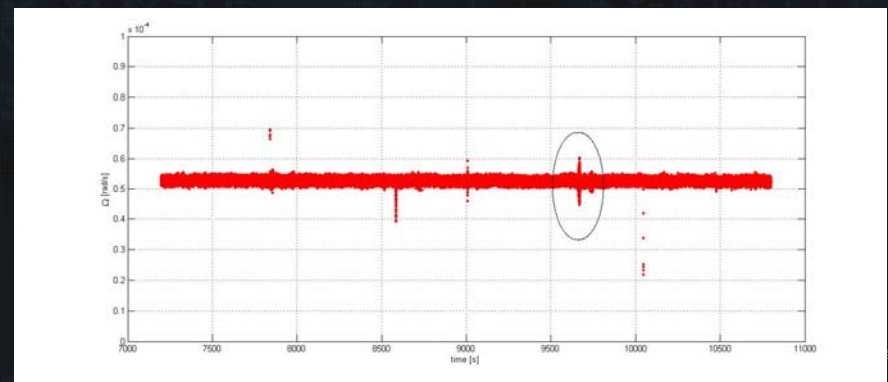
Data after linear regression approximation

AFORS - 2



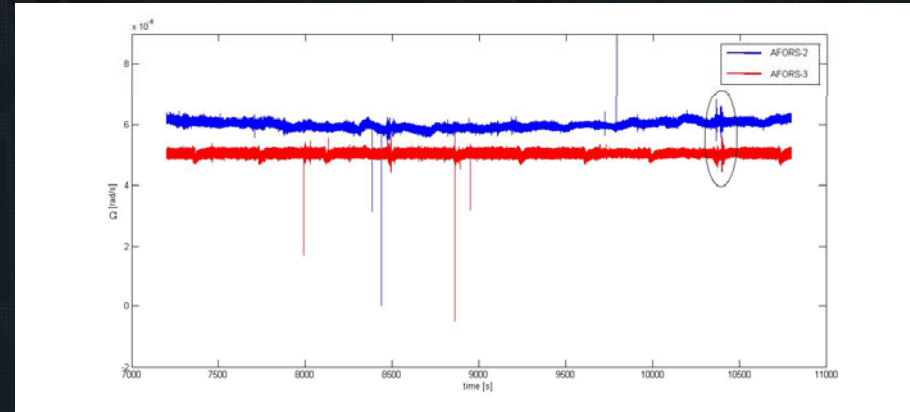
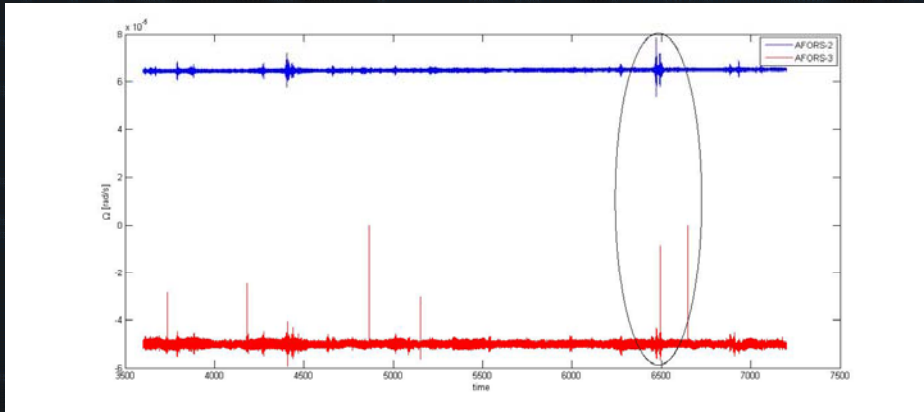
Data after linear regression approximation

AFORS - 3



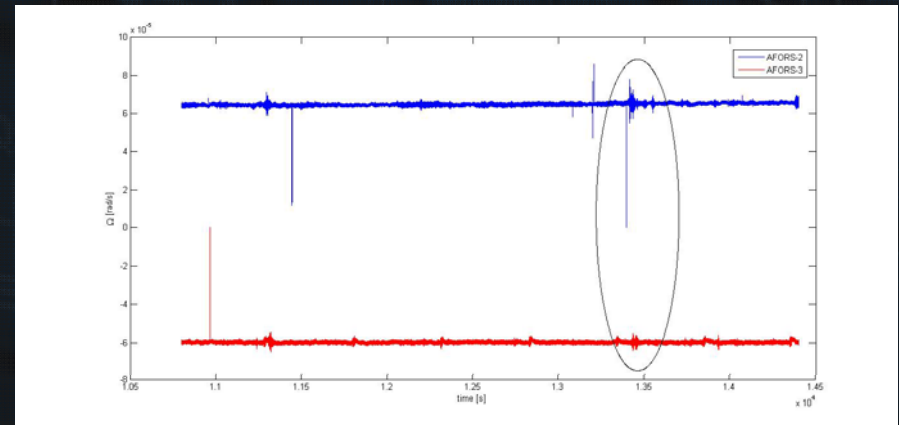
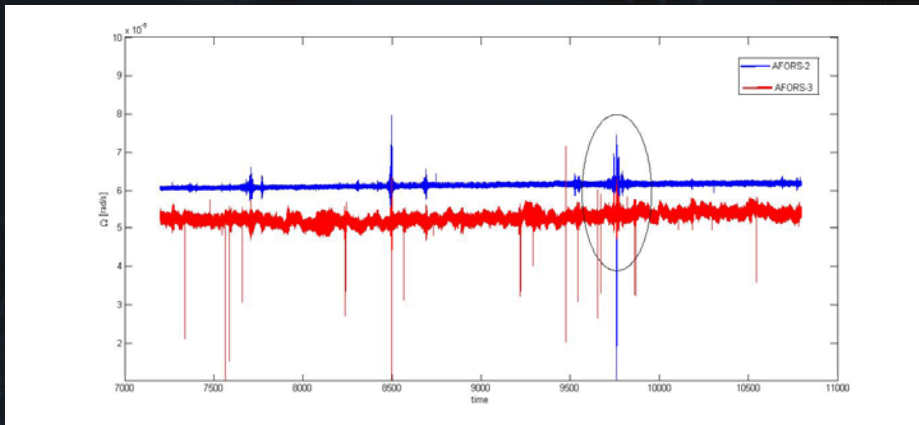
AFORS – 2, ground floor refernce

AFORS – 3, ground floor refernce



AFORS-2 -- ground floor AFORS-3 -- first floor

AFORS-3 -- ground floor AFORS-2 -- first floor



AFORS-2 -- ground floor AFORS-3 -- third floor

AFORS-3 -- ground floor AFORS-2 -- third floor

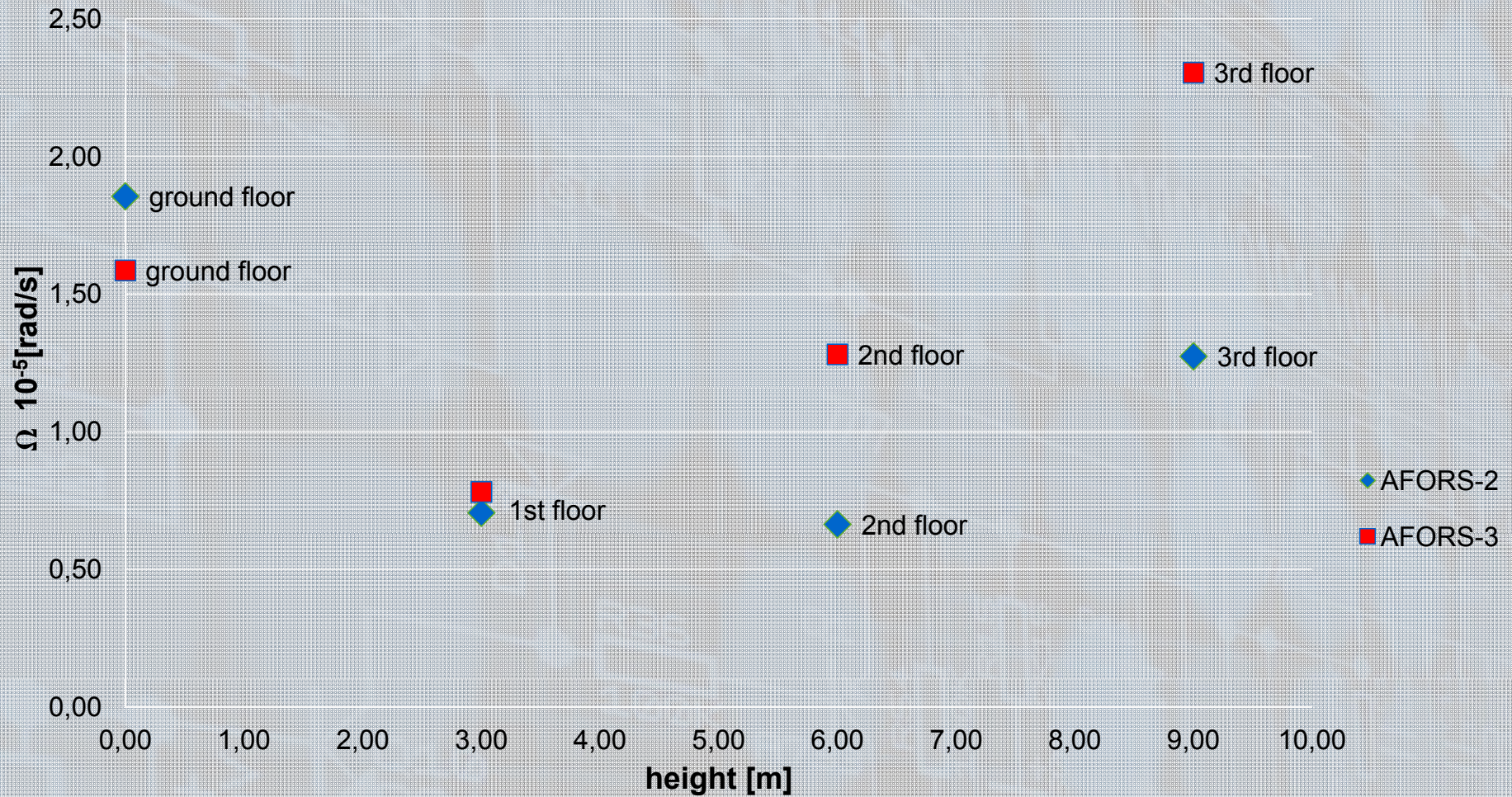


	LOCATION	AMPLITUDE FOR 21 Hz DETECTION BAND [rad/s]	AFTER CALIBRATION [rad/s]
AFORS-2	Ground floor	$1,586 \cdot 10^{-5}$	$1,586 \cdot 10^{-5}$
AFORS-3	Ground floor	$0,784 \cdot 10^{-5}$	$1,586 \cdot 10^{-5}$
AFORS-2	Ground floor	$0,921 \cdot 10^{-5}$	$0,921 \cdot 10^{-5}$
AFORS-3	First floor	$0,386 \cdot 10^{-5}$	$0,781 \cdot 10^{-5}$
AFORS-2	Ground floor	$0,942 \cdot 10^{-5}$	$0,942 \cdot 10^{-5}$
AFORS-3	Second floor	$0,633 \cdot 10^{-5}$	$1,281 \cdot 10^{-5}$
AFORS-2	Ground floor	$1,855 \cdot 10^{-5}$	$1,855 \cdot 10^{-5}$
AFORS-3	Third floor	$1,139 \cdot 10^{-5}$	$2,304 \cdot 10^{-5}$

	LOCATION	AMPLITUDE FOR 21 Hz DETECTION BAND [rad/s]	AFTER CALIBRATION [rad/s]
AFORS-2	Ground floor	$1,586 \cdot 10^{-5}$	$1,586 \cdot 10^{-5}$
AFORS-3	Ground floor	$0,784 \cdot 10^{-5}$	$1,586 \cdot 10^{-5}$
AFORS-2	First floor	$0,706 \cdot 10^{-5}$	$0,706 \cdot 10^{-5}$
AFORS-3	Ground floor	$0,594 \cdot 10^{-5}$	$1,202 \cdot 10^{-5}$
AFORS-2	Second floor	$0,664 \cdot 10^{-5}$	$0,664 \cdot 10^{-5}$
AFORS-3	Ground floor	$0,536 \cdot 10^{-5}$	$1,084 \cdot 10^{-5}$
AFORS-2	Third floor	$1,274 \cdot 10^{-5}$	$1,274 \cdot 10^{-5}$
AFORS-3	Ground floor	$0,430 \cdot 10^{-5}$	$0,870 \cdot 10^{-5}$



Maximum amplitude



Conclusions

1. The main advantages of AFORS systems:

- mobile with remote control of their main parameters,
- continuously monitoring of seismic rotational events,
- immediate information about recorded events,
- enough accuracy and frequency bandpass for seismic application.

2. The main disadvantages of AFORS systems:

- extremely high cost (uses only for limited applications),
- problem with verification of their proper works,
- single axis rotation measurements.
- errors under highly temperatures (above 60 °C)

3. Solution FOSREM project – we should have five systems in next year

