BEGINNINGS OF REGULAR SEISMIC SERVICE AND RESEARCH IN THE AUSTRO-HUNGARIAN MONARCHY: PART II

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ABSTRACT

We closed the preceding part of our paper with the statements that a regular macroseismic service of unprecedented effectivity had been successfully established in the Austrian part of the Monarchy in 1896–1899, and that first continuous instrumental observations had been started at the seismic stations in Ljubljana, Trieste and Kremsmünster in 1897, 1898 and 1899, respectively. In the present part we report how the macroseismic service performed its task from the beginning of the 20th century until the outbreak of World War I, we briefly summarize the beginnings and development of observational seismology in the Hungarian part of the Monarchy, and we inform the reader about the state of European seismometry at the time of establishment of the first stations of the Austro-Hungarian seismographic network.

Main topics of the present paper are the history of the development, the principles and properties of the instruments, and the milestones in the interpretation of instrumental observations in both parts of the Monarchy in 1897–1914. The wealth of information extracted from over seventy original papers and books of geoscientists of the time is summarized in the form of two, to a large extent self explaining tables. In Table 1 the altogether seventeen seismic stations gradually established in the Austrian as well as Hungarian parts of the Monarchy in 1897–1914 are ordered chronologically according to the date of initiation of regular measurements at them, and the instruments by which the stations were originally equipped and later successively upgraded are specified. The most important facts about progress in the instrumentation and in the analysis, interpretation and archivation of the observational material are summed up in the last column of Table 1. The principles of the altogether sixteen different types of seismic instruments that were in operation at the stations of the Austro-Hungarian network in the discussed period are explained and their basic technical parameters are specified in Table 2. Those instrumental problems, those moments in the methodology of interpretation of the instrumental observations, and the contributions of those scientists who most decisively influenced the progress of Austro-Hungarian seismology in 1897–1914 are commented in more detail in the text.

At the end of the first decade of the 20th century, the instrumentation of the stations of the Austro-Hungarian seismographic network as well as the scientific erudition and publication activities of the station directors and involved geosavants, especially of A. Belar, H. Benndorf, R. Kövesligethy, V. Láska, E. Mazelle, A. and S. Mohorovičić and

A. Réthly, had reached a standard comparable with that of analogous activities in Italy and Germany. The well developed Austrian macroseismic service gradually disintegrated during World War I. After the war, seismology progressed in the newly constituted states Czechoslovakia, Poland and Yugoslavia in broader, all-European collaboration.

Keywords: history of earthquake research, macroseismic and instrumental observations, Austro-Hungarian Monarchy

1. INTRODUCTION

As demonstrated in Part I of this paper (*Kozák and Plešinger, 2003*), the project formulated by the Austrian geologist and paleontologist Edmund von Mojsisovics in the mid-nineties of the 19th century and presented by him to the April 25, 1895 session of the Imperial Academy of Sciences (Kaiserliche Akademie der Wissenschaften) in Vienna, must be admired as an unprecedented effort to organize and run in the Austrian part of the Monarchy a regular, reliable seismic survey. According to the project, the main two tasks of the Earthquake Commission (Erdbeben-Kommission) established by the Academy at the mentioned session, were (1) to compile a catalogue of "all reliably documented historical earthquakes on the territory of Austria, especially in the region of the Eastern Alps", and (2) to "organize a seismic survey in the Austrian countries" involving (a) "a number of seismographic stations equipped with autonomously recording earthquake-meters" and (b) "a network of permanent observers" of macroseismic effects of earthquakes.

Task (1) was never accomplished in the way and to an extent approaching the original intentions of the Earthquake Commission (Prof. Dr. Rudolf Hoernes from the Graz University was entrusted with the organization of this part of the project, and three years were originally estimated to be necessary for its accomplishment). According to particulars given in the section on earthquake catalogues of Sieberg's Handbuch der Erdbebenkunde (*Sieberg, 1904*), lists and descriptions of historical earthquakes on the territory of the Monarchy and its surroundings had been compiled and published already in the second half of the 19th century by *Jeitteles (1860)* for the Carpathians and the Sudeten, by *Mitteis (1862)* for Krain, by *Suess (1873)* for Lower Austria, and by *Hoefer (1880)* for Kärnten. As stated much later by *Toperczer and Trapp (1950)*, most stimulating for efforts of geoscientists to compile data about historical earthquakes on the territory of Europe had been the fundamental catalogue for Lower Austria compiled by *Suess (1873)*. Hoernes evidently did not succeed in promoting further analogous efforts within the Mojsisovics project in the supposed time span of three years: in none of the altogether 21 reports of the first (1897–1899) series of the Communications of the Earthquake Commission (*Mittheilungen der Erdbeben-Kommission, 1897–1900*) any progress in this direction by the end of the 19th century was mentioned. Task (1) of the project however cannot be classified as completely unsuccessful since eventually, with a delay of almost five years in comparison with the original intention, three further catalogues compiled by Hoernes himself and by other two of the altogether 16 reporters (Referenten) of the meanwhile well performing macroseismic network, professors V. Láska (Lvov/Lemberg) and J. Schorn (Innsbruck), appeared in the "new series" of the

Mittheilungen der Erdbeben-Kommission (1900−1912) and in the Zeitschrift des Ferdinandeums - catalogues of historical earthquakes in the Steiermark (*Hoernes, 1902*), in Silesia/Poland (*Láska, 1902*), and in the Tirol and Vorarlberg provinces (*Schorn, 1903*).

The history and progress of the gradual implementation of the network of macroseismic observers and of the installation of the first "earthquake indicators" (Erdbebenmelder) and "earthquake meters" (Erdbebenmesser) in the period from the initiation of the Mojsisovics project in late 1895 until the end of the 19th century has been described and discussed in Part I of this paper. In the present part we summarize how the successfully established and reliably functioning macroseismic service of the Austrian part of the Monarchy performed its task from the beginning of the 20th century until its collapse in the course of World War I, and we also include a summary of the history of macroseismic observations in the Hungarian part of the Monarchy.

Main topics of the present article are the development, the instruments, and the milestones of "microseismic" observations in both parts of the Monarchy inclusive of Galicia, Slavonia, Croatia and Bosnia, from their beginning in1897 until the outbreak of World War I. To our knowledge the history of instrumental observations in the Monarchy in this period has never been described in due consistency before. We therefore treat this matter somewhat more thoroughly, leaning on facts and data which we compiled from relevant contemporaneous books, geoscientific periodicals and from over seventy papers of reputable geoscientists of the time.

2. MACROSEISMIC SERVICE IN THE AUSTRIAN PART OF THE MONARCHY 1900−1914

At the beginning of the 20th century the established network of permanent observers (point 2b of the Mojsisovics Project) was successfully performing the task of a reliable regional macroseismic service: over 1700 observers were reporting macroseismic observations from all sixteen provinces of the Austrian part of the Monarchy to professional regional representatives, so-called Referenten, a number of whom were outstanding natural scientists of the time (for details see Part I of this paper).

In the first four years, annual bulletins for the whole territory, entitled Allgemeiner Bericht und Chronik der im Jahre 1900 (1901,1902,1903) im Beobachtungsgebiet eingetretenen Erdbeben, were compiled by Mojsisovics himself and published as, respectively, Nos. II, X, XIX and XXV of the "new series" of the *Mittheilungen der Erdbeben–Kommission (1900−1912)*. These bulletins contained not only summarizing macroseismic data for individual events and regions and basic monthly and annual statistics of the seismicity of the whole region, but also details and isoseismal maps of stronger events as well as topical news on progress in the microseismic (instrumental) part of the project. From the variety of interesting macroseismic information let us mention at least the reports on two large earthquake swarms on the territory of Bohemia, one between July 1 and August 21, 1900 in West-Bohemia (No. II of *Mittheilungen der Erdbeben–Kommission (1900−1912)*; maximum observed intensity V−VI), the other between February 13 and May 6, 1903 in the Ore-Mountains (No. XXV of *Mittheilungen der Erdbeben–Kommission (1900−1912)*; over 2000 macroseismic observations of about 500 shocks).

In his introduction to the latter report Mojsisovics mentioned that the Erdbeben-Kommission had always been fully aware of its only temporary role in the organization of regular seismic observations in the Monarchy, and he stated that in late 1903 the seismic service, established and successively expanded by the Commission in 1896–1899 and conducted by it in the following three years, appeared to function quite satisfactorily. The Erdbeben-Kommission therefore recommended to entrust with the further administration and supervision of the seismic observations a state institution. Willingness to take over the "complete micro- and macroseismic service" was expressed by the directorial board of the *k.k.* (king and emperor's) Zentralanstalt für Meteorologie und Erdmagnetismus (established by the Academy of Sciences in Vienna in 1851). The respective official authorization to do so under the new designation Zentralanstalt für Meteorologie und Geodynamik was issued by the *k.k.* Ministery for Culture and Education on February 23, 1904 (*Toperczer and Trapp 1950; Hammerl et al. 2001*).

In early 1904 the Austrian seismic service was thus nationalized. From this year on the regular annual bulletins were published under the slightly modified title Allgemeiner Bericht und Chronik der im Jahre 1904 (1905, ...,1921) in Österreich beobachteten Erdbeben (*Allgemeiner Bericht und Chronik der in Österreich beobachteten Erdbeben, 1906–1922*) by the Zentralanstalt für Meteorologie und Geodynamik, while the Erdbeben-Kommission focused its activities further on mainly at the promotion of scientific works and at the publication of scientific papers.

Since the Zentralanstalt had the privilege of a charge-free correspondence with its observers, the local observers now sent their reports directly to Vienna, and the Zentralanstalt forwarded them to the regional reporters. This was some unforced initial step towards the centralization of the seismic service in the Austrian part of the Monarchy. The Zentralanstalt also issued an improved macroseismic questionnaire with instructions in postcard form, and from 1909 the annual bulletins (*Allgemeiner Bericht und Chronik der in Österreich beobachteten Erdbeben, 1906–1922*) were published in an improved, condensed form containing the onset times, locations, intensities (Stärkegrad) and number of submitted reports for all observed events. After the outbreak of World War I, the well developed Austrian seismic service, directed at that time by Dr. Rudolf Schneider from the Zentralinstalt, gradually disintegrated and declined. The last annual report in its usual and complete form appeared in 1914 as No. XI of *Allgemeiner Bericht und Chronik der in Österreich beobachteten Erdbeben (1906–1922).*

Most evident was the process of gradual disintegration of the macroseismic observations especially in the non-German countries of the Monarchy. Volumes X (1913), XI (1914) and XII (1915, published 1919) of *Allgemeiner Bericht und Chronik der in Österreich beobachteten Erdbeben (1906–1922)* demonstrate and illustrate the situation clearly. For the Austrian countries, reports on earthquake observations appeared in them - even though only in a reduced and incomplete scope without the contributions of the regional reporters who had to join the army - regularly. For the Italian Adige region, Bohemia (Czech region), Moravia, Silesia, Galicia, Istria/Dalmatia and Bukovina the reports however became more and more brief and scarce.

In the last war volume, No. XIII (1916–21, published 1922), reports from non-German regions are missing at all. Only three reports (those by J. N. Dörr, F. Heritsch and J. Schorn for Lower and Upper Austria and for the Austrian regions Salzburg, Tirol, Vorarlberg and Steiermark), complemented by a brief earthquake catalogue for Austria 1916–1921, were included in this incomplete, rather summarizing volume of the Allgemeine Berichte for the past six years. In his preface to this volume the director of the Zentralanstalt für Meteorologie und Geodynamik Dr. Felix M. Exner stated that the Zentralinstalt "is no longer able to issue the Allgemeine Berichte in the usual way" and that due to increased printing expenses it further on "has to restrict merely to a continuation of the current Übersichtstabelle (Table of macroseismically felt ground motions with basic geological, orographic, geographical and intensity data) accompanied by quite brief reports about larger earthquakes". After the breakdown of the Monarchy in 1918 Dr. Rudolf Schneider, the head of the Austrian seismic service, moved to Prague and became director of the Czechoslovak Meteorological Service.

In the new states Poland, Yugoslavia and Czechoslovakia, scientific contacts with Austria and Hungary had been substantially reduced for many years. Natural sciences, besides them also seismology (called Erdbebenkunde or Erdbebengeologie at that time), however developed rapidly in broader, all-European collaboration. The history of this development in Czechoslovakia (former German and Czech parts of Bohemia, Moravia, Slovakia and Carpathian Ruthenia) from 1919 till the outbreak of World War II has been described by the Czech post-war seismologists Alois Zátopek (*Zátopek, 1981*) and Jiří Vaněk (*J. Vaněk, unpublished data*).

3. BEGINNINGS OF SEISMOLOGY IN THE HUNGARIAN PART OF THE MONARCHY

Seismological research, as well as many other disciplines, developed in the Hungarian part of the Empire separately from that pursued in the Austrian part. A commission for the promotion of seismological observations within the Hungarian part of the Monarchy had been established as early as in 1881 by the Hungarian Geological Society on proposal of Franz X. Schafarzik (*Schafarzik, 1883*), professor of Geology at the Polytechnic University in Budapest, a keen promoter of seismological research in Hungary (*Schafarzik, 1884,1902a,b*). After visitation of the Kaiserliche Hauptstation für Erdbebenforschung (Central Imperial Station for Earthquake Research) in Strassburg and of some other European seismic stations in 1900, Radó v. Kövesligethy, university professor, member of the Hungarian Academy of Sciences and later first Secretary General of the IASPEI (International Association for Seismology and Physics of the Earth's Interior)[1], suggested the commission to establish a network of five seismic stations in the Hungarian part of the Monarchy, one of them at the Meteorological and Geomagnetic Observatory in Ógyalla (also Ó-Gyalla, original Hungarian name for the present Slovak town Hurbanovo).

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[1] Kövesligethy became known especially as the author of a special procedure enabling the assessment of energy of strong earthquakes (*Kövesligethy, 1904*) and as the inventor of the method of determination of the relation between the energy and intensity of an earthquake (*Kövesligethy, 1907*).

Table 1. Seismic stations in the Austro-Hungarian Monarchy from the beginnings of instrumental observations (1887) till the outbreak of World War I (1914), their instrumentation, and important facts concerning their establishment, operation and research activities. The numbers # correspond to the numbering of the stations in the map of Austro-Hungaria shown in Fig. 1. Numbers 1 – 11 indicate stations in the Austrian provinces, numbers 12 – 17 indicate stations in the Hungarian part of the Monarchy. Kalocsa (#18 in Fig. 1) is not included since only a Rossi Aviatore seismoscope had been in operation at this station temporarily. The physical principles of the individual instruments are explained and their basic technical parameters are given in Table 2.

Station	#	Instrunment(s)	In operation since	Reference	Remarks
Ljubljana (Laibach)	1	Two Vicentini Horizontal Microseismographs	Sep. 1897, Jan. 1898	Belar (1898), Mojsisovics (1898)	First continuously operating seismological station in the Monarchy. Station reports published regularly in [3]. First mention of estimation of epicentral distance from differences between the arrivals of the *Vorphas*e and *Hauptphase*.
		Grablovitz Horizontal Pendulum Seismograph	1898	Mojsisovics (1900)	
		Vicentini Vertical Pendulum	1898	Faidiga (1903)	
		Rebeur-Ehlert Tripple Horizontal Pendulum	1906	[3] (**IX**, 1910)	
Kremsmünster	2	Rebeur-Ehlert Tripple Horizontal Pendulum	Jan. 1899	Schwab (1900)	First report on observations of oceanic microseisms (*Pendelunruhe*). Station reports published in [1] and [2]. Pfaundler Seismoscope installed in Feb. 1898, no triggering ever reported.
Trieste	3	Rebeur-Ehlert Tripple Horizontal Pendulum	Aug. 1898	*Mazelle (1899, 1900, 1901)*	Pfaundler Seismoscope installed in Jan. 1898, no triggering ever reported. Considerations on connection of the *Pendelunruhe* with regional meteorological phenomena. First attempts at earthquake statistics. Station reports published in [1] and [2].
		Vicentini Universal-Microseismograph	Apr. 1900	*Mazelle (1902, 1903)*	Instrument identical with that of the Hydrographical Institute in Genua. Installation under Vicentini's personal supervision.
Lvov (Lemberg)	4	Rebeur-Ehlert Tripple Horizontal Pendulum	Jun. 1899	Láska (1901a) Láska (1901b)	Station reports published regularly in [2]. First descriptive classification of different phases of earthquake recordings. Estimation of the epicentral distance from the *Vor- und Hauptstörung*.

Table 1. continuation

Station	#	Instrunment(s)	In operation since	Reference	Remarks
Lvov (Lemberg)	4	Rebeur-Ehlert Tripple Horizontal Pendulum	Jun. 1899	Láska (1903)	First considerations on the "dynamic resonance" of the Rebeur-Ehlert instrument. Pfaundler Seismoscope installed in Jun. 1899, no triggering ever reported.
				Belar (1909)	Tables for the computation of the spherical distance of teleseismic events from onset times of the *Vorphase* and *Hauptphase* and for epicentrum location from data from 3 stations. Table of 24 European seismic stations. Regular issue of station reports stopped in 1907.
Wien	5	Rebeur-Ehlert Tripple Horizontal Pendulum	1899 (exper.)	Mojsisovics (1901, 1902)	Instrument sent 1901 to Wiechert in Göttingen for experiments and for completion by damping elements. Station reports published in [2].
		Rebeur-Ehlert Tripple Horizontal Pendulum	Early 1903	Conrad (1909)	Imperfect hinges and bearings. No damping. Classified as "seismoscope with inaccurate time information". Operation terminated in January 1907.
		Vicentini Universal-Microseismograph	Oct. 1903	Conrad (1909)	Installed in an office on the 1st floor of the observatory. Records heavily disturbed by wind. Moved to the basement of the observatory in 1905
		Wiechert Horizontal Seismograph	Aug. 1905	Conrad (1909)	Former Příbram instrument. Experimental operation (damping & recording elements sent to Göttingen for reconstruction). In routine operation with reconstructed damping and recording elements since July 1906.
		Wiechert Vertical Seismometer	Jan. 1908	Schneider (1914)	Installed to improve recording of vertical ground motions (Vicentini Z-component considered as "not satisfactory"). Mid 1913: first mention of observatory time check by radio (*Funkentelegraphie*) time signal.
Pula (Pola)	6	Vicentini Horizontal Microseismograph	Oct. 1900	Mojsisovics (1902)	Station of the Hydrographical Office of the Military Navy. Station reports published in [5].
		Vicentini Vertical Seismograph	1901	Ribarič (1989)	Complemented by a Conrad Horizontal Pendulum in 1913 and by a Wiechert Horizontal Seismograph in 1914; both in operation till 1918.

Table 1. continuation

Station	#	Instrunment(s)	In operation since	Reference	Remarks
Rijeka (Fiume)	13	Vicentini-Konkoly Horizontal Microseismograph	1901	Ribarič (1989)	Station reports published in *Réthly (1906-1908)*.
		Vicentini Vertical Seismograph	1905	Réthly (1906)	
Gorje (Bled)	7	Belar Horizontal Seismograph Belar Tremormeters	1902	Ribarič (1989)	Belar's private station. No regular station reports found in accessible historical sources.
Ógyalla (Hurbanovo)	14	Pair of Strassburg Heavy Horizontal Pendulums	Jan. 1902	Réthly (1909)	Station reports published in *Réthly (1906-1909)*.
		Vicentini-Konkoly Horizontal Microseismograph	1905	Réthly (1906)	
Budapest	15	Pair of Strassburg Heavy Horizontal Pendulums	Mar. 1902	Réthly (1909)	Station reports published in *Réthly (1906-1909)*. Assessment of energy of strong earthquakes from the seismograms *(Kövesligethy 1904)*. Determination of the relation between the energy and *Stärkegrad* (intensity) of an earthquake *(Kövesligethy 1907)*.
		Wiechert Inverted Pendulum	1905	Réthly (1907)	
		Vicentini-Konkoly Pendulum			
Temesvár	16	Vicentini-Konkoly Horizontal Microseismograph.	1905	Réthly (1906)	Station reports published in *Réthly (1906-1909)*.
Příbram	8	Two Wiechert Horizontal Seismographs (inverted vertical pendulums)	Feb. 1903	Benndorf (1903) (in Mojsisovic, 1903) Conrad (1908)	Unique *Doppelstation*: one at the surface, the other at a depth of 1100 m. Comparison of surface and subsurface noise amplitudes. Identification of the sources of local short-period and long-period seismic noise. Operation stopped in March 1905, both Wiechert instruments dismounted and sent to the Zentralinstalt in Vienna.
Krakau (Kraków)	9	Two Strassburg Heavy Horizontal Pendulums	Nov. 1903	[3] (**V**, 1905/06)	Station reports published in [3].

Table 1. continuation

Station	#	Instrument(s)	In operation since	Reference	Remarks
Graz	10	Wiechert Horizontal Seismograph	1905	Benndorf (1905)	Former Příbram instrument. Installed under supervision of station director Prof. Hans Benndorf. No station reports found in accessible sources.
				Belar (1909)	Operation of the station stopped in 1908 due to lack of financial means (governmental subvention applied for by Benndorf was not granted).
Zagreb (Agram)	17	Vicentini-Konkoly Horizontal Microseismograph	1906	Réthly (1907)	Royal University observatory. Beginnig of systematic instrumental observations in Croatia. Chief observer A. Mohorovičić, discoverer of the Moho-discontinuity (*Mohorovičić 1910*). Station reports published in [6].
		Wiechert Small Vertical Seismograph	Mar. 1909	Ribarič (1989)	Station reports published in *Réthly (1907-1908)*.
		Wiechert Horizontal Seismograph			
Cheb (Eger)	11	Belar Horizontal Seismograph	Nov. 1908	Irgang (1912)	Primary purpose: monitoring of Vogtland/NW-Bohemia earthquake swarms. Wilfahrt and Conrad instruments only experimentally. Station reports published in [7].
		Wilfahrt Horizontal Pendulum	Jul. 1909		
		Conrad Horizontal Pendulum	Jul. 1910		
		Mainka Horizontal Pendulum	Feb. 1914	Irgang (1914)	Bosch/Strassburg 450 kg version for recording of local shocks and near earthquakes.
Sarajevo	12	Vicentini Horizontal Microseismograph	1908	[3] (**VIII**, 1908/09)	Reports on observed earthquakes published in [8].

[1] Mittheilungen der Erdbeben–Kommission (1897–1900)
[2] Mittheilungen der Erdbeben–Kommission (1900–1912)
[3] Die Erdbebenwarte (1901–1910)
[4] Allgemeiner Bericht und Chronik (1906–1922)
[5] Jahrbuch der meteorologischen, erdmagnetischen und seismischen Beobachtungen (1907–1908)
[6] Jahrbuch des Meteorol. Observatoriums in Agram (1906–1907)
[7] Seismische Registrierungen der Erdbebenwarte in Eger (1908–1919)
[8] Zusammenstellung der Ergebnisse … (1907–1909)

Table 2. Physical principles and basic technical parameters of instruments installed at the seismic stations of the Austro-Hungarian Monarchy listed and commented in Table 1 and of instruments mentioned in Table 3.

Instrument	Comp.	Principle and Parameters[1)]	Recording	References
Belar Horizontal Seismograph ("Zlatorog")	NS, EW	$M \leq 1$ kg; $T_0 \sim 6 \div 21$ s; undamped, or very weak air damping ($D \sim 0 \div 0.03$); $V \sim 105 \div 110$	Optical; p.s. 5 mm/min.	Irgang (1912)
Belar Tremormeter	Z	M several kilograms, spiral spring; $T_0 \sim 1$s; undamped; $V \sim 20 \div 150$	Mechanical (smoke-paper)	Ribarič (1989)
Conrad Horizontal Pendulum	1	$M \sim 20$ kg; $T_0 \sim 3 \div 4$; oil damping, $D \sim 0.35 \div 0.4$; $V \sim 10 \div 50$	Mechanical; p.s. ~ 10÷12 mm/min	Conrad (1910b) Irgang (1912)
Grablovitz Horizontal Pendulum Seismograph	1	$M \sim 20$ kg hung on a bifilar suspension of two 2.6 m long wires; $T_0 \sim 7$ s; undamped; $V \sim 10$	Mechanical (Belar modification) or contact of metal stylus with mercury electrode (seismoscope)	Grablovitz (1896), Belar (1898)
Milne Horizontal Pendulum	1	$M < 1$ kg pivoted on a boom held up by a wire; $T_0 \sim 15$ s; undamped; $V \sim 6 \div 7$	Optical (light shine onto photographic paper through the intersection of two mutually perpendicular slits); p.s. ~ 6÷12 cm/h	Milne (1894), Dewey and Byerly (1969)
Mainka Horizontal Pendulum	NS, EW	Two independent, bifilarly suspended vertical pendulums mounted on a common base; modifications $M \sim 135$, 450, and 2000 kg, $T_0 \sim 3 \div 30$ s; air damping; $V \sim 60 \div 600$	Mechanical (smoke-paper), p.s. 13÷18 mm/min	Sieberg (1923)
Omori Horizontal Pendulum	1	$M \sim 15$ kg on the end of a 0.75 m long horizontal swing arm (brass rod) suspended on two steel wires from the top of a 1.3 m high cast-iron post; $T_0 \sim 10 \div 30$ s; originally undamped (modification with air damping constructed 1907 by Bosch); $V \sim 10 \div 15$	Mechanical (smoke-paper), p.s. 15 mm/min	Omori (1899), Sieberg (1923)
Pfaundler Seismoscope		Marble falling from a thin stick closes an electrical contact which triggers a camera	Photograph of the dial of the observatory clock	Pfaundler (1897)
Rebeur-Ehlert Tripple Horizontal Pendulum	3, mutual orientation 120^0	Garden gate principle; $M < 1$ kg; originally undamped, later damped modifications; $T_0 \sim 4 \div 10$ s; $D \sim 0 \div 0.4$; $V \sim 100 \div 350$; for details see Fig. 3.	Optical; p.s. 4÷36 cm/h	Ehlert (1898b), Mazelle (1899), Schwab (1900)

Table 2. continuation

Instrument	Comp.	Principle and Parameters[1)]	Recording	References
Strassburg Heavy Horizontal Pendulum	1	Same principle as the Omori and Grablovitz horizontal pendulums; manufacturer J.& A. Bosch; $T_0 \sim 9 \div 30$ s; undamped; $V \sim 15$	Mechanical (smoke-paper); p.s. 15 mm/min	Sieberg (1904)
Vicentini Horizontal Microseismograph	NS, EW	$M \sim 100$ kg on a 1.5 m long steel wire hinge; $T_0 \sim 1 \div 2$ s; undamped ; $V \sim 10 \div 100$; for details see Fig. 5.	Mechanical (smoke-paper); p.s. ~ 5 mm/min	Vicentini and Pacher (1896), Ehlert (1898a)
Vicentini Vertical Seismograph	Z	$M \sim 150$ kg at massive horizontal leaf spring ("Waggonfeder"); undamped; $T_0 \sim 1 \div 1.5$ s; $V \sim 100$; for details see Fig. 5.	Mechanical (smoke-paper); p.s. ~ 5 mm/min	Vicentini and Pacher (1898), Sieberg (1904)
Vicentini Universal-Microseismograph	Z, NS, EW	$M \sim 100$ kg ; undamped; $T_{0\ hor} \sim 1.5 \div 2.5$ s; $V \sim 5 \div 100$; $T_{0\ vert} \sim 0.95 \div 1.5$ s; $V \sim 40 \div 120$	Mechanical; p.s. 5 ÷25 mm/min;	Sieberg (1904), Conrad (1909)
Vicentini-Konkoly Microseismograph	Z, NS, EW	Vicentini Universal-Microseismograph with improved recording device (event-controlled doubling of paper speed, developed at the Royal Hungarian State Institute for Meteorology and Earth Magnetism in Budapest headed by N. Th. v. Konkoly)	Mechanical; p.s. 5 (10) ÷ 25 (50) mm/min	Sieberg (1904)
Wiechert Horizontal Seismograph (Inverted Vertical Pendulum)	NS, EW	$M \sim 1100$ kg, balanced upon a pivot, kept in equilibrium through a balancing rod and a pair of horizontal springs; air damping; $T_0 \sim 9 \div 13$ s; $D \sim 0.4 \div 0.5$; $V \sim 150 \div 300$.	Mechanical (smoke-paper); p.s ~ 10÷15 mm/min	Wiechert (1904), Conrad (1908)
Wiechert Vertical Seismograph	Z	$M \sim 1300$ kg on two spiral steel wire springs ; astatization device; temperature compensation; $T_0 \sim 3$ s; $D \sim 0.45$; $V \sim 40 \div 200$;	Mechanical (smoke-paper); p.s ~ 10÷15 mm/min	Wiechert (1906), Conrad (1908)
Wiechert Small Vertical Seismograph	Z	Astatized pendulum - spiral spring system, $M \sim 80$kg; temperature compensation; $T_{0max} \sim 8$ s; $D \sim 0.45$; $V \sim 40 \div 160$	Mechanical (smoke-paper); p.s ~ 15 mm/min	Wiechert (1906), Sieberg (1923)
Wilfahrt Horizontal Pendulum	NS, EW	$M \sim 1$ kg, undamped; from 1911magnetic damping; parameters T_0, D and V similar to those of the Conrad Horizontal Pendulum.	Optical; p.s. ~ 1 cm/min	Irgang (1912)

1) M - inertial mass; T_0 - free period; V - magnification; D - damping constant; p.s. - paper speed.

In April 1901 both Schafarzik and Kövesligethy attended, together with Antal Réthly, the later author of the Hungarian earthquake catalogue for 1900–1902 (*Réthly, 1909*), the First International Seismological Conference in Strassburg[2]. The impact of this stimulating event on their further activities was immediate: a new seismic pavilion at the Ógyalla observatory was built, two Strassburg Heavy Horizontal Pendulums (Straßburger Horizontal-Schwerpendel) and a Vicentini-Konkoly Pendulum (for details about both devices see Table 2) were installed there in late 1901, and continuous recording of earthquakes at Ógyalla with these instruments began on January 1, 1902 (*Réthly, 1906; Moczo et al., 2000*). Reports on earthquakes recorded at Ógyalla and other stations in the Hungarian part of the Monarchy - Budapest and Temesvár since 1902 (*Stöckl, 1902; Schafarzik, 1902b*), Rijeka since 1903 (*Réthly, 1906*), Kalocsa in 1904–1905 (*Réthly, 1906*), and Zagreb since 1906 (*Réthly, 1907*) - were then published more or less regularly in Hungarian annual bulletins edited by Antal Réthly (*Réthly, 1906,1907,1908,1909*). Later Réthly also compiled a complete historical Hungarian earthquake catalogue covering the time interval 455–1918 (*Réthly, 1952*).

Réthly specified in his bulletins also the types and basic constants of the instruments gradually installed at the abovementioned stations of the Hungarian part of the Monarchy in 1901–1909. A map of these stations and of the seismographic stations established in the Austrian part of the Monarchy within the Mojsisovics project is shown in Fig. 1. Details about the individual stations are given in Table 1, and the principles and parameters of the individual instruments are described in Table 2. In the following paragraphs we discuss the history of instrumental observations jointly for both parts of the Austro-Hungarian Monarchy.

One year after the Hungarian commission, in October 1882, a committee for research into earthquake phenomena was established as well by the South Slavic Academy of Sciences[3] in Zagreb (*Kišpatič, 1884*). From 1883 on this Committee distributed macroseismic questionnaires with instructions, compiled by its president Josip Torbar and printed by the Academy, among "correspondents" (voluntary reporters of macroseismic effects of earthquakes) in Croatia, Dalmatia, Bosnia and Herzegovina. Most important for success of this effort to systematize the collection of reliable macroseismic data also in the southern part of the Monarchy was the support the Committee found especially at headquarters of telegraph offices and telegraph stations which disposed not only of compliant personnel, but also of accurate clocks. Until 1892, reports on earthquakes felt in the mentioned south slavic countries were published more or less regularly by the teacher of geology at the Zagreb science grammar school Dr. Mišo Kišpatić (*Kišpatič, 1885,1889, 1891,1892*). In the annual report of this school for the year 1879, Kišpatić published also a chronicle of earthquakes near Zagreb in the period from 1502 to 1879 (*Kišpatić, 1879*).

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[2] For details about this important event in the early history of European seismology see *Kozák (2001).*

[3] Later Croatian Academy of Sciences and Arts. Its foundation was first proposed to the Croatian parliament at its session on April 29, 1861 by bishop Josip Juraj Strossmayer. The Academy however was established not before the final confirmation of the proposed statute by Francis Joseph I, Emperor of Austria and King of Hungary, on March 4, 1866.

Fig. 1. Map of all seismographic stations which had been in operation in the Austro-Hungarian Monarchy in the time span from the beginnings of instrumental observations (1887) until the outbreak of World War I (1914) for at least three years. 1 to 11: stations in the Austrian part of the Monarchy; 12 to 18: stations in the Hungarian part of the Monarchy. 1 - Ljubljana, 2 - Kremsmünster, 3 - Trieste, 4 - Lvov, 5 - Vienna, 6 - Pula, 7 - Bled, 8 - Příbram, 9 - Kraków, 10 - Graz, 11 - Cheb, 12 - Sarajevo, 13 - Rijeka, 14 - Ógyalla, 15 - Budapest, 16 - Temesvár, 17 - Zagreb, 18 - Kalocsa. For details about the individual stations see Table 1.

In outlining the early history of systematic seismological observations and research in the south-slavic part of the Monarchy, we must not omit the Croatian seismologist Andrija Mohorovičić (1857–1936), director of the Zagreb meteorological and seismological observatory, who discovered the sharp boundary separating the Earth's crust from its uppermost mantle - the Moho-discontinuity (*Andrija Mohorovičić, 1910; Stjepan Mohorovičić, 1913*)[4]. Details about A. Mohorovičić and the Zagreb (Agram) observatory are given in Section 5.

[4] Stjepan was Andrija's son.

4. EUROPEAN SEISMOMETRY AT THE TURN OF THE 19th AND 20th CENTURIES

In order to understand the circumstances under which the responsible members of the Austrian Earthquake-Commission - most probably Mojsisovics himself and the Referenten for the initial (1896–1898) period of the project - had to decide about the basic type of an "autonomously recording earthquake-meter" most suitable for their network, let us first briefly summarize the state of European seismometry at that time.

The global history of seismometry from the invention of the earliest seismoscope in China in 132 A.D. to the turn of the 19th and 20th century has been thoroughly portrayed by *Dewey and Byerly (1969)*. According to these authors, the first "true" seismograph, i.e., a device recording the relative motion of an inertial mass and the Earth as a function of time, was the machine built in 1875 by the Italian seismologist P.F. Cecchi. Due to its low sensitivity and high costs, Cecchi's seismograph however had relatively little impact upon European seismology.

In the course of the following two decades, an impressive number of different seismoscopes and seismographs, including devices with inertial masses moving on ball bearings on horizontal plates, instruments indicating or recording surface motions of heavy fluids (mercury), and simple as well as astatized horizontal and vertical pendulums with mechanical (smoked paper) or optical (photographic paper) recording, was constructed by European, predominantly Italian and German scientists, and by British geoscientists active in Japan. A comprehensive summary with descriptions of the principles, advantages, disadvantages, possible applications and costs of over seventy different types of seismographs and seismoscopes invented during the 19th century by many designers in Europe and Japan (among them Agamennone, Alexander, Ayrton, Bertelli, Brassart, Cancani, Cavalleri, Cecchi, Chaplin, Comrie, Darwin, Davison, Ehlert, Ewing, Forster, Galli, Grablovitz, Gray, Johnston-Lavis, Lang, Mallet, Milne, Palmieri, Pacher, Schmidt, Stevenson, von Rebeur-Paschwitz, Vicentini and Wagener) was published in 1898 by the German geoscientist Reinhold Ehlert under the title "Summary, explanation and critical examination of the most important seismometers with special regard to their practical applicability" (*Ehlert, 1898a*). This paper was awarded the Crown Price of the Faculty for Philosophy of the Kaiser-Wilhelms-University in Strassburg, and the large number of references of contemporaneous European seismologists to it evidences that it was highly appreciated by them as a fundamental source of information on seismic instruments existing at the time when the Austrian Earthquake-Commission had to make its decision.

Even the most successful instruments of category "recording earthquake-meter" among the devices described by Ehlert were still indicators of relative (inertial mass vs. ground) motions in some direction or twodimensionally in the horizontal plane rather than recorders of individual (Z, N, E) components of the motions as a function of time. None of them was damped[5], and the records of most of them were of rather low quality (highly

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5 With his horizontal pendulum, *Rebeur-Paschwitz (1861-1895)* was the first who continuously recorded ground motions on photographic paper. In 1889 he started experiments with viscous

non-linear due to internal friction and disturbed by mechanical instabilities and hysteresis). Details about the most wide-spread of these instruments - the Gray, Ewing, Milne, Rebeur-Paschwitz and Vicentini horizontal seismographs - are given, together with recording examples in *Dewey and Byerly (1969)*. These seismographs were gradually improved during the first decade of the 20th century, and further designers of seismic instruments, among them Belar, Bosch, Conrad, Omori, Repsold and Wiechert, emerged in this decade. An excellent paper on the beginnings of instrumental seismology in Germany and Japan giving many details about the successful constructions by Ernst von Rebeur-Paschwitz, John Milne, Fusakichi Omori and about the contributions of many other outstanding natural scientists of the time has been written recently by *Schweitzer (2003)*.

Theory had been rather neglected in the early stage of the development of the inertial seismograph, and this was the main reason why the crucial pre-requisites for successful recording of "true" ground motions excited by local, regional or distant earthquakes - damping of the motions of the inertial mass (pendulum) and choice of its natural period with respect to the nature of the earth's vibrations to be recorded - was paid little attention until the end of the 19th century. This changed principally after the First International Seismological Conference in Strassburg at which Wiechert presented an erudite lecture on the "principles of evaluation of the efficiency of seismographs" (*Wiechert, 1902)*, and after the issue of his fundamental paper "Theory of automatic seismographs" (*Wiechert, 1903*). In this paper Wiechert derived the analytical expressions for the magnification curve and the phase delay of the damped inertial (pendulum or translational mass) seismometer and published first considerations on how to estimate the actual amplitudes of ground vibrations from the records of such instruments.

Wiechert, Ehlert and their contemporaries considered only undercritically damped instruments and defined the "damping ratio" ε of a pendulum seismometer as the exponent of the ratio of the "free period of the damped pendulum" T and the double of its "relaxation time τ", $T/2\tau = \ln\varepsilon$. By comparison of *Wiechert's (1903)* formula for the magnification curve of his instruments with the standard form of the transfer function of a damped mechanical oscillator we obtain

$$\varepsilon = \exp\left[\pi\sqrt{D^2/(1-D)^2}\right], \; D = \ln\varepsilon \Big/ \sqrt{\pi^2 + (\ln\varepsilon)^2} \;,$$

where D is the dimensionless damping constant which equals 0 for no damping, 0.707 for optimum damping (maximally flat frequency response), and 1 for critical damping (no overshoot of the response to a step of ground acceleration). The corresponding values of ε are, respectively, 1, 23.14, and ∞. The most common ε values for Wiechert seismographs and other damped instruments of the time were $\varepsilon = 4 \div 6$ which corresponds to $D = 0.40 \div 0.49$. All instruments employed at that time were thus fairly underdamped.

In interpreting the seismograms recorded by his instruments at the seismographic station of the Göttingen University (*Wiechert, 1906*), Emil Wiechert also introduced the classification of seismic waves according to their predominant periods, distinguished

damping of his instrument but gave them up soon because of problems with the damping fluid (glycerin).

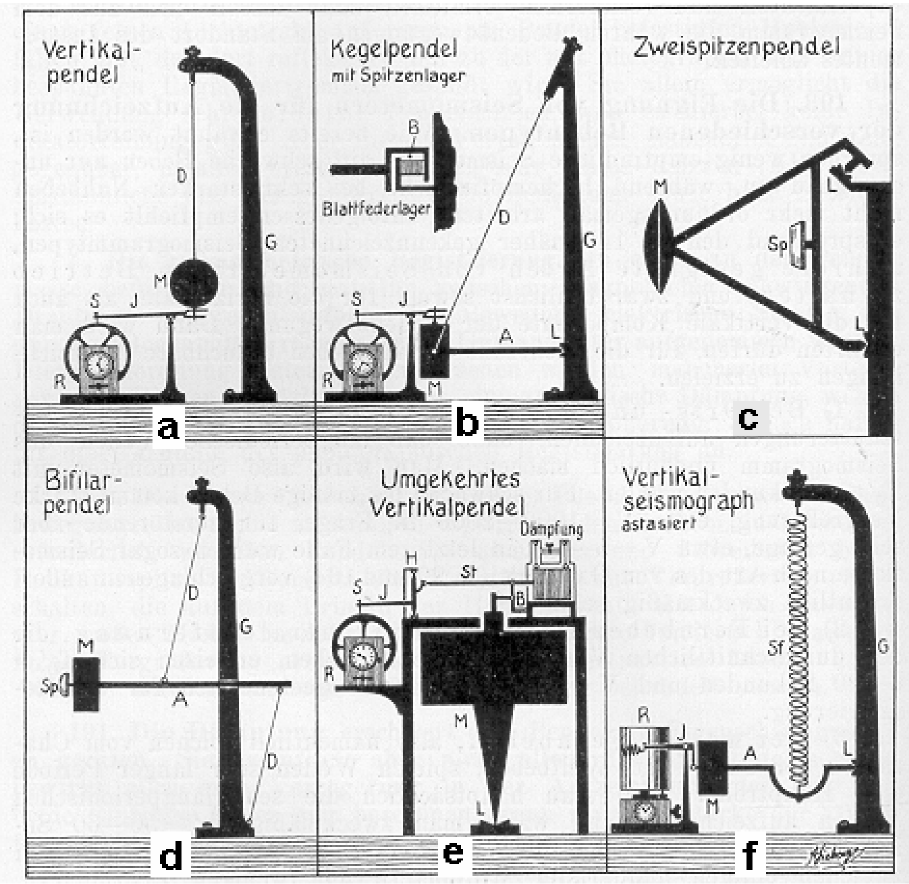

Fig. 2. Basic types of earthquake recording instruments of the first two decades of the 20th century. Reproduced from *Sieberg (1923)*. **a** - vertical pendulum (simplest representative of a horizontal seismograph), **b** - cone pendulum with blade or edge bearing (Omori/Bosch heavy horizontal seismographs), **c** - "garden gate" double edge bearing horizontal pendulum (Rebeur-Ehlert horizontal seismograph), **d** - bifilar (two-wire) pendulum (Zöllner/Repsold horizontal seismograph), **e** - inverted vertical pendulum (Wiechert horizontal seismograph) with air damping, **f** - astatized vertical seismograph (Wiechert). All constructions except **f** were horizontal seismographs. Types **a**, **b**, **e** and **f** recorded the relative motion of the inertial mass to the ground mechanically (on smoked paper mounted on a revolving drum), types **c** and **d** were photographically-recording instruments. G - frame, M - inertial mass, D - wire (suspension), Sf - spiral spring, A - swing arm, L - eadge bearing, B - leaf spring, J - lever, S - stylus, R - recorder, Sp - mirror, St - tie rod, H - bent lever.

"kurze Wellen, mittellange Wellen and sehr lange Wellen", and specified instrument pass-bands for their optimum recording ($T < 2$ s, $T = 3 \div 20$ s and $T > 20$ s, respectively).

As to their constructional principles, any of the models of inertial seismographs existing in Europe at the time of gradual deployment of Austro-Hungarian seismographic stations, can be included in one of the six basic categories depicted in Fig. 2. All constructions except **f** were horizontal seismographs, i. e. instruments recording motions of the inertial mass relative to the ground in one or two horizontal directions, or two-dimensionally in the horizontal plane. Types **a**, **b**, **e** and **f** magnified relative ground motions mechanically and recorded them on smoked paper, types **c** and **d** recorded a light beam reflected from mirror *Sp* on photographic paper. The instruments with optical recording had lower inertial masses and longer natural periods than those with mechanical recording but their operation was much more expensive. The records given by mechanically recording seismographs were generally sharper and easier to interprete than those from photographically recording instruments.

Very popular among the category of mechanically recording horizontal seismographs was the Wiechert inverted vertical pendulum, **e**, with a typical stationary mass of about one ton kept in stable position by a system of horizontal springs and equipped with an air damping device. Typical representatives of horizontal seismographs of categories **b** and **c** were, respectively, the Omori/Bosch (Strassburg) heavy pendulums and the Rebeur-Ehlert tripple pendulum. Another, unastatized representative of a vertical (category **f**) seismograph with a robust leaf spring instead of the spiral spring was Vicentini's vertical pendulum. This device and those of the outlined variety of instruments that were installed at the stations of the Austro-Hungarian network are described in more detail in Section 5.

What eventually should be mentioned in respect of the main topic of this paper treated in Section 5 is (1) which of the seismographs existing at the time of initiation of instrumental observations in Austro-Hungaria were regarded as "the best" by seismologists of the time, and (2) how many seismic stations were in operation in Europe outside the Monarchy at the turn of the 19th and 20th centuries.

The answer to the first question can be found in the papers by *Schlüter (1903)* and *Benndorf (1905*), and in chapter *Erdbeben-Messinstrumente* of Sieberg's "Manual of Earthquake Science" (*Sieberg, 1904*). These seismologists and their contemporaries classified the "degree of applicability" of existing instruments after two criteria resembling, in today's terminology, the specification of standard-class short-period and long-period seismographs: "large magnification for short-period ground oscillations", and "high sensitivity for long-period waves and distant earthquakes". The result of their classification is summarized in Table 3. Winners were the Wiechert heavy pendulum seismograph in the former category, and the Rebeur-Ehlert tripple horizontal pendulum in the latter. Details about the instruments mentioned in Table 3 are given in Section 5.

Reliable information about seismic stations operating in Europe at the time of the beginnings of instrumental observations in the Monarchy gives *Faidiga's (1903)* report on the large Sinj, Dalmatia earthquake of July 2, 1898. This extensive monography contains - besides macroseismic data, a map of intensities, and travel time curves - also lists of all stations and instruments by which the prominent Sinj event was recorded[6]. According to them, thirteen stations (Casamicciola, Ferrara, Firenze, Minea, Padua, Pavia, Piacenza, Portici, Rocca di Papa, Roma, Siena, Spinea, Quarto Castello) had been in operation in

[6] Another extensive monography demonstrating the state of global instrumental seismology eight years after the 1898 Sinj earthquake, *Lawson's et al. (1908)* "Atlas of Maps and Seismograms of the 1906 California Earthquake", was published by the Carnegie Institution of Washington.

Table 3. Seismic instruments most common in Europe at the turn of the 19th and 20th centuries and their "degree of applicability" (Grad der Verwendbarkeit) according to criteria and classification by contemporaneous European seismologists. *M* - mass, *V* - magnification.

Criterion / Rank	"Large magnification for short-period ground oscillations" (*Schlüter, 1903; Benndorf, 1905*)	"High sensitivity for long-period waves and distant earthquakes" (*Sieberg, 1904*)
1	Wiechert Heavy Pendulums *M* ~ 17000 kg, *V* ~ 2000 *M* ~ 1000 kg, *V* ~ 200	Rebeur-Ehlert Horizontal Pendulum, especially its three-component damped modification
2	Vicentini Long Pendulum, *V* ~ 160	Milne Horizontal Pendulum
3	Ehlert Pendulum with damping, *V* ~ 100	Vicentini Universal Microseismograph
4	Vicentini Short Pendulum, *V* ~ 100	Strassburg Heavy Horizontal Pendulum
5	Omori Horizontal Pendulum, *V* ~ 10	Wiechert Inverted Vertical Pendulum

Italy, four (Hohenheim, Potsdam, Strassburg, Wilhelmshaven) in Germany, two (Shide/Newport, Kew) in the United Kingdom, and one each in the Ukraine (Nikolajew), in Russia (Jurjew), and in Krain (Laibach) at that time. The stations were equipped with most diverse instruments: Agamennone small seismographs, Brassart Seismometrographs, a Cecchi seismograph, Ehlert tripple horizontal pendulums, Milne seismographs, and Vicentini microseismographs.

5. HISTORY OF INSTRUMENTAL SEISMIC OBSERVATIONS AND RESEARCH IN THE AUSTRO-HUNGARIAN MONARCHY 1897–1914

After several fruitless attempts to summarize the wealth of facts extracted from papers, periodicals and books of the time in an intelligible textual form, we eventually decided to present the reader the history of Austro-Hungarian instrumental seismology in the form of two, to a large extent self-explaining tables - Table 1 and Table 2.

In Table 1 the seismic stations gradually installed in the Monarchy within the discussed period are ordered chronologically according to the date of initiation of regular measurements at them, and the instruments by which the stations were originally equipped and later successively upgraded are specified. The physical principles of all instruments that were in operation at the individual stations within the discussed period are outlined and their basic technical parameters are given in Table 2. The most important facts about progress in the instrumentation and in the analysis, interpretation and archivation of the observational material are summed up in the last column of Table 1 (Remarks).

The two tables reflect the history of Austro-Hungarian instrumental seismic observations in the time span from their beginning until the outbreak of the first world war in a most condensed form but, as we believe in respect of the extent of original historical material it was compiled from, authentically and, perhaps, completely. In the following text we discuss more in detail only those instrumental problems and aspects, those moments in the analysis and interpretation of instrumental observations, and those contributions of contemporaneous scientists which most decisively influenced the progress of Austro-Hungarian instrumental seismology in 1897–1914.

As we already mentioned in Section 4 of Part I of our paper (*Kozák and Plešinger, 2003*), the type of "autonomously recording earthquake-meter" chosen by the Erdbeben-Kommission as the most suitable basic equipment for the intended seismographic network, was the Rebeur-Ehlert tripple horizontal pendulum. Constructional details and examples of typical recordings of this instrument are shown and commented in Fig. 3 and Fig. 4. From the data given in Tables 1 and 2 we learn that Rebeur-Ehlert pendulums were successively installed at the stations Kremsmünster, Trieste, Lvov, Wien and Ljubljana

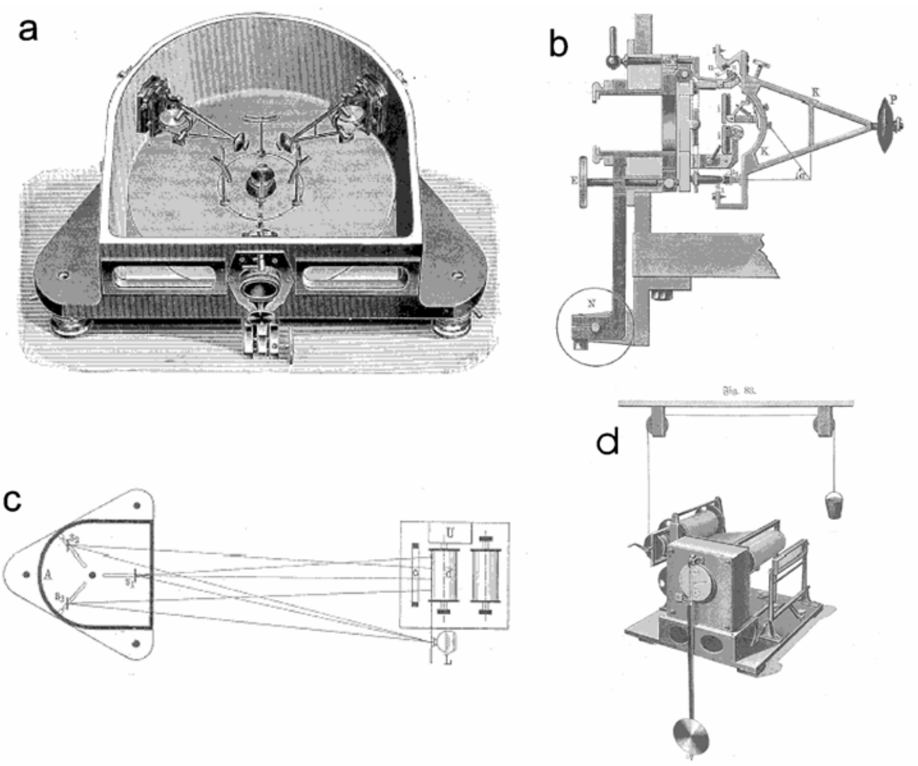

Fig. 3. Rebeur-Ehlert's tripple horizontal pendulum seismograph. **a** - seismometer block (three identical pendulums mounted in a common metal case with swing axes oriented 120^0 against each other); **b** - single pendulum in detail (P - inertial mass, K - swing arm, B - pin bearings, E - period adjusting screw); **c** - complete seismograph (L - point-light carbide lamp, $S_{1,2,3}$ - mirrors, O - lens, U - photorecorder drum); **d** - complete photorecorder with pendulum clock and drum drive device. For examples of recordings of different seismic signals with this instrument see Fig. 4.

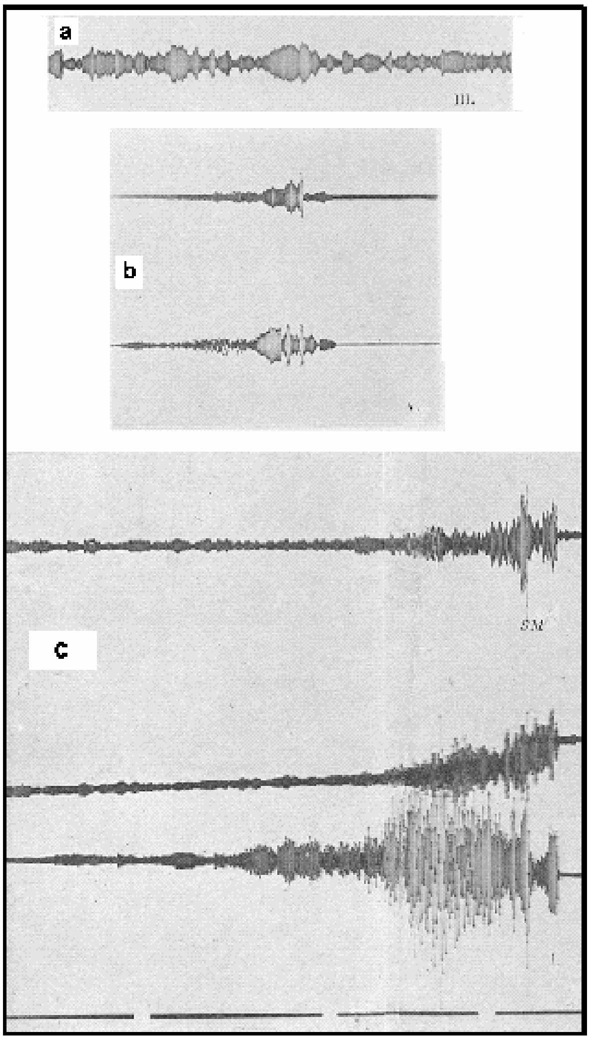

Fig. 4. Examples of recordings of the Rebeur-Ehlert tripple horizontal pendulum seismograph installed 1899 in Lvov/Lemberg. Reproduced from (*Láska, 1901a*), horizontally flipped. **a** - oceanic ($T \sim 6$ s) microseisms, called Pendelunruhe (pendulum unrest) by contemporaneous observers. **b** - June 14, 1899 event as example of "a moderate disturbance of combined type with fairly developed pre-, main-, and post-disturbances (Vorstörung, Hauptstörung, Nachstörung)". **c** - November 23, 1899 earthquake. Each segment of the broken line on the bottom represents 55 minutes. According to this time scale, both **b** and **c** were teleseismic ($D \sim 30°$ and $D \sim 40°$) events, and the maximum on the first component denoted SM (Stossmaximum) by the station analyst should correspond to the L_Q phase. The inconsistency of the other two components with this interpretation and the presence of signal generated spurious pendulum motions (very long period excursion and permanent change of the zero-line) on all three components are indications for non-linearities and instabilities in the pendulum hinges.

(see Table 1), and that they had natural periods of typically 4 to 10 seconds (see Table 2). These periods exactly coincide with those of oceanic microseisms - the dominant component of natural seismic noise worldwide, especially in winter months. Since the pendulums were almost undamped, they worked as very-narrow-band systems for selective recording of oceanic microseisms, and of intermediate-band earthquake signals such as, e. g., surface waves of regional earthquakes. It is therefore not surprising that the first reports on observations by means of these instruments (*Schwab, 1900; Mazelle, 1901, 1902a,b*) dealt with the analysis of the permanently present "pendulum unrest" (Pendelunruhe) rather than of earthquake records.

The interpreters of Rebeur-Ehlert seismograms, among them especially Václav Láska, Eduard Mazelle and Franz Schwab, soon realized the shortcomings of this instrument[7] with regard to their major purpose (sensitive recording of the Vorstörung and Hauptstörung, i.e., of *P*- and *S*-phases of near-regional earthquakes), began to strive for completion of their stations by seismomographs with "large magnification for short-period ground oscillations". As far as the total number of instruments of this category operating permanently or temporarily at Austro-Hungarian stations in 1897−1914 is concerned, most popular were Vicentini seismographs. The principles and constructional details of both the horizontal and vertical versions of Vicentini seismographs are shown and commented in Fig. 5. An example of a three-component seismogram of Vicentini's universal microseismograph (teleseismic event recorded at the Padua station) is reproduced for illustration in Fig. 6.

The first continuously operating Austro-Hungarian seismic station was that of Ljubljana (#1 in Table 1). The station was established under supervision of Albin Belar (1864−1939), chemist and natural scientist, founder and promoter of seismological research in Slovenia. Belar became assistant for chemistry and natural sciences at the Naval Academy (Marine-Akademie) in Rijeka (Fiume) in 1890, and in 1896 he was appointed professor of chemistry and natural sciences at the Oberrealschule (State High School) of Ljubljana. At that time Belar was already interested in seismology and had contributed by own macroseismic data to the monography about the strong April 14, 1895 Ljubljana earthquake published 1896 in Vienna by Eduard Suess (*Suess, 1896*). The decisive impetus for Belar's deeper involvement in earthquake research obviously was the Kamnik earthquake that struck the Ljubljana region on January 17, 1897. Aware of the importance of regular instrumental observations for studies into the nature of earthquakes, Belar submitted the director of the Oberrealschule a respective proposal and succeeded promtly: official approval for the establishment of a seismological station was given by the local authorities already two months later, in March 1897. The Krain Savings Bank and the Science Grammar School of Ljubljana readily provided necessary financial support, and Tönnies' Locksmith Workshop, later also the Samassa Foundry, participated in manufacturing proper instruments (copies of Vicentini seismographs; for details see Table 2). The Ljubljana station was equipped and gradually upgraded with the help and advice of experienced experts from abroad, among them P. Tacchini (Central Meteorological Office, Rome), G. Vicentini (University of Padua), G. Gerland (University

[7] Most strict in criticism of the tripple Rebeur-Ehlert pendulum was *Conrad (1909)* who classified it as an instrument with "imperfect hinges and bearings and inaccurate time information".

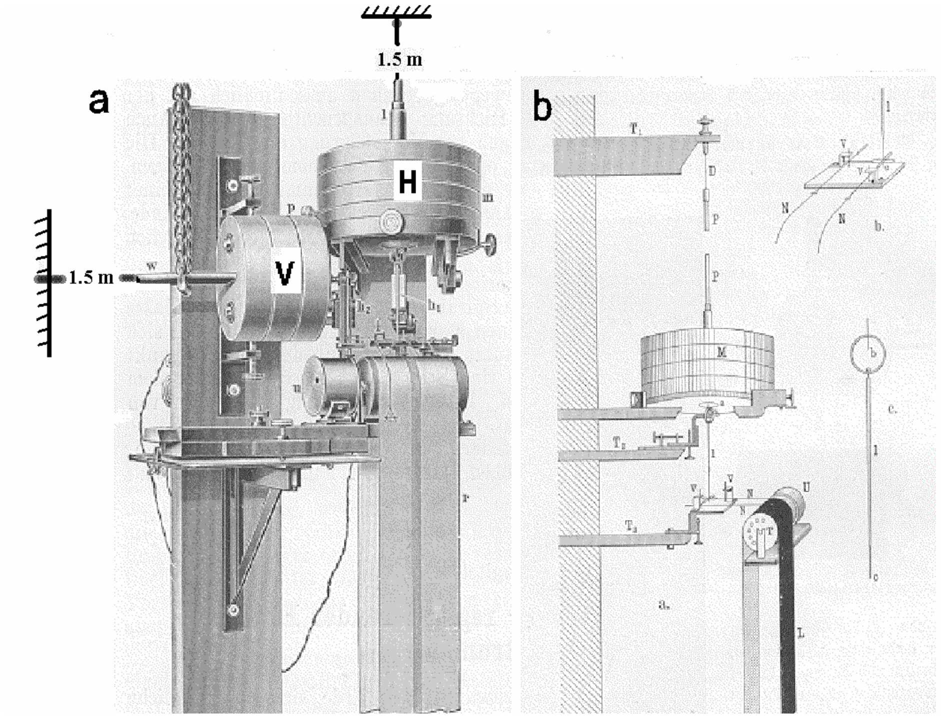

Fig. 5. Vicentini's universal microseismograph. **a** - complete three-component device; *H* - inertial mass of the two horizontal components (lead discs with a total mass of about 100 kg hung on a 1.5 m long wire/rod suspension), beneath it the lever of the mechanical two-component relative motion magnification system and the drum of the two-component smoke-paper recorder; *V* - inertial mass of the vertical component (about 50 kg at the end of a horizontal, 1.5 m long, 7.5 cm broad and 12 mm thick waggon leaf spring fastened to a steel console) with its relative motion magnification system (right-hand side) and drum recorder (below). **b** - detailed schematical sketch of the horizontal device; $T_{1,2,3}$ - consoles, *M* - inertial mass, D - steel wire, P - metal rod, l - lever of the motion magnification system, V - stylus holders, N - glass fibre needles. An example of a recording of a teleseismic event by this instrument is reproduced in Fig. 6.

of Strasbourg), G. Grablovitz (Seismological Station Casamicciola, Ischia), and Belar occupied the position of its director by the end of World War I. Belar also designed several own seismic instruments, the most successful of which were his horizontal "Zlatorog" seismograph and his vertical "Tremormeter" (for details see Table 2). The former instrument was awarded the first price at an exhibition of meteorological and seismological instruments in Faenza, Italy, in 1909. Two "Zlatorogs" manufactured in Ljubljana were installed in 1908 at the Bohemian station Cheb (Eger, #11 in Table 1) where they had been in operation till the end of World War I.

From 1901 to 1910 Belar was editor of the periodical *Die Erdbenwarte (1901–1910)* (The Earthquake Observatory) and of its supplement Neueste Erdbebennachrichten (Earthquake News). A great deal of fundamental contributions on earthquake research of

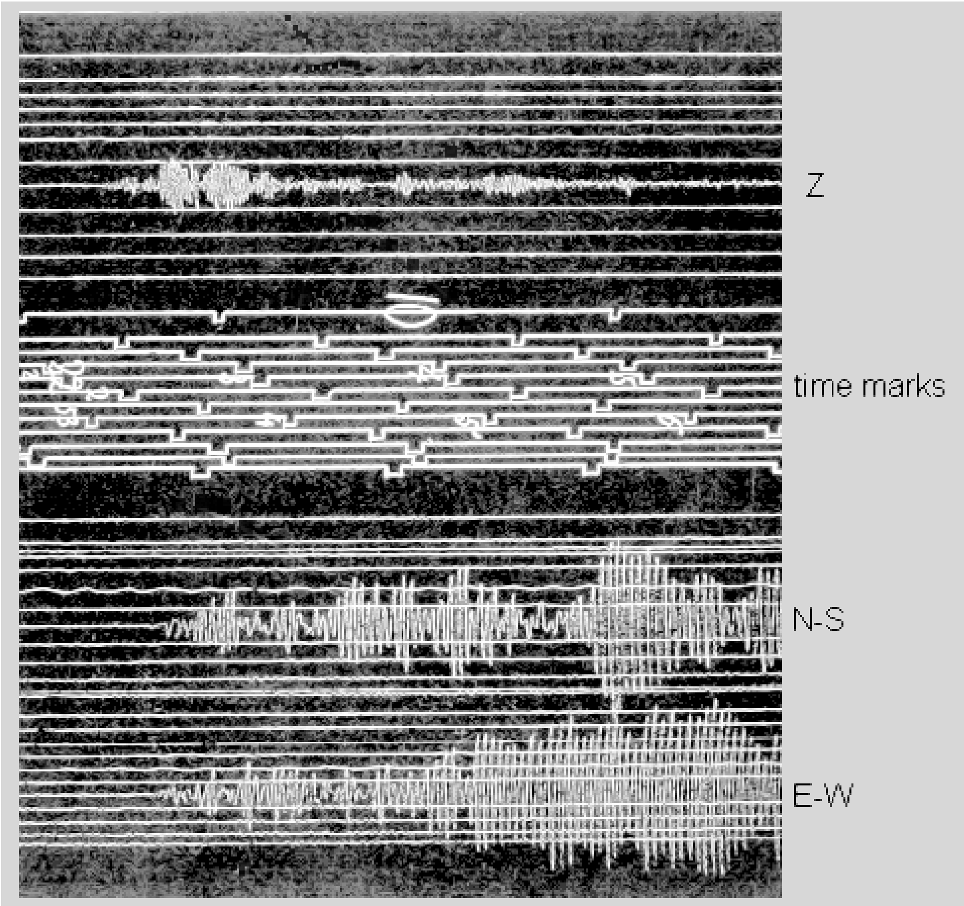

Fig. 6. Example of a three-component seismogram of a teleseismic event (Alaska, 10 Sept. 1899, 21h41m GMT, $M_S \sim 8.0$) recorded by Vicentini's universal microseismograph in Padua. Reproduced from (*Sieberg, 1923*). The magnification of the vertical system evidently was about 3-times lower than that of the horizontal systems, the distance between two time marks corresponds to approximately 15 minutes.

the time appeared in this journal, and as far as its scientific standard and its impact on the progress of earthquake research in the Austro-Hungarian Monarchy is concerned, the Erdbenwarte represented a periodical well comparable with the new series of the Viennese *Mittheilungen der Erdbeben-Kommission (1900–1912).* At the same time (from 1899 to 1914, see *Kozák and Plešinger, 2003*), Belar served as *Referent* of macroseismic observations for Dalmatia within the Mojsisovics project. In 1910 Belar constructed together with baron Anton v. Codelli, an expert in wireless communication, a radio receiver capable of receiving in Ljubljana radio time signals from Paris and Norddeich. This eventually solved the problem of accurate time service for the seismic station.

Another outstanding scientific personality in the history of Austro-Hungarian seismology was Prof. Václav Láska (1862–1943). Láska was originally known as an astronomer and as author of advanced textbooks on astronomy. In 1896 he left his post at the Klementinum Astronomical Observatory in Prague and, after being appointed professor at the Lvov/Lemberg Technical University, he performed research into geophysical disciplines as head of the Lvov Astronomical-meteorological and seismological observatory (station Lemberg, #4 in Table 1). As soon as in 1901 Láska suggested a descriptive classification of different phases of earthquakes - Vorstörung (*P*-phase), Hauptstörung (*S*-phase) and Nachstörung (coda waves) and distinguished between different types of waveforms - Ausschwingung (impulsive), Anschwellung (emergent) and Ausbauchung (exponentially emerging and decaying wavegroup), and derived formulae for the estimation of the epicentral distance from the time difference between the onsets of the Vorstörung and Hauptstörung. Láska was among the first seismologists who fully realized and repeatedly emphasized in his reports the necessity to damp seismometers (*Láska, 1901a,b*) and published first critical considerations on the undesirable "dynamic resonance" of the Rebeur-Ehlert instrument (*Láska, 1903a*). He also derived tables for the computation of the spherical distance of teleseismic events from the onset times of the Vorphase and Hauptphase and for the location of the epicentres of distant earthquakes on the basis of data from three stations (*Láska, 1903b*). In 1911 Láska returned to Prague where he was offered the post of a professor of applied mathematics at the Charles University. After Czechoslovakia came into existence, Láska established the State Geophysical Institute in Prague and became its director (for a brief history of this institute see *Zátopek, 1981*). Láska died in summer 1943, leaving to the posterity several books and over 300 scientific papers.

Quite unique among the altogether 17 Austro-Hungarian stations was the Doppelstation (surface and subsurface station) Příbram in Central Bohemia (#8 in Table 1), established under the supervision of the later station director Prof. Hans Benndorf (*Benndorf, 1903*). The Wiechert horizontal seismograph (for details see Table 2) installed at a depth of 1100 meters in the Příbram metal ore mine was the first subsurface installation of a sensitive, damped, rather broadband instrument in the world. Unfortunately, the seismograms from both the surface and subsurface Wiechert seismographs obviously were never processed systematically. With the exception of *Benndorf's (1903)* remarks on observed differences between surface and subsurface noise amplitudes, on successful identification of the sources of man-made local short-period and long-period seismic noise (mining machinery), and the statement that the earthquakes which occurred in February–March 1903 in NW-Bohemia were almost indistinguishable on the records, no further reports on analyses/interpretations of seismograms from the Příbram Doppelstation appeared - neither in *Mittheilungen der Erdbeben-Kommission (1900–1912)*, nor in *Die Erdbenwarte (1901–1910)*. We also didn't find any information about wether the observational material had been archived somewhere at all. After two years of operation, the two costly devices were dismounted and sent to Vienna. Both were re-installed in Austria in 1905, one at the seismic station of the Graz university (#10 in Table 1, *Benndorf, 1905*), the other at the Zentralanstalt für Meteorologie und Geodynamik in Vienna (#5 in Table 1, *Conrad, 1909*).

The director of the Zagreb station (#17 in Table 2) A. Mohorovičić[8], Croatian meteorologist and seismologist of international reputation, has become famous especially for his rigorous evidence of the existence of a crustal part of the Earth's interior substantially differing in its composition from the deeper parts (*Mohorovičić, 1910; Benndorf, 1912*). The existence of prominent differences between the velocities of seismic body waves in the uppermost part of the Earth, the Earth's crust, and the layer beneath, the upper mantle, had been surmised by a number of geoscientists (e.g. by J. Milne, R.D. Oldham, H. Benndorf, E. Wiechert) before, but Mohorovičić was the first who proved this unambiguously on the basis of records of the October 8, 1909 Kupa Valley earthquake near Zagreb from almost all seismic stations that had been in operation in Europe at that time. Mohorovičić also developed a simple method of precise determination of focal depths on the basis of near-station data. From 1918 to 1922 Mohorovičić was the secretary of the Department for Mathematics and Natural Science of the Yugoslavian Academy.

Other essential moments in the history and further facts about the operation of the individual stations are mentioned in column Remarks of Table 1. What we wish to add in general is that in the first decade of the 20th century contemporaneous "earthquake geologists" were already fully aware that earthquakes are fault processes in "blocks of the earth's crust under compression", that they distinguished between folding and rifting and among normal, strike-slip and dip-slip "movements of earth blocks upon earthquake faults", that they modelled folding in the laboratory by laterally compressing waxy layers, and that in order "to illustrate the cause of earthquakes" they arranged laboratory experiments with a system of rectangular prismatic wooden blocks subjected to variable lateral compression in a tank partially filled with water (*Hobbs, 1907; Hobbs and Ruska, 1910*).

Austro-Hungarian scientific personalities who most markedly contributed to the progress in the methodology of the analysis of instrumental seismic observations and to their correct seismological interpretation undoubtedly were A. Belar, H. Benndorf, R. Kövesligethy, V. Láska, E. Mazelle, A. and S. Mohorovičić and A. Réthly. To the development of seismic instrumentation, Austro-Hungarian scientists contributed only slightly: A. Belar by his "Zlatorog" seismograph, a small undamped horizontal

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[8] Andrija Mohorovičić (1857−1936), graduate of the grammar school in Rijeka, at the age of 15 fluent in Italian, English and French, later also in German and Czech. Studied 1875−79 at the Department of Mathematics and Physics of the Faculty of Philosophy of the Prague University, where one of his professors was the famous physicist Ernst Mach. After completion of his university studies, Mohorovičić was twelve years active as teacher (grammar school Zagreb 1879−80; secondary school Osijek 1980−81; Nautical School Bakar near Rijeka 1882−91), at Bakar especially of meteorology. In early 1892 Mohorovičić became director of the Meteorological observatory of the Science grammar school in Zagreb. During the first years in this position he was still interested primarily in meteorology, in 1893 he was awarded the PhD degree for his thesis "On the observation of clouds and the daily and annual cloud period in Bakar*"*. In the same year he became associate member and five years later full member of the South Slavic Academy of Sciences. Towards the end of the 19th century Mohorovičić focused his scientific activities ever more on seismology. After the turn of the century, instrumental seismological observations and the interpretation of observed seismic waves became his major concern.

instrument; V. Conrad by a heavy, oil-damped horizontal pendulum seismograph; and Th. v. Konkoly by the improvement of the recording device of the Vicentini microseismograph.

6. CONCLUSION

The mosaic of historical facts presented in this paper and in its preceding part (*Kozák and Plešinger, 2003*) evidences that the early development of Austro-Hungarian seismology, especially the beginning of regular instrumental observations, was far not a straight-forward, unperturbed process. Let us briefly summarize the most essential moments of the whole story.

The strong Zagreb 1880 and Ljubljana 1895 earthquakes stimulated geologists, astronomers and other natural scientists of the time to initiate systematic macroseismic as well as instrumental observations in order to learn more about the nature of earthquakes and to mitigate their effects. A network of observers of macroseismic effects of regional earthquakes was proposed in 1896 by the Earthquake-Commission of the Academy of Sciences in Vienna and gradually established within the following three years. In 1904 the network, consisting of almost 1700 observers active in 16 provinces of the Austrian part of the Monarchy, was nationalized and ran further on - as centrally controlled Austrian Seismic Service - successfully until the outbreak of World War I. The bulletins of the collected macroseismic data were published more or less regularly in contemporaneous periodicals *Mittheilungen der Erdbeben-Kommission (1897-1900;1900–1912)*, *Die Erdbebenwarte (1901–1910)* and *Allgemeiner Bericht und Chronik (1906–1922).*

The network served as an exemplary model of a well performing regional macroseismic service. Today we admire it as a system that was effective even in the multi-ethnic background of the Monarchy. We can speculate on the reasons. First, there was a relatively well educated layer of inhabitants in all countries of the Empire, and a long tradition in the study of natural phenomena not only in Vienna but also in the other capitals and centres of the Empire such as Prague, Brno, Lvov, Ljubljana, Leoben (*Hammerl et al., 2001*). Further, a positive moment helping that the project went through was the centralistic administration of the Empire. And as last but not least reason, the phenomenal personal energy, invention and organizational abilities of Edmund von Mojsisovics must be pointed out.

Although a commission for the promotion of seismological observations within the Hungarian part of the Monarchy had been established by the Hungarian Geological Society as early as in 1881, no regular activities similar to those performed within the macroseismic part of the Mojsisovics project were reported by Hungarian geoscientists. Another committee for research into earthquake phenomena was established by the South Slavic Academy of Sciences in Zagreb in late 1882. From 1883 on this committee distributed macroseismic questionnaires among voluntary reporters of macroseismic effects of earthquakes in Croatia, Dalmatia, Bosnia and the Herzegovina. Reports on earthquakes felt in these countries in 1883–1892 were published more or less regularly by the Croatian teacher M. Kišpatić.

In context with the beginnings of instrumental observations in the Monarchy, two important facts must be stressed: several tens of different types of seismographs with optical (photopaper) or mechanical (smoked paper) recording designed by Italian, German and British geoscientists, among them Agamennone, Cecchi, Davison, Ehlert, Ewing, Grablovitz, Milne, von Rebeur-Paschwitz and Vicentini, existed at the time when the Austrian Earthquake-Commission had to decide about the most suitable type of basic instrument for the planned network, and at least 22 seismographic stations were in operation in Europe at that time - 13 in Italy, 4 in Germany, 2 in the U.K., and one each in the Ukraine, in Russia, and in Krain (Ljubljana). The individual stations were equipped with most diverse instruments including, among others, Agamennone seismographs, a Cecchi seismograph, Ehlert tripple horizontal pendulums, Milne seismographs, and Vicentini microseismographs. The Ljubljana station, founded in 1897 by Albin Belar and equipped with two Vicentini microseismographs, was the first Austro-Hungarian seismographic station at all. The members of the Austrian Earthquake Commissison thus had a good chance to profit from this great deal of experience.

Nevertheless the history of the instrumental part of the Mojsisovics project began with the questionable decision to employ Rebeur-Ehlert pendulums manufactured by J. & A. Bosch in Strassburg as basic "earthquake-meter" for the intended regional seismographic network. These instruments had typical natural periods of 4 to 10 seconds and worked, since they were undamped, as very-narrow-band systems selectively recording oceanic microseisms and intermediate-period surface waves rather than *P* and *S* waves from near and regional earthquakes. The first reports on observations with these instruments therefore dealt with the analysis of the "pendulum unrest" (long period seismic noise) rather than with the interpretation of earthquake recordings.

The interpreters of seismograms recorded by Rebeur-Ehlert instruments, among them especially station directors Václav Láska, Eduard Mazelle and Franz Schwab, soon realized the unsuitability of this instrument for the study of near-regional earthquakes and began to strive for completion of their stations by seismomographs with "large magnification for short-period ground oscillations". Dominant among the instruments of this category, working temporarily or permanently at Austro-Hungarian stations in the whole time span from 1897 to 1914, eventually were different (horizontal, vertical, universal) modifications of Vicentini seismographs and different (horizontal, vertical, inverted, small) modifications of Wiechert seismographs, see Table 1. Technical details about all instruments that were in operation at Austro-Hungarian stations within the discussed period are given in Table 2.

In the Hungarian part of the Monarchy, the history of instrumental observations began with the installation of two Strassburg heavy horizontal pendulums and a Vicentini-Konkoly horizontal microseismograph in the seismic pavilion of the observatory in Ógyalla (Hurbanovo), and of another instrument of the latter type at the Rijeka (Fiume) station in late 1901. Three further, similarly equipped stations (Budapest, Temesvár, Zagreb/Agram) were established within the following five years.

At the end of the first decade of the 20th century, the instrumentation of the stations of the Austro-Hungarian seismographic network had reached a standard comparable with that of analogous activities in Italy and Germany. Of the total number of 37 instruments operational at both the Austrian and Hungarian stations of the network contemporarily or permannently in 1897–1914, two thirds were Vicentini and Wiechert seismographs. Reports on earthquakes recorded by the Austrian stations were published rather regularly in periodicals *Erdbeben-Kommission (1900–1912)*, *Die Erdbebenwarte (1901–1910)*, *Allgemeiner Bericht und Chronik (1906–1922)*, *Jahrbuch der meteorologischen, erdmagnetischen und seismischen Beobachtungen (1907–1908)* and *Seismische Registrierungen der Erdbebenwarte in Eger (1908–1917)*, those on earthquakes recorded by the Hungarian stations more or less regularly by A. Réthly and in periodicals *Jahrbuch des Meteorol. Observatoriums in Agram (1906–1907)* and *Zusammenstellung der Ergebnisse ... (1907–1909)*.

Austro-Hungarian scientific personalities who most markedly contributed to the progress in the methodology of the analysis of instrumental seismic observations and to their correct seismological interpretation undoubtedly were A. Belar, H. Benndorf, R. Kövesligethy, V. Láska, E. Mazelle, A. and S. Mohorovičić and A. Réthly. To the development of seismic instrumentation, Austro-Hungarian scientists contributed only slightly. During World War I the well developed Austrian macroseismic service gradually disintegrated. After the war, seismology progressed in the newly constituted states Czechoslovakia, Poland and Yugoslavia in broader, all-European collaboration.

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References

Allgemeiner Bericht und Chronik, 1906–1922. *Allgemeiner Bericht und Chronik der in Österreich beobachteten Erdbeben*, K.k. Zentralanstalt für Meteorologie und Geodynamik, Wien 1906–1922 (13 volumes, Nos. I–XIII).

Becke F., 1898. Bericht über das Graslitzer Erdbeben 24. October bis 25. November 1897. In: *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897–1900, Bd. CVII, No.VIII, 789–959.

Belar A., 1898. Über Erdbebenbeobachtung in alter und gegenwärtiger Zeit und die Erdbebenwarte in Laibach. Buchdruckerei Ig. v. Kleinmayr & Fed. Bamberg in Laibach, 1-43.

Belar A., 1909. Die Vorkämpfer und Begründer unserer Wissenschaft in Österreich. In: *Die Erdbebenwarte, Monatsschrift*. Ed. Albin Belar. Laibach 1901–1910, VIII. Jahrg., 85–94.

Belar A., 1910. Aufzeichnungen auf dem Ehlert-Pendel an der Erdbebenwarte in Laibach in den Jahren 1906 bis Ende 1909. In: *Die Erdbebenwarte, 1901–1910*, IX. Jahrg., 34–49.

Benndorf H., 1903. Vorläufiger Bericht über die Aufstellung zweier Seismographen im Bergwerk zu Příbram. In: *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XIX, Anhang, 156–160.

Benndorf H., 1905. Über die Art der Fortpflanzung der Erdbebenwellen im Erdinneren. In: *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XXIX, 1–24.

Benndorf H., 1912. A. Mohorovičić, Das Beben vom 8.X.1909. In: *Besprechungen, Gerl. Beiträge zur Geophysik*, **Bd.XI**, Leipzig, 348–352.

Berlage H.P., 1932. Seismometer. In: Gutenberg B. (Ed.), *Handbuch der Geophysik*, **Band 4**, Erdbeben, Verlag v. Gebrüder Borntraeger, Berlin, 299–526.

Commenda H., 1907. Erdbeben und Erdbebennachrichten aus Oberösterreich. In: *Die Erdbebenwarte, Monatsschrift*. Ed. Albin Belar. Laibach 1901–1910, VI. Jahrg., 38–45.

Conrad V., 1909. Beschreibung des seismischen Observatoriums der k. k. Zentralanstalt für Meteorologie und Geodynamik in Wien. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XXXIII, 1–28.

Conrad V., 1910a. Seismische Registrierungen in Wien, k. k. Zentralanstalt für Meteorologie und Geodynamik, im Jahre 1909. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XXXIX, 1–44.

Conrad V., 1910b. Ein einfaches Instrument für seismische Stationen in habituellen Stossgebieten. *Beiträge zur Geophysik*, **Bd.X**, Heft 3, 157–160.

Dewey J. and Byerly P., 1969. The early history of seismometry (to 1900). *Bull. Seismol. Soc. Amer.*, **59,** 183–227.

Die Erdbebenwarte, 1901–1910. *Die Erdbebenwarte, Monatsschrift*. Ed. Albin Belar. Laibach 1901–1910 (9 volumes, Jahrg. I–IX).

Ehlert R., 1898a. Zusammenstellung, Erläuterung und kritische Beurtheilung der wichtigsten Seismometer mit besonderer Berüchsichtigung ihrer praktischen Verwendbarkeit. Beiträge zur Geophysik. *Zeitschrift für physikalische Erdkunde*, III. Band, Verl. W. Engelmann, Leipzig 1898, 350–475 (Kap. XIII).

Ehlert R., 1898b. Das dreifache Horizontalpendel. Beiträge zur Geophysik. *Zeitschrift für physikalische Erdkunde*, III. Band, Verl. W. Engelmann, Leipzig 1898, 481–494.

Faidiga A., 1903. Das Erdbeben von Sinj am 2. Juli 1898. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XVII, 1–162.

Grablovitz G., 1896. Pendoli orizzontali a registratione meccanica continua. *Bolletina della Società sismologica Italiana*, **2**, 171–179.

Günther S., 1897. *Handbuch der Geophysik*. 1. Band, Verlag von Ferdinand Enke, Stuttgart.

Hammerl Ch., Lenhardt W., Steinacker R. and Steinhauser P., 2001. *Die Zentralanstalt für Meteorologie und Geodynamik 1851–2001, 150 Jahre Meteorologie und Geophysik in Österreich*. Leykam Buchverlagsgesellschaft, Graz 2001.

Hobbs W.H. and Ruska J., 1910. *Erdbeben - Eine Einführung in die Erdbenkunde*. Erweiterte Ausgabe in Deutscher Übersetzung, Verlag v. Quelle & Meyer, Leipzig.

Hobbs W.H., 1907. *Earthquakes - An Introduction to Seismic Geology*. D. Appleton & Comp., New York.

Hochstetter F. v., 1886. Die feste Erdrinde nach ihrer Zusammensetzung, ihrem Bau und ihrer Bildung (Geologie). In: J. Hann, F. v. Hochstetter and A. Pokorny (Eds.), *Allgemeine Erdkunde - Astronomische und physische Geographie, Geologie und Biologie*, 4. Auflage, Prag-Leipzig.

Hoefer H., 1880. *Die Erdbeben Kärntens und deren Stosslinien*. Denkschrift der Kais. Akad. d. Wissensch. in Wien, Band 42.

Hoernes R., 1881. Die Erdbeben in der Steiermark während des Jahres 1880. *Mittheilungen des naturwiss. Vereins für Steiermark*, Jahrg. 1880, Graz, 65–114.

Hoernes R., 1893. *Erdbebenkunde. Die Erscheinungen und Ursachen der Erdbeben, die Methoden ihrer Beobachtung*. Verlag von Veit/Comp., Leipzig.

Hoernes R., 1902. Erdbeben und Stosslinien Steiermarks. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. VII, 1–115.

Hoernes R., 1905. Bericht über das Erdbeben in Untersteiermark und Krain am 31. März 1904. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XXVII, 1–47.

Irgang G., 1912. Seismische Registrierungen der Erdbebenwarte in Eger vom 20. November 1908 bis 31. Dezember 1911. *Jahresbericht der k.k. Staats-Oberrealschule in Eger 1911/12*, 15–44.

Irgang G., 1913. Seismische Registrierungen der Erdbebenwarte in Eger im Jahre 1912. *Jahresbericht der k.k. Staats-Oberrealschule in Eger 1912/13*, 1–11.

Irgang G., 1914. Seismische Registrierungen der Erdbebenwarte in Eger vom 1. Januar 1913 bis 30. April 1914. *Jahresbericht der k.k. Staats-Oberrealschule in Eger 1913/14*, 29–50.

Jahrbuch der meteorologischen, erdmagnetischen und seismischen Beobachtungen, 1907–1908. Hydrographisches Amt der k. u. k. Kriegsmarine, Pola 1907-1908 (2 volumes).

Jahrbuch des Meteorol. Observatoriums in Agram, 1906–1907. Jahrg. VI–VII, Agram 1906–1907.

Jeitteles L.H., 1860. Versuch einer Geschichte der Erdbeben in den Karpathen- und Sudeten-Ländern bis zu Ende des 18. Jahrhunderts. *Zeitschrift der Deutschen Geologischen Gesellschaft*, **XII**, 287–349.

Kišpatić M., 1879. Zagreb Earthquakes. *Godišnje izvješće Kraljevske velike realke u Zagrebu koncem školske godine 1879*, Zagreb (in Croatian).

Kišpatić M., 1884. First report of the Earthquake Committee for the year 1883. *Rad Jugoslavenske akademije znanosti i umjetnosti u Zagrebu*, **knj. 69**, 239–250.

Kišpatić M., 1885. Die Erdbeben Croatiens im Jare 1883. *Verhandlungen der k.k. geologischen Reichsanstalt*, Wien, No. 11, 265–273.

Kišpatić M., 1889. Bericht über die Kroatisch - Slavonisch - Dalmatinischen, sowie über die Bosnisch - Herzegovinischen Erdbeben in den Jahren 1884, 1885 und 1886. *Földtani Közlöny*, **19**, 82–101.

Kišpatić M., 1891. Potresi u Hrvatskoj. *Rad JAZU*, Zagreb, Knj. 107, 81–164.

Kišpatić M., 1892. Potresi u Hrvatskoj (Svršetak I. diela). *Rad JAZU*, Zagreb, Knj. 109, 1–79.

Knett J., 1898. Verhalten der Karslbader Thermen während des vogtländisch-westböhmischen Erdbebens im October-November 1897. In: *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897–1900, Bd. CVII, No. VII, 669–698.

Knett J., 1900. Über die Beziehungen zwischen Erdbeben und Detonationen. In: *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897–1900, Bd. CIX, No. XX, 700–734.

Kövesligethy R. v., 1904. Über die Energie grosser Erdbeben. In: *Die Erdbebenwarte, Monatsschrift*. Ed. Albin Belar. Laibach 1901–1910, III. Jahrg., 196–202.

Kövesligethy R. v., 1907. Seismischer Stärkegrad und Intensität der Beben. *Beiträge zur Geophys.*, **Bd.VII**, 363–366.

Kozák J. and Plešinger A., 2003. Beginnings of regular seismic service and research in the Austro-Hungarian Monarchy: Part I. *Stud. Geophys. Geod.*, **47**, 99–119.

Kozák J., 2001. 100-year Aniversary of the first International Seismological Conference. *Stud. Geophys. Geod.*, **45,** 200–209.

Láska W., 1901a. Bericht über die Erdbebenbeobachtungen in Lemberg. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.I, 1-64.

Láska W., 1901b. Bericht über die Erdbeben-Beobachtungen in Lemberg während des Jahres 1901. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. IX, 1–55.

Láska W., 1902. Die Erdbeben Polens. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. VIII, 1–36.

Láska W., 1903a. Bericht über die seismologischen Aufzeichnungen des Jahres 1902 in Lemberg. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XXII, 1–37.

Láska W., 1903b. Über die Berechnung von Fernbeben. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.XIV, 1–14.

Lawson A.C., Gilbert G.K., Reid H.F., Branner J.C., Leuschner A.O., Davidson G., Burckhalter Ch. and Campbell W.W., 1908. *Atlas of Maps and Seismograms Accompanying the Report of the State Earthquake Investigation Commission upon the California Earthquake of April 18, 1906*. Carnegie Institution of Washington, Washington D.C.

Mallet R., 1854. *Earthquake Catalogue*. Reports on the State of Science, British Assoc., London.

Mazelle E., 1899. Die Einrichtung der seismischen Station in Triest und die vom Horizontalpendel augezeichneten Erdbebenstörungen von Ende August 1898 bis Ende Februar 1899. In: *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw.* Klasse, Abth. I., 1897–1900, Bd.CVIII, No.XI, 357–394.

Mazelle E., 1900a Erdbebenstörungen zu Triest beobachtet am Rebeur-Ehlert´schen Horizontalpendel vom 1. März bis Ende Dezember 1899. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897–1900, Bd.CIX, No.XVII, 89–138.

Mazelle E., 1900b. Die tägliche periodische Schwankung des Erdbodens nach den Aufzeichnungen eines dreifachen Horizontalpendels zu Triest. In: *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897–1900, Bd.CIX, No.XIX, 527–579.

Mazelle E., 1901. Erdbebenstörungen zu Triest, Beobachtungen am Rebeur-Ehlert´schen Horizontalpendel im Jahre 1900. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.V, 1–52.

Mazelle E., 1902a. Erdbebenstörungen zu Triest, beobachtet am Rebeur-Ehlert´schen Horizontalpendel im Jahre 1901, nebst einem Anhange über die Aufstellung des Vicentini'schen Mikroseismographen. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900−1912, No.XI, 1−66.

Mazelle E., 1902b: Die mikroseismische Pendelunruhe und ihr Zusammenhang mit Wind und Luftdruck. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900−1912, No.XV, 1−87.

Milne J., 1894. A note on horizontal pendulums. *Seism. J. Japan*, **3**, 55−60.

Mitteis H., 1862. Über Erderschütterungen in Krain. *Jahreshefte des Vereins des krainischen Landesmuseums*, III.Heft.

Mittheilungen der Erdbeben–Kommission, 1897−1900. *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897−1900 (21 volumes, Nos. I – XXI).

Mittheilungen der Erdbeben–Kommission, 1900−1912. *Mittheilungen der Erdbeben–Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900−1912 (47 volumes, Nos. I – XLVII).

Moczo P., Labák P., Cipciar A., Kristek J., Kristeková M., Bielik M., Šajgalíková J. and Režuchová D., 2002. *100 Years of Seismology in Slovakia*. Geofyzikální ústav SAV and Fakulta matematiky, fyziky a informatiky UK, Bratislava, Slovakia.

Mohorovičić A., 1914. Die Bestimmung des Epizentrums eines Nahbebens. *Gerl. Beiträge zur Geophysik*, **XIV**, Leipzig und Berlin, 199−205.

Mohorovičić S., 1913. Die reduzierte Laufzeitkurve und die Abhängigkeit der Herdtiefe eines Bebens von der Entfernung des Inflexionspunktes der primären Laufzeitkurve. I. Mitteilung: Die Ausbreitung der Erdbebenstrahlen in den obersten Schichten der Erde. *Gerl. Beiträge zur Geophysik*, **XIII**, Leipzig und Berlin, 217−240.

Mohorovičić S., 1914. Die reduzierte Laufzeitkurve und die Abhängigkeit der Herdtiefe eines Bebens von der Entfernung des Inflexionspunktes der primären Laufzeitkurve. II. Mitteilung: Die Ausbreitung der Erdbebenstrahlen in den tiefen Schichten der Erde. *Gerl. Beiträge zur Geophysik*, **XIV**, Leipzig und Berlin, 187−198.

Mohorovičić A., 1910. Das Beben vom 8. X. 1909. *Jahrbuch des Meteorologischen Observatoriums in Agram für das Jahr 1909* (GodišnjeIzvješće Zagrebačkog Meterološkog Opservatorija za godinu 1909), Jahrgang IX, IV. Teil, Abschnitt 1. Tiskara i Litografija C.Albrechta, Zagreb.

Mohorovičić A., 1913. Development of seismology in the past 50 years. *Ljetopis JAZU*, **27**, Zagreb (Razvoj seizmologije posljednjih pedeset godina, in Croatian).

Mojsisovics E., 1899. Allgemeiner Bericht und Chronik der im Jahre 1898 innerhalb des Beobachtungsgebietes erfolgten Erdbeben. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897−1900, Bd. CVIII, No. X, 33−226.

Mojsisovics E., 1900. Allgemeiner Bericht und Chronik der im Jahre 1899 innerhalb des Beobachtungsgebietes erfolgten Erdbeben. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897−1900, Bd. CIX, No. XVIII, 151−314.

Mojsisovics E., 1901. Allgemeiner Bericht und Chronik der im Jahre 1900 im Beobachtungsgebiete eingetretenen Erdbeben. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.II, 1–184.

Mojsisovics E., 1902. Allgemeiner Bericht und Chronik der im Jahre 1901 im Beobachtungsgebiete eingetretenen Erdbeben. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.X, 1–114.

Mojsisovics E., 1903. Allgemeiner Bericht und Chronik der im Jahre 1902 im Beobachtungsgebiete eingetretenen Erdbeben. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No. XIX, 1–160.

Omori F., 1899. Horizontal pendulums for the mechanical registration of seismic and other earth movements. *J. College of Science, Imperial Univ. of Tokyo*, **11**, 121–145.

Pfaundler L., 1897. Über einen Erdbebenregistrator. *Sitzungsberichte der kaiserl. Akad. d. Wissensch. in Wien*, **Bd.CVI**, Abth. II, 551.

Réthly A., 1906. *Die Erdbeben in Ungarn im Jahre 1903–1905*. Ed. Königliche ungarische Reichsanstalt für Meteorologie und Erdmagnetismus, Budapest.

Réthly A., 1907. *Die Erdbeben in Ungarn im Jahre 1906*. Ed. Königliche ungarische Reichsanstalt für Meteorologie und Erdmagnetismus, Budapest.

Réthly A., 1908. *Die Erdbeben in Ungarn im Jahre 1907*. Ed. Königliche ungarische Reichsanstalt für Meteorologie und Erdmagnetismus, Budapest.

Réthly A., 1909. *Die Erdbeben in Ungarn in den Jahren 1900, 1901, 1902*. Ed. Königliche ungarische Reichsanstalt für Meteorologie und Erdmagnetismus, Budapest.

Réthly A., 1914. Die Erdbebenkarte Ungarns. *Gerl. Beiträge zur Geophysik*, **XIII**, Leipzig und Berlin, 283–305.

Réthly A., 1952: *Earthquakes in Carpathian Basin (455-1918)*. Akadémiai Kiadó, Budapest (*A Kárpátmedencék Földrengései*, in Hungarian).

Ribarič V., 1990. A short history of instrumental seismology in Yugoslavia (1880–1941). In: G. Ferrari (Ed.), *Historical Seismic Instruments, Italy and the European Framework*. G. Ferrari, 165–176.

Schafarzik F., 1883. Über die Thätigkeit der Erdbeben-Commission der Ungarischen Geologischen Gesellschaft während des ersten Jahres ihres Bestandes. *Földtani Közlöny*, **13**, 252–254.

Schafarzik F., 1884. Statistik der Erdbeben in Ungarn im Jahre 1883. *Földtani Közlöny*, **14**, 151–160.

Schafarzik F., 1902a. Die Erdbebenkommission in Ungarn. In: E. Rudolph (Ed.), *Proc. of the First International Seismological Conference*, Strassburg, April 11-13, 1901, Leipzig.

Schafarzik F., 1902b. Erdbebenbeobachtungsdienst in Ungarn. In: *Die Erdbebenwarte, Monatsschrift*. Ed. Albin Belar. Laibach 1901–1910, II. Jahrg., 281.

Schlüter W., 1903. Schwingungsart und Weg der Erdbebenwellen. *Gerl. Beitr. zur Geophysik*, **V**, 314.

Schneider R., 1909. Über die pulsatorische Oszillationen (mikroseismische Unruhe) des Erdbodens im Winter 1907/1908 in Wien. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.XXXV, 1–48.

Schneider R., 1911. Seismische Registrierungen in Wien, k.k. Zentralanstalt für Meteorologie und Geodynamik, im Jahre 1910. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.XLI, 1–49.

Schneider R., 1914. Seismische Registrierungen in Wien, k.k. Zentralanstalt für Meteorologie und Geodynamik, im Jahre 1912. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.XLVII, 1–56.

Schorn J., 1903. Die Erdbeben von Tirol und Vorarlberg. *Zeitschrift des Ferdinandeums*, **III**, 46 Heft.

Schröder W., 2000. Emil Wiechert - Physiker, Geophysiker, Wissenschaftsorganisator. *Mitteil. d. Arbeitskreises Geschichte d. Geophysik*, **19**, Heft 1-2, DGG.

Schwab F., 1900. Bericht über Erdbebenbeobachtungen in Kremsmünster. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien, Sitzungsberichte der mathem.-naturw*. Klasse, Abth. I., 1897–1900, Bd.CIX, No.XV, 19–68.

Schwab F., 1901. Bericht über Erdbebenbeobachtungen in Kremsmünster im Jahre 1900. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.IV, 1–24.

Schwab F., 1903. Bericht über Erdbebenbeobachtungen in Kremsmünster im Jahre 1902. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900–1912, No.XXI, 1–23.

Schweitzer J., 2003. Early German Contributions to Modern Seismology. In: Lee W.H.K. et al. (Eds.), *International Handbook of Earthquake and Engeneering Seismology*, Academic Press, Part B, Chapter 79.24, in press.

Seismische Registrierungen der Erdbebenwarte in Eger, 1908–1919. In: *Jahresberichte der k.k. Staats-Oberrealschule in Eger.* Ed. Georg Irgang, Eger 1908–1919 (4 volumes: 1908/11, 1912, 1913/14, 1914/19).

Sieberg A., 1904. *Handbuch der Erdbebenkunde*. Verlag Friedrich Vieweg & Sohn, Braunschweig.

Sieberg A., 1923. *Geologische, physikalische und angewandte Erdbebenkunde* (Mit Beiträgen von Dr. Beno Gutenberg in Darmstadt). Verlag von Gustav Fischer, Jena.

Skoko D. and Mokrović J., 1982. *Andrija Mohorovičić*. Školska Knjiga, Zagreb.

Stöckl E., 1902. Mitteilungen über die erste Einrichtung der Erdbebenwarte in Budapest. In: *Die Erdbebenwarte, Monatsschrift*. Ed. Albin Belar. Laibach 1901–1910, II. Jahrg., 124.

Suess E., 1873. *Die Erdbeben Niederösterreichs*. Denkschrift der Kais. Akademie d. Wissensch. in Wien, Band 33.

Suess E., 1874. *Die Erdbeben im südlichen Italien*. Denkschrift der Kais. Akademie d. Wissensch. in Wien, Band 34 .

Suess E., 1896. Das Erdbeben von Laibach am 14. April 1895. In: *Jahrbuch der kaiserlich-königlichen Geologischen Reichsanstalt*, **XLVI**, 411–890.

Toperczer M. and Trapp E., 1950. Ein Beitrag zur Erdbebengeographie Österreichs nebst Erdbebenkatalog 1904–1948 und Chronik der Starkbeben. *Mitteilungen der Erdbeben-Kommission*, Neue Folge, Nr. 65, Wien.

Vicentini G. and Pacher G., 1896. Considerazioni sugli apparecchi sismici registratori e modificacione del microsismografo a due componenti. *Bolletina della Società sismologica Italiana*, **11**, 107−121.

Vicentini G. and Pacher G., 1898: Microsismografo per la componente verticale. *Atti Ist. veneto Sci.*, **7(10)**, 65−89.

Wiechert E., 1902. Prinzipien für die Beurteilung der Wirksamkeit von Seismographen. In: E. Rudolph (Ed.), *Proc. of the First International Seismological Conference*, Strassburg April 11-13, 1901, Leipzig.

Wiechert E., 1903. Theorie der automatischen Seismographen. *Abhandlungen der k. Gesellschaft der Wissensch. zu Göttingen, Mathem.-phys. Klasse*, Neue Folge, Bd. II, Nr. 1, 1−128.

Wiechert E., 1904. Ein astatisches Pendel hoher Empfindlichkeit zur mechanischen Registrierung von Erdbeben. *Gerl. Beiträge zur Geophysik*, **VI**, 435−460.

Wiechert E., 1906. Übersicht der registrierenden Seismometer der Göttinger Station. *Göttinger Berichte*, No.376.

Woldřich J.N., 1901. Das Nordostböhmische Erdbeben vom 10. Jänner 1901. In: *Mittheilungen der Erdbeben-Kommission der kaiserl. Akad. d. Wissensch. in Wien*, Neue Folge, 1900−1912, No.V, 1−56.

Zátopek A., 1981. Sixty years since the foundation of the (State) Institute of Geophysics at the Charles University in Prague. *Stud. Geophys. Geod.*, **25,** 296−311.

Zusammenstellung der Ergebnisse …, 1907−1909. *Zusammenstellung der Ergebnisse der in Bosnien und der Herzegowina stattgefundenen Erdbebenbeobachtungen*. Bosn.-Herzeg. Landesregierung, Sarajevo 1907−1909 (2 volumes: 1906/07, 1908).