Publications of the Institute of Geophysics, Polish Academy of Sciences
Geophysical Data Bases, Processing and Instrumentation
vol. 446 (A-32), 2023, pp. 57-63
DOI: 10.25171/InstGeoph_PAS_Publs-2023-014

Wonderful and Yet Strange is This World – My Tribute to Professor Roman Teisseyre

Leszek R. JAROSZEWICZ

Institute of Applied Physics, Military University of Technology, Warszawa, Poland

✉ jarosz@wat.edu.pl

On 21 November 2022, Monday, a few minutes after 10 am, during the session of the 6th Meeting of International Working Group on Rotational Seismology (IWGoRS), I received a text message with the sad news from Krzysztof Teisseyre that his dad Roman had just passed away. We were at the Insititut de Physique du Globe in Paris, in a straight line about 100 m from the Marie Curie-Sklodowska's Laboratory, room kept as if she had just left for a while. It is significant that at this moment in the room Dr. Anjali C. Dhuba (post-doctoral fellowship at Universität Hamburg) was presenting a paper: "A Rotational Low Noise Model Reduced Micropolar Theory: an alternative to model the Earth Medium and simulate earthquake ground motions?". Thus, Roman's ideas are not going away, they are still alive....

I have known Prof. Roman Teisseyre for more than 20 years. At the beginning of this century, based on a conversation with Prof. Katarzyna Chałasińska-Macukow, Her Magnificence Rector of the University of Warsaw, during the SPIE congress in San Diego, USA, I got a contact to Prof. Roman Teisseyre for consultation regarding the possible occurrence of rotation in the ground. We observed such effects with the help of a uniaxial fiber-optic gyroscope installed at the Military University of Technology (MUT) after a streetcar passed nearby. Interestingly, the MUT located in Warsaw on Gen. Sylwester Kaliski Street is the closest scientific unit to the Institute of Geophysics, PAS (IG PAS) located on Księcia Janusza Street, and contacts are made in the US… Then I met Prof. Teisseyre for the first time, at his place in the Institute, and he immediately suggested to me – then a postdoctoral fellow – that we call each other by our first names. Based on this meeting, at the end of 2001, we made a joint check of the TAPS (Twin Antiparallel Pendulum Seismometers) system of IG PAS, based on FOG – a fiber-optic gyroscope adapted as FORS-1 (Fiber-Optic Rotational Seismometer), archival photos of which are in Fig. 1.

I think it is important to emphasize that Roman was an outstanding scientist, a physicist, but a theoretician. He was fully aware of this and said "that he is such an incorrigible theoretician that when he eats a soft-boiled egg for breakfast, I get all splattered with it". I, on the other hand, consider myself to be a technical physicist, which often led to some consternation, because Roman knew how something should work, while I knew how something works – and that's a crazy difference. Hence, in the early days of our acquaintance when I started working

Fig. 1. November 2001: IG PAS joint launch of the two systems, TAPS and FORS-1. Left photo – Prof. Teisseyre and Dr. Eng. Jaroszewicz point fingers at their own children, TAPS and FORS-1. Right photo – Prof. Teisseyre with employees of IG PAS and MUT analyse recordings from both systems.

on a fibre-optic rotating seismometer, it was difficult for me to get information from Roman about the required technical parameters of this system – our conversation: "Roman – what sensitivity? Leszek – as high as possible, Roman – what detection bandwidth? Leszek – you know it should be adequate to measure everything, Roman – and what is the maximum amplitude of measured angular velocities? Leszek – obviously very large. Roman – and on top of that the arrangement is probably supposed to be small, portable, operating autonomously, Leszek after all that's obvious."

I recall two important facts from the first period of our collaboration. Firstly, the theoretical and experimental work related to the analysis of the operation of the TAPS system and the validation of its indications by means of FORS-1, a system being a mobile adaptation of the model of the FOG created within the framework of my doctoral thesis of 1988 (Jaroszewicz et al. 2003 b; Solarz et al. 2004). However, more important is the second issue – Roman's inspiration to give him a rotational seismograph in line with his theoretical inspirations: with maximum sensitivity, wide amplitude of measured rotations, extreme bandwidth, etc., which we managed to define for the field of rotational seismology as late as in 2016 (Jaroszewicz et al. 2016b). The FORS-1 system, with a sensitivity of the order of 10^{-6} rad/s, proved to be an undersensitive instrument, as indicated by its use together with a set of two TAPSs in the existing Seismological Observatory in Ojców (Jaroszewicz and Krajewski 2002; Jaroszewicz et al. 2003a) as well as in Książ (Jaroszewicz et al. 2005b) at the beginning of the 21st century. Nonetheless, field studies from the late 2002 and early 2003 (Jaroszewicz and Krajewski 2002; Jaroszewicz et al. 2003a) probably represent some of the first works in the world demonstrating the feasibility of building a fibre-optic rotating seismograph based on the use of the Sagnac effect.

It was at Roman's inspiration that we undertook the construction of a new fibre-optic rotational seismometer – FORS-II (with a 0.63 m diameter sensing loop, containing 11 130 m of SMF fibre, which provided a sensitivity of $4 \cdot 10^{-8}$ rad/s). The essence of its application (together with a two-TAPSs) in the Seismological Observatory in Ojców was the recording at the end of 2004 of the occurrence of a delay of the rotational component in relation to classical *P* and *S* seismic waves in the near field for events generated in the Lubin or Silesia regions (Jaroszewicz et al. 2005a; 2006b). I consider this to be one of the most important statements that, through Roman's theoretical work (Teisseyre and Majewski 2001; Teisseyre 2004), lead to the occurrence of rotational seismic waves according to his ideas. Unfortunately, a single measurement system was insufficient for further validation of the results, especially as we did not have a re-

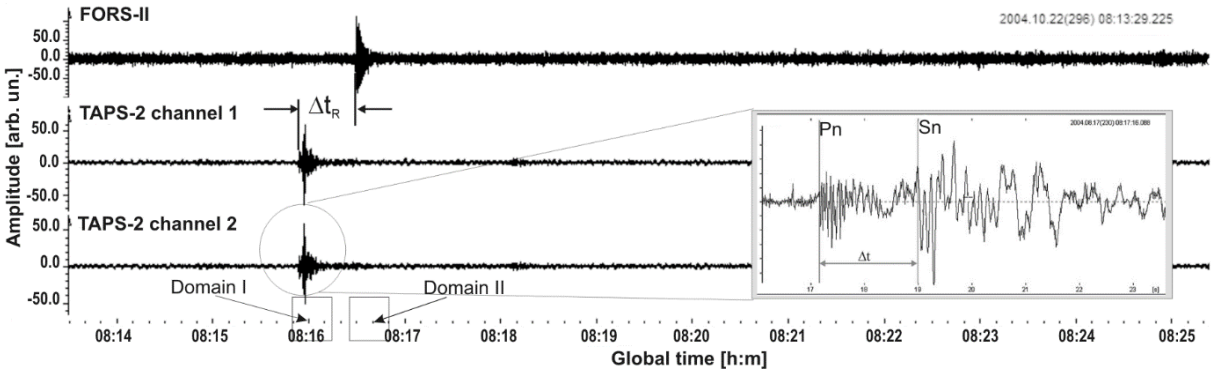

Fig. 2. Seismogram of the seismic events recorded on 22 October 2004 at 8 h 13 min by FORS-II and Second TAPS with two selected domains: Domain I where two channels of TAPS-2 detected classical seismic wave, and Domain II delayed about Δt_R where FORS-II detected rotational component. The insets show the method of time delay identification between *S*-waves (*Sn* line) and *P*-waves (*Pn* line) (from Jaroszewicz et al. 2006b).

liable data recording system at the time, and the electronic part was based on the use of laboratory equipment difficult to stay in the humid environment of the seismological laboratory in Ojców. Nonetheless, thanks to the cooperation with Roman, we came up with our concept of using a fibre-optic rotational seismometer in significant book positions published by him as co-editor in the Springer Publishing House in 2006 (Jaroszewicz et al. 2006a; Jaroszewicz and Wiszniowski 2008) (see Fig. 2).

The next one of our AFORS-1 (Autonomous Fiber-Optic Rotational Seismograph) measuring instruments is a fully mobile single-axis rotational seismometer that measures rotational disturbances autonomously. It was installed at the Seismological Observatory in Książ under Roman's supervision in July 2010, as evidenced by the archive photos below (Fig. 3). This system, with a sensitivity of 10^{-9} rad/s, was continuously operated for seven years, recording torsion-type disturbances from earthquakes in the far field as well as in the near field (Jaroszewicz et al. 2011, 2012; Kurzych et al. 2014), until it was found to be faulty in July 2017 – the fibre-optic cables had been bitten by rats (see an inner window in the photo below). During this

Fig. 3. July 2010: Prof. Jaroszewicz, Prof. Teisseyre, and an employee of the IG PAS Seismological Observatory in Książ (left photo) during the installation of the AFORS-1 in the measurement chamber at the Seismological Observatory in Książ (right photo) together with the view in the lower right window of the AFORS-1 destroyed by rats in July 2017.

period, it was possible to confirm that torsion-type disturbances are recorded synchronously by the AFORS system as well as TAPSs, i.e., that they are not correlated with *P* or *S*-waves (Jaroszewicz et al. 2012).

Towards the end of the first decade of the 21st century, issues of rotation took on a new face related to their vital importance for construction and, more specifically, the effect of the rotational component on irregular and complex structures. In a way, they were stimulated by Dr. William H.K. (Willie) Lee from the US Geological Survey, who unfortunately also passed away from us in November 2022; he selected from all over the world various persons dealing with the subject of seismic rotation (including Prof. Teisseyre, Prof. Majewski, and Prof. Zembaty from Poland) and invited them to Menlo Park, California. This meeting was, in fact, the first seminar of the newly formed International Working Group on Rotational Seismology (IWGoRS, https://www.rotational-seismology.org), which is still active today. The May 2009 special issue of the *Bull. Seismol. Soc. Am.* [vol. 99, no. 2B], which includes two papers by Roman, is the foundation of the research area for rotational seismology defined there as, quote: "an emerging area of analysis of all aspects of rotational ground motions forced by earthquakes, explosions, and ambient vibrations" (Lee et al. 2009). Roman was a recognised member of the IWGoRS, while the group itself is extremely active as evidenced, for example, by joint tests of various types of rotational seismometers, one of which took place in Germany near Munich in 2019, gathering more than 40 instruments in one place (Kurzych et al. 2020; Bernauer et al. 2021).

Hence, rotational seismology, in addition to research strictly related to seismology, also includes the so-called engineering applications referred to by Prof. Zembaty as seismic engineering of irregular structures. In this field, regular conferences have been held for years within the framework of the European Workshop on the Irregular and Complex Structures (EWICS), which have resulted, among other things, in monographs published by prominent publishing houses such as Springer. Constructed, undoubtedly under Roman's inspiration, our fibre-optic rotating seismometers AFORS, FOS4, FOS5 are used in this research – see e.g. (Jaroszewicz et al. 2013, 2016a; Jaroszewicz and Kurzych 2018).

In 2011, the 6th EWIC Conference was held in Haifa, Israel. Roman, at 82 years of age at the time, took an extremely active part in the event, as documented by the photos below. As a reminiscence, I will cite here two amusing incidents that perfectly illustrate him as a person. I was flying to Haifa with my wife via Vienna, at the time there was no direct connection from Poland, and because of my size, I always chose the seat next to the aisle. Suddenly, someone grabs my right arm, I raise my eyes and see a beaming Roman standing over me, I am completely surprised. So, I ask what he is doing here and Roman in his style says: "Leszek how good to see you, what are you doing here?". I say: "My wife Krysia and I are going to Haifa for the 6-EWIC Conference", and Roman says: "That's great, because, you know, me and Bogna (Roman's wife) are going to this conference too, but you know, I don't know anything about it, I don't know what days it is, where the sessions are going to take place and in general I was very worried about it, but you're going to be here, so I'm calm". All Roman, flying all over Europe, without a plan, somehow it will happen – pure theorist. After the conference, we hired a car to visit the cradle of Christianity, especially as Roman and I as well as our wives were in Israel for the first time. Roman was particularly excited about visiting the Dead Sea and being able to swim in it. Bathing in the Dead Sea is exciting because of its salinity, which causes the swimmer to float on the surface, but one must be particularly careful not to choke on this brine or get their eyes wet. Well, I am swimming, floating on the surface of the Dead Sea and I see Roman who carefully steps onto the pier and then runs and JUMPS HEADFIRST into the water!!! There were dozens of people in the water and on the shore, all frozen. The moment Roman emerged from the water the closest people rushed to help him, bringing him ashore and then

sacrificing their own fresh water, invaluable due to the 40+ degree heat, to wash his eyes and face. When Roman has cooled down a little, I ask him: "Romek what have you done, after all we talked about being VERY careful in the bath and under no circumstances dipping your head in the sea". To which Romek replied: "Leszek, I know it, but all my life I've dreamt of bathing in the Dead Sea so much, so that when I saw it, I just went mad", it is the whole Romek. Some photos of our trip to Israel are in Figs. 4 and 5.

As I mentioned in the introduction, I am a technical physicist not a theoretical one, hence the intricacies of the tensor notation used by Roman are not achievable to me. However, when analysing his works, I believe that in many of them he was guided by scientific intuition, a trait of the few, often unsupported by a proper argument, which he was repeatedly reproached for. Perhaps this was influenced by his initial scientific path in the 1950s in Leopold Infeld's theoretical physics group. I regard this scientific intuition as extremely important: when in the 1970s he postulated the existence of at least a rotational component in seismic waves, let alone the existence of seismic rotational waves, nobody was taking it seriously. Today, however, after half a century, the existence of rotation even in homogeneous media is widely recognised and studied. Admittedly, they require a new class of measuring instruments, but this provides a field of scientific work for others, including myself, which I am very pleased about.

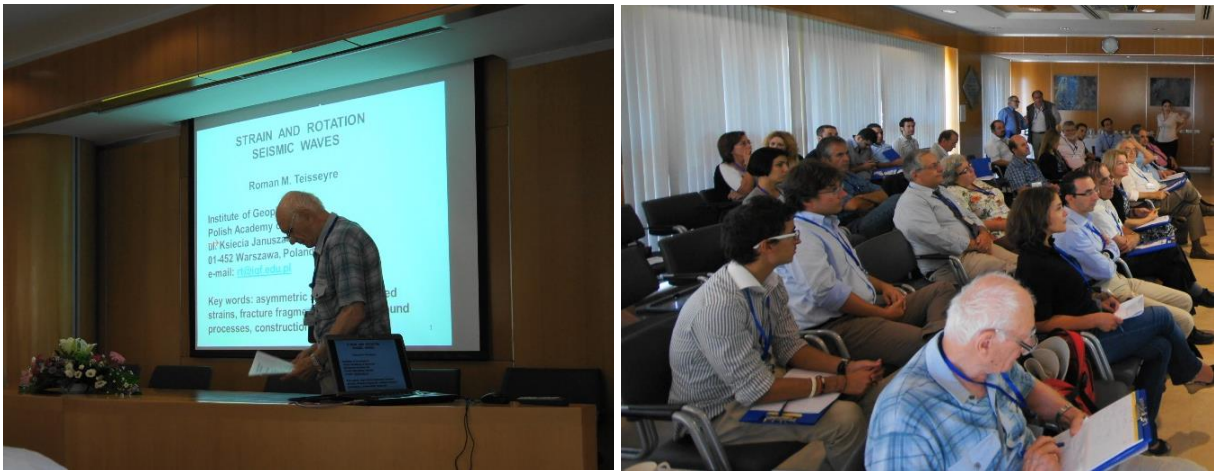

Fig. 4. September 2011: Prof. R. Teisseyre at a plenary address and session during the 6th EWICS, Haifa, Israel.

Fig. 5. September 2011: during the 6-EWICS tour in Israel. Left photo: Prof. R. Teisseyre with my wife in front of the board indicating zero level on the way to the Dead Sea located in a 300 m depression. Right photo: Roman with his wife Bogna in Nazareth.

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Received 19 July 2023
Received in revised form 16 November 2023
Accepted 22 November 2023